Ing. Alejandro Vera Lázaro

EMPRESA EDITORA MACRO®

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PROBLEMAS RESUELTOS

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Líneas de investigación

- Aplicación del método de los elementos finitos a la Ingeniería en Diseño de máquinas.
- Proyectos, planificación, gestión en energías renovables.
- Diseño y dimensionamiento de sistemas eólicos *onshore* y *offshore*.

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A todas las personas que, de alguna u otra forma, me apoyaron para que esta obra salga a la luz.

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A Isabel Ramos, por la confianza depositada en mi persona.

Dedicatoria

A Evelyn Montoya, por ser una gran amiga, haberme apoyado en los momentos que más lo necesitaba y sobre todo por confiar en mi trabajo; siempre te dije: “Las promesas se cumplen; sino la palabra de un hombre no vale nada”.

Introducción

La presencia de la existencia de las computadoras ha dado un cambio en el estudio de la ingeniería; por esta razón, el libro *Análisis estructural con matrices* tiene como finalidad desarrollar el denominado «método de la rigidez de cálculo matricial», aplicado a estructuras bidimensionales formadas por barras y vigas, a partir de elementos unidimensionales, desde el más básico como es el elemento resorte. Este mismo esquema puede ser extendido a otras formas de discretizar una estructura o un medio continuo. De hecho, el método de los elementos finitos es la extensión del método de cálculo matricial, donde se trata con elementos que no son solo barras; sino volúmenes de distintas formas geométricas que modelan un mayor número de problemas mecánicos o físicos.

En todo el desarrollo del método, se aceptan las hipótesis generales en las que normalmente se desarrollan los cursos de la teoría de estructuras, es decir: el comportamiento elástico y lineal del material, así como el estado de pequeños desplazamientos.

El libro pretende que el estudiante pueda plantear las distintas matrices de rigidez para los diferentes elementos estructurales, los analice, los pueda plantear y con el apoyo del software MATLAB pueda resolver los cálculos finales para obtener una respuesta rápida; por este motivo en cada uno de los problemas se anexa el desarrollo en el software MATLAB. En el último capítulo, se proponen dos aplicaciones para tener un acercamiento a la realidad.

El autor

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CAPÍTULO

1

MÉTODO DE LA RIGIDEZ

1.1. HIPÓTESIS

- Estructura lineal. Todos los movimientos y esfuerzos son funciones lineales de las cargas.
- Pequeñas deformaciones. Ecuaciones de equilibrio en la estructura no distorsionada.
- Las barras son rectas y de sección constante.
- Para estudiar una estructura por el método de la rigidez, al igual que en cualquier otro problema elástico, se dispone de tres conjuntos de ecuaciones que deben cumplirse:
  - Ecuaciones de compatibilidad
  - Ecuaciones constitutivas
  - Ecuaciones de equilibrio

1.2. ASPECTOS GENERALES

Las ecuaciones de compatibilidad relacionan las deformaciones de barras con los desplazamientos nodales. Introduciendo estas relaciones en las ecuaciones constitutivas, asocie las fuerzas en los extremos de barras con los desplazamientos nodales. Introduciendo estas últimas relaciones en las ecuaciones de equilibrio, se obtiene un conjunto de ecuaciones de fuerzas nodales en función a desplazamientos nodales, que pueden ser consideradas como ecuaciones de equilibrio de la estructura en función de desplazamientos.

La resolución de este sistema de ecuaciones permite obtener el valor de las incógnitas (desplazamientos nodales) a partir de los cuales se obtienen las solicitaciones de las barras de la estructura, así como las reacciones.

Cuando se van a calcular las relaciones esfuerzos de extremo de barra-desplazamientos, es natural escoger un sistema de coordenadas que haga estas ecuaciones lo más sencillas posible. Se tomará, por lo tanto, como eje X el que coincide con el eje geométrico de la pieza y los ejes Y y Z coincidentes con los ejes principales de la sección transversal. Tal sistema pertenece a la barra y no depende de la orientación de la misma en la estructura y se le denominará «sistemas de ejes locales». Por el contrario, cuando las piezas se unen entre sí para formar la estructura, es necesario tener un sistema de coordenadas común para todos los movimientos y esfuerzos de extremo de barras para poder aplicar las condiciones de equilibrio y compatibilidad. A dicho sistema, se le denominará «sistema de ejes globales». Dichos esfuerzos de extremos de barras y desplazamientos, dependerán del tipo de estructura que está resolviendo, para barras de:

- *Reticulado plano:* Dos desplazamientos por nudo.
- *Reticulado espacial:* Tres desplazamientos por nudo.
  En ambos casos, solo se obtendrán esfuerzos normales.
- *Pórtico plano:* Tres desplazamientos por nudo (una rotación en el plano del pórtico y dos traslaciones). Como solicitaciones de extremo de barra una fuerza axial: un esfuerzo de corte y un momento flector.
- *Pórtico espacial:* Seis desplazamientos por nudo, tres traslaciones y tres rotaciones. Como solicitaciones de extremo de barra una fuerza axial: dos esfuerzos de corte, dos momentos flectores y un momento torsor.
- *Emparrillado de vigas:* Tres desplazamientos nodales (un corrimiento normal al plano de la grilla) y dos rotaciones alrededor de los ejes contenidos en el plano mencionado. Los esfuerzos son un cortante y dos momentos (un torsor y un flector).

1.3. MÉTODO DE LA RIGIDEZ UTILIZANDO UNA COMPUTADORA

Una de las características más importantes del método de la rigidez es la forma en que las propiedades elásticas de las piezas y su orientación dentro de la estructura, son introducidas en el cálculo antes de que se efectúe alguna consideración sobre el equilibrio o la compatibilidad de los nudos.

Esto permite establecer relaciones entre las fuerzas de extremo de barras y los desplazamientos de nudo. Dichas relaciones expresadas en forma matricial, se denomina «matriz de rigidez de barra».

Al considerar la interrelación de cada barra con las demás, se obtiene un sistema global de ecuaciones que define el comportamiento de toda la estructura y conduce a la solución del problema.

Se considera seis etapas fundamentales en la solución de un problema:

- Identificación estructural
- Cálculo de la matriz de rigidez de barra y del vector de cargas nodales equivalentes
- Cálculo de la matriz de rigidez global y del vector de cargas global de la estructura
- Introducción de las condiciones de borde
- Solución del sistema de ecuaciones
- Cálculo de solicitaciones en los extremos de barras y reacciones nodales

1.3.1. Identificación estructural

Esta etapa consiste en definir a través de números y datos las barras de la estructura.

- *Definir un sistema de ejes globales para la estructura:* Las coordenadas de los nudos se refieren a dicho sistema.
- *Conectividad de los elementos:* Identificando para cada barra el nudo inicial y el final. A cada barra está asociado un sistema de ejes locales al cual se refieren todas las dimensiones y características de la barra. El mismo queda definido automáticamente por el orden establecido para la numeración de los nudos de la barra. El eje X local coincide con el eje geométrico de la barra, siendo el sentido positivo el que va del nudo inicial (nudo de menor numeración) al final (nudo de mayor numeración). Los otros ejes locales deberán coincidir con los ejes principales de inercia de la sección transversal de la barra formando un triedro directo.
- *Propiedades de la sección transversal de cada barra:* Dependiendo del tipo de estructura (reticulado, pórtico plano, pórtico espacial, emparrillado), se debe dar el área de la sección transversal, los momentos de inercia en relación a los ejes principales y la inercia a la torsión.
- *Propiedades del material:* Se debe indicar, para cada barra, el módulo de elasticidad longitudinal o el módulo de elasticidad transversal.
- *Especificación de los vínculos:* Se debe indicar el nombre del nudo que tiene una o más restricciones y cuáles son las mismas.
- *Descripción de la carga:* Se da el nombre del nudo y los componentes de globales de las cargas externas y las reacciones de empotramiento perfecto en relación a los ejes locales de la barra si hay cargas en el tramo.

CAPÍTULO

2

ANÁLISIS DE RESORTES

2.1. VISIÓN GENERAL

El método de la rigidez de la matriz es la base de casi todos los programas comerciales de análisis estructural. Se trata de un caso particular del método de los elementos finitos más generales y fue, en parte, responsable por el desarrollo del método de los elementos finitos. Por tanto, una comprensión de la teoría subyacente, las limitaciones y los medios de aplicación del método es esencial para que el usuario del software de análisis no es solo operar un "cuadro negro". Estos usuarios deben ser capaces de entender los posibles errores en la modelización de las estructuras que normalmente vienen como advertencias obtusos como "giro cero" o "determinante cero: estructura inestable: abortar". Entender los conceptos básicos presentados en este documento debe conducir a un uso más provechoso de los programas disponibles.

2.2. CONCEPTOS BÁSICOS

2.2.1. Nodo

El nombre más general de una conexión entre los miembros adyacentes se denomina un «nodo». Para vigas y marcos de los términos comunes y nodo son intercambiables. Para estructuras más complejas (por ejemplo, platos), no lo son.

2.2.2. Elemento

Para vigas y marcos, **elemento** significa lo mismo que miembro. Para estructuras más complejas, este no es el caso.

2.2.3. Grado de libertad (GDL)

El número de posibles direcciones que los desplazamientos o las fuerzas en un nodo pueden existir es lo que se denomina un« grado de libertad» (DOF). Algunos ejemplos son los siguientes:

- *Plano armadura:* Tiene dos grados de libertad en cada nodo: traslación y fuerzas en las direcciones X e Y.
- *Vigas:* Con dos grados de libertad por nodo: desplazamiento; fuerzas verticales y rotación; y momento.
- *Plano del marco:* Con tres grados de libertad en cada nodo: las traducciones, fuerzas similar a una armadura de avión y la rotación o momento en la articulación.
- *Armadura de espacio:* Una armadura en tres dimensiones tiene tres grados de libertad: traducción o de fuerzas a lo largo de cada eje en el espacio.
- *Marco de espacio:* Tiene 6 grados de libertad en cada nodo: traducción; fuerzas a lo largo de cada eje y la rotación; y momentos alrededor de cada eje. Así, una celosía plana con 10 articulaciones tiene 20 grados de libertad. Un marco plano con dos miembros tendrá tres articulaciones (una común a ambos miembros) y, por lo tanto, 9 grados de libertad en total.

2.2.4. Local y global

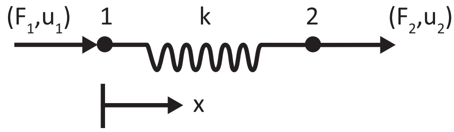
Fuerzas, desplazamientos y matrices de rigidez a menudo se derivan y se definen por un sistema de ejes locales para el miembro. Sin embargo existirá un sistema general o global, eje de la estructura en su conjunto. Por tanto, se debe transformar las fuerzas, desplazamientos, etc. desde el sistema de coordenadas local en el sistema de coordenadas global.

2.2.5. Enfoque básico

A. Elemento individual

Se considera aquí la forma más básica de análisis de la rigidez.

En este caso, se representa un miembro estructural por un resorte que tiene un nodo (o conexión) en cada extremo. También se considera que solo puede moverse en la dirección x. Por lo tanto, solo tiene 1 GDL por nodo. En cada uno de sus nodos, que puede tener una fuerza y un desplazamiento (de nuevo tanto en la dirección x):



Nótese que se ha sacado la fuerza y las flechas de vectores de desplazamiento positivo de la dirección x. El análisis matricial obliga a ser muy estrictos en las convenciones de signos.

Usando la relación básica que la fuerza es igual a la rigidez por el desplazamiento, se puede determinar la fuerza en el nodo 1 como:

$$F_1 = k \text{ (desplazamiento en 1)}$$

Así:

$$F_1 = k(u_1 - u_2) = ku_1 - ku_2 \qquad \text{...(1)}$$

Del mismo modo para el nodo 2:

$$F_2 = k(u_2 - u_1) = -ku_1 + ku_2 \qquad \text{...(2)}$$

Se puede escribir las ecuaciones (1) y (2) en forma de matriz para obtener la matriz de rigidez del elemento para un elemento axial 1-GDL:

$$\begin{Bmatrix} F_1 \\ F_2 \end{Bmatrix} = \begin{bmatrix} k & -k \\ -k & k \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix}$$

Y usando la notación de matrices, se escribe así:

$$\{F\} = \{k\}\{u\}$$

Donde:

{F} es el vector de fuerza del elemento
{k} es la matriz de rigidez del elemento
{u} es el vector de desplazamiento elemento

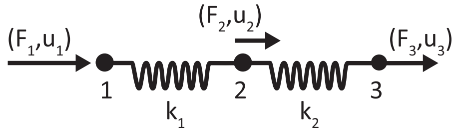
Debe quedar claro que la matriz de rigidez elemento es de importancia fundamental -que une fuerzas nodales a desplazamientos nodales- esto comprende cómo el elemento se comporta bajo carga.

La derivación de la matriz del elemento rigidez para diferentes tipos es probablemente la parte más difícil del método de matriz de rigidez. No obstante, esto no supone un gran inconveniente ya que solo hay unos pocos tipos de elementos para derivar y una vez obtenida se encuentra a disposición para su uso en cualquier problema.

B. Conjunto de elementos

Estructuras reales se componen de conjuntos de elementos; por lo tanto, se debe determinar cómo conectar las matrices de rigidez de los elementos individuales para formar una matriz de rigidez global (o global) para la estructura.

Considere la siguiente estructura simple:



Tenga en cuenta que los elementos individuales tienen diferentes rigideces: k_1 y k_2. Por lo tanto, se puede escribir la relación de desplazamiento de fuerza para ambos elementos como:

$$\begin{Bmatrix} F_1 \\ F_2 \end{Bmatrix} = \begin{bmatrix} k_1 & -k_1 \\ -k_1 & k_1 \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} \qquad ...(3)$$

$$\begin{Bmatrix} F_2 \\ F_3 \end{Bmatrix} = \begin{bmatrix} k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix} \begin{Bmatrix} u_2 \\ u_3 \end{Bmatrix} \qquad ...(4)$$

Se puede ampliar estas ecuaciones para que abarquen todos los nodos de la estructura:

$$\begin{Bmatrix} F_1 \\ F_2 \\ F_3 \end{Bmatrix} = \begin{bmatrix} k_1 & -k_1 & 0 \\ -k_1 & k_1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix} \qquad ...(5)$$

$$\begin{Bmatrix} F_1 \\ F_2 \\ F_3 \end{Bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & k_2 & -k_2 \\ 0 & -k_2 & k_2 \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix} \qquad ...(6)$$

Se puede añadir las ecuaciones (5) y (6) para determinar el total de ambas, las fuerzas y desplazamientos en cada nodo en la estructura:

$$\begin{Bmatrix} F_1 \\ F_2 \\ F_3 \end{Bmatrix} = \begin{bmatrix} k_1 & -k_1 & 0 \\ -k_1 & k_1 + k_2 & -k_2 \\ 0 & -k_2 & k_2 \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix} \qquad ...(7)$$

Como puede verse a partir de esta ecuación, mediante la adición de, se tiene la rigidez total de en cada nodo, con contribuciones como apropiada por cada miembro. En particular, el nodo 2, donde los miembros se reúnen, tiene la rigidez total de $k_1 + k_2$. Se puede reescribir esta ecuación como:

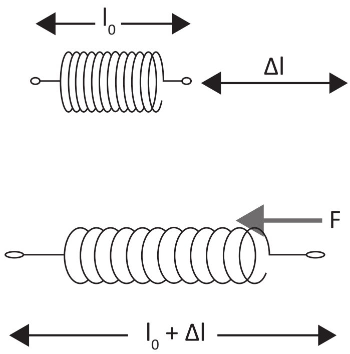
$$\{F\} = [K]\{u\}$$

Donde:
{F} es el vector de fuerza de la estructura
{K} es la matriz de rigidez global de la estructura
{u} es el vector de desplazamiento de la estructura

2.3. ASOCIACIÓN DE RESORTES

2.3.1. La fuerza y energía elásticas de un resorte o muelle

Un resorte o muelle es un dispositivo mecánico que puede comprimirse o dilatarse y que vuelve a su posición original o natural, siempre que el desplazamiento no sea demasiado grande, existiendo un límite para estos desplazamientos; más allá de ellos, el resorte no volvería a su longitud natural. Para pequeñas compresiones o estiramientos, la fuerza ejercida por el resorte es directamente proporcional a ellos.



Si l_0 es la longitud natural del resorte y se alarga Δl cuando actúa la fuerza F, entonces:

$$\vec{F} = -K\,\Delta\vec{l}$$

La energía potencial elástica de un resorte vale lo siguiente:

$$U = \frac{1}{2}K(\Delta l)^2$$

Entonces cada resorte o muelle viene caracterizado por una constante **K**, llamada «constante elástica o recuperadora». El signo negativo indica que los sentidos de los vectores **F** y **Δl** son contrarios.

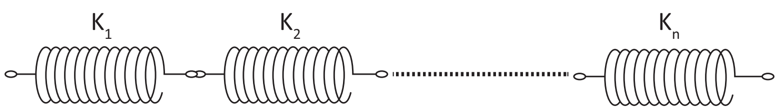
2.3.2. Asociación o acoplamiento de resortes

Los resortes, al igual que las resistencias eléctricas y los condensadores, pueden acoplarse de dos formas radicalmente diferentes: serie y paralelo. Por supuesto, cualquier otra asociación mixta que se pueda formar entre estas dos.

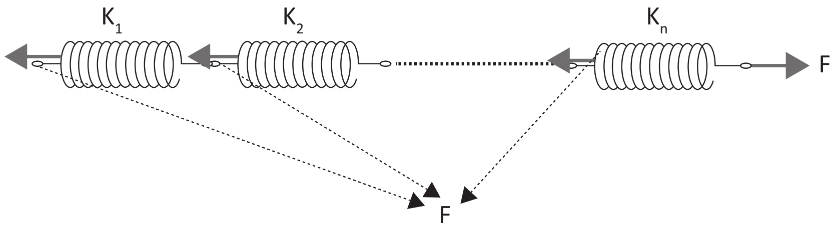
Estudiar una "batería" de resortes, conociendo las propiedades que tienen en cada una de las configuraciones base, simplifica extraordinariamente el cálculo de las mismas.

A. Asociación serie

Una cantidad n de resortes están asociados o acoplados en serie, si cada uno de ellos se inserta a continuación de otro en la misma línea de acción:



Si sobre uno de los extremos de los resortes, se ejecuta una fuerza de compresión o de estiramiento **F**, manteniendo fijo el otro extremo, esta fuerza será la que actúe sobre cada uno de los resortes, sufriendo cada uno de ellos su propia compresión o estiramiento, respectivamente, según valgan sus constantes recuperadoras.



Los resortes habrán sufrido unos incrementos de longitud, directamente proporcionales a sus constantes recuperadoras. Así:

Resorte 1º:	$F = K_1\, \Delta l_1$	$\Delta l_1 = F / K_1$
“ 2º:	$F = K_2\, \Delta l_2$	$\Delta l_2 = F / K_2$
....	....	....
“ nº:	$F = K_n\, \Delta l_n$	$\Delta l_n = F / K_n$

Se desea conocer cuál sería la constante recuperadora de un solo resorte que, sometido a la misma fuerza F que el sistema en serie, sufriese un incremento de longitud equivalente a la suma de los incrementos sufridos por cada uno de ellos y que, por tanto, tuviese la misma energía potencial elástica que el sistema en serie.

$$\Delta L = \Delta l_1 + \Delta l_2 + \ldots\ldots + \Delta l_n$$

Es decir:

$$\frac{F}{K_s} = \frac{F}{K_1} + \frac{F}{K_2} + \ldots\ldots\ldots\ldots + \frac{F}{K_n}$$

Simplificando:

$$\frac{1}{K_s} = \frac{1}{K_1} + \frac{1}{K_2} + \ldots\ldots\ldots\ldots + \frac{1}{K_n}$$

O lo que es lo mismo:

$$\frac{1}{K_s} = \frac{1}{K_1} + \frac{1}{K_2} + \ldots\ldots + \frac{1}{K_n}$$

Por lo tanto:

$$K_s = \frac{1}{\sum_{i=1}^{n} \frac{1}{K_i}}$$

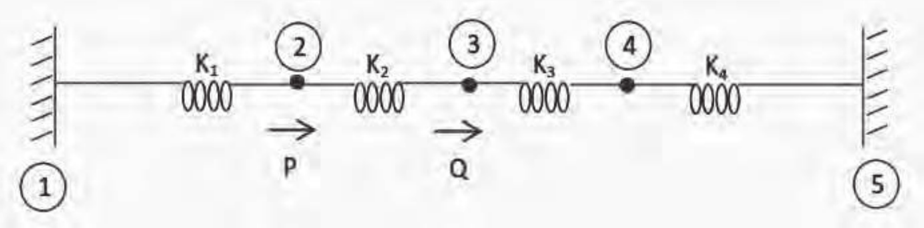
De todo lo anterior se deduce que para **n** resortes acoplados en serie, si uno de los extremos se deja fijo y sobre el otro se ejecuta una fuerza **F**, se cumple que:

- Cada resorte presenta la misma fuerza **F**, coincidente con la que actuó sobre el sistema.
- Cada resorte presenta su propio incremento de longitud $\mathbf{\Delta l_i}$, con un módulo inversamente proporcional a la constante elástica del resorte $\mathbf{K_i}$, ya que se cumple que: $\mathbf{\Delta l_i = F / K_i}$.
- La constante elástica del único resorte equivalente en serie, vale lo siguiente:

$$K_s = \frac{1}{\displaystyle\sum_{i=1}^{n} \frac{1}{K_i}}$$

EJEMPLO 1

En el sistema mostrado, determinar los desplazamientos nodales así como las fuerzas de las paredes.



K_1 = 600 KN/m P = 6000 N

K_2 = 800 KN/m Q = 8000 N

K_3 = 1000 KN/m K_4 = 1200 KN/m

A. Resolución

Paso 1: Genere la matriz de rigidez de cada elemento resorte:

$$K_1 = \begin{bmatrix} K_1 & -K_1 & 0 & 0 & 0 \\ -K_1 & K_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_2 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & K_2 & -K_2 & 0 & 0 \\ 0 & -K_2 & K_2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_3 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & K_3 & -K_3 & 0 \\ 0 & 0 & -K_3 & K_3 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_4 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & K_4 & -K_4 \\ 0 & 0 & 0 & -K_4 & K_4 \end{bmatrix}$$

Paso 2: La matriz ensamblada es igual a la suma de las matrices parciales:

$$\mathrm{IK} = K_1 + K_2 + K_3 + K_4$$

Donde:

$$\mathrm{IK} = \begin{bmatrix} K_1 & -K_1 & 0 & 0 & 0 \\ -K_1 & K_1 + K_2 & -K_2 & 0 & 0 \\ 0 & -K_2 & K_2 + K_3 & -K_3 & 0 \\ 0 & 0 & -K_3 & K_3 + K_4 & -K_4 \\ 0 & 0 & 0 & -K_4 & K_4 \end{bmatrix}$$

Esta es la matriz de rigidez global. Analizando el sistema se observa dos paredes, en los nodos 1 y 5. En dichos puntos, no puede haber desplazamiento, razón por la cual:

$$U_1 = U_5 = 0$$

Paso 3: Por esta razón, utilizando el método de eliminación, cancele las filas y columnas 1 y 5:

$$1000\begin{bmatrix} 600 & -600 & 0 & 0 & 0 \\ -600 & 1400 & -800 & 0 & 0 \\ 0 & -800 & 1800 & -1000 & 0 \\ 0 & 0 & -1000 & 2200 & -1200 \\ 0 & 0 & 0 & -1200 & 1200 \end{bmatrix} \times \begin{bmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \\ U_5 \end{bmatrix} = \begin{bmatrix} F_1 \\ 6000 \\ 8000 \\ 0 \\ F_5 \end{bmatrix}$$

De tal manera que la matriz simplificada es como sigue:

$$1000\begin{bmatrix} 1400 & -800 & 0 \\ -800 & 1800 & -1000 \\ 0 & -1000 & 2200 \end{bmatrix} \times \begin{bmatrix} U_2 \\ U_3 \\ U_4 \end{bmatrix} = \begin{bmatrix} 6000 \\ 8000 \\ 0 \end{bmatrix}$$

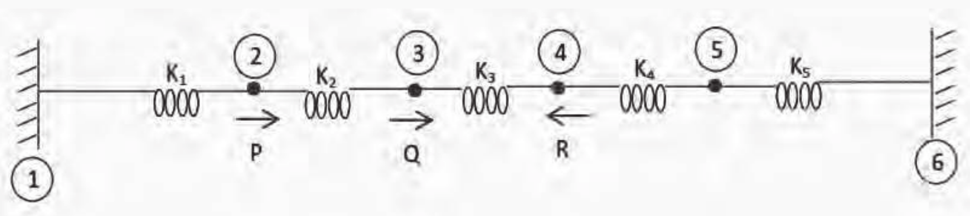
B. Resolución con MATLAB

```
>> A = 1000*[1400 -800 0; -800 1800 -1000; 0 -1000 2200]

A =

     1400000     -800000           0
     -800000     1800000    -1000000
           0    -1000000     2200000

>> f = [6000; 8000; 0]

f =

        6000
        8000
           0
```

```
>> u = inv(A)*f

u =

    0.0116
    0.0129
    0.0058

>>  % LA MATRIZ GLOBAL K ES:
>> K = 1000*[600 -600 0 0 0; -600 1400 -800 0 0; 0 -800 1800 -1000 0; 0 0 1000
2200 -1200; 0 0 0 -1200 1200]

K =

      600000     -600000           0           0           0
     -600000     1400000     -800000           0           0
           0     -800000     1800000    -1000000           0
           0           0     1000000     2200000    -1200000
           0           0           0    -1200000     1200000

>> % EL VECTOR DESPLAZAMIENTO GLOBAL U ES:
>> U = [0; 0.0116; 0.0129; 0.0058; 0]

U =

         0
    0.0116
    0.0129
    0.0058
         0

>> % LA FUERZA EN LAS PAREDES ES:
>> F = K*U

F =

  1.0e+004 *

   -0.6960
    0.5920
    0.8140
    2.5660
   -0.6960
```

Ejemplo 2

Según el gráfico y los datos presentados, resolver lo siguiente:



$K_1 = 600$ kN/m P = 5000 N S = –10000 N (Fuerza de Eq.)
$K_2 = K_3 = 1200$ kN/m Q = 7000 N
$K_4 = K_5 = 1800$ kN/m R = –2000N

A. Resolución

Paso 1: Genere la matriz de rigidez de cada elemento resorte:

$$K_1 = \begin{bmatrix} K_1 & -K_1 & 0 & 0 & 0 & 0 \\ -K_1 & K_1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_2 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & K_2 & -K_2 & 0 & 0 & 0 \\ 0 & -K_2 & K_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_3 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & K_3 & -K_3 & 0 & 0 \\ 0 & 0 & -K_3 & K_3 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_4 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & K_4 & -K_4 & 0 \\ 0 & 0 & 0 & -K_4 & K_4 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_5 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & K_5 & -K_5 \\ 0 & 0 & 0 & 0 & -K_5 & K_5 \end{bmatrix}$$

Paso 2: La matriz ensamblada es igual a la suma de las matrices parciales:

$$IK = K_1 + K_2 + K_3 + K_4 + K_5$$

$$K = 10^3 \begin{bmatrix} 600 & -600 & 0 & 0 & 0 & 0 \\ -600 & 1800 & -1200 & 0 & 0 & 0 \\ 0 & -1200 & 2400 & -1200 & 0 & 0 \\ 0 & 0 & -1200 & 3000 & -1800 & 0 \\ 0 & 0 & 0 & -1800 & 3600 & -1800 \\ 0 & 0 & 0 & 0 & -1800 & 1800 \end{bmatrix} \times \overset{IU}{\begin{bmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \\ U_5 \\ U_6 \end{bmatrix}} = \overset{IF}{\begin{bmatrix} F_1 \\ 5000 \\ 7000 \\ -2000 \\ 0 \\ F_6 \end{bmatrix}}$$

Paso 3: Esta es la matriz de rigidez global. Analizando el sistema, se observa dos paredes, en los nodos 1 y 6. En dichos puntos, no puede haber desplazamiento, razón por la cual:

$$U_1 = U_6 = 0$$

Paso 4: Por esta razón, utilizando el método de eliminación, cancele las filas y columnas 1 y 6:

$$IK = \begin{bmatrix} \cancel{600} & \cancel{-600} & \cancel{0} & \cancel{0} & \cancel{0} & \cancel{0} \\ \cancel{-600} & 1800 & -1200 & 0 & 0 & \cancel{0} \\ \cancel{0} & -1200 & 2400 & -1200 & 0 & \cancel{0} \\ \cancel{0} & 0 & -1200 & 3000 & -1800 & \cancel{0} \\ \cancel{0} & 0 & 0 & -1800 & 3600 & \cancel{-1800} \\ \cancel{0} & \cancel{0} & \cancel{0} & \cancel{0} & \cancel{-1800} & \cancel{1800} \end{bmatrix} \times \overset{IU}{\begin{bmatrix} \cancel{U_1} \\ U_2 \\ U_3 \\ U_4 \\ U_5 \\ \cancel{U_6} \end{bmatrix}} = \overset{IF}{\begin{bmatrix} \cancel{F_1} \\ 5000 \\ 7000 \\ -2000 \\ F_5 \\ \cancel{F_6} \end{bmatrix}}$$

De tal manera que la matriz simplificada es como sigue:

$$1000 \begin{bmatrix} 1800 & -1200 & 0 & 0 \\ -1200 & 2400 & -1200 & 0 \\ 0 & -1200 & 3000 & -1800 \\ 0 & 0 & -1800 & 0 \end{bmatrix} \times \begin{bmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \end{bmatrix} = \begin{bmatrix} 5000 \\ 7000 \\ -2000 \\ 0 \end{bmatrix}$$

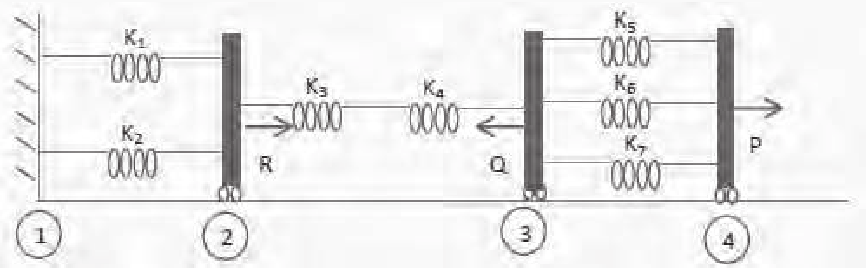
B. Resolución con MATLAB

```
>> A = 1000*[1800 -1200 0 0; -1200 2400 -1200 0; 0 -1200 3000 -1800; 0 0 -1800 0]

A =

     1800000    -1200000           0           0
    -1200000     2400000    -1200000           0
           0    -1200000     3000000    -1800000
           0           0    -1800000           0

>> f = [5000; 7000; -2000; 0]
```

```
f =
        6000
        5000
        7000
       -2000
           0

>> U = inv(A)*f

U =

    0.0071 m
    0.0065 m
   -0.0000 m
   -0.0032 m

>> % LA MATRIZ ENSAMBLADA K ES:

>> K = 1000* [600 -600 0 0 0 0; -600 1800 -1200 0 0 0; 0 -1200 2400 -1200 0 0; 0
0 -1200 3000 -1800 0; 0 0 0 -1800 3600 -1800; 0 0 0 0 -1800 1800]

K =

      600000     -600000           0           0           0           0
     -600000     1800000    -1200000           0           0           0
           0    -1200000     2400000    -1200000           0           0
           0           0    -1200000     3000000    -1800000           0
           0           0           0    -1800000     3600000    -1800000
           0           0           0           0    -1800000     1800000

>> % EL VECTOR DESPLAZAMIENTO GLOBAL D ES:
>> D = [0; 0.0071; 0.0065;  -0.0000; -0.0032; 0]

D =

         0
    0.0071
    0.0065
         0
   -0.0032
         0

>> F = K*D

F =

       -4260
        4980
        7080
       -2040
      -11520
```

EJEMPLO 3

Resolver según el diagrama y los datos siguientes:



$K_1 = K_3 = 2000$ kN/m

$K_2 = K_4 = 4000$ kN/m

$K_5 = K_6 = 6000$ kN/m

$K_7 = 10000$ kN/m

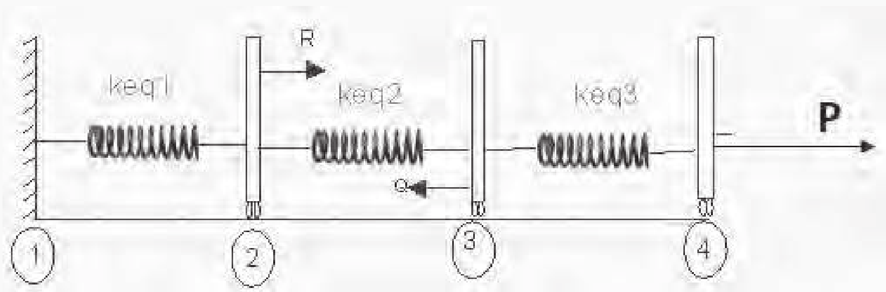
P = 3000 N

Q = 8000 N

R = 15000 N

A. Resolución

Paso 1: Redibujando el sistema:



Paso 2: Hallando los valores de K_{eq}:

$$Keq_1 = 2000\,KN/m + 4000\,KN/m = 6000\,KN/m$$

$$\frac{1}{Keq_2} = \frac{1}{2000}\frac{KN}{m} + \frac{1}{4000}KN/m = 1333.33\,KN/m$$

$$Keq_3 = 6000\,KN/m + 6000\,KN/m + 10000\,KN/m = 22000\,KN/m$$

B. Resolución con MATLAB

```
>> keq1 = 1000*[6000 6000 0 0; -6000 6000 0 0; 0 0 0 0; 0 0 0 0]

keq1 =

     6000000     6000000           0           0
    -6000000     6000000           0           0
           0           0           0           0
           0           0           0           0
```

```
>> keq2 = 1000*[0 0 0 0; 0 1333.33 -1333.33 0; 0 -1333.33 1333.33 0; 0 0 0 0]

keq2 =

          0          0          0          0
          0    1333330   -1333330          0
          0   -1333330    1333330          0
          0          0          0          0

>> keq3 = 1000*[0 0 0 0; 0 0 0 0; 0 0 22000 -22000; 0 0 -22000 22000]

keq3 =

          0          0          0          0
          0          0          0          0
          0          0   22000000  -22000000
          0          0  -22000000   22000000

>> K = keq1 + keq2 + keq3

K =

    6000000    6000000          0          0
   -6000000    7333330   -1333330          0
          0   -1333330   23333330  -22000000
          0          0  -22000000   22000000

>> Y = [7333330    -1333330 0; -1333330    23333330   -22000000; 0   -22000000
22000000]

Y =

    7333330   -1333330          0
   -1333330   23333330  -22000000
          0  -22000000   22000000

>> F = [15000; -8000; 12000]

F =

      15000
      -8000
      12000

>> U = inv(Y)*F

U =

    0.0032
    0.0062
    0.0067
```

Equilibrando fuerzas

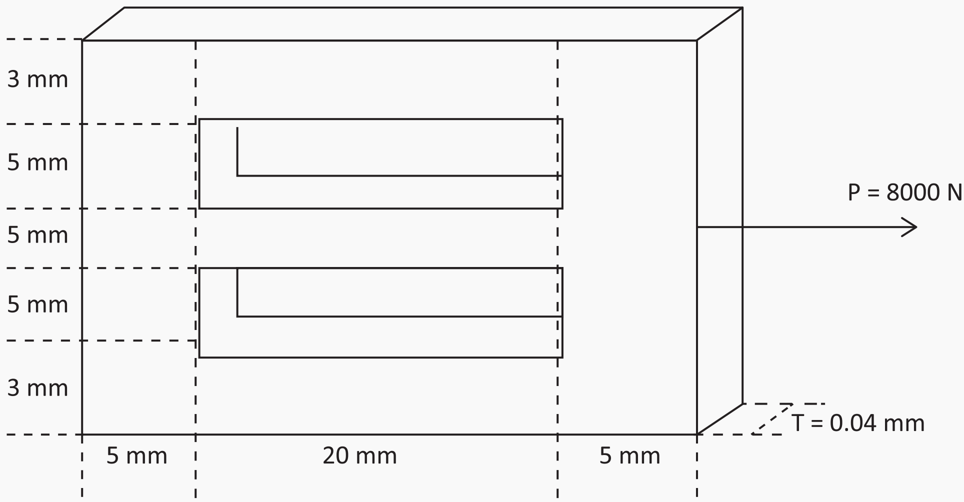
$$F_4 = -keq_3 \times U_3 + keq_4 \times U_4$$

$$\left(-22000\frac{N}{m}10^3\right)\times(0.0062)+\left(22000\frac{N}{m}10^3\right)\times(0.0067)=11000\,N$$

Ejemplo 4

Resolver según el diagrama y los datos siguientes:

E = 250 G Pa



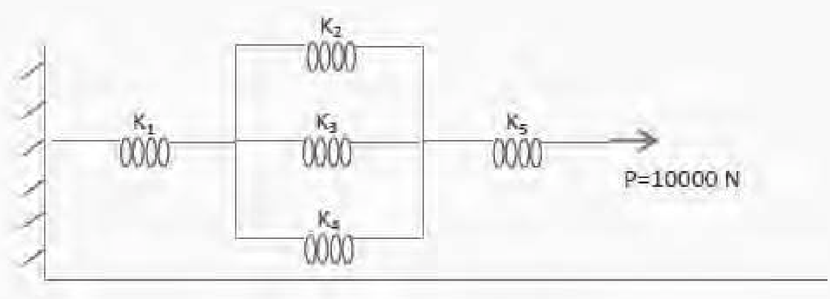
$K_1 = K_3 = 2000$ kN/m P = 3000 N

$K_2 = K_4 = 4000$ kN/m Q = 8000 N

$K_5 = K_6 = 6000$ kN/m R = 15000 N

$K_7 = 10000$ kN/m

A. Resolución



Cálculo de K:

$$k_1 = k_5 = \frac{(21\times10^{-3})(0.04\times10^{-3})(250\times10^{9})}{(5\times10^{-3})} = 42000\ \text{KN/m}$$

$$k_2 = k_4 = \frac{(3\times10^{-3})(0.04\times10^{-3})(250\times10^{9})}{(20\times10^{-3})} = 1500\ \text{KN/m}$$

$$k_3 = \frac{(5\times10^{-3})(0.04\times10^{-3})(250\times10^{9})}{(20\times10^{-3})} = 2500\ \text{KN/m}$$

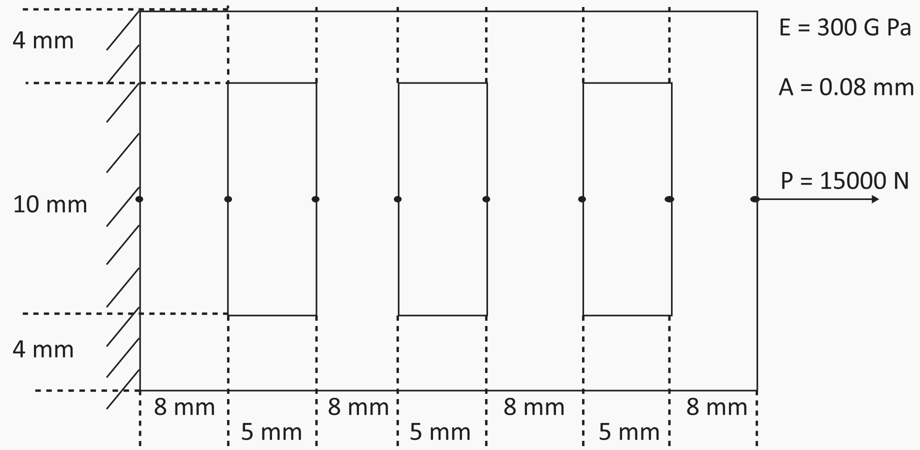
$$K_{eq1} = K_2 + K_3 + K_4 = 1500\frac{kN}{m} + 2500\frac{kN}{m} + 1500\frac{kN}{m} = 5500\frac{kN}{m}$$

B. Resolución con MATLAB

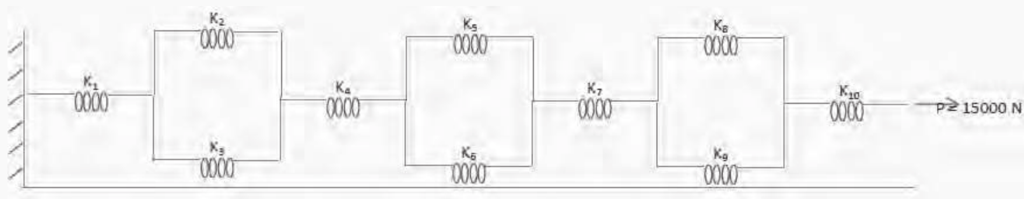
```
>> k1=1000*[42000 -42000 0 0;-42000 42000 0 0; 0 0 0 0; 0 0 0 0]

k1 =

    42000000   -42000000           0           0
   -42000000    42000000           0           0
           0           0           0           0
           0           0           0           0

>> keq1=1000*[0 0 0 0; 0 5500 -5500 0; 0 -5500 5500 0; 0 0 0 0]

keq1 =

           0           0           0           0
           0     5500000    -5500000           0
           0    -5500000     5500000           0
           0           0           0           0

>> k5=1000*[0 0 0 0; 0 0 0 0; 0 0 42000 -42000; 0 0 -42000 42000]

k5 =

           0           0           0           0
           0           0           0           0
           0           0    42000000   -42000000
           0           0   -42000000    42000000

>> K=k1+keq1+k5

K =

    42000000   -42000000           0           0
   -42000000    47500000    -5500000           0
           0    -5500000    47500000   -42000000
           0           0   -42000000    42000000

>> Y= [47500000 -5500000 0; -5500000 47500000 -42000000; 0 -42000000 42000000]

Y =

    47500000    -5500000           0
    -5500000    47500000   -42000000
           0   -42000000    42000000

>> F= [0; 0; 10000]

F =

           0
           0
       10000

>> U=inv(Y)*F

U =

    0.0002
    0.0021
    0.0023
```

Ejemplo 5

Resolver según el diagrama y los datos siguientes:



A. Resolución



Cálculo de K:

$$k_1 = k_4 = k_7 = k_{10} = \frac{(18\times10^{-3})(0.08\times10^{-3})(300\times10^{9})}{(8\times10^{-3})} = 54000\ KN/m$$

$$k_2 = k_3 = k_5 = k_6 = k_8 = k_9 = \frac{(4\times10^{-3})(0.08\times10^{-3})(300\times10^{9})}{(5\times10^{-3})} = 19200\ KN/m$$

Valores de K:

$$k_1 = k_4 = k_7 = k_{10} = 54000\ KN/m$$

$$keq_1 = keq_2 = keq_3 = 19200\frac{kN}{m} + 19200\frac{kN}{m} = 38400\frac{kN}{m}$$

B. Resolución con MATLAB

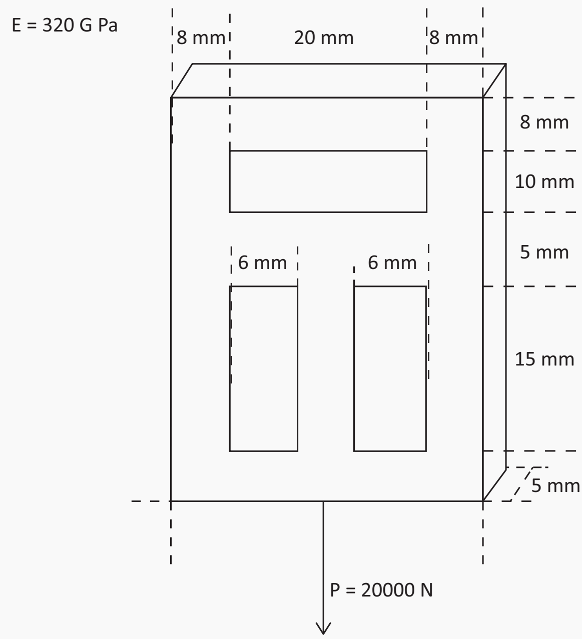
```
>>k1=1000*[54000 -54000 0 0 0 0 0 0; -54000 54000 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0]

k1 =

    54000000   -54000000           0           0           0           0           0           0
   -54000000    54000000           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0

>>keq1=1000*[0 0 0 0 0 0 0 0; 0 384000 -38400 0 0 0 0 0; 0 -38400 38400 0 0 0 0 0; 0 0 0 0 0 0 0
0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0]

keq1 =

           0           0           0           0           0           0           0           0
           0    38400000   -38400000           0           0           0           0           0
           0   -38400000    38400000           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0

>>k4=1000*[0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 54000 -54000 0 0 0 0; 0 0 -54000 54000 0 0 0 0;
0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0]

k4 =

           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0    54000000   -54000000           0           0           0           0
           0           0   -54000000    54000000           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0

>>keq2=1000*[0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 38400 -38400 0 0 0; 0 0 0
38400 38400 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0]

keq2 =

           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0    38400000   -38400000           0           0           0
           0           0           0   -38400000    38400000           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
```

```
>>k7=1000*[0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 54000
-54000 0 0; 0 0 0 0 -54000 54000 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0]

k7 =

           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0    54000000   -54000000           0           0
           0           0           0           0   -54000000    54000000           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0

>>keq3=1000*[0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0;
0 0 0 0 0 38400 -38400 0; 0 0 0 0 0 -38400 38400 0; 0 0 0 0 0 0 0 0]

keq3 =

           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0    38400000   -38400000           0
           0           0           0           0           0   -38400000    38400000           0
           0           0           0           0           0           0           0           0

>>k10=1000*[0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0; 0 0 0 0 0 0 54000 -54000; 0 0 0 0 0 0 -54000 54000]

k10 =

           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0           0           0
           0           0           0           0           0           0    54000000   -54000000
           0           0           0           0           0           0   -54000000    54000000

>> K= k1+keq1+k4+keq2+ k7+ keq3+ k10

K =

    54000000   -54000000           0           0           0           0           0           0
   -54000000    92400000   -38400000           0           0           0           0           0
           0   -38400000    32400000   -54000000           0           0           0           0
           0           0   -54000000    92400000   -38400000           0           0           0
           0           0           0   -38400000    92400000   -54000000           0           0
           0           0           0           0   -54000000    92400000   -38400000           0
           0           0           0           0           0   -38400000    92400000   -54000000
           0           0           0           0           0           0   -54000000    54000000

>>Y = [92400000 -38400000 0 0 0 0 0; -38400000 92400000 -54000000 0 0 0 0; 0 -54000000 92400000
-38400000 0 0 0; 0 0 -38400000 92400000 -54000000 0 0; 0 0 0 -54000000 92400000 -38400000 0; 0 0
0 0 -38400000 92400000 -54000000 0; 0 0 0 0 0 -54000000 54000000]
```

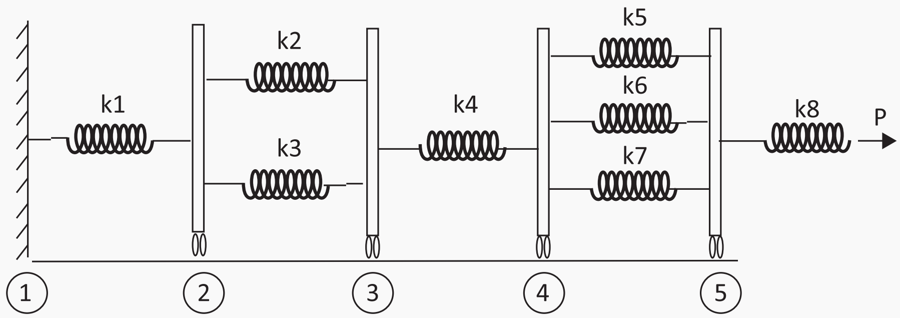
```
Y =

    92400000   -38400000           0           0           0           0           0
   -38400000    92400000   -54000000           0           0           0           0
           0   -54000000    92400000   -38400000           0           0           0
           0           0   -38400000    92400000   -54000000           0           0
           0           0           0   -54000000    92400000   -38400000           0
           0           0           0           0   -38400000    92400000   -54000000
           0           0           0           0           0   -54000000    54000000

>> F = [0; 0; 0; 0; 0; 0; 15000]

F =
           0
           0
           0
           0
           0
           0
       15000

>> U= inv (Y)*F

U =
    0.0003
    0.0007
    0.0009
    0.0013
    0.0016
    0.0020
    0.0023
```

EJEMPLO 6

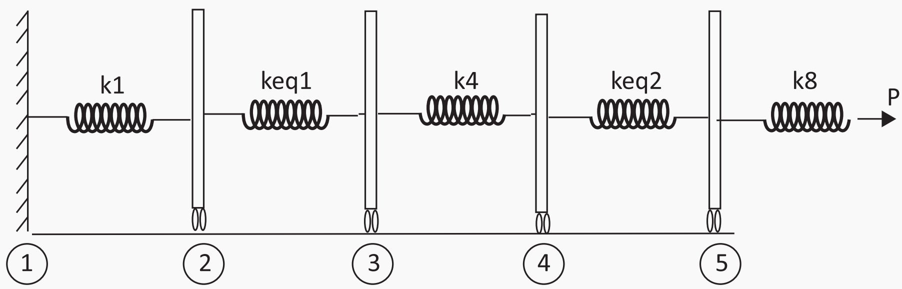
Resolver según el diagrama (en la parte superior el sistema está empotrado) y los datos siguientes:



A. Resolución



Redibujando:



Cálculo de K:

$$k_1 = \frac{(36\times10^{-3})(0.075\times10^{-3})(320\times10^{9})}{(8\times10^{-3})} = 108000\ \text{KN/m}$$

$$k_2 = k_3 = \frac{(8\times10^{-3})(0.075\times10^{-3})(320\times10^{9})}{(10\times10^{-3})} = 19200\ \text{KN/m}$$

$$k_4 = k_8 = \frac{(36\times10^{-3})(0.075\times10^{-3})(320\times10^{9})}{(5\times10^{-3})} = 172800\ \text{KN/m}$$

$$k_5 = k_7 = \frac{(8\times10^{-3})(0.075\times10^{-3})(320\times10^{9})}{(15\times10^{-3})} = 12800\ \text{KN/m}$$

$$k_6 = \frac{(8\times10^{-3})(0.075\times10^{-3})(320\times10^{9})}{(15\times10^{-3})} = 12800\ \text{KN/m}$$

Valores de K:

$$k_1 = 108000\ \text{KN/m}$$

$$keq_1 = 19200\text{KN/m} + 19200\text{KN/m} = 38400\ \text{KN/m}$$

$$k_4 = k_8 = 172800\ \text{KN/m}$$

$$keq_2 = 12800\text{KN/m} + 320000\text{KN/m} + 12800\text{KN/m} = 38400\ \text{KN/m}$$

B. Resolución con MATLAB

```
>> k1=1000*[108000 -108000 0 0 0 0;-108000 108000 0 0 0 0;0 0 0 0 0 0;0 0 0 0 0;0 0 0 0 0 0;0 0 0 0 0 0 ]

k1 =

   108000000  -108000000           0           0           0           0
  -108000000   108000000           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0

>> keq1=1000*[0 0 0 0 0 0; 0 38400 -38400 0 0 0;0 -38400 38400 0 0 0;0 0 0 0 0 0;0 0 0 0 0 0;0 0 0 0 0 0 ]

keq1 =

           0           0           0           0           0           0
           0    38400000   -38400000           0           0           0
           0   -38400000    38400000           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0

>> k4=1000*[0 0 0 0 0 0;0 0 0 0 0 0;0 0 172800 -172800 0 0;0 0 -172800 172800 0 0;0 0 0 0 0 0;0 0 0 0 0 0 ]

k4 =

           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0   172800000  -172800000           0           0
           0           0  -172800000   172800000           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0

>> keq2=1000*[0 0 0 0 0 0; 0 0 0 0 0 0; 0 0 0 0 0 0; 0 0 0 83200 -83200 0;0 0 0 -83200 83200 0;0 0 0 0 0 0 ]

keq2 =

           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0    83200000   -83200000           0
           0           0           0   -83200000    83200000           0
           0           0           0           0           0           0

>> k=1000*[0 0 0 0 0 0; 0 0 0 0 0 0;0 0 0 0 0 0;0 0 0 0 0 0;0 0 0 0 172800 -172800;0 0 0 0 -172800 172800 ]

k =

           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0   172800000  -172800000
           0           0           0           0  -172800000   172800000
```

```
>> K=k1+keq1+k4+keq2+k

K =

   108000000  -108000000           0           0           0           0
  -108000000   146400000   -38400000           0           0           0
           0   -38400000   211200000  -172800000           0           0
           0           0  -172800000   256000000   -83200000           0
           0           0           0   -83200000   256000000  -172800000
           0           0           0           0  -172800000   172800000

>> Y = [1.4640 -0.3840 0 0 0;-0.3840 2.1120 -1.7280 0 0;0 -1.7280 2.5600 -0.8320
0;0 0 -0.8320  2.5600 -1.7280;0 0 0 -1.7280 1.7280]

Y =

    1.4640   -0.3840         0         0         0
   -0.3840    2.1120   -1.7280         0         0
         0   -1.7280    2.5600   -0.8320         0
         0         0   -0.8320    2.5600   -1.7280
         0         0         0   -1.7288    1.7280

>> F= [0; 0; 0; 0; 20000]

F =

           0
           0
           0
           0
       20000

>> U=inv(Y)*F

U =

  1.0e+005 *

    0.1852
    0.7060
    0.8218
    1.0621
    1.1779
```

CAPÍTULO

3

PRINCIPIO DE HIPERESTATICIDAD

3.1. GRADOS DE INDETERMINACIÓN

En el análisis estructural, se consideran dos tipos de indeterminación: la estática y cinemática. La primera, tiene relación con las fuerzas y, la segunda, con los desplazamientos.

3.1.1. Indeterminación estática

Se refiere a un exceso de reacciones y fuerzas internas desconocidas, comparadas con las ecuaciones de equilibrio de la estática. Esto da lugar a clasificar las estructuras como estáticamente determinadas y estáticamente indeterminadas. Las fuerzas internas o reacciones desconocidas que no se pueden obtener con las ecuaciones de equilibrio se denominan «fuerzas redundantes» y el número de fuerzas redundantes define el grado de indeterminación estática o hiperestaticidad.

Existen dos tipos de indeterminación estática: externa e interna. La **indeterminación externa** se refiere al número de reacciones redundantes de la estructura y la **indeterminación interna** al número de fuerzas de la estructura que no pueden conocerse con las ecuaciones de la estática. El grado total de indeterminación es la suma de ambas.

3.1.2. Indeterminación cinemática

Se refiere al número de desplazamientos desconocidos o redundantes que describen el comportamiento de la estructura (movimiento) cuando esta se sujeta a acciones de carga.

3.2. CLASIFICACIÓN DE ESTRUCTURAS

Las estructuras se dividen, desde el punto de vista de los métodos de análisis, en isostáticas o estáticamente determinadas, hiperestáticas o estáticamente indeterminadas. Las ***estructuras isostáticas*** son aquellas que se pueden resolver utilizando únicamente las ecuaciones de equilibrio de la estática. Por el contrario, para analizar ***estructuras hiperestáticas*** es necesario plantear, además de las ecuaciones de equilibrio, ecuaciones de compatibilidad de deformaciones entre los elementos de la estructura y los apoyos.

3.3. CÁLCULO DEL GRADO DE INDETERMINACIÓN O HIPERESTATICIDAD

Cuando una estructura es isostática, su grado de indeterminación $GH = 0$; ya que es estáticamente determinada. Las estructuras hiperestáticas pueden tener distintos grados de indeterminación $GH > 0$ si una estructura es inestable su grado de indeterminación es $GH < 0$.

Es decir:

$GH > 0$ Estructuras hiperestáticas

$GH = 0$ Estructuras isoestáticas

$GH < 0$ Estructuras inestables

En el caso de armaduras y marcos, pueden ser externas o internamente indeterminadas. Son ***externamente indeterminadas*** cuando el número de reacciones es mayor que el número de las ecuaciones de equilibrio más las ecuaciones de condición. La ***indeterminación interna*** ocurre cuando el número de miembros es mayor al mínimo necesario para que la estructura sea estable.

Elemento	Grado de Hiperestaticidad	Grado de libertad
Vigas	GHT = NR – NEE – C	GL = 3NN – NR
Armaduras	GHT = GHE + GHI GHE = NR – NEE GHI = NE – 2NN + 3(2D) GHI = NE – 3NN + 6(3D)	GL = 2NN – NR(2D) GL = 3NN – NR(3D)
Marcos	GHT = GHE + GHI GHE = NR – NEE – C GHI = 3NE – 3NN + NEE(2D) GHI = 6NE – 6NN + NEE(3D)	GL = 3NN – NR(2D) GL = 6NN – NR(3D)

Donde:

GHT : Grado de hiperestaticidad total

GHE : Grado de hiperestaticidad externa

GHI : Grado de hiperestaticidad interna

NR : Número de reacciones

NEE : Número de ecuaciones de la estática

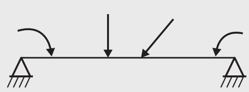
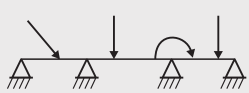
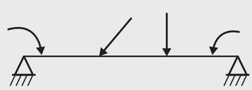
NE : Número de elementos

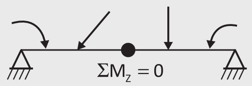
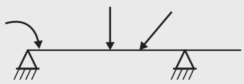
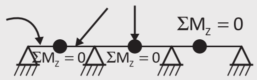
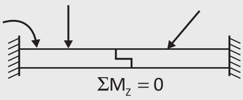
NN : Número de nodos

C : Ecuaciones adicionales de condición

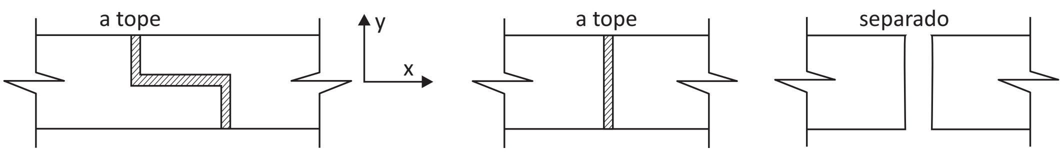
GL : Grado de libertad o desplazamiento redundante

Determine el grado de hiperestaticidad de las siguientes vigas

Estructura	NN	NR	NEE	C	GH	GL	
	2	3	3	0	0	3	Isostática
	4	5	3	0	2	7	Hiperestática grado 2
	2	2	3	0	–1	4	Inestable

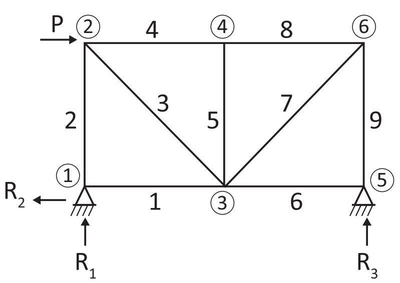
ESTRUCTURA	NN	NR	NEE	C	GH	GL	
	2	4	3	1	0	2	isostática
	2	3	3	0	0	3	isostática
	4	5	3	3	–1	7	Inestable
	2	6	3	1	2	0	Hiperestática grado 2

Ecuaciones de condición



$\Sigma Fx \neq 0$	$\Sigma Fx \neq 0$	$\Sigma Fx = 0$
$\Sigma Fy \neq 0$	$\Sigma Fy = 0$	$\Sigma Fy = 0$
$\Sigma M_z = 0$	$\Sigma M_z = 0$	$\Sigma M_z = 0$

Determine el grado de hiperestaticidad de las siguientes armaduras



NN = 6
NE = 9
NR = 3
NEE = 3

a) Cálculo del Grado de hiperestaticidad

Grado de hiperestaticidad externo

GHE = NR – NEE = 3 – 3 = 0

Grado de hiperestaticidad interno

GHI = NE – 2NN + NEE = 9 – 2(6) + 3 = 0

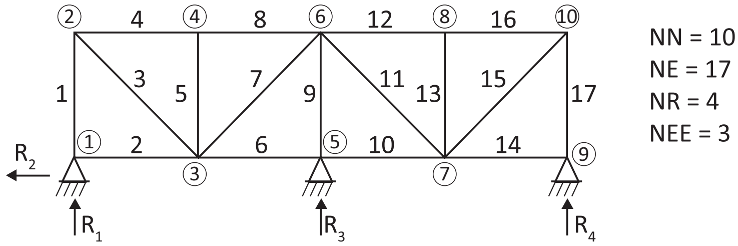
Grado de hiperestaticidad total

GHT = 0

Armadura estáticamente determinada externa e internamente (ISOSTÁTICA)

b) Cálculo del grado de libertad

GL = 2NN – NR = 2(6) – 3 = 9



a) Cálculo del Grado de hiperestaticidad

GHE = NA – NEE = 4 – 3 = 1

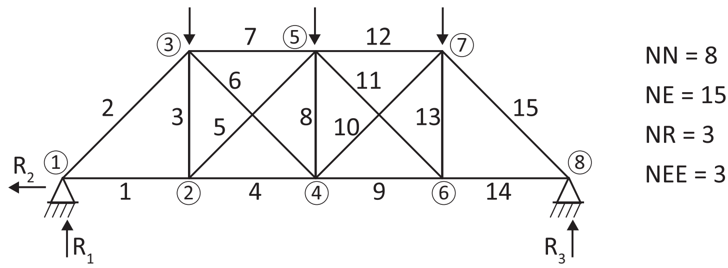
GHI = NE – 2NN + NEE = 17 – 2(10) + 3 = 0

GTH = 1 + 0 = 1

Armadura estáticamente indeterminada externamente de grado 1 y determinada internamente

b) Cálculo del grado de libertad

GL = 2NN – NR = 2(10) – 4 = 16



a) Cálculo del Grado de hiperestaticidad

GHE = NR – NEE = 3 – 3 = 0

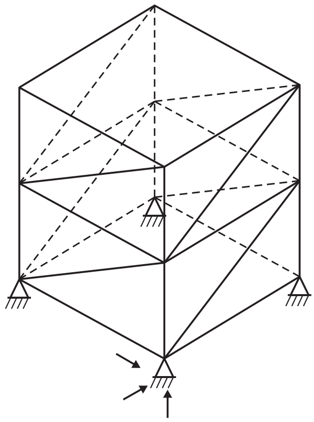
GHI = NE – 2NN + NEE = 15 – 2(8) + 3 = 2

GHT = GHE + GHI = 0 + 2 = 2

Armadura estáticamente determinada externamente e indeterminado internamente de grado 2

b) Cálculo del grado de libertad

GL = 2NN – NR = 2(8) – 3 = 13



NN = 12

NE = 29

NR = 12

NEE = 6

a) Cálculo del Grado de hiperestaticidad

$$GHE = NR - NEE = 12 - 6 = 6$$

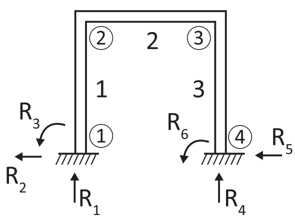
$$GHI = NE - 3NN + NEE = 28 - 3(12) + 6 = -2$$

Armadura estáticamente indeterminada externamente de grado 2 e inestable internamente

b) Cálculo del grado de libertad

$$GL = 3NN - NR = 3(12) - 12 = 24$$

Determine el grado de hiperestaticidad (indeterminación) y de libertad de los siguientes marcos.



NN = 4

NE = 3

NR = 6

NEE = 3

C = 0

a) Cálculo del Grado de hiperestaticidad

$$GHE = NR - NEE - C = 6 - 3 - 0 = 3$$

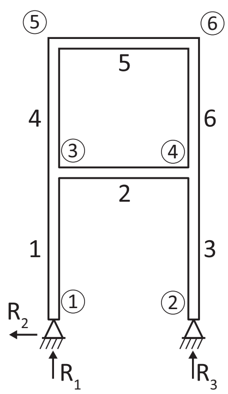
$$GHI = 3NE - 3NN + NEE = 3(3) - 3(4) + 3 = 0$$

$$GHT = GHE + GHI = 3$$

Marco estáticamente indeterminado externamente de grado 3 y determinado internamente (isostático)

b) Cálculo del grado de libertad

$$GL = 3NN - NR = 3(4) - 6 = 6$$



NN = 6

NE = 6

NR = 3

NEE = 3

C = 0

a) Cálculo del Grado de hiperestaticidad

$$GHE = NR - NEE - C = 3 - 3 - 0 = 0$$

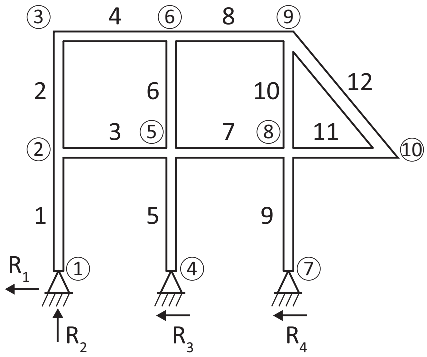
$$GHI = 3NE - 3NN + NEE = 3(6) - 3(6) + 3 = 3$$

$$GHT = GHE + GHI = 0 + 3 = 3$$

Marco estáticamente determinado externamente (isostático) e indeterminado internamente de grado 3

b) Cálculo del grado de libertad

$$GL = 3NN - NR = 3(6) - 3 = 15$$



NN = 10

NE = 12

NR = 4

NEE = 3

C = 0

a) Cálculo del Grado de hiperestaticidad

GHE = NR – NEE – C = 4 – 3 – 0 = 1

GHI = 3NE – 3NN + NEE = 3(12) – 3(10) + 3 = 9

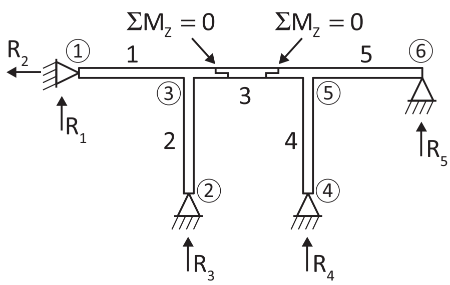
GHT = GHE + GHI = 1 + 9 = 10

Marco estáticamente indeterminado externamente de grado 1 e internamente de grado 9

Nota: Por cada crujia cerrada en los marcos, se tienen 3 grados de indeterminación interna.

b) Cálculo del grado de libertad

GL = 3NN – NR = 3(10) – 4 = 26



NN = 6

NE = 5

NR = 5

NEE = 3

C = 2

a) Cálculo del Grado de hiperestaticidad

GHE = NR – NEE – C = 5 – 3 – 2 = 0

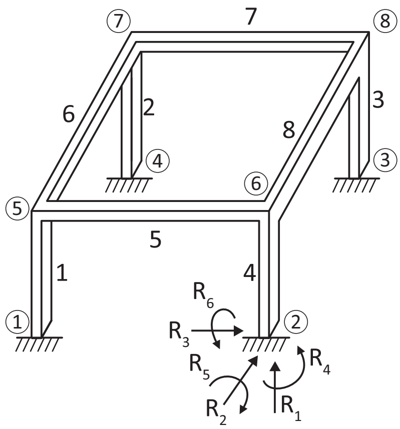
GHI = 3NE – 3NN + NEE = 3(5) – 3(6) + 3 = 0

GHT = 6GHE + 6GHI = 0 + 0 = 0

Marco estáticamente determinado externa e internamente

b) Cálculo del grado de libertad

GL = 3NN – NR = 3(6) – 5 = 11



NN = 8
NE = 8
NR = 24
NEE = 6
C = 0

a) Cálculo del Grado de hiperestaticidad

GHE = NR – NEE – C = 24 – 6 = 18

GHI = 6NE – 6NN + NEE = 6(8) – 6(8) + 6 = 6

GHT = 6GHE + GHI = 18 + 6 = 24

Marco estáticamente indeterminado externamente de grado 18 e internamente de grado 6

b) Cálculo del grado de libertad

GL = 6NN – NR = 6(8) – 24 = 11

CAPÍTULO

4

BARRA 1D

4.1. ANÁLISIS ESTÁTICO LINEAL

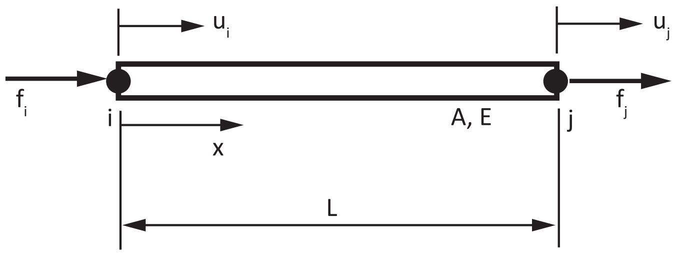
Más problemas del análisis estructural pueden tratarse como los problemas estáticos lineales, basado en las asunciones siguientes:

- Las deformaciones pequeñas (el modelo cargando no se cambia a la forma deformada).
- Los materiales elásticos (ninguna plasticidad).
- Las cargas estáticas (la carga se aplica a la estructura en un modo lento).

El análisis lineal puede proporcionar la mayoría de la información sobre la conducta de una estructura y puede ser una aproximación adecuada para muchos análisis. También, constituye la base de análisis no lineal en la mayoría de los casos.

4.1.1. Construir el elemento

Considere una barra prismática uniforme:



Donde:

L	Longitud
A	Área de la sección transversal
E	Módulo de elasticidad
$u = u(x)$	Desplazamiento
$\varepsilon = \varepsilon(x)$	Deformación
$\sigma = \sigma(x)$	Esfuerzo

La relación de deformación-desplazamiento:

$$\varepsilon = \frac{du}{dx} \tag{1}$$

La relación del esfuerzo-deformación:

$$\sigma = E\varepsilon \tag{2}$$

4.1.2. Matriz de rigidez y el método directo

Asumiendo que el desplazamiento $u_{(y)}$ está variando linealmente a lo largo del eje de la barra, es decir:

$$u(x) = \left(1 - \frac{x}{L}\right)u_i + \frac{x}{L}u_j \tag{3}$$

Se obtiene lo siguiente:

$$\sigma = \frac{u_j - u_i}{L} = \frac{\Delta}{L} \quad (\Delta = \text{Elongación}) \tag{4}$$

$$\sigma = E\varepsilon = \frac{E\Delta}{L} \tag{5}$$

Entonces:

$$\sigma = \frac{F}{A} \quad (F = \text{Fuerza en la barra}) \qquad (8)$$

Así, (5) y (6) lleva a:

$$F = \frac{EA}{L}\Delta = k\Delta \qquad (7)$$

Donde:

$$k = \frac{EA}{L} \text{ es la rigidez de la barra}$$

En este caso, la barra está actuando como un resorte y se concluye que la matriz de rigidez de la barra es como sigue:

$$k = \begin{bmatrix} k & -k \\ -k & k \end{bmatrix} = \begin{bmatrix} \frac{EA}{L} & -\frac{EA}{L} \\ -\frac{EA}{L} & \frac{EA}{L} \end{bmatrix}$$

$$k = \frac{EA}{L}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \qquad (8)$$

Esto puede verificarse considerando el equilibrio de las fuerzas a los dos nodos.

La ecuación de equilibrio del elemento estaría dada por la siguiente:

$$\frac{EA}{L}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}\begin{Bmatrix} u_i \\ u_j \end{Bmatrix} = \begin{Bmatrix} f_i \\ f_j \end{Bmatrix}$$

- El grado de libertad (dof)
- El número de componentes del vector del desplazamiento a un nodo
- Para 1D, el elemento de la barra: un dof a cada nodo.
- El significado físico de los coeficientes en k

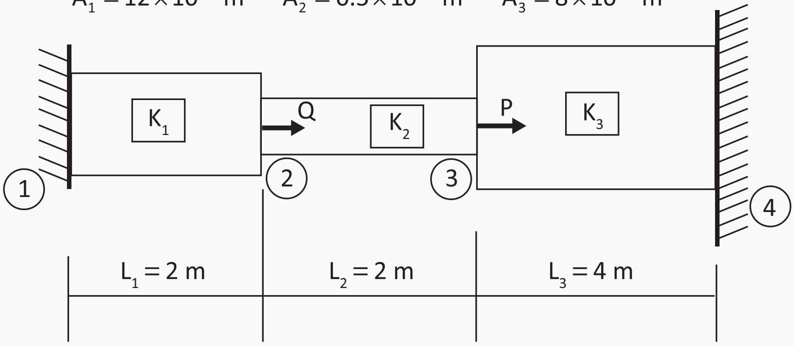
La j-ésima columna de k (aquí j = 1 o 2) representa las fuerzas aplicadas a la barra para mantener una forma deformada con el desplazamiento de la unidad al nodo j y cero desplazamiento al otro nodo.

EJERCICIO 1

Hallar los desplazamientos nodales, los esfuerzos y las fuerzas en las paredes en el siguiente sistema de barras sometidas a cargas axiales:

$E_1 = 200 \text{ GPa}$ $E_2 = 120 \text{ GPa}$ $E_3 = 150 \text{ GPa}$

$A_1 = 12 \times 10^{-4} \text{ m}^2$ $A_2 = 0.5 \times 10^{-4} \text{ m}^2$ $A_3 = 8 \times 10^{-4} \text{ m}^2$



$P = 2500 \text{ kN}$ $Q = 3000 \text{ kN}$

A. Resolución

Paso 1: Calcule las rigideces de cada barra.

$$K_1 = \frac{E_1 \times A_1}{L_1} = \frac{\left(\dfrac{200 \times 10^9 \text{N}}{\text{m}^2}\right) \times (2 \times 10^{-4} \text{m}^2)}{2\text{m}} = 20 \times 10^6 \text{N/m}$$

$$K_2 = \frac{E_1 \times A_1}{L_2} = \frac{\left(\dfrac{120 \times 10^9 \text{N}}{\text{m}^2}\right) \times (0.5 \times 10^{-4} \text{m}^2)}{2\text{m}} = 3 \times 10^6 \text{N/m}$$

$$K_3 = \frac{E_2 \times A_2}{L_3} = \frac{\left(\dfrac{150 \times 10^9 \text{N}}{\text{m}^2}\right) \times (8 \times 10^{-4} \text{m}^2)}{4\text{m}} = 30 \times 10^6 \text{N/m}$$

Paso 2: Defina cada una de las rigideces.

$$K_1 = \begin{pmatrix} 20 \times 10^6 & -20 \times 10^6 & 0 & 0 \\ -20 \times 10^6 & 20 \times 10^6 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

$$K_2 = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 3 \times 10^6 & -3 \times 10^6 & 0 \\ 0 & -3 \times 10^6 & 3 \times 10^6 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

$$K_3 = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 30\times10^6 & -30\times10^6 \\ 0 & 0 & -30\times10^6 & 30\times10^6 \end{pmatrix}$$

La matriz ensamblada es como sigue.

$$\begin{array}{c} \quad\quad \mathbf{u_1} \quad\quad \mathbf{u_2} \quad\quad \mathbf{u_3} \quad\quad \mathbf{u_4} \end{array}$$

$$K = \begin{bmatrix} K_1 & -K_1 & 0 & 0 \\ -K_1 & K_1 + K_2 & -K_2 & 0 \\ 0 & -K_2 & K_2 + K_3 & -K_3 \\ 0 & 0 & -K_3 & K_3 \end{bmatrix} \begin{bmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \end{bmatrix} = \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \end{bmatrix}$$

$$K_T = \begin{pmatrix} 20\times10^6 & -20\times10^6 & 0 & 0 \\ -20\times10^6 & 23\times10^6 & -3\times10^6 & 0 \\ 0 & -3\times10^6 & 33\times10^6 & -30\times10^6 \\ 0 & 0 & -30\times10^6 & 30\times10^6 \end{pmatrix} \begin{pmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \end{pmatrix} = \begin{pmatrix} r_1 \\ Q \\ P \\ r_4 \end{pmatrix}$$

Paso 3: Como los nodos 1 y 4 están conectados a la pared, sus desplazamientos son cero; razón por la cual se pueden eliminar las filas y columnas 1 y 4, respectivamente; de tal manera que la matriz simplificada estaría dada por:

$$K = \begin{bmatrix} 23\times10^6 & -3\times10^6 \\ -3\times10^6 & 33\times10^6 \end{bmatrix} \begin{bmatrix} U_2 \\ U_3 \end{bmatrix} = \begin{bmatrix} 2.5\times10^6 \\ 3\times10^6 \end{bmatrix}$$

$$u_2 = 0.1220 \text{ m}$$

$$u_3 = 0.1020 \text{ m}$$

Paso 4: Por tanto, las fuerzas estarían dadas por los siguientes valores:

$$F_1 = -K_1 \times u_2 = -2.44\times10^6$$

$$F_4 = -K_3 \times u_3 = -3.06\times10^6$$

Paso 5: Calcule los esfuerzos introduciendo los datos en MATLAB y su procedimiento para cada uno, aplicando la fórmula siguiente:

$$\sigma = \frac{E}{L}\begin{bmatrix} -1 & 1 \end{bmatrix}\begin{bmatrix} u_i \\ u_j \end{bmatrix}$$

$$\sigma_{1-2} = \left(\frac{200\times10^9}{2}\right)\begin{bmatrix} -1 & 1 \end{bmatrix}\begin{bmatrix} 0 \\ 0.1220 \end{bmatrix}$$

$$\sigma_{1-2} = 12.2 \text{ GPa}$$

$$\sigma_{2-3} = \left(\frac{120\times10^{9}}{2}\right)\begin{bmatrix}-1 & 1\end{bmatrix}\begin{bmatrix}0.1220\\0.1020\end{bmatrix}$$

$$\sigma_{2-3} = -1.2\text{ GPa}$$

$$\sigma_{3-4} = \left(\frac{150\times10^{9}}{4}\right)\begin{bmatrix}-1 & 1\end{bmatrix}\begin{bmatrix}0.1020\\0\end{bmatrix}$$

$$\sigma_{3-4} = -3.825\text{ GPa}$$

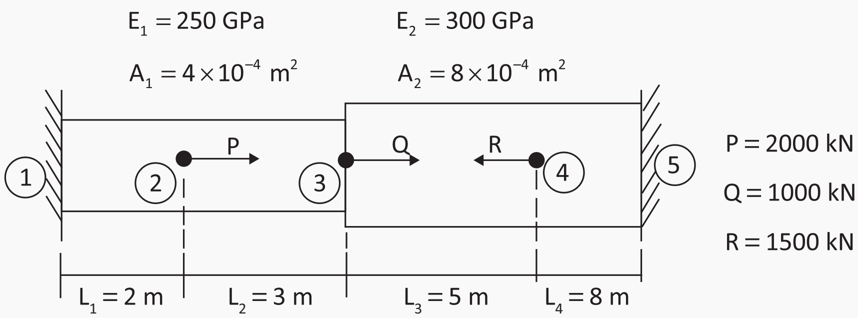
B. Resolución con MATLAB

```
>> A = 10^6*[23 -3; -3 33]

A =

    23000000    -3000000
    -3000000    33000000

>> f = 10^3*[2500; 3000]

f =

     2500000
     3000000

>> u = inv(A)*f

u =

    0.1220
    0.1020

>> % CALCULO DE LOS ESFUERZOS:
>> E1 = 200*10^9;
>> E2 = 120*10^9;
>> E3 = 150*10^9;
>> L1 = 2;
>> L2 = 2;
>> L3 = 4;
>> U1 = 0;
>> U2 = 0.1220;
>> U3 = 0.1023;
>> U4 = 0;
>> % ESFUERZO ENTRE 1 Y 2:
>> G12 = (E1/L1)*[-1 1]*[U1; U2]

G12 =

  1.2200e+010

>> % ESFUERZO ENTRE 2 Y 3:
>> G23 = (E2/L2)*[-1 1]*[U2; U3]

G23 =

 -1.2000e+009
```

```
>> % ESFUERZO ENTRE 3 Y 4:
>> G34 = (E3/L3)*[-1 1]*[U3; U4]

G34 =

 -3.8250e+009


>> % LA MATRIZ ENSAMBLADA K ES:
>> K = [20*10^6 -20*10^6 0 0; -20*10^6 23*10^6 -3*10^6 0; 0 -3*10^6 33*10^6
-30*10^6; 0 0 -30*10^6 30*10^6]

K =

    20000000   -20000000           0           0
   -20000000    23000000    -3000000           0
           0    -3000000    33000000   -30000000
           0           0   -30000000    30000000

>> % EL VECTOR DESPLAZAMIENTO ES:
>> U = [0; 0.1220; 0.1020; 0]

U =

         0
    0.1220
    0.1020
         0

>> % CALCULO DE LAS FUERZAS EN LAS PAREDES:
>> F = K*U

F =

    -2440000
     2500000
     3000000
    -3060000
```

Ejercicio 2

Hallar los desplazamientos nodales, los esfuerzos y las fuerzas en las paredes en el siguiente sistema de barras sometidas a cargas axiales:



A. Resolución

$$K_1 = \frac{E_1 \times A_1}{L_1} = \frac{\left(250\times10^9\right)(4\times10^{-4})}{2} = 50\times10^6\ N/m$$

$$K_2 = \frac{E_1 \times A_1}{L_2} = \frac{\left(250\times10^9\right)(4\times10^{-4})}{3} = 33\times10^6\ N/m$$

$$K_3 = \frac{E_2 \times A_2}{L_3} = \frac{\left(300\times10^9\right)(8\times10^{-4})}{5} = 48\times10^6\ N/m$$

$$K_4 = \frac{E_2 \times A_2}{L_4} = \frac{\left(300\times10^9\right)(8\times10^{-4})}{8} = 30\times10^6\ N/m$$

$$K = \begin{array}{c} \begin{array}{ccccc} \mu_1 & \mu_2 & \mu_3 & \mu_4 & \mu_5 \end{array} \\ \begin{bmatrix} K_1 & -K_1 & 0 & 0 & 0 \\ -K_1 & K_1+K_2 & -K_2 & 0 & 0 \\ 0 & -K_2 & K_2+K_3 & -K_3 & 0 \\ 0 & 0 & -K_3 & K_3+K_4 & -K_4 \\ 0 & 0 & 0 & -K_4 & K_4 \end{bmatrix} \end{array} \begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \\ \mu_5 \end{bmatrix} = \begin{bmatrix} F_1 \\ P \\ R \\ -Q \\ F_5 \end{bmatrix}$$

$$\underbrace{\begin{pmatrix} 83\times10^6 & -33\times10^6 & 0 \\ -33\times10^6 & 81\times10^6 & -48\times10^6 \\ 0 & -48\times10^6 & 78\times10^6 \end{pmatrix}}_{K} \underbrace{\begin{pmatrix} \mu_2 \\ \mu_3 \\ \mu_4 \end{pmatrix}}_{\mu} = \underbrace{\begin{pmatrix} 2\times10^6 \\ 1.5\times10^6 \\ -1\times10^6 \end{pmatrix}}_{F}$$

$$\mu_2 = 0.0523$$

$$\mu_3 = 0.0709$$

$$\mu_4 = 0.0629$$

$$\sigma = \frac{E}{L}\begin{bmatrix} -1 & 1 \end{bmatrix}\begin{pmatrix} \mu_i \\ \mu_j \end{pmatrix}$$

$$\sigma_1 = \frac{250\times10^9}{2}\begin{bmatrix} -1 & 1 \end{bmatrix}\begin{bmatrix} 0 \\ 0.0523 \end{bmatrix} = 6.5375\ GPa$$

$$\sigma_2 = \frac{250\times10^9}{3}\begin{bmatrix} -1 & 1 \end{bmatrix}\begin{bmatrix} 0.0523 \\ 0.0709 \end{bmatrix} = 1.55\ GPa$$

$$\sigma_3 = \frac{300\times10^9}{5}\begin{bmatrix} -1 & 1 \end{bmatrix}\begin{bmatrix} 0.0709 \\ 0.0629 \end{bmatrix} = -4.80\ GPa$$

$$\sigma_4 = \frac{300\times10^9}{8}\begin{bmatrix} -1 & 1 \end{bmatrix}\begin{bmatrix} 0.0629 \\ 0 \end{bmatrix} = -2.3588\ GPa$$

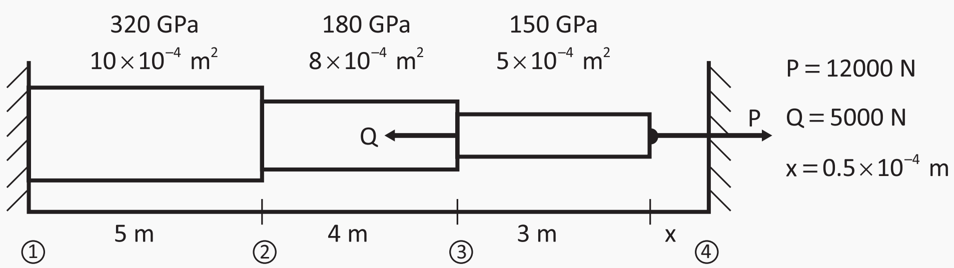
B. Resolución con MATLAB

```
>> A = 10^6*[83 -33 0; -33 81 -48; 0 -48 78]

A =

    83000000   -33000000           0
   -33000000    81000000   -48000000
           0   -48000000    78000000

>> f = 10^3*[2000; 1000; 1500]

f =

     2000000
     1000000
     1500000

>> u = inv(A)*f

u =

    0.0523
    0.0709
    0.0629

>> % LA MATRIZ ENSAMBLADA K ES:

>> K= [50*10^6 -50*10^6 0 0 0; -50*10^6 83*10^6 -33*10^6 0 0; 0 -33*10^6 81*10^6
-48*10^6 0; 0 0 -48*10^6 78*10^6 -30*10^6; 0 0 0 -30*10^6 30*10^6

K =

    50000000   -50000000           0           0           0
   -50000000    83000000   -33000000           0           0
           0   -33000000    81000000   -48000000           0
           0           0   -48000000    78000000   -30000000
           0           0           0   -30000000    30000000

>> % EL VECTOR DESPLAZAMIENTO ES:
>> U = [0; 0.0523; 0.0709; 0.0629; 0]

U =

         0
    0.0523
    0.0709
    0.0629
         0

>> % CALCULO DE LAS FUERZAS EN LAS PAREDES:
>> F = K*U

F =

    -2615000
     2001200
      997800
     1503000
    -1887000
```

```
>> % CALCULO DE LOS ESFUERZOS:
>> E1 = 250*10^9;
>> E2 = 250*10^9;
>> E3 = 300*10^9;
>> E4 = 300*10^9;
>> L1 = 2;
>> L2 = 3;
>> L3 = 5;
>> L4 = 8;
>> U1 = 0;
>> U2 = 0;0523;
>> U3 = 0.0709;
>> U4 = 0.0629;
>> U5 = 0;
>> % ESFUERZO ENTRE 1 Y 2:
>> G12 = (E1/L1)*[-1 1]*[U1; U2]

G12 =

  6.5375e+009

>> % ESFUERZO ENTRE 2 Y 3:
>> G23 = (E2/L2)*[-1 1]*[U2; U3]

G23 =

  1.5500e+009

>> % ESFUERZO ENTRE 3 Y 4:
>> G34 = (E3/L3)*[-1 1]*[U3; U4]

G34 =

 -4.8000e+008

>> % ESFUERZO ENTRE 4 y 5:
>> G45 = (E4/L4)*[-1 1]*[U4; U5]

G45 =

 -2.3588e+009
```

EJERCICIO 3

En el sistema estructural, mostrado determinar si la barra más pequeña choca con la pared y además calcular los esfuerzos en cada una de las barras.



A. Resolución

Paso 1: Calcule las rigideces de cada barra.

$$k_1 = \frac{320\times10^9 Pa\left(10\times10^{-4}m^2\right)}{5m}\times\begin{bmatrix}1 & -1 & 0 & 0\\ -1 & 1 & 0 & 0\\ 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0\end{bmatrix}$$

$$k_2 = \frac{180\times10^9 Pa\left(8\times10^{-4}m^2\right)}{4m}\times\begin{bmatrix}0 & 0 & 0 & 0\\ 0 & 1 & -1 & 0\\ 0 & -1 & 1 & 0\\ 0 & 0 & 0 & 0\end{bmatrix}$$

$$k_3 = \frac{150\times10^9 Pa\left(5\times10^{-4}m^2\right)}{3m}\times\begin{bmatrix}0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0\\ 0 & 0 & 1 & -1\\ 0 & 0 & -1 & 1\end{bmatrix}$$

La matriz ensamblada sería la siguiente:

$$\Sigma k = 10^6\times\begin{bmatrix}64 & -64 & 0 & 0\\ -64 & 100 & -36 & 0\\ 0 & -36 & 61 & -25\\ 0 & 0 & -25 & 25\end{bmatrix}\times\begin{bmatrix}0\\ u_2\\ u_3\\ u_4\end{bmatrix}=\begin{bmatrix}F_1\\ 0\\ -5000\\ 12000\end{bmatrix}$$

Paso 2: Como solo hay una pared en el nodo 1, de ahí que solo se elimine la fila y columna perteneciente a ese nodo, es decir el 1, quedando lo siguiente:

$$k = 10^6\times\begin{bmatrix}100 & -36 & 0\\ -36 & 61 & -25\\ 0 & -25 & 25\end{bmatrix}\times\begin{bmatrix}u_2\\ u_3\\ u_4\end{bmatrix}=\begin{bmatrix}0\\ -5000\\ 12000\end{bmatrix}$$

$$u = inv(k)\times F$$

Paso 3: Resolviendo se obtienen los siguientes desplazamientos:

$$u_2 = 0.1094\times10^{-3}m$$

$$u_3 = 0.3038\times10^{-3}m$$

$$u_4 = 0.7838\times10^{-3}m$$

Paso 4: Para determinar si choca o no, se tienen que sumar todos los desplazamientos y verificar si es mayor o menor que "x" $\left(x = 0.5\times10^{-4}\ m\right)$

$$\Sigma u = 1.197\times10^{-3}m$$

Se observa que el resultado final es mayor que "x", razón por la cual las barras sí chocan.

Paso 5: Calcule los esfuerzos:

$$\sigma_{1-2} = \frac{320\times10^{9}\,\text{Pa}}{5\text{m}}\times\begin{bmatrix}-1 & 1\end{bmatrix}\times\begin{bmatrix}0\\0.1094\times10^{-3}\end{bmatrix} = 7001600\ \text{Pa}$$

$$\sigma_{2-3} = \frac{180\times10^{9}\,\text{Pa}}{4\text{m}}\times\begin{bmatrix}-1 & 1\end{bmatrix}\times\begin{bmatrix}0.1094\times10^{-3}\\0.3038\times10^{-3}\end{bmatrix} = 874800\ \text{Pa}$$

$$\sigma_{3-4} = \frac{150\times10^{9}\,\text{Pa}}{3\text{m}}\times\begin{bmatrix}-1 & 1\end{bmatrix}\times\begin{bmatrix}0.3038\times10^{-3}\\0.7838\times10^{-3}\end{bmatrix} = 2.4\times10^{7}\,\text{Pa}$$

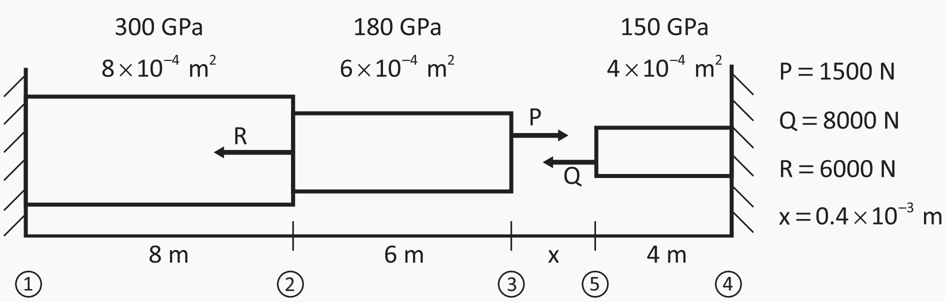
B. Resolución con MATLAB

```
>> A = 10^6*[100 -36 0; -36 61 -25; 0 -25 25]

A =

   100000000   -36000000           0
   -36000000    61000000   -25000000
           0   -25000000    25000000

>> f = [0; -5000; 12000]

f =

           0
       -5000
       12000

>> u = inv(A)*f

u =

  1.0e-003 *

    0.1094
    0.3038
    0.7838

>> u1 = 0.1094;
>> u2 = 0.3038;
>> u3 = 0.7838;
>> U = u1+u2+u3

U =

    1.1970

>> % SE OBSERVA QUE EL DESPLAZAMIENTO TOTAL U ES MAYOR QUE X, POR LO TANTO LAS
BARRAS CHOCAN.

>> % CALCULO DE ESFUERZOS:
>> E1 = 320*10^9;
>> E2 = 180*10^9;
```

```
>> E2 = 150*10^9;
>> L1 = 5;
>> L2 = 4;
>> L3 = 3;
>> U1 = 0;
>> U2 = 0.1094*10^-3;
>> U3 = 0.3038*10^-3;
>> U4 = 0.7838*10^-3;
>> % ESFUERZO ENTRE 1 Y 2:
>> G12 = (E1/L1)*[-1 1]*[Ù1; U2]

G12 =

     7001600

>> % ESFUERZO ENTRE 2 Y 3:
>> G23 = (E2/L2)*[-1 1]*[U2; U3]

G23 =

     8748000

>> % ESFUERZO ENTRE 3 Y 4:
>> G34 = (E3/L3)*[-1 1]*[U3; U4]

G34 =

  2.4000e+007
```

EJERCICIO 4

En el sistema estructural mostrado, determinar si la barra más pequeña choca con la pared y además calcular los esfuerzos en cada una de las barras.



A. Resolución

Paso 1: Calcule las rigideces de las barras de la izquierda:

$$k_1 = \frac{300\times10^9\,\text{Pa}\left(8\times10^{-4}\,\text{m}^2\right)}{8\text{m}}\begin{bmatrix} 1 & -1 & 0 \\ -1 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$k_2 = \frac{180\times10^9\,\text{Pa}\left(6\times10^{-4}\,\text{m}^2\right)}{6\text{m}}\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & -1 \\ 0 & -1 & 1 \end{bmatrix}$$

$$\Sigma k = 10^6 \times \begin{bmatrix} 3 & -3 & 0 \\ -3 & 4.8 & -1.8 \\ 0 & -1.8 & 1.8 \end{bmatrix} \times \begin{bmatrix} 0 \\ u_2 \\ u_3 \end{bmatrix} = \begin{bmatrix} F_1 \\ -6000 \\ 15000 \end{bmatrix}$$

Paso 2: Como se tiene la pared en el nodo 1, se elimina fila y columna:

$$k \times u = F$$

$$10^6 \times \begin{bmatrix} 4.8 & -1.8 \\ -1.8 & 1.8 \end{bmatrix} \times \begin{bmatrix} u_2 \\ u_3 \end{bmatrix} = \begin{bmatrix} -6000 \\ 15000 \end{bmatrix}$$

$$u = \text{inv}(k) \times F$$

Paso 3: Una vez resuelto se obtienen los siguientes desplazamientos:

$$u_2 = 0.0003\text{ m}$$

$$u_3 = 0.0011\text{ m}$$

Paso 4: Calcule la rigidez de la barra 3 de la derecha. Como se tiene la pared en el nodo 4, se elimina fila y columna:

$$k_3 = \frac{150\times10^9\,\text{Pa}\left(4\times10^{-4}\,\text{m}^2\right)}{4\text{m}} \times \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

$$k \times u = F$$

$$10^6 \times \begin{bmatrix} 15 & -15 \\ -15 & 15 \end{bmatrix} \times \begin{bmatrix} 0 \\ u_5 \end{bmatrix} = \begin{bmatrix} F_4 \\ 8000 \end{bmatrix}$$

De donde se obtiene lo siguiente:

$$u_5 = 5.33\times10^{-4}\text{ m}$$

Paso 5: De ahí que los desplazamientos, estarían dados por:

$$u_1 = 0\text{m}$$

$$u_2 = 0.0003\text{m}$$

$$u_5 = 5.33\times10^{-4}\text{m}$$

Paso 6: Para determinar si choca o no, se tienen que sumar todos los desplazamientos y verificar si es mayor o menor que "x" $\left(x = 0.4\times10^{-3}\text{ m}\right)$.

$$\Sigma u = 1.933\times10^{-3}\text{m}$$

Paso 7: Se observa que el resultado final es mayor que "x", razón por la cual las barras sí chocan.

$$\sigma_{1-2} = \frac{300\times 10^{9}\,\text{Pa}}{8\text{m}}\times\begin{bmatrix}-1 & 1\end{bmatrix}\times\begin{bmatrix}0\\ 0.0003\end{bmatrix} = 1.125\times 10^{7}\,\text{Pa}$$

$$\sigma_{2-3} = \frac{180\times 10^{9}\,\text{Pa}}{6\text{m}}\times\begin{bmatrix}-1 & 1\end{bmatrix}\times\begin{bmatrix}0.0003\\ 0.0011\end{bmatrix} = 2.4\times 10^{7}\,\text{Pa}$$

$$\sigma_{4-5} = \frac{150\times 10^{9}\,\text{Pa}}{4\text{m}}\times\begin{bmatrix}-1 & 1\end{bmatrix}\times\begin{bmatrix}0\\ 5.33\times 10^{-4}\end{bmatrix} = 1.9988\times 10^{7}\,\text{Pa}$$

B. Resolución con MATLAB

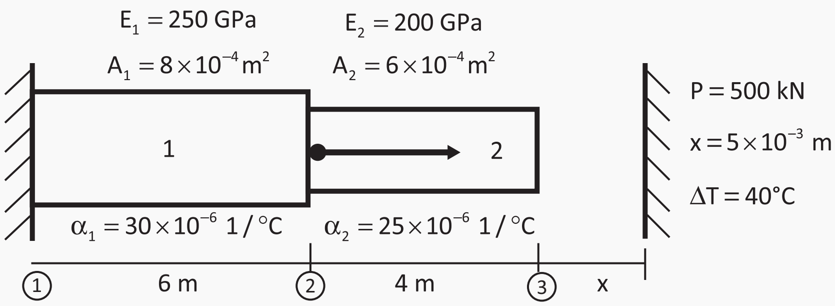
```
>> A = 10^6*[4.8 -1.8; -1.8 1.8]

A =

     4800000    -1800000
    -1800000     1800000

>> f = [-6000; 15000]

f =

       -6000
       15000

>> u = inv(A)*f

u =

    0.0030
    0.0113

>> solve('15*10^6*u5=8000','u5')

ans =

1/1875

>> e = 1/1875

e =

  5.3333e-004

>> % EL DESPLAZAMIENTO TOTAL U ES IGUAL A LA SUMA DE LOS DESPLAZAMIENTOS PARCIALES
>> U1 = 0.0030;
>> U2 = 0.0113;
>> U3 = 5.3333*10^-4;
>> u = U1+U2+U3

U =

    0.0148

>> % SE OBSERVA QUE EL DESPLAZAMIENTO TOTAL U ES MAYOR QUE X, POR LO TANTO LAS
BARRAS CHOCAN.
```

```
>> % CALCULO DE ESFUERZOS:
>> E1 = 300*10^9;
>> E2 = 180*10^9;
>> E3 = 150*10^9;
>> L1 = 8;
>> L2 = 6;
>> L3 = 4;
>> U1 = 0;
>> U2 = 0.0003;
>> U3 = 0.0011;
>> U4 = 0;
>> U5 = 5.33*10^-4;
>> % ESFUERZO ENTRE 1 Y 2:
>> G12 = (E1/L1)*[-1 1]*[Ù1; U2]

G12 =

  1.1250e+007

>> % ESFUERZO ENTRE 2 Y 3:
>> G23 = (E2/L2)*[-1 1]*[U2; U3]

G23 =

  2.4000e+007

>> % ESFUERZO ENTRE 4 Y 5:
>> G45 = (E3/L3)*[-1 1]*[U4; U5]

G45 =

  1.9988e+007
```

4.2. BARRA 1D CON EFECTOS TÉRMICOS

EJERCICIO 1

Calcular los desplazamientos nodales, los esfuerzos en cada una de las barras y analizar si choca o no con la pared.



A. Resolución

Paso 1: Calcule las rigideces de cada barra.

$$k_1 = \frac{250 \times 10^9 \text{Pa}\left(8 \times 10^{-4} \text{m}^2\right)}{6\text{m}} \times \begin{bmatrix} 1 & -1 & 0 \\ -1 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$k_2 = \frac{200 \times x10^9 \text{Pa}\left(6 \times 10^{-4} \text{m}^2\right)}{4\text{m}} \times \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & -1 \\ 0 & -1 & 1 \\ 0 & 0 & 0 \end{bmatrix}$$

Paso 2: Calcule las cargas térmicas.

$$\theta = E \times A \times \alpha \times \Delta T \times \begin{bmatrix} -1 \\ 1 \end{bmatrix}$$

$$\theta_{1-2} = \left(250 \times 10^9 \text{Pa}\right)\left(8 \times 10^{-4} \text{m}^2\right)\left(\frac{30 \times 10^{-6}}{°C}\right)(40°C) \times \begin{bmatrix} -1 \\ 1 \end{bmatrix} = -240000 \quad +240000 \qquad 0$$

$$\theta_{2-2} = \left(200 \times 10^9 \text{Pa}\right)\left(6 \times 10^{-4} \text{m}^2\right)\left(\frac{25 \times 10^{-6}}{°C}\right)(40°C) \times \begin{bmatrix} -1 \\ 1 \end{bmatrix} = \qquad -120000 \quad +120000$$

$$-240000 \quad +120000 \quad +120000$$

Paso 3: Calcule los desplazamientos.

$$k \times u = F + \theta$$

$$u = \text{inv}\ (k) \times (F + \theta)$$

$$\begin{bmatrix} 33333333.33 & -33333333.33 & 0 \\ -33333333.33 & 63333333.33 & -30000000 \\ 0 & -30000000 & 30000000 \end{bmatrix} \times \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix} = \begin{bmatrix} F_1 - 240000 \\ 500 \times 10^3 + 120000 \\ 0 + 120000 \end{bmatrix}$$

Resolviendo se obtienen los siguientes desplazamientos:

$$u_2 = 0.0222\text{m}$$

$$u_3 = 0.0262\text{m}$$

Paso 4: Para determinar si choca o no, se tiene que sumar todos los desplazamientos y verificar si es mayor o menor que "x" $(x = 5\times10^{-3}\,\text{m})$.

$$\Sigma u = 44.8 \times 10^{-3}\text{m}$$

Se observa que el resultado final es mayor que "x", razón por la cual las barras sí chocarían.

Paso 5: Calcule los esfuerzos.

$$\sigma_{i-j} = \left[\frac{E}{L} \times \begin{bmatrix} -1 & 1 \end{bmatrix} \times \begin{bmatrix} u_i \\ u_j \end{bmatrix}\right] - E \times \alpha \times \Delta T$$

$$\sigma_{1-2} = \left[\frac{250 \times 10^9\,\text{Pa}}{6\text{m}} \times \begin{bmatrix} -1 & 1 \end{bmatrix} \times \begin{bmatrix} 0 \\ 0.0222 \end{bmatrix}\right] - \left[\left(250 \times 10^9\right) \times \left(\frac{30 \times 10^{-6}}{°\text{C}}\right)(40°\text{C})\right] = 62.5 \times 10^7$$

$$\sigma_{2-3} = \left[\frac{200 \times 10^9\,\text{Pa}}{4\text{m}} \times \begin{bmatrix} -1 & 1 \end{bmatrix} \times \begin{bmatrix} 0.02222 \\ 0.0262 \end{bmatrix}\right] - \left[\left(200 \times 10^9\right) \times \left(\frac{25 \times 10^{-6}}{°\text{C}}\right)(40°\text{C})\right] = -1.1921 \times 10^{-7} \cong 0$$

B. Resolución con MATLAB

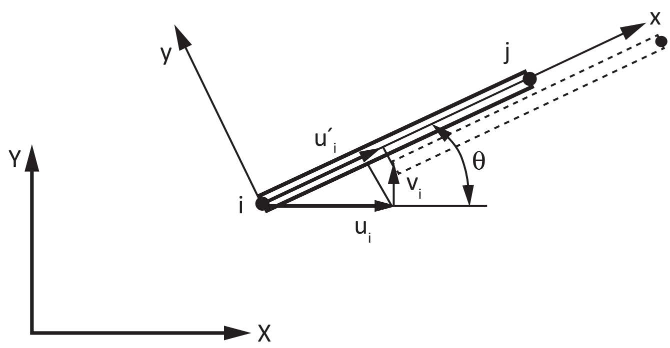
```
>> A = [63333333.33 -30000000; -30000000 30000000]

A =

   1.0e+007 *

     6.3333   -3.0000
    -3.0000    3.0000

>> f = [500*10^3+120000; 120000]

f =

      620000
      120000

>> u = inv(A)*f

u =

     0.0222
     0.0262
```

```
>> % SE CALCULARA EL DESPLAZAMIENTO TOTAL U QUE VIENE A SER LA SUMA DE LOS
DESPLAZAMIENTOS NADALES:
>> u1 = 0.0222;
>> u2 = 0.0262;
>> U = u1+u2

U =

    0.0484

>> % EL VALOR OBTENIDO ES MAYOR QUE X, POP LO TANTO LA BARRA CHOCA EN LA PARED

>> % CALCULO DE ESFUERZOS:
>> E1 = 250*10^9;
>> E2 = 200*10^9;
>> L1 = 6;
>> L2 = 4;
>> U1 = 0;
>> U2 = 0.0222;
>> U3 = 0.0262;
>> a1 = 30*10^-6;
>> a2 = 25*10^-6;
>> dT = 40;
>> % ESFUERZO ENTRE 1 Y 2:
>> G12 = ((E1/L1)*[-1 1]*[U1; U2])-(E1*a1*dT)

G12 =

   625000000

>> % ESFUERZO ENTRE 2 Y 3:
>> G23 = ((E2/L2)*[-1 1]*[U2; U3])-(E2*a2*dT)

G23 =

     0
```

CAPÍTULO

5

BARRA 2D



Local	Global
x , y	X , Y
u'_i , v'_i	u_i , v_i
En el nodo de 1, GDL	En el nodo de 2, GDL

Nota. El desplazamiento lateral v_i no contribuye al estiramiento de la barra, dentro de la teoría lineal.

5.1. TRANSFORMACIÓN

$$u'_i = u_i\cos\theta + v_i\,\mathrm{sen}\theta = \begin{bmatrix} c & s \end{bmatrix}\begin{Bmatrix} u_i \\ v_i \end{Bmatrix}$$

$$v'_i = -u_i\,\mathrm{sen}\theta + v_i\cos\theta = \begin{bmatrix} -s & c \end{bmatrix}\begin{Bmatrix} u_i \\ v_i \end{Bmatrix}$$

Donde:

$$c = \cos\theta$$

$$s = \mathrm{sen}\theta$$

Se tiene la siguiente forma de la matriz:

$$\begin{Bmatrix} u'_i \\ v'_i \end{Bmatrix} = \begin{bmatrix} c & s \\ -s & c \end{bmatrix}\begin{Bmatrix} u_i \\ v_i \end{Bmatrix}$$

$$u'_i = \tilde{T}u_i$$

Donde la matriz de transformación sería como sigue:

$$\tilde{T} = \begin{bmatrix} c & s \\ -s & c \end{bmatrix}$$

Se observa que la matriz es ortogonal, es decir:

$$\tilde{T}^{-1} = \tilde{T}^{T}$$

Para los dos nodos del elemento de la barra, se tiene lo siguiente:

$$\begin{Bmatrix} u'_i \\ v'_i \\ u'_j \\ v'_j \end{Bmatrix} = \begin{bmatrix} c & s & 0 & 0 \\ -s & c & 0 & 0 \\ 0 & 0 & c & s \\ 0 & 0 & -s & c \end{bmatrix} \begin{Bmatrix} u_i \\ v_i \\ u_j \\ v_j \end{Bmatrix}$$

$$u' = Tu \ \text{ con } \ T = \begin{bmatrix} \tilde{T} & 0 \\ 0 & T \end{bmatrix}$$

Las fuerzas nodales se transforman de la misma manera:

$$f' = Tf$$

5.2. MATRIZ DE RIGIDEZ EN 2D

En el sistema de coordenadas local, se tiene lo siguiente:

$$\frac{EA}{L} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{Bmatrix} u'_i \\ u'_j \end{Bmatrix} = \begin{Bmatrix} f'_i \\ f'_j \end{Bmatrix}$$

Aumentando esta ecuación, simplemente escriba lo siguiente:

$$\frac{EA}{L} \begin{bmatrix} 1 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 \\ -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{Bmatrix} u'_i \\ v'_i \\ u'_j \\ v'_j \end{Bmatrix} = \begin{Bmatrix} f'_i \\ 0 \\ f'_j \\ 0 \end{Bmatrix}$$

$$k'u' = f'$$

Usando las transformaciones obtenidas, se tiene que:

$$k'Tu = Tf$$

Multiplicándose ambos lados por T^T y notando que $T^T T = I$ estaría dado por:

$$T^T k' Tu = f$$

Así, la matriz de rigidez de elemento k en el sistema de la coordenada global sería $k = T^T k' T$ que es una matriz simétrica de 4x 4. En forma explícita:

$$k = \frac{EA}{L} \begin{array}{c} \begin{array}{cccc} u_i & v_i & u_j & v_j \end{array} \\ \begin{bmatrix} c^2 & cs & -c^2 & -cs \\ cs & s^2 & -cs & -s^2 \\ -c^2 & -cs & s^2 & cs \\ -cs & -s^2 & cs & s^2 \end{bmatrix} \end{array}$$

El cálculo de los cosenos direccionales l y m:

$$c = \cos\theta = \frac{X_j - X_i}{L} \quad , \quad m = \operatorname{sen}\theta = \frac{Y_j - Y_i}{L}$$

La matriz de rigidez de estructura se ensambla usando los elementos de la matriz de rigidez de la manera usual, como en el caso 1D.

5.3. ESFUERZO DEL ELEMENTO

$$\sigma = E\varepsilon = EB\begin{Bmatrix} u'_i \\ u'_j \end{Bmatrix} = E\begin{bmatrix} -\frac{1}{L} & \frac{1}{L} \end{bmatrix}\begin{bmatrix} c\,s\,0\,0 \\ 0\,0\,c\,s \end{bmatrix}\begin{Bmatrix} u_i \\ v_i \\ u_j \\ v_j \end{Bmatrix}$$

Es decir:

$$\sigma = \frac{E}{L}\begin{bmatrix} -c & -s & c & s \end{bmatrix}\begin{Bmatrix} u_i \\ v_i \\ u_j \\ v_j \end{Bmatrix}$$

EJERCICIO 1

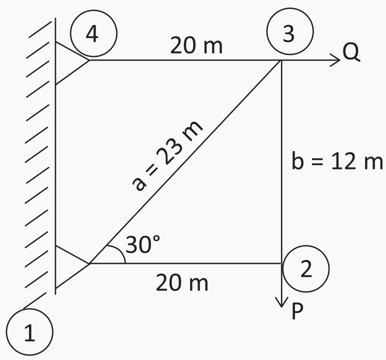
Hallar los desplazamientos, fuerzas y esfuerzos en cada caso.

$E = 250\ \text{GPa}$

$A = 5 \times 10^{-4}\ \text{m}^2$

$P = 10000\ \text{kN}$

$Q = 8000\ \text{kN}$



A. Resolución

Paso 1: Calcule las longitudes de a y b.

- Para el caso de a:

$$\cos 30^\circ = \frac{ca}{hip} \rightarrow 0.87 = \frac{20}{hip} \rightarrow hip = 22.98 \approx 23\ \text{m}$$

- Para el caso de b:

$$\tan 30^\circ = \frac{co}{ca} \rightarrow 0.58 = \frac{co}{20} \rightarrow co = 11.6 \approx 12\ \text{m}$$

Paso 2: Calcule los ángulos.

k	Barra	θ	C	S	C²	S²	CS	Longitud (m)
k_1	1-2	0	1	0	1	0	0	20
k_2	2-3	90	0	1	0	1	0	12
k_3	1-3	30	0.86	0.5	0.74	0.25	0.43	23
k_4	3-4	180	-1	0	1	0	0	30

Paso 3: Realice el cálculo para cada barra:

$$J_i = \frac{EA}{L}$$

$$J_1 = \frac{\left(5\times10^{-4}\right)\left(250\times10^{9}\right)}{20} = 6250\ \text{kPa}$$

$$J_2 = \frac{\left(5\times10^{-4}\right)\left(250\times10^{9}\right)}{12} = 10417\ \text{kPa}$$

$$J_3 = \frac{\left(5\times10^{-4}\right)\left(250\times10^{9}\right)}{23} = 5435\ \text{kPa}$$

$$J_4 = \frac{\left(5\times10^{-4}\right)\left(250\times10^{9}\right)}{20} = 6250\ \text{kPa}$$

Paso 4: Desarrolle las matrices.

$$kij = \frac{A\times E}{L}\begin{bmatrix} u_i & v_i & u_j & v_j \\ c^2 & cs & -c^2 & -cs \\ cs & s^2 & -cs & -s^2 \\ -c^2 & -cs & s^2 & cs \\ -cs & -s^2 & cs & s^2 \end{bmatrix}$$

Barra 1-2:

$$k_1 = 6250\ \text{kPa}\times\begin{bmatrix} u_1 & v_1 & u_2 & v_2 & u_3 & v_3 & u_4 & v_4 \\ 1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Barra 2-3

$$k_2 = 10417\,\text{kPa} \times \begin{array}{c} \begin{matrix} u_1 & v_1 & u_2 & v_2 & u_3 & v_3 & u_4 & v_4 \end{matrix} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Barra 1-3

$$k_3 = 5434\,\text{kPa} \times \begin{array}{c} \begin{matrix} u_1 & v_1 & u_2 & v_2 & u_3 & v_3 & u_4 & v_4 \end{matrix} \\ \begin{bmatrix} 0.74 & 0.43 & 0 & 0 & -0.74 & -0.43 & 0 & 0 \\ 0.43 & 0.25 & 0 & 0 & -0.43 & -0.25 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.74 & -0.43 & 0 & 0 & 0.74 & 0.43 & 0 & 0 \\ -0.43 & -0.25 & 0 & 0 & 0.43 & 0.25 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Barra 3-4

$$k_4 = 6250\,\text{kPa} \times \begin{array}{c} \begin{matrix} u_1 & v_1 & u_2 & v_2 & u_3 & v_3 & u_4 & v_4 \end{matrix} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Por tanto, la matriz ensamblada sería como sigue:

```
>> K = [ 10271160 2336620 -6250000 0 -4021160 -2336620 0 0; 2336620 1358500 0 0
-2336620 -1358500 0 0; -6250000 0 6250000 0 0 0 0 0; 0 0 0 10417000 0 -10417000 0
0; -4021160 -23366200 0 10271160 2336620 11775500 0 0; 0 0 0 0 -6250000 0 6250000
0; 0 0 0 0 0 0 0 0]
```

```
K =
  Columns 1 throunh 6
    10271160      2336620    -6250000           0    -4021160    -2336620
     2336620      1358500           0           0    -2336620    -1358500
    -6250000            0     6250000           0           0           0
           0            0           0    10417000           0   -10417000
    -4021160    -23366200           0    10271160     2336620    11775500
           0            0           0           0    -6250000           0
           0            0           0           0           0           0
  Columns 7 throunh 8
           0            0
           0            0
           0            0
           0            0
           0            0
     6250000            0
           0            0
```

Paso 5: Elimine filas y columnas en los nodos 1 y 4 (por ser articulaciones).

$$\begin{bmatrix} 10271160 & 2336620 & -6250000 & 0 & -4021160 & -2336620 & 0 & 0 \\ 2336620 & 1358500 & 0 & 0 & -2336620 & -1358500 & 0 & 0 \\ -6250000 & 0 & 6250000 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 10417000 & 0 & -10417000 & 0 & 0 \\ -4021160 & -2336620 & 0 & 0 & 10271160 & 2336620 & -6250000 & 0 \\ -2336620 & -1358500 & 0 & -10417000 & 2336620 & 11775500 & 0 & 0 \\ 0 & 0 & 0 & 0 & -6250000 & 0 & 6250000 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \\ u_3 \\ v_3 \\ u_4 \\ v_4 \end{bmatrix} = \begin{bmatrix} f_{x1} \\ f_{y1} \\ 0 \\ -10000\ \text{kN} \\ 8000\ \text{kN} \\ 0 \\ f_{x4} \\ f_{y4} \end{bmatrix}$$

Paso 6: Calcule los desplazamientos nodales.

$$u_2 = 0\ \text{m}$$

$$v_2 = -15.2537\ \text{m}$$

$$u_3 = 4.0306\ \text{m}$$

$$v_3 = -14.2937\ \text{m}$$

B. Resolución con MATLAB

```
>> A = [6250000 0 0 0; 0 10417000 0 -10417000; 0 0 10271160 2336620; 0 -10417000
2336620 11775500]
A =
     6250000           0           0           0
           0    10417000           0   -10417000
           0           0    10271160     2336620
           0   -10417000     2336620    11775500
>> F = [0; -10000*10^3; 8000*10^3; 0]
F =
           0
   -10000000
     8000000
           0
```

```
>> u = inv(A)*F
u =
         0
  -15.2537
    4.0306
  -14.2937
```

Cálculo de las fuerzas en cada articulación

$$F_{x1} = -(4021160)(4.0306) - (2336620)(-14.2537) = -17098 \text{ kN}$$

$$F_{y1} = -(2336620)(4.0306) - (1358500)(-14.2537) = 9946 \text{ kN}$$

$$F_{x4} = -(6250000)(4.0306) = -25191 \text{ kN}$$

```
>> K = [10271160 2336620 -6250000 0 -4021160 -2336620 0 0; 2336620 1358500 0 0
-2336620 -1358500 0 0;...
-6250000 0 6250000 0 0 0 0 0; 0 0 0 10417000 0 -10417000 0 0; -4021160 -23366200
0 10271160 2336620 11775500 0 0;...
0 0 0 0 -6250000 0 6250000 0; 0 0 0 0 0 0 0 0]
K =
  Columns 1 through 6
    10271160     2336620    -6250000           0    -4021160    -2336620
     2336620     1358500           0           0    -2336620    -1358500
    -6250000           0     6250000           0           0           0
           0           0           0    10417000           0   -10417000
    -4021160   -23366200           0    10271160     2336620    11775500
           0           0           0           0    -6250000           0
           0           0           0           0           0           0
  Columns 7 through 8
           0           0
           0           0
           0           0
           0           0
           0           0
     6250000           0
           0           0
>> U = [0; 0; 0; -15.2537; 4.0306; -14.2937; 0; 0]
U =
         0
         0
         0
  -15.2537
    4.0306
  -14.2937
         0
         0

>> F = K*U
F =
   1.0e+08 *
    0.1719
    0.1000
         0
   -0.1000
   -3.1557
   -0.2519
         0
```

Cálculo de los esfuerzos en cada barra

$$\sigma_{ij} = \frac{E}{L}\begin{bmatrix} -1 & 1 \end{bmatrix}\begin{bmatrix} c & s & 0 & 0 \\ 0 & 0 & c & s \end{bmatrix}\begin{bmatrix} u_i \\ v_i \\ u_j \\ v_j \end{bmatrix}$$

$$\sigma_{12} = \frac{250\times 10^9}{20}\begin{bmatrix} -1 & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}\begin{bmatrix} 0 \\ 0 \\ 0 \\ -15.2537 \end{bmatrix} = 0$$

$$\sigma_{23} = \frac{250\times 10^9}{12}\begin{bmatrix} -1 & 1 \end{bmatrix}\begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} 0 \\ -15.2537 \\ 4.0306 \\ -14.2937 \end{bmatrix} = 19.9\text{ GPa}$$

$$\sigma_{13} = \frac{250\times 10^9}{23}\begin{bmatrix} -1 & 1 \end{bmatrix}\begin{bmatrix} 0.86 & 0.5 & 0 & 0 \\ 0 & 0 & 0.86 & 0.5 \end{bmatrix}\begin{bmatrix} 0 \\ 0 \\ 4.0306 \\ -14.2937 \end{bmatrix} = 39.7\text{ GPa}$$

$$\sigma_{34} = \frac{250\times 10^9}{20}\begin{bmatrix} -1 & 1 \end{bmatrix}\begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \end{bmatrix}\begin{bmatrix} 4.0306 \\ -14.2937 \\ 0 \\ 0 \end{bmatrix} = 50.3\text{ GPa}$$

```
>> % CALCULO DE LOS ESFUERZOS:
>> % ESFUERZO DE 1 A 2:
>> E = (250*10^9/20)*[-1 1]*[1 0 0 0; 0 0 1 0]*[0; 0; 0; -15.2537]
E =
     0
>> % ESFUERZO DE 2 A 3:
>> E2 = (250*10^9/12)*[-1 1]*[0 1 0 0; 0 0 0 1]*[0; -15.2537; 4.0306; -14.2937]
E2 =
   2.0000e+10
>> % ESFUERZO DE 1 A 3:
>> E3 = (250*10^9/23)*[-1 1]*[0.86 0.5 0 0; 0 0 0.86 0.5]*[0; 0; 4.0306; -14.2937]
E3 =
  -4.0006e+10
>> % ESFUERZO DE 3 A 4:
>> E4 = (250*10^9/20)*[-1 1]*[-1 0 0 0; 0 0 -1 0]*[4.0306; -14.2937; 0; 0]
E4 =
   5.0383e+10
```

EJERCICIO 2

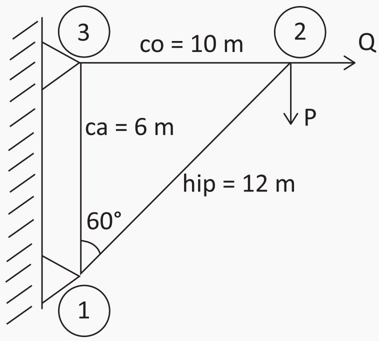
Hallar los desplazamientos, fuerzas y esfuerzos.

$E = 300\ \text{GPa}$

$A = 8 \times 10^{-4}\ \text{m}^2$

$P = 5000\ \text{kN}$

$Q = 8000\ \text{kN}$



A. Resolución

Paso 1: Calcule las longitudes de a y b.

- Para el caso de la hipotenusa:

$$\text{sen}60° = \frac{co}{hip} \rightarrow 0.87 = \frac{10}{hip} \rightarrow hip = 11.49 \approx 12\ \text{m}$$

- Para el caso de ca:

$$\cos 60° = \frac{ca}{hip} \rightarrow 0.50 = \frac{ca}{12} \rightarrow ca = 6\ \text{m}$$

Paso 2: Calcule los ángulos.

k	Barra	θ	C	S	C^2	S^2	CS	Longitud (m)
k_1	1-2	30	0.86	0.5	0.75	0.25	0.43	12
k_2	2-3	180	–1	0	1	0	0	10
k_3	1-3	90	0	1	0	1	0	6

Paso 3: Realice los cálculos para cada barra.

$$J_i = \frac{EA}{L}$$

$$J_1 = \frac{(8 \times 10^{-4})(300 \times 10^9)}{12} = 20\,000 \frac{\text{kN}}{\text{m}}$$

$$J_2 = \frac{(8 \times 10^{-4})(300 \times 10^9)}{10} = 24\,000 \frac{\text{kN}}{\text{m}}$$

$$J_3 = \frac{(8 \times 10^{-4})(300 \times 10^9)}{6} = 40\,000 \frac{\text{kN}}{\text{m}}$$

Paso 4: Desarrolle las matrices.

Barra 1–2

$$k_1 = 20000\frac{kN}{m}\times \begin{array}{c} \begin{array}{cccccc} u_1 & \nu_1 & u_2 & \nu_2 & u_3 & \nu_3 \end{array} \\ \begin{bmatrix} 0.75 & 0.43 & -0.75 & -0.43 & 0 & 0 \\ 0.43 & 0.25 & -0.43 & -0.25 & 0 & 0 \\ -0.75 & -0.43 & 0.75 & 0.43 & 0 & 0 \\ -0.43 & -0.25 & 0.43 & 0.25 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Barra 2–3

$$k_2 = 24000\frac{kN}{m}\times \begin{array}{c} \begin{array}{cccccc} u_1 & \nu_1 & u_2 & \nu_2 & u_3 & \nu_3 \end{array} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Barra 1-3

$$k_3 = 40000\frac{kN}{m}\times \begin{array}{c} \begin{array}{cccccc} u_1 & \nu_1 & u_2 & \nu_2 & u_3 & \nu_3 \end{array} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 1 \end{bmatrix} \end{array}$$

Por tanto, la matriz ensamblada sería así:

```
>> K = [15000000 860000 -15000000 -860000 0 0; 860000 45000000 -860000 -5000000 0
-40000000; -15000000 -860000 39000000 860000 -24000000 0; -860000 -5000000 860000
5000000 0 0; 0 0 -24000000 0 24000000 0; 0 -40000000 0 0 0 40000000]
K =
    15000000      860000   -15000000     -860000           0           0
      860000    45000000     -860000    -5000000           0   -40000000
   -15000000     -860000    39000000      860000   -24000000           0
     -860000    -5000000      860000     5000000           0           0
           0           0   -24000000           0    24000000           0
           0   -40000000           0           0           0    40000000
```

Paso 5: Elimine filas y columnas en los nodos 1 y 3 (por ser articulaciones).

$$\begin{bmatrix} 1500000 & 860000 & -15000000 & -860000 & 0 & 0 \\ 860000 & 45000000 & -860000 & -5000000 & 0 & -40000000 \\ -15000000 & -860000 & 39000000 & 860000 & -24000000 & 0 \\ -860000 & -5000000 & 860000 & 5000000 & 0 & 0 \\ 0 & 0 & -24000000 & 0 & 240000000 & 0 \\ 0 & -40000000 & 0 & 0 & 0 & 40000000 \end{bmatrix} \times \begin{bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \\ u_3 \\ v_3 \end{bmatrix} = \begin{bmatrix} f_{x1} \\ f_{y1} \\ 8000\text{ kN} \\ -5000\text{ kN} \\ f_{x4} \\ f_{y4} \end{bmatrix}$$

Paso 6: Calcule los desplazamientos nodales.

$$u_2 = 0.2280\,\text{m}$$

$$v_2 = -1.0392\,\text{m}$$

B. Resolución con MATLAB

```
>> A = [39000000 860000; 860000 5000000]
A =
    39000000      860000
      860000     5000000
>> F = [8000*10^3; -5000*10^3]
F =
     8000000
    -5000000
>> U = inv(A)*F
U =
    0.2280
   -1.0392
```

Cálculo de las fuerzas en cada articulación

```
>> K = [15000000 860000 -15000000 -860000 0 0; 860000 45000000 -860000 -5000000 0
-40000000; -15000000 -860000 39000000 860000 -24000000 0; -860000 -5000000 860000
5000000 0 0; 0 0 -24000000 0 24000000 0; 0 -40000000 0 0 0 40000000]
K =
    15000000      860000   -15000000     -860000           0           0
      860000    45000000     -860000    -5000000           0   -40000000
   -15000000     -860000    39000000      860000   -24000000           0
     -860000    -5000000      860000     5000000           0           0
           0           0   -24000000           0    24000000           0
           0   -40000000           0           0           0    40000000
>> U = [0; 0; 0.2280; -1.0392; 0; 0]
U =
         0
         0
    0.2280
   -1.0392
         0
         0
```

```
>> F = K*U
F =
   1.0e+06 *
   -2.5263
    4.9999
    7.9983
   -4.9999
   -5.4720
         0
```

Cálculo de los esfuerzos en cada barra

$$\sigma_{12} = \frac{300\times10^{9}}{12}\begin{bmatrix}-1 & 1\end{bmatrix}\begin{bmatrix}0.86 & 0.5 & 0 & 0\\ 0 & 0 & 0.86 & 0.5\end{bmatrix}\begin{bmatrix}0\\ 0\\ 0.8657\\ -2.1794\end{bmatrix} = -8.6299\text{ GPa}$$

$$\sigma_{23} = \frac{300\times10^{9}}{12}\begin{bmatrix}-1 & 1\end{bmatrix}\begin{bmatrix}-1 & 0 & 0 & 0\\ 0 & 0 & -1 & 0\end{bmatrix}\begin{bmatrix}0.8657\\ -2.1794\\ 0\\ 0\end{bmatrix} = 2.59\times10^{10}\text{ Pa}$$

$$\sigma_{13} = \frac{300\times10^{9}}{6}\begin{bmatrix}-1 & 1\end{bmatrix}\begin{bmatrix}0 & 1 & 0 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\begin{bmatrix}0\\ 0\\ 0\\ 0\end{bmatrix} = 0\text{ Pa}$$

```
>> % CALCULO DE LOS ESFUERZOS:
>> % ESFUERZO DE 1 A 2:
>> E12 = (300*10^9/12)*[-1 1]*[0.86 0.5 0 0; 0 0 0.86 0.5]*[0; 0; 0.8657; -2.1794]
E12 =
  -8.6299e+09
>> % ESFUERZO DE 2 A 3:
>> E23 = (300*10^9/10)*[-1 1]*[-1 0 0 0; 0 0 -1 0]*[0.8657; -2.1794; 0; 0]
E23 =
   2.5971e+10
>> % ESFUERZO DE 1 A 3:
>> E13 = (300*10^9/6)*[-1 1]*[0 1 0 0; 0 0 0 1]*[0; 0; 0; 0]
E13 =
     0
```

EJERCICIO 3

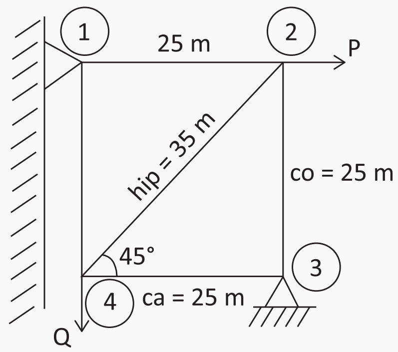
Hallar los desplazamientos, fuerzas y esfuerzos.

$E = 200\ \text{GPa}$

$A = 5 \times 10^{-4}\ \text{m}^2$

$P = 3000\ \text{kN}$

$Q = 6000\ \text{kN}$



A. Resolución

Paso 1: Calcule las longitudes de a y b.

- Para el caso de la hipotenusa:

$$\text{sen}45° = \frac{\text{co}}{\text{hip}} \rightarrow 0.707 = \frac{25}{\text{hip}} \rightarrow \text{hip} = 35.35 \approx 35\ \text{m}$$

- Para el caso de ca:

$$\cos 45° = \frac{\text{ca}}{\text{hip}} \rightarrow 0.707 = \frac{\text{ca}}{35} \rightarrow \text{ca} = 24.75 \approx 25\ \text{m}$$

Paso 2: Calcule los ángulos.

k	Barra	θ	C	S	C^2	S^2	CS	Longitud (m)
k_1	1-2	0	1	0	1	0	0	25
k_2	1-4	270	0	–1	0	1	0	25
k_3	4-2	45	0.7	0.7	0.49	0.49	0.49	35
k_4	4-3	0	1	0	1	0	0	25
k_5	3-2	90	0	1	0	1	0	25

Paso 3: Calcule los valores para cada barra.

$$J_i = \frac{EA}{L}$$

Para las barras 1-2, 1-4, 4-3 y 3-2, se tiene las mismas longitudes, por lo tanto:

$$J_1 = \frac{(5 \times 10^{-4})(200 \times 10^{9})}{25} = 4\,\text{MPa}$$

Para la barra 4-2, se tiene que:

$$J_2 = \frac{\left(5\times 10^{-4}\right)\left(200\times 10^{9}\right)}{35} = 2.85\,\text{MPa}$$

Paso 4: Desarrolle las matrices.

Barra 1-2

$$k_1 = 4\ \text{MPa}\times \begin{array}{c} \begin{matrix} u_1 & \nu_1 & u_2 & \nu_2 & u_3 & \nu_3 & u_4 & \nu_4 \end{matrix} \\ \begin{bmatrix} 1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Barra 1-4

$$k_2 = 4\ \text{MPa}\times \begin{array}{c} \begin{matrix} u_1 & \nu_1 & u_2 & \nu_2 & u_3 & \nu_3 & u_4 & \nu_4 \end{matrix} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \end{array}$$

Barra 4-2

$$k_3 = 2.85\,\text{MPa}\times \begin{array}{c} \begin{matrix} u_1 & \nu_1 & u_2 & \nu_2 & u_3 & \nu_3 & u_4 & \nu_4 \end{matrix} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.49 & 0.49 & 0 & 0 & -0.49 & -0.49 \\ 0 & 0 & 0.49 & 0.49 & 0 & 0 & -0.49 & -0.49 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -0.49 & -0.49 & 0 & 0 & 0.49 & 0.49 \\ 0 & 0 & -0.49 & -0.49 & 0 & 0 & 0.49 & 0.49 \end{bmatrix} \end{array}$$

Barra 4-3

$$k_4 = 4\ \text{MPa} \times \begin{array}{c} \begin{matrix} u_1 & \nu_1 & u_2 & \nu_2 & u_3 & \nu_3 & u_4 & \nu_4 \end{matrix} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Barra 3-2

$$k_5 = 4\ \text{MPa} \times \begin{array}{c} \begin{matrix} u_1 & \nu_1 & u_2 & \nu_2 & u_3 & \nu_3 & u_4 & \nu_4 \end{matrix} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Por tanto la matriz ensamblada estaría dado por lo siguiente:

```
>> K = [4000000 0 -4000000 0 0 0 0 0; 0 4000000 0 0 0 0 0 -4000000; -4000000 0
5396500 1396500 0 0 -1396500 -1396500; 0 0 1396500 5396500 0 -4000000 -1396500
-1396500; 0 0 0 0 4000000 0 -4000000 0; 0 0 0 -4000000 0 4000000 0 0; 0 0 -1396500
-1396500 -4000000 0 5396500 1396500; 0 -4000000 -1396500 -1396500 0 0 1396500
5396500]
K =
  Columns 1 through 6
     4000000           0    -4000000           0           0           0
           0     4000000           0           0           0           0
    -4000000           0     5396500     1396500           0           0
           0           0     1396500     5396500           0    -4000000
           0           0           0           0     4000000           0
           0           0           0    -4000000           0     4000000
           0           0    -1396500    -1396500    -4000000           0
           0    -4000000    -1396500    -1396500           0           0
  Columns 7 through 8
           0           0
           0    -4000000
    -1396500    -1396500
    -1396500    -1396500
    -4000000           0
           0           0
     5396500     1396500
     1396500     5396500
```

Paso 5: Elimine filas y columnas en los nodos 1 y 3 (por ser articulaciones).

$$\begin{bmatrix} 4000000 & 0 & -4000000 & 0 & 0 & 0 & 0 & 0 \\ 0 & 4000000 & 0 & 0 & 0 & 0 & 0 & -4000000 \\ -4000000 & 0 & 5396500 & 1396500 & 0 & 0 & -1396500 & -1396500 \\ 0 & 0 & 1396500 & 5396500 & 0 & -4000000 & -1396500 & -1396500 \\ 0 & 0 & 0 & 0 & 4000000 & 0 & -4000000 & 0 \\ 0 & 0 & 0 & -4000000 & 0 & 4000000 & 0 & 0 \\ 0 & 0 & -1396500 & -1396500 & -4000000 & 0 & 5396500 & 1396500 \\ 0 & -4000000 & -1396500 & -1396500 & 0 & 0 & 1396500 & 5396500 \end{bmatrix} \times \begin{bmatrix} u_1 \\ \nu_1 \\ u_2 \\ \nu_2 \\ u_3 \\ \nu_3 \\ u_4 \\ \nu_4 \end{bmatrix} = \begin{bmatrix} f_{x1} \\ f_{y1} \\ 3000\ \text{kN} \\ 0 \\ f_{x3} \\ f_{y3} \\ 0 \\ -6000\ \text{kN} \end{bmatrix}$$

Paso 6: Calcule los desplazamientos nodales:

$$u_2 = 0.8593$$

$$v_2 = 0.1093$$

$$u_4 = -0.1093$$

$$v_2 = 1.3907$$

```
>> A = [5396500 1396500 -1396500 -1396500; 1396500 5396500 -1396500 -1396500;
-1396500 -1396500 5396500 1396500; -1396500 -1396500 1396500 5396500]
A =
     5396500     1396500    -1396500    -1396500
     1396500     5396500    -1396500    -1396500
    -1396500    -1396500     5396500     1396500
    -1396500    -1396500     1396500     5396500
>> f = [3000*10^3; 0; 0; 6000*10^3]
f =
     3000000
           0
           0
     6000000
>> U = inv(A)*F
U =
    0.8593
    0.1093
   -0.1093
    1.3907
```

Paso 7: Calcule las fuerzas en cada articulación.

```
>> K = [4000000 0 -4000000 0 0 0 0 0; 0 4000000 0 0 0 0 0 -4000000; -4000000 0
5396500 1396500 0 0 -1396500 -1396500; 0 0 1396500 5396500 0 -4000000 -1396500
-1396500; 0 0 0 0 4000000 0 -4000000 0; 0 0 0 -4000000 0 4000000 0 0; 0 0 -1396500
–1396500 -4000000 0 5396500 1396500; 0 -4000000 -1396500 -1396500 0 0 1396500
5396500]
```

```
K =
  Columns 1 through 6
     4000000           0    -4000000           0           0           0
           0     4000000           0           0           0           0
    -4000000           0     5396500     1396500           0           0
           0           0     1396500     5396500           0    -4000000
           0           0           0           0     4000000           0
           0           0           0    -4000000           0     4000000
           0           0    -1396500    -1396500    -4000000           0
           0    -4000000    -1396500    -1396500           0           0
  Columns 7 through 8
           0           0
           0    -4000000
    -1396500    -1396500
    -1396500    -1396500
    -4000000           0
           0           0
     5396500     1396500
     1396500     5396500
>> U = [0; 0; 0.8593; 0.1093; 0; 0; -0.1093; 1.3907}
U =
         0
         0
    0.8593
    0.1093
         0
         0
   -0.1093
    1.3907

>> F = K*U
F =
   1.0e+06 *
   -3.4372
   -5.5628
    3.0004
    0.0004
    0.4372
   -0.4372
   -0.0004
    5.9996
```

Paso 8: Calcule los esfuerzos.

```
>> % CALCULO DE LOS ESFUERZOS:
>> % ESFUERZO DE 1 A 2:
>> E12 = ((200*10^9)/25)*[-1 1]*[1 0 0 0; 0 0 1 0]*[0; 0; 0.8593; 0.1093]

E12 =

  6.8744e+009

>> % ESFUERZO DE 1 A 4:
>> E14 = ((200*10^9)/25)*[-1 1]*[0 -1 0 0; 0 0 0 -1]*[0; 0; -0.1093; 1.3907]

E14 =

 -1.1126e+010
```

```
>> % ESFUERZO DE 4 A 2:
>>  E42  =  ((200*10^9)/35)*[-1  1]*[0.7  0.7  0  0;  0  0  0.7  0.7]*[-0.1093;  1.3907;
0.8593; 0.1093]

E42 =

 -1.2512e+009

>> % ESFUERZO DE 4 A 3:
>> E14 = ((200*10^9)/25)*[-1 1]*[1 0 0 0; 0 0 1 0]*[-0.1093; 1.3907; 0: 0]

E14 =

   874400000

>> % ESFUERZO DE 3 A 2:
>> E32 = ((200*10^9)/25)*[-1 1]*[0 1 0 0; 0 0 0 1]*[0; 0; 0.8593; 0.1093]

E32 =

   874400000
```

Ejercicio 4

Hallar los desplazamientos, fuerzas y esfuerzas en cada caso.

$E = 200$ GPa

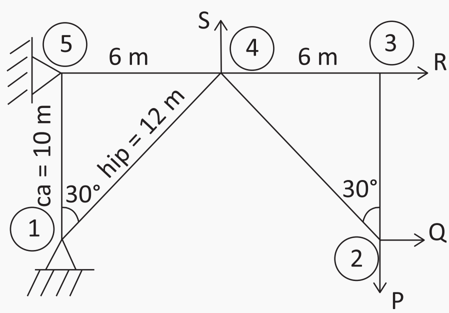
$A = 3 \times 10^{-4}\,m^2$

$P = 12000$ kN

$Q = 10000$ kN

$R = 8000$ kN

$S = 5000$ kN



A. Resolución

Paso 1: Calcule las longitudes de a y b.

- Para el caso de ca:

$$\cos 30^\circ = \frac{ca}{hip} \rightarrow 0.87 = \frac{ca}{12} \rightarrow ca = 10.4 \approx 10\ m$$

- Para el caso de la hipotenusa:

$$sen 30^\circ = \frac{co}{hip} \rightarrow 0.5 = \frac{6}{hip} \rightarrow hip = 12\ m$$

Paso 2: Calcule los ángulos.

k	Barra	θ	C	S	C²	S²	CS	Longitud (m)
k_1	1-4	60	0.5	0.87	0.25	0.757	0.435	12
k_2	1-5	90	0	1	0	1	0	10
k_3	5-4	0	1	0	1	0	0	6
k_4	4-3	0	1	0	1	0	0	6
k_5	2-4	120	-0.5	0.86	0.25	0750	-0.43	12
k_6	2-3	90	0	1	0	1	0	10

Paso 3: Calcule los valores para cada barra.

$$J_i = \frac{EA}{L}$$

Para las barras 1-4 y 2-4, se tiene las mismas longitudes, por lo tanto:

$$J_1 = \frac{\left(3\times10^{-4}\right)\left(200\times10^{9}\right)}{12} = 5\text{MPa}$$

Para las barras 5-4 y 4-3, se tienen las mismas longitudes entonces:

$$J_2 = \frac{\left(3\times10^{-4}\right)\left(200\times10^{9}\right)}{6} = 10\text{MPa}$$

Para las barras 1-5 y 2-3, se tienen las mismas longitudes, por ende:

$$J_3 = \frac{\left(3\times10^{-4}\right)\left(200\times10^{9}\right)}{10} = 6\text{MPa}$$

Paso 4: Desarrolle las matrices.

Barra 1-4

$$k_1 = 5\,\text{MPa}\times\begin{bmatrix} u_1 & v_1 & u_2 & v_2 & u_3 & v_3 & u_4 & v_4 & u_5 & v_5 \\ 0.25 & 0.435 & 0 & 0 & 0 & 0 & -0.25 & -0.435 & 0 & 0 \\ 0.435 & 0.757 & 0 & 0 & 0 & 0 & -0.435 & -0.757 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.25 & -0.435 & 0 & 0 & 0 & 0 & 0.25 & 0.435 & 0 & 0 \\ -0.435 & -0.757 & 0 & 0 & 0 & 0 & 0.435 & 0.757 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Barra 1-5

$$k_2 = 6\,\text{MPa} \times \begin{array}{c} \begin{matrix} u_1 & \nu_1 & u_2 & \nu_2 & u_3 & \nu_3 & u_4 & \nu_4 & u_5 & \nu_5 \end{matrix} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \end{array}$$

Barra 5-4

$$k_3 = 10\,\text{MPa} \times \begin{array}{c} \begin{matrix} u_1 & \nu_1 & u_2 & \nu_2 & u_3 & \nu_3 & u_4 & \nu_4 & u_5 & \nu_5 \end{matrix} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Barra 4-3

$$k_4 = 10\,\text{MPa} \times \begin{array}{c} \begin{matrix} u_1 & \nu_1 & u_2 & \nu_2 & u_3 & \nu_3 & u_4 & \nu_4 & u_5 & \nu_5 \end{matrix} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Barra 2-4

$$k_5 = 5\,\text{MPa}\times \begin{array}{c} \begin{array}{cccccccccc} u_1 & \nu_1 & u_2 & \nu_2 & u_3 & \nu_3 & u_4 & \nu_4 & u_5 & \nu_5 \end{array} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.25 & -0.43 & 0 & 0 & -0.25 & 0.43 & 0 & 0 \\ 0 & 0 & -0.43 & 0.75 & 0 & 0 & 0.43 & -0.75 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -0.25 & 0.43 & 0 & 0 & 0.25 & -0.43 & 0 & 0 \\ 0 & 0 & 0.43 & -0.75 & 0 & 0 & -0.43 & 0.75 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Barra 2-3

$$k_6 = 6\,\text{MPa}\times \begin{array}{c} \begin{array}{cccccccccc} u_1 & \nu_1 & u_2 & \nu_2 & u_3 & \nu_3 & u_4 & \nu_4 & u_5 & \nu_5 \end{array} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Por tanto, la matriz ensamblada estaría dada por:

```
>> K= [1250000 2175000 0 0 0 0 -1250000 -2175000 0 0; 2175000 9785000 0 0 0 0
-21750000 -3785000 0 -6000000; 0 0 1250000 -2150000 0 0 -1250000 2150000 0 0; 0 0
-2150000 9750000 0 -6000000 2150000 -3750000 0 0; 0 0 0 0 10000000 0 -10000000 0 0
0;0 0 0 -6000000 0 6000000 0 0 0 0; -1250000 2175000 -1250000 2150000 -10000000 0
22500000 25000 -10000000 0; -2175000 -3785000 2150000 -3750000 0 0 25000 7535000
0 0; 0 0 0 0 0 0 -10000000 0 10000000 0; 0 -6000000 0 0 0 0 0 0 0 6000000]

K =

  1250000    2175000          0          0          0          0   -1250000   -2175000          0          0
  2175000    9785000          0          0          0          0   -2175000   -3785000          0   -6000000
        0          0    1250000   -2150000          0          0   -1250000    2150000          0          0
        0          0   -2150000    9750000          0   -6000000    2150000   -3750000          0          0
        0          0          0          0   10000000          0  -10000000          0          0          0
        0          0          0   -6000000          0    6000600          0          0          0          0
 -1250000   -2175000   -1250000    2150000  -10000000          0   22500000      25000  -10000000          0
 -2175000   -3785000    2150000   -3750000          0          0      25000    7535000          0          0
        0          0          0          0          0          0  -10000000          0   10000000          0
        0   -6000000          0          0          0          0          0          0          0    6000000
```

Paso 5: Elimine filas y columnas en los nodos 1 y 3 (por ser articulaciones).

$$\begin{bmatrix} 1250000 & 2175000 & 0 & 0 & 0 & 0 & -1250000 & -2175000 & 0 & 0 \\ 2175000 & 9785000 & 0 & 0 & 0 & 0 & -2175000 & -3785000 & 0 & -5000000 \\ 0 & 0 & 1280000 & -2150000 & 0 & 0 & -1250000 & 2180000 & 0 & 0 \\ 0 & 0 & -2150000 & 9750000 & 0 & -6000000 & 2150000 & -3750000 & 0 & 0 \\ 0 & 0 & 0 & 0 & 10000000 & 0 & -10000000 & 0 & 0 & 0 \\ 0 & 0 & 0 & -6000000 & 0 & 6000000 & 0 & 0 & 0 & 0 \\ -1250000 & -2175000 & -1250000 & 2150000 & -10000000 & 0 & 22500000 & 25000 & -10000000 & 0 \\ -2175000 & -3785000 & 2150000 & -3750000 & 0 & 0 & 25000 & 7535000 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -10000000 & 0 & 10000000 & 0 \\ 0 & -6000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 6000000 \end{bmatrix} \times \begin{bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \\ u_3 \\ v_3 \\ u_4 \\ v_4 \\ u_5 \\ v_5 \end{bmatrix} = \begin{bmatrix} f_{x1} \\ f_{y1} \\ 10000\text{ kN} \\ -12000\text{ kN} \\ 8000\text{ kN} \\ 0 \\ 0 \\ 5000\text{ kN} \\ f_{x5} \\ f_{y5} \end{bmatrix}$$

Paso 6: Calcule los desplazamientos nodales.

$$u_2 = 182.2022 \text{ m}$$

$$v_2 = 96.8851 \text{ m}$$

$$u_3 = 3.0022 \text{ m}$$

$$v_3 = 96.8851 \text{ m}$$

$$u_4 = 2.2022 \text{ m}$$

$$v_4 = -3.1149 \text{ m}$$

B. Resolución con MATLAB

```
>> A = [1250000 -2150000 0 0 -1250000 2150000; -2150000 9750000 0 -6000000 2150000
-3750000; 0 0 10000000 0 -10000000 0; 0 -6000000 0 6000000 0 0; -1250000 2150000
-10000000 0 22500000 25000; 2150000 -3750000 0 0 25000 7535000]

A =
     1250000    -2150000           0           0    -1250000     2150000
    -2150000     9750000           0    -6000000     2150000    -3750000
           0           0    10000000           0   -10000000           0
           0    -6000000           0     6000000           0           0
    -1250000     2150000   -10000000           0    22500000       25000
     2150000    -3750000           0           0       25000     7535000

>> F = [10000*10^3; -12000*10^3; 8000*10^3; 0; 0; 5000*10^3]

F =
    10000000
   -12000000
     8000000
           0
           0
     5000000

>> U = inv(A)*F

U =
  182.2022
   96.8851
    3.0022
   96.8851
    2.2022
   -3.1149
```

Cálculo de las fuerzas en cada articulación

$$F_{x1} = -1250000(2.2022) - (2175000)(-3.1149) = 4022157.5 \text{ N}$$

$$F_{y1} = -2175000(2.2022) - (3785000)(-3.1149) = 7000111.5 \text{ N}$$

$$F_{x5} = -10000000(2.2022) = -22022000 \text{ N}$$

$$F_{y5} = 0 \text{ N}$$

```
>> K= [1250000 2175000 0 0 0 0 -1250000 -2175000 0 0; 2175000 9785000 0 0 0 0
-2175000 -3785000 0 -6000000; 0 0 1250000 -2150000 0 0 -1250000 2150000 0 0; 0 0
-2150000 9750000 0 -6000000 2150000 -3750000 0 0; 0 0 0 0 10000000 0 -10000000 0
0 0; 0 0 0 -600000 0 6000000 0 0 0 0; -1250000 -2175000 -1250000 2150000 -1000000
0 22500000 25000 -1000000 0; -2175000 -3785000 2150000 -3750000 0 025000 7535000
0 0; 0 0 0 0 0 0 -10000000 0 10000000 0; 0 -6000000 0 0 0 0 0 0 0 6000000]

K =

   1250000    2175000          0          0          0          0   -1250000   -2175000          0          0
   2175000    9785000          0          0          0          0   -2175000   -3785000          0   -6000000
         0          0    1250000   -2150000          0          0   -1250000    2150000          0          0
         0          0   -2150000    9750000          0   -6000000    2150000   -3750000          0          0
         0          0          0          0   10000000          0  -10000000          0          0          0
         0          0          0   -6000000          0    6000000          0          0          0          0
  -1250000   -2175000   -1250000    2150000  -10000000          0   22500000      25000  -10000000          0
  -2175000   -3785000    2150000   -3750000          0          0      25000    7535000          0          0
         0          0          0          0          0          0  -10000000          0   10000000          0
         0   -6000000          0          0          0          0          0          0          0    6000000

>> U = [0; 0; 182.2022; 96.8851; 3.0022; 96.8851; 2.2022; -3.1149; 0; 0]

U =
         0
         0
  182.2022
   96.8851
    3.0022
   96.8851
    2.2022
   -3.1149
         0
         0

>> F = K*U

F =

  1.0e+007 *

    0.4022
    0.7000
    1.0000
   -1.2000
    0.8000
         0
   -0.0000
    0.5000
   -2.2022
         0
```

Cálculo de los esfuerzos

$$\sigma_{14} = \frac{200\times10^9}{12}\begin{bmatrix}-1 & 1\end{bmatrix}\begin{bmatrix}0.5 & 0.87 & 0 & 0\\ 0 & 0 & 0.5 & 0.87\end{bmatrix}\begin{bmatrix}0\\0\\2.2022\\-3.1149\end{bmatrix} = -2.7\times10^{10}\ \text{Pa}$$

$$\sigma_{15} = \frac{200\times10^9}{10}\begin{bmatrix}-1 & 1\end{bmatrix}\begin{bmatrix}0 & 1 & 0 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\begin{bmatrix}0\\0\\0\\0\end{bmatrix} = 0\ \text{Pa}$$

$$\sigma_{54} = \frac{200\times10^9}{6}\begin{bmatrix}-1 & 1\end{bmatrix}\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 0 & 1 & 0\end{bmatrix}\begin{bmatrix}0\\0\\2.2022\\-3.1149\end{bmatrix} = 7.27\times10^{10}\ \text{Pa}$$

$$\sigma_{43} = \frac{200\times10^9}{6}\begin{bmatrix}-1 & 1\end{bmatrix}\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 0 & 1 & 0\end{bmatrix}\begin{bmatrix}2.2022\\-3.1149\\3.0022\\96.851\end{bmatrix} = 2.64\times10^{10}\ \text{Pa}$$

$$\sigma_{24} = \frac{200\times10^9}{12}\begin{bmatrix}-1 & 1\end{bmatrix}\begin{bmatrix}-0.5 & 0.86 & 0 & 0\\ 0 & 0 & -0.5 & 0.86\end{bmatrix}\begin{bmatrix}182.2022\\96.8851\\2.2022\\-3.1149\end{bmatrix} = 6.8\times10^{10}\ \text{Pa}$$

$$\sigma_{23} = \frac{200\times10^9}{10}\begin{bmatrix}-1 & 1\end{bmatrix}\begin{bmatrix}0 & 1 & 0 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\begin{bmatrix}182.2022\\96.8851\\3.0022\\96.851\end{bmatrix} = -682\ \text{MPa}$$

```
>> % CALCULO DE LOS ESFUERZOS:
>> % ESFUERZO DE 1 A 4:
>> E14 = ((200*10^9)/12)*[-1 1]*[0.5 0.87 0 0; 0 0 0.5 0.87]*[0; 0; 2.2022;
-3.1149]

E14 =

 -2.6814e+010

>> % ESFUERZO DE 1 A 5:
>> E15 = ((200*10^9)/10)*[-1 1]*[0 1 0 0; 0 0 0 1]*[0; 0; 0; 0]

E15 =

     0
```

```
>> % ESFUERZO DE 5 A 4:
>> E54 = ((200*10^9)/6)*[-1 1]*[1 0 0 0; 0 0 1 0]*[0; 0; 2.2022; -3.1149]

E54 =

  7.3407e+010

>> % ESFUERZO DE 4 A 3:
>> E43 = ((200*10^9)/6)*[-1 1]*[1 0 0 0; 0 0 1 0]*[2.2022; -3.1149; 3.0022; 96.851]

E43 =

  2.6667e+010

>> % ESFUERZO DE 2 A 4:
>> E14 = ((200*10^9)/12)*[-1 1]*[-0.5 0.86 0 0; 0 0 -0.5 0.86]*[182.2022; 96.8851;
2.2022; -3.1149]

E24 =

 -6.6667e+010

>> % ESFUERZO DE 2 A 3:
>> E23 = ((200*10^9)/10)*[-1 1]*[0 1 0 0; 0 0 0 1]*[182.2022; 96.8851; 3.0022;
96.851]

E23 =

  -682000000
```

EJERCICIO 5

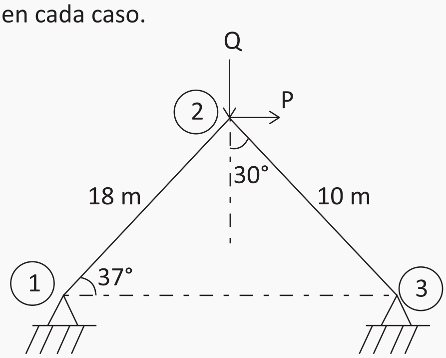
Hallar los desplazamientos, fuerzas y esfuerzos en cada caso.

$E = 320 \text{ GPa}$

$A = 5 \times 10^{-4} m^2$

$P = 7000 \text{ kN}$

$Q = 9000 \text{ kN}$



A. Resolución

Paso 1: Calcule los ángulos.

k	Barra	θ	C	S	C²	S²	CS	Longitud (m)
k_1	1-2	37	0.8	0.60	0.64	0.36	0.48	18
k_2	2-3	300	0.5	–0.87	0.25	0.76	–0.44	10

Paso 2: Calcule los valores para cada barra.

$$J_i = \frac{EA}{L}$$

$$J_1 = \frac{\left(5\times10^{-4}\right)\left(320\times10^{9}\right)}{18} = 8.8 \text{ MPa}$$

$$J_2 = \frac{\left(5\times10^{-4}\right)\left(320\times10^{9}\right)}{10} = 16 \text{ MPa}$$

Paso 3: Desarrolle las matrices.

Barra 1-2

$$k_1 = 8.8\,\text{MPa}\times \begin{array}{c} \begin{matrix} u_1 & \nu_1 & u_2 & \nu_2 & u_3 & \nu_3 \end{matrix} \\ \begin{bmatrix} 0.64 & 0.48 & -0.64 & -0.48 & 0 & 0 \\ 0.48 & 0.36 & -0.48 & -0.36 & 0 & 0 \\ -0.64 & -0.48 & 0.64 & 0.48 & 0 & 0 \\ -0.48 & -0.36 & 0.48 & 0.36 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Barra 2-3

$$k_2 = 16\,\text{MPa}\times \begin{array}{c} \begin{matrix} u_1 & \nu_1 & u_2 & \nu_2 & u_3 & \nu_3 \end{matrix} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.25 & -0.44 & -0.25 & 0.44 \\ 0 & 0 & -0.44 & 0.76 & 0.44 & -0.76 \\ 0 & 0 & -0.25 & 0.44 & 0.25 & -0.44 \\ 0 & 0 & 0.44 & -0.76 & -0.44 & 0.76 \end{bmatrix} \end{array}$$

Por tanto, la matriz ensamblada estaría dada por:

```
>> K = [5632000 4224000 -5632000 -4224000 0 0; 4224000 3168000 -4224000 -31680000 0
0; -5632000 -4224000 9362000 -2816000 -4000000 7040000; -4224000 -3168000 -2816000
15328000 7040000 -12160000; 0 0 -4000000 7040000 4000000 -7040000; 0 0 7040000
-12160000 -7040000 12160000]

K =

     5632000     4224000    -5632000    -4224000           0           0
     4224000     3168000    -4224000   -31680000           0           0
    -5632000    -4224000     9632000    -2816000    -4000000     7040000
    -4224000    -3168000    -2816000    15328000     7040000   -12160000
           0           0    -4000000     7040000     4000000    -7040000
           0           0     7040000   -12160000    -7040000    12160000
```

Paso 4: Elimine filas y columnas en los nodos 1 y 3 (por ser articulaciones).

$$\begin{bmatrix} 5632000 & 4224000 & -5632000 & -4224000 & 0 & 0 \\ 422400 & 3168000 & -4224000 & -31680000 & 0 & 0 \\ -5632000 & -4224000 & 9632000 & -2816000 & -4000000 & 7040000 \\ -4224000 & -3168000 & -2816000 & 15328000 & 7040000 & -12160000 \\ 0 & 0 & -4000000 & 7040000 & 4000000 & -7040000 \\ 0 & 0 & 7040000 & -12160000 & -7040000 & 12160000 \end{bmatrix} \times \begin{bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \\ u_3 \\ v_3 \end{bmatrix} = \begin{bmatrix} f_{x1} \\ f_{y1} \\ 7000\text{ kN} \\ -9000\text{ kN} \\ f_{x3} \\ f_{y3} \end{bmatrix}$$

Paso 5: Calcule los desplazamientos nodales.

$$u_2 = 0.5866 \text{ m}$$

$$v_2 = -0.4794 \text{ m}$$

B. Resolución con MATLAB

```
>> A = [9632000 -2816000; -2816000 15328000]

A =

     9632000    -2816000
    -2816000    15328000

>> F = [7000-10^3; -9000*10^3]

F =

     7000000
    -9000000

>> U = inv(A)*F

U =

    0.5866
   -0.4794
```

Cálculo de las fuerzas en cada articulación

$$F_{x1} = -5632000(0.5866) - (4224000)(-0.4794) = -1278746 \text{ N}$$

$$F_{y1} = -4224000(0.5866) - (3168000)(-0.4794) = 12709594 \text{ N}$$

$$F_{x3} = -4000000(0.5866) + (7040000)(-0.4794) = -5721376 \text{ N}$$

$$F_{y3} = -7040000(0.5866) + (12160000)(-0.4794) = 9959168 \text{ N}$$

```
>> K = [5632000 4224000 -5632000 -4224000 0 0; 4224000 3168000 -4224000 -31680000 0
0; -5632000 -4224000 9632000 -2816000 -4000000 7040000; -4224000 -3168000 -2816000
15328000 7040000 -12160000; 0 0 -4000000 7040000 4000000 -7040000; 0 0 7040000
-12160000 -7040000 12160000]

K =
     5632000     4224000    -5632000    -4224000           0           0
     4224000     3168000    -4224000   -31680000           0           0
    -5632000    -4224000     9632000    -2816000    -4000000     7040000
    -4224000    -3168000    -2816000    15328000     7040000   -12160000
           0           0    -4000000     7040000     4000000    -7040000
           0           0     7040000   -12160000    -7040000    12160000

>> U = [ 0; 0; 0.5866; -0.4794; 0;0]

U =
         0
         0
    0.5866
   -0.4794
         0
         0

>> F = K*U

F =

  1.0e+007 *

   -0.1279
    1.2710
    0.7000
   -0.9000
   -0.5721
    0.9959
```

Cálculo de los esfuerzos

$$\sigma_{12} = \frac{320\times10^9}{18}\begin{bmatrix}-1 & 1\end{bmatrix}\begin{bmatrix}0.8 & 0.8 & 0 & 0\\ 0 & 0 & 0.8 & 0.6\end{bmatrix}\begin{bmatrix}0\\0\\0.5866\\-0.4794\end{bmatrix} = 3.3\times10^{10}\ \text{Pa}$$

$$\sigma_{23} = \frac{320\times10^9}{10}\begin{bmatrix}-1 & 1\end{bmatrix}\begin{bmatrix}0.5 & -0.87 & 0 & 0\\ 0 & 0 & 0.5 & -0.87\end{bmatrix}\begin{bmatrix}0.5866\\-0.4794\\0\\0\end{bmatrix} = -2.3\times10^{10}\ \text{Pa}$$

```
>> % CALCULO DE LOS ESFUERZOS:
>> % ESFUERZO DE 1 A 2:
>> E12 = ((320*10^9)/18)*[-1 1]*[0.8 0.6 0 0; 0 0 0.8 0.6]*[0; 0; 0.5866; -0.4794]

E12 =

  3.2292e+009

>> % ESFUERZO DE 2 A 3:
>> E23 = ((320*10^9)/10)*[-1 1]*[0.5 -0.87 0 0; 0 0 0.5 -0.87]*[0.5866; -0.4794; 0; 0]

E23 =

 -2.2732e+010
```

EJERCICIO 6

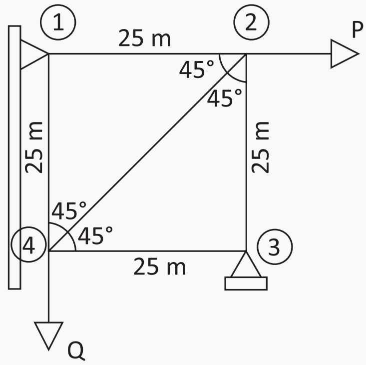
Hallar los desplazamientos, fuerzas y esfuerzos en cada caso.

$E = 200$ GPa

$A = 5 \times 10^{-4} m^2$

$P = 3000$ KN

$Q = 6000$ KN



A. Resolución

Paso 1: Calcule los ángulos.

$$K_1 = \frac{(200 \times 10^9)(5 \times 10^{-4})}{25} = 4000\frac{KN}{m} = K_2 = K_3 = K_5$$

$$K_4 = \frac{(200 \times 10^9)(5 \times 10^{-4})}{35.35} 2828.85 = \frac{KN}{m}$$

k	Barra	θ	C	S	C²	S²	CS	Longitud (m)
k_1	1-2	0	1	0	1	0	0	12
k_2	1-4	270°	0	–1	0	1	0	10
k_3	2-3	270°	0	–1	0	1	0	6
k_4	2-4	225°	–0.71	–0.71	0.50	0.50	0.50	6
k_5	3-4	180°	–1	0	1	0	0	12

$$1.0e+003 \times \begin{bmatrix} 4.0000 & 0 & 4.0000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 4.0000 & 0 & 0 & 0 & 0 & 0 & 4.0000 & 0 & 0 \\ -4.0000 & 0 & 5.4111 & 1.4144 & 0 & 0 & -1.4144 & -1.4144 & 0 & 0 \\ 0 & 0 & 1.4144 & 5.4144 & 0 & -4.0000 & -1.4144 & -1.4144 & 0 & 0 \\ 0 & 0 & 0 & 0 & 4.0000 & 0 & -4.0000 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1.4144 & -1.4144 & -4.0000 & 0 & 5.4144 & 1.4144 & 0 & 0 \\ 0 & -4.0000 & -1.4144 & -5.4144 & 0 & 4.0000 & 1.4144 & 5.4144 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

B. Resolución con MATLAB

```
>> k1=4000*[1 0 -1 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0 0 0;-1 0 1 0 0 0 0 0 0 0;0 0 0 0
0 0 0 0 0 0;0 0 0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0 0 0;0 0 0 0
0 0 0 0 0;0 0 0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0 0 0]
k1 =
  Columns 1 through 6
        4000           0       -4000           0           0           0
           0           0           0           0           0           0
       -4000           0        4000           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
  Columns 7 through 10
           0           0           0           0
           0           0           0           0
           0           0           0           0
           0           0           0           0
           0           0           0           0
           0           0           0           0
           0           0           0           0
           0           0           0           0
           0           0           0           0
           0           0           0           0
k2 =
  Columns 1 through 6
           0           0           0           0           0           0
           0        4000           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0       -4000           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
  Columns 7 through 10
           0           0           0           0
           0       -4000           0           0
           0           0           0           0
           0           0           0           0
           0           0           0           0
           0           0           0           0
           0           0           0           0
           0        4000           0           0
           0           0           0           0
           0           0           0           0
>> k3=4000*[0 0 0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0 0 0;0 0 0 1 0
-1 0 0 0 0;0 0 0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0 0 0;0 0 -1 0
1 0 0 0 0;0 0 0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0 0 0]
k3 =
  Columns 1 through 6
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0        4000           0       -4000
```

```
          0           0           0           0           0           0
          0           0           0           0           0           0
          0           0           0           0           0           0
          0           0           0       -4000           0        4000
          0           0           0           0           0           0
          0           0           0           0           0           0
  Colunns 7 through 10
          0           0           0           0
          0           0           0           0
          0           0           0           0
          0           0           0           0
          0           0           0           0
          0           0           0           0
          0           0           0           0
          0           0           0           0
          0           0           0           0
          0           0           0           0
>> k4=2828.85*[0 0 0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0 0 0;0 0 0.50 0.50 0 0 -0.50
-0.50 0 0;0 0 0.50 0.50 0 0 -0.50 -0.50 0 0;0 0 0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0
0;0 0 -0.50 -0.50 0 0 0.50 0.50 0 0;0 0 -0.50 -0.50 0 0 0.50 0.50 0 0;0 0 0 0 0
0 0 0 0;0 0 0 0 0 0 0 0 0 0]
k4 =
   1.0e+03 *
  Columns 1 through 7
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0    1.4144    1.4144         0         0   -1.4144
        0         0    1.4144    1.4144         0         0   -1.4144
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0   -1.4144   -1.4144         0         0    1.4144
        0         0   -1.4144   -1.4144         0         0    1.4144
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
  Columns 8 through 10
        0         0         0
        0         0         0
  -1.4144         0         0
  -1.4144         0         0
        0         0         0
        0         0         0
   1.4144         0         0
   1.4144         0         0
        0         0         0
        0         0         0
>> k5=4000*[0 0 0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0 0 0;0 0 0 0
0 0 0 0 0 0;0 0 0 0 1 0 -1 0 0 0;0 0 0 0 0 0 0 0 0 0;0 0 0 0 -1 0 1 0 0 0;0 0 0 0
0 0 0 0 0 0;0 0 0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0 0 0]
k5 =
  Columns 1 through 6
          0           0           0           0           0           0
          0           0           0           0           0           0
          0           0           0           0           0           0
          0           0           0           0           0           0
          0           0           0           0        4000           0
          0           0           0           0           0           0
          0           0           0           0       -4000           0
          0           0           0           0           0           0
          0           0           0           0           0           0
          0           0           0           0           0           0
```

```
  Columns 7 through 10
         0           0           0           0
         0           0           0           0
         0           0           0           0
         0           0           0           0
     -4000           0           0           0
         0           0           0           0
      4000           0           0           0
         0           0           0           0
         0           0           0           0
         0           0           0           0
>> K=k1+k2+k3+k4+k5
K =
   1.0e+03 *
  Columns 1 through 7
    4.0000         0   -4.0000         0         0         0         0
         0    4.0000         0         0         0         0         0
   -4.0000         0    5.4144    1.4144         0         0   -1.4144
         0         0    1.4144    5.4144         0   -4.0000   -1.4144
         0         0         0         0    4.0000         0   -4.0000
         0         0         0         0         0         0         0
         0         0   -1.4144   -1.4144   -4.0000         0    5.4144
         0   -4.0000   -1.4144   -5.4144         0    4.0000    1.4144
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
  Columns 8 through 10
         0         0         0
   -4.0000         0         0
   -1.4144         0         0
   -1.4144         0         0
         0         0         0
         0         0         0
    1.4144         0         0
    5.4144         0         0
         0         0         0
         0         0         0
```

Cálculos de los esfuerzos

```
>> % CALCULOS DE LOS ESFUERZOS:
>> % ESFUERZO DE 1 A 2:
>> G12= 8000000*[-1 1]*[1 0 0 0; 0 0 1 0]*[0; 0; 0.3639; -0.3861]
G12 =
     2911200
>> % ESFUERZO DE 1 A 4:
>> G14 = 8000000* [-1 1] * [0 -1 0 0; 0 0 0 -1] * [0; 0; 0.3639; -0.3861]
G14 =
     3088800
>> % ESFUERZO DE 2 A 3:
>> G23 = 8000000*[-1 1]*[0 -1 0 0; 0 0 0 -1]*[ 0.3639; -0.3861; 0; 0]
G23 =
    -3088800
>> % ESFUERZO DE 2 A 4:
>> G24 = 5657708628* [-1 1] * [-0.71 -0.71 0 0; 0 0 -0.71 -0.71] * [0.3861;
-1.5000; 0; 0]
G24 =
  -4.4745e+09
>> % ESFUERZO DE 3 A 4:
>> G34 = 8000000*[-1 1]*[-1 0 0 0; 0 0  -1 0]*[0; 0;  0.3861;-1.5]
G34 =
    -3088800
```

EJERCICIO 7

Hallar los desplazamientos, fuerzas y esfuerzos en cada caso.

$E = 200$ GPa

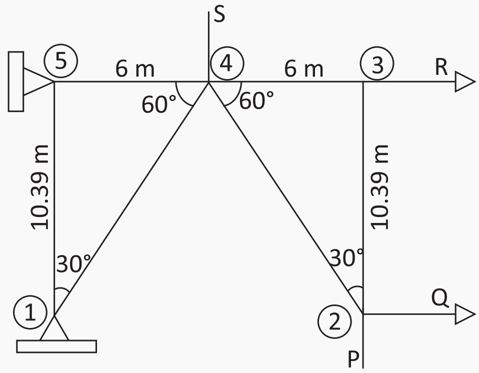
$A = 3 \times 10^{-4} m^2$

$P = 12000$ KN

$Q = 10000$ KN

$R = 8000$ KN

$S = 5000$ KN



A. Resolución

Calcule las rigideces de cada barra.

$$K_1 = \frac{(200 \times 10^9)(3 \times 10^{-4})}{12} = 5000 \frac{KN}{m} = K_4$$

$$K_2 = \frac{(200 \times 10^9)(3 \times 10^{-4})}{10.39} = 5774.78 \frac{KN}{m} = K_3$$

$$K_5 = \frac{(200 \times 10^9)(3 \times 10^{-4})}{6} = 10000 \frac{KN}{m} = K_6$$

k	Barra	θ	C	S	C^2	S^2	CS
k_1	2-3	90	0	1	0	1	0
k_2	2-4	120	0.5	0.87	0.25	0.7569	0.1892
k_3	1-4	60	0.5	0.87	0.25	0.7569	0.1892
k_4	4-5	180	–1	0	1	0	0
k_5	3-4	180	–1	0	1	0	0
k_6	1-5	90°	0	1	0	1	0

B. Resolución con MATLAB

```
>> k1=5000*[0.25 0.435 0 0 0 0 -0.25 -0.435 0 0 0 0; 0.435 0.75 0 0 0 0 -0.435
-0.75 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0
0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0;-0.25 -0.435 0 0 0 0 0.25 0.435 0 0 0 0; -0.435
-0.75 0 0 0 0 0.435 0.75 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0]
k1 =
  Columns 1 through 6
        1250        2175           0           0           0           0
        2175        3750           0           0           0           0
           0           0           0           0           0           0
```

```
            0           0           0           0           0           0
            0           0           0           0           0           0
            0           0           0           0           0           0
        -1250       -2175           0           0           0           0
        -2175       -3750           0           0           0           0
            0           0           0           0           0           0
            0           0           0           0           0           0
            0           0           0           0           0           0
            0           0           0           0           0           0
  Columns 7 through 12
        -1250       -2175           0           0           0           0
        -2175       -3750           0           0           0           0
            0           0           0           0           0           0
            0           0           0           0           0           0
            0           0           0           0           0           0
            0           0           0           0           0           0
         1250        2175           0           0           0           0
         2175        3750           0           0           0           0
            0           0           0           0           0           0
            0           0           0           0           0           0
            0           0           0           0           0           0
            0           0           0           0           0           0

>> k2=5774.78*[ 0 0 0 0 0 0 0 0 0 0 0 0; 0 1 0 0 0 0 0 0 0 -1 0 0;  0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0
0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0
-1 0 0 0 0 0 0 0 1 0 0;  0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0]
k2 =
   1.0e+03 *
  Columns 1 through 7
          0         0         0         0         0         0         0
          0    5.7748         0         0         0         0         0
          0         0         0         0         0         0         0
          0         0         0         0         0         0         0
          0         0         0         0         0         0         0
          0         0         0         0         0         0         0
          0         0         0         0         0         0         0
          0         0         0         0         0         0         0
          0         0         0         0         0         0         0
          0   -5.7748         0         0         0         0         0
          0         0         0         0         0         0         0
          0         0         0         0         0         0         0
  Columns 8 through 12
          0         0         0         0         0
          0         0   -5 7748         0         0
          0         0         0         0         0
          0         0         0         0         0
          0         0         0         0         0
          0         0         0         0         0
          0         0         0         0         0
          0         0         0         0         0
          0         0         0         0         0
          0         0    5.7748         0         0
          0         0         0         0         0
          0         0         0         0         0

>> k3=5774.78*[ 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0
0 0 0 0; 0 0 0 1 0 -1 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 -1 0 1 0 0 0 0
0 0;  0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0]
```

```
k3 =
   1.0e+03 *
  Columns 1 through 7
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0    5.7748         0   -5.7748         0
         0         0         0         0         0         0         0
         0         0         0   -5.7748         0    5.7748         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
  Columns 8 through 12
         0         0         0         0         0
         0         0         0         0         0
         0         0         0         0         0
         0         0         0         0         0
         0         0         0         0         0
         0         0         0         0         0
         0         0         0         0         0
         0         0         0         0         0
         0         0         0         0         0
         0         0         0         0         0
         0         0         0         0         0
         0         0         0         0         0

>> k4=5000*[ 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0.25 -0.435 0
0 -0.25 0.435 0 0 0 0; 0 0 -0.435 0.75 0 0  0.435 -0.75  0 0 0 0; 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 -0.25 0.435 0 0 0.25;-0.435 0 0 0 0; 0 0
0.435 -0.75  0 0 -0.435 0.75 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0
0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0]
k4 =
  Columns 1 through 6
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0        1250       -2175           0           0
           0           0       -2175        3750           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0       -1250        2175           0           0
           0           0        2175       -3750           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
  Columns 7 through 12
           0           0           0           0           0           0
           0           0           0           0           0           0
       -1250        2175           0           0           0           0
        2175       -3750           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
        1250       -2175           0           0           0           0
       -2175        3750           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
```

```
>> K5=10000*[ 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0
0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 1 0 -1 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 -1 0 1 0 0 0 0 0;  0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0
0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0]
K5 =
  Columns 1 through 6
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0       10000           0
           0           0           0           0           0           0
           0           0           0           0      -10000           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
  Columns 7 through 12
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
      -10000           0           0           0           0           0
           0           0           0           0           0           0
       10000           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0

>> K6=10000*[ 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0
0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 1 0 -1 0 0 0;  0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 -1 0 1 0 0 0; 0 0
0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0]
K6 =
  Columns 1 through 6
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
  Columns 7 through 12
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
       10000           0      -10000           0           0           0
           0           0           0           0           0           0
      -10000           0       10000           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
```

```
>> KT=k1+k2+k3+k4+k5+k6
KT =
   1.0e+04 *
  Columns 1 through 7
    0.1250    0.2175         0         0         0         0   -0.1250
    0.2175    0.9525         0         0         0         0   -0.2175
         0         0    0.1250   -0.2175         0         0   -0.1250
         0         0   -0.2175    0.9525         0   -0.5775    0.2175
         0         0         0         0    1.0000         0   -1.0000
         0         0         0   -0.5775         0    0.5775         0
   -0.1250   -0.2175   -0.1250    0.2175   -1.0000         0    2.2500
   -0.2175   -0.3750    0.2175   -0.3750         0         0         0
         0         0         0         0         0         0   -1.0000
         0   -0.5775         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
  Columns 8 through 12
   -0.2175         0         0         0         0
   -0.3750         0   -0.5775         0         0
    0.2175         0         0         0         0
   -0.3750         0         0         0         0
         0         0         0         0         0
         0         0         0         0         0
         0   -1.0000         0         0         0
    0.7500         0         0         0         0
         0    1.0000         0         0         0
         0         0    0.5775         0         0
         0         0         0         0         0
         0         0         0         0         0
```

0.1250	0.2175	0	0	0	0	−0.1250	−0.2175	0	0	0	0
0.2175	0.9525	0	0	0	0	−0.2175	−0.3750	0	−0.5775	0	0
0	0	0.1250	−0.2175	0	0	−0.1250	0.2175	0	0	0	0
0	0	−0.2175	0.9525	0	−0.5775	0.2175	−0.3750	0	0	0	0
0	0	0	0	1.0000	0	−1.0000	0	0	0	0	0
0	0	0	−0.5775	0	0.5775	0	0	0	0	0	0
−0.1250	−0.2175	−0.1250	0.2175	−1.0000	0	2.2500	0	−1.0000	0	0	0
−0.2175	−0.3750	0.2175	−0.3750	0	0	0	0.7500	0	0	0	0
0	0	0	0	0	0	1.0000	0	1.0000	0	0	0
0	0.5775	0	0	0	0	0	0	0	0.5775	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0

```
>> Y= 1.0e+004 *[0.1250 -0.2175 0 0 -0.1250 0.2175 ; -0.2175 0.9525 0 -0.5775
0.2175 -0.3750; 0 0 1.0000 0 -1.0000 0 ; 0 -0.5775 0 0.5775 0 0; -0.1250 0.2175
-1.0000 0 2.2500 0; 0.2175 -0.3750 0 0 0 0.7500]
Y =
        1250       -2175           0           0       -1250        2175
       -2175        9525           0       -5775        2175       -3750
           0           0       10000           0      -10000           0
           0       -5775           0        5775           0           0
       -1250        2175      -10000           0       22500           0
        2175       -3750           0           0           0        7500
```

```
>> M=[10000; -12000 ; 8000; 0; 0 ; 5000]
M =
       10000
      -12000
        8000
           0
           0
        5000

>> U=inv(Y)*M
U =
 -262.1393
 -159.6694
    3.0085
 -159.6694
    2.2085
   -3.1476
```

Cálculo de los esfuerzos

```
>> % CALCULO DE LOS ESFUERZOS:
>> % ESFUERZO DE 1 A 4:
>> G14 = 16666666.67*[-1 1]*[0.5 0.87 0 0; 0 0 0.5 0.87]*[0; 0; 2.2085; -3.1476]
G14 =
  -2.7236e+07
>> % ESFUERZO DE 1 A 5:
>> G15 = 19249278*[-1 1]*[0 1 0 0; 0 0 0 1]*[0; 0; 0; 0]
G15 =
     0
>> % ESFUERZO DE 2 A 3:
>>  G23  =  19249278*[-1  1]*[0  1  0  0;  0  0  0  1]*[-262.1393;  -159.6694;  3.0085;
-159.6694]
G23 =
     0
>> % ESFUERZO DE 2 A 4:
>> G24 = 16666666.67*[-1 1]*[-0.5 0.87 0 0; 0 0 -0.5 0.87]*[-262.1393; -159.6694;
2.2085; -3.1476]
G24 =
   6.6668e+07
>> % ESFUERZO DE 3 A 4:
>>  G34  =  33333333.33*[-1  1]*[-1  0  0  0;  0  0  -1  0]*[3.0085;  -159.6694;  2.2085;
-3.1476]
G34 =
   2.6667e+07
>> % ESFUERZO DE 4 A 5:
>> G45 = 33333333.33*[-1 1]*[-1 0 0 0; 0 0 -1 0]*[2.2085; -3.1476; 0; 0]
G45 =
   7.3617e+07
```

EJERCICIO 8

Hallar los desplazamientos, fuerzas y esfuerzos en cada caso.

$E = 200\ \text{GPa}$

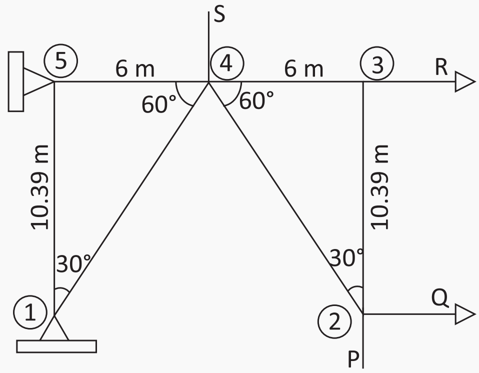
$A = 3 \times 10^{-4}\ \text{m}^2$

$P = 12000\ \text{KN}$

$Q = 10000\ \text{KN}$

$R = 8000\ \text{KN}$

$S = 5000\ \text{KN}$



A. Resolución

Paso 1: Calcule las rigideces de cada barra.

$$K_1 = \frac{(320 \times 10^9)(5 \times 10^{-4})}{18} = 8888.89 \frac{\text{KN}}{\text{m}}$$

$$K_2 = \frac{(320 \times 10^9)(5 \times 10^{-4})}{10} = 16000 \frac{\text{KN}}{\text{m}}$$

k	Barra	θ	C	S	C^2	S^2	CS
k_1	1-2	37	0.80	0.6	0.64	0.36	0.48
k_2	2-3	300	0.5	–0.87	0.25	0.75	–0.435

B. Resolución con MATLAB

```
>> k1 = 8888.89*[0.64 0.48 -0.64 -0.48 0 0;0.48 0.36 -0.48 -0.36 0 0; -0.64 -0.48
0.64 0.48 0 0; -0.48 -0.36 0.48 0.36 0 0; 0 0 0 0 0 0; 0 0 0 0 0 0]
k1 =
   1.0e+03 *
    5.6889    4.2667   -5.6889   -4.2667         0         0
    4.2667    3.2000   -4.2667   -3.2000         0         0
   -5.6889   -4.2667    5.6889    4.2667         0         0
   -4.2667   -3.2000    4.2667    3.2000         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0

>> k2 = 16000* [0 0 0 0 0 0; 0 0 0 0 0 0; 0 0 0.25 -0.44 -0.25 0.44; 0 0 -0.44 0.75
0.44 -0.75; 0 0 -0.25 0.44 0.25 -0.44; 0 0 0.44 -0.75 -0.44 0.75]
k2 =
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0        4000       -7040       -4000        7040
           0           0       -7040       12000        7040      -12000
           0           0       -4000        7040        4000       -7040
           0           0        7040      -12000       -7040       12000
```

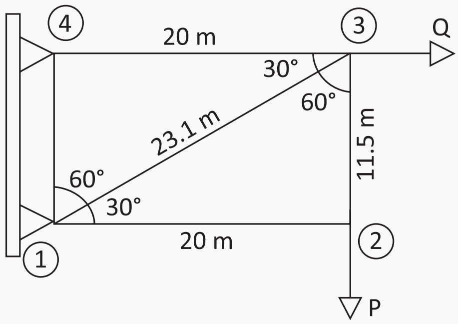
```
>> kT = k1 + k2
KT =
   1.0e+04 *
    0.5689    0.4267   -0.5689   -0.4267         0         0
    0.4267    0.3200   -0.4267   -0.3200         0         0
   -0.5689   -0.4267    0.9689   -0.2773   -0.4000    0.7040
   -0.4267   -0.3200   -0.2773    1.5200    0.7040   -1.2000
         0         0   -0.4000    0.7040    0.4000   -0.7040
         0         0    0.7040   -1.2000   -0.7040    1.2000

>> Y = 1.0e+004*[0.9689   -0.2773; -0.2773    1.5200]
Y =
        9689       -2773
       -2773       15200
>> F = [7000; -9000]
F =
        7000
       -9000
>> U = inv (Y) * F
U =
    0.5835
   -0.4857
```

Cálculo de los esfuerzos

```
>> % CALCULO DE LOS ESFUERZOS:
>> % ESFUERZO DE 1 A 2:
>> G12 = 17777777.78 * [-1 1] * [0.8 0.6 0 0; 0 0 0.8 0.6] * [0; 0; 0.5835; -0.4857]

G12 =

  3.1179e+006

>> % ESFUERZO DE 2 A 3:
>> G23 = 32000000 * [-1 1] * [0.5 -0.87 0 0; 0 0 0.5 -0.87] * [0.5835; -0.4857;
0; 0]

G23 =

   -22857888
```

EJERCICIO 9

Hallar los desplazamientos, fuerzas y esfuerzos en cada caso.



$E = 250\ GPa$

$A = 5\times10^{-4}m^2$

$P = 10000\ KN$

$Q = 8000\ KN$

A. Resolución

Paso 1: Calcule las rigideces de cada barra.

$$K_1 = \frac{(5\times10^{-4}m^2)(250\times10^9\frac{N}{m^2})}{20m} = 62500\frac{KN}{m}$$

$$K_2 = \frac{(5\times10^{-4}m^2)(250\times10^9\frac{N}{m^2})}{11.55m} = 10822\frac{KN}{m}$$

$$K_3 = \frac{(5\times10^{-4}m^2)(250\times10^9\frac{N}{m^2})}{23.10m} = 5411\frac{KN}{m}$$

$$K_4 = \frac{(5\times10^{-4}m^2)(250\times10^9\frac{N}{m^2})}{20m} = 62500\frac{KN}{m}$$

k	Barra	θ	C	S	C^2	S^2	CS
k_1	1-2	0	1	0	1	0	0
k_2	2-3	90°	0	1	0	1	0
k_3	1-3	30°	0.87	0.5	0.76	0.25	0.44
k_4	3-4	180°	–1	0	1	0	0

B. Resolución con MATLAB

```
>> k1=62500*1000*[1 0 1 0 0 0 0 0; 0 0 0 0 0 0 0 0;1 0 1 0 0 0 0 0;0 0 0 0 0 0 0
0;0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0]
k1 =
  Columns 1 through 6
    62500000           0    62500000           0           0
           0           0           0           0           0
    62500000           0    62500000           0           0
```

```
           0           0           0           0           0
           0           0           0           0           0
           0           0           0           0           0
           0           0           0           0           0
           0           0           0           0           0
  Columns 7 through 8
           0           0
           0           0
           0           0
           0           0
           0           0
           0           0
           0           0
           0           0

>> k2=10822*1000*[0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0; 0 0 0 1 0 1 0
0;0 0 0 0 0 0 0 0; 0 0 0 1 0 1 0 0;0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0]
k2 =
  Columns 1 through 6
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0    10822000           0    10822000
           0           0           0           0           0           0
           0           0           0    10822000           0    10822000
           0           0           0           0           0           0
           0           0           0           0           0           0
  Columns 7 through 8
           0           0
           0           0
           0           0
           0           0
           0           0
           0           0
           0           0
           0           0

>> k3=5411*1000*[0.76 0.44 0 0 -0.76 -0.44 0 0; 0.44 0.25 0 0 -0.44 -0.25 0 0; 0
0 0 0 0 0 0 0;0 0 0 0 0 0 0 0;-0.76 -0.44 0 0 0.76 0.44 0 0;-0.44 -0.25 0 0 0.44
0.25 0 0;0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0]
k3 =
  Columns 1 through 6
     4112360     2380840           0           0    -4112360    -2380840
     2380840     1352750           0           0    -2380840    -1352750
           0           0           0           0           0           0
           0           0           0           0           0           0
    -4112360    -2380840           0           0     4112360     2380840
    -2380840    -1352750           0           0     2380840     1352750
           0           0           0           0           0           0
           0           0           0           0           0           0
  Columns 7 through 8
           0           0
           0           0
           0           0
           0           0
           0           0
           0           0
           0           0
           0           0
```

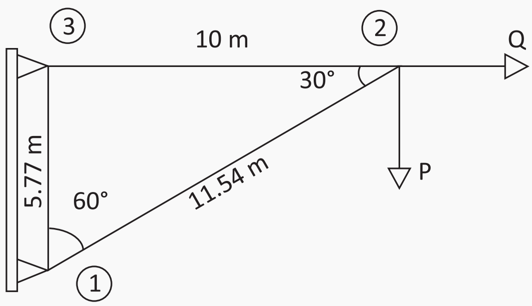
```
>> k4=62500*1000*[0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0;
0 0 0 0 1 0 -1 0; 0 0 0 0 0 0 0 0; 0 0 0 0 -1 0 1 0;0 0 0 0 0 0 0 0]
k4 =
  Columns 1 through 6
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0    62500000           0
           0           0           0           0           0           0
           0           0           0           0   -62500000           0
           0           0           0           0           0           0
  Columns 7 through 8
           0           0
           0           0
           0           0
           0           0
   -62500000           0
           0           0
    62500000           0
           0           0

>> K=k1+k2+k3+k4
K =
  Columns 1 through 6
    66612360     2380840    62500000           0    -4112360    -2380840
     2380840     1352750           0           0    -2380840    -1352750
    62500000           0    62500000           0           0           0
           0           0           0    10822000           0    10822000
    -4112360    -2380840           0           0    66612360     2380840
    -2380840    -1352750           0    10822000     2380840    12174750
           0           0           0           0   -62500000           0
           0           0           0           0           0           0
  Columns 7 through 8
           0           0
           0           0
           0           0
           0           0
   -62500000           0
           0           0
    62500000           0
           0           0

>> Y = [62500000 0 0 0; 0 10822000 0 10822000; 0 0 66612360 2380840; 0 10822000
2380840 12174750]
Y =
    62500000           0           0           0
           0    10822000           0    10822000
           0           0    66612360     2380840
           0    10822000     2380840    12174750
>> F = 1000*[0;-10000; 8000;0]
F =
           0
   -10000000
     8000000
           0
>> U=inv(Y)*F
U =
         0
   -8.5871
   -0.1538
    7.6630
```

Cálculo de los esfuerzos

```
>> % CALCULO DE LOS ESFUERZOS:
>> % ESFUERZO DE 1 A 2:
>> G12 = 12500000*[-1 1]*[1 0 0 0; 0 0 1 0]*[0; 0; 0; -8.5871]
G12 =
     0
>> % ESFUERZO DE 2 A 3:
>> G23 = 21645021*[-1 1]*[0 1 0 0; 0 0 0 1]*[0; -8.5871; -0.1538; 7.6630]
G23 =
   3.5173e+08
>> % ESFUERZO DE 1 A 3:
>> G13 = 10822510.82*[-1 1]*[0.87 0.5 0 0; 0 0 0.87 0.5]*[0; 0; -0.1538; 7.6630]
G13 =
   4.0018e+07
>> % ESFUERZO DE 3 A 4:
>> G34 = 12500000*[-1 1]*[-1 0 0 0; 0 0 -1 0]*[-0.1538; 7.6630; 0;0]
G34 =
    -1922500
```

EJERCICIO 10

Hallar los desplazamientos, fuerzas y esfuerzos en cada caso.



$E = 300\ \text{GPa}$

$A = 8 \times 10^{-4}\ m^2$

$P = 5000\ \text{KN}$

$Q = 8000\ \text{KN}$

A. Resolución

Paso 1: Calcule los siguientes valores.

k	Barra	θ	C	S	C^2	S^2	CS
k_1	1-2	30°	0.87	0.5	0.75	0.25	0.44
k_2	2-3	180°	–1	0	1	0	0
k_3	1-3	90°	0	1	0	1	0

Paso 2: Calcule las rigideces de cada barra.

$$K_1 = \frac{(300 \times 10^9)(8 \times 10^{-4})}{11.5} = 20779.22 \frac{KN}{m}$$

$$K_2 = \frac{(300\times10^9)(8\times10^{-4})}{10} = 24000\frac{KN}{m}$$

$$K_3 = \frac{(300\times10^9)(8\times10^{-4})}{5.77} = 41594.45\frac{KN}{m}$$

B. Resolución con MATLAB

```
>> k1= 20779.22 * 1000 * [ 0.75 0.44 -0.75 -0.44 0 0 ;0.44 0.25 -0.44 -0.25 0 0 ;
-0.75 -0.44 0.75 0.44 0 0 ; -0.44 -0.25 0.44 0.25 0 0 ; 0 0 0 0 0 0 ;0 0 0 0 0 0 ]

k1 =

  1.0e+007 *

    1.5584    0.9143   -1.5584   -0.9143         0         0
    0.9143    0.5195   -0.9143   -0.5195         0         0
   -1.5584   -0.9143    1.5584    0.9143         0         0
   -0.9143   -0.5195    0.9143    0.5195         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0

>> k2= 24000 * 1000 * [ 0 0 0 0 0 0 ;0 0 0 0 0 0 ; 0 0 1 0 -1 0 ; 0 0 0 0 0 0 ;
0 0 -1 0 1 0 ;0 0 0 -1 0 1 ]

k2 =

           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0    24000000           0   -24000000           0
           0           0           0           0           0           0
           0           0   -24000000           0    24000000           0
           0           0           0   -24000000           0    24000000

>> k3= 41594.45 * 1000 * [ 0 0 0 0 0 0 ;0 1 0 0 0 -1 ; 0 0 0 0 0 0 ; ...
0 0 0 0 0 0 ; 0 0 0 0 0 0 ;0 -1 0 0 0 1 ]

k3 =

           0           0           0           0           0           0
           0    41594450           0           0           0   -41594450
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0   -41594450           0           0           0    41594450

>> KT= k1+k2+k3

KT =

  1.0e+007 *

    1.5584    0.9143   -1.5584   -0.9143         0         0
    0.9143    4.6789   -0.9143   -0.5195         0   -4.1594
   -1.5584   -0.9143    3.9584    0.9143   -2.4000         0
   -0.9143   -0.5195    0.9143    0.5195         0         0
         0         0   -2.4000         0    2.4000         0
         0   -4.1594         0   -2.4000         0    6.5594
```

1.5584	0.9143	−1.5584	−0.9143	0	0
0.9143	4.6789	−0.9143	−0.5195	0	−4.1594
−1.5584	−0.9143	3.9584	0.9143	−2.4000	0
−0.9143	−0.5195	0.9143	0.5195	0	0
0	0	−2.4000	0	2.4000	0
0	−4.1594	0	−2.4000	0	6.5594

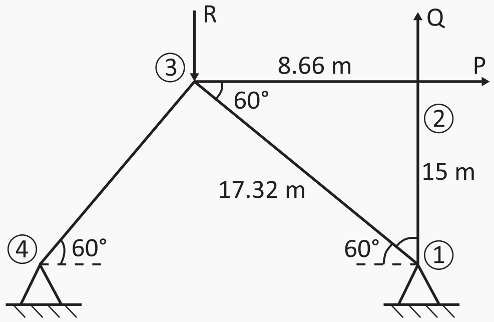
```
>> Y= [ 3.9584    0.9143 ;    0.9143    0.5195 ]

Y =

    3.9584    0.9143
    0.9143    0.5195

>> F= 1000 * [ 8000 ; -5000 ]

F =

     8000000
    -5000000

>> U= inv(Y)*F

U =

  1.0e+007 *

    0.7151
   -2.2210
```

Cálculo de los esfuerzos

```
>> % CALCULO DE LOS ESFUERZOS:
>> % ESFUERZO DE 1 A 2:
>> G12 = 2.60e+010 * [-1 1] * [0.87 0.5 0 0; 0 0 0.87 0.5] * [0; 0; 0.7151; -2.2210]

G12 =

 -1.2697e+010

>> % ESFUERZO DE 2 A 3:
>> G23 = 3.0e+010 * [-1 1] * [-1 0 0 0; 0 0 -1 0] * [0.7151; -2.2210; 0; 0]

G23 =

  2.1453e+010

>> % ESFUERZO DE 1 A 3:
>> 5.19e+010  * [-1 1] * [0 1 0 0; 0 0 0 1] * [0 ; 0 ; 0; 0]

ans =

     0
```

EJERCICIO 11

Hallar los desplazamientos nodales, esfuerzos y las fuerzas en los siguientes sistemas estructurales:



$E_1 = 320\ \text{GPa}$

$A_1 = 6\times10^{-4}\ \text{m}^2$

$P = 2000\ \text{KN}$

$Q = 2300\ \text{KN}$

$R = 2500\ \text{KN}$

A. Resolución

Paso 1: Calcule los ángulos.

Elemento	Nodo	θ	C	S	C²	S²	CS
1	1 – 2	90°	0	1	0	1	0
2	2 – 3	180°	–1	0	1	0	0
3	3 – 4	240°	–0.5	–0.87	0.25	0.76	0.44
4	1 – 3	120°	–0.5	0.87	0.25	0.76	–0.44

Paso 2: Calcule las matrices de rigidez de cada barra.

$$k_1 = \frac{320\times10^{9}\,\text{Pa}\left(6\times10^{-4}\,\text{m}^2\right)}{15\text{m}} \times \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_1 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 128\times10^{5} & 0 & -128\times10^{5} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -128\times10^{5} & 0 & 128\times10^{5} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_2 = \frac{320\times10^9\,\mathrm{Pa}\left(6\times10^{-4}\,\mathrm{m}^2\right)}{8.66\mathrm{m}}\times\begin{bmatrix} 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&1&0&-1&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&-1&0&1&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0 \end{bmatrix}$$

$$k_2 = \begin{bmatrix} 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&2.2171\times10^7&0&-2.2171\times10^7&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&-2.2171\times10^7&0&2.2171\times10^7&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0 \end{bmatrix}$$

$$k_3 = \frac{320\times10^9\,\mathrm{Pa}\left(6\times10^{-4}\,\mathrm{m}^2\right)}{17.32\mathrm{m}}\times\begin{bmatrix} 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&2.7746\times10^6&4.8832\times10^6&-2.7746\times10^6&-4.8832\times10^6\\ 0&0&0&0&4.8832\times10^6&8.4347\times10^6&-4.8832\times10^6&-8.4347\times10^6\\ 0&0&0&0&-2.7746\times10^6&-4.8832\times10^6&2.7746\times10^6&4.8832\times10^6\\ 0&0&0&0&-4.8832\times10^6&-8.4347\times10^6&4.8832\times10^6&8.4347\times10^6 \end{bmatrix}$$

$$k_3 = \begin{bmatrix} 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0.25&0.44&-0.25&-0.44\\ 0&0&0&0&0.44&0.76&-0.44&-0.76\\ 0&0&0&0&-0.25&-0.44&0.25&0.44\\ 0&0&0&0&-0.44&-0.76&0.44&0.76 \end{bmatrix}$$

$$k_4 = \frac{320\times10^9\,\mathrm{Pa}\left(6\times10^{-4}\,\mathrm{m}^2\right)}{17.32\mathrm{m}}\times\begin{bmatrix} 2.7746\times10^6&-4.8832\times10^6&0&0&-2.7746\times10^6&4.8832\times10^6&0&0\\ -4.8832\times10^6&8.4347\times10^6&0&0&4.8832\times10^6&-8.4347\times10^6&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0\\ -2.7746\times10^6&4.8832\times10^6&0&0&2.7746\times10^6&-4.8832\times10^6&0&0\\ 4.8832\times10^6&-8.4347\times10^6&0&0&-4.8832\times10^6&8.4347\times10^6&0&0\\ 0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0 \end{bmatrix}$$

$$k_4 = \begin{bmatrix} 0.25 & -0.44 & 0 & 0 & -0.25 & 0.44 & 0 & 0 \\ -0.44 & 0.76 & 0 & 0 & 0.44 & -0.76 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.25 & 0.44 & 0 & 0 & 0.25 & -0.44 & 0 & 0 \\ 0.44 & -0.76 & 0 & 0 & -0.44 & 0.76 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Se obtiene la siguiente matriz de rigidez:

$$KT = \begin{bmatrix} 2.77\times10^6 & -4.8832\times10^6 & 0 & 0 & -2.77\times10^6 & 4.8832\times10^6 & 0 & 0 \\ 4.8832\times10^6 & 2.1235\times10^7 & 0 & 128\times10^5 & 4.8832\times0^6 & -8.4347\times10^6 & 0 & 0 \\ 0 & 0 & 2.2171\times10^7 & 0 & -2.2171\times10^7 & 0 & 0 & 0 \\ 0 & 128\times10^5 & 0 & -128\times10^7 & 0 & 0 & 0 & 0 \\ -2.7746\times10^5 & 4.8832\times10^6 & -2.2171\times10^7 & 0 & 2.7720\times10^7 & 0 & -2.7746\times10^6 & -4.8832\times10^6 \\ 4.8832\times10^6 & -8.4347\times10^6 & 0 & 0 & 0 & 16.8694\times10^6 & -4.8832\times10^6 & -8.4347\times10^6 \\ 0 & 0 & 0 & 0 & -2.7746\times10^6 & -4.8832\times10^6 & 2.7746\times10^6 & 4.8832\times10^6 \\ 0 & 0 & 0 & 0 & -4.8832\times10^6 & -8.4347\times10^6 & 4.8832\times10^6 & 8.4347\times10^6 \end{bmatrix}$$

Se obtiene la siguiente matriz ensamblada:

$$K = \begin{bmatrix} 2.77\times10^6 & -4.8832\times10^6 & 0 & 0 & -2.77\times10^6 & 4.8832\times10^6 & 0 & 0 \\ 4.8832\times10^6 & 2.1235\times10^7 & 0 & 128\times10^5 & 4.8832\times10^6 & -8.4347\times10^6 & 0 & 0 \\ 0 & 0 & 2.2171\times10^7 & 0 & -2.2171\times10^7 & 0 & 0 & 0 \\ 0 & 128\times10^5 & 0 & -128\times10^7 & 0 & 0 & 0 & 0 \\ -2.7746\times10^5 & 4.8832\times10^6 & -2.2171\times10^7 & 0 & 2.7720\times10^7 & 0 & -2.7746\times10^6 & -4.8832\times10^6 \\ 4.8832\times10^6 & -8.4347\times10^6 & 0 & 0 & 0 & 16.8694\times10^6 & -4.8832\times10^6 & -8.4347\times10^6 \\ 0 & 0 & 0 & 0 & -2.7746\times10^6 & -4.8832\times10^6 & 2.7746\times10^6 & 4.8832\times10^6 \\ 0 & 0 & 0 & 0 & -4.8832\times10^6 & -8.4347\times10^6 & 4.8832\times10^6 & 8.4347\times10^6 \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ u_{2x} \\ v_{2y} \\ u_{3x} \\ v_{3y} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} F_{1x} \\ F_{1Y} \\ 2000\times10^3 \\ 2300\times10^3 \\ 0 \\ -2500\times10^3 \\ F_{4x} \\ F_{4y} \end{bmatrix}$$

Paso 3: Elimine filas y columnas en los nodos 1 y 4 (por ser articulaciones).

$$K = \begin{bmatrix} 2.77\times10^6 & -4.8832\times10^6 & 0 & 0 & -2.77\times10^6 & 4.8832\times10^6 & 0 & 0 \\ 4.8832\times10^6 & 2.1235\times10^7 & 0 & 128\times10^5 & 4.8832\times10^6 & -8.4347\times10^6 & 0 & 0 \\ 0 & 0 & 2.2171\times10^7 & 0 & -2.2171\times10^7 & 0 & 0 & 0 \\ 0 & 128\times10^5 & 0 & -128\times10^7 & 0 & 0 & 0 & 0 \\ -2.7746\times10^5 & 4.8832\times10^6 & -2.2171\times10^7 & 0 & 2.7720\times10^7 & 0 & -2.7746\times10^6 & -4.8832\times10^6 \\ 4.8832\times10^6 & -8.4347\times10^6 & 0 & 0 & 0 & 16.8694\times10^6 & -4.8832\times10^6 & -8.4347\times10^6 \\ 0 & 0 & 0 & 0 & -2.7746\times10^6 & -4.8832\times10^6 & 2.7746\times10^6 & 4.8832\times10^6 \\ 0 & 0 & 0 & 0 & -4.8832\times10^6 & -8.4347\times10^6 & 4.8832\times10^6 & 8.4347\times10^6 \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ u_{2x} \\ v_{2y} \\ u_{3x} \\ v_{3y} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} F_{1x} \\ F_{1Y} \\ 2000\times10^3 \\ 2300\times10^3 \\ 0 \\ -2500\times10^3 \\ F_{4x} \\ F_{4y} \end{bmatrix}$$

$$K = \begin{bmatrix} 2.2171\times10^7 & 0 & -2.2171\times10^7 & 0 \\ 0 & -128\times10^7 & 0 & 0 \\ -2.2171\times10^7 & 0 & 2.7720\times10^7 & 0 \\ 0 & 0 & 16.8694\times10^6 & 0 \end{bmatrix} \times \begin{bmatrix} u_{2x} \\ v_{2y} \\ u_{3x} \\ v_{3y} \end{bmatrix} = \begin{bmatrix} 2000\times10^3 \\ 2300\times10^3 \\ 0 \\ -2500\times10^3 \end{bmatrix}$$

Paso 4: Calcule los desplazamientos nodales.

$$u_2 = 0.4506 \text{ m}$$
$$v_2 = -0.0018 \text{ m}$$
$$u_3 = 0.3604 \text{ m}$$
$$v_3 = -0.1482 \text{ m}$$

B. Resolución con MATLAB

```
>> A = [2.2171*10^7 0 -2.2171*10^7 0; 0 -128*10^7 0 0; -2.217*10^7 0 2.7720*10^7 0;
0 0 0 16.8694*10^6]

A =

  1.0e+009 *

    0.0222         0   -0.0222         0
         0   -1.2800         0         0
   -0.0222         0    0.0277         0
         0         0         0    0.0169

>> F = [2000*10^3; 2300*10^3; 0; -2500*10^3]

F =

     2000000
     2300000
           0
    -2500000

>> U = inv(A)*F

U =

    0.4506
   -0.0018
    0.3603
   -0.1482
```

Cálculo de las fuerzas en cada articulación

$$F_{1x} = \left(-2.7746\times10^6\right)\left(0.3604\right) + (4.8832\times10^6)(-0.1482)$$
$$F_{1x} = -1724211 \text{ N}$$
$$F_{1y} = \left(128\times10^5\right)\left(0.1797\right) + (4.8832\times10^6)(0.3604)$$
$$F_{1y} = 2.9869\times10^6 \text{ N}$$
$$F_{4x} = \left(-2.7746\times10^6\right)\left(0.3604\right) + (-4.8832\times10^6)(-0.1482)$$
$$F_{4x} = -2.7628\times10^5 \text{ N}$$
$$F_{4y} = \left(-4.8832\times10^6\right)\left(0.3604\right) + (-8.4347\times10^6)(-0.1482)$$
$$F_{4y} = -5.0988\times10^5 \text{ N}$$

```
>> K = [2.77*10^6 -4.8832*10^6 0 0 -2.77*10^6 4.8832*10^6 0 0; 4.8832*10^6 2.1235*10^7
0 128*10^5 4.8832*10^6 -8.4347*10^6 0 0; 0 0 2.2171*10^7 0 -2.2171*10^7 0 0 0; 0
128*10^5 0 -128*10^7 0 0 0 0; -2.7746*10^5 4.8832*10^6 -2.2171*10^7 0 2.7720*10^7 0
-2.7764*10^6 -4.8832*10^6; 4.8832*10^6 -8.4347*10^6 0 0 0 16.8694*10^6 -4.8832*10^6
-8.4347*10^6; 0 0 0 0 -2.7746*10^6 -4.8832*10^6 2.7746*10^6 4.8832*10^6; 0 0 0 0
-4.8832*10^6 -8.4347*10^6 4.8832*10^6 8.4347*10^6]

K =

  1.0e+009 *

    0.0028   -0.0049         0         0   -0.0028    0.0049         0         0
    0.0049    0.0212         0    0.0128    0.0049   -0.0084         0         0
         0         0    0.0222         0   -0.0222         0         0         0
         0    0.0128         0   -1.2800         0         0         0         0
   -0.0003    0.0049   -0.0222         0    0.0277         0   -0.0028   -0.0049
    0.0049   -0.0084         0         0         0    0.0169   -0.0049   -0.0084
         0         0         0         0   -0.0028   -0.0049    0.0028    0.0049
         0         0         0         0   -0.0049   -0.0084    0.0049    0.0084

>> U = [0; 0; 0.4506; -0.0018; 0.3604; -0.1482; 0; 0]

U =

         0
         0
    0.4506
   -0.0018
    0.3604
   -0.1482
         0
         0

>> F = K*U

F =

  1.0e+009 *

   -1.7220
    2.9869
    1.9998
    2.3040
    0.0000
   -2.5000
   -0.2763
   -0.5099
```

Cálculo de los esfuerzos

$$\sigma_{i-j} = \left[\frac{E}{L} \times \left[-C \; -S \;\; C \;\; S \right] \times \begin{bmatrix} u_i \\ v_i \\ u_j \\ v_j \end{bmatrix} \right]$$

$$\sigma_{1-2} = \left[\frac{320\times10^{9}\,\text{Pa}}{15\text{m}} \times \begin{bmatrix} 0 & -1 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ 0.4506 \\ -0.0018 \end{bmatrix} \right] = 3.84\times10^{7}$$

$$\sigma_{2-3} = \left[\frac{320\times10^{9}\,\text{Pa}}{8.66\text{m}} \times \begin{bmatrix} 1 & 0 & -1 & 0 \end{bmatrix} \times \begin{bmatrix} 0.4506 \\ -0.0018 \\ 0.3604 \\ -0.1482 \end{bmatrix} \right] = 3.3330\times10^{9}$$

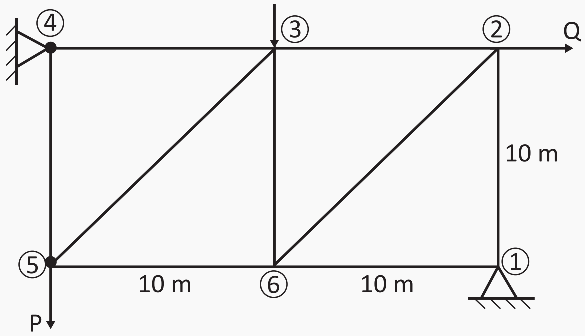
$$\sigma_{3-4} = \left[\frac{320\times10^{9}\,\text{Pa}}{17.32\text{m}} \times \begin{bmatrix} 0.5 & 0.87 & -0.5 & -0.87 \end{bmatrix} \times \begin{bmatrix} 0.3604 \\ -0.1482 \\ 0 \\ 0 \end{bmatrix} \right] = 9.4718\times10^{8}$$

$$\sigma_{1-3} = \left[\frac{320\times10^{9}\,\text{Pa}}{17.32\text{m}} \times \begin{bmatrix} 0.5 & -0.87 & -0.5 & 0.87 \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ 0.3604 \\ -0.1482 \end{bmatrix} \right] = -5.7115\times10^{9}$$

```
>> % CALCULO DE LOS ESFUERZOS:
>> % ESFUERZO DE 1 A 2:
>> E12 = ((320*10^9)/15)*10 -1 0 1]*[0; 0; 0.4506; -0.0018]

E12 =

   -38400000

>> % ESFUERZO DE 2 A 3:
>> E23 = ((320*10^9)/8.66)*[1 0 -1 0]*[0.4506; -0.0018; 0.3604; -0.1482]

E23 =

  3.3330e+009

>> % ESFUERZO DE 3 A 4:
>> E34 = ((320*10^9)/17.32)*[0.5 0.87 -0.5 -0.87]*[0.3604; -0.1482; 0; 0]

E34 =

  9.4718e+008

>> % ESFUERZO DE 1 A 3:
>> E34 = ((320*10^9)/17.32)*[0.5 0.87 -0.5 -0.87]*[0; 0; 0.3604; -0.1482]

E34 =

 -9.4718e+008

>> % ESFUERZO DE 1 A 3:
>> E13 = ((320*10^9)/17.32)*[0.5 -0.87 -0.5 0.87]*[0; 0; 0.3604; -0.1482]

E13 =

 -5.7115e+009
```

Ejercicio 12

Hallar los desplazamientos nodales, los esfuerzos y las fuerzas en los siguientes sistemas estructurales:



$E = 320\ GPa$

$A = 5 \times 10^{-4} m^2$

$P = 2500\ KN$

$Q = 2800\ KN$

$R = 3000\ KN$

A. Resolución

Paso 1: Calcule los ángulos.

Elemento	Nodo	θ	C	S	C^2	S^2	CS
1	1 – 2	90°	0	1	0	1	0
2	2 – 3	180°	-1	0	1	0	0
3	3 – 4	180°	-1	0	1	0	0
4	4 - 5	270°	0	-1	0	1	0
5	5 - 6	0	1	0	1	0	0
6	1 - 6	180	-1	0	1	0	0
7	2 - 6	225	-0.71	-0.71	-0.71	0.5	0.5
8	3 - 4	225	-0.71	-0.71	0.50	0.5	0.5
9	3 - 6	270	0	-1	0	1	0

Paso 2: Calcule las matrices de rigidez de cada barra.

$$k_1 = \frac{350 \times 10^9 Pa\left(5 \times 10^{-4} m^2\right)}{10m} \times \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_1 = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 17.5\times10^6 & 0 & -17.5\times10^6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -17.5\times10^6 & 0 & 17.5\times10^6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$k_2 = \frac{350\times10^9\,\text{Pa}\left(5\times10^{-4}\,\text{m}^2\right)}{10\text{m}} \times \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$k_2 = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 17.5\times10^6 & 0 & -17.5\times10^6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -17.5\times10^6 & 0 & 17.5\times10^6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$k_3 = \frac{350\times10^9\,\text{Pa}\left(5\times10^{-4}\,\text{m}^2\right)}{10\text{m}}\times\begin{bmatrix} 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&1&0&-1&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&-1&0&1&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0 \end{bmatrix}$$

$$k_3 = \begin{bmatrix} 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&17.5\times10^6&0&-17.5\times10^6&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&-17.5\times10^6&0&17.5\times10^6&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0 \end{bmatrix}$$

$$k_4 = \frac{350\times10^9\,\text{Pa}\left(5\times10^{-4}\,\text{m}^2\right)}{10\text{m}}\times\begin{bmatrix} 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&1&0&-1&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&-1&0&1&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0 \end{bmatrix}$$

$$k_4 = \begin{bmatrix} 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&17.5\times10^6&0&-17.5\times10^6&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&-17.5\times10^6&0&17.5\times10^6&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0 \end{bmatrix}$$

$$k_5 = \frac{350\times10^9\,\text{Pa}\left(5\times10^{-4}\,\text{m}^2\right)}{10\text{m}} \times \begin{bmatrix} 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&1&0&-1&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&-1&0&1&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0 \end{bmatrix}$$

$$k_5 = \frac{350\times10^9\,\text{Pa}\left(5\times10^{-4}\,\text{m}^2\right)}{10\text{m}} \times \begin{bmatrix} 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&17.5\times10^6&0&-17.5\times10^6&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&-17.5\times10^6&0&17.5\times10^6&0\\ 0&0&0&0&0&0&0&0&0&0&0&0 \end{bmatrix}$$

$$k_6 = \frac{350\times10^9\,\text{Pa}\left(5\times10^{-4}\,\text{m}^2\right)}{10\text{m}}\times\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_6 = \begin{bmatrix} 17.5\times10^6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -17.5\times10^6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -17.5\times10^6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 17.5\times10^6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_7 = \frac{350\times10^9\,\text{Pa}\left(5\times10^{-4}\,\text{m}^2\right)}{10\sqrt{2}\text{m}}\times\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.5 & 0.5 & 0 & 0 & 0 & 0 & 0 & 0 & -0.5 & -0.5 \\ 0 & 0 & 0.5 & 0.5 & 0 & 0 & 0 & 0 & 0 & 0 & -0.5 & -0.5 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -0.5 & -0.5 & 0 & 0 & 0 & 0 & 0 & 0 & 0.5 & 0.5 \\ 0 & 0 & -0.5 & -0.5 & 0 & 0 & 0 & 0 & 0 & 0 & 0.5 & 0.5 \end{bmatrix}$$

$$k_7=\begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&6.185\times10^{6}&6.185\times10^{6}&0&0&0&0&0&0&-6.185\times10^{6}&-6.185\times10^{6}0\\
0&0&6.185\times10^{6}&6.185\times10^{6}&0&0&0&0&0&0&-6.185\times10^{6}&-6.185\times10^{6}\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&-6.185\times10^{6}&-6.185\times10^{6}&0&0&0&0&0&0&6.185\times10^{6}&6.185\times10^{6}\\
0&0&-6.185\times10^{6}&-6.185\times10^{6}&0&0&0&0&0&0&6.185\times10^{6}&6.185\times10^{6}
\end{bmatrix}$$

$$k_8=\frac{350\text{x}10^{9}\,\text{Pa}\left(5\times10^{-4}\,\text{m}^{2}\right)}{10\sqrt{2}\text{m}}\times\begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0.5&0.5&0&0&-0.5&-0.5&0&0\\
0&0&0&0&0.5&0.5&0&0&-0.5&-0.5&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&-0.5&-0.5&0&0&0.5&0.5&0&0\\
0&0&0&0&-0.5&-0.5&0&0&0.5&0.5&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0
\end{bmatrix}$$

$$k_8=\begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&6.185\times10^{6}&6.185\times10^{6}&0&0&-6.185\times10^{6}&-6.185\times10^{6}&0&0\\
0&0&0&0&6.185\times10^{6}&6.185\times10^{6}&0&0&-6.185\times10^{6}&-6.185\times0^{6}&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&-6.185\times10^{6}&-6.185\times10^{6}0&0&0&6.185\times10^{6}&6.185\times10^{6}&0&0\\
0&0&0&0&-6.185\times10^{6}&-6.185\times10^{6}&0&0&6.185\times10^{6}&6.185\times10^{6}&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0
\end{bmatrix}$$

$$k_9 = \frac{350\times10^9\,\text{Pa}\left(5\times10^{-4}\,\text{m}^2\right)}{10\text{m}}\times\begin{bmatrix} 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&1&0&0&0&0&0&-1\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&-1&0&0&0&0&0&1 \end{bmatrix}$$

$$k_9 = \begin{bmatrix} 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&17.5\times10^6&0&0&0&0&0&-17.5\times10^6\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&-17.5\times10^6&0&0&0&0&0&17.5\times10^6 \end{bmatrix}$$

Se obtiene la siguiente matriz de rigidez:

$$KT = \begin{bmatrix} 17500000&0&0&0&0&0&0&0&0&0&17500000&0\\ 0&17500000&0&17500000&0&0&0&0&0&0&0&0\\ 0&0&23685000&6185000&-17500000&0&0&0&0&0&-6185000&-6185000\\ 0&-17500000&6185000&23685000&0&0&0&0&0&0&-6185000&-6185000\\ 0&0&-17500000&0&-17500000&6185000&-17500000&0&-6185000&-6185000&0&0\\ 0&0&0&0&6185000&23685000&0&0&-6185000&-6185000&0&-17500000\\ 0&0&0&0&6185000&23685000&0&0&-6185000&-6185000&0&-17500000\\ 0&0&0&0&-17500000&0&17500000&0&0&0&0&0\\ 0&0&0&0&-6185000&-6185000&0&0&23685000&6185000&-17500000&0\\ 0&0&0&0&-6185000&-6185000&0&-17500000&6185000&23685000&0&0\\ 17500000&0&-6185000&-6185000&0&0&0&0&-17500000&0&41185000&6185000\\ 0&0&-6185000&-6185000&0&-17500000&0&0&0&0&6185000&23685000 \end{bmatrix}$$

Se obtiene la siguiente matriz ensamblada.

$$K = \begin{bmatrix} 17500000&0&0&0&0&0&0&0&0&0&17500000&0\\ 0&17500000&0&17500000&0&0&0&0&0&0&0&0\\ 0&0&23685000&6185000&-17500000&0&0&0&0&0&-6185000&-6185000\\ 0&-17500000&6185000&23685000&0&0&0&0&0&0&-6185000&-6185000\\ 0&0&-17500000&0&-17500000&6185000&-17500000&0&-6185000&-6185000&0&0\\ 0&0&0&0&6185000&23685000&0&0&-6185000&-6185000&0&-17500000\\ 0&0&0&0&6185000&23685000&0&0&-6185000&-6185000&0&-17500000\\ 0&0&0&0&-17500000&0&17500000&0&0&0&0&0\\ 0&0&0&0&-6185000&-6185000&0&0&23685000&6185000&-17500000&0\\ 0&0&0&0&-6185000&-6185000&0&-17500000&6185000&23685000&0&0\\ 17500000&0&-6185000&-6185000&0&0&0&0&-17500000&0&41185000&6185000\\ 0&0&-6185000&-6185000&0&-17500000&0&0&0&0&6185000&23685000 \end{bmatrix}\times\begin{bmatrix} 0\\ 0\\ u_{2x}\\ v_{2y}\\ u_{3x}\\ v_{3y}\\ 0\\ 0\\ u_{5x}\\ v_{5y}\\ u_{6x}\\ v_{6y} \end{bmatrix}=\begin{bmatrix} F_{1x}\\ F_{1Y}\\ 2.8\times10^6\\ 0\\ 0\\ -2.5\times10^6\\ F_{4x}\\ F_{4Y}\\ 0\\ -2.5\times10^6\\ 0\\ 0 \end{bmatrix}$$

Paso 3: Elimine filas y columnas en los nodos 1 y 4 (por ser articulaciones).

$$\sum k = 10^6 \begin{bmatrix} 17500000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 17500000 & 0 \\ 0 & 17500000 & 0 & 17500000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 23685000 & 6185000 & -17500000 & 0 & 0 & 0 & 0 & 0 & -6185000 & -6185000 \\ 0 & -17500000 & 6185000 & 23685000 & 0 & 0 & 0 & 0 & 0 & 0 & -6185000 & -6185000 \\ 0 & 0 & -17500000 & 0 & -17500000 & 6185000 & -17500000 & 0 & -6185000 & -6185000 & 0 & 0 \\ 0 & 0 & 0 & 0 & 6185000 & 23685000 & 0 & 0 & -6185000 & -6185000 & 0 & -17500000 \\ 0 & 0 & 0 & 0 & 6185000 & 23685000 & 0 & 0 & -6185000 & -6185000 & 0 & -17500000 \\ 0 & 0 & 0 & 0 & -17500000 & 0 & 17500000 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -6185000 & -6185000 & 0 & 0 & 23685000 & 6185000 & -17500000 & 0 \\ 0 & 0 & 0 & 0 & -6185000 & -6185000 & 0 & -17500000 & 6185000 & 23685000 & 0 & 0 \\ 17500000 & 0 & -6185000 & -6185000 & 0 & 0 & 0 & 0 & -17500000 & 0 & 41185000 & 6185000 \\ 0 & 0 & -6185000 & -6185000 & 0 & -17500000 & 0 & 0 & 0 & 0 & 6185000 & 23685000 \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ u_{2x} \\ v_{2y} \\ u_{3x} \\ v_{3y} \\ 0 \\ 0 \\ u_{5x} \\ v_{5y} \\ u_{6x} \\ v_{6y} \end{bmatrix} = \begin{bmatrix} F_{1x} \\ F_{1Y} \\ 2.8\times10^6 \\ 0 \\ 0 \\ -2.5\times10^6 \\ F_{4x} \\ F_{4Y} \\ 0 \\ -2.5\times10^6 \\ 0 \\ 0 \end{bmatrix}$$

$$K = \begin{bmatrix} 23685000 & 6185000 & -17500000 & 0 & 0 & 0 & -6185000 & -6185000 \\ 6185000 & 23685000 & 0 & 0 & 0 & 0 & -6185000 & -6185000 \\ -17500000 & 0 & 41185000 & 6185000 & -6185000 & 6185000 & 0 & 0 \\ 0 & 0 & 6185000 & 23685000 & -6185000 & -6185000 & 0 & -17500000 \\ 0 & 0 & -6185000 & 6185000 & 23685000 & 6185000 & -17500000 & 0 \\ 0 & 0 & 6185000 & -6185000 & 6185000 & 23685000 & 0 & 0 \\ -6185000 & -6185000 & 0 & 0 & -17500000 & 0 & 41185000 & -6185000 \\ -6185000 & -6185000 & 0 & -17500000 & 0 & 0 & 6185000 & 23685000 \end{bmatrix} + \begin{bmatrix} u_{2x} \\ v_{2y} \\ u_{3x} \\ v_{3y} \\ u_{5x} \\ v_{5y} \\ u_{6x} \\ v_{6y} \end{bmatrix} = \begin{bmatrix} 2.8\times10^6 \\ 0 \\ 0 \\ -2.5\times10^6 \\ 0 \\ -2.5\times10^6 \\ 0 \\ 0 \end{bmatrix}$$

Paso 4: Calcule los desplazamientos nodales.

$$u_1 = 0 \text{ m}$$
$$v_1 = 0 \text{ m}$$
$$u_2 = 0.3890 \text{ m}$$
$$v_2 = -0.1217 \text{ m}$$
$$u_3 = 0.3507 \text{ m}$$
$$v_3 = -0.3851 \text{ m}$$
$$u_4 = 0 \text{ m}$$
$$v_4 = 0 \text{ m}$$
$$u_5 = 0.4375 \text{ m}$$
$$v_5 = -0.4119 \text{ m}$$
$$u_6 = 0.1865 \text{ m}$$
$$v_6 = -0.2634 \text{ m}$$

B. Resolución con MATLAB

```
>> A = [23685000 6185000 -17500000 0 0 0 -6185000 -6185000; 6185000 23685000 0 0 0
0 -6185000 -6185000; -17500000 0 41185000 6185000 -6185000 6185000 0 0; 0 0 6185000
23685000 -6185000 -6185000 0 -17500000; 0 0 -6185000 6185000 23685000 6185000
-17500000 0; 0 0 6185000 -6185000 6185000 23685000 0 0; -6185000 -6185000 0 0
-17500000 0 41185000 -6185000; -6185000 -6185000 0 -17500000 0 0 6185000 23685000]

A =

   23685000    6185000   -17500000          0          0          0    -6185000    -6185000
    6185000   23685000           0          0          0          0    -6185000    -6185000
  -17500000          0    41185000    6185000   -6185000    6185000           0           0
          0          0     6185000   23685000   -6188500   -6185000           0   -17500000
```

```
          0          0   -6185000    6185000   23685000    6185000  -17500000          0
          0          0    6185000   -6185000    6185000   23685000          0          0
   -6185000   -6185000          0          0  -17500000          0   41185000   -6185000
   -6185000   -6185000          0  -17500000          0          0    6185000   23685000

>> F = [2.8*10^6; 0; 0; -2.5*10^6; 0; -2.5*10^6; 0; 0]

F =

     2800000
           0
           0
    -2500000
           0
    -2500000
           0
           0

>> U = inv(A)*F

U =

    0.3890
   -0.1217
    0.3507
   -0.3851
    0.4375
   -0.4119
    0.1865
   -0.2634
```

Cálculo de las fuerzas en cada articulación

$$F_{1x} = 0.3264 \times 10^7 N$$

$$F_{1y} = -0.2130 \times 10^7 N$$

$$F_{2x} = 0.2799 \times 10^7 N$$

$$F_{2y} = -0.0001 \times 10^7 N$$

$$F_{3x} = -1.5485 \times 10^7 N$$

$$F_{3y} = -0.2501 \times 10^7 N$$

$$F_{4x} = -0.2501 \times 10^7 N$$

$$F_{4y} = -0.6137 \times 10^7 N$$

$$F_{5x} = -0.4767 \times 10^7 N$$

$$F_{5y} = -0.6837 \times 10^7 N$$

$$F_{6x} = -0.3258 \times 10^7 N$$

$$F_{6y} = 0.0001 \times 10^7 N$$

```
>> K = [17500000 0 0 0 0 0 0 0 0 0 17500000 0; 0 17500000 0 17500000 0 0 0 0 0 0 0 0;
0 0 23685000 6185000 -17500000 0 0 0 0 0 -6185000 -6185000; 0 -17500000 6185000
23685000 0 0 0 0 0 0 -6185000 -6185000; 0 0 -17500000 0 -17500000 6185000
-17500000 0 -6185000 -6185000 0 0; 0 0 0 0 6185000 23685000 0 0 -6185000 -6185000
0 -17500000; 0 0 0 0 6185000 23685000 0 0 -6185000 -6185000 0 -17500000; 0 0 0 0
-17500000 0 17500000 0 0 0 0 0; 0 0 0 0 -61850000 -6185000 0 0 23685000 6185000
-17500000 0; 0 0 0 0 -6185000 -6185000 0 -17200000 6185000 23685000 0 0; 17500000
0 -6185000 -6185000 0 0 0 0 -17500000 0 41185000 6185000; 0 0 -6185000 -6185000 0
-17500000 0 0 0 0 6185000 23685000]

K =

  Columns 1 through 10

 17500000         0         0         0         0         0         0         0         0         0
        0  17200000         0  17500000         0         0         0         0         0         0
        0         0  23685000   6185000 -17500000         0         0         0         0         0
        0 -17500000   6185000  23685000         0         0         0         0         0         0
        0         0 -17500000         0 -17500000   6185000 -17500000         0  -6185000  -6185000
        0         0         0         0   6185000  23685000         0         0  -6185000  -6185000
        0         0         0         0   6185000  23685000         0         0  -6185000  -6185000
        0         0         0         0 -17500000         0  17500000         0         0         0
        0         0         0         0  -6185000  -6185000         0         0  23685000   6185000
        0         0         0         0  -6185000  -6185000         0 -17200000   6185000  23685000
 17500000         0  -6185000  -6185000         0         0         0         0 -17500000         0
        0         0  -6185000  -6185000         0 -17500000         0         0         0         0

  Columns 11 through 12

    17500000           0
           0           0
    -6185000    -6185000
    -6185000    -6185000
           0           0
           0   -17500000
           0   -17500000
           0           0
   -17500000           0
           0           0
    41185000     6185000
     6185000    23685000

>> U = [0; 0; 0.3890; -0.1217; 0.3507; -0.3851; 0; 0; 0.4375; -0.4119; 0.1865;
-0.2634]

U =

         0
         0
    0.3890
   -0.1217
    0.3507
   -0.3851
         0
         0
    0.4375
   -0.4119
    0.1865
   -0.2634
```

```
>> F = K*U

F =

  1.0e+007 *

    0.3264
   -0.2130
    0.2799
   -0.0001
   -1.5485
   -0.2501
   -0.2501
   -0.6137
    0.4764
   -0.6837
   -0.3258
    0.0001
```

Cálculo de los esfuerzos

$$\sigma_{i-j} = \left[\frac{E}{L} \times \begin{bmatrix} -C-S & C & S \end{bmatrix} \times \begin{bmatrix} u_i \\ v_i \\ u_j \\ v_j \end{bmatrix} \right]$$

$$\sigma_{1-2} = \left[\frac{350 \times 10^9 \text{Pa}}{10\text{m}} \times \begin{bmatrix} 0 - 1 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ 0.3890 \\ -0.1217 \end{bmatrix} \right] = -4.2595 \text{GPa}$$

$$\sigma_{2-3} = \left[\frac{350 \times 10^9 \text{Pa}}{10\text{m}} \times \begin{bmatrix} 1 & 0 & -1 & 0 \end{bmatrix} \times \begin{bmatrix} 0.3890 \\ -0.1217 \\ 0.3507 \\ -0.3851 \end{bmatrix} \right] = 1.3405 \text{GPa}$$

$$\sigma_{3-4} = \left[\frac{350 \times 10^9 \text{Pa}}{10\text{m}} \times \begin{bmatrix} 1 & 0 & -1 & 0 \end{bmatrix} \times \begin{bmatrix} 0.3507 \\ -0.3851 \\ 0 \\ 0 \end{bmatrix} \right] = 1.2275 \text{GPa}$$

$$\sigma_{4-5} = \left[\frac{350 \times 10^9 \text{Pa}}{10\text{m}} \times \begin{bmatrix} 0 & 1 & 0 & -1 \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ 0.4375 \\ -0.4119 \end{bmatrix} \right] = 1.4417 \text{GPa}$$

$$\sigma_{5-6} = \left[\frac{350\times10^{9}\,\text{Pa}}{10\text{m}} \times \begin{bmatrix} -1 & 0 & 1 & 0 \end{bmatrix} \times \begin{bmatrix} 0.4375 \\ -0.4119 \\ 0.1865 \\ -0.2634 \end{bmatrix} \right] = -8.7850\,\text{GPa}$$

$$\sigma_{1-6} = \left[\frac{350\times10^{9}\,\text{Pa}}{10\text{m}} \times \begin{bmatrix} 1 & 0 & -1 & 0 \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ 0.1865 \\ -0.2634 \end{bmatrix} \right] = -6.5275\,\text{GPa}$$

$$\sigma_{2-6} = \left[\frac{350\times10^{9}\,\text{Pa}}{10\sqrt{2}\text{m}} \times \begin{bmatrix} 0\,.71 & 0.71 & -0.71 & -0.71 \end{bmatrix} \times \begin{bmatrix} 0.3890 \\ -0.1217 \\ 0.1865 \\ -0.2634 \end{bmatrix} \right] = 8.5534\,\text{GPa}$$

$$\sigma_{3-5} = \left[\frac{350\times10^{9}\,\text{Pa}}{10\sqrt{2}\text{m}} \times \begin{bmatrix} 0.71 & 0.71 & -0.71 & -0.71 \end{bmatrix} \times \begin{bmatrix} 0.3507 \\ -0.3851 \\ 0.4375 \\ -0.4119 \end{bmatrix} \right] = -1.4910\,\text{GPa}$$

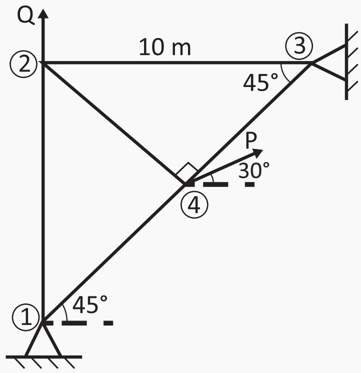
$$\sigma_{3-6} = \left[\frac{350\times10^{9}\,\text{Pa}}{10\text{m}} \times \begin{bmatrix} 0 & 1 & 0 & -1 \end{bmatrix} \times \begin{bmatrix} 0.3507 \\ -0.3851 \\ 0.1865 \\ -0.2634 \end{bmatrix} \right] = -4.2595\,\text{GPa}$$

```
>> % CALCULO DE LOS ESFUERZOS:
>> % ESFUERZO DE 1 A 2:
>> E12 = ((350*10^9)/10)*[0 -1 0 1]*[0; 0; 0.3890; -0.1217]

E12 =

 -4.2595e+009

>> % ESFUERZO DE 2 A 3:
>> E23=((350*10^9)/10)*[1 0 -1 0]*[0.3890; -0.1217; 0.3507; -0.3851]

E23 =

  1.3405e+009

>> % ESFUERZO DE 3 A 4:
>> E34 = ((350*10^9)/10)*[1 0 -1 0]*[0.3507; -0.3851; 0; 0]
```

```
E34 =

  1.2275e+010

>> % ESFUERZO DE 4 A 5:
>> E45 = ((350*10^9)/10)*[0 1 0 -1]*[0; 0; 0.4375; -0.4119]

E45 =

  1.4417e+010

>> % ESFUERZO DE 1 A 2:
>> E56 = ((350*10^9)/10)*[-1 0 1 0]*[0.4375; -0.4119; 0.1865; -0.2634]

E56 =

 -8.7850e+009

>> % ESFUERZO DE 1 A 6:
>> E16 = ((350*10^9)/10)*[1 0 -1 0]*[0; 0; 0.1865; -0.2634]

E16 =

 -6.5275e+009

>> % ESFUERZO DE 2 A 6:
>>  E26  =  ((350*10^9)/(10*(2^1/2)))*[0  71  0.71  -0.71  -0.71]*[0.3890;  -0.1217;
0.1865; -0.2634]

E26 =

  8.5534e+009

>> % ESFUERZO DE 3 A 5:
>>  E26  =  ((350*10^9)/(10*(2^1/2)))*[0.71  0.71  -0.71  -0.71]*[0.3507;  -0.3851;
0.4375; -0.4119]

E26 =

 -1.4910e+009

>> % ESFUERZO DE 3 A 6:
>> E36 = ((350*10^9)/10)*[0 1 0 -1]*[0.3507; -0.3851; 0.1865; -0.2634]

E36 =

 -4.2595e+009
```

Ejercicio 13

Hallar los desplazamientos nodales, los esfuerzos y las fuerzas en los siguientes sistemas estructurales:



$E = 300$ GPa

$A = 6 \times 10^{-4} m^2$

$P = 3000$ KN

$Q = 4000$ KN

A. Resolución

Paso 1: Calcule los ángulos.

Elemento	Nodo	θ	C	S	C²	S²	CS
1	1–2	90°	0	1	0	1	0
2	2–3	0°	1	0	1	0	0
3	3–4	225°	-0.707	-0.707	0.499849	0.499849	0.499849
4	1–4	45°	0.707	0.707	0.499849	0.499849	0.499849

Paso 2: Calcule las matrices de rigidez de cada barra.

$$k_1 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 22400000 & 0 & -22400000 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -22400000 & 0 & 22400000 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_2 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 22400000 & 0 & -22400000 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -22400000 & 0 & 22400000 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_3 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 15834408.46 & 15834408.46 & -15834408.46 & -15834408.46 \\ 0 & 0 & 0 & 0 & 15834408.46 & 15834408.46 & -15834408.46 & -15834408.46 \\ 0 & 0 & 0 & 0 & -15834408.46 & -15834408.46 & 15834408.46 & 15834408.46 \\ 0 & 0 & 0 & 0 & -15834408.46 & -15834408.46 & 15834408.46 & 15834408.46 \end{bmatrix}$$

$$k_4 = \begin{bmatrix} 15834408.46 & 15834408.46 & 0 & 0 & 0 & 0 & -15834408.46 & -15834408.46 \\ 15834408.46 & 15834408.46 & 0 & 0 & 0 & 0 & -15834408.46 & -15834408.46 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -15834408.46 & -15834408.46 & 0 & 0 & 0 & 0 & 15834408.46 & 15834408.46 \\ -15834408.46 & -15834408.46 & 0 & 0 & 0 & 0 & 15834408.46 & 15834408.46 \end{bmatrix}$$

Se obtiene la siguiente matriz de rigidez:

$$\sum k = 10^6 \begin{bmatrix} 15834408.46 & 15834408.46 & 0 & 0 & 0 & 0 & -15834408.46 & -15834408.46 \\ 15834408.46 & 38234408.46 & 0 & -22400000 & 0 & 0 & -15834408.46 & -15834408.46 \\ 0 & 0 & 38234408.46 & -15834408.46 & -22400000 & 0 & -15834408.46 & 15834408.46 \\ 0 & -22400000 & -15834408.46 & 38234408.46 & 0 & 0 & 15834408.46 & -15834408.46 \\ 0 & 0 & 22400000 & 0 & 38234408.46 & 15834408.46 & -15834408.46 & -15834408.46 \\ 0 & 0 & 0 & 0 & 15834408.46 & 15834408.46 & -15834408.46 & -15834408.46 \\ -15834408.46 & -15834408.46 & -15834408.46 & 15834408.46 & -15834408.46 & -15834408.46 & 47503225.39 & -15834408.46 \\ -15834408.46 & -15834408.46 & 15834408.46 & -15834408.46 & -15834408.46 & 15834408.46 & 15834408.46 & 47503225.39 \end{bmatrix}$$

Se obtiene la siguiente matriz ensamblada:

$$\sum k = 10^6 \begin{bmatrix} 15834408.46 & 15834408.46 & 0 & 0 & 0 & 0 & -15834408.46 & -15834408.46 \\ 15834408.46 & 38234408.46 & 0 & -22400000 & 0 & 0 & -15834408.46 & -15834408.46 \\ 0 & 0 & 38234408.46 & -15834408.46 & -22400000 & 0 & -15834408.46 & 15834408.46 \\ 0 & -22400000 & -15834408.46 & 38234408.46 & 0 & 0 & 15834408.46 & -15834408.46 \\ 0 & 0 & 22400000 & 0 & 38234408.46 & 15834408.46 & -15834408.46 & -15834408.46 \\ 0 & 0 & 0 & 0 & 15834408.46 & 15834408.46 & -15834408.46 & -15834408.46 \\ -15834408.46 & -15834408.46 & -15834408.46 & 15834408.46 & -15834408.46 & -15834408.46 & 47503225.39 & -15834408.46 \\ -15834408.46 & -15834408.46 & 15834408.46 & -15834408.46 & -15834408.46 & 15834408.46 & 15834408.46 & 47503225.39 \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ u_{2x} \\ v_{2y} \\ 0 \\ 0 \\ u_{4x} \\ u_{4y} \end{bmatrix} = \begin{bmatrix} F_{1x} \\ F_{1Y} \\ 0 \\ 4000000 \\ F_{3x} \\ F_{3y} \\ 2598076.211 \\ 1500000 \end{bmatrix}$$

Paso 3: Elimine filas y columnas en los nodos 1 y 3 (por ser articulaciones).

$$\sum k = 10^6 \begin{bmatrix} 15834408.46 & 15834408.46 & 0 & 0 & 0 & 0 & -15834408.46 & -15834408.46 \\ 15834408.46 & 38234408.46 & 0 & -22400000 & 0 & 0 & -15834408.46 & -15834408.46 \\ 0 & 0 & 38234408.46 & -15834408.46 & -22400000 & 0 & -15834408.46 & 15834408.46 \\ 0 & -22400000 & -15834408.46 & 38234408.46 & 0 & 0 & 15834408.46 & -15834408.46 \\ 0 & 0 & 22400000 & 0 & 38234408.46 & 15834408.46 & -15834408.46 & -15834408.46 \\ 0 & 0 & 0 & 0 & 15834408.46 & 15834408.46 & -15834408.46 & -15834408.46 \\ -15834408.46 & -15834408.46 & -15834408.46 & 15834408.46 & -15834408.46 & -15834408.46 & 47503225.39 & -15834408.46 \\ -15834408.46 & -15834408.46 & 15834408.46 & -15834408.46 & -15834408.46 & 15834408.46 & 15834408.46 & 47503225.39 \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ u_{2x} \\ v_{2y} \\ 0 \\ 0 \\ u_{4x} \\ u_{4y} \end{bmatrix} = \begin{bmatrix} F_{1x} \\ F_{1Y} \\ 0 \\ 4000000 \\ F_{3x} \\ F_{3y} \\ 2598076.211 \\ 1500000 \end{bmatrix}$$

$$K = \begin{bmatrix} 38234408.46 & -15834408.46 & -15834408.46 & 15834408.46 \\ -15834408.46 & 38234408.46 & 15834408.46 & -15834408.46 \\ -15834408.46 & 15834408.46 & 47503225.39 & -15834408.46 \\ 15834408.46 & -15834408.46 & 15834408.46 & 47503225.39 \end{bmatrix} \times \begin{bmatrix} u_{2x} \\ v_{2y} \\ u_{4x} \\ v_{4y} \end{bmatrix} = \begin{bmatrix} 0 \\ 4000000 \\ 2598076.211 \\ 1500000 \end{bmatrix}$$

Paso 4: Calcule los desplazamientos nodales.

$$u_2 = 0.02451063 \text{ m}$$

$$v_2 = 0.154060799 \text{ m}$$

$$u_4 = -0.01508718 \text{ m}$$

$$v_4 = 0.079789253 \text{ m}$$

B. Resolución con MATLAB

```
>> A = [38234408.46 -15834408.46 -15834408.46 15834408.46; -15834408.46 38234408.46
15834408.46 -15834408.46; -15834408.46 15834408.46 47503225.39 -15834408.46;
15834408.46 -15834408.46 15834408.46 47503225.39]

A =

  1.0e+007 *

    3.8234   -1.5834   -1.5834    1.5834
   -1.5834    3.8234    1.5834   -1.5834
   -1.5834    1.5834    4.7503   -1.5834
    1.5834   -1.5834    1.5834    4.7503

>> F = [0; 4000000; 2598076.211; 1500000]

F =

  1.0e+006 *

         0
    4.0000
    2.5981
    1.5000

>> U = inv(A)*F

U =

    0.0533
    0.1252
    0.0443
    0.0408
```

Cálculo de las fuerzas en cada articulación

```
>> K = [15834408.46 15834408.46 0 0 0 0 -15834408.46 -15834408.46; 15834408.46
38234408.46 0 -22400000 0 0 -15834408.46 -15834408.46; 0 0 38234408.46 -15834408.46
-22400000 0 -15834408.46 15834408.46; 0 -22400000 -15834408.46 38234408.46 0 0
15834408.46 -1584408.46; 0 0 22400000 0 38234408.46 15834408.46 -15834408.46
-15834408.46; 0 0 0 0 15834408.46 15834408.46 -15834408.46 -15834408.46;
-15834408.46 -15834408.46 -15834408.46 15834408.46 -15834408.46 -15834408.46
47503225.39 -15834408.46; -15834408.46 -15834408.46 15834408.46 -15834408.46
-15834408.46 15834408.46 15834408.46 47503225.39

K =

  1.0e+007 *

    1.5834    1.5834         0         0         0         0   -1.5834   -1.5834
    1.5834    3.8234         0   -2.2400         0         0   -1.5834   -1.5834
         0         0    3.8234   -1.5834   -2.2400         0   -1.5834    1.5834
         0   -2.2400   -1.5834    3.8234         0         0    1.5834   -1.5834
         0         0    2.2400         0    3.8234    1.5834   -1.5834   -1.5834
         0         0         0         0    1.5834    1.5834   -1.5834   -1.5834
   -1.5834   -1.5834   -1.5834    1.5834   -1.5834   -1.5834    4.7503   -1.5834
   -1.5834   -1.5834    1.5834   -1.5834   -1.5834    1.5834    1.5834    4.7503

>> U = [0; 0; 0.0533; 0.1252; 0; 0; 0.0443; 0.0408]

U =

         0
         0
    0.0533
    0.1252
         0
         0
    0.0443
    0.0408

>> F = K*U

F =

  1.0e+006 *

   -1.3475
   -4.1520
    0.0000
    3.9984
   -0.1536
   -1.3475
    2.5968
    1.5011
```

Cálculo de los esfuerzos

$$\sigma_{i-j} = \left[\frac{E}{L} \times \begin{bmatrix} -C & -S & C & S \end{bmatrix} \times \begin{bmatrix} u_i \\ v_i \\ u_j \\ v_j \end{bmatrix} \right]$$

$$\sigma_{1-2} = \left[\frac{300 \times 10^9 \text{Pa}}{10\text{m}} \times \begin{bmatrix} 0 & -1 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ 0.0533 \\ 0.1252 \end{bmatrix} \right] = 3.7560 \, \text{GPa}$$

$$\sigma_{2-3} = \left[\frac{300 \times 10^9 \text{Pa}}{10\text{m}} \times \begin{bmatrix} 1 & 0 & -1 & 0 \end{bmatrix} \times \begin{bmatrix} 0.0533 \\ 0.1252 \\ 0 \\ 0 \end{bmatrix} \right] = 1.5990 \, \text{GPa}$$

$$\sigma_{3-4} = \left[\frac{300 \times 10^9 \text{Pa}}{7.07\text{m}} \times \begin{bmatrix} 0.707 & 0.707 & -0.707 & -0.707 \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ 0.0443 \\ 0.0408 \end{bmatrix} \right] = -2.5530 \, \text{GPa}$$

$$\sigma_{1-4} = \left[\frac{300 \times 10^9 \text{Pa}}{7.07\text{m}} \times \begin{bmatrix} -0.707 & -0.707 & 0.707 & 0.707 \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ 0.0443 \\ 0.0408 \end{bmatrix} \right] = 2.5530 \, \text{GPa}$$

```
>> % CALCULO DE LOS ESFUERZOS:
>> % ESFUERZO DE 1 A 2:
>> E12 = ((300*10^9)/10)*[0 -1 0 1]*[0; 0; 0.0533; 0.1252]

E12 =

  3.7560e+009

>> % ESFUERZO DE 2 A 3:
>> E23=((300*10^9)/10)*[1 0 -1 0]*[0.0533; 0.1252; 0; 0]

E23 =

  1.5990e+009

>> % ESFUERZO DE 3 A 4:
>> E34 = ((300*10^9)/7.07)*[0.707 0.707 -0.707 -0.707]*[0; 0; 0.0443; 0.0408]

E34 =

 -2.5530e+009

>> % ESFUERZO DE 1 A 4:
>> E14 = ((300*10^9)/7.07)*[-0.707 -0.707 0.707 0.707]*[0; 0; 0.0443; 0.0408]

E14 =

  2.5530e+009
```

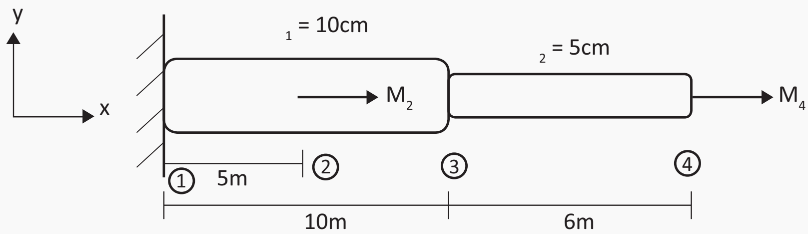
CAPÍTULO

6

TORSIÓN

EJERCICIO 1

En la siguiente estructura, determinar los ángulos girados en los nodos indicados.



$M_2 = 300$ Nm
$M_4 = 500$ Nm
$G_1 = 80$ GPa
$G_2 = 80$ Gpa

Elemento	J(m⁴)	G	L(m)	GJ/L
1-2	$7{,}854\times10^{-5}$	80GPa	5m	1256640
2-2	$7{,}854\times10^{-5}$	80GPa	5m	1256640
3-4	$4{,}909\times10^{-6}$	60GPa	5m	49090

A. Resolución

$$\begin{bmatrix} GJ/L & -GJ/L & 0 & 0 \\ -GJ/L & GJ/L & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{1-2} = \begin{bmatrix} 1256640 & -1256640 & 0 & 0 \\ -1256640 & 1256640 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{2-3} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1256640 & -1256640 & 0 \\ 0 & -1256640 & 1256640 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{3-4} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1256640 & -1256640 \\ 0 & 0 & -1256640 & 1256640 \end{bmatrix}$$

Matriz Ensamblada:

$$\sum K = \begin{bmatrix} 1256640 & -1256640 & 0 & 0 \\ -1256640 & 12513280 & -1256640 & 0 \\ 0 & -1256640 & 1305730 & -49090 \\ 0 & 0 & -49090 & 49090 \end{bmatrix} \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} M_1 \\ M_2 \\ M_3 \\ M_4 \end{bmatrix}$$

Eliminando filas y columnas:

$$\sum K = \begin{bmatrix} 1256640 & -1256640 & 0 & 0 \\ -1256640 & 12513280 & -1256640 & 0 \\ 0 & -1256640 & 1305730 & -49090 \\ 0 & 0 & -49090 & 49090 \end{bmatrix} \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} M_1 \\ M_2 \\ M_3 \\ M_4 \end{bmatrix}$$

Matriz reducida:

$$K = \begin{bmatrix} 2513280 & -1256640 & 0 \\ -1256640 & 1305730 & -49090 \\ 0 & -49090 & 49090 \end{bmatrix} \begin{bmatrix} \theta_2 \\ \theta_3 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} 300 \\ 0 \\ 500 \end{bmatrix}$$

Desplazamientos Nodales:

$$\theta_2 = 0{,}0006 \text{ rad}$$
$$\theta_3 = 0{,}0010 \text{ rad}$$
$$\theta_4 = 0{,}0014 \text{ rad}$$

Momento:

$$M_1 = -753{,}9840 \text{ Nm}$$

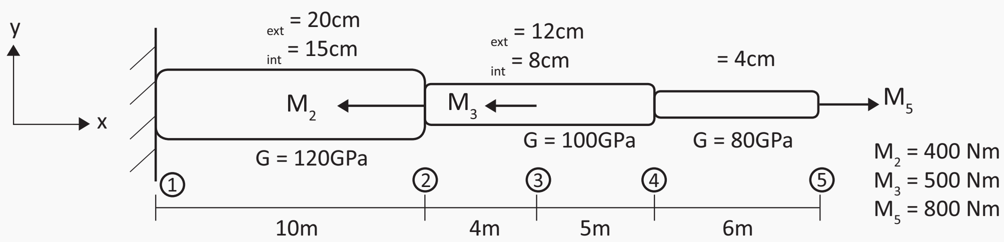
B. Resolución con MATLAB

```
>> k1 = [1256640 -1256640 0 0; -1256640 1256640 0 0; 0 0 0 0; 0 0 0 0]

k1 =

     1256640    -1256640           0           0
    -1256640     1256640           0           0
           0           0           0           0
           0           0           0           0

>> k2 = [0 0 0 0; 0 1256640 -1256640 0; 0 -1256640 1256640 0; 0 0 0 0]

k2 =

           0           0           0           0
           0     1256640    -1256640           0
           0    -1256640     1256640           0
           0           0           0           0

>> k3 = [0 0 0 0; 0 0 0 0; 0 0 1256640 -1256640; 0 0 -1256640 1256640]

k3 =

           0           0           0           0
           0           0           0           0
           0           0     1256640    -1256640
           0           0    -1256640     1256640
```

```
>> KT = k1 + k2 + k3

KT =

     1256640    -1256640           0           0
    -1256640     2513280    -1256640           0
           0    -1256640     2513280    -1256640
           0           0    -1256640     1256640

>> KR = [2513280 -1256640 0; -1256640 2513280 -1256640; 0 -1256640 1256640]

KR =

     2513280    -1256640           0
    -1256640     2513280    -1256640
           0    -1256640     1256640

>> F = [300; 0; 500]

F =

   300
     0
   500

>> U = inv(KR)*F

U =

    0.0006
    0.0010
    0.0014

>> U = [0; 0.0006; 0.0010; 0.0014]

U =

         0
    0.0006
    0.0010
    0.0014

>> M = KT*U

M =

 -753.9840
  251.3280
    0.0000
  502.6560
```

Ejercicio 2

En la siguiente estructura, determinar los ángulos girados en los nodos indicados.



Elemento	J(m⁴)	G	L(m)	GJ/L
1-2	$8{,}59\times10^{-4}$	120GPa	10m	10308000
2-2	$1{,}307\times10^{-4}$	100GPa	4m	3267500
3-4	$1{,}307\times10^{-4}$	100GPa	5m	2614000
4-5	$2{,}011\times10^{-6}$	80GPa	6m	26813,3353

A. Resolución

$$K_{a-b}=\begin{bmatrix} GJ/L & -GJ/L & 0 & 0\\ -GJ/L & GJ/L & 0 & 0\\ 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0\end{bmatrix}$$

$$K_{1-2}=\begin{bmatrix} 10308000 & -10308000 & 0 & 0 & 0\\ -10308000 & 10308000 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0\end{bmatrix}$$

$$K_{2-3}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0\\ 0 & 10308000 & -10308000 & 0 & 0\\ 0 & -10308000 & 10308000 & 0 & 0\\ 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0\end{bmatrix}$$

$$K_{3-4}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 2614000 & -2614000 & 0\\ 0 & 0 & -2614000 & 2614000 & 0\\ 0 & 0 & 0 & 0 & 0\end{bmatrix}$$

$$K_{4-5} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 26813,3353 & -26813,3353 \\ 0 & 0 & 0 & -26813,3353 & 26813,3353 \end{bmatrix}$$

Matriz Ensamblada:

$$\sum K = \begin{bmatrix} 10308000 & -10308000 & 0 & 0 & 0 \\ -10308000 & 13575500 & -3267500 & 0 & 0 \\ 0 & -3267500 & 5881500 & -2614000 & 0 \\ 0 & 0 & -2614000 & 26400813,33 & -26813,3353 \\ 0 & 0 & 0 & -26813,3353 & 26813,3353 \end{bmatrix} \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \\ \theta_5 \end{bmatrix} = \begin{bmatrix} M_1 \\ M_2 \\ M_3 \\ M_4 \\ M_5 \end{bmatrix}$$

Eliminando filas y columnas:

$$\sum K = \begin{bmatrix} 10308000 & -10308000 & 0 & 0 & 0 \\ -10308000 & 13575500 & -3267500 & 0 & 0 \\ 0 & -3267500 & 5881500 & -2614000 & 0 \\ 0 & 0 & -2614000 & 26400813,33 & -26813,3353 \\ 0 & 0 & 0 & -26813,3353 & 26813,3353 \end{bmatrix} \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \\ \theta_5 \end{bmatrix} = \begin{bmatrix} M_1 \\ M_2 \\ M_3 \\ M_4 \\ M_5 \end{bmatrix}$$

Matriz reducida:

$$K = \begin{bmatrix} 13575500 & -3267500 & 0 & 0 \\ -3267500 & 5881500 & -2614000 & 0 \\ 0 & -2614000 & 26400813,33 & -26813,3353 \\ 0 & 0 & -26813,3353 & 26813,3353 \end{bmatrix} \begin{bmatrix} \theta_2 \\ \theta_3 \\ \theta_4 \\ \theta_5 \end{bmatrix} = \begin{bmatrix} -400 \\ -500 \\ 0 \\ 800 \end{bmatrix}$$

Desplazamientos Nodales:

$$\theta_2 = -0,0001 \text{ rad}$$
$$\theta_3 = -0,0001 \text{ rad}$$
$$\theta_4 = 0,00004 \text{ rad}$$
$$\theta_5 = 0,0299 \text{ rad}$$

Momentos:

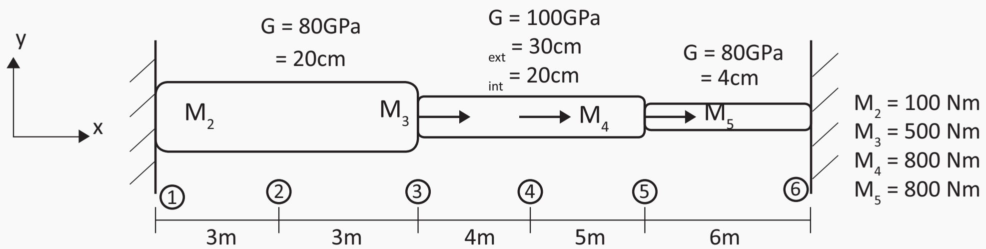
$$M_1 = 4.1232 \times 10^9 \text{ Nm}$$
$$M_2 = -3.7965 \times 10^9 \text{ Nm}$$
$$M_3 = -1.6338 \times 10^9 \text{ Nm}$$
$$M_4 = 1.2855 \times 10^9 \text{ Nm}$$
$$M_5 = 0.0215 \times 10^9 \text{ Nm}$$

Con MATLAB:

```
>> KT = [10308000 -10308000 0 0 0; -10308000 13575500 -3267500 0 0; 0 -3267500 5881500
-2614000 0; 0 0 -2614000 26400813.33 -26813.3353; 0 0 0 -26813.3353 26813.3353]

KT =

  1.0e+007 *

    1.0308   -1.0308         0         0         0
   -1.0308    1.3576   -0.3267         0         0
         0   -0.3267    0.5881   -0.2614         0
         0         0   -0.2614    2.6401   -0.0027
         0         0         0   -0.0027    0.0027

>> KR = [13575500 -3267500 0 0; -3267500 5881500 -2614000 0; 0 -2614000 26400813.33
-26813.3353; 0 0 -26813.3353 26813.3353]

KR =

  1.0e+007 *

    1.3576   -0.3267         0         0
   -0.3267    0.5881   -0.2614         0
         0   -0.2614    2.6401   -0.0027
         0         0   -0.0027    0.0027

>> F = [-400; -500; 0; 800]

F =

  -400
  -500
     0
   800

>> U = inv(KR)*F

U =

   -0.0001
   -0.0001
    0.0000
    0.0299

>> UT = [0; -400; -500; 0; 800]

UT =

     0
  -400
  -500
     0
   800

>> M = KT*UT

M =

  1.0e+009 *

    4.1232
   -3.7965
   -1.6338
    1.2855
    0.0215
```

EJERCICIO 3

En la siguiente estructura, determinar los ángulos girados en los nodos indicados.



Elemento	J(m^4)	G	L(m)	GJ/L
1-2	1,257	80GPa	3m	$3{,}352\times10^{10}$
2-2	1,257	80GPa	3m	$3{,}352\times10^{10}$
3-4	$5{,}105\times10^{-3}$	100GPa	4m	127625000
4-5	$6{,}362\times10^{-3}$	100GPa	5m	127240000
5-6	$3{,}976\times10^{-4}$	120GPa	6m	7952000

A. Resolución

$$K_{a-b}=\begin{bmatrix} GJ/L & -GJ/L & 0 & 0 \\ -GJ/L & GJ/L & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{1-2}=\begin{bmatrix} 3{,}352\times10^{10} & -3{,}352\times10^{10} & 0 & 0 & 0 & 0 \\ -3{,}352\times10^{10} & 3{,}352\times10^{10} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{2-3}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 3{,}352\times10^{10} & -3{,}352\times10^{10} & 0 & 0 & 0 \\ 0 & -3{,}352\times10^{10} & 3{,}352\times10^{10} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{3-4}=\begin{bmatrix}0&0&0&0&0&0\\0&0&0&0&0&0\\0&0&127625000&-127625000&0&0\\0&0&-127625000&127625000&0&0\\0&0&0&0&0&0\\0&0&0&0&0&0\end{bmatrix}$$

$$K_{4-5}=\begin{bmatrix}0&0&0&0&0&0\\0&0&0&0&0&0\\0&0&0&0&0&0\\0&0&0&127240000&-127240000&0\\0&0&0&-127240000&127240000&0\\0&0&0&0&0&0\end{bmatrix}$$

$$K_{5-6}=\begin{bmatrix}0&0&0&0&0&0\\0&0&0&0&0&0\\0&0&0&0&0&0\\0&0&0&0&0&0\\0&0&0&0&7952000&-7952000\\0&0&0&0&-7952000&7952000\end{bmatrix}$$

Matriz Ensamblada:

$$\sum K=\begin{bmatrix}3,352\times10^{10}&-3,352\times10^{10}&0&0&0&0\\-3,352\times10^{10}&6,7040\times10^{9}&-3,352\times10^{10}&0&0&0\\0&-3,3520\times10^{10}&3,3648\times10^{9}&-0,0128\times10^{9}&0&0\\0&0&-0,0128\times10^{9}&0,0255\times10^{9}&-0,0127\times10^{9}&0\\0&0&0&-0,0127\times10^{9}&0,01350\times10^{9}&-7952000\\0&0&0&0&-7952000&7952000\end{bmatrix}\begin{bmatrix}\theta_1\\\theta_2\\\theta_3\\\theta_4\\\theta_5\\\theta_6\end{bmatrix}=\begin{bmatrix}M_1\\M_2\\M_3\\M_4\\M_5\\M_6\end{bmatrix}$$

Eliminando Filas y Columnas:

$$\sum K=\begin{bmatrix}3,352\times10^{10}&-3,352\times10^{10}&0&0&0&0\\-3,352\times10^{10}&6,7040\times10^{9}&-3,352\times10^{10}&0&0&0\\0&-3,3520\times10^{10}&3,3648\times10^{9}&-0,0128\times10^{9}&0&0\\0&0&-0,0128\times10^{9}&0,0255\times10^{9}&-0,0127\times10^{9}&0\\0&0&0&-0,0127\times10^{9}&0,01350\times10^{9}&-7952000\\0&0&0&0&-7952000&7952000\end{bmatrix}\begin{bmatrix}\theta_1\\\theta_2\\\theta_3\\\theta_4\\\theta_5\\\theta_6\end{bmatrix}=\begin{bmatrix}M_1\\M_2\\M_3\\M_4\\M_5\\M_6\end{bmatrix}$$

Matriz reducida:

$$K=\begin{bmatrix} 6,7040\times10^{9} & -3,352\times10^{10} & 0 & 0 \\ -3,3520\times10^{10} & 3,3648\times10^{9} & -0,0128\times10^{9} & 0 \\ 0 & -0,0128\times10^{9} & 0,0255\times10^{9} & -0,0127\times10^{9} \\ 0 & 0 & -0,0127\times10^{9} & 0,01350\times10^{9} \end{bmatrix}\begin{bmatrix}\theta_2\\ \theta_3\\ \theta_4\\ \theta_5\end{bmatrix}=\begin{bmatrix}-100\\ 500\\ 800\\ 800\end{bmatrix}$$

Desplazamientos Nodales:

$$\theta_2=-0,0001\times10^{-3}\text{ rad}$$
$$\theta_3=-0,0000\text{ rad}$$
$$\theta_4=0,1146\times10^{-3}\text{ rad}$$
$$\theta_5=0,1670\times10^{-3}\text{ rad}$$

Momentos:

$$M_1=3352\text{ Nm}$$
$$M_6=1328\text{ Nm}$$

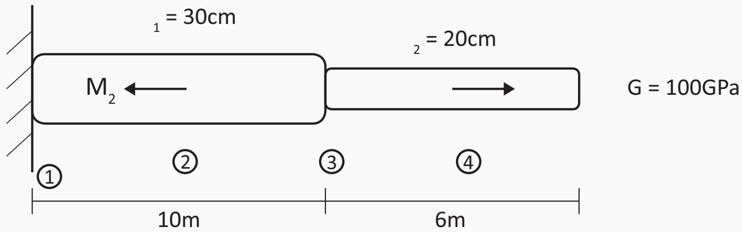
Con MATLAB:

```
>> KT = [3.352*10^10 -3.352*10^10 0 0 0 0; -3.352*10^10 6.7040*10^9 -3.352*10^10
0 0 0; 0 -3.3520*10^10 3.3648*10^9 -0.0128*10^9 0 0; 0 0 -0.0128*10^9 0.0255*10^9
-0.0127*10^9 0; 0 0 0 -0.0127*10^9 0.01350*10^9 -7952000; 0 0 0 0 -7952000 7952000]

KT =

  1.0e+010 *

    3.3520   -3.3520         0         0         0         0
   -3.3520    0.6704   -3.3520         0         0         0
         0   -3.3520    0.3365   -0.0013         0         0
         0         0   -0.0013    0.0026   -0.0013         0
         0         0         0   -0.0013    0.0014   -0.0008
         0         0         0         0   -0.0008    0.0008

>> KR = [ 6.7040*10^9 -3.352*10^10 0 0; -3.3520*10^10 3.3648-10^9 -0.0128*10^9 0;
0 -0.0128*10^9 0.0255*10^9 -0.0127*10^9; 0 0 -0.0127*10^9 0.01350*10^9]

KR =

  1.0e+010 *

    0.6704   -3.3520         0         0
   -3.3520    0.3365   -0.0013         0
         0   -0.0013    0.0026   -0.0013
         0         0   -0.0013    0.0014

>> F = [-100; 500; 800; 800]

F =

  -100
   500
   800
   800
```

```
>> F = [-100; 500; 800; 800]

F =

  -100
   500
   800
   800

>> u = inv(KR)*F

u =

  1.0e-003 *

   -0.0001
   -0.0000
    0.1146
    0.1670

>> U = 10^-3*[0; -0.0001; 0; 0.1146; 0.1670; 0]

U =

  1.0e-003 *

         0
   -0.0001
         0
    0.1146
    0.1670
         0

>> M = KT*U

M =

  1.0e+003 *

    3.3520
   -0.6704
    1.8851
    0.8014
    0.7991
   -1.3280
```

EJERCICIO 4

En la siguiente estructura, determinar los ángulos girados en los nodos indicados.



Elemento	J(m⁴)	G	L(m)	GJ/L
1-2	0,00636	1×10^{11} GPa	6m	106×10^{6}
2-2	0,00636	1×10^{11} GPa	6m	106×10^{6}
3-4	0,00126	8×10^{10} GPa	4m	252×10^{5}
4-5	0,00126	8×10^{10} GPa	5m	2016×10^{4}

A. Resolución

$$K_{a-b}=\begin{bmatrix} GJ/L & -GJ/L & 0 & 0 \\ -GJ/L & GJ/L & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{1-2}=\begin{bmatrix} 106000000 & -106000000 & 0 & 0 & 0 \\ -106000000 & 106000000 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{2-3}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 106000000 & -106000000 & 0 \\ 0 & 0 & -106000000 & 106000000 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{3-4}=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 252\times10^{5} & -252\times10^{5} & 0 \\ 0 & 0 & -252\times10^{5} & 252\times10^{5} & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{4-5} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2016\times10^4 & -2016\times10^4 \\ 0 & 0 & 0 & -2016\times10^4 & 2016\times10^4 \end{bmatrix}$$

Matriz Ensamblada:

$$\sum K = \begin{bmatrix} 106000000 & -106000000 & 0 & 0 & 0 \\ -106000000 & 212000000 & -106000000 & 0 & 0 \\ 0 & -106000000 & 131200000 & -25200000 & 0 \\ 0 & 0 & -25200000 & 45360000 & -20160000 \\ 0 & 0 & 0 & -20160000 & 20160000 \end{bmatrix} \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \\ \theta_5 \end{bmatrix} = \begin{bmatrix} M_1 \\ M_2 \\ M_3 \\ M_4 \\ M_5 \end{bmatrix}$$

Matriz reducida:

$$K = \begin{bmatrix} 212000000 & -106000000 & 0 & 0 \\ -106000000 & 131200000 & -25200000 & 0 \\ 0 & -25200000 & 45360000 & -20160000 \\ 0 & 0 & -20160000 & 20160000 \end{bmatrix} \begin{bmatrix} \theta_2 \\ \theta_3 \\ \theta_4 \\ \theta_5 \end{bmatrix} = \begin{bmatrix} -400 \\ 0 \\ 600 \\ 0 \end{bmatrix}$$

Desplazamientos Nodales:

$$\theta_1 = 0 \text{ rad}$$
$$\theta_2 = 1{,}89\times10^{-6} \text{ rad}$$
$$\theta_3 = 7{,}55\times10^{-6} \text{ rad}$$
$$\theta_4 = 3{,}14\times10^{-5} \text{ rad}$$
$$\theta_5 = 3{,}14\times10^{-5} \text{ rad}$$

Momentos:

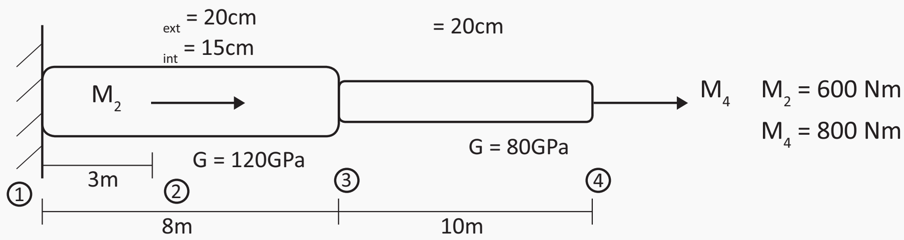
$$M_1 = -200 \text{ Nm}$$
$$M_2 = -400 \text{ Nm}$$
$$M_3 = -0.0520 \text{ Nm}$$
$$M_4 = 600 \text{ Nm}$$
$$M_5 = 0 \text{ Nm}$$

Con MATLAB:

```
>> KT = [106000000 -106000000 0 0 0; -10600000 212000000 -106000000 0 0; 0 -106000000
131200000 -25200000 0; 0 0 -25200000 45360000 -20160000; 0 0 0 -20160000 20160000]

KT =

   106000000  -106000000           0           0           0
   -10600000   212000000  -106000000           0           0
           0  -106000000   131200000   -25200000           0
           0           0   -25200000    45360000   -20160000
           0           0           0   -20160000    20160000

>> KR = [212000000 -106000000 0 0; -106000000 131200000 -25200000 0; 0 -25200000
45360000 -20160000; 0 0 -20160000 20160000]

KR =

   212000000  -106000000           0           0
  -106000000   131200000   -25200000           0
           0   -25200000    45360000   -20160000
           0           0   -20160000    20160000

>> F = [-400; 0; 600; 0]

F =

  -400
     0
   600
     0

>> u = inv(KR)*F

u =

  1.0e-004 *

    0.0189
    0.0755
    0.3136
    0.3136

>> U = 10^-4*[0; 0.0189; 0.0755; 0.3136; 0.3136]

U =

  1.0e-004 *

         0
    0.0189
    0.0755
    0.3136
    0.3136

>> MT = KT*U

MT =

 -200.3400
 -399.6200
   -0.0520
  600.0120
         0
```

EJERCICIO 5

En la siguiente estructura, determinar los ángulos girados en los nodos indicados.



Elemento	$J(m^4)$	G	L(m)	GJ/L
1-2	0,00118	$1{,}2\times10^{11}$ GPa	3m	472×10^5
2-2	0,00118	$1{,}2\times10^{11}$ GPa	5m	2832×10^4
3-4	0,00261	8×10^{10} GPa	10m	2088×10^4

A. Resolución

$$K_{a-b}=\begin{bmatrix} GJ/L & -GJ/L & 0 & 0 \\ -GJ/L & GJ/L & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{1-2}=\begin{bmatrix} 472\times10^5 & -472\times10^5 & 0 & 0 \\ -472\times10^5 & 472\times10^5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{2-3}=\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 2832\times10^4 & -2832\times10^4 & 0 \\ 0 & -2832\times10^4 & 2832\times10^4 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{3-4}=\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 2088\times10^4 & -2088\times10^4 \\ 0 & 0 & -2088\times10^4 & 2088\times10^4 \end{bmatrix}$$

Matriz Ensamblada:

$$\sum K=\begin{bmatrix} 472\times10^5 & -472\times10^5 & 0 & 0 \\ -472\times10^5 & 75520000 & -2832\times10^4 & 0 \\ 0 & -2832\times10^4 & 49200000 & -2088\times10^4 \\ 0 & 0 & -2088\times10^4 & 2088\times10^4 \end{bmatrix}\begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \end{bmatrix}=\begin{bmatrix} M_1 \\ M_2 \\ M_3 \\ M_4 \end{bmatrix}$$

Matriz Reducida:

$$K = \begin{bmatrix} 75520000 & -2832\times10^4 & 0 \\ -2832\times10^4 & 49200000 & -2088\times10^4 \\ 0 & -2088\times10^4 & 2088\times10^4 \end{bmatrix} \begin{bmatrix} \theta_2 \\ \theta_3 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} M_2 \\ M_3 \\ M_4 \end{bmatrix}$$

Desplazamientos Nodales:

$$\theta_1 = 0 \text{ rad}$$
$$\theta_2 = 0{,}2966\times10^{-4} \text{ rad}$$
$$\theta_3 = 0{,}5791\times10^{-4} \text{ rad}$$
$$\theta_4 = 0{,}9622\times10^{-4} \text{ rad}$$

Momentos:

$$M_1 = -1400 \text{ Nm}$$
$$M_2 = 2076 \text{ Nm}$$
$$M_3 = 756.2 \text{ Nm}$$
$$M_4 = 800 \text{ Nm}$$

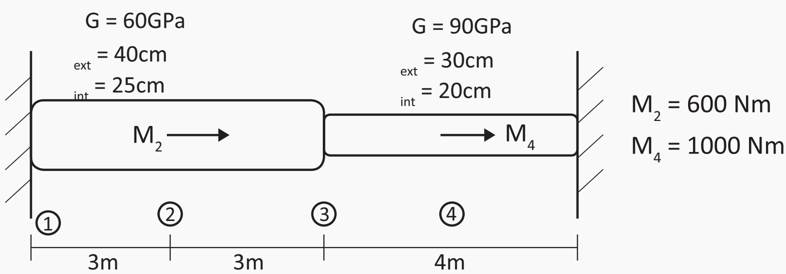
Con MATLAB:

```
>> KT = [472*10^5 -472-10^5 0 0; -472*10^5 75520000 -283*10^4 0; 0 -283*10^4
49200000 -2088*10^4; 0 0 -2088*10^4 2088*10^4]

KT =

    47200000   -47200000           0           0
   -47200000    75520000    -2830000           0
           0    -2830000    49200000   -20880000
           0           0   -20880000    20880000

>> KR = [75520000 -2832*10^4 0; -2832*10^4 49200000 -2088*10^4; 0 -2088*10^4 2088*10^4]

KR =

    75520000   -28320000           0
   -28320000    49200000   -20880000
           0   -20880000    20880000

>> F = [600; 0; 800]

F =

   600
     0
   800

>> u = inv(KR)*F

u =

  1.0e-004 *

    0.2966
    0.5791
    0.9622
```

```
>> U = 10^-4*[0; 0.2966; 0.5791; 0.9622]

U =

  1.0e-004 *

         0
    0.2966
    0.5791
    0.9622

>> MT = KT*U

MT =

  1.0e+003 *

   -1.4000
    2.0760
    0.7562
    0.7999
```

Ejercicio 6

En la siguiente estructura, determinar los ángulos girados en los nodos indicados.



Nota

Ambas barras solo tienen diámetro interior en sus primeros 6 metros, los últimos 8 metros y 4 metros respectivamente son completamente sólidos.

Elemento	$J(m^4)$	G	L(m)	GJ/L
1-2	0,01704	60GPa	6m	170400000
2-2	0,20011	60GPa	8m	150825000
3-4	0,00511	90GPa	6m	76650000
4-5	0,00636	90GPa	4m	143100000

A. Resolución

$$K_{1-2} = \begin{bmatrix} 170400000 & -170400000 & 0 & 0 & 0 \\ -170400000 & 170400000 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{2-3} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 150825000 & -150825000 & 0 & 0 \\ 0 & -150825000 & 150825000 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{3-4} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 76650000 & -76650000 & 0 \\ 0 & 0 & -76650000 & 76650000 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{4-5} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 143100000 & -143100000 \\ 0 & 0 & 0 & -143100000 & 143100000 \end{bmatrix}$$

Matriz Ensamblada:

$$\sum K = \begin{bmatrix} 170400000 & -170400000 & 0 & 0 & 0 \\ -170400000 & 321225000 & -150825000 & 0 & 0 \\ 0 & -150825000 & 22745000 & -76650000 & 0 \\ 0 & 0 & -76650000 & 219750000 & -14310000 \\ 0 & 0 & 0 & 14310000 & -14310000 \end{bmatrix} \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \\ \theta_5 \end{bmatrix} = \begin{bmatrix} M_1 \\ M_2 \\ M_3 \\ M_4 \\ M_5 \end{bmatrix}$$

Matriz Reducida:

$$K = \begin{bmatrix} 321225000 & -150825000 & 0 \\ -150825000 & 227475000 & -76650000 \\ 0 & -76650000 & 219750000 \end{bmatrix} \begin{bmatrix} \theta_2 \\ \theta_3 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} 600 \\ 0 \\ 1000 \end{bmatrix}$$

Desplazamientos Nodales:

$$\theta_1 = 0 \text{ rad}$$
$$\theta_2 = 4{,}1465 \times 10^{-6} \text{ rad}$$
$$\theta_3 = 4{,}85309 \times 10^{-6} \text{ rad}$$
$$\theta_4 = 6{,}24341 \times 10^{-6} \text{ rad}$$
$$\theta_5 = 0 \text{ rad}$$

Momentos:

$$M_1 = -706{,}5679 \text{ Nm}$$
$$M_2 = 600 \text{ Nm}$$
$$M_3 = -0.0610 \text{ Nm}$$
$$M_4 = 1000 \text{ Nm}$$
$$M_5 = 893{,}4329758 \text{ Nm}$$

Con MATLAB:

```
>> KT = [170400000 -170400000 0 0 0; -170400000 321225000 -150825000 0 0; 0
-150825000 227475000 -76650000 0; 0 0 -76650000 219750000 -143100000; 0 0 0
143100000 -143100000]

KT =

   170400000  -170400000           0           0           0
  -170400000   321225000  -150825000           0           0
           0  -150825000   227475000   -76650000           0
           0           0   -76650000   219750000  -143100000
           0           0           0   143100000  -143100000

>> KR = [321225000 -150825000 0; -150825000 227475000 -76650000; 0 -76650000 219750000]

KR =

   321225000  -150825000           0
  -150825000   227475000   -76650000
           0   -76650000   219750000

>> F = [600; 0; 1000]

F =

         600
           0
        1000
```

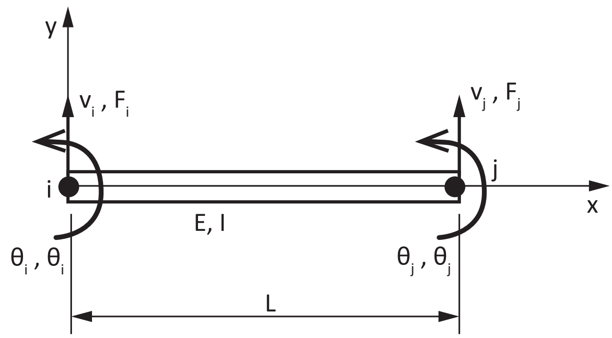
```
>> u = inv(KR)*F

u =

  1.0e-005 *

    0.4147
    0.4853
    0.6243

>> U = 10^-5*[0; 0.4147; 0.4853; 0.6243; 0]

U =

  1.0e-005 *

         0
    0.4147
    0.4853
    0.6243
         0

>> MT = KT*U

MT =

 -706.6488
  600.1663
   -0.0610
  999.9168
  893.3733
```

CAPÍTULO

7

VIGAS

7.1. ELEMENTO VIGA SIMPLE (1D)



L	Longitud
I	Momento de inercia del área de la sección transversal
E	Módulo de elasticidad
$v = v(x)$	Deflexión (el desplazamiento lateral) del eje neutro
$\theta = \dfrac{dv}{dx}$	Rotación sobre el eje Z
$F = F(x)$	Fuerza cortante o de cizalladura
$M = M(x)$	Momento sobre el eje Z

7.2. TEORÍA DE LA VIGA ELEMENTAL

$$EI\frac{d^2v}{dx^2} = M(x)$$

$$\sigma = -\frac{My}{I}$$

7.2.1. Método directo

Usando los resultados de la teoría de la viga elemental se puede calcular cada columna de la matriz de rigidez. La ecuación de rigidez de elemento (el nodo local: i, j o 1, 2), se obtiene lo siguiente:

$$\begin{array}{cc} & \begin{array}{cccc} v_i & \theta_i & v_j & \theta_j \end{array} \\ \dfrac{EI}{L^3} & \begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix} \end{array} \begin{Bmatrix} v_i \\ \theta_i \\ v_j \\ \theta_j \end{Bmatrix} = \begin{Bmatrix} F_i \\ M_i \\ F_j \\ M_j \end{Bmatrix}$$

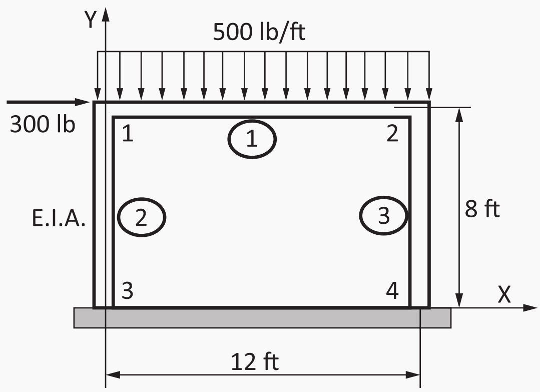
A. Para una viga 2D

$$k=\begin{array}{c}
\begin{array}{cccccc} u_i & v_i & \theta_i & u_j & v_j & \theta_j \end{array}\\
\begin{bmatrix}
\frac{EA}{L} & 0 & 0 & -\frac{EA}{L} & 0 & 0\\
0 & \frac{12EI}{L^3} & \frac{6EI}{L^2} & 0 & -\frac{12EI}{L^3} & \frac{6EI}{L^2}\\
0 & \frac{6EI}{L^2} & \frac{4EI}{L} & 0 & -\frac{6EI}{L^2} & \frac{2EI}{L}\\
-\frac{EA}{L} & 0 & 0 & \frac{EA}{L} & 0 & 0\\
0 & -\frac{12EI}{L^3} & -\frac{6EI}{L^2} & 0 & \frac{12EI}{L^3} & -\frac{6EI}{L^2}\\
0 & \frac{6EI}{L^2} & \frac{2EI}{L} & 0 & -\frac{6EI}{L^2} & \frac{4EI}{L}
\end{bmatrix}
\end{array}$$

7.2.2. Análisis de estructuras de marcos planos

Se considera que los miembros en un marco son conectados rígidamente. Pueden transmitirse fuerzas y momentos a través de sus juntas. Se necesita el elemento viga general (las combinaciones de barra y los elementos de la viga simples) para modelar los marcos.

Ejercicio 1



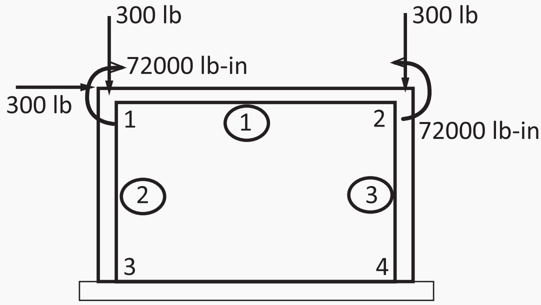
Dado que:

$E = 30\times10^6$ psi , $I = 65$ in^4 , $A = 6.8$ in^2

Hallar los desplazamientos y rotaciones de las dos juntas (1 y 2).

A. Resolución

Paso 1: Para este caso, se ha convertido la carga distribuida primero a sus cargas nodales equivalentes.



Paso 2: En el sistema de la coordenada local, la matriz de rigidez para un elemento 2D de la viga general es como sigue:

$$k = \begin{array}{c} \begin{array}{cccccc} u_i & v_i & \theta_i & u_j & v_j & \theta_j \end{array} \\ \begin{bmatrix} \frac{EA}{L} & 0 & 0 & -\frac{EA}{L} & 0 & 0 \\ 0 & \frac{12EI}{L^3} & \frac{6EI}{L^2} & 0 & -\frac{12EI}{L^3} & \frac{6EI}{L^2} \\ 0 & \frac{6EI}{L^2} & \frac{4EI}{L} & 0 & -\frac{6EI}{L^2} & \frac{2EI}{L} \\ -\frac{EA}{L} & 0 & 0 & \frac{EA}{L} & 0 & 0 \\ 0 & -\frac{12EI}{L^3} & -\frac{6EI}{L^2} & 0 & \frac{12EI}{L^3} & -\frac{6EI}{L^2} \\ 0 & \frac{6EI}{L^2} & \frac{2EI}{L} & 0 & -\frac{6EI}{L^2} & \frac{4EI}{L} \end{bmatrix} \end{array}$$

Tabla de conectividad de elementos

Elemento	Nodo i (1)	Nodo j (2)
1	1	2
2	3	1
3	4	2

Paso 3: Para el elemento 1, se tiene lo siguiente:

$$k_1 = k_1' = 10^4 \times \begin{array}{c} \begin{array}{cccccc} u_1 & v_1 & \theta_1 & u_2 & v_2 & \theta_2 \end{array} \\ \begin{bmatrix} 141.7 & 0 & 0 & -141.7 & 0 & 0 \\ 0 & 0.784 & 56.4 & 0 & -0.784 & 56.4 \\ 0 & 56.4 & 5417 & 0 & -56.4 & 2708 \\ -141.7 & 0 & 0 & 141.7 & 0 & 0 \\ 0 & -0.784 & -56.4 & 0 & 0.784 & -56.4 \\ 0 & 56.4 & 2708 & 0 & -56.4 & 5417 \end{bmatrix} \end{array}$$

Paso 4: Para los elementos 2 y 3, se tiene la matriz de rigidez en el sistema local.

$$k_2' = k_3' = 10^4 \times \begin{array}{c} \begin{array}{cccccc} u_i' & v_i' & \theta_i' & u_j' & v_j' & \theta_j' \end{array} \\ \begin{bmatrix} 212.5 & 0 & 0 & -212.5 & 0 & 0 \\ 0 & 2.65 & 1.27 & 0 & -2.65 & 127 \\ 0 & 127 & 8125 & 0 & -127 & 4063 \\ -212.5 & 0 & 0 & 212.5 & 0 & 0 \\ 0 & -2.65 & -1.27 & 0 & 2.65 & -127 \\ 0 & 127 & 4063 & 0 & -127 & 8125 \end{bmatrix} \end{array}$$

Donde: i = 3, j = 1 para el elemento 2; i = 4, j = 2 para el elemento 3.

Paso 5: En general, la matriz de la transformación T es así:

$$T = \begin{bmatrix} c & s & 0 & 0 & 0 & 0 \\ -s & c & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & c & s & 0 \\ 0 & 0 & 0 & -s & c & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Entonces:

$$c = 0\,; \quad s = 1$$

Paso 6: Para ambos elementos 2 y 3, se tiene lo siguiente:

$$T = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Paso 7: Usando la relación de la transformación, se tiene que:

$$k = T^{T} k' T$$

Paso 8: Se obtiene la matriz de rigidez en el sistema de la coordenada global para los elementos 2 y 3.

$$k_2 = 10^4 \times \begin{array}{c} \begin{array}{cccccc} u_3 & v_3 & \theta_3 & u_1 & v_1 & \theta_1 \end{array} \\ \begin{bmatrix} 2.65 & 0 & -127 & -2.65 & 0 & -127 \\ 0 & 212.5 & 0 & 0 & -212.5 & 0 \\ -127 & 0 & 8125 & 127 & 0 & 4063 \\ -2.65 & 0 & 127 & 2.65 & 0 & 127 \\ 0 & -212.5 & 0 & 0 & 212.5 & 0 \\ -127 & 0 & 4063 & 127 & 0 & 8125 \end{bmatrix} \end{array}$$

$$k_3 = 10^4 \times \begin{array}{c} \begin{array}{cccccc} u_4 & v_4 & \theta_4 & u_2 & v_2 & \theta_2 \end{array} \\ \begin{bmatrix} 2.65 & 0 & -127 & -2.65 & 0 & -127 \\ 0 & 212.5 & 0 & 0 & -212.5 & 0 \\ -127 & 0 & 8125 & 127 & 0 & 4063 \\ -2.65 & 0 & 127 & 2.65 & 0 & 127 \\ 0 & -212.5 & 0 & 0 & 212.5 & 0 \\ -127 & 0 & 4063 & 127 & 0 & 8125 \end{bmatrix} \end{array}$$

Paso 9: Ensamblando la ecuación global y notando las siguientes condiciones de contorno.

$$
\begin{aligned}
&u_3 = v_3 = \theta_3 = u_4 = v_4 = \theta_4 = 0 \\
&F_{1X} = 3000 \text{ lb} \\
&F_{2X} = 0 \\
&F_{1Y} = F_{2Y} = -3000 \text{ lb} \\
&M_1 = -72000 \text{ lb.in} \\
&M_2 = 72000 \text{ lb.in}
\end{aligned}
$$

Paso 10: Se obtiene la ecuación condensada.

$$
10^4 \times \begin{bmatrix} 144.3 & 0 & 127 & -141.7 & 0 & 0 \\ 0 & 213.3 & 56.4 & 0 & -0.784 & 56.4 \\ 127 & 56.4 & 13542 & 0 & -56.4 & 2708 \\ -141.7 & 0 & 0 & 1443 & 0 & 127 \\ 0 & -0.784 & -56.4 & 0 & 213.3 & -56.4 \\ 0 & 56.4 & 2708 & 127 & -56.4 & 13542 \end{bmatrix} \begin{Bmatrix} u_1 \\ v_1 \\ \theta_1 \\ u_2 \\ v_2 \\ \theta_2 \end{Bmatrix} = \begin{Bmatrix} 3000 \\ -3000 \\ -72000 \\ 0 \\ -3000 \\ 72000 \end{Bmatrix}
$$

Paso 11: Resolviendo esto, se obtiene que:

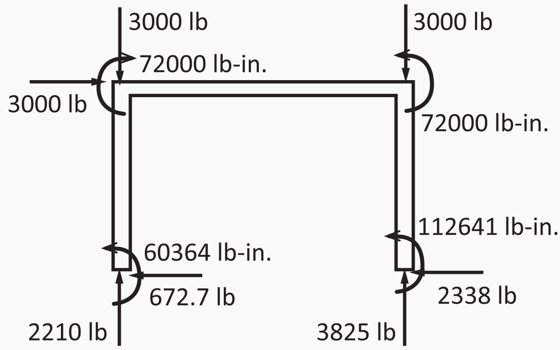
$$
\begin{Bmatrix} u_1 \\ v_1 \\ \theta_1 \\ u_2 \\ v_2 \\ \theta_2 \end{Bmatrix} = \begin{Bmatrix} 0.092 \text{ in} \\ -0.00104 \text{ in} \\ -0.00139 \text{ rad} \\ 0.0901 \text{ in} \\ -0.0018 \text{ in} \\ -3.88 \times 10^{-5} \text{ rad} \end{Bmatrix}
$$

Paso 12: Para calcular la reacción de fuerza y momentos a los dos extremos, emplee las ecuaciones para los elemento 2 y 3.

$$
\begin{Bmatrix} F_{3X} \\ F_{3Y} \\ M_3 \end{Bmatrix} = \begin{Bmatrix} -672.7 \text{ lb} \\ 2210 \text{ lb} \\ 60364 \text{ lb in} \end{Bmatrix}
$$

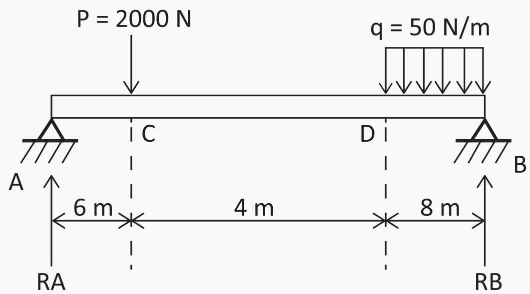
$$
\begin{Bmatrix} F_{4X} \\ F_{4Y} \\ M_4 \end{Bmatrix} = \begin{Bmatrix} -2338 \text{ lb} \\ 3825 \text{ lb} \\ 112641 \text{ lb in} \end{Bmatrix}
$$

Paso 13: Verifique los resultados. Dibuje el diagrama de libre-cuerpo del marco. Se mantiene el equilibrio con las fuerzas calculadas y momentos.



EJERCICIO 2

Escribir las ecuaciones de momentos flexionantes y fuerzas cortantes de la viga cargada que se muestra en la figura y trazar los diagramas correspondientes.



A. Resolución

Paso 1: Calcule las reacciones en los apoyos:

$$\Sigma M_A = 0$$

$$18R_B = 400N(14\,m) + 2000N(6\,m) = 977.78N.m$$

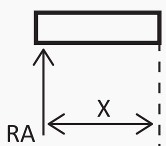
$$\Sigma M_B = 0$$

$$18R_A = 2000N(12\,m) + 400N(4\,m) = 1422.22N.m$$

Paso 2: Calcule los cortantes y flectores en las secciones de la viga.

- Segmento A–C $(0 \leq X \leq 6)$

 Las fuerzas aplicadas a considerar son las que aparecen en la siguiente figura:



V_{AC} = 1422.22 N

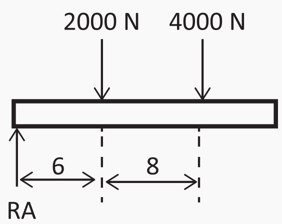
M_{AC} = 1422.22 X N

X	M
0	0
2	2844.44
4	5688.88
6	8533.332

Estas expresiones son válidas solamente desde x = 0 hasta x = 6 m.

- Segmento C – D ($10 \leq X \leq 18$)

Las fuerzas aplicadas a considerar son las que aparecen en la siguiente figura:



$V_{DB} = -50X - 77$ N

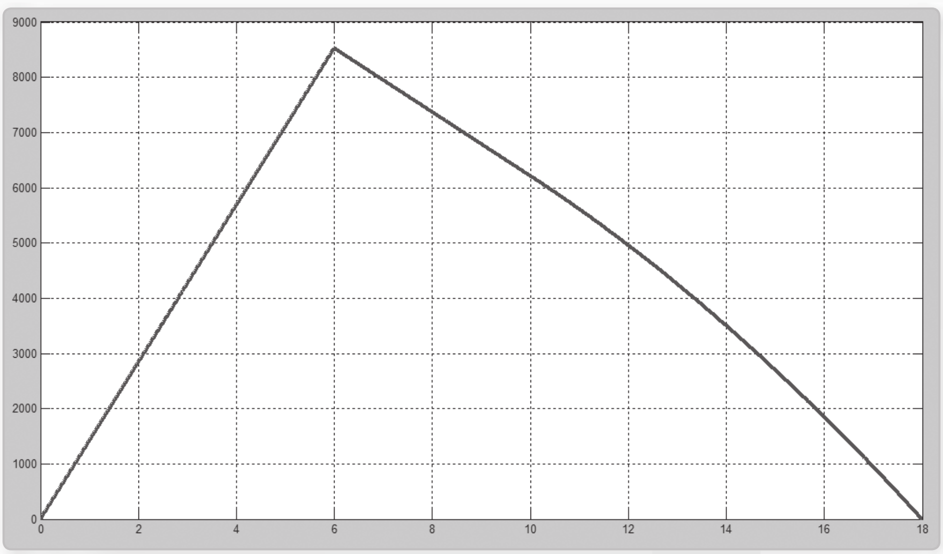
$M_{DB} = -25X^2 - 77.7X + 9500$

X	M
10	6222.2
12	4966.76
14	3511.22
16	1855.68
18	0.14

Estas expresiones son válidas solamente desde x = 10 m hasta x = 18 m.

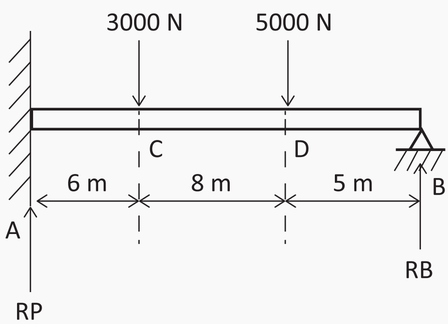
B. Resolución con MATLAB

```
>> % TRAMO A – C, DONDE X VARIA ENTRE 0 Y 6m:
>> x = 0:0.01:6;
>> M = 1422.22.*x;
>> plot(x,M)
>> grid on
>> hold on
>> % TRAMO C – D, DONDE X VARIA ENTRE 6 Y 10m:
>> x = 6:0.01:10;
>> M = -577.78.*x+12000;
>> plot(x,M)
>> grid on
>> hold on
>> % TRAMO D – B, DONDE X VARIA ENTRE 10 Y 18m:
>> x = 10:0.01:18;
>> M = -25.*x.^2-77.7.*x+9500;
>> plot(x,M)
>> grid on
>> hold off
```



EJERCICIO 3

Escribir las ecuaciones de momentos flexionantes y fuerzas cortantes de la viga cargada que se muestra en la figura y trazar los diagramas correspondientes.



A. Resolución

Paso 1: Calcule las reacciones en los apoyos.

Fuerza: 4526.607 N

Momento: 22005.54 N*m (si el valor es positivo, la fuerza se da en sentido contrario a las agujas del reloj).

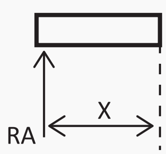
RB = 3473.39 N

Carga total = 8000 N

Paso 2: Calcule los cortantes y flectores en las secciones de las vigas:

- Segmento A–C ($0 \leq X \leq 6$)

Las fuerzas aplicadas a considerar son las que aparecen en figura siguiente:



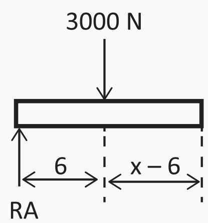
$V_{AC} = 4526.6$ N

$M_{AC} = 4526.60\ X - 22005.54$ N

X	M
0	–2205.54
2	–12952.34
4	–3899.14
6	5154

Estas expresiones son válidas solamente desde x = 0 hasta x = 6 m.

- Segmento C–D ($6 \leq X \leq 14$)

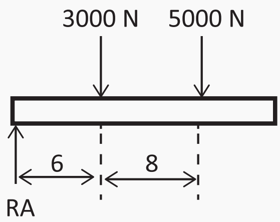


$V_{CD} = 4526.60 - 3000 = 1526.6$ N

$M_{CD} = 1526.60X - 4005.54$

X	M
6	5154.06
10	11260.46
12	14313.66
14	17366.86

- Segmento D–B ($14 \leq X \leq 19$)



$V_{DB} = -3473.39$ N

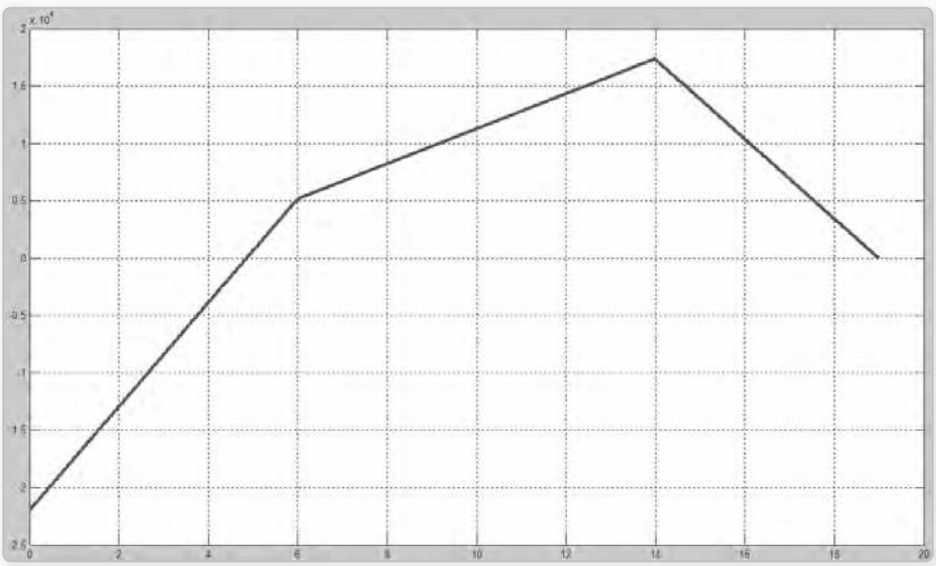
$M_{DB} = -3473.39X + 65994.46$N

X	M
14	17367
16	10420.22
18	3473.44
19	0.05

Estas expresiones son válidas solamente desde x = 14m hasta x = 19 m.

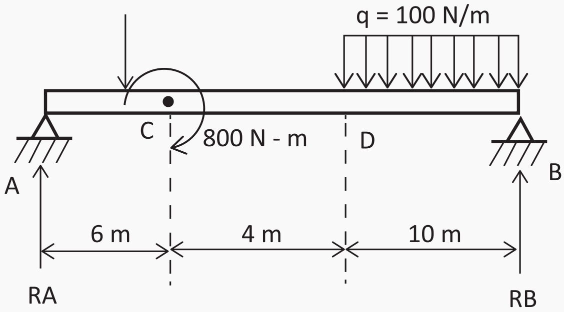
B. Resolución con MATLAB

```
>> % TRAMO A – C, DONDE X VARIA DE 0 A 6m:
>> x = 0:0.01:6;
>> M = 4526.60.*x-22004.54;
>> plot(x,M)
>> grid on
>> hold on
>> % TRAMO C – D, DONDE X VARIA DE 6 A 14m:
>> x = 6:0.01:14;
>> M = 1526.60.*x-4005.54;
>> plot(x,M)
>> grid on
>> hold on
>> % TRAMO D – B, DONDE X VARIA DE 14 A 19m:
>> x = 14:0.01:18;
>> M = -3473.39.*X+65994.46;
>> plot(x,M)
>> grid on
>> hold off
```



EJERCICIO 4

Escribir las ecuaciones de momentos flexionantes y fuerzas cortantes de la viga cargada que se muestra en la figura y trazar los diagramas correspondientes.



A. Resolución

Paso 1: Calcule las reacciones en los apoyos:

Apoyo A = 290 N

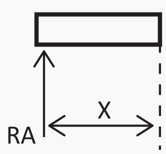
Apoyo B = 710 N

Carga total = 1000 N

Paso 2: Calcule los cortantes y flectores en las secciones de las vigas:

- Segmento A–C (0 ≤ X ≤ 6)

Las fuerzas aplicadas a considerar son las que aparecen en la figura siguiente:



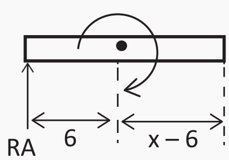
V_{AC} = 290 N

M_{AC} = 290 X N

X	M
0	0
2	580
4	1160
6	1740

Estas expresiones son válidas solamente desde x = 0 hasta x = 6 m.

- Segmento C–D (6 ≤ X ≤ 10)

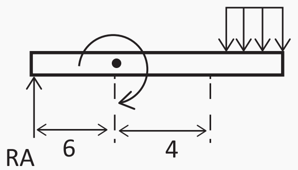


V_{CD} = 290 N

M_{CD} = 290X – 800

X	M
6	940
8	1520
10	2100

- Segmento D–B ($10 \le X \le 20$)



$$V_{DB} = -100X + 1290 \text{ N}$$

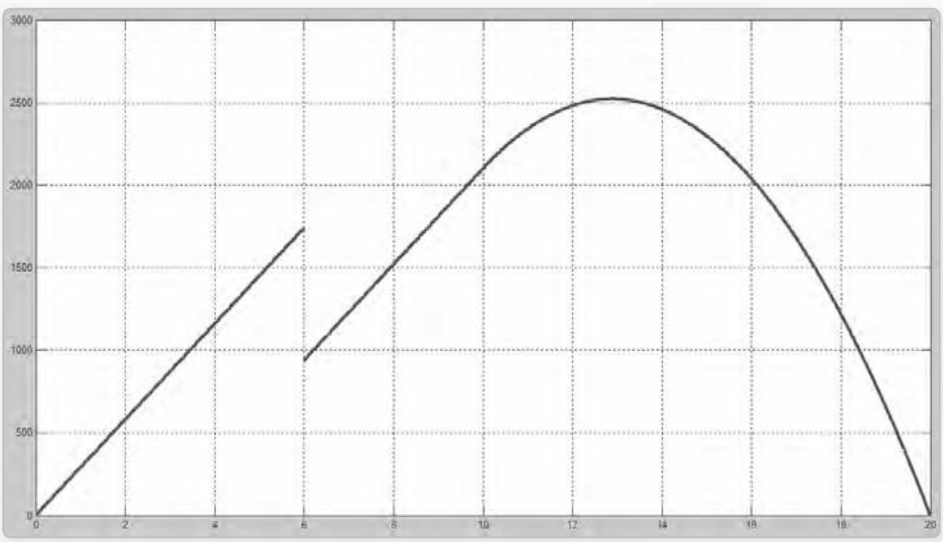
$$M_{DB} = -50X^2 + 1290X - 5800 \text{ N}$$

X	M
10	2100
12	2480
14	2460
16	2040
18	1220
20	0

Estas expresiones son válidas solamente desde x=10m hasta x=20 m.

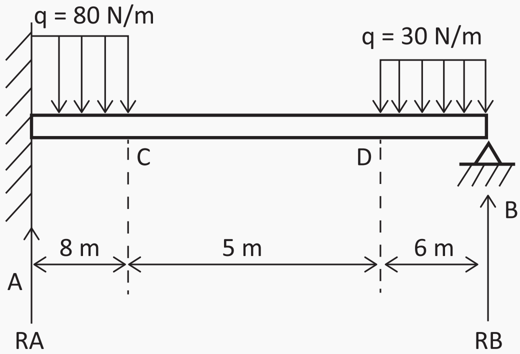
B. Resolución con MATLAB

```
>> % TRAMO A – C, DONDE X VARIA DE 0 A 6m:
>> x = 0:0.01:6;
>> M = 290.*x;
>> plot(x,M)
>> grid on
>> hold on
>> % TRAMO C – D, DONDE X VARIA DE 6 A 10m:
>> x = 6:0.01:10;
>> M = 290.*x-800;
>> plot(x,M)
>> grid on
>> hold on
>> % TRAMO D – B, DONDE X VARIA DE 10 A 20m:
>> x = 10:0.01:20;
>> M = -50.*x.^2+1290.*x-5800;
>> plot(x,M)
>> grid on
>> hold off
```



EJERCICIO 5

Escribir las ecuaciones de momentos flexionantes y fuerzas cortantes de la viga cargada que se muestra en la figura y trazar los diagramas correspondientes.



A. Resolución

Paso 1: Calcule las reacciones en los apoyos:

Fuerza = 631.16 N

Momento = 1852.10 N*m

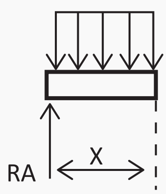
Apoyo A = 188.84

Carga total = 820 N

Paso 2: Calcule los cortantes y flectores en las secciones de las vigas.

- Segmento A–C (0 ≤ X ≤ 8)

  Las fuerzas aplicadas a considerar son las que aparecen en la figura siguiente:



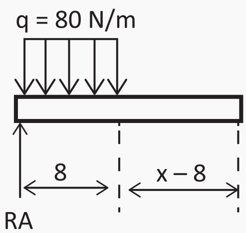
$V_{AC} = -80X + 631.16$ N

$M_{AC} = 631.16X - 1852.10$ N

X	M
0	–1852.1
2	–589.78
4	672.54
6	1934.86
8	3197.18

Estas expresiones son válidas solamente desde x = 0 hasta x = 8 m.

- Segmento C–D (8 ≤ X ≤ 13)



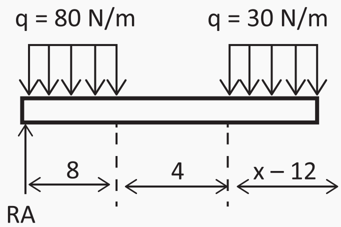
$V_{CD} = -8.8365$

$M_{CD} = -8.84X + 707.89$

X	M
8	637.17
10	619.49
12	601.81
13	592.97

Estas expresiones son válidas solamente desde x = 8m hasta x = 13 m.

- Segmento D–B ($13 \leq X \leq 19$)



$V_{DB} = -30X + 381.16$

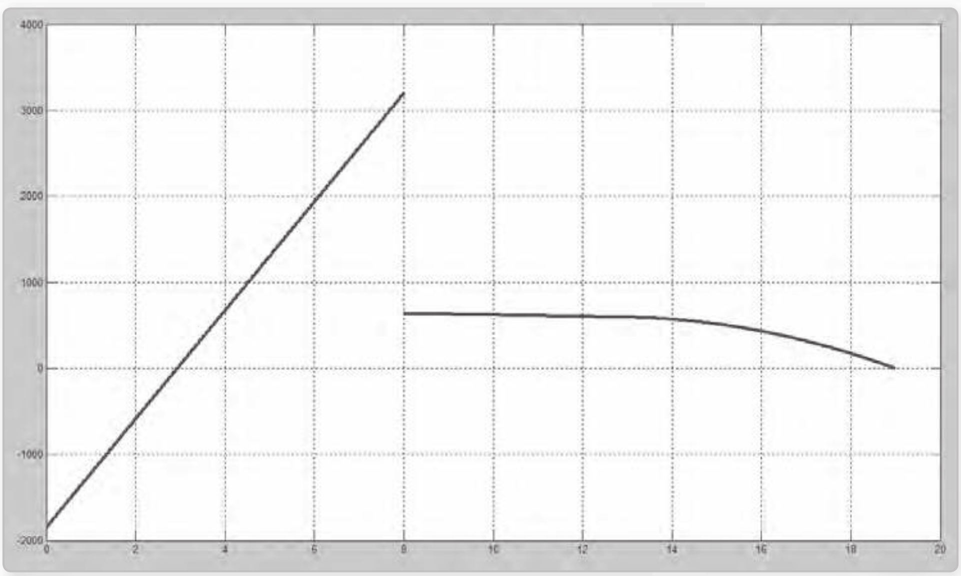
$M_{DB} = -15x^2 + 381.16x - 1827.10$

X	M
13	592.98
15	515.3
17	317.62
19	–0.06

Estas expresiones son válidas solamente desde x = 13 m hasta x = 19 m.

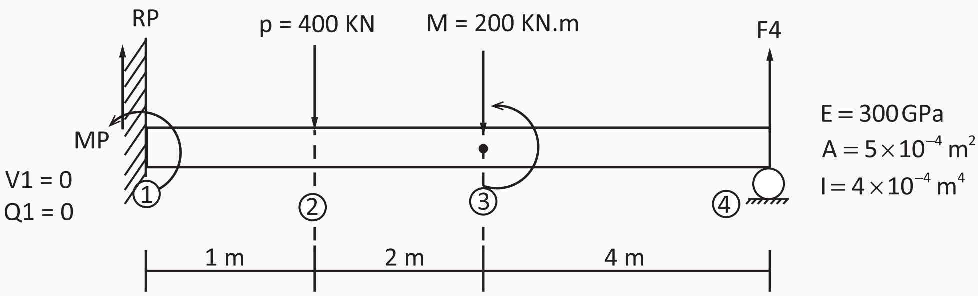
B. Resolución con MATLAB

```
>> % TRAMO A - C, DONDE X VARIA DE 0 A 8m:
>> x = 0:0.01:8;
>> M = 631.16.*x-1852.10;
>> plot(x,M)
>> grid on
>> hold on
>> % TRAMO C - D, DONDE X VARIA DE 8 A 13m:
>> x = 6:0.01:13;
>> M = -8.84.*x+707.89;
>> plot(x,M)
>> grid on
>> hold on
>> % TRAMO D - B, DONDE X VARIA DE 13 A 19m:
>> x = 13:0.01:19;
>> M = -15.*x.^2+381.16.*x-1827.10;
>> plot(x,M)
>> grid on
>> hold off
```



EJERCICIO 6

Escribir las ecuaciones de momentos flexionantes y fuerzas cortantes de la viga cargada que se muestra en la figura y trazar los diagramas correspondientes.



A. Resolución

$$K1 = \frac{\left(4\times10^{-4}\,m^4\right)\left(300\times10^9\,\dfrac{N}{m^2}\right)}{(1\ m)^3} = 120000\frac{KN}{m}$$

$$K2 = \frac{\left(5\times10^{-4}\,m^4\right)\left(300\times10^9\,\dfrac{N}{m^2}\right)}{(2\ m)^3} = 15000\frac{KN}{m}$$

$$K3 = \frac{\left(5\times10^{-4}\,m^4\right)\left(300\times10^9\,\dfrac{N}{m^2}\right)}{(4\ m)^3} = 1875\frac{KN}{m}$$

B. Resolución con MATLAB

```
>> k1 = 120000 * [12 6 -12 6 0 0 0 0; 6 4 -6 2 0 0 0 0; -12 -6 12 -6 0 0 0 0; 6 2
-6 4 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0]
k1 =
  Columns 1 through 6
     1440000       720000    -1440000       720000            0            0
      720000       480000     -720000       240000            0            0
    -1440000      -720000     1440000      -720000            0            0
      720000       240000     -720000       480000            0            0
           0            0           0            0            0            0
           0            0           0            0            0            0
           0            0           0            0            0            0
           0            0           0            0            0            0
  Columns 7 through 8
           0            0
           0            0
           0            0
           0            0
           0            0
           0            0
           0            0
           0            0
```

```
>> k2 = 15000 * [0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 12 12 -12 12 0 0; 0 0 12 16 -12
8 0 0; 0 0 -12 -12 12 -12 0 0; 0 0 12 8 -12 16 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0]
k2 =
  Columns 1 through 6
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0    180000    180000   -180000    180000
         0         0    180000    240000   -180000    120000
         0         0   -180000   -180000    180000   -180000
         0         0    180000    120000   -180000    240000
         0         0         0         0         0         0
         0         0         0         0         0         0
  Columns 7 through 8
         0         0
         0         0
         0         0
         0         0
         0         0
         0         0
         0         0
         0         0

>> k3 = 1875 * [0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0
0 0 12 24 -12 24; 0 0 0 0 24 64 -24 32; 0 0 0 0 -12 -24 12 -24; 0 0 0 0 24 32 -24 64]
k3 =
  Columns 1 through 6
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0     22500     45000
         0         0         0         0     45000    120000
         0         0         0         0     22500     45000
         0         0         0         0     45000     60000
  Columns 7 through 8
         0         0
         0         0
         0         0
         0         0
    -22500     45000
    -45000     60000
     22500    -45000
    -45000    120000

>> KT= k1 + k2 + k3
KT =
  Columns 1 through 6
   1440000    720000  -1440000    720000         0         0
    720000    480000   -720000    240000         0         0
  -1440000   -720000   1620000   -540000   -180000    180000
    720000    240000   -540000    720000   -180000    120000
         0         0   -180000   -180000    202500   -135000
         0         0    180000    120000   -135000    360000
         0         0         0         0    -22500    -45000
         0         0         0         0     45000     60000
  Columns 7 through 8
         0         0
         0         0
         0         0
         0         0
    -22500     45000
    -45000     60000
     22500    -45000
    -45000    120000
```

La matriz ensamblada estaría dada por:

$$\begin{bmatrix} 1440000 & 720000 & -1440000 & 720000 & 0 & 0 & 0 & 0 \\ 720000 & 480000 & -720000 & 240000 & 0 & 0 & 0 & 0 \\ -1440000 & -720000 & 1620000 & -540000 & -180000 & 180000 & 0 & 0 \\ 720000 & 240000 & -540000 & 720000 & -180000 & 120000 & 0 & 0 \\ 0 & 0 & -180000 & -180000 & 202500 & -135000 & -22500 & 45000 \\ 0 & 0 & 180000 & 120000 & -135000 & 360000 & -45000 & 60000 \\ 0 & 0 & 0 & 0 & -22500 & -45000 & 22500 & -45000 \\ 0 & 0 & 0 & 0 & 45000 & 60000 & -45000 & 12000 \end{bmatrix}$$

Elimine filas y columnas.

$$\begin{bmatrix} 144000 & 720000 & -144000 & 720000 & 0 & 0 & 0 & 0 \\ 720000 & 480000 & -720000 & 240000 & 0 & 0 & 0 & 0 \\ -144000 & -720000 & 1620000 & -540000 & -180000 & 180000 & 0 & 0 \\ 720000 & 240000 & -540000 & 720000 & -180000 & 120000 & 0 & 0 \\ 0 & 0 & -180000 & -180000 & 202500 & -135000 & -22500 & 45000 \\ 0 & 0 & 180000 & 120000 & -135000 & 360000 & -45000 & 60000 \\ 0 & 0 & 0 & 0 & -22500 & -45000 & 22500 & -45000 \\ 0 & 0 & 0 & 0 & 45000 & 60000 & -45000 & 12000 \end{bmatrix} \times \begin{bmatrix} \nu_1 \\ \theta_1 \\ \nu_2 \\ \theta_2 \\ \nu_3 \\ \theta_3 \\ \nu_4 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} F_{1y} \\ M_1 \\ F_{2y} \\ M_2 \\ F_{3y} \\ M_3 \\ F_{4y} \\ M_4 \end{bmatrix}$$

Se obtiene la siguiente matriz simplificada:

$$\begin{bmatrix} 1620000 & -540000 & -180000 & 180000 & 0 \\ -540000 & 720000 & -180000 & 120000 & 0 \\ -180000 & -180000 & 202500 & -135000 & 45000 \\ 180000 & 120000 & -135000 & 360000 & 60000 \\ 0 & 0 & 45000 & 60000 & 12000 \end{bmatrix} \times \begin{bmatrix} \nu_2 \\ \theta_2 \\ \nu_3 \\ \theta_3 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} F_{2y} \\ M_2 \\ F_{3y} \\ M_3 \\ M_4 \end{bmatrix}$$

Cálculo de los desplazamientos

```
>> Y = [1620000 -540000 -180000 180000 0; -540000 720000 -180000 120000 0; -180000
-180000 202500 -135000 45000; 180000 120000 -135000 360000 60000; 0 0 45000 60000
120000]
Y =
     1620000      -540000      -180000       180000            0
     -540000       720000      -180000       120000            0
     -180000      -180000       202500      -135000        45000
      180000       120000      -135000       360000        60000
           0            0        45000        60000       120000
```

```
>> F = [400; 0; 0; 20; 0]
F =
   400
     0
     0
    20
     0
>> U = inv (Y) * F
U =
     0.0008
     0.0010
     0.0019
     0.0002
    -0.0008
```

Desplazamientos

$$\nu_1 = 0 \text{ m}$$
$$\theta_1 = 0 \text{ rad}$$
$$\nu_2 = 0.0008 \text{ m}$$
$$\theta_2 = 0.0010 \text{ rad}$$
$$\nu_3 = 0.0019 \text{ m}$$
$$\theta_3 = 0.0002 \text{ rad}$$
$$\nu_4 = 0 \text{ m}$$
$$\theta_4 = -0.0008 \text{ rad}$$

Cálculo de las fuerzas

```
>> KT =[1440000 720000 -1440000 720000 0 0 0 0; 720000 480000 -720000 240000 0 0
0 0;  -1440000 -720000 1620000 -540000 -180000 180000 0 0; 720000 240000 -540000
720000 -180000 120000 0 0; 0 0 -180000 -180000 202500 -135000 -22500 45000; 0 0
180000 120000 -135000 360000 -45000 60000; 0 0 0 0 -22500 -45000 22500 -45000; 0
0 0 0 45000 60000 -45000 12000]
KT =
  Columns 1 through 6
     1440000      720000    -1440000      720000           0           0
      720000      480000     -720000      240000           0           0
    -1440000     -720000     1620000     -540000     -180000      180000
      720000      240000     -540000      720000     -180000      120000
           0           0     -180000     -180000      202500     -135000
           0           0      180000      120000     -135000      360000
           0           0           0           0      -22500      -45000
           0           0           0           0       45000       60000
  Columns 7 through 8
           0           0
           0           0
           0           0
           0           0
      -22500       45000
      -45000       60000
       22500      -45000
      -45000       12000
```

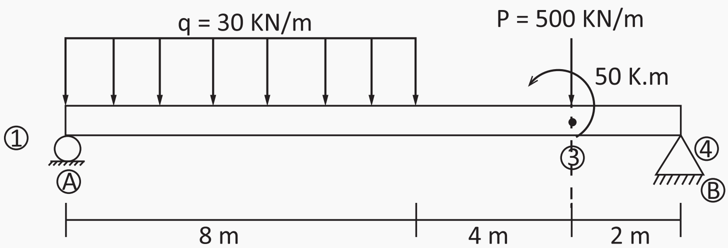
```
>> U = [0; 0; 0.0008; 0.0010; 0.0019; 0.0002; 0; -0.0008]
U =
         0
         0
    0.0008
    0.0010
    0.0019
    0.0002
         0
   -0.0008

>> F = KT*U
F =
 -432.0000
 -336.0000
  450.0000
  -30.0000
   -2.2500
   31.5000
  -15.7500
   87.9000
```

Fuerzas

$$F_{1y} = -432\ \text{N}$$
$$M_1 = -336\ \text{N.m}$$
$$F_{2y} = 450\ \text{N}$$
$$M_2 = -30\ \text{N.m}$$
$$F_{3y} = -2.25\ \text{N}$$
$$M_3 = 31.5\ \text{N.m}$$
$$F_{4y} = -15.75\ \text{N}$$
$$M_4 = 87.9\ \text{N.m}$$

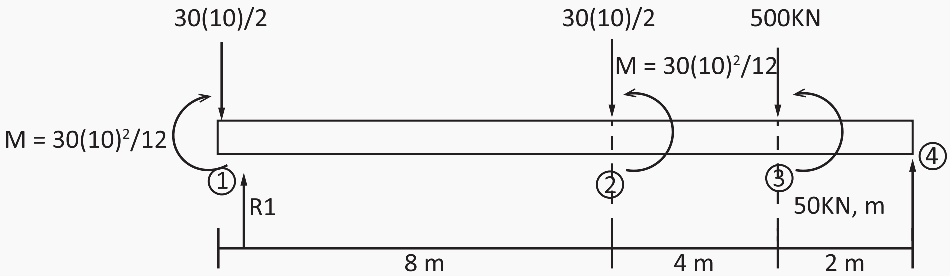
Ejercicio 7

Escribir las ecuaciones de momentos flexionantes y fuerzas cortantes de la viga cargada que se muestra en la figura y trazar los diagramas correspondientes.



$$E = 300\,\text{GPa}$$
$$A = 5 \times 10^{-4}\ \text{m}^2$$
$$I = 4 \times 10^{-4}\ \text{m}^4$$

A. Resolución



$$K1 = \frac{\left(4\times10^{-4}\,m^4\right)\left(300\times10^9\,\frac{N}{m^2}\right)}{(10\ \ m)^3} = 120\frac{KN}{m}$$

$$K2 = \frac{\left(4\times10^{-4}\,m^4\right)\left(300\times10^9\,\frac{N}{m^2}\right)}{(4\ \ m)^3} = 1875\frac{KN}{m}$$

$$K3 = \frac{\left(4\times10^{-4}\,m^4\right)\left(300\times10^9\,\frac{N}{m^2}\right)}{(2\ \ m)^3} = 15000\frac{KN}{m}$$

B. Resolución con MATLAB

```
>> k1 = 120 * [12 60 -12 60 0 0 0 0; 60 400 -60 200 0 0 0 0; -12  -60 12 -60 0 0
0 0; 60 200 -60 400 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0]
k1 =
  Columns 1 through 6
        1440        7200       -1440        7200           0           0
        7200       48000       -7200       24000           0           0
       -1440       -7200        1440       -7200           0           0
        7200       24000       -7200       48000           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
  Columns 7 through 8
           0           0
           0           0
           0           0
           0           0
           0           0
           0           0
           0           0
           0           0

>> k2 = 1875 * [0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 12 24 -12 24 0 0; 0 0 24 64
-24 32 0 0; 0 0 -12 -24 12 -24 0 0; 0 0 32 32 -24 64 0 0; 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0]
```

```
k2 =
  Columns 1 through 6
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0     22500     45000    -22500     45000
         0         0     45000    120000    -45000     60000
         0         0    -22500    -45000     22500    -45000
         0         0     60000     60000    -45000    120000
         0         0         0         0         0         0
         0         0         0         0         0         0
  Columns 7 through 8
         0         0
         0         0
         0         0
         0         0
         0         0
         0         0
         0         0
         0         0

>> k3 = 15000 * [0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0
0 0 0 12 12 -12 12; 0 0 0 0 12 16 -12 8; 0 0 0 0 -12 -12 12 -12; 0 0 0 0 12 8 -12 16]
k3 =
  Columns 1 through 6
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0    180000    180000
         0         0         0         0    180000    240000
         0         0         0         0   -180000   -180000
         0         0         0         0    180000    120000
  Columns 7 through 8
         0         0
         0         0
         0         0
         0         0
   -180000    180000
   -180000    120000
    180000   -180000
   -180000    240000

>> K = k1 + k2 + k3
K =
  Columns 1 through 6
      1440      7200     -1440      7200         0         0
      7200     48000     -7200     24000         0         0
     -1440     -7200     23940     37800    -22500     45000
      7200     24000     37800    168000    -45000     60000
         0         0    -22500    -45000    202500    135000
         0         0     60000     60000    135000    360000
         0         0         0         0   -180000   -180000
         0         0         0         0    180000    120000
  Columns 7 through 8
         0         0
         0         0
         0         0
         0         0
   -180000    180000
   -180000    120000
    180000   -180000
   -180000    240000
```

Se obtiene la siguiente matriz ensamblada:

$$\begin{bmatrix} 1440 & 7200 & 1440 & 7200 & 0 & 0 & 0 & 0 \\ 7200 & 48000 & -7200 & 24000 & 0 & 0 & 0 & 0 \\ -1440 & -7200 & 23940 & 37800 & -22500 & 45000 & 0 & 0 \\ 7200 & 24000 & 37800 & 168000 & -45000 & 60000 & 0 & 0 \\ 0 & 0 & -22500 & -45000 & 202500 & 135000 & -180000 & 180000 \\ 0 & 0 & 60000 & 60000 & 135000 & 360000 & -180000 & 120000 \\ 0 & 0 & 0 & 0 & 180000 & 180000 & 180000 & 180000 \\ 0 & 0 & 0 & 0 & 180000 & 120000 & -180000 & 240000 \end{bmatrix} \times \begin{bmatrix} \nu_1 \\ \theta_1 \\ \nu_2 \\ \theta_2 \\ \nu_3 \\ \theta_3 \\ \nu_4 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} F_{1y} \\ M_1 \\ F_{2y} \\ M_2 \\ F_{3y} \\ M_3 \\ F_{4y} \\ M_4 \end{bmatrix}$$

Elimine filas y columnas:

$$\begin{bmatrix} 1440 & 7200 & 1440 & 7200 & 0 & 0 & 0 & 0 \\ 7200 & 48000 & -7200 & 24000 & 0 & 0 & 0 & 0 \\ -1440 & -7200 & 23940 & 37800 & -22500 & 45000 & 0 & 0 \\ 7200 & 24000 & 37800 & 168000 & -45000 & 60000 & 0 & 0 \\ 0 & 0 & -22500 & -45000 & 202500 & 135000 & -180000 & 180000 \\ 0 & 0 & 60000 & 60000 & 135000 & 360000 & -180000 & 120000 \\ 0 & 0 & 0 & 0 & 180000 & 180000 & 180000 & 180000 \\ 0 & 0 & 0 & 0 & 180000 & 120000 & -180000 & 240000 \end{bmatrix} \times \begin{bmatrix} \nu_1 \\ \theta_1 \\ \nu_2 \\ \theta_2 \\ \nu_3 \\ \theta_3 \\ \nu_4 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} F_{1y} \\ M_1 \\ F_{2y} \\ M_2 \\ F_{3y} \\ M_3 \\ F_{4y} \\ M_4 \end{bmatrix}$$

Se obtiene la siguiente matriz simplificada:

$$\begin{bmatrix} 48000 & -7200 & 24000 & 0 & 0 & 0 \\ -7200 & 23940 & 37800 & -22500 & 45000 & 0 \\ 24000 & 37800 & 168000 & -45000 & 60000 & 0 \\ 0 & -22500 & -45000 & 202500 & 135000 & 180000 \\ 0 & 60000 & 60000 & 135000 & 360000 & 120000 \\ 0 & 0 & 0 & 180000 & 120000 & 240000 \end{bmatrix} \times \begin{bmatrix} \theta_1 \\ \nu_2 \\ \theta_2 \\ \nu_3 \\ \theta_3 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} M_1 \\ F_{2y} \\ M_2 \\ F_{3y} \\ M_3 \\ M_4 \end{bmatrix}$$

Cálculo de los desplazamientos

```
>> Y = [48000 -7200 24000 0 0 0; -7200 23940 37800 -22500 45000 0; 24000 37800
168000 -45000 60000 0; 0 -22500 -45000 202500 135000 180000; 0 60000 60000 135000
360000 120000; 0 0 0 180000 120000 240000]
Y =
       48000        -7200        24000            0            0            0
       -7200        23940        37800       -22500        45000            0
       24000        37800       168000       -45000        60000            0
           0       -22500       -45000       202500       135000       180000
           0        60000        60000       135000       360000       120000
           0            0            0       180000       120000       240000
```

```
>> F = [-250; -150; 250; -500; 50; 0]
F =
  -250
  -150
   250
  -500
    50
     0
>> U = inv(Y) * F
U =
    0.0440
    0.3097
   -0.0054
    0.1474
   -0.0828
   -0.0692
```

Desplazamientos

$$\theta_1 = 0.0440 \text{ rad}$$
$$\nu_2 = 0.3097 \text{ m}$$
$$\theta_2 = -0.0054 \text{ rad}$$
$$\nu_3 = 0.1474 \text{ m}$$
$$\theta_3 = -0.0828 \text{ rad}$$
$$\theta_4 = -0.0692 \text{ rad}$$

Cálculo de fuerzas

```
>> K = [1440 7200 1440 7200 0 0 0 0; 7200 48000 -7200 24000 0 0 0 0; -1440 -7200
23940 37800 -22500 45000 0 0; 7200 24000 37800 168000 -45000 60000 0 0; 0 0 -22500
-45000 202500 135000 -180000 180000; 0 0 60000 60000 135000 360000 -180000 120000;
0 0 0 0 180000 180000 180000 180000; 0 0 0 0 180000 120000 -180000 240000]

K =
        1440        7200        1440        7200           0           0
        7200       48000       -7200       24000           0           0
       -1440       -7200       23940       37800      -22500       45000
        7200       24000       37800      168000      -45000       60000
           0           0      -22500      -45000      202500      135000
           0           0       60000       60000      135000      360000
           0           0           0           0      180000      180000
           0           0           0           0      180000      120000

>> U = [0; 0.0440; 0.3097; -0.0054; 0.1474; -0.0828; 0; -0.0692]

U =
         0
    0.0440
    0.3097
   -0.0054
    0.1474
   -0.0828
         0
   -0.0692
```

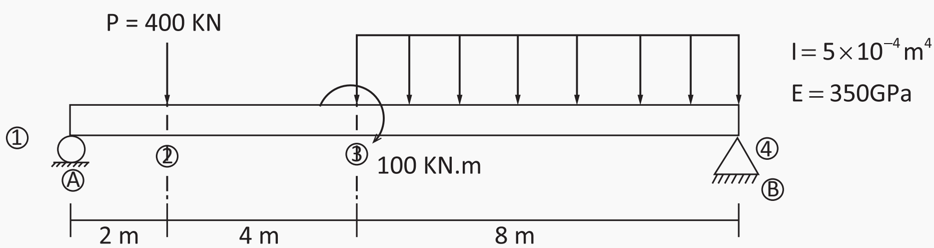
```
>> F = K*U

F =

  723.8880
 -247.4400
 -149.2020
  254.4600
 -510.7500
   45.0000
 -828.0000
  -12.0000
```

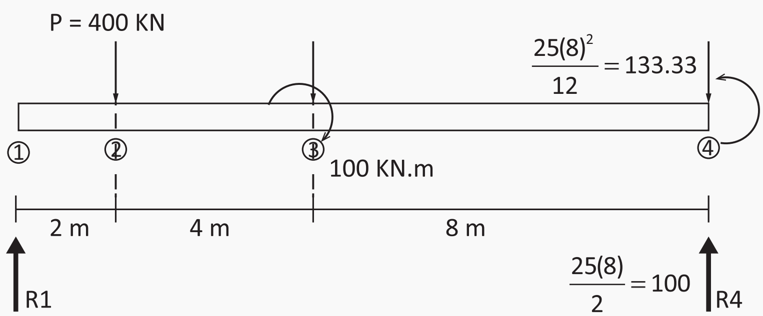
Fuerzas

$$F_{1y} = 723.8880 \text{ N}$$
$$M_1 = -247.4400 \text{ N.m}$$
$$F_{2y} = -149.2020 \text{ N}$$
$$M_2 = 254.4600 \text{ N.m}$$
$$F_{3y} = -510.7500 \text{ N}$$
$$M_3 = 45 \text{ N.m}$$
$$F_{4y} = -828 \text{ N}$$
$$M_4 = -12 \text{ N.m}$$

EJERCICIO 8

Escribir las ecuaciones de momentos flexionantes y fuerzas cortantes de la viga cargada que se muestra en la figura y trazar los diagramas correspondientes.





A. Resolución

$$K1=\frac{\left(5\times10^{-4}m^{4}\right)\left(350\times10^{9}\ \frac{N}{m^{2}}\right)}{(2\ \ m)^{3}}=21875\frac{KN}{m}$$

$$K2=\frac{\left(5\times10^{-4}m^{4}\right)\left(350\times10^{9}\ \frac{N}{m^{2}}\right)}{(4\ \ m)^{3}}=2734.375\frac{KN}{m}$$

$$K3=\frac{\left(5\times10^{-4}m^{4}\right)\left(350\times10^{9}\ \frac{N}{m^{2}}\right)}{(8\ \ m)^{3}}=341.797\frac{KN}{m}$$

B. Resolución con MATLAB

```
>> k1=21875*[12 12 -12 12 0 0 0 0; 12 16 -12 8 0 0 0 0; -12 -12 12 -12 0 0 0 0; -12
8 -12 16 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0]

k1 =

     262500    262500   -262500    262500         0         0         0         0
     262500    350000   -262500    175000         0         0         0         0
    -262500   -262500    262500   -262500         0         0         0         0
    -262500    175000   -262500    350000         0         0         0         0
          0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0

>> k2= 2734.375* [ 0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0; 0 0 12 24 -12 24 0 0; 0 0 24
64 24 32 0 0; 0 0 -12 -24 12 -24 0 0;0 0 -24 32 -24 32 0 0;0 0 0 0 0 0 0 0;0 0 0
0 0 0 0 0]

k2 =

  1.0e+005 *

          0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0
          0         0    0.3281    0.6563   -0.3281    0.6563         0         0
          0         0    0.6563    1.7500    0.6563    0.8750         0         0
          0         0   -0.3281   -0.6563    0.3281   -0.6563         0         0
          0         0   -0.6563    0.8750   -0.6563    0.8750         0         0
          0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0

>> k3=341.797*[0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0;0 0 0 0 0 0 0 0; 0
0 0 0 12 48 -12 48;0 0 0 0 48 256 -48 128;0 0 0 0 -12 -48 12 -48;0 0 0 0 48 128
-48 256]
```

```
k3 =

  1.0e+004 *

         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0    0.4102    1.6406   -0.4102    1.6406
         0         0         0         0    1.6406    8.7500   -1.6406    4.3750
         0         0         0         0   -0.4102   -1.6406    0.4102   -1.6406
         0         0         0         0    1.6406    4.3750   -1.6406    8.7500

>> KT = k1+k2+k3

KT =

  1.0e+005 *

    2.6250    2.6250   -2.6250    2.6250         0         0         0         0
    2.6250    3.5000   -2.6250    1.7500         0         0         0         0
   -2.6250   -2.6250    2.9531   -1.9688   -0.3281    0.6563         0         0
   -2.6250    1.7500   -1.9688    5.2500    0.6563    0.8750         0         0
         0         0   -0.3281   -0.6563    0.3691   -0.4922   -0.0410    0.1641
         0         0   -0.6563    0.8750   -0.4922    1.7500   -0.1641    0.4375
         0         0         0         0   -0.0410   -0.1641    0.0410   -0.1641
         0         0         0         0    0.1641    0.4375   -0.1641    0.8750
```

Se obtiene la siguiente matriz ensamblada:

$$10^5 \times \begin{bmatrix} 2.6250 & 2.6250 & -2.6250 & 2.6250 & 0 & 0 & 0 & 0 \\ 2.6250 & 3.5000 & -2.6250 & 1.7500 & 0 & 0 & 0 & 0 \\ -2.6250 & -2.6250 & 2.9531 & -1.9688 & -0.3281 & 0.6563 & 0 & 0 \\ -2.6250 & 1.7500 & -1.9688 & 5.2500 & 0.6563 & 0.8750 & 0 & 0 \\ 0 & 0 & -0.3281 & -0.6563 & 0.3691 & -0.4922 & -0.0410 & 0.1641 \\ 0 & 0 & -0.6563 & 0.8750 & -0.4922 & 1.7500 & -0.1641 & 0.4375 \\ 0 & 0 & 0 & 0 & -0.0410 & -0.1641 & 0.0410 & -0.1641 \\ 0 & 0 & 0 & 0 & 0.1641 & 0.4375 & -0.1641 & 0.8750 \end{bmatrix} \times \begin{bmatrix} \nu_1 \\ \theta_1 \\ \nu_2 \\ \theta_2 \\ \nu_3 \\ \theta_3 \\ \nu_4 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} F_{1y} \\ M_1 \\ F_{2y} \\ M_2 \\ F_{3y} \\ M_3 \\ F_{4y} \\ M_4 \end{bmatrix}$$

Elimine filas y columnas.

$$10^5 \times \begin{bmatrix} 2.6250 & 2.6250 & -2.6250 & 2.6250 & 0 & 0 & 0 & 0 \\ 2.6250 & 3.5000 & -2.6250 & 1.7500 & 0 & 0 & 0 & 0 \\ -2.6250 & -2.6250 & 2.9531 & -1.9688 & -0.3281 & 0.6563 & 0 & 0 \\ -2.6250 & 1.7500 & -1.9688 & 5.2500 & 0.6563 & 0.8750 & 0 & 0 \\ 0 & 0 & -0.3281 & -0.6563 & 0.3691 & -0.4922 & -0.0410 & 0.1641 \\ 0 & 0 & -0.6563 & 0.8750 & -0.4922 & 1.7500 & -0.1641 & 0.4375 \\ 0 & 0 & 0 & 0 & -0.0410 & -0.1641 & 0.0410 & -0.1641 \\ 0 & 0 & 0 & 0 & 0.1641 & 0.4375 & -0.1641 & 0.8750 \end{bmatrix} \times \begin{bmatrix} \nu_1 \\ \theta_1 \\ \nu_2 \\ \theta_2 \\ \nu_3 \\ \theta_3 \\ \nu_4 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} F_{1y} \\ M_1 \\ F_{2y} \\ M_2 \\ F_{3y} \\ M_3 \\ F_{4y} \\ M_4 \end{bmatrix}$$

Se obtiene la siguiente matriz simplificada:

$$\begin{bmatrix} 3.5\times10^5 & -2.6250\times10^5 & 1.75\times10^5 & 0 & 0 & 0 \\ -2.6250\times10^5 & 2.9531\times10^5 & -1.9688\times10^5 & -0.3281\times10^5 & 0.6563\times10^5 & 0 \\ 1.75\times10^5 & -1.9688\times10^5 & 5.25\times10^5 & 0.6563\times10^5 & 0.8750\times10^5 & 0 \\ 0 & -0.3281\times10^5 & -0.6563\times10^5 & 0.3691\times10^5 & -0.4922\times10^5 & 0.1641\times10^5 \\ 0 & -0.6563\times10^5 & 0.8750\times10^5 & -0.4922\times10^5 & 1.75\times10^5 & 0.4375\times10^5 \\ 0 & 0 & 0.1641\times10^5 & 0.1641\times10^5 & 0.4375\times10^5 & 0.8750\times10^5 \end{bmatrix} \times \begin{bmatrix} \theta_1 \\ \nu_2 \\ \theta_2 \\ \nu_3 \\ \theta_3 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} M_1 \\ F_{2y} \\ M_2 \\ F_{3y} \\ M_3 \\ M_4 \end{bmatrix}$$

Cálculo de los desplazamientos

```
>> Y = [3.5*10^5 -2.6250*10^5 1.75*10^5 0 0 0; -2.6250*10^5 2.9531*10^5 -1.9688*10^5
-0.3281*10^5  0.6563*10^5  0;  1.75*10^5  -1.9688*10^5  5.25*10^5  0.6563*10^5
0.8750*10^5 0; 0 -0.3281*10^5 -0.6563*10^5 0.3691*10^5 -0.4922*10^5 0.1641*10^5;
0 -0.6563*10^5 0.8750*10^5 -0.4922*10^5 1.75*10^5 0.4375*10^5; 0 0 0.1641*10^5
0.1641*10^5 0.4375*10^5 0.8750*10^5]

Y =

      350000     -262500      175000           0           0           0
     -262500      295310     -196880      -32810       65630           0
      175000     -196880      525000       65630       87500           0
           0      -32810      -65630       36910      -49220       16410
           0      -65630       87500      -49220      175000       43750
           0           0       16410       16410       43750       87500

>> F=[0; -400; 0; -100;-100; -100; 133.33]

>> B= [0; -400; 0; -100; -100; 133.33]

B =

         0
 -400.0000
         0
 -100.0000
 -100.0000
  133.3300

>> A = inv(Y)*B

A =

   -0.0022
   -0.0010
    0.0029
   -0.0109
   -0.0071
    0.0066
```

Desplazamientos

$$\theta_1 = -0.0022 \text{ rad}$$
$$\nu_2 = -0.0010 \text{ m}$$
$$\theta_2 = 0.0029 \text{ rad}$$
$$\nu_3 = -0.0109 \text{ m}$$
$$\theta_3 = -0.0071 \text{ rad}$$
$$\theta_4 = 0.0066 \text{ rad}$$

Cálculo de las fuerzas

```
>> K = [2.6250*10^5 2.6250*10^5 -2.6250*10^5 2.6250*10^5 0 0 0 0; 2.6250*10^5
3.5*10^5 -2.6250*10^5 1.75*10^5 0 0 0 0; -2.6250*10^5 -2.6250*10^5 2.9531*10^5
-1.9688*10^5 -0.381*10^5 0.6563*10^5 0 0; -2.6250*10^5 1.75*10^5 -1.9688*10^5
5.25*10^5 0.6563*10^5 0.8750*10^5 0 0; 0 0 -0.3281*10^5 -0.6563*10^5 0.3961*10^5
-0.4922*10^5 -0.0410*10^5 0.4161*10^5; 0 0 -0.6563*10^5 0.8750*10^5 -0.4922*10^5
1.75*10^5 -0.1641*10^5 0.4375*10^5; 0 0 0 0 -0.0410*10^5 -0.1641*10^5 0.0410*10^5
-0.1641*10^5; 0 0 0 0.1641*10^5 0.4375*10^5 -0.1641*10^5 0.8750*10^5]

K =

    262500    262500   -262500    262500         0         0         0         0
    262500    350000   -262500    175000         0         0         0         0
   -262500   -262500    295310   -196880    -32810     65630         0         0
   -262500    175000   -196880    525000     65630     87500         0         0
         0         0    -32810    -65630     39610    -49220     -4100     14610
         0         0    -65630     87500    -49220    175000    -16410     43750
         0         0         0         0     -4100    -16410      4100    -16410
         0         0         0         0     16410     43750    -16410     87500

>> U = [0; -0.0022; -0.0010; 0.0029; -0.0109; -0.0071; 0; 0.0066]

U =

         0
   -0.0022
   -0.0010
    0.0029
   -0.0109
   -0.0071
         0
    0.0066

>> F = K*U

F =

  446.2500
   -0.0000
 -397.1060
   -2.2370
 -143.3780
  -97.8720
   52.8950
   88.0060
```

Fuerzas

$$F_{1y} = 446.25\ \text{N}$$

$$M_1 = 0\ \text{N.m}$$

$$F_{2y} = -397.1060\ \text{N}$$

$$M_2 = -2.2370\ \text{N.m}$$

$$F_{3y} = -143.3780\ \text{N}$$

$$M_3 = -97.8720\ \text{N.m}$$

$$F_{4y} = 52.8950\ \text{N}$$

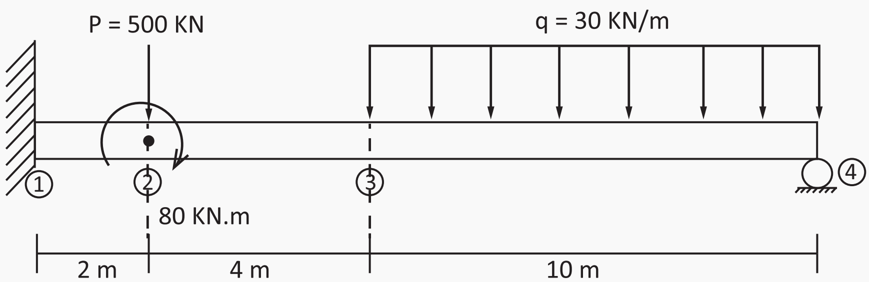
$$M_4 = 88.0060\ \text{N.m}$$

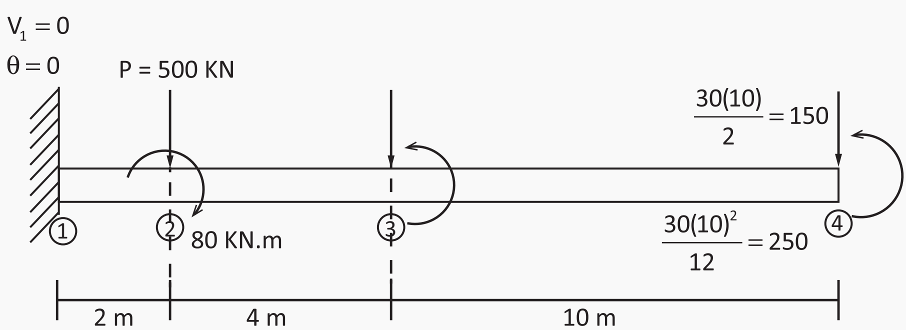
EJERCICIO 9

Escribir las ecuaciones de momentos flexionantes y fuerzas cortantes de la viga cargada que se muestra en la figura y trazar los diagramas correspondientes.

$$I = 4 \times 10^{-4}\,\text{m}^4$$

$$E = 280\text{GPa}$$





A. Resolución

$$K_1 = \frac{\left(280\times10^{9}\right)\left(4\times10^{-4}\right)}{2^3} = 14000\,KN/m$$

$$K_2 = \frac{(280\times10^{9})(4\times10^{-4})}{2^3} = 1750\,KN/m$$

$$V_1 = 0$$
$$\theta = 0$$

$$K_3 = \frac{(280\times10^{9})(4\times10^{-4})}{10^3} = 112\,KN/m$$

B. Resolución con MATLAB

```
>> k1= 14000 *[ 12 12 -12  12 0 0 0 0 ; 12 16 -12 8 0 0 0 0 ; -12 -12 12 -12 0 0
0 0 ; 12 8 -12 16 0 0 0 0 ; 0 0 0 0 0 0 0 0 ;0 0 0 0 0 0 0 0 ;0 0 0 0 0 0 0 0; 0
0 0 0 0 0 0 0 ]

k1 =

   168000    168000    -168000     168000         0         0         0         0
   168000    224000    -168000     112000         0         0         0         0
  -168000   -168000     168000    -168000         0         0         0         0
   168000    112000    -168000     224000         0         0         0         0
        0         0          0          0         0         0         0         0
        0         0          0          0         0         0         0         0
        0         0          0          0         0         0         0         0
        0         0          0          0         0         0         0         0

>> k2= 1750 *[ 0 0 0 0 0 0 0 0 ; 0 0 0 0 0 0 0 0 ; 0 0 12 24 -12 24 0 0 ; 0 0 24
64 -24 32 0 0 ; 0 0 -12 -24 12 -24 0 0 ; 0 0 24 32 -24 64 0 0; 0 0 0 0 0 0 0 0 ;
0 0 0 0 0 0 0 0 ]

k2 =

        0         0         0          0          0          0         0         0
        0         0         0          0          0          0         0         0
        0         0     21000      42000     -21000      42000         0         0
        0         0     42000     112000     -42000      56000         0         0
        0         0    -21000     -42000      21000     -42000         0         0
        0         0     42000      56000     -42000     112000         0         0
        0         0         0          0          0          0         0         0
        0         0         0          0          0          0         0         0

>> k3= 112 *[ 0 0 0 0 0 0 0 0 ; 0 0 0 0 0 0 0 0 ;0 0 0 0 0 0 0 0 ; 0 0 0 0 0 0 0
0 ; 0 0 0 0 12 60 -12 60 ;0 0 0 0 60 400 -60 200 ;0 0 0 0 -12 -60 12 -60 ; 0 0 0
0 60 200 -60 400 ]

k3 =

          0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0
          0         0         0         0      1344      6720     -1344      6720
          0         0         0         0      6720     44800     -6720     22400
          0         0         0         0     -1344     -6720      1344     -6720
          0         0         0         0      6720     22400     -6720     44800
```

```
>> KT = k1+k2+k3

KT =

  168000    168000   -168000    168000         0         0         0         0
  168000    224000   -168000    112000         0         0         0         0
 -168000   -168000    189000   -126000    -21000     42000         0         0
  168000    112000   -126000    336000    -42000     56000         0         0
       0         0    -21000    -42000     22344    -35280     -1344      6720
       0         0     42000     56000    -35280    156800     -6720     22400
       0         0         0         0     -1344     -6720      1344     -6720
       0         0         0         0      6720     22400     -6720     44800
```

Se obtiene la siguiente matriz ensamblada:

$$\begin{bmatrix} 168000 & 168000 & -168000 & 168000 & 0 & 0 & 0 & 0 \\ 168000 & 224000 & -168000 & 112000 & 0 & 0 & 0 & 0 \\ -168000 & -168000 & 189000 & -126000 & -21000 & 42000 & 0 & 0 \\ 168000 & 112000 & -126000 & 336000 & -42000 & 56000 & 0 & 0 \\ 0 & 0 & -21000 & -42000 & 22344 & -35280 & -1344 & 6720 \\ 0 & 0 & 42000 & 56000 & -35280 & 156800 & -6720 & 22400 \\ 0 & 0 & 0 & 0 & -1344 & -6720 & 1344 & -6720 \\ 0 & 0 & 0 & 0 & 6720 & 22400 & -6720 & 44800 \end{bmatrix} x \begin{bmatrix} \nu_1 \\ \theta_1 \\ \nu_2 \\ \theta_2 \\ \nu_3 \\ \theta_3 \\ \nu_4 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} F_{1y} \\ M_1 \\ F_{2y} \\ M_2 \\ F_{3y} \\ M_3 \\ F_{4y} \\ M_4 \end{bmatrix}$$

Elimine filas y columnas:

$$\begin{bmatrix} 168000 & 168000 & -168000 & 168000 & 0 & 0 & 0 & 0 \\ 168000 & 224000 & -168000 & 112000 & 0 & 0 & 0 & 0 \\ -168000 & -168000 & 189000 & -126000 & -21000 & 42000 & 0 & 0 \\ 168000 & 112000 & -126000 & 336000 & -42000 & 56000 & 0 & 0 \\ 0 & 0 & -21000 & -42000 & 22344 & -35280 & -1344 & 6720 \\ 0 & 0 & 42000 & 56000 & -35280 & 156800 & -6720 & 22400 \\ 0 & 0 & 0 & 0 & -1344 & -6720 & 1344 & -6720 \\ 0 & 0 & 0 & 0 & 6720 & 22400 & -6720 & 44800 \end{bmatrix} \times \begin{bmatrix} \nu_1 \\ \theta_1 \\ \nu_2 \\ \theta_2 \\ \nu_3 \\ \theta_3 \\ \nu_4 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} F_{1y} \\ M_1 \\ F_{2y} \\ M_2 \\ F_{3y} \\ M_3 \\ F_{4y} \\ M_4 \end{bmatrix}$$

Se obtiene la siguiente matriz simplificada:

$$\begin{bmatrix} 189000 & -126000 & -21000 & 42000 & 0 \\ -126000 & 336000 & -42000 & 56000 & 0 \\ -21000 & -42000 & 22344 & -35280 & 6720 \\ 42000 & 56000 & -35280 & 156800 & 22400 \\ 0 & 0 & 6720 & 22400 & 44800 \end{bmatrix} \times \begin{bmatrix} \nu_2 \\ \theta_2 \\ \nu_3 \\ \theta_3 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} F_{2y} \\ M_2 \\ F_{3y} \\ M_3 \\ M_4 \end{bmatrix}$$

B. Resolución con MATLAB

Cálculo de los desplazamientos

```
>> Y = [189000 -126000 -21000 42000 0; -126000 336000 -42000 56000 0; -21000 -42000
22344 -35280 6720; 42000 56000 -35280 156800 22400; 0 0 6720 22400 44800]
Y =
      189000     -126000      -21000       42000           0
     -126000      336000      -42000       56000           0
      -21000      -42000       22344      -35280        6720
       42000       56000      -35280      156800       22400
           0           0        6720       22400       44800
>> f = [-500; -30; -150; 250; 250]
F =
  -500
   -30
  -150
   250
   250
>> U = inv(Y)*F
U =
   -0.0173
   -0.0134
   -0.0622
   -0.0055
    0.0177
```

Desplazamientos

$$\nu_2 = -0.0173 \text{ m}$$
$$\theta_2 = -0.0134 \text{ rad}$$
$$\nu_3 = -0.0622 \text{ m}$$
$$\theta_3 = -0.0055 \text{ rad}$$
$$\theta_4 = 0.0177 \text{ rad}$$

Cálculo de las fuerzas

```
>> K = [168000 168000 -168000 168000 0 0 0 0; 168000 224000 -168000 112000 0 0 0
0; -168000 -168000 189000 -126000 -21000 42000 0 0; 168000 112000 -126000 336000
-42000 56000 0 0; 0 0 -21000 -42000 22344 -35280 -1344 6720; 0 0 42000 56000 -35280
156800 -6720 22400; 0 0 0 0 -1344 -6720 1344 -6720; 0 0 0 0 6720 22400 -6720 44800]

K =

  Columns 1 through 6
      168000      168000     -168000      168000           0           0
      168000      224000     -168000      112000           0           0
     -168000     -168000      189000     -126000      -21000       42000
      168000      112000     -126000      336000      -42000       56000
           0           0      -21000      -42000       22344      -35280
           0           0       42000       56000      -35280      156800
           0           0           0           0       -1344       -6720
           0           0           0           0        6720       22400
```

```
  Columns 7 through 8
           0           0
           0           0
           0           0
           0           0
       -1344        6720
       -6720       22400
        1344       -6720
       -6720       44800

>> U = [0; 0; -0.0134; -0.0134; -0.0622; -0.0055; 0; 0.0177]
U =
         0
         0
   -0.0134
   -0.0134
   -0.0622
   -0.0055
         0
    0.0177

>> F = [K*U]
F =
         0
  750.4000
  231.0000
 -509.6000
 -232.6128
  415.2930
    1.6128
  251.7760
```

Fuerzas

$$F_{1y} = 0\ \text{N}$$

$$M_1 = 750.40\ \text{N.m}$$

$$F_{2y} = 231\ \text{N}$$

$$M_2 = -509.60\ \text{N.m}$$

$$F_{3y} = -232.6128\ \text{N}$$

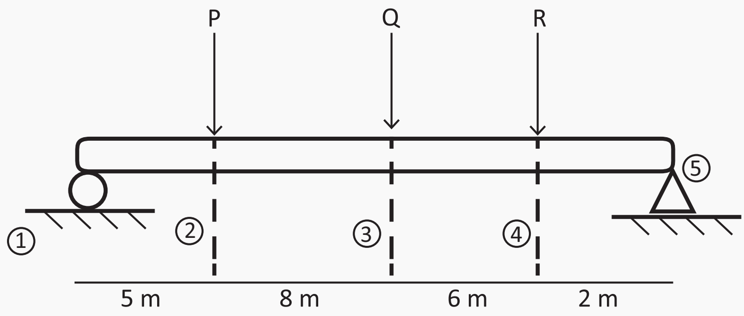
$$M_3 = 415.2960\ \text{N.m}$$

$$F_{4y} = 1.6128\ \text{N}$$

$$M_4 = 251.7760\ \text{N.m}$$

EJERCICIO 10

Hallar los desplazamientos nodales (lineales y angulares), así como las cargas (fuerzas y momentos) en las vigas mostradas:



P = 2000 N
Q = 3000
R = 3500 N
E = 250 GPa
$I = 6 \times 10^{-6}\ m^4$

A. Resolución

Paso 1: Calcule las matrices.

$$K_{12} = \frac{250\times 10^{9} \times 5\times 10^{-6}}{5^{3}}\begin{bmatrix} 12 & 30 & -12 & 30 & 0 & 0 & 0 & 0 & 0 & 0 \\ 30 & 100 & -30 & 50 & 0 & 0 & 0 & 0 & 0 & 0 \\ -12 & -30 & 12 & -30 & 0 & 0 & 0 & 0 & 0 & 0 \\ 30 & 50 & -30 & 100 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{23} = \frac{250\times 10^{9} \times 5\times 10^{-6}}{8^{3}}\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 12 & 48 & -12 & 48 & 0 & 0 & 0 & 0 \\ 0 & 0 & 48 & 256 & 48 & 128 & 0 & 0 & 0 & 0 \\ 0 & 0 & -12 & -48 & 12 & -48 & 0 & 0 & 0 & 0 \\ 0 & 0 & 48 & 128 & -48 & 256 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{34}=\frac{250\times10^{9}\times5\times10^{-6}}{6^{3}}\begin{bmatrix}0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0\\0&0&0&0&12&36&-12&36&0&0\\0&0&0&0&36&144&-36&72&0&0\\0&0&0&0&-12&-36&12&-36&0&0\\0&0&0&0&36&72&-36&144&0&0\\0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0\end{bmatrix}$$

$$K_{45}=\frac{250\times10^{9}\times5\times10^{-6}}{2^{3}}\begin{bmatrix}0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&12&12&-12&12\\0&0&0&0&0&0&12&16&-12&8\\0&0&0&0&0&0&-12&-12&12&-12\\0&0&0&0&0&0&12&8&-12&16\end{bmatrix}$$

Paso 2: Se obtiene la siguiente matriz ensamblada.

$$K_T=\begin{bmatrix}120000&300000&-120000&300000&0&0&0&0&0&0\\300000&1000000&-300000&500000&0&0&0&0&0&0\\-120000&-300000&149296.88&-182812.5&-29296.88&117187.5&0&0&0&0\\300000&500000&-182812.5&1625000&-117187.5&312500&0&0&0&0\\0&0&-29296.88&-117187.5&98741.32&91145.83&69444.44&208333.33&0&0\\0&0&117187.5&312500&91145.833&1458333.33&208333.33&416666.6667&0&0\\0&0&0&0&69444.44&208333.33&1944444.44&1666666.667&-1875000&-1875000\\0&0&0&0&208333.33&416666.66&1666666.67&3333333.333&-1875000&1250000\\0&0&0&0&0&0&-1875000&-1875000&1875000&-185000\\0&0&0&0&0&0&1875000&1250000&-1875000&2500000\end{bmatrix}\times\begin{bmatrix}\nu_1\\\theta_1\\\nu_2\\\theta_2\\\nu_3\\\theta_3\\\nu_4\\\theta_4\\\nu_5\\\theta_5\end{bmatrix}=\begin{bmatrix}F_{1y}\\0\\-3000000\\0\\-2000000\\0\\-3500000\\0\\F_{5y}\\0\end{bmatrix}$$

Paso 3: Elimine filas y columnas.

$$K_T=\begin{bmatrix}120000&300000&-120000&300000&0&0&0&0&0&0\\300000&1000000&-300000&500000&0&0&0&0&0&0\\-120000&-300000&149296.88&-182812.5&-29296.88&117187.5&0&0&0&0\\300000&500000&-182812.5&1625000&-117187.5&312500&0&0&0&0\\0&0&-29296.88&-117187.5&98741.32&91145.83&69444.44&208333.33&0&0\\0&0&117187.5&312500&91145.833&1458333.33&208333.33&416666.6667&0&0\\0&0&0&0&69444.44&208333.33&1944444.44&1666666.667&-1875000&-1875000\\0&0&0&0&208333.33&416666.66&1666666.67&3333333.333&-1875000&1250000\\0&0&0&0&0&0&-1875000&-1875000&1875000&-185000\\0&0&0&0&0&0&1875000&1250000&-1875000&2500000\end{bmatrix}\times\begin{bmatrix}\nu_1\\\theta_1\\\nu_2\\\theta_2\\\nu_3\\\theta_3\\\nu_4\\\theta_4\\\nu_5\\\theta_5\end{bmatrix}=\begin{bmatrix}F_{1y}\\0\\-3000000\\0\\-2000000\\0\\-3500000\\0\\F_{5y}\\0\end{bmatrix}$$

Paso 4: Se obtiene la siguiente matriz simplificada:

$$\begin{bmatrix} 1000000 & -300000 & 500000 & 0 & 0 & 0 & 0 & 0 \\ -300000 & 149296.68 & -182812.5 & -29296.88 & 117187.5 & 0 & 0 & 0 \\ 500000 & -182812.5 & 1625000 & -117187.5 & 312500 & 0 & 0 & 0 \\ 0 & -29296.88 & -117187.5 & 98741.32 & 91145.83 & 69444.44 & 208333.33 & 0 \\ 0 & 117187.5 & 312500 & 91145.83 & 1458333.33 & 208333.33 & 416666.667 & 0 \\ 0 & 0 & 0 & 69444.44 & 208333.33 & 1944444.44 & 1666666.667 & -1875000 \\ 0 & 0 & 0 & 208333.33 & 416666.66 & 1666666.667 & 3333333.33 & 1250000 \\ 0 & 0 & 0 & 0 & 0 & 1875000 & 1250000 & 2500000 \end{bmatrix} \times \begin{bmatrix} \theta_1 \\ \nu_2 \\ \theta_2 \\ \nu_3 \\ \theta_3 \\ \nu_4 \\ \theta_4 \\ \theta_5 \end{bmatrix} = \begin{bmatrix} 0 \\ -3000000 \\ 0 \\ -2000000 \\ 0 \\ -3500000 \\ 0 \\ 0 \end{bmatrix}$$

B. Resolución con MATLAB

Cálculo de los desplazamientos nodales

```
>> K = [1000000 -300000 500000 0 0 0 0 0; -300000 149296.68 -182812.5 -29296.88
117187.5 0 0 0; 500000 -182812.5 1625000 -117187.5 312500 0 0 0; 0 -29296.88 -117187.5
98741.32 91145.83 69444.44 208333.33 0; 0 117185.5 312500 91145.83 1458333.33 208333.33
416666.667 0; 0 0 0 69444.44 208333.33 1944444.44 1666666.667 -1875000; 0 0 0 208333.33
416666 66 1666666.667 3333333.33  1250000; 0 0 0 0 0 1875000 1250000 2500000]
K =
   1.0e+06 *
  Columns 1 through 7
    1.0000   -0.3000    0.5000         0         0         0         0
   -0.3000    0.1493   -0.1828   -0.0293    0.1172         0         0
    0.5000   -0.1828    1.6250   -0.1172    0.3125         0         0
         0   -0.0293   -0.1172    0.0987    0.0911    0.0694    0.2083
         0    0.1172    0.3125    0.0911    1.4583    0.2083    0.4167
         0         0         0    0.0694    0.2083    1.9444    1.6667
         0         0         0    0.2083    0.4167    1.6667    3.3333
         0         0         0         0         0    1.8750    1.2500
  Column 8
         0
         0
         0
         0
         0
   -1.8750
    1.2500
    2.5000
>> F = [0; -3000000; 0; -2000000; 0; -3500000; 0; 0]
F =
           0
    -3000000
           0
    -2000000
           0
    -3500000
           0
           0
>> u = inv(K)*F
u =
  -44.4615
 -185.7452
  -22.5240
 -140.1792
   27.0352
   -6.2829
    8.3153
    0.5545
```

Desplazamientos nodales

$$\nu_1 = 0 \text{ m}$$
$$\theta_1 = -44.4615 \text{ rad}$$
$$\nu_2 = -185.7452 \text{ m}$$
$$\theta_2 = -22.5240 \text{ rad}$$
$$\nu_3 = -140.1792 \text{ m}$$
$$\theta_3 = 27.0352 \text{ rad}$$
$$\nu_4 = -6.2829 \text{ m}$$
$$\theta_4 = 8.3153 \text{ rad}$$
$$\nu_5 = 0 \text{ m}$$
$$\theta_5 = 0.5545 \text{ rad}$$

Cálculo de las cargas

```
>> KT = [ 120000 300000 -120000 300000 0 0 0 0 0 0; 300000 1000000 -300000 500000
0 0 0 0 0 0; -120000 -300000 149296.88 -182812.5 -29296.88 117187.5 0 0 0 0;
300000 500000 -182812.5 1625000 -117187.5 342500 0 0 0 0; 0 0 -29296.88 -117187.5
98741.32 91145.83 69444.44 208333.33 0 0; 0 0 117187.5 312500 91145.833 1458333.33
208333.33 416666.6667 0 0; 0 0 0 0 69444.44 208333.33 1944444.44 1666666.667
-1875000 -1875000; 0 0 0 0 208333.33 416666.66 1666666.667 3333333.333 -1875000
1250000; 0 0 0 0 0 0 -1875000 -1875000 1875000 -1875000; 0 0 0 0 0 0 1875000
1250000 -1875000 2500000]

KT =

   1.0e+06 *

  Columns 1 through 7

    0.1200    0.3000   -0.1200    0.3000         0         0         0
    0.3000    1.0000   -0.3000    0.5000         0         0         0
   -0.1200   -0.3000    0.1493   -0.1828   -0.0293    0.1172         0
    0.3000    0.5000   -0.1828    1.6250   -0.1172    0.3425         0
         0         0   -0.0293   -0.1172    0.0987    0.0911    0.0694
         0         0    0.1172    0.3125    0.0911    1.4583    0.2083
         0         0         0         0    0.0694    0.2083    1.9444
         0         0         0         0    0.2083    0.4167    1.6667
         0         0         0         0         0         0   -1.8750
         0         0         0         0         0         0    1.8750

  Columns 8 through 10

         0         0         0
         0         0         0
         0         0         0
         0         0         0
    0.2083         0         0
    0.4167         0         0
    1.6667   -1.8750   -1.8750
    3.3333   -1.8750    1.2500
   -1.8750    1.8750   -1.8750
    1.2500   -1.8750    2.5000

>> U = [ 0; -44.4615; -185.7452; -22.5240; -140.1792; 27.0352; -6.2829; 8.3153;
0; 0.5545]
```

```
U =
          0
   -44.4615
  -185.7452
   -22.5240
  -140.1792
    27.0352
    -6.2829
     8.3153
          0
     0.5545

>> F = KT*U
F =
    1.0e+06 *
     2.1938
     0.0001
    -3.0001
     0.8111
    -2.0000
    -0.0004
    -3.4999
    -0.0000
    -4.8504
    -0.0001
```

Cargas (fuerzas y momentos)

$$F_{1y} = 2.1938 \times 10^{6}\ \text{N}$$

$$M_1 = 0.0001 \times 10^{6}\ \text{N.m}$$

$$F_{2y} = -3.0001 \times 10^{6}\ \text{N}$$

$$M_2 = 0.8111 \times 10^{6}\ \text{N.m}$$

$$F_{3y} = -2.00 \times 10^{6}\ \text{N}$$

$$M_3 = -0.0004 \times 10^{6}\ \text{N.m}$$

$$F_{4y} = -3.4999 \times 10^{6}\ \text{N}$$

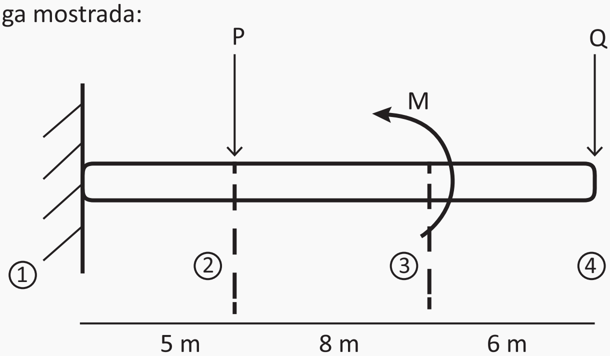
$$M_4 = 0\ \text{N.m}$$

$$F_{5y} = -4.8504 \times 10^{6}\ \text{N}$$

$$M_5 = -0.0001 \times 10^{6}\ \text{N.m}$$

Ejercicio 11

Hallar los desplazamientos nodales (lineales y angulares), así como las cargas (fuerzas y momentos) en la viga mostrada:



A. Resolución

Paso 1: Calcule lo siguiente.

$$k_1 = \frac{320\times10^9\,\text{Pa}\left(8\times10^{-6}\,\text{m}^4\right)}{(5\,\text{m})^3}\times10^3\times\begin{bmatrix} 12 & 30 & -12 & 30 & 0 & 0 & 0 & 0 \\ 30 & 100 & -30 & 50 & 0 & 0 & 0 & 0 \\ -12 & -30 & 12 & -30 & 0 & 0 & 0 & 0 \\ 30 & 50 & -30 & 100 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_1 = 10^3\times\begin{bmatrix} 245.76 & 614.4 & -245.76 & 614.4 & 0 & 0 & 0 & 0 \\ 614.4 & 20480 & -614.4 & 1024 & 0 & 0 & 0 & 0 \\ -245.76 & -614.4 & 245.76 & -614.4 & 0 & 0 & 0 & 0 \\ 614.4 & 1024 & 614.4 & 20480 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_2 = \frac{320\times10^9\,\text{Pa}\left(8\times10^{-6}\,\text{m}^4\right)}{(8\,\text{m})^3}\times10^3\times\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 12 & 48 & -12 & 48 & 0 & 0 \\ 0 & 0 & 48 & 256 & -48 & 128 & 0 & 0 \\ 0 & 0 & -12 & -48 & 12 & 48 & 0 & 0 \\ 0 & 0 & 48 & 128 & 48 & 256 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_2 = 10^3 \times \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 60 & 240 & -60 & 240 & 0 & 0 \\ 0 & 0 & 240 & 1280 & -240 & 640 & 0 & 0 \\ 0 & 0 & -60 & -240 & 60 & 240 & 0 & 0 \\ 0 & 0 & 240 & 640 & 240 & 1280 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_3 = \frac{320\times10^9\,\text{Pa}\left(8\times10^{-6}\,\text{m}^4\right)}{\left(6\,\text{m}\right)^3}\times10^3\times \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 12 & 36 & -12 & 36 \\ 0 & 0 & 0 & 0 & 36 & 144 & -36 & 72 \\ 0 & 0 & 0 & 0 & -12 & -36 & 12 & -36 \\ 0 & 0 & 0 & 0 & 36 & 72 & 36 & 144 \end{bmatrix}$$

$$k_3 = 10^3 \times \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 142.22 & 426.66 & -142.22 & 426.66 \\ 0 & 0 & 0 & 0 & 426.66 & 1706.67 & -426.66 & 853.33 \\ 0 & 0 & 0 & 0 & -142.22 & -426.66 & 142.22 & -426.66 \\ 0 & 0 & 0 & 0 & 426.66 & 853.33 & 426.66 & 1706.67 \end{bmatrix}$$

Paso 2: Se obtiene la siguiente matriz ensamblada.

$$KT = \begin{bmatrix} 245.76 & 614.4 & -245.76 & 0 & 0 & 0 & 0 & 0 \\ 614.4 & 20480 & -614.4 & 1024 & 0 & 0 & 0 & 0 \\ -245.76 & -614.4 & 305.76 & -374.4 & -60 & 240 & 0 & 0 \\ 614.4 & 1024 & 614.4 & 21760 & -240 & 640 & 0 & 0 \\ 0 & 0 & 0 & -240 & 202.22 & 666.66 & 0 & 0 \\ 0 & 0 & 0 & 640 & 666.66 & 2986.87 & -426.66 & 853.33 \\ 0 & 0 & 0 & 0 & 142.22 & -426.66 & 142.22 & -426.66 \\ 0 & 0 & 0 & 0 & 426.66 & 853.33 & 426.66 & 1706.67 \end{bmatrix} \times \begin{bmatrix} v_1 \\ \theta_2 \\ v_2 \\ \theta_2 \\ v_3 \\ \theta_3 \\ v_4 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} F_{1y} \\ 0 \\ 3000 \\ 0 \\ 0 \\ 500\times10^3 \\ 4000 \\ 0 \end{bmatrix}$$

Paso 3: Elimine filas y columnas.

$$
KT = \begin{bmatrix}
245.76 & 614.4 & -245.76 & 0 & 0 & 0 & 0 & 0 \\
614.4 & 20480 & -614.4 & 1024 & 0 & 0 & 0 & 0 \\
-245.76 & -614.4 & 305.76 & -374.4 & -60 & 240 & 0 & 0 \\
614.4 & 1024 & 614.4 & 21760 & -240 & 640 & 0 & 0 \\
0 & 0 & 0 & -240 & 202.22 & 666.66 & 0 & 0 \\
0 & 0 & 0 & 640 & 666.66 & 2986.87 & -426.66 & 853.33 \\
0 & 0 & 0 & 0 & 142.22 & -426.66 & 142.22 & -426.66 \\
0 & 0 & 0 & 0 & 426.66 & 853.33 & 426.66 & 1706.67
\end{bmatrix}
\times
\begin{bmatrix} v_1 \\ \theta_2 \\ v_2 \\ \theta_2 \\ v_3 \\ \theta_3 \\ v_4 \\ \theta_4 \end{bmatrix}
=
\begin{bmatrix} F_{1y} \\ 0 \\ 3000 \\ 0 \\ 0 \\ 500\times10^3 \\ 4000 \\ 0 \end{bmatrix}
$$

Paso 4: Se obtiene la siguiente matriz simplificada.

$$
K = \begin{bmatrix}
305.76 & -374.4 & -60 & 240 & 0 & 0 \\
614.4 & 21760 & -240 & 640 & 0 & 0 \\
0 & -240 & 202.22 & 666.66 & 0 & 0 \\
0 & 640 & 666.66 & 2986.87 & -426.66 & 853.33 \\
0 & 0 & 142.22 & -426.66 & 142.22 & -426.66 \\
0 & 0 & 426.66 & 853.33 & 426.66 & 1706.67
\end{bmatrix}
\times
\begin{bmatrix} \nu_2 \\ \theta_2 \\ \nu_3 \\ \theta_3 \\ \nu_4 \\ \theta_4 \end{bmatrix}
=
\begin{bmatrix} 3000 \\ 0 \\ 0 \\ 500\times10^3 \\ 4000 \\ 0 \end{bmatrix}
$$

B. Resolución con MATLAB

Cálculo de los desplazamientos nodales

```
>> K = [ 305.76 -374.4 -60 240 0 0; 614.4 21760 -240 640 0 0; 0 -240 202.22 666.66
0 0; 0 640 666.66 2986.87 -426.66 853.33; 0 0 142.22 -426.66 142.22 -426.66; 0 0
426.66 853.33 426.66 1706.67]

K =

  1.0e+004 *

    0.0306   -0.0374   -0.0060    0.0240         0         0
    0.0614    2.1760   -0.0240    0.0640         0         0
         0   -0.0240    0.0202    0.0667         0         0
         0    0.0640    0.0667    0.2987   -0.0427    0.0853
         0         0    0.0142   -0.0427    0.0142   -0.0427
         0         0    0.0427    0.0853    0.0427    0.1707

>> F = [ 3000; 0; 0; 500*10^3; 4000; 0]

F =

        3000
           0
           0
      500000
        4000
           0
```

```
>> u = inv(K)*F

u =

  1.0e+003 *

    0.4665
    0.0074
    1.0353
   -0.3114
   -1.2861
    0.2184
```

Desplazamientos nodales

$$\nu_1 = 0 \text{ m}$$
$$\theta_1 = 0 \text{ rad}$$
$$\nu_2 = 0.4665 \times 10^3 \text{ m}$$
$$\theta_2 = 0.0074 \times 10^3 \text{ rad}$$
$$\nu_3 = 1.0353 \times 10^3 \text{ m}$$
$$\theta_3 = -0.3114 \times 10^3 \text{ rad}$$
$$\nu_4 = -1.2861 \times 10^3 \text{ m}$$
$$\theta_4 = 0.2184 \times 10^3 \text{ rad}$$

Cálculo de las fuerzas

```
>> KT = [245.76 614.4 -245.76 0 0 0 0 0; 614.4 20480 -614.4 1024 0 0 0 0; -245.76
-614.4 305.76 -374.4 -60 240 0 0; 614.4 1024 614.4 21760 -240 640 0 0; 0 0 0 -240
202.22 666.66 0 0; 0 0 0 640 666.66 2986.87 -426.66 853.33; 0 0 0 0 142.22 -426.66
142.22 -426.66; 0 0 0 0 426.66 853.33 426.66 1706.67]

KT =

  1.0e+004 *

    0.0246    0.0614   -0.0246         0         0         0         0         0
    0.0614    2.0480   -0.0614    0.1024         0         0         0         0
   -0.0246   -0.0614    0.0306   -0.0374   -0.0060    0.0240         0         0
    0.0614    0.1024    0.0614    2.1760   -0.0240    0.0640         0         0
         0         0         0   -0.0240    0.0202    0.0667         0         0
         0         0         0    0.0640    0.0667    0.2987   -0.0427    0.0853
         0         0         0         0    0.0142   -0.0427    0.0142   -0.0427
         0         0         0         0    0.0427    0.0853    0.0427    0.1707

>> U = [0; 0; 0.4665*10^3; 0.0074*10^3; 1.0353*10^3; -0.3114*10^3; -1.2861*10^3;
0.2184*10^3]

U =

  1.0e+003 *
```

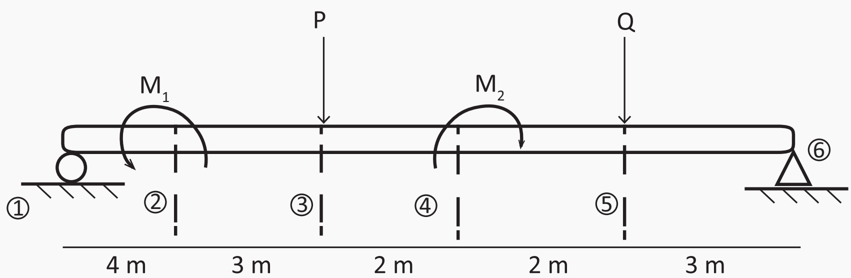
```
           0
           0
      0.4665
      0.0074
      1.0353
     -0.3114
     -1.2861
      0.2184

>> F = KT*U

F =

   1.0e+005 *

     -1.1465
     -2.7904
      0.0301
     -0.0013
     -0.0002
      4.9991
      0.0401
      0.0000
```

Cargas (fuerzas y momentos)

$$F_{1y} = -1.1465 \times 10^5 \text{ N}$$
$$M_1 = -2.7904x10^5 \text{ N.m}$$
$$F_{2y} = 0.0301 \times 10^5 \text{ N}$$
$$M_2 = -0.0013 \times 10^5 \text{ N.m}$$
$$F_{3y} = -0.0002 \times 10^5 \text{ N}$$
$$M_3 = 4.9991 \times 10^5 \text{ N.m}$$
$$F_{4y} = 0.0401 \times 10^5 \text{ N}$$
$$M_4 = 0 \text{ N.m}$$

EJERCICIO 12

Hallar los desplazamientos nodales (lineales y angulares), así como las cargas (fuerzas y momentos) en la viga mostrada:



$E = 200$ GPa

$I = 7 \times 10^{-6} m^4$

$M_1 = 600$ KNm

$M_2 = 500$ KNm

$P = 1500$ KN

$Q = 2500$ KN

$R = 3000$ KN

A. Resolución

Paso 1: Calcule los valores:

$$k_1 = \frac{280\times 10^9\,\mathrm{Pa}\left(7\times 10^{-6}\,\mathrm{m}^4\right)}{(4\ \mathrm{m})^3}\times\begin{bmatrix} 12 & 24 & -12 & 24 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 24 & 64 & -24 & 32 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -12 & -24 & 12 & -24 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 24 & 32 & 24 & 64 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_1 = 10^3\times\begin{bmatrix} 367.5 & 735 & -367.5 & 735 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 735 & 1960 & -735 & 980 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -367.5 & -735 & 367.5 & -735 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 735 & 980 & 735 & 1960 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_2 = \frac{280\times 10^9\,\mathrm{Pa}\left(7\times 10^{-6}\,\mathrm{m}^4\right)}{(3\ \mathrm{m})^3}\times\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 12 & 18 & -12 & 18 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 18 & 36 & -18 & 18 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -12 & -18 & 12 & -18 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 18 & 18 & -18 & 36 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_2 = 10^5 \times \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 8.711 & 13.067 & -8.711 & 13.067 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 13.067 & 26.133 & -13.067 & 13.067 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -8.711 & -13.067 & 8.711 & -13.067 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 13.067 & 13.067 & -13.067 & 26.133 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_3 = \frac{280 \times 10^9\,\text{Pa}\left(7 \times 10^{-6}\,\text{m}^4\right)}{(2\text{ m})^3} \times \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 12 & 12 & -12 & 12 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 12 & 16 & -12 & 8 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -12 & -12 & 12 & -12 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 12 & 8 & 12 & 16 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_3 = 10^5 \times \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 29.4 & 29.4 & -29.4 & 29.4 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 29.4 & 39.2 & -29.4 & 19.6 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -29.4 & -29.4 & 29.4 & -29.4 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 29.4 & 19.6 & -29.4 & 39.2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_4 = \frac{280\times10^9\,\text{Pa}(7\times10^{-6}\,\text{m}^4)}{(2\,\text{m})^3}\times\begin{bmatrix} 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&12&12&-12&12&0&0\\ 0&0&0&0&0&0&12&16&-12&8&0&0\\ 0&0&0&0&0&0&-12&-12&12&-12&0&0\\ 0&0&0&0&0&0&12&8&12&16&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0 \end{bmatrix}$$

$$k_4 = 10^5\times\begin{bmatrix} 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&29.4&29.4&-29.4&29.4&0&0\\ 0&0&0&0&0&0&29.4&39.2&-29.4&19.6&0&0\\ 0&0&0&0&0&0&-29.4&-29.4&29.4&-29.4&0&0\\ 0&0&0&0&0&0&29.4&19.6&29.4&39.2&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0 \end{bmatrix}$$

$$k_5 = \frac{280\times10^9\,\text{Pa}\left(7\times10^{-6}\,\text{m}^4\right)}{(3\,\text{m})^3}\times\begin{bmatrix} 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&12&18&-12&18\\ 0&0&0&0&0&0&0&0&18&36&-18&18\\ 0&0&0&0&0&0&0&0&-12&-18&12&-18\\ 0&0&0&0&0&0&0&0&18&18&-18&36 \end{bmatrix}$$

$$k_5 = 10^5 \times \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8.711 & 13.067 & -8.711 & 13.067 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 13.067 & 26.133 & -13.067 & 13.067 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -8.711 & -13.067 & 8.711 & -13.067 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 13.067 & 13.067 & -13.067 & 26.133 \end{bmatrix}$$

Paso 2: Se obtiene la siguiente matriz ensamblada:

$$KT = 10^5 \times \begin{bmatrix} -3.675 & 7.35 & -3.675 & 7.35 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 7.35 & 19.6 & -7.35 & 9.8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -3.675 & -7.35 & 12.386 & 5.717 & -8.711 & 13.067 & 0 & 0 & 0 & 0 & 0 & 0 \\ 7.35 & 9.8 & 5.717 & 45.733 & -13.067 & 13.067 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -8.711 & -13.067 & 38.111 & 16.333 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 13.067 & 13.067 & 16.333 & 65.333 & -29.4 & 19.6 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -29.4 & -29.4 & 58.8 & 0 & -29.4 & -29.4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 29.4 & 19.6 & 0 & 78.4 & -29.4 & 19.6 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -29.4 & -29.4 & 38.111 & -16.333 & -8.711 & 13.067 \\ 0 & 0 & 0 & 0 & 0 & 0 & 29.4 & 19.6 & -16.333 & 65.333 & -13.067 & 13.067 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -8.711 & -13.067 & 8.711 & -13.067 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 13.067 & 13.067 & -13.067 & 26.133 \end{bmatrix} \times \begin{bmatrix} 0 \\ \theta_1 \\ v_2 \\ \theta_2 \\ v_3 \\ \theta_3 \\ v_4 \\ \theta_4 \\ v_5 \\ \theta_5 \\ 0 \\ \theta_6 \end{bmatrix} = \begin{bmatrix} R_1 \\ 0 \\ 0 \\ 600\times10^3 \\ -1500\times10^3 \\ 0 \\ 0 \\ -800\times10^3 \\ -2500\times10^3 \\ 0 \\ R_6 \\ 0 \end{bmatrix}$$

Paso 3: Elimine filas y columnas:

$$KT = 10^5 \times \begin{bmatrix} -3.675 & 7.35 & -3.675 & 7.35 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 7.35 & 19.6 & -7.35 & 9.8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -3.675 & -7.35 & 12.386 & 5.717 & -8.711 & 13.067 & 0 & 0 & 0 & 0 & 0 & 0 \\ 7.35 & 9.8 & 5.717 & 45.733 & -13.067 & 13.067 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -8.711 & -13.067 & 38.111 & 16.333 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 13.067 & 13.067 & 16.333 & 65.333 & -29.4 & 19.6 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -29.4 & -29.4 & 58.8 & 0 & -29.4 & -29.4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 29.4 & 19.6 & 0 & 78.4 & -29.4 & 19.6 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -29.4 & -29.4 & 38.111 & -16.333 & -8.711 & 13.067 \\ 0 & 0 & 0 & 0 & 0 & 0 & 29.4 & 19.6 & -16.333 & 65.333 & -13.067 & 13.067 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -8.711 & -13.067 & 8.711 & -13.067 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 13.067 & 13.067 & -13.067 & 26.133 \end{bmatrix} \times \begin{bmatrix} 0 \\ \theta_1 \\ v_2 \\ \theta_2 \\ v_3 \\ \theta_3 \\ v_4 \\ \theta_4 \\ v_5 \\ \theta_5 \\ 0 \\ \theta_6 \end{bmatrix} = \begin{bmatrix} R_1 \\ 0 \\ 0 \\ 600\times10^3 \\ -1500\times10^3 \\ 0 \\ 0 \\ -800\times10^3 \\ -2500\times10^3 \\ 0 \\ R_6 \\ 0 \end{bmatrix}$$

Paso 4: Se obtiene la siguiente matriz simplificada:

$$K = 10^5 \times \begin{bmatrix} 19.6 & -7.35 & 9.8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -7.35 & 12.386 & 5.717 & -8.711 & 13.067 & 0 & 0 & 0 & 0 & 0 \\ 9.8 & 5.717 & 45.733 & -13.067 & 13.067 & 0 & 0 & 0 & 0 & 0 \\ 0 & -8.711 & -13.067 & 38.111 & 16.333 & 0 & 0 & 0 & 0 & 0 \\ 0 & 13.067 & 13.067 & 16.333 & 65.333 & -29.4 & 19.6 & 0 & 0 & 0 \\ 0 & 0 & 0 & -29.4 & -29.4 & 58.8 & 0 & -29.4 & -29.4 & 0 \\ 0 & 0 & 0 & 29.4 & 19.6 & 0 & 78.4 & -29.4 & 19.6 & 0 \\ 0 & 0 & 0 & 0 & 0 & -29.4 & -29.4 & 38.111 & -16.333 & 13.067 \\ 0 & 0 & 0 & 0 & 0 & 29.4 & 19.6 & -16.333 & 65.333 & 13.067 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 13.067 & 13.067 & 26.133 \end{bmatrix} \begin{bmatrix} \theta_1 \\ v_2 \\ \theta_2 \\ v_3 \\ \theta_3 \\ v_4 \\ \theta_4 \\ v_5 \\ \theta_5 \\ \theta_6 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 600\times10^3 \\ -1500\times10^3 \\ 0 \\ 0 \\ -800\times10^3 \\ -2500\times10^3 \\ 0 \\ 0 \end{bmatrix}$$

B. Resolución con MATLAB

Cálculo de los desplazamientos nodales

```
>> K = [19.6*10^5 -7.35*10^5 9.8*10^5 0 0 0 0 0 0 0; -7.35*10^5 12.386*10^5 5.717*10^5
-8.711*10^5 13.067*10^5 0 0 0 0 0; 9.8*10^5 5.717*10^5 45.733*10^5 -13.067*10^5
13.067*10^5 0 0 0 0 0; 0 -8.711*10^5 -13.067*10^5 38.111*10^5 16.333*10^5 0 0 0 0
0; 0 13.067*10^5 13.067*10^5 16.333*10^5 65.333*10^5 -29.4*10^5 19.6*10^5 0 0 0;
0 0 0 -29.4*10^5 -29.4*10^5 58.8*10^5 0 -29.4*10^5 -29.4*10^5 0; 0 0 0 29.4*10^5
19.6*10^5 0 78.4*10^5 -29.4*10^5 19.6*10^5 0; 0 0 0 0 0 -29.4*10^5 -29.4*10^5
39.111*10^5 -16.333*10^5 13.067*10^5; 0 0 0 0 0 29.4*10^5 19.6*10^5 -16.333*10^5
65.333*10^5 13.067*10^5; 0 0 0 0 0 0 0 13.067*10^5 13.067*10^5 26.133*10^5]

K =

  1.0e+006 *

  1.9600 -0.7350  0.9800       0       0       0       0       0       0       0
 -0.7350  1.2386  0.5717 -0.8711  1.3067       0       0       0       0       0
  0.9800  0.5717  4.5733 -1.3067  1.3067       0       0       0       0       0
       0 -0.8711 -1.3067  3.8111  1.6333       0       0       0       0       0
       0  1.3067  1.3067  1.6333  6.5333 -2.9400  1.9600       0       0       0
       0       0       0 -2.9400 -2.9400  5.8800       0 -2.9400 -2.9400       0
       0       0       0  2.9400  1.9600       0  7.8700 -2.9400  1.9600       0
       0       0       0       0       0 -2.9400 -2.9400  3.9111 -1.6333  1.3067
       0       0       0       0       0  2.9400  1.9600 -1.6333  6.5333  1.3067
       0       0       0       0       0       0       0  1.3067  1.3067  2.6133

>> F = [0; 0; 600*10^3; -1500*10^3; 0; 0; -800*10^3; -2500*10^3; 0; 0]

F =

          0
          0
     600000
   -1500000
          0
          0
    -800000
   -2500000
          0
          0

>> u = inv(K)*F

u =

    0.6361
    2.1093
    0.3098
    0.7439
   -1.2813
   -2.5933
   -1.8518
   -4.7255
    0.0762
    2.3247
```

Desplazamientos nodales

$$\nu_1 = 0 \text{ m}$$
$$\theta_1 = 0.6361 \text{ rad}$$
$$\nu_2 = 2.1093 \text{ m}$$
$$\theta_2 = 0.3098 \text{ rad}$$
$$\nu_3 = 0.7439 \text{ m}$$
$$\theta_3 = -1.2813 \text{ rad}$$
$$\nu_4 = -2.5933 \text{ m}$$
$$\theta_4 = -1.8518 \text{ rad}$$
$$\nu_5 = -4.7255 \text{ m}$$
$$\theta_5 = 0.0762 \text{ rad}$$
$$\nu_6 = 0 \text{ m}$$
$$\theta_6 = 2.3247 \text{ rad}$$

Cálculo de las cargas

```
>> KT = [-3.675*10^5 7.35*10^5 -3.675*10^5 7.35*10^5 0 0 0 0 0 0 0 0; 7.35*10^5
19.6*10^5 -7.35*10^5 9.8*10^5 0 0 0 0 0 0 0 0; -3.675*10^5 -7.35*10^5 12.386*10^5
5.717*10^5 -8.711*10^5 13.067*10^5 0 0 0 0 0 0; 7.35*10^5 9.8*10^5 5.717*10^5
45.733*10^5 -13.067*10^5 13.067*10^5 0 0 0 0 0 0; 0 0 -8.711*10^5 -13.067*10^5
38.111*10^5 16.333*10^5 0 0 0 0 0 0; 0 0 13.067*10^5 13.067*10^5 16.333*10^5
65.333*10^5 -29.4*10^5 19.6*10^5 0 0 0 0; 0 0 0 0-29.4*10^5 -29.4*10^5 58.8*10^5
0 -29.4*10^5 -29.4*10^5 0 0; 0 0 0 0 29.4*10^5 19.6*10^5 0 78.4*10^5 -29.4*10^5
19.6*10^5 0 0; 0 0 0 0 0 0 -29.4*10^5 -29.4*10^5 38.111*10^5 -16.333*10^5 -8.711*10^5
13.067*10^5; 0 0 0 0 0 0 29.7*10^5 19.6*10^5 -16.333*10^5 65.333*10^5 -13.067*10^5
13.067*10^5; 0 0 0 0 0 0 0 0 -8.711*10^5 -13.067*10^5 8.711*10^5 -13.067*10^5; 0
0 0 0 0 0 0 0 13.067*10^5 13.067*10^5 -13.067*10^5 26.133*10^5]

KT =

  1.0e+006 *

-0.3675  0.7350 -0.3675  0.7350       0       0       0       0       0       0       0       0
 0.7350  1.9600 -0.7350  0.9800       0       0       0       0       0       0       0       0
-0.3675 -0.7350  1.2386  0.5717 -0.8711  1.3067       0       0       0       0       0       0
 0.7350  0.9800  0.5717  4.5733 -1.3067  1.3067       0       0       0       0       0       0
      0       0 -0.8711 -1.3067  3.8111  1.6333       0       0       0       0       0       0
      0       0  1.3067  1.3067  1.6333  6.5333 -2.9400  1.9600       0       0       0       0
      0       0       0       0 -2.9400 -2.9400  5.8800       0 -2.9400 -2.9400       0       0
      0       0       0       0  2.9400  1.9600       0  7.8400 -2.9400  1.9600       0       0
      0       0       0       0       0       0 -2.9400 -2.9400  3.8111 -1.6333 -0.8711  1.3067
      0       0       0       0       0       0  2.9400  1.9600 -1.6333  6.5333 -1.3067  1.3067
      0       0       0       0       0       0       0       0 -0.8711 -1.3067  0.8711 -1.3067
      0       0       0       0       0       0       0       0  1.3067  1.3067 -1.3067  2.6133

>> U = [0; 0.6361; 2.1093; 0.3098; 0.7439; -1.2813; -2.5933; -1.8518; -4.7255;
0.0762; 0; 2.3247]

U =

        0
   0.6361
```

```
    2.1093
    0.3098
    0.7439
   -1.2813
   -2.5933
   -1.8518
   -4.7255
    0.0762
         0
    2.3247

>> F = KT*U

F =

  1.0e+006 *

   -0.0799
    0.0000
   -0.0001
    0.5997
   -1.4999
   -0.0003
    0.0003
   -0.8001
   -2.0275
   -0.0001
    0.9791
   -0.0001
```

Cargas (fuerzas y momentos)

$$F_{1y} = -0.0799 \times 10^6 \text{ N}$$

$$M_1 = 0 \text{N.m}$$

$$F_{2y} = -0.0001 \times 10^6 \text{ N}$$

$$M_2 = 0.5997 \times 10^6 \text{ N.m}$$

$$F_{3y} = -1.4999 \times 10^6 \text{ N}$$

$$M_3 = -0.0003 \times 10^6 \text{ N.m}$$

$$F_{4y} = 0.0003 \times 10^6 \text{ N}$$

$$M_4 = -0.8001 \times 10^6 \text{ N.m}$$

$$F_{5y} = -2.0275 \times 10^6 \text{ N}$$

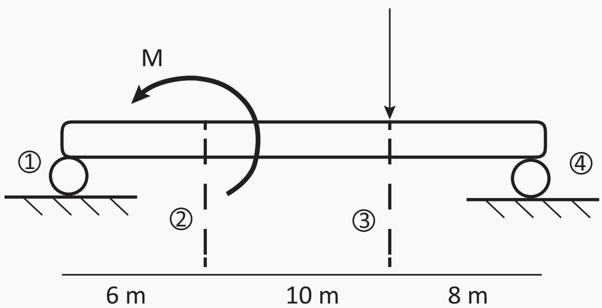
$$M_5 = -0.0001 \times 10^6 \text{ N.m}$$

$$F_{6y} = 0.9791 \times 10^6 \text{ N}$$

$$M_6 = -0.0001 \times 10^6 \text{ N.m}$$

EJERCICIO 13

Hallar los desplazamientos nodales (lineales y angulares), así como las cargas (fuerzas y momentos) en la viga mostrada:



$P = 3000\ \text{N}$

$M = 800\ \text{KN.m}$

$E = 320\ \text{GPa}$

$I = 10 \times 10^{-6}\,\text{m}^4$

A. RESOLUCIÓN

Paso 1: Calcule los siguientes valores:

$$k_1 = \frac{320\times10^{9}\,\text{Pa}\left(10\times10^{-6}\,\text{m}^4\right)}{(6\ \text{m})^3}\times10^3\times\begin{bmatrix} 12 & 36 & -12 & 30 & 0 & 0 & 0 & 0 \\ 36 & 144 & -36 & 72 & 0 & 0 & 0 & 0 \\ -12 & -36 & 12 & -36 & 0 & 0 & 0 & 0 \\ 36 & 72 & -60 & 144 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_2 = \frac{320\times10^{9}\,\text{Pa}\left(10\times10^{-6}\,\text{m}^4\right)}{(10\ \text{m})^3}\times10^3\times\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 12 & 60 & -12 & 60 & 0 & 0 \\ 0 & 0 & 60 & 400 & -60 & 200 & 0 & 0 \\ 0 & 0 & -12 & -60 & 12 & -60 & 0 & 0 \\ 0 & 0 & 60 & 200 & -60 & 400 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_3 = \frac{320\times10^{9}\,\text{Pa}\left(10\times10^{-6}\,\text{m}^4\right)}{(8\ \text{m})^3}\times10^3\times\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 12 & 48 & -12 & 48 \\ 0 & 0 & 0 & 0 & 48 & 256 & -48 & 128 \\ 0 & 0 & 0 & 0 & -12 & -48 & 12 & -48 \\ 0 & 0 & 0 & 0 & 48 & 128 & -48 & 256 \end{bmatrix}$$

Paso 2: Se obtiene la matriz ensamblada:

$$KT = 10^6 \times \begin{bmatrix} 0.1778 & 0.5333 & -0.1778 & 0.5333 & 0 & 0 & 0 & 0 \\ 0.5333 & 2.133 & -0.5333 & 1.0667 & 0 & 0 & 0 & 0 \\ -0.1778 & -0.533 & 0.2162 & -0.341 & -0.0384 & 0.192 & 0 & 0 \\ 0.5333 & 1.067 & -0.3413 & 3.4133 & -0.1920 & 0.64 & 0 & 0 \\ 0 & 0 & -0.0384 & -0.192 & 0.1134 & 0.108 & -0.075 & 0.3 \\ 0 & 0 & 0.1920 & 0.64 & 0.1080 & 2.88 & -0.30 & 0.8 \\ 0 & 0 & 0 & 0 & -0.075 & -0.3 & 0.075 & -0.3 \\ 0 & 0 & 0 & 0 & 0.3 & 0.8 & -0.3 & 1.6 \end{bmatrix} \begin{bmatrix} \nu_1 \\ \theta_1 \\ \nu_2 \\ \theta_2 \\ \nu_3 \\ \theta_3 \\ 0 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} F_{1y} \\ M_{1y} \\ 0 \\ 800\times10^3 \\ -3000\times10^3 \\ 0 \\ R_4 \\ 0 \end{bmatrix}$$

Paso 3: Elimine filas y columnas:

$$KT = 10^6 \times \begin{bmatrix} 0.1778 & 0.5333 & -0.1778 & 0.5333 & 0 & 0 & 0 & 0 \\ 0.5333 & 2.133 & -0.5333 & 1.0667 & 0 & 0 & 0 & 0 \\ -0.1778 & -0.533 & 0.2162 & -0.341 & -0.0384 & 0.192 & 0 & 0 \\ 0.5333 & 1.067 & -0.3413 & 3.4133 & -0.1920 & 0.64 & 0 & 0 \\ 0 & 0 & -0.0384 & -0.192 & 0.1134 & 0.108 & -0.075 & 0.3 \\ 0 & 0 & 0.1920 & 0.64 & 0.1080 & 2.88 & -0.30 & 0.8 \\ 0 & 0 & 0 & 0 & -0.075 & -0.3 & 0.075 & -0.3 \\ 0 & 0 & 0 & 0 & 0.3 & 0.8 & -0.3 & 1.6 \end{bmatrix} \begin{bmatrix} \nu_1 \\ \theta_1 \\ \nu_2 \\ \theta_2 \\ \nu_3 \\ \theta_3 \\ 0 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} F_{1y} \\ M_{1y} \\ 0 \\ 800\times10^3 \\ -3000\times10^3 \\ 0 \\ R_4 \\ 0 \end{bmatrix}$$

Paso 4: Se obtiene la siguiente matriz simplificada:

$$K = \begin{bmatrix} 2.133\times10^6 & -0.5333\times10^6 & 1.0667\times10^6 & 0 & 0 & 0 \\ -0.533\times10^6 & 0.2162\times10^6 & -0.341\times10^6 & -0.0384\times10^6 & 0.192\times10^6 & 0 \\ 1.067\times10^6 & -0.3413\times10^6 & 3.4133\times10^6 & -0.1920\times10^6 & 0.64\times10^6 & 0 \\ 0 & -0.0384\times10^6 & -0.192\times10^6 & 0.1134\times10^6 & 0.108\times10^6 & 0.3\times10^6 \\ 0 & 0.1920\times10^6 & 0.64\times10^6 & 0.1080\times10^6 & 2.88\times10^6 & 0.8\times10^6 \\ 0 & 0 & 0 & 0.3\times10^6 & 0.8\times10^6 & 1.6\times10^6 \end{bmatrix} \times \begin{bmatrix} \theta_1 \\ \nu_2 \\ \theta_2 \\ \nu_3 \\ \theta_3 \\ \theta_4 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 800\times10^3 \\ -3000\times10^3 \\ 0 \\ 0 \end{bmatrix}$$

B. Resolución con MATLAB

Cálculo de los desplazamientos nodales

```
>> K = [2.133*10^6 -0.5333*10^6 1.0667*10^6 0 0 0; -0.533*10^6 0.2162*10^6 -0.341*10^6
-0.0384*10^6 0.192*10^6 0; 1.067*10^6 -0.3413*10^6 3.4133*10^6 -0.1920*10^6 0.64*10^6
0;  0  -0.0384*10^6  -0.1920*10^6  0.1134*10^6  0.108*10^6  0.3*10^6;  0  0.1920*10^6
0.64*10^6 0.1080*10^6 2.88*10^6 0.8*10^6; 0 0 0 0.3*10^6 0.8*10^6 1.6*10^6]

K =

     2133000      -533300      1066700            0            0            0
     -533000       216200      -341000       -38400       192000            0
     1067000      -341300      3413300      -192000       640000            0
           0       -38400      -192000       113400       108000       300000
           0       192000       640000       108000      2880000       800000
           0            0            0       300000       800000      1600000
```

```
>> F = [0; 0; 800*10^3; -3000*10^3; 0; 0]

F =

           0
           0
      800000
    -3000000
           0
           0

>> u = inv(K)*F

u =

  -25.7944
 -143.2747
  -20.0516
 -206.7455
   12.7655
   32.3820
```

Desplazamientos nodales

$$\nu_1 = 0 \text{ m}$$
$$\theta_1 = -25.7944 \text{ rad}$$
$$\nu_2 = -143.2747 \text{ m}$$
$$\theta_2 = -20.0516 \text{ rad}$$
$$\nu_3 = -206.7455 \text{ m}$$
$$\theta_3 = 12.7655 \text{ rad}$$
$$\nu_4 = 0 \text{ m}$$
$$\theta_4 = 32.3820 \text{ rad}$$

Cálculo de las cargas

```
>> KT = [0.1778*10^6 0.5333*10^6 -0.1778*10^6 0.5333*10^6 0 0 0 0; 0.5333*10^6
2.133*10^6 -0.5333*10^6 1.0667*10^6 0 0 0 0; -0.1778*10^6 -0.5333*10^6 0.2162*10^6
-0.3413*10^6  -0.0384*10^6  0.192*10^6  0  0;  0.533*10^6  1.067*10^6  -0.3413*10^6
3.4133*10^6 -0.1920*10^6 0.64*10^6 0 0; 0 0 -0.0384*10^6 -0.192*10^6 0.1134*10^6
0.108*10^6 -0.075*10^6 0.3*10^6; 0 0 0.1920*10^6 0.64*10^6 0.1080*10^6 2.88*10^6
-0.30*10^6 0.8*10^6; 0 0 0 0 -0.075*10^6 -0.3*10^6 0.075*10^6 -0.3*10^6; 0 0 0 0
0.3*10^6 0.8*10^6 -0.3*10^6 1.6*10^6]

KT =

 177800     533300    -177800     533300          0          0          0          0
 533300    2133000    -533300    1066700          0          0          0          0
-177800    -533300     216200    -341300     -38400     192000          0          0
 533000    1067000    -341300    3413300    -192000     640000          0          0
      0          0     -38100    -192000     113400     108000     -75000     300000
      0          0     192000     640000     108000    2880000    -300000     800000
      0          0          0          0     -75000    -300000      75000    -300000
      0          0          0          0     300000     800000    -300000    1600000
```

```
>> U = [0; -25.7944; -143.2747; -20.0516; -206.7455; 12.7655; 0; 32.3820]

U =

         0
  -25.7944
 -143.2747
  -20.0516
 -206.7455
   12.7655
         0
   32.3820

>> F = KT*U

F =

  1.0e+006 *

    1.0246
   -0.0001
    0.0138
    0.8000
   -3.0000
   -0.0000
    1.9617
   -0.0001
```

Cargas (fuerzas y momentos)

$$F_{1y} = 1.0246 \times 10^6 \text{ N}$$

$$M_1 = -0.0001 \times 10^6 \text{ N.m}$$

$$F_{2y} = 0.0138 \times 10^6 \text{ N}$$

$$M_2 = -0.8000 \times 10^6 \text{ N.m}$$

$$F_{3y} = -3 \times 10^6 \text{ N}$$

$$M_3 = 0 \text{N.m}$$

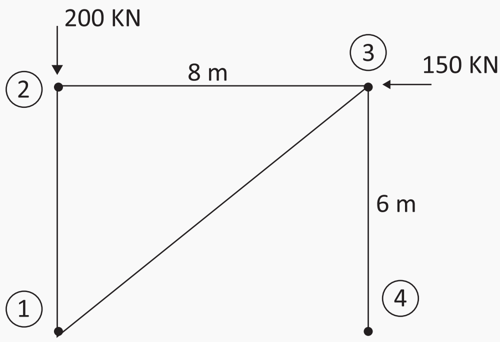
$$F_{4y} = 1.9617 \times 10^6 \text{ N}$$

$$M_4 = -0.0001 \text{N.m}$$

7.3. VIGA 2D

Ejercicio 1

Determinar los desplazamientos y las cargas en la estructura mostrada



$E = 280\ \text{GPa}$

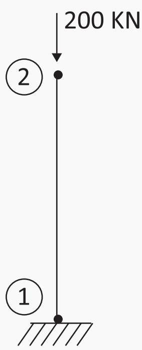
$I = 6 \times 10^{4}\ m^{4}$

$A = 5 \times 10^{-2}\ m^{2}$

A. Resolución

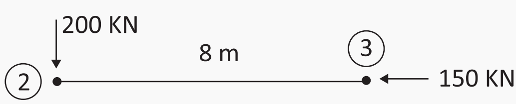
Matrices individuales

$$K = \frac{E}{L}$$



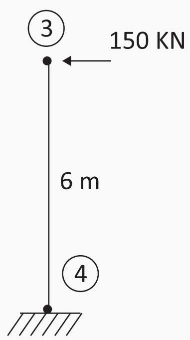
1-2) $\alpha = 90$; $C = 0$; $S = 1$; $L = 6$

$$K(1-2) = 10^{9} \times \begin{vmatrix} 0.0093 & 0 & -0.0280 & -0.0093 & 0 & -0.0280 \\ 0 & 2.3333 & 0 & 0 & -2.3333 & 0.0280 \\ -0.0280 & 0 & 0.1120 & 0.0280 & 0 & 0.0560 \\ -0.0093 & 0 & 0.0280 & 0.0093 & 0 & 0.0280 \\ 0 & -2.3333 & 0 & 0 & 2.3333 & 0 \\ -0.0280 & 0.0280 & 0.0560 & 0.0280 & 0 & 0.1120 \end{vmatrix}$$



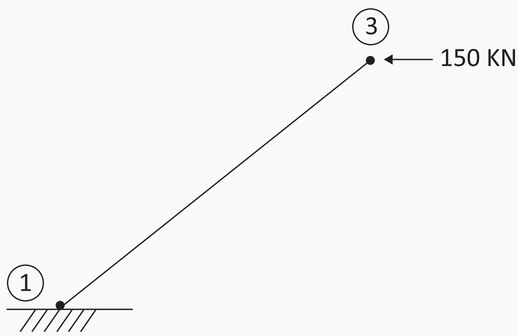
2-3) $\alpha = 0$; $C = 1$; $S = 0$; $L = 8$

$$K(2-3) = 10^9 \times \begin{vmatrix} 1.7500 & 0 & 0 & -1.7500 & 0 & 0 \\ 0 & 0.0039 & -0.0158 & 0 & -0.0039 & 0 \\ 0 & 0.0158 & 0.0840 & 0 & -0.0158 & 0.0420 \\ -1.7500 & 0 & 0 & 1.7500 & 0 & 0 \\ 0 & -0.0039 & -0.0158 & 0 & 0.0039 & -0.0158 \\ 0 & 0 & 0.0420 & 0 & -0.0158 & 0.0840 \end{vmatrix}$$



3-4) $\alpha = 90$; $C = 0$; $S = 1$; $L = 6$

$$K(3-4) = 10^9 \times \begin{vmatrix} 0.0093 & 0 & 0.0280 & -0.0093 & 0 & 0.0280 \\ 0 & 2.3333 & 0 & 0 & -2.3333 & -0.0280 \\ 0.0280 & 0 & 0.1120 & -0.0280 & 0 & 0.0560 \\ -0.0093 & 0 & -0.0280 & 0.0093 & 0 & -0.0280 \\ 0 & -2.3333 & 0 & 0 & 2.3333 & 0 \\ 0.0280 & -0.0280 & 0.0560 & -0.0280 & 0 & 0.1120 \end{vmatrix}$$



1-3) $\alpha = 53$; $C = 0.798$; $S = 0.6018$; $L = 10$

$$K(1-3) = 10^9 \times \begin{vmatrix} 0.89368 & 0.67191 & -0.00607 & -0.89368 & -0.67191 & -0.00607 \\ 0.67191 & 0.50834 & -0.00805 & -0.67191 & -0.50834 & 0.00607 \\ -0.00607 & 0.00805 & 0.06720 & 0.00607 & -0.00805 & 0.03360 \\ -0.89368 & -0.67191 & 0.00607 & 0.89368 & 0.67191 & 0.00607 \\ -0.67191 & -0.50834 & -0.00805 & 0.67191 & 0.50834 & -0.00805 \\ -0.00607 & 0.00607 & 0.03360 & 0.00607 & -0.00805 & 0.06720 \end{vmatrix}$$

Matriz ensamblada

$10^9 \times M$

$$M = \begin{bmatrix} 0.90298 & 0 & -0.03407 & -0.0093 & 0 & -0.0280 & -0.89368 & -0.67191 & -0.00607 & 0 & 0 & 0 \\ 0.67191 & 2.84164 & -0.00805 & 0 & -2.3333 & 0.0280 & -0.67191 & -0.50834 & 0.00607 & 0 & 0 & 0 \\ -0.03407 & 0.00805 & 0.1792 & 0.0280 & 0 & 0.0560 & 0.00607 & -0.00805 & 0.03360 & 0 & 0 & 0 \\ -0.0093 & 0 & 0.0280 & 1.7593 & 0 & 0.0280 & -1.7500 & 0 & 0 & 0 & 0 & 0 \\ 0 & -2.3333 & 0 & 0 & 2.3372 & -0.0158 & 0 & -0.0039 & 0 & 0 & 0 & 0 \\ -0.0280 & 0.0280 & 0.0560 & 0.0280 & 0.0158 & 0.196 & 0 & -0.0158 & 0.0420 & 0 & 0 & 0 \\ -0.89360 & -0.67191 & 0.00607 & -1.7500 & 0 & 0 & 2.65298 & 0.67191 & 0.03407 & -0.0093 & 0 & 0.0280 \\ -0.37191 & -0.50834 & -0.00805 & 0 & -0.0039 & -0.0158 & 0.67191 & 2.84554 & -0.02385 & 0 & -2.3333 & -0.0280 \\ -0.00607 & 0.00607 & 0.03360 & 0 & 0 & 0.0420 & 0.03407 & -0.02985 & 0.2632 & -0.0280 & 0 & 0.0560 \\ 0 & 0 & 0 & 0 & 0 & 0 & -0.0093 & 0 & -0.0280 & 0.0093 & 0 & -0.0280 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -2.3333 & 0 & 0 & 2.3333 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.0280 & -0.0280 & 0.0560 & -0.0280 & 0 & 0.1120 \end{bmatrix} \times \begin{bmatrix} u_1 = 0 \\ \nu_1 = 0 \\ \phi_1 = 0 \\ u_2 \\ \nu_2 \\ \phi_2 \\ u_3 \\ \nu_3 \\ \phi_3 \\ u_4 = 0 \\ \nu_4 = 0 \\ \phi_4 = 0 \end{bmatrix} = \begin{bmatrix} R_{x1} \\ R_{Y1} \\ M_1 \\ R_{x2} = 0 \\ R_{Y2} = -200000 \\ M_2 = 0 \\ R_{x3} = -150000 \\ R_{Y3} = 0 \\ M_3 = 0 \\ R_{x4} \\ R_{Y4} \\ M_4 \end{bmatrix}$$

Desplazamientos y momentos

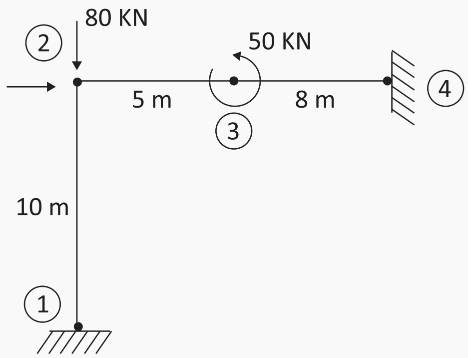
$$u_2 = -0.02212 \text{ mm}$$
$$\nu_2 = -0.0852 \text{ mm}$$
$$\phi_2 = 0.0423 \text{ mrad}$$
$$u_3 = -0.2217 \text{ mm}$$
$$\nu_3 = 0.0525 \text{ mm}$$
$$\phi_3 = 0.0018 \text{ mrad}$$

Reacciones

$$F_{x1} = 164.78 \text{ MN}$$
$$F_{Y1} = 3.2227 \text{ MN}$$
$$M_1 = 2240 \text{ Nm}$$
$$F_{x4} = 2.0114 \text{ MN}$$
$$F_{Y4} = -122.49 \text{ MN}$$
$$M_4 = -7.57 \text{ MNm}$$

EJERCICIO 2

Determinar los desplazamientos y las cargas en la estructura mostrada



$E = 300\ \text{GPa}$

$I = 2 \times 10^{4}\, m^{4}$

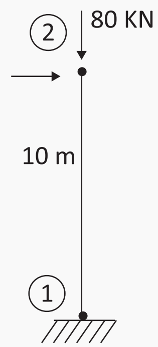
$A = 0.5 \times 10^{-2}\, m^{2}$

A. Resolución

Matrices individuales

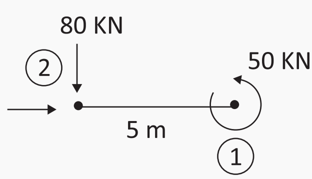
$K \times T$

$K = \dfrac{E}{L}$



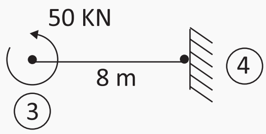
1-2) $\alpha = 90$; $C = 0$; $S = 1$; $L = 6$

$$K(1-2) = 10^{8} \times \begin{vmatrix} 0.0072 & 0 & -0.0360 & -0.0072 & 0 & -0.0360 \\ 0 & 1.50000 & 0 & -1.5000 & 0.0360 & 0 \\ -0.0360 & 0 & 0.2400 & 0.0360 & 0 & 0.1200 \\ -0.00720 & 0.03600 & 0.0072 & 0 & 0.3600 & 0 \\ 0 & -1.50000 & 0 & 1.5000 & 0 & 0 \\ -0.0360 & 0.0360 & 0.1200 & 0.0360 & 0 & 0.2400 \end{vmatrix}$$



2-3) $\alpha = 0$; C = 1 ; S = 0 ; L = 5

$$K(2-3) = 10^8 \times \begin{vmatrix} 3.0000 & 0 & 0 & -3.0000 & 0 & 0 \\ 0 & 0.0576 & -0.1440 & 0 & -0.0576 & 0 \\ 0 & 0.1440 & 0.4800 & 0 & -0.1440 & 0.2400 \\ -3.0000 & 0 & 0 & 3.0000 & 0 & 0 \\ 0 & -0.0576 & -0.1440 & 0 & 0.0576 & -0.1440 \\ 0 & 0 & 0.2400 & 0 & -0.1440 & 0.4800 \end{vmatrix}$$



3-4) $\alpha = 0$; C = 1 ; S = 0 ; L = 8

$$K(3-4) = 10^8 \times \begin{vmatrix} 1.8750 & 0 & 0 & -1.870 & 0 & 0 \\ 0 & 0.0141 & -0.0563 & 0 & -0.0141 & 0 \\ 0 & 0.0563 & 0.3000 & 0 & -0.0563 & 0.1500 \\ -1.8750 & 0 & 0 & 1.8750 & 0 & 0 \\ 0 & -0.0141 & -0.0563 & 0 & 0.0141 & -0.0563 \\ 0 & 0 & 0.1500 & 0 & -0.0563 & 0.3000 \end{vmatrix}$$

Matriz ensamblada

$10^8 \times M$

$$M = \begin{bmatrix} 0.0072 & 0 & -0.0360 & -0.0072 & 0 & -0.0360 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1.5000 & 0 & 0 & -1.5000 & 0.0360 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.0360 & 0 & 0.2400 & 0.0360 & 0 & 0.1200 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.0072 & 0 & 0.0360 & 3.0072 & 0 & 0.0360 & -3.000 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1.5000 & 0 & 0 & 1.5576 & -0.1440 & 0 & -0.0576 & 0 & 0 & 0 & 0 \\ -0.0360 & 0.0360 & 0.1200 & 0.0360 & 0.1440 & 0.72 & 0 & -0.1440 & 0.2400 & 0 & 0 & 0 \\ 0 & 0 & 0 & -3.0000 & 0 & 0 & 3.8750 & 0 & 0 & -1.8750 & 0 & 0 \\ 0 & 0 & 0 & 0 & -0.0576 & -0.1440 & 0 & 0.0435 & -0.0707 & 0 & 0.0141 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.2400 & 0 & -0.0877 & 0.7800 & 0 & -0.0563 & 0.1500 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1.8750 & 0 & 0 & 1.8750 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0141 & -0.0563 & 0 & 0.0141 & -0.0563 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.1500 & 0 & -0.0563 & 0.3000 \end{bmatrix} \times \begin{bmatrix} u_1 = 0 \\ \nu_1 = 0 \\ \phi_1 = 0 \\ u_2 \\ \nu_2 \\ \phi_2 \\ u_3 \\ \nu_3 \\ \phi_3 \\ u_4 = 0 \\ \nu_4 = 0 \\ \phi_4 = 0 \end{bmatrix} = \begin{bmatrix} R_{x1} \\ R_{Y1} \\ M_1 \\ R_{x2} = 8000 \\ R_{Y2} = 0 \\ M_2 = 0 \\ R_{x3} = 0 \\ R_{Y3} = 0 \\ M_3 = 50000 \\ R_{x4} \\ R_{Y4} \\ M_4 \end{bmatrix}$$

Desplazamientos y momentos

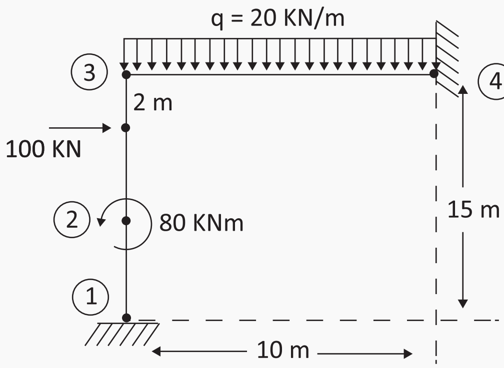
$$u_2 = 0.001\text{ m}$$
$$\nu_2 = 0.001\text{ m}$$
$$\phi_2 = -0.0000004\text{ rad}$$
$$u_3 = 0.001\text{ m}$$
$$\nu_3 = 0.0014\text{ m}$$
$$\phi_3 = 0.008\text{ rad}$$

Reacciones

$$F_{x1} = -82.4\ \text{N}$$
$$F_{Y1} = -7507.1\ \text{N}$$
$$M_1 = 415.08\ \text{Nm}$$
$$F_{x4} = -6966.1\ \text{N}$$
$$F_{Y4} = -6376.5\ \text{N}$$
$$M_4 = 11901.5\ \text{Nm}$$

EJERCICIO 3

Determinar los desplazamientos y las cargas en la estructura mostrada

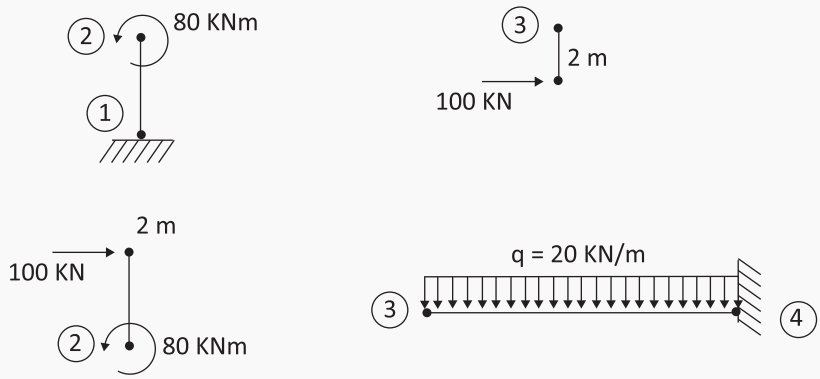


$E = 320\ \text{GPa}$

$I = 5 \times 10^4\ \text{m}^4$

$A = 3 \times 10^{-2}\ \text{m}^2$

A. Resolución



$$K \times T$$

$$K = \frac{E}{L}$$

1-2) $E = 320 \times 10^9$; $I = 5 \times 10^{-4}$; $A = 3 \times 10^{-2}$; $C = 0$; $S = 1$; $L = 3$

$$K(1-2) = 10^9 \times \begin{vmatrix} 0.0711 & 0 & -0.1067 & -0.0711 & 0 & -0.1067 \\ 0 & 3.2000 & 0 & 0 & -32000 & 0.1067 \\ -0.1067 & 0 & 0.2133 & 0.1067 & 0 & 0.1067 \\ -0.0711 & 0 & 0.1067 & 0.0711 & 0 & 0.1067 \\ 0 & -32000 & 0 & 0 & 3.2000 & 0 \\ -0.1067 & 0.1067 & 0.1067 & 0.1067 & 0 & 0.2133 \end{vmatrix}$$

2-3) $E = 320 \times 10^9$; $I = 5 \times 10^{-4}$; $A = 3 \times 10^{-2}$; $C = 0$; $S = 1$; $L = 10$

$$K(2-3) = 10^9 \times \begin{vmatrix} 0.00192 & 0 & -0.0096 & -0.00192 & 0 & -0.0096 \\ 0 & 0.960 & 0 & 0 & -0.96 & 0.0096 \\ -0.0096 & 0 & 0.0064 & 0.0096 & 0 & 0.032 \\ -0.00192 & 0 & 0.0096 & 0.00192 & 0 & 0.0096 \\ 0 & -0.96 & 0 & 0 & 0.96 & 0 \\ -0.0096 & 0.0096 & 0.032 & 0.0096 & 0 & 0.064 \end{vmatrix}$$

3-4) $E = 320 \times 10^9$; $I = 5 \times 10^{-4}$; $A = 3 \times 10^{-2}$; $C = 0$; $S = 1$; $L = 2$

$$K(3-4) = 10^9 \times \begin{vmatrix} 0.2400 & 0 & -0.2400 & -0.2400 & 0 & -0.2400 \\ 0 & 4.8000 & 0 & 0 & -4.8000 & 0.2400 \\ -0.2400 & 0 & 0.3200 & 0.2400 & 0 & 0.1600 \\ -0.2400 & 0 & 0.2400 & 0.2400 & 0 & 0.2400 \\ 0 & -4.8000 & 0 & 0 & 4.8000 & 0 \\ -0.2400 & 0.2400 & 0.1600 & 0.2400 & 0 & 0.3200 \end{vmatrix}$$

4-5) $E = 320 \times 10^9$; $I = 5 \times 10^{-4}$; $A = 3 \times 10^{-2}$; $C = 1$; $S = 0$; $L = 10$

$$K(4-5) = 10^9 \times \begin{vmatrix} 0.96 & 0 & 0 & -0.96 & 0 & 0 \\ 0 & 0.00192 & -0.0096 & 0 & -0.00192 & 0 \\ 0 & 0.0096 & 0.064 & 0 & -0.0096 & 0.032 \\ -0.96 & 0 & 0 & 0.96 & 0 & 0 \\ 0 & -0.00192 & -0.0096 & 0 & 0.00192 & -0.0096 \\ 0 & 0 & 0.032 & 0 & -0.0096 & 0.064 \end{vmatrix}$$

Matriz ensamblada

$10^9 \times M$

$$M = \begin{bmatrix} 0.0711 & 0 & -0.1067 & -0.0711 & 0 & -0.1067 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 3.2 & 0 & 0 & -3.2 & 0.1067 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.1067 & 0 & 0.2133 & 0.1067 & 0 & 0.1067 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.0711 & 0 & 0.1067 & 0.0732 & 0 & 0.0971 & -0.00192 & 0 & -0.0096 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -3.2 & 0 & 0 & 4.16 & 0 & 0 & -0.96 & 0.0096 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.1067 & 0.1067 & 0.1067 & 0.0971 & 0 & 0.2773 & 0.0096 & 0 & 0.032 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -0.00192 & 0 & 0.0096 & 0.24192 & 0 & -0.2304 & -0.24 & 0 & -0.24 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -0.96 & 0 & 0 & 5.76 & 0 & 0 & -4.8 & 0.24 & 0 & 0 & 0 \\ 0 & 0 & 0 & -0.0096 & 0.0096 & 0.032 & -0.2304 & 0 & 0.384 & 0.24 & 0 & 0.16 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -0.24 & 0 & 0.24 & 1.2 & 0 & 0.24 & -0.96 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -4.8 & 0 & 0 & 4.8192 & -0.0096 & 0 & -0.00192 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -0.24 & 0.24 & 0.16 & 0.24 & 0.0096 & 0.96 & 0 & -0.0096 & 0.032 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.96 & 0 & 0 & 0.96 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.00192 & -0.0096 & 0 & 0.00192 & -0.0096 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.032 & 0 & -0.0096 & 0.064 \end{bmatrix} x \begin{bmatrix} u_1 = 0 \\ \nu_1 = 0 \\ \phi_1 = 0 \\ u_2 \\ \nu_2 \\ \phi_2 \\ u_3 \\ \nu_3 \\ \phi_3 \\ u_4 \\ \nu_4 \\ \phi_4 \\ u_5 = 0 \\ \nu_5 = 0 \\ \phi_5 = 0 \end{bmatrix} = \begin{bmatrix} R_{x1} \\ R_{Y1} \\ M_1 \\ R_{x2} = 0 \\ R_{Y2} = 0 \\ M_2 = 80000 \\ R_{x3} = 100000 \\ R_{Y3} = 0 \\ M_3 = 0 \\ R_{x4} = 0 \\ R_{Y4} = R_{Y4} - qL/2 \\ M_4 = M_4 + qL^2/12 \\ R_{x5} \\ R_{y5} = R_{y5} - qL/2 \\ M_5 = M_5 + qL^2/12 \end{bmatrix}$$

Desplazamientos y momentos

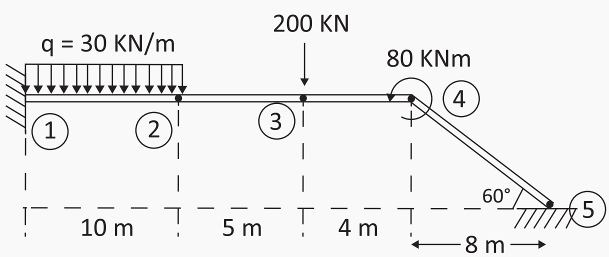
$$u_2 = -0.0001\ \text{m}$$
$$\nu_2 = -0.001\ \text{m}$$
$$\phi_2 = 0.0002\ \text{rad}$$
$$u_3 = 0.0018\ \text{m}$$
$$\nu_3 = -0.0003\ \text{m}$$
$$\phi_3 = 0.0008\ \text{rad}$$
$$u_4 = 0.0001\ \text{m}$$
$$\nu_4 = -0.0001\ \text{m}$$
$$\phi_4 = 0.0005\ \text{rad}$$

Reacciones

$$F_{x1} = -12370.13\ \text{N}$$
$$F_{Y1} = 243681.32\ \text{N}$$
$$M_1 = 9565.13\ \text{Nm}$$
$$F_{x5} = -87629.86\ \text{N}$$
$$F_{Y5} = -4581.64\ \text{N}$$
$$M_5 = 17298.32\ \text{Nm}$$

EJERCICIO 4

Determinar los desplazamientos y las cargas en la estructura mostrada

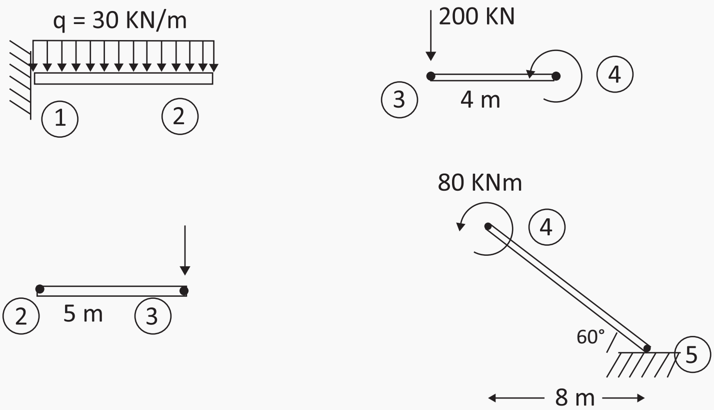


$E = 300\ \text{GPa}$

$I = 8 \times 10^4\ \text{m}^4$

$A = 5 \times 10^{-2}\ \text{m}^2$

A. Resolución



1-2)

$$K(1-2)=\begin{vmatrix} 0.0500 & 0.0000 & 0.0000 & -0.0500 & 0.0000 & 0.0000 \\ 0.0000 & 0.0001 & 0.0005 & 0.0000 & -0.0001 & 0.0005 \\ 0.0000 & 0.0005 & 0.0032 & 0.0000 & -0.0005 & 0.0016 \\ -0.0500 & 0.0000 & 0.0000 & 0.0500 & 0.0000 & 0.0000 \\ 0.0000 & -0.0001 & -0.0005 & 0.0000 & 0.0001 & -0.0005 \\ 0.0000 & 0.0005 & 0.0016 & 0.0000 & -0.0005 & 0.0032 \end{vmatrix}$$

2-3)

$$K(2-3)=\begin{vmatrix} 0.0500 & 0.0000 & 0.0000 & -0.0500 & 0.0000 & 0.0000 \\ 0.0000 & 0.0004 & 0.0010 & 0.0000 & -0.0004 & 0.0010 \\ 0.0000 & 0.0010 & 0.0032 & 0.0000 & -0.0010 & 0.0016 \\ -0.0500 & 0.0000 & 0.0000 & 0.0500 & 0.0000 & 0.0000 \\ 0.0000 & -0.0004 & -0.0010 & 0.0000 & 0.0004 & -0.0010 \\ 0.0000 & 0.0010 & 0.0016 & 0.0000 & -0.0010 & 0.0032 \end{vmatrix}$$

3-4)

$$K(3-4)=\begin{vmatrix} 0.0500 & 0.0000 & 0.0000 & -0.0500 & 0.0000 & 0.0000 \\ 0.0000 & 0.0006 & 0.0012 & 0.0000 & -0.0006 & 0.0012 \\ 0.0000 & 0.0012 & 0.0032 & 0.0000 & -0.0012 & 0.0016 \\ -0.0500 & 0.0000 & 0.0000 & 0.0500 & 0.0000 & 0.0000 \\ 0.0000 & -0.0006 & -0.0012 & 0.0000 & 0.0006 & -0.0012 \\ 0.000 & 0.0012 & 0.0016 & 0.0000 & -0.0012 & 0.0032 \end{vmatrix}$$

4-5)

$$K(4-5)=\begin{vmatrix} 0.0125 & -0.0216 & -0.0003 & -0.0125 & 0.0216 & -0.0003 \\ -0.0216 & 0.0375 & -0.0002 & 0.0216 & -0.0375 & -0.0002 \\ -0.0003 & -0.0002 & 0.0032 & 0.0003 & 0.0002 & 0.0016 \\ -0.0125 & 0.0216 & 0.0003 & 0.0125 & -0.0216 & 0.0003 \\ 0.0216 & -0.0375 & 0.0002 & -0.0216 & 0.0375 & 0.0002 \\ -0.0003 & -0.0002 & 0.0016 & 0.0003 & 0.0002 & 0.0032 \end{vmatrix}$$

Matriz ensamblada

$$M=\begin{bmatrix} 1500 & 0 & 0 & 1500 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 3 & 14 & 0 & -3 & 14 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 14 & 96 & 0 & -14 & 48 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1500 & 0 & 0 & 4500 & 0 & 0 & -3000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -3 & 14 & 0 & 26 & 43 & 0 & -23 & 58 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 14 & 48 & 0 & 43 & 288 & 0 & -58 & 96 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -3000 & 0 & 0 & 6750 & 0 & 0 & -3750 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -23 & -58 & 0 & 68 & 32 & 0 & -45 & 90 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 58 & 96 & 0 & 32 & 432 & 0 & -90 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -3750 & 0 & 0 & 3985 & -406 & -5 & 235 & 406 & -5 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -45 & -90 & -406 & 748 & -93 & 406 & 703 & -3 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 90 & 120 & -5 & -93 & 300 & 5 & 3 & 30 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -235 & 406 & 5 & 235 & -406 & 5 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 406 & -703 & 3 & -406 & 703 & 3 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -5 & -3 & 30 & 5 & 3 & 60 \end{bmatrix} \times \begin{bmatrix} u_1=0 \\ \nu_1=0 \\ \phi_1=0 \\ u_2 \\ \nu_2 \\ \phi_2 \\ u_3 \\ \nu_3 \\ \phi_3 \\ u_4 \\ \nu_4 \\ \phi_4 \\ u_5=0 \\ \nu_5=0 \\ \phi_5=0 \end{bmatrix} = \begin{bmatrix} R_{x1} \\ R_{Y1} \\ M_1 \\ R_{x2}=0 \\ R_{Y2}=0 \\ M_2=80000 \\ R_{x3}=100000 \\ R_{Y3}=0 \\ M_3=0 \\ R_{x4}=0 \\ R_{Y4}=R_{Y4}-qL/2 \\ M_4=M_4+qL^2/12 \\ R_{x5} \\ R_{y5}=R_{y5}-qL/2 \\ M_5=M_5+qL^2/12 \end{bmatrix}$$

Desplazamientos y momentos

U_1 = 0.000000 m

V_1 = 0.000000 m

ϕ_1 = 0.000000 rad

U_2 = –0.000044 m

V_2 = –0.054930 m

ϕ_2 = –0.000983 rad

U_3 = –0.000066 m

V_3 = –0.037099 m

ϕ_3 = 0.008012 rad

U_4 = –0.000084 m

V_4 = –0.000309 m

ϕ_4 = 0.008095 rad

U_5 = 0.000000 m

V_5 = 0.000000 m

ϕ_5 = 0.000000 rad

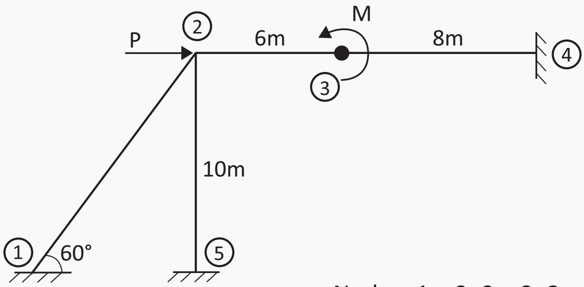
Fuerzas y momentos

$$F_{1X} = 66.15 \text{ KN}$$
$$F_{1Y} = 144.05 \text{ KN}$$
$$M_1 = 743.82 \text{ KNm}$$
$$F_{2X} = 0.00 \text{ KN}$$
$$F_{2Y} = -150.00 \text{ KN}$$
$$M_2 = 250.00 \text{ KNm}$$
$$F_{3X} = 0.00 \text{ KN}$$
$$F_{3Y} = -200.00 \text{ KN}$$
$$M_3 = 0.00 \text{ KNm}$$
$$F_{4X} = 0.00 \text{ KN}$$
$$F_{4Y} = 0.00 \text{ KN}$$
$$M_4 = 80.00 \text{ KNm}$$
$$F_{5X} = -66.15 \text{ KN}$$
$$F_{5Y} = 205.95 \text{ KN}$$
$$M_5 = 244.11 \text{ KNm}$$

7.4. ESTRUCTURAS 2 – D

EJERCICIO 1

En la siguiente estructura, determinar los ángulos girados en los nodos indicados.



$E = 3000GPa$

$I = 8 \times 10^{-6} m^4$

$A = 4 \times 10^{-4} m^2$

$P = 5000N$

$M = 600Nm$

Nodos: 1 – 2; 2 – 3; 3 – 4; 2 – 5

A. Resolución

Elemento	Nodo	θ	C	S	C²	S²	SC
1	1 – 2	60°	0.5	0.866	0.25	0.749956	0.433
2	2 – 3	0°	1	0	1	0	0
3	3 – 4	0°	1	0	1	0	0
4	2 – 5	270°	0	–1	0	1	0

$$K_{1-2} = \frac{(300 \times 10^9)}{11.5470m} \begin{bmatrix} 0.00010054 & 0.000172888 & -3.5999E-06 & -0.00010054 & -0.000172888 & -3.5999E-06 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.000172888 & 0.000300162 & 2.07846E-06 & -0.000172888 & -0.000300162 & 2.07846E-06 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -3.5999E-06 & 2.07846E-06 & 831384.7753 & 3.5999E-06 & -2.07846E-06 & 0.000016 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.00010054 & -0.000172888 & 3.5999E-06 & 0.00010054 & 0.000172888 & 3.5999E-06 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.000172888 & -0.000300162 & -2.07846E-06 & 0.000172888 & 0.000300162 & -2.07846E-06 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -3.5999E-06 & 2.07846E-06 & 0.000016 & 3.5999E-06 & -2.07846E-06 & 0.000032 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{1-2} = \begin{bmatrix} 2612106.231 & 4491770.322 & -93528.08721 & -2612106.231 & -4491770.322 & -93528.08721 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 4491770.322 & 7798451.55 & 54000.05036 & -4491770.322 & -7798451.55 & 54000.05036 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -93528.08721 & 54000.05036 & 831384.7753 & 93528.08721 & -54000.05036 & 415692.3876 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -2612106.231 & -4491770.322 & 93528.08721 & 2612106.231 & 4491770.322 & 93528.08721 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -4491770.322 & -7798451.55 & -54000.05036 & 4491770.322 & 7798451.55 & -54000.05036 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -93528.08721 & 54000.05036 & 415692.3876 & 93528.08721 & -54000.05036 & 831384.7753 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{2-3}=\frac{\left(300\times10^{9}\right)}{6m}\left[\begin{array}{ccccccccccccccc}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0.0004&0&0&-0.0004&0&0&0&0&0&0&0&0\\
0&0&0&0&2.66667E-06&0.000008&0&-2.66667E-06&0.000008&0&0&0&0&0&0\\
0&0&0&0&0.000008&0.000032&0&-0.000008&0.000016&0&0&0&0&0&0\\
0&0&0&-0.0004&0&0&0.0004&0&0&0&0&0&0&0&0\\
0&0&0&0&-2.66667E-06&-0.000008&0&2.66667E-06&-0.000008&0&0&0&0&0&0\\
0&0&0&0&0.000008&0.000016&0&-0.000008&0.000032&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{array}\right]$$

$$K_{2-3}=\left[\begin{array}{ccccccccccccccc}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&20000000&0&0&-20000000&0&0&0&0&0&0&0&0\\
0&0&0&0&133333.3333&400000&0&-133333.3333&400000&0&0&0&0&0&0\\
0&0&0&0&400000&1600000&0&-400000&800000&0&0&0&0&0&0\\
0&0&0&-20000000&0&0&20000000&0&0&0&0&0&0&0&0\\
0&0&0&0&-133333.3333&-400000&0&133333.3333&-400000&0&0&0&0&0&0\\
0&0&0&0&400000&800000&0&-400000&1200000&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{array}\right]$$

$$K_{3-4}=\frac{\left(300\times10^{9}\right)}{8m}\left[\begin{array}{ccccccccccccccc}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0.0004&0&0&-0.0004&0&0&0&0&0\\
0&0&0&0&0&0&0&0.0000015&0.000006&0&-0.0000015&0.000006&0&0&0\\
0&0&0&0&0&0&0&0.000006&0.000032&0&0.000006&0.000016&0&0&0\\
0&0&0&0&0&0&-0.0004&0&0&0.0004&0&0&0&0&0\\
0&0&0&0&0&0&0&-0.0000015&-0.000006&0&0.0000015&-0.000006&0&0&0\\
0&0&0&0&0&0&0&0.000006&0.000016&0&-0.000006&0.000032&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{array}\right]$$

$$K_{3-4}=\left[\begin{array}{ccccccccccccccc}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&15000000&0&0&-15000000&0&0&0&0&0\\
0&0&0&0&0&0&0&56250&225000&0&-56250&225000&0&0&0\\
0&0&0&0&0&0&0&225000&1200000&0&225000&600000&0&0&0\\
0&0&0&0&0&0&-15000000&0&0&15000000&0&0&0&0&0\\
0&0&0&0&0&0&0&-56250&-225000&0&56250&-225000&0&0&0\\
0&0&0&0&0&0&0&225000&600000&0&-225000&1200000&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{array}\right]$$

$$K_{2-5} = \frac{(300 \times 10^9)}{10m} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.00000096 & 0 & 0.0000048 & 0 & 0 & 0 & 0 & 0 & 0 & -0.00000096 & 0 & 0.0000048 \\ 0 & 0 & 0 & 0 & 0.0004 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0004 & 0 \\ 0 & 0 & 0 & 0.0000048 & 0 & 0.000032 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0000048 & 0 & 0.000016 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -0.00000096 & 0 & -0.0000048 & 0 & 0 & 0 & 0 & 0 & 0 & 0.00000096 & 0 & -0.0000048 \\ 0 & 0 & 0 & 0 & -0.0004 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.0000048 & 0 & 0.000016 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0000048 & 0.0004 & 0.000032 \end{bmatrix}$$

$$K_{2-5} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 28800 & 0 & 144000 & 0 & 0 & 0 & 0 & 0 & 0 & -28800 & 0 & 144000 \\ 0 & 0 & 0 & 0 & 12000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -12000000 & 0 \\ 0 & 0 & 0 & 144000 & 0 & 960000 & 0 & 0 & 0 & 0 & 0 & 0 & 144000 & 0 & 480000 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -28800 & 0 & -144000 & 0 & 0 & 0 & 0 & 0 & 0 & 28800 & 0 & -144000 \\ 0 & 0 & 0 & 0 & -12000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 12000000 & 0 \\ 0 & 0 & 0 & 144000 & 0 & 480000 & 0 & 0 & 0 & 0 & 0 & 0 & -144000 & 0 & 960000 \end{bmatrix}$$

Matriz Ensamblada:

$$\sum k = \begin{bmatrix} 2612106.231 & 4491770.3220 & -93528.08721 & -2612106.231 & -4491770.3220 & 93528.08721 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 4491770.3220 & 7798451.55 & 54000.05036 & -4491770.3220 & -7798451.55 & 54000.05036 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -93528.08721 & 54000.05036 & 831384.7753 & 93528.08721 & -54000.05036 & 415692.3876 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -2612106.231 & -4491770.322 & 93528.08721 & 22640906.23 & 4491770.3220 & 237528.0872 & -20000000 & 0 & 0 & 0 & 0 & 0 & -28800 & 0 & 144000 \\ -4491770.3220 & 7798451.55 & -54000.05036 & 4491770.3220 & 19931784.88 & 345999.9496 & 0 & -133333.3333 & 400000 & 0 & 0 & 0 & 0 & -12000000 & 0 \\ -93528.08721 & 54000.05036 & 415692.3876 & 237528.0872 & 345999.9496 & 3391384.775 & 0 & -400000 & 800000 & 0 & 0 & 0 & -144000 & 0 & 480000 \\ 0 & 0 & 0 & -20000000 & 0 & 0 & 35000000 & 0 & 0 & -15000000 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -133333.3333 & -400000 & 0 & 189583.3333 & -175000 & 0 & -56250 & 225000 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 400000 & 800000 & 0 & -175000 & 2800000 & 0 & -225000 & 600000 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -15000000 & 0 & 0 & 15000000 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -56250 & -225000 & 0 & 56250 & -225000 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 225000 & 600000 & 0 & -225000 & 1200000 & 0 & 0 & 0 \\ 0 & 0 & 0 & -28800 & 0 & -144000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -144000 \\ 0 & 0 & 0 & 0 & -12000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -28800 & 12000000 & 0 \\ 0 & 0 & 0 & 144000 & 0 & 480000 & 0 & 0 & 0 & 0 & 0 & 0 & -144000 & 0 & 960000 \end{bmatrix} \begin{bmatrix} u_1 \\ v_1 \\ \theta_1 \\ u_2 \\ v_2 \\ \theta_2 \\ u_3 \\ v_3 \\ \theta_3 \\ u_4 \\ v_4 \\ \theta_4 \\ u_5 \\ v_5 \\ \theta_5 \end{bmatrix} = \begin{bmatrix} F_{iX} \\ F_{1Y} \\ M_1 \\ 5000 \\ 0 \\ 0 \\ 0 \\ 0 \\ 600 \\ F_{4X} \\ F_{4Y} \\ M_4 \\ F_{5X} \\ F_{5Y} \\ M_5 \end{bmatrix}$$

Eliminando Filas y Columnas:

$$KR = \begin{bmatrix} 22640906.23 & 4491770.3220 & 237528.0872 & -20000000 & 0 & 0 \\ 4491770.3220 & 19931784.88 & 345999.9496 & 0 & -133333.3333 & 400000 \\ 237528.0872 & 345999.9496 & 3391384.775 & 0 & -400000 & 800000 \\ -20000000 & 0 & 0 & 35000000 & 0 & 0 \\ 0 & -133333.3333 & -400000 & 0 & 189583.3333 & -175000 \\ 0 & 400000 & 800000 & 0 & -175000 & 2800000 \end{bmatrix} \begin{bmatrix} u_2 \\ v_2 \\ \theta_2 \\ u_3 \\ v_3 \\ \theta_3 \end{bmatrix} = \begin{bmatrix} 5000 \\ 0 \\ 0 \\ 0 \\ 0 \\ 600 \end{bmatrix}$$

B. Resolución con MATLAB

```
>> K1 = [2612106.231 4491770.332 -93528.08721 -2612106.231 -4491770.332 -93528.08721
0 0 0 0 0 0 0 0 0 0; 4491770.322 7798451.55 54000.05036 -4491770.332 -7798451.55
54000.0536 0 0 0 0 0 0 0 0 0 0; -93528.08721 54000.05036 831384.7753 93528.08721
-54000.05036 415692.3876 0 0 0 0 0 0 0 0 0; -2612106.231 -4491770.322 93528.08721
2612106.231 4491770.322 93528.08721 0 0 0 0 0 0 0 0 0; -4491770.322 -779845.55
-54000.05036 4491770.322 779845.155 -54000.05036 0 0 0 0 0 0 0 0 0; -93528.08721
54000.05036 415692.3876 93528.08721 -54000.05036 831384.7753 0 0 0 0 0 0 0 0 0; 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]

K1 =

  1.0e+006 *

  Columns 1 through 8

    2.6121    4.4918   -0.0935   -2.6121   -4.4918   -0.0935         0         0
    4.4918    7.7958    0.0540   -4.4918   -7.7985    0.0540         0         0
   -0.0935    0.0540    0.8314    0.0935   -0.0540    0.4157         0         0
   -2.6121   -4.4918    0.0935    2.6121    4.4918    0.0935         0         0
   -4.4918   -0.7798   -0.0540    4.4918    0.7798   -0.0540         0         0
   -0.0935    0.0540    0.4157    0.0935   -0.0540    0.8314         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0

  Columns 9 through 15

         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0

>> K2 = [ 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0; 0 0 0 20000000 0 0 -20000000 0 0 0 0 0 0 0 0; 0 0 0 0 133333.3333
400000 0 -133333.3333 400000 0 0 0 0 0 0; 0 0 0 0 400000 1600000 0 -400000 800000
0 0 0 0 0 0; 0 0 0 -20000000 0 0 20000000 0 0 0 0 0 0 0 0; 0 0 0 0 -133333.3333
-400000 0 133333.33 -400000 0 0 0 0 0 0; 0 0 0 0 400000 800000 0 -400000 1200000
0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
```

```
K2 =

  1.0e+007 *

  Columns 1 through 8

         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0    2.0000         0         0   -2.0000         0
         0         0         0         0    0.0133    0.0400         0   -0.0133
         0         0         0         0    0.0400    0.1600         0   -0.0400
         0         0         0   -2.0000         0         0    2.0000         0
         0         0         0         0   -0.0133   -0.0400         0    0.0133
         0         0         0         0    0.0400    0.0800         0   -0.0400
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0

   Columns 9 through 15

         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
    0.0400         0         0         0         0         0         0
    0.0800         0         0         0         0         0         0
         0         0         0         0         0         0         0
   -0.0400         0         0         0         0         0         0
    0.1200         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0

>> K3 = [ 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 15000000 0 0 -15000000 0 0 0 0 0; 0 0 0 0 0 0
0 56250 225000 0 -56250 225000 0 0 0; 0 0 0 0 0 0 0 225000 1200000 0 225000 600000
0 0 0; 0 0 0 0 0 0 -15000000 0 0 15000000 0 0 0 0 0; 0 0 0 0 0 0 0 -56250 -225000 0
56250 -225000 0 0 0; 0 0 0 0 0 0 0 225000 600000 0 -225000 1200000 0 0 0; 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]

K3 =

  Columns 1 through 6

           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
```

```
  Columns 7 through 12

           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
    15000000           0           0   -15000000           0           0
           0       56250      225000           0      -56250      225000
           0      225000     1200000           0      225000      600000
   -15000000           0           0    15000000           0           0
           0      -56250     -225000           0       56250     -225000
           0      225000      600000           0     -225000     1200000
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0

  Columns 13 through 15

           0           0           0
           0           0           0
           0           0           0
           0           0           0
           0           0           0
           0           0           0
           0           0           0
           0           0           0
           0           0           0
           0           0           0
           0           0           0
           0           0           0
           0           0           0
           0           0           0
           0           0           0

>> K4 = [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0; 0 0 0 28800 0 144000 0 0 0 0 0 0 -28800 0 144000; 0 0 0 0 12000000
0 0 0 0 0 0 0 0 -12000000 0; 0 0 0 144000 0 960000 0 0 0 0 0 0 144000 0 480000; 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0; 0 0 0 -28800 0 -144000 0 0 0 0 0 0 28000 0 -144000; 0 0 0 0 -12000000
0 0 0 0 0 0 0 0 12000000 0; 0 0 0 14000 0 480000 0 0 0 0 0 0 -144000 0 960000]

K4 =

  Columns 1 through 6

           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0       28800           0      144000
           0           0           0           0    12000000           0
           0           0           0      144000           0      960000
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0      -28000           0     -144000
           0           0           0           0   -12000000           0
           0           0           0       14000           0      480000
```

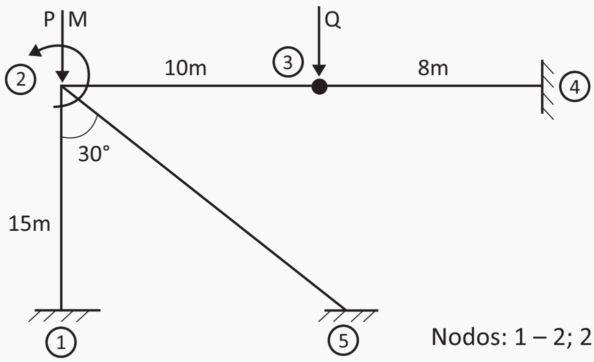
```
  Columns 7 through 12

         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0

  Columns 13 through 15

         0         0         0
         0         0         0
         0         0         0
    -28800         0    144000
         0 -12000000         0
    144000         0    480000
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
     28800         0   -144000
         0  12000000         0
   -144000         0    960000

>> KT = K1 + K2 + K3 + K4

KT =

  1.0e+007 *

  Columns 1 through 8

    0.2612    0.4492   -0.0094   -0.2612   -0.4492   -0.0094         0         0
    0.4492    0.7798    0.0054   -0.4492   -0.7798    0.0054         0         0
   -0.0094    0.0054    0.0831    0.0094   -0.0054    0.0416         0         0
   -0.2612   -0.4492    0.0094    2.2641    0.4492    0.0238   -2.0000         0
   -0.4492   -0.0780   -0.0054    0.4492    1.2913    0.0346         0   -0.0133
   -0.0094    0.0054    0.0416    0.0238    0.0346    0.3391         0   -0.0400
         0         0         0   -2.0000         0         0    3.5000         0
         0         0         0         0   -0.0133   -0.0400         0    0.0190
         0         0         0         0    0.0400    0.0800         0   -0.0175
         0         0         0         0         0         0   -1.5000         0
         0         0         0         0         0         0         0   -0.0056
         0         0         0         0         0         0         0    0.0225
         0         0         0   -0.0029         0   -0.0144         0         0
         0         0         0         0   -1.2000         0         0         0
         0         0         0    0.0014         0    0.0480         0         0
```

```
  Columns 9 through 15

         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0   -0.0029         0    0.0144
    0.0400         0         0         0         0   -1.2000         0
    0.0800         0         0         0    0.0144         0    0.0480
         0   -1.5000         0         0         0         0         0
   -0.0175         0   -0.0056    0.0225         0         0         0
    0.2400         0    0.0225    0.0600         0         0         0
         0    1.5000         0         0         0         0         0
   -0.0225         0    0.0056   -0.0225         0         0         0
    0.0600         0   -0.0225    0.1200         0         0         0
         0         0         0         0    0.0029         0   -0.0144
         0         0         0         0         0    1.2000         0
         0         0         0         0   -0.0144         0    0.0960

>>  KR  =  [  22640906.23  4491770.3220  237528.0872  -20000000  0  0;  4491770.3220
19931784.88 345999.9496 0 -133333.3333 400000; 237528.0872 345999.9496 3391384.775
0 -400000 800000; -20000000 0 0 35000000 0 0; 0 -133333.3333 -400000 0 189583.3333
-175000; 0 400000 800000 0 -175000 2800000]

KR =

  1.0e+007 *

    2.2641    0.4492    0.0238   -2.0000         0         0
    0.4492    1.9932    0.0346         0   -0.0133    0.0400
    0.0238    0.0346    0.3391         0   -0.0400    0.0800
   -2.0000         0         0    3.5000         0         0
         0   -0.0133   -0.0400         0    0.0190   -0.0175
         0    0.0400    0.0800         0   -0.0175    0.2800

>> f = [5000; 0; 0; 0; 0; 600]

f =

        5000
           0
           0
           0
           0
         600

>> u = inv(KR)*f

u =

  1.0e-003 *

    0.4939
   -0.1151
   -0.0860
    0.2822
   -0.0284
    0.2535
```

```
U =

   1.0e-003 *

          0
          0
          0
     0.4939
    -0.1151
    -0.0860
     0.2822
    -0.0284
     0.2535
          0
          0
          0
          0
          0
          0

>> F = KT * U

F =

   1.0e+003 *

    -0.7650
    -1.3257
     0.0169
     5.0009
     0.8077
     0.0003
    -0.0010
    -0.0001
     0.4985
    -4.2330
    -0.0554
     0.1457
    -0.0019
     1.3812
    -0.0344
```

EJERCICIO 2

Hallar los Desplazamientos Nodales y las Cargas generadas en la estructura mostrada.



$E = 220GPa$

$I = 5 \times 10^{-6} m^4$

$A = 2 \times 10^{-4} m^2$

$P = 8000N$

$Q = 12000N$

$M = 800Nm$

Nodos: 1 – 2; 2 – 3; 3 – 4; 2 – 5

A. Resolución

Elemento	Nodo	θ	C	S	C²	S²	SC
1	1 – 2	90°	0	1	0	1	0
2	2 – 3	0°	1	0	1	0	0
3	3 – 4	0°	1	0	1	0	0
4	2 – 5	300°	0.5	–0.866	0.25	0.749956	–0.433

$$K_{1-2} = \frac{(220 \times 10^9)}{15m} \begin{bmatrix} 2.66667E-07 & 0 & 0.000002 & -2.66667E-07 & 0 & -0.000002 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.0002 & 0 & 0 & -0.0002 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.000002 & 2.07846E-06 & 0.00002 & 0.000002 & 0 & 0.00001 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -2.66667E-07 & -0.000172888 & -0.000002 & 2.66667E-07 & 0 & 0.000002 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -0.0002 & 0 & 0 & 0.0002 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.000002 & 2.07846E-06 & 0.00001 & 0.000002 & 0 & 0.000002 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{1-2} = \begin{bmatrix} 3911.111111 & 0 & -29333.33333 & -3911.111111 & 0 & -29333.33333 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 29333.33333 & 0 & 0 & -29333.33333 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -29333.33333 & 0 & 29333.33333 & 29333.33333 & 0 & 146666.6667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -3911.111111 & 0 & 29333.33333 & 3911.111111 & 0 & 29333.33333 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -29333.33333 & 0 & 0 & 29333.33333 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -29333.33333 & 0 & 146666.6667 & 29333.33333 & 0 & 29333.33333 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{2-3}=\frac{\left(220\times10^{9}\right)}{10\mathrm{m}}\begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0.0002&0&0&-0.0002&0&0&0&0&0&0&0&0\\
0&0&0&0&0.0000006&0.000003&0&-0.0000006&0.000003&0&0&0&0&0&0\\
0&0&0&0&0.000003&0.00002&0&-0.000003&0.00001&0&0&0&0&0&0\\
0&0&0&-0.0002&0&0&0.0002&0&0&0&0&0&0&0&0\\
0&0&0&0&-0.0000006&-0.000003&0&0.0000006&-0.000003&0&0&0&0&0&0\\
0&0&0&0&0.000003&0.00001&0&-0.000003&0.00002&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{bmatrix}$$

$$K_{2-3}=\begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&4400000&0&0&-4400000&0&0&0&0&0&0&0&0\\
0&0&0&0&13200&66000&0&-13200&66000&0&0&0&0&0&0\\
0&0&0&0&66000&4400000&0&-66000&220000&0&0&0&0&0&0\\
0&0&0&-4400000&0&0&4400000&0&0&0&0&0&0&0&0\\
0&0&0&0&-13200&-66000&0&-13200&-66000&0&0&0&0&0&0\\
0&0&0&0&66000&220000&0&-66000&4400000&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{bmatrix}$$

$$K_{3-4}=\frac{\left(220\times10^{9}\right)}{8\mathrm{m}}\begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0.0002&0&0&-0.0002&0&0&0&0&0\\
0&0&0&0&0&0&0&9.375E-07&0.00000375&0&-9.375E-07&0.00000375&0&0&0\\
0&0&0&0&0&0&0&0.00000375&0.00002&0&-0.00000375&0.00001&0&0&0\\
0&0&0&0&0&0&-0.0002&0&0&0.0002&0&0&0&0&0\\
0&0&0&0&0&0&0&-9.375E-07&-0.00000375&0&9.375E-07&-0.00000375&0&0&0\\
0&0&0&0&0&0&0&0.00000375&0.00001&0&-0.00000375&0.0002&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{bmatrix}$$

$$K_{3-4}=\begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&5500000&0&0&-5500000&0&0&0&0&0\\
0&0&0&0&0&0&0&25781.25&103125&0&-25781.25&1031250&0&0&0\\
0&0&0&0&0&0&0&103125&550000&0&-103125&275000&0&0&0\\
0&0&0&0&0&0&-5500000&0&0&5500000&0&0&0&0&0\\
0&0&0&0&0&0&0&-25781.25&-103125&0&25781.25&-103125&0&0&0\\
0&0&0&0&0&0&0&103125&275000&0&-103125&550000&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{bmatrix}$$

$$K_{2-5}=\frac{\left(220\times10^{9}\right)}{17.32m}\begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0.00005015&-8.65134E-05&0.0000015&0&0&0&0&0&0&-0.00005015&8.65134E-05&0.0000015\\
0&0&0&-8.65134E-05&0.0000015&8.66051E-07&0&0&0&0&0&0&8.65134E-05&-0.0000015&8.66051E-07\\
0&0&0&0.0000015&8.65134E-05&0.00002&0&0&0&0&0&0&-0.0000015&-8.66051E-07&0.00001\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&-0.00005015&8.656134E-05&-0.0000015&0&0&0&0&0&0&0.00005015&-8.65134E-05&-0.0000015\\
0&0&0&8.65134E-05&-0.0000015&-8.66051E-07&0&0&0&0&0&0&8.65134E-05&0.0000015&-8.66051E-07\\
0&0&0&0.0000015&8.66051E-07&127020.7852&0&0&0&0&0&0&-0.0000015&-8.65134E-05&0.00002
\end{bmatrix}$$

$$K_{2-5}=\begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&637009.2379&-1098899.935&19053.11778&0&0&0&0&0&0&-637009.2379&1098899.935&19053.11778\\
0&0&0&-1098899.935&19053.11778&11000.64537&0&0&0&0&0&0&1098899.935&-19053.11778&11000.64537\\
0&0&0&19053.11778&11000.64537&254041.5704&0&0&0&0&0&0&-19053.11778&-11000.64537&127020.7852\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&-637009.2379&1098899.935&-19053.11778&0&0&0&0&0&0&637009.2379&-1098899.935&-19053.11778\\
0&0&0&1098899.935&-19053.11778&-11000.64537&0&0&0&0&0&0&0&19053.11778&-11000.64537\\
0&0&0&19053.11778&11000.64537&127020.7852&0&0&0&0&0&0&-19053.11778&-11000.64537&254041.5704
\end{bmatrix}$$

Matriz ensamblada:

$$\sum k=\begin{bmatrix}
3911.111111&0&-29333.33333&-3911.111111&0&-2933333.333&0&0&0&0&0&0&0&0&0\\
0&29333.33333&0&0&-2933333.333&0&0&0&0&0&0&0&0&0&0\\
-29333.33333&0&29333.33333&29333.33333&0&146666.6667&0&0&0&0&0&0&0&0&0\\
-2612106.231&0&29333.33333&5040920.349&-1098899.935&48386.45112&-4400000&0&0&0&0&0&-637009.2379&1098899.935&19053.11778\\
-4491770.3220&-29333.33333&0&-1098899.935&4852368.475&77000.64537&0&-13200&66000&0&0&0&1098899.935&-19053.11778&11000.64537\\
-93528.08721&0&146666.6667&48386.45112&77000.64537&987374.9038&0&-66000&220000&0&0&0&-19053.11778&-11000.64537&127020.7852\\
0&0&0&-440000&0&0&9900000&0&0&-5500000&0&0&0&0&0\\
0&0&0&0&-13200&-66000&0&38981.25&37125&0&-25781.25&103125&0&0&0\\
0&0&0&0&66000&220000&0&37125&990000&0&-103125&275000&0&0&0\\
0&0&0&0&0&0&-5500000&0&0&5500000&0&0&0&0&0\\
0&0&0&0&0&0&0&-25781.25&-103125&0&25781.25&-103125&0&0&0\\
0&0&0&0&0&0&0&103125&275000&0&-103125&550000&0&0&0\\
0&0&0&-637009.2379&1098899.935&-19053.11778&0&0&0&0&0&0&637009.2379&-1098899.935&-19053.11778\\
0&0&0&1098899.935&-1905835.141&11000.64537&0&0&0&0&0&0&-1098899.935&19053.11778&-11000.64537\\
0&0&0&19053.11778&11000.64537&127020.7852&0&0&0&0&0&0&19053.11778&-11000.64537&254041.5704
\end{bmatrix}\begin{bmatrix}u_1\\v_1\\\theta_1\\u_2\\v_2\\\theta_2\\u_3\\v_3\\\theta_3\\u_4\\v_4\\\theta_4\\u_5\\v_5\\\theta_5\end{bmatrix}=\begin{bmatrix}F_{iX}\\F_{1Y}\\M_1\\0\\-8000\\800\\-1200\\0\\0\\F_{4X}\\F_{4Y}\\M_4\\F_{5X}\\F_{5Y}\\M_5\end{bmatrix}$$

Eliminando filas y columnas:

$$k=\begin{bmatrix}
5040920.349&-1098899.935&48386.45112&-4400000&0&0\\
-1098899.935&4852368.475&77000.64537&0&-13200&66000\\
48386.45112&77000.64537&987374.9038&0&-66000&220000\\
-4400000&0&0&9900000&0&0\\
0&-13200&-66000&0&38981.25&37125\\
0&66000&220000&0&37125&990000
\end{bmatrix}\begin{bmatrix}u_2\\v_2\\\theta_2\\u_3\\v_3\\\theta_3\end{bmatrix}=\begin{bmatrix}0\\-8000\\800\\-12000\\0\\0\end{bmatrix}$$

B. Resolución con MATLAB

```
>> K1 = [ 3911.111111 0 -29333.33333 -3911.111111 0 -29333.33333 0 0 0 0 0 0 0 0
0; 0 29333.33333 0 0 -29333.33333 0 0 0 0 0 0 0 0 0 0; -29333.33333 0 29333.33333
29333.33333 0 146666.6667 0 0 0 0 0 0 0 0 0; -3911.111111 0 29333.33333 3911.111111
0 29333.33333 0 0 0 0 0 0 0 0 0; 0 -29333.33333 0 0 29333.33333 0 0 0 0 0 0 0 0 0
0; -29333.33333 0 146666.6667 29333.33333 0 29333.33333 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0]

K1 =

  1.0e+005 *

  Columns 1 through 8

    0.0391         0   -0.2933   -0.0391         0   -0.2933         0         0
         0    0.2933         0         0   -0.2933         0         0         0
   -0.2933         0    0.2933    0.2933         0    1.4667         0         0
   -0.0391         0    0.2933    0.0391         0    0.2933         0         0
         0   -0.2933         0         0    0.2933         0         0         0
   -0.2933         0    1.4667    0.2933         0    0.2933         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0

  Columns 9 through 15

         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0

>> K2 = [ 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0; 0 0 0 4400000 0 0 -4400000 0 0 0 0 0 0 0 0; 0 0 0 0 13200 66000
0 -13200 66000 0 0 0 0 0 0; 0 0 0 0 66000 4400000 0 -66000 220000 0 0 0 0 0 0; 0 0
0 -400000 0 0 4400000 0 0 0 0 0 0 0 0; 0 0 0 0 -13200 -66000 0 -13200 -66000 0 0 0
0 0 0; 0 0 0 0 66000 220000 0 -66000 4400000 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
```

```
K2 =

  Columns 1 through 6

         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0   4400000         0         0
         0         0         0         0     13200     66600
         0         0         0         0     66000   4400000
         0         0         0   -400000         0         0
         0         0         0         0    -13200    -66000
         0         0         0         0     66000    220000
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0

  Columns 7 through 12

         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
  -4400000         0         0         0         0         0
         0    -13200     66000         0         0         0
         0    -66000    220000         0         0         0
   4400000         0         0         0         0         0
         0    -13200    -66000         0         0         0
         0    -66000   4400000         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0

  Columns 13 through 15

         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
```

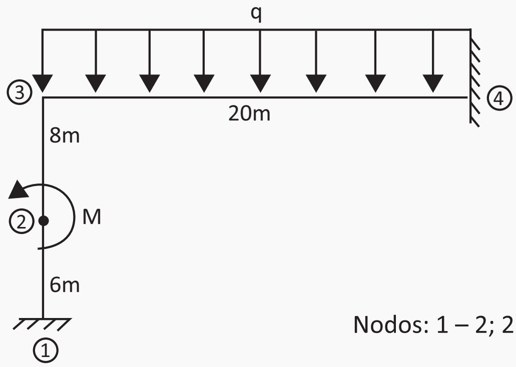
```
>> K3 = [ 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 5500000 0 0 -5500000 0 0 0 0 0; 0 0
0 0 0 0 25781.25 103125 0 -25781.25 103125 0 0 0; 0 0 0 0 0 0 0 103125 550000 0
-103125 275000 0 0 0; 0 0 0 0 0 0 -5500000 0 0 5500000 0 0 0 0 0; 0 0 0 0 0 0 0
-25781.25 -103125 0 25781.25 -103125 0 0 0; 0 0 0 0 0 0 0 103125 275000 0 -103125
550000 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0]

K3 =

  1.0e+006 *

  Columns 1 through 8

         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0    5.5000         0
         0         0         0         0         0         0         0    0.0258
         0         0         0         0         0         0         0    0.1031
         0         0         0         0         0         0   -5.5000         0
         0         0         0         0         0         0         0   -0.0258
         0         0         0         0         0         0         0    0.1031
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0

  Columns 9 through 15

         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0   -5.5000         0         0         0         0         0
    0.1031         0   -0.0258    0.1031         0         0         0
    0.5500         0   -0.1031    0.2750         0         0         0
         0    5.5000         0         0         0         0         0
   -0.1031         0    0.0258   -0.1031         0         0         0
    0.2750         0   -0.1031    0.5500         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0

>> K4 = [ 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0; 0 0 0 637009.2379 -1098899.935 19053.11778 0 0 0 0 0 0
-637009.2379 1098899.935 19053.1178; 0 0 0 -1098899.935 19053.11778 11000.64537
0 0 0 0 0 0 1098899.935 -19053.11778 11000.64537; 0 0 0 19053.11778 11000.64537
254041.5704 0 0 0 0 0 0 -19053.11778 -11000.64537 127020.7852; 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 -637009.2379 1098899.935 -19053.11778 0 0 0 0 0 0 637009.2379 -1098899.935
-19053.1178; 0 0 0 1098899.935 -19053.11778 -11000.64537 0 0 0 0 0 0 19053.11778
-11000.64537; 0 0 0 19053.11778 11000.64537 127020.7852 0 0 0 0 0 0 -19053.11778
-11000.64537 254041.5704]
```

```
K4 =

  1.0e+006 *

     0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
     0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
     0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
     0       0       0  0.6370 -1.0989  0.0191       0       0       0       0       0       0 -0.6370  1.0989  0.0191
     0       0       0 -1.0989  0.0191  0.0110       0       0       0       0       0       0  1.0989 -0.0191  0.0110
     0       0       0  0.0191  0.0110  0.2540       0       0       0       0       0       0 -0.0191 -0.0110  0.1270
     0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
     0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
     0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
     0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
     0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
     0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
     0       0       0 -0.6370  1.0989 -0.0191       0       0       0       0       0       0  0.6370 -1.0989 -0.0191
     0       0       0  1.0989 -0.0191 -0.0110       0       0       0       0       0       0       0  0.0191 -0.0110
     0       0       0  0.0191  0.0110  0.1270       0       0       0       0       0       0 -0.0191 -0.0110  0.2540

>> KT = K1 + K2 + K3 + K4

KT =

  1.0e+006 *

  0.0039       0 -0.0293 -0.0039       0 -0.0293       0       0       0       0       0       0       0       0       0
       0  0.0293       0       0 -0.0293       0       0       0       0       0       0       0       0       0       0
 -0.0293       0  0.0293  0.0293       0  0.1467       0       0       0       0       0       0       0       0       0
 -0.0039       0  0.0293  5.0409 -1.0989  0.0484 -4.4000       0       0       0       0       0 -0.6370  1.0989  0.0191
       0 -0.0293       0 -1.0989  0.0616  0.0770       0 -0.0132  0.0660       0       0       0  1.0989 -0.0191  0.0110
 -0.0293       0  0.1467  0.0484  0.0770  4.6834       0 -0.0660  0.2200       0       0       0 -0.0191 -0.0110  0.1270
       0       0       0 -0.4000       0       0  9.9000       0       0 -5.5000       0       0       0       0       0
       0       0       0       0 -0.0132 -0.0660       0  0.0126  0.0371       0 -0.0258  0.1031       0       0       0
       0       0       0       0  0.0660  0.2200       0  0.0371  4.9500       0 -0.1031  0.2750       0       0       0
       0       0       0       0       0       0 -5.5000       0       0  5.5000       0       0       0       0       0
       0       0       0       0       0       0       0 -0.0258 -0.1031       0  0.0258 -0.1031       0       0       0
       0       0       0       0       0       0       0  0.1031  0.2750       0 -0.1031  0.5500       0       0       0
       0       0       0 -0.6370  1.0989 -0.0191       0       0       0       0       0       0  0.6370 -1.0989 -0.0191
       0       0       0  1.0989 -0.0191 -0.0110       0       0       0       0       0       0       0  0.0191 -0.0110
       0       0       0  0.0191  0.0110  0.1270       0       0       0       0       0       0 -0.0191 -0.0110  0.2540

>> KR = [ 5040920.349 -1098899.935 48386.45112 -4400000 0 0; -1098899.935 4852368.475 77000.64537 0 -13200 66000; 48386.45112 77000.64537 987374.9038 0 -66000 2520000; -4400000 0 0 9900000 0 0; 0 -13200 -66000 0 38981.25 37125; 0 66000 220000 0 37125 990000]

KR =

  1.0e+006 *

    5.0409   -1.0989    0.0484   -4.4000         0         0
   -1.0989    4.8524    0.0770         0   -0.0132    0.0660
    0.0484    0.0770    0.9874         0   -0.0660    2.5200
   -4.4000         0         0    9.9000         0         0
         0   -0.0132   -0.0660         0    0.0390    0.0371
         0    0.0660    0.2200         0    0.0371    0.9900
```

```
>> f = [ 0; -8000; 800; -12000; 0; 0]

f =
           0
       -8000
         800
      -12000
           0
           0

>> u = inv(KR)*f

u =

   -0.0026
   -0.0023
    0.0051
   -0.0024
    0.0092
   -0.0013

>> U = [ 0; 0; 0; -0.0026; -0.0023; 0.0051; -0.0024; 0.0092; -0.0013; 0; 0; 0; 0; 0; 0]

U =
         0
         0
         0
   -0.0026
   -0.0023
    0.0051
   -0.0024
    0.0092
   -0.0013
         0
         0
         0
         0
         0
         0

>> F = KT * U

F =

  1.0e+004 *

   -0.0139
    0.0067
    0.0672
    0.0228
    0.2901
    2.2689
   -2.2720
   -0.0239
   -0.5123
    1.3200
   -0.0103
    0.0591
   -0.0968
   -0.2869
    0.0573
```

Ejercicio 3

Hallar los Desplazamientos Nodales y las Cargas generadas en la estructura mostrada.



$E = 280GPa$

$I = 8 \times 10^{-6} m^4$

$A = 6 \times 10^{-4} m^2$

$q = 150N/m$

$M = 700Nm$

Nodos: 1 – 2; 2 – 3; 3 – 4

A. Resolución

Elemento	Nodo	θ	C	S	C²	S²	SC
1	1 – 2	90°	0	1	0	1	0
2	2 – 3	90°	0	1	0	1	0
3	3 – 4	0°	1	0	1	0	0

$$k_{1-2} = \frac{280 \times 10^{9} Pa}{6m} \begin{bmatrix} 266667E-06 & 0 & -0.000008 & -2.66667E-06 & 0 & -0.000008 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.0006 & 0 & 0 & -0.0006 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.000008 & 0 & 0.000032 & 0.000008 & 0 & 0.000016 & 0 & 0 & 0 & 0 & 0 & 0 \\ -2.66667E-06 & 0 & 0.000008 & 2.66667E-06 & 0 & 0.000008 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.0006 & 0 & 0 & 0.0006 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.000008 & 0 & 0.000016 & 0.000008 & 0 & 0.000032 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_{1-2} = \begin{bmatrix} 124444.4444 & 0 & -373333.3333 & -124444.4444 & 0 & -373333.3333 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.0006 & 0 & 0 & -28000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -373333.3333 & 0 & 1493333.333 & 373333.3333 & 0 & 746666.6667 & 0 & 0 & 0 & 0 & 0 & 0 \\ -124444.4444 & 0 & 373333.3333 & 124444.4444 & 0 & 373333.3333 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.0006 & 0 & 0 & -28000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -373333.3333 & 0 & 746666.6667 & 373333.3333 & 0 & 1493333.333 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$k_{2-3}=\frac{280\times10^{9}\,\text{Pa}}{8\text{m}}\begin{bmatrix}0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0.0000015&0&-0.000006&-0.0000015&0&-0.000006&0&0&0\\0&0&0&0&0.0006&0&0&-0.000006&0&0&0&0\\0&0&0&-0.000006&0&0.000032&0.000006&0&-0.000016&0&0&0\\0&0&0&-0.0000015&0&0.000006&0.0000015&0&0.000006&0&0&0\\0&0&0&0&-0.0006&0&0&0.000006&0&0&0&0\\0&0&0&-0.000006&0&0.000016&0.000006&0&-0.000032&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\end{bmatrix}$$

$$k_{2-3}=\begin{bmatrix}0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&52500&0&-210000&-52500&0&-210000&0&0&0\\0&0&0&0&210000&0&0&-210000&0&0&0&0\\0&0&0&-210000&0&1120000&210000&0&560000&0&0&0\\0&0&0&-52500&0&210000&52500&0&210000&0&0&0\\0&0&0&0&-210000&0&0&210000&0&0&0&0\\0&0&0&-210000&0&560000&210000&0&-1120000&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\end{bmatrix}$$

$$k_{3-4}=\frac{280\times10^{9}\,\text{Pa}}{20\text{m}}\begin{bmatrix}0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0.0006&0&0&-0.0006&0&0\\0&0&0&0&0&0&0&0.00000024&0.00000024&0&-0.00000024&0.00000024\\0&0&0&0&0&0&0&0.0000024&0.000032&0&-0.0000024&0.000016\\0&0&0&0&0&0&-0.0006&0&0&0.0006&0&0\\0&0&0&0&0&0&0&-0.00000024&-0.00000024&0&0.00000024&-0.00000024\\0&0&0&0&0&0&0&0.0000024&0.000016&0&-0.0000024&0.000032\end{bmatrix}$$

$$k_{3-4}=\begin{bmatrix}0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&8400000&0&0&-8400000&0&0\\0&0&0&0&0&0&0&3360&33600&0&-3360&3360\\0&0&0&0&0&0&0&33600&448000&0&-33600&224000\\0&0&0&0&0&0&-8400000&0&0&8400000&0&0\\0&0&0&0&0&0&0&-3360&-3360&0&3360&-3360\\0&0&0&0&0&0&0&224000&33600&0&-33600&448000\end{bmatrix}$$

Matriz ensamblada:

$$\sum k=\begin{bmatrix}124444.4444 & 0 & -373333.3333 & -124444.4444 & 0 & -373333.3333 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 28000000 & 0 & 0 & -28000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\ -373333.3333 & 0 & 1493333.333 & 373333.3333 & 0 & 746666.6667 & 0 & 0 & 0 & 0 & 0 & 0\\ 124444.4444 & 0 & 373333.3333 & 176944.4444 & 0 & 163333.3333 & -52500 & 0 & -210000 & 0 & 0 & 0\\ 0 & -28000000 & 746666.6667 & 0 & 49000000 & 0 & 0 & -21000000 & 0 & 0 & 0 & 0\\ -373333.3333 & 0 & 0 & 163333.3333 & 0 & 2613333.333 & 210000 & 0 & 560000 & 0 & 0 & 0\\ 0 & 0 & 0 & -52500 & 0 & 210000 & 8452500 & 0 & 210000 & -8400000 & 0 & 0\\ 0 & 0 & 0 & 0 & -21000000 & 0 & 0 & 21003360 & 33600 & 0 & 3360 & 33600\\ 0 & 0 & 0 & -210000 & 0 & 560000 & 210000 & 33600 & 1568000 & 0 & -33600 & 224000\\ 0 & 0 & 0 & 0 & 0 & 0 & -8400000 & 0 & 0 & 8400000 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3360 & -33600 & 0 & 3360 & -33600\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 33600 & 224000 & 0 & -33600 & 448000\end{bmatrix}\begin{bmatrix}0\\0\\u_{2x}\\v_{2y}\\u_{3x}\\v_{3y}\\0\\0\\u_{5x}\\v_{5y}\\u_{6x}\\v_{6y}\end{bmatrix}=\begin{bmatrix}F_{1x}\\F_{1y}\\M_1\\0\\0\\700\\F_{3x}\\F_{3y}\\M_3\\F_{4x}\\F_{4y}-1500\\M_4-5000\end{bmatrix}$$

Eliminando filas y columnas:

$$k=\begin{bmatrix}176944.4444 & 0 & 163333.3333 & -52500 & 0 & -210000\\ 0 & 49000000 & 0 & 0 & -21000000 & 0\\ 163333.3333 & 0 & 2613333.333 & 210000 & 0 & 560000\\ -52500 & 0 & 210000 & 8452500 & 0 & 210000\\ 0 & -21000000 & 0 & 0 & 21003360 & 33600\\ -210000 & 0 & 560000 & 210000 & 33600 & 1568000\end{bmatrix}\begin{bmatrix}u_{2x}\\v_{2y}\\\theta_2\\u_{3x}\\v_{3y}\\\theta_3\end{bmatrix}=\begin{bmatrix}0\\0\\700\\0\\-1500\\-5000\end{bmatrix}$$

B. Resolución con MATLAB

```
>> K1 = [ 124444.4444 0 -373333.3333 -124444.4444 0 -373333.3333 0 0 0 0 0 0;
0 0.0006 0 0 -28000000 0 0 0 0 0 0 0; -373333.3333 0 1493333.333 373333.3333 0
746666.6667 0 0 0 0 0 0; -124444.4444 0 373333.3333 124444.4444 0 373333.3333
0 0 0 0 0 0; 0 0.0006 0 0 -28000000 0 0 0 0 0 0 0; -373333.3333 0 746666.6667
373333.3333 0 1493333.333 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0
0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0]

K1 =

  1.0e+007 *

  Columns 1 through 8

    0.0124         0   -0.0373   -0.0124         0   -0.0373         0         0
         0    0.0000         0         0   -2.8000         0         0         0
   -0.0372         0    0.1493    0.0373         0    0.0747         0         0
   -0.0124         0    0.0372    0.0124         0    0.0373         0         0
         0    0.0000         0         0   -2.8000         0         0         0
   -0.0373         0    0.0747    0.0373         0    0.1493         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
```

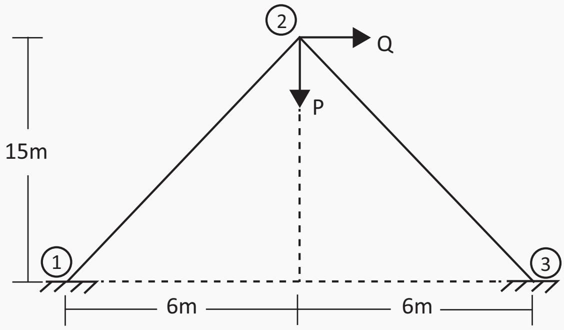
```
  Columns 9 through 12

         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0

>> K2 = [ 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 52500 0 -210000 -52500 0 -210000 0 0 0; 0 0 0 0 210000 0 0 -210000 0 0 0 0; 0 0 0 -210000 0 1120000 210000 0 560000 0 0 0; 0 0 0 -52500 0 210000 52500 0 210000 0 0 0; 0 0 0 0 -210000 0 0 210000 0 0 0 0; 0 0 0 -210000 0 560000 210000 0 -1120000 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0]

K2 =

  Columns 1 through 6

           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0       52500           0     -210000
           0           0           0           0      210000           0
           0           0           0     -210000           0     1120000
           0           0           0      -52500           0      210000
           0           0           0           0     -210000           0
           0           0           0     -210000           0      560000
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0

  Columns 7 through 12

           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
      -52500           0     -210000           0           0           0
           0     -210000           0           0           0           0
      210000           0      560000           0           0           0
       52500           0      210000           0           0           0
           0      210000           0           0           0           0
      210000           0    -1120000           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0

>> K3 = [ 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 8400000 0 0 -8400000 0 0; 0 0 0 0 0 0 0 3360 33600 0 -3360 3360; 0 0 0 0 0 0 0 33600 448000 0 -33600 224000; 0 0 0 0 0 0 -8400000 0 0 8400000 0 0; 0 0 0 0 0 0 0 -3360 -3360 0 3360 -3360; 0 0 0 0 0 0 0 224000 33600 0 -33600 448000]
```

```
K3 =

  Columns 1 through 6

         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0

  Columns 7 through 12

         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
         0         0         0         0         0         0
   8400000         0         0  -8400000         0         0
         0      3360     33600         0     -3360      3360
         0     33600    448000         0    -33600    224000
  -8400000         0         0   8400000         0         0
         0     -3360     -3360         0      3360     -3360
         0    224000     33600         0    -33600    448000

>> KT = K1 + K2 + K3

KT =

  1.0e+007 *

  Columns 1 through 8

    0.0124         0   -0.0373   -0.0124         0   -0.0373         0         0
         0    0.0000         0         0   -2.8000         0         0         0
   -0.0373         0    0.1493    0.0373         0    0.0747         0         0
   -0.0124         0    0.0373    0.0177         0    0.0163   -0.0053         0
         0    0.0000         0         0   -2.7790         0         0   -0.0210
   -0.0373         0    0.0747    0.0163         0    0.2613    0.0210         0
         0         0         0   -0.0053         0    0.0210    0.8452         0
         0         0         0         0   -0.0210         0         0    0.0213
         0         0         0   -0.0210         0    0.0560    0.0210    0.0034
         0         0         0         0         0         0   -0.8400         0
         0         0         0         0         0         0         0   -0.0003
         0         0         0         0         0         0         0    0.0224

  Columns 9 through 12

         0         0         0         0
         0         0         0         0
         0         0         0         0
   -0.0210         0         0         0
         0         0         0         0
    0.0560         0         0         0
    0.0210   -0.8400         0         0
    0.0034         0   -0.0003    0.0003
   -0.0672         0   -0.0034    0.0224
         0    0.8400         0         0
   -0.0003         0    0.0003   -0.0003
    0.0034         0   -0.0034    0.0448
```

```
>> KR = [ 176944.4444 0 163333.3333 -52500 0 -210000; 0 49000000 0 0 -21000000 0;
163333.3333 0 2613333.333 210000 0 560000; -52500 0 210000 8452500 0 210000; 0
-21000000 0 0 21003360 33600; -210000 0 560000 210000 33600 1568000]

KR =

  1.0e+007 *

    0.0177         0    0.0163   -0.0053         0   -0.0210
         0    4.9000         0         0   -2.1000         0
    0.0163         0    0.2613    0.0210         0    0.0560
   -0.0053         0    0.0210    0.8452         0    0.0210
         0   -2.1000         0         0    2.1003    0.0034
   -0.0210         0    0.0560    0.0210    0.0034    0.1568

>> f = [ 0; 0; 700; 0; -1500; -5000]

f =
          0
          0
        700
          0
      -1500
      -5000

>> u = inv(KR)*f

u =
   -0.0073
   -0.0000
    0.0017
    0.0000
   -0.0001
   -0.0048

>> U = [ 0; 0; 0; -0.0073; 0; 0.0017; 0; -0.0001; -0.0048; 0; 0; 0]

U =
         0
         0
         0
   -0.0073
         0
    0.0017
         0
   -0.0001
   -0.0048
         0
         0
         0

>> F = KT * U

F =

  1.0e+003 *

    0.2738
         0
   -1.4560
   -0.0060
    0.0210
    0.5623
   -0.2677
   -0.1826
    5.7072
         0
    0.0165
   -0.1837
```

EJERCICIO 4

Hallar los Desplazamientos Nodales y las Cargas generadas en la estructura mostrada.



$E = 260GPa$

$A = 8 \times 10^{-2} m^2$

$P = 120KN$

Nodos: 1 – 2; 2 – 3

A. Resolución

Nodo	θ	C	S	C²	S²	SC
1 – 2	68.19°	0.37	0.92	0.14	0.86	0.34
2 – 3	291.8°	0.37	–0.92	0.14	0.86	–0.34

$$K_1 = 10^9 \begin{bmatrix} 0.1806 & 0.4376 & -0.0027 & -0.1806 & -0.4376 & -0.0027 & 0 & 0 & 0 \\ 0.4376 & 1.1073 & 0.0011 & -0.4376 & -1.1073 & 0.0011 & 0 & 0 & 0 \\ -0.0027 & 0.0011 & 0.0322 & 0.0027 & -0.0011 & 0.0161 & 0 & 0 & 0 \\ -0.1806 & -0.4376 & 0.0027 & 0.1806 & 0.4376 & 0.0027 & 0 & 0 & 0 \\ -0.4376 & -0.1073 & -0.0027 & 0.4376 & 1.1073 & -0.0011 & 0 & 0 & 0 \\ -0.0027 & 0.0011 & 0.0161 & 0.0027 & -0.0011 & 0.0322 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_2 = 10^9 \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.1806 & -0.4376 & 0.0027 & -0.1806 & 0.4376 & -0.0027 \\ 0 & 0 & 0 & -0.4376 & 1.1073 & 0.0011 & 0.4376 & -1.1073 & 0.0011 \\ 0 & 0 & 0 & 0.0027 & 0.0011 & 0.0322 & -0.0027 & -0.0011 & 0.0161 \\ 0 & 0 & 0 & -0.1806 & 0.4376 & -0.0027 & 0.1806 & -0.4376 & -0.0027 \\ 0 & 0 & 0 & 0.4376 & -1.1073 & 0.0027 & -0.4376 & 1.1073 & -0.0011 \\ 0 & 0 & 0 & 0.0027 & 0.0011 & 0.0161 & -0.0027 & -0.0011 & 0.0322 \end{bmatrix}$$

Matriz Ensamblada:

$$KT = 10^9 \begin{bmatrix} 0.1806 & 0.4376 & -0.0027 & -0.1806 & -0.4376 & -0.0027 & 0 & 0 & 0 \\ 0.4376 & 1.1073 & 0.0011 & -0.4376 & -1.1073 & 0.0011 & 0 & 0 & 0 \\ -0.0027 & 0.0011 & 0.0322 & 0.0027 & 0.0011 & 0.0161 & 0 & 0 & 0 \\ -0.1806 & -0.4376 & 0.0027 & 0.3611 & 0 & 0.0055 & -0.1806 & 0.4376 & -0.0027 \\ -0.4376 & -1.1073 & -0.0027 & 0 & 2.2147 & 0 & 0.4376 & -1.1073 & 0.0011 \\ -0.0027 & 0.0011 & -0.0161 & 0.0055 & 0 & 0.0644 & -0.0027 & -0.0011 & 0.0161 \\ 0 & 0 & 0 & -0.1806 & 0.4376 & -0.0027 & 0.1806 & -0.4376 & -0.0027 \\ 0 & 0 & 0 & 0.4376 & -1.1073 & -0.0027 & -0.4376 & 1.1073 & -0.0011 \\ 0 & 0 & 0 & 0.0027 & 0.0011 & 0.0161 & -0.0027 & -0.0011 & 0.0322 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \\ u_2 \\ \gamma_2 \\ \theta_2 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} Fx_1 \\ Fy_1 \\ M_1 \\ 150000N \\ -120000N \\ 0 \\ Fx_3 \\ Fy_3 \\ M_3 \end{bmatrix}$$

Eliminando filas y columnas:

$$K = 10^9 \begin{bmatrix} 0.3611 & 0 & 0.0055 \\ 0 & 2.2147 & 0 \\ 0.0055 & 0 & 0.0644 \end{bmatrix} \begin{bmatrix} u_2 \\ \gamma_2 \\ \theta_2 \end{bmatrix} = \begin{bmatrix} 150000N \\ -120000N \\ 0 \end{bmatrix}$$

B. Resolución con MATLAB

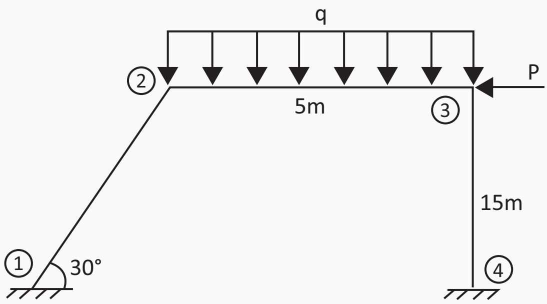
```
>> K1 = (10^9)*[ 0.1806 0.4376 -0.0027 -0.1806 -0.4376 -0.0027 0 0 0; 0.4376 1.1073
-0.0011 -0.4376 -1.1073 0.0011 0 0 0; -0.0027 0.0011 0.0322 0.0027 -0.0011 0.0161
0 0 0; -0.1806 -0.4376 0.0027 0.1806 0.4376 0.0027 0 0 0; -0.4376 -0.1073 -0.0027
0.4376 1.1073 -0.0011 0 0 0; -0.0027 0.0011 0.0161 0.0027 -0.0011 0.0322 0 0 0; 0
0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0]

K1 =

   1.0e+009 *

   Columns 1 through 8

     0.1806    0.4376   -0.0027   -0.1806   -0.4376   -0.0027         0         0
     0.4376    1.1073   -0.0011   -0.4376   -1.1073    0.0011         0         0
    -0.0027    0.0011    0.0322    0.0027   -0.0011    0.0161         0         0
    -0.1806   -0.4376    0.0027    0.1806    0.4376    0.0027         0         0
    -0.4376   -0.1073   -0.0027    0.4376    1.1073   -0.0011         0         0
    -0.0027    0.0011    0.0161    0.0027   -0.0011    0.0322         0         0
          0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0

   Column 9

          0
          0
          0
          0
          0
          0
          0
          0
          0
```

```
>> K2 = (10^9)*[ 0.0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0; 0 0 0
0.1806 -0.4376 0.0027 -0.1806 0.4376 -0.0027; 0 0 0 -0.4376 1.1073 0.0011 0.4376
-1.1073 0.0011; 0 0 0 0.0027 0.0011 0.0322 -0.0027 -0.0011 0.0161; 0 0 0 -0.1806
0.4376 -0.0027 0.1806 -0.4376 -0.0027; 0 0 0 0.4376 -1.1073 0.0027 -0.4376 1.1073
-0.0011; 0 0 0 0.0027 0.0011 0.0161 -0.0027 -0.0011 0.0322}

K2 =

  1.0e+009 *

  Columns 1 through 8

         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0    0.1806   -0.4376    0.0027   -0.1806    0.4376
         0         0         0   -0.4376    1.1073    0.0011    0.4376   -1.1073
         0         0         0    0.0027    0.0011    0.0322   -0.0027   -0.0011
         0         0         0   -0.1806    0.4376   -0.0027    0.1806   -0.4376
         0         0         0    0.4376   -1.1073    0.0027   -0.4376    1.1073
         0         0         0    0.0027    0.0011    0.0161   -0.0027   -0.0011

  Column 9

         0
         0
         0
   -0.0027
    0.0011
    0.0161
   -0.0027
   -0.0011
    0.0322

>> KT = K1 + K2

KT =

  1.0e+009 *

  Columns 1 through 8

    0.1806    0.4376   -0.0027   -0.1806   -0.4376   -0.0027         0         0
    0.4376    1.1073   -0.0011   -0.4376   -1.1073    0.0011         0         0
    0.0027    0.0011    0.0322    0.0027   -0.0011    0.0161         0         0
    0.1306   -0.4376    0.0027    0.3612         0    0.0054   -0.1806    0.4376
   -0.4376   -0.1073   -0.0027         0    2.2146         0    0.4376   -1.1073
   -0.0027    0.0011    0.0161    0.0054         0    0.0644   -0.0027   -0.0011
         0         0         0   -0.1806    0.4376   -0.0027    0.1806   -0.4376
         0         0         0    0.4376   -1.1073    0.0027   -0.4376    1.1073
         0         0         0    0.0027    0.0011    0.0161   -0.0027   -0.0011

  Column 9

         0
         0
         0
   -0.0027
    0.0011
    0.0161
   -0.0027
   -0.0011
    0.0322
```

```
>> KR = (10^9)*[ 0.3611 0 0.0055; 0 2.2147 0; 0.0055 0 0.0644]

KR =

  1.0e+009 *

    0.3611         0    0.0055
         0    2.2147         0
    0.0055         0    0.0644

>> f = [ 150000; -120000; 0]

f =

      150000
     -120000
           0

>> u = inv(KR)*f

u =

  1.0e-003 *

    0.4159
   -0.0542
   -0.0355

>> U = [ 0; 0; 0; 0.4159; -0.0542; -0.0355; 0; 0; 0]

U =

         0
         0
         0
    0.4159
   -0.0542
   -0.0355
         0
         0
         0

>> F = KT * U

F =

   -51297770
  -122021230
      611000
   150031380
  -120031320
      -40340
   -98733610
   241917650
      491760
```

EJERCICIO 5

Determinar los Desplazamientos y las Cargas generadas en cada nodo, en la estructura mostrada, según la secuencia indicada.



$E = 220GPa$

$I = 8 \times 10^{-4} m^4$

$A = 6 \times 10^{-2} m^2$

$q = 60KN/m$

$P = 120Nm$

Nodos: 1 – 2; 2 – 3; 3 – 4

A. Resolución

Elemento	Nodo	θ	C	S	C²	S²	SC
1	1 – 2	30°	0.87	0.5	0.7569	0.25	0.435
2	2 – 3	0°	1	0	1	0	0
3	3 – 4	270°	0	–1	0	1	0

$$K_1 = 10^8 \begin{bmatrix} 33002 & 1.8917 & -0.0059 & -3.3002 & -1.8917 & -0.0059 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1.8917 & 1.1006 & 0.0102 & -1.8917 & -1.1006 & 0.0102 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.0059 & 0.0102 & 0.2347 & 0.0059 & -0.0102 & 0.1173 & 0 & 0 & 0 & 0 & 0 & 0 \\ -3.3002 & -1.8917 & 0.0059 & 3.3002 & 1.8917 & 0.0059 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1.8917 & -1.1006 & -0.0059 & 1.8917 & 1.1006 & -0.0102 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.0059 & 0.0102 & 0.1173 & 0.0059 & -0.0102 & 0.2347 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_2 = 10^9 \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2.6400 & 0 & 0 & -2.6400 & 0 & -0.0035 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.0169 & 0.0422 & 0 & -0.0169 & 0.0422 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.0422 & 0.1408 & 0 & -0.0422 & 0.0704 & 0 & 0 & 0 \\ 0 & 0 & 0 & -2.6400 & 0 & 0 & 2.6400 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -0.0169 & 0 & 0 & 0.0169 & -0.0422 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.0422 & 0.0704 & 0 & -0.0422 & 0.1408 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_3 = 10^8 \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.0063 & 0 & 0.0469 & -0.0063 & 0 & 0.0469 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8.8000 & 0 & 0 & -8.8000 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -0.0063 & 0 & 0.4693 & -0.0469 & 0 & 0.2347 \\ 0 & 0 & 0 & 0 & 0 & 0 & -0.0063 & 0 & -0.0469 & 0.0063 & 0 & -0.0469 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -8.8000 & 0.0469 & 0 & 8.8000 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.0469 & 0 & 0.2347 & -0.0469 & 0 & 0.4693 \end{bmatrix}$$

$$KT = 10^9 \begin{bmatrix} 0.3300 & 0.1892 & -0.0006 & -0.330 & -0.1892 & -0.0006 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.1892 & 0.1101 & 0.0010 & -0.189 & -0.1101 & 0.0010 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.0006 & 0.0010 & 0.0235 & 0.0006 & -0.0010 & 0.0117 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.330 & -0.189 & 0.0006 & 2.9700 & 0.1892 & 0.0006 & -2.6400 & 0 & -0.0035 & 0 & 0 & 0 \\ -0.1892 & -0.110 & -0.0006 & 0.1892 & 0.1270 & 0.0412 & 0 & -0.0169 & 0.0422 & 0 & 0 & 0 \\ -0.0006 & 0.0010 & 0.0117 & 0.0006 & 0.0412 & 0.1643 & 0 & -0.042 & 0.0704 & 0 & 0 & 0 \\ 0 & 0 & 0 & -2.640 & 0 & 0 & 2.6406 & 0 & 0.0047 & -0.0006 & 0 & 0.0047 \\ 0 & 0 & 0 & 0 & -0.0169 & 0 & 0 & 0.8969 & -0.0422 & 0 & -0.880 & 0 \\ 0 & 0 & 0 & 0 & 0.0422 & 0.0704 & 0.0047 & -0.042 & 0.1877 & -0.0047 & 0 & 0.0235 \\ 0 & 0 & 0 & 0 & 0 & 0 & -0.0006 & 0 & -0.0047 & 0.0006 & 0 & -0.0047 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.880 & 0.0047 & 0 & 0.880 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.0047 & 0 & 0.0235 & -0.0047 & 0 & 0.0469 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \\ u_2 \\ \gamma_2 \\ \theta_2 \\ u_3 \\ \gamma_3 \\ \theta_3 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} Fx_1 \\ Fy_1 \\ M_1 \\ 0 \\ -150000N \\ -125000Nm \\ -120000N \\ -150000N \\ 125000Nm \\ Fx_3 \\ Fy_3 \\ M_3 \end{bmatrix}$$

Eliminando filas y columnas:

$$K = 10^9 \begin{bmatrix} 2.9700 & 0.1892 & 0.0006 & -2.6400 & 0 & -0.0035 \\ 0.1892 & 0.1270 & 0.0412 & 0 & -0.0169 & 0.0422 \\ 0.0006 & 0.0412 & 0.1643 & 0 & -0.0422 & 0.0704 \\ -2.6400 & 0 & 0 & 2.6406 & 0 & 0.0047 \\ 0 & -0.0169 & 0 & 0 & 0.8969 & -0.0422 \\ 0 & 0.0422 & 0.0704 & 0.0047 & -0.0422 & 0.1877 \end{bmatrix} \begin{bmatrix} u_2 \\ v_2 \\ \theta_2 \\ u_3 \\ v_3 \\ \theta_3 \end{bmatrix} = 10^3 \begin{bmatrix} 0 \\ -150N \\ -125Nm \\ -120N \\ -150N \\ 125Nm \end{bmatrix}$$

B. Resolución con MATLAB

```
>> K1 = (10^8)*[33002 1.8917 -0.0059 -3.3002 -1.8917 -0.0059 0 0 0 0 0 0; 1.8917
1.1006 0.0102 -1.8917 -1.1006 0.0102 0 0 0 0 0 0; -0.0059 0.0102 0.2347 0.0059
-0.0102 0.1173 0 0 0 0 0 0; -3.3002 -1.8917 0.0059 3.3002 1.8917 0.0059 0 0 0 0
0 0; -1.8917 -1.1006 -0.0059 1.8917 1.1006 -0.0102 0 0 0 0 0 0; -0.0059 0.0102
0.1173 0.0059 -0.0102 0.2347 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0
0 0; 0 0 0 0 0 0 0 0 0 0 0 0]
```

```
K1 =

   1.0e+12 *

  Columns 1 through 8

    3.3002    0.0002   -0.0000   -0.0003   -0.0002   -0.0000         0         0
    0.0002    0.0001    0.0000   -0.0002   -0.0001    0.0000         0         0
   -0.0000    0.0000    0.0000    0.0000   -0.0000    0.0000         0         0
   -0.0003   -0.0002    0.0000    0.0003    0.0002    0.0000         0         0
   -0.0002   -0.0001   -0.0000    0.0002    0.0001   -0.0000         0         0
   -0.0000    0.0000    0.0000    0.0000   -0.0000    0.0000         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0

  Columns 9 through 12

         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0

>> K2 =(10^9)* [ 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0
0 0 0 0 0 0; 0 0 0 2.6400 0 0 -2.6400 0 -0.0035 0 0 0; 0 0 0 0 0.0169 0.0422 0
-0.0169 0.0422 0 0 0; 0 0 0 0 0.0422 0.1408 0 -0.0422 0.0704 0 0 0; 0 0 0 -2.6400
0 0 2.6400 0 0 0 0 0; 0 0 0 0 -0.0169 0 0 0.0169 -0.0422 0 0 0; 0 0 0 0 0.0422
0.0704 0 -0.0422 0.1408 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0]

K2 =

   1.0e+09 *

  Columns 1 through 8

         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0    2.6400         0         0   -2.6400         0
         0         0         0         0    0.0169    0.0422         0   -0.0169
         0         0         0         0    0.0422    0.1408         0   -0.0422
         0         0         0   -2.6400         0         0    2.6400         0
         0         0         0         0   -0.0169         0         0    0.0169
         0         0         0         0    0.0422    0.0704         0   -0.0422
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
```

```
  Columns 9 through 12

         0         0         0         0
         0         0         0         0
         0         0         0         0
   -0.0035         0         0         0
    0.0422         0         0         0
    0.0704         0         0         0
         0         0         0         0
   -0.0422         0         0         0
    0.1408         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0

>> K3 = (10^8)*[0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0
0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0; 0 0 0 0 0 0 0.0063 0 0.0469 -0.0063 0 0 0469; 0 0 0 0 0 0 0 8.8000 0 0 -8.8000
0; 0 0 0 0 0 0 -0.0063 0 0.4693 -0.0469 0 0.2347; 0 0 0 0 0 0 -0.0063 0 -0.0469
0.0063 0 -0.0469; 0 0 0 0 0 0 0 -8.8000 0.0469 0 8.8000 0; 0 0 0 0 0 0 0.0469 0
0.2347 -0.0469 0 0.4693]

K3 =

   1.0e+09 *

  Columns 1 through 8

         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0    0.0063         0
         0         0         0         0         0         0         0    8.8000
         0         0         0         0         0         0   -0.0063         0
         0         0         0         0         0         0   -0.0063         0
         0         0         0         0         0         0         0   -8.8000
         0         0         0         0         0         0    0.0469         0

  Columns 9 through 12

         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
    0.0469   -0.0063         0    0.0469
         0         0   -8.8000         0
    0.4693   -0.0469         0    0.2347
   -0.0469    0.0063         0   -0.0469
    0.0469         0    8.8000         0
    0.2347   -0.0469         0    0.4693
```

```
>> KT = K1 + K2 + K3

KT =

   1.0e+12 *

  Columns 1 through 8

    3.3002    0.0002   -0.0000   -0.0003   -0.0002   -0.0000         0         0
    0.0002    0.0001    0.0000   -0.0002   -0.0001    0.0000         0         0
   -0.0000    0.0000    0.0000    0.0000   -0.0000    0.0000         0         0
   -0.0003   -0.0002    0.0000    0.0030    0.0002    0.0000   -0.0026         0
   -0.0002   -0.0001   -0.0000    0.0002    0.0001    0.0000         0   -0.0000
   -0.0000    0.0000    0.0000    0.0000    0.0000    0.0002         0   -0.0000
         0         0         0   -0.0026         0         0    0.0026         0
         0         0         0         0   -0.0000         0         0    0.0009
         0         0         0         0    0.0000    0.0001   -0.0000   -0.0000
         0         0         0         0         0         0   -0.0000         0
         0         0         0         0         0         0         0   -0.0009
         0         0         0         0         0         0    0.0000         0

  Columns 9 through 12

         0         0         0         0
         0         0         0         0
         0         0         0         0
   -0.0000         0         0         0
    0.0000         0         0         0
    0.0001         0         0         0
    0.0000   -0.0000         0    0.0000
   -0.0000         0   -0.0009         0
    0.0002   -0.0000         0    0.0000
   -0.0000    0.0000         0   -0.0000
    0.0000         0    0.0009         0
    0.0000   -0.0000         0    0.0000

>> KR = (10^9)*[2.9700 0.1892 0.0006 -2.6400 0 -0.0035; 0.1892 0.1270 0.0412 0
-0.0169 0.0422; 0.0006 0.0412 0.1643 0 -0.0422 0.0704; -2.6400 0 0 2.6406 0 0.0047;
0 -0.0169 0 0 0.8969 -0.0422; 0 0.0422 0.0704 0.0047 -0.0422 0.1877]

KR =

   1.0e+09 *

    2.9700    0.1892    0.0006   -2.6400         0   -0.0035
    0.1892    0.1270    0.0412         0   -0.0169    0.0422
    0.0006    0.0412    0.1643         0   -0.0422    0.0704
   -2.6400         0         0    2.6406         0    0.0047
         0   -0.0169         0         0    0.8969   -0.0422
         0    0.0422    0.0704    0.0047   -0.0422    0.1877

>> f = (10^3)*[ 0; -150; -125; -120; -150; 125]

f =
          0
    -150000
    -125000
    -120000
    -150000
     125000
```

```
>> u = inv(KR)*f

u =
    0.0083
   -0.0151
    0.0015
    0.0082
   -0.0003
    0.0032

>> U = [10; 0; 0; 0.0083; -0.0151; 0.0015; 0.0082; -0.0003; 0.0032; 0; 0; 0]

U =
         0
         0
         0
    0.0083
   -0.0151
    0.0015
    0.0082
   -0.0003
    0.0032
         0
         0
         0

>> F = KT * U

F =
      116416
       93325
       37894
      136384
     -145105
     -132576
     -243826
     -148920
       76610
      -20174
      279008
      113562
```

Desplazamientos:

$$U = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0.0083m \\ -0.0151m \\ 0.0015rad \\ 0.0082m \\ -0.0003m \\ 0.0032rad \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

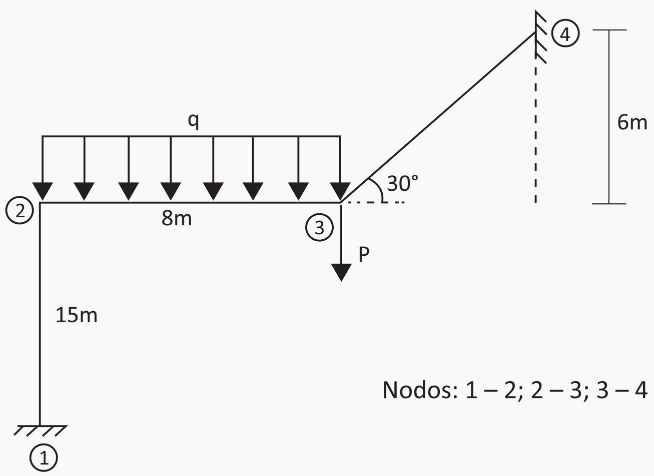
Fuerzas:

$$F = K \times U$$

$$F = 10^5 \times \begin{bmatrix} 1.1637N \\ 0.9334N \\ 0.3788Nm \\ 1.3637N \\ -1.4487N \\ -1.3319Nm \\ -2.4385N \\ -1.4911N \\ 1.1968Nm \\ -0.2015N \\ 2.7902N \\ 1.1358Nm \end{bmatrix}$$

EJERCICIO 6

Determinar los Desplazamientos y las Cargas generadas en cada nodo, en la estructura mostrada, según la secuencia indicada.



$E = 250GPa$

$I = 6 \times 10^{-4} m^4$

$A = 8 \times 10^{-2} m^2$

$P = 100KN$

$q = 30KN/m$

Nodos: 1 – 2; 2 – 3; 3 – 4

A. Resolución

Nodo	θ	C	S	C²	S²	SC
1 – 2	90°	0	1	0	1	0
2 – 3	0°	1	0	1	0	0
3 – 4	30°	0.87	0.5	0.75	0.25	0.43

$$K_1 = 10^9 \times \begin{bmatrix} 0.0005 & 0 & -0.0040 & 0 & -0.0040 & -0.0040 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1.3333 & 0 & 0 & -1.3333 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.0040 & 0 & 0.0040 & 0.0040 & 0 & 0.0200 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.0005 & 0 & 0.0040 & 0.0005 & 0 & 0.0040 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1.3333 & -0.0040 & 0 & 1.3333 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.0040 & 0 & 0.0200 & 0.0040 & 0 & 0.0040 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_2 = 10^9 \times \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2.5000 & 0 & 0 & -2.5000 & 0 & -0.0075 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.0035 & 0.0141 & 0 & -0.0035 & 0.0141 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.0141 & 0.0750 & 0 & -0.0141 & 0.0375 & 0 & 0 & 0 \\ 0 & 0 & 0 & -2.5000 & 0 & 0 & 2.5000 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -0.0035 & 0 & 0.0035 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.0141 & 0.0375 & 0 & -0.0141 & 0.0750 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_3 = 10^9 \times \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1.2503 & 0.7162 & -0.0031 & -1.2503 & -0.7162 & -0.0031 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.7162 & 0.4174 & 0.0054 & -0.7162 & -0.4174 & 0.0054 \\ 0 & 0 & 0 & 0 & 0 & 0 & -0.0031 & 0.0054 & 0.0500 & 0.0031 & -0.0054 & 0.0250 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1.2503 & -0.7162 & 0.0031 & 0.0031 & -0.0054 & 0.0031 \\ 0 & 0 & 0 & 0 & 0 & 0 & -0.7162 & -0.4174 & -0.0031 & 0.7162 & 0.4174 & -0.0054 \\ 0 & 0 & 0 & 0 & 0 & 0 & -0.0031 & 0.0054 & 0.0250 & 0.0031 & -0.0054 & 0.0500 \end{bmatrix}$$

Matriz Ensamblada:

$$KT = 10^9 \times \begin{bmatrix} 0.0005 & 0 & -0.004 & -0.0005 & 0 & -0.0040 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1.3333 & 0 & 0 & -1.3333 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.0040 & 0 & 0.0040 & 0.0040 & 0 & 0.0200 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.005 & 0 & 0.0040 & 2.5005 & 0 & 0.0040 & -2.500 & 0 & -0.0075 & 0 & 0 & 0 \\ 0 & -1.3333 & -0.004 & 0 & 1.3368 & 0.0141 & 3.7503 & -0.0035 & 0.0141 & 0 & 0 & 0 \\ -0.0040 & 0 & 0.0200 & 0.0040 & 0.0141 & 0.1150 & -0.003 & -0.0141 & 0.0375 & 0 & 0 & 0 \\ 0 & 0 & 0 & -2.500 & 0 & 0 & -1.250 & 0.7162 & -0.0031 & -1.2503 & -0.7162 & -0.0031 \\ 0 & 0 & 0 & 0 & -0.0035 & 0 & -0.716 & 0.4210 & -0.0086 & -0.7162 & -0.4174 & 0.0054 \\ 0 & 0 & 0 & 0 & -0.0141 & 0.0375 & -0.003 & -0.0086 & 0.1250 & 0.0031 & -0.0054 & 0.0250 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.7162 & 0.0031 & 1.2503 & 0.7162 & 0.0031 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.4174 & -0.0031 & 0.7162 & 0.4174 & -0.0054 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0054 & 0.0250 & 0.0031 & -0.0054 & 0.0500 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \\ u_2 \\ \gamma_2 \\ \theta_2 \\ u_3 \\ \gamma_3 \\ \theta_3 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} Fx_1 \\ Fy_1 \\ M_1 \\ 0 \\ -120000N \\ -160000Nm \\ 0 \\ -220000N \\ 160000Nm \\ Fx_3 \\ Fy_3 \\ M_3 \end{bmatrix}$$

Eliminando Filas y columnas:

$$K = 10^9 \begin{bmatrix} 2.5005 & 0 & 0.0040 & -2.5000 & 0 & -0.0075 \\ 0 & 1.3368 & 0.0141 & 0 & -0.0035 & 0.0141 \\ 0.0040 & 0.0141 & 0.1150 & 0 & 0.0141 & 0.0375 \\ -2.5000 & 0 & 0 & 3.7503 & 0.7162 & -0.0031 \\ 0 & -0.0035 & 0 & 0.7162 & 0.4210 & -0.0086 \\ 0 & 0.0141 & 0.0375 & -0.0031 & -0.0086 & 0.1250 \end{bmatrix} \begin{bmatrix} u_2 \\ v_2 \\ \theta_2 \\ u_3 \\ v_3 \\ \theta_3 \end{bmatrix} = 10^3 \begin{bmatrix} 0 \\ -120N \\ -160Nm \\ 0 \\ -220N \\ 160Nm \end{bmatrix}$$

B. Resolución con MATLAB

```
>> K1 = (10^9)*[30.0005 0 -0.0040 0 -0.0040 -0.0040 0 0 0 0 0 0; 0 1.3333 0 0
-1.3333 0 0 0 0 0 0 0; -0.0040 0 0.0040 0.0040 0 0.0200 0 0 0 0 0 0; -0.0005 0
0.0040 0.0005 0 0.0040 0 0 0 0 0 0; 0 -1.3333 -0.0040 0 1.3333 0 0 0 0 0 0 0;
-0.0040 0 0.0200 0.0040 0 0.0040 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0
0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0
0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0]

K1 =

   1.0e+09 *

  Columns 1 through 8

    0.0005         0   -0.0040         0   -0.0040   -0.0040         0         0
         0    1.3333         0         0   -1.3333         0         0         0
   -0.0040         0    0.0040    0.0040         0    0.0200         0         0
   -0.0005         0    0.0040    0.0005         0    0.0040         0         0
         0   -1.3333   -0.0040         0    1.3333         0         0         0
   -0.0040         0    0.0200    0.0040         0    0.0040         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
```

```
  Columns 9 through 12

         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0

>> K2 = (10^9)* [ 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0
0 0 0 0; 0 0 0 2.5000 0 0 -2.5000 0 -0.0075 0 0 0; 0 0 0 0 0.0035 0.0141 0 -0.0035
0.0141 0 0 0; 0 0 0 0 0.0141 0.0750 0 -0.0141 0.0375 0 0 0; 0 0 0 -2.5000 0 0
2.5000 0 0 0 0 0; 0 0 0 0 -0.0035 0 0.0035 0 0 0 0 0; 0 0 0 0 0.0141 0.0375 0 0 0
0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0]

K2 =

   1.0e+09 *

  Columns 1 through 8

         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0    2.5000         0         0   -2.5000         0
         0         0         0         0    0.0035    0.0141         0   -0.0035
         0         0         0         0    0.0141    0.0750         0   -0.0141
         0         0         0   -2.5000         0         0    2.5000         0
         0         0         0         0   -0.0035         0    0.0035         0
         0         0         0         0    0.0141    0.0375         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0

  Columns 9 through 12

         0         0         0         0
         0         0         0         0
         0         0         0         0
   -0.0075         0         0         0
    0.0141         0         0         0
    0.0375         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0

>> K3 = (10^9)*[ 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0
0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0; 0 0 0 0 0 0 1.2503 0.7162 -0.0031 -1.2503 -0.7162 -0.0031; 0 0 0 0 0 0 0.7162
0.4174 -0.0054 -0.7162 -0.4174 0.0054; 0 0 0 0 0 0 -0.0031 0.0054 0.0500 0.0031
-0.0054 0.0250; 0 0 0 0 0 0 -1.2503 -0.7162 0.0031 0.0031 -0.0054 0.0031; 0 0 0
0 0 0 -0.7162 -0.4174 -0.0031 0.7162 0.4174 -0.0054; 0 0 0 0 0 0 -0.0031 0.0054
0.0250 0.0031 -0.0054 0.0500]
```

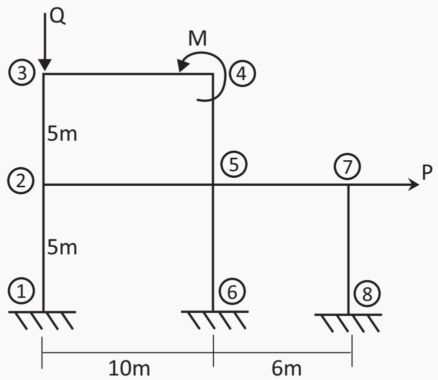
```
K3 =

   1.0e+09 *

  Columns 1 through 8

         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0    1.2503    0.7162
         0         0         0         0         0         0    0.7162    0.4174
         0         0         0         0         0         0   -0.0031    0.0054
         0         0         0         0         0         0   -1.2503   -0.7162
         0         0         0         0         0         0   -0.7162   -0.4174
         0         0         0         0         0         0   -0.0031    0.0054

  Columns 9 through 12

         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
         0         0         0         0
   -0.0031   -1.2503   -0.7162   -0.0031
   -0.0054   -0.7162   -0.4174    0.0054
    0.0500    0.0031   -0.0054    0.0250
    0.0031    0.0031   -0.0054    0.0031
   -0.0031    0.7162    0.4174   -0.0054
    0.0250    0.0031   -0.0054    0.0500

>> KT = K1 + K2 + K3

KT =

   1.0e+09 *

  Columns 1 through 8

    0.0005         0   -0.0040         0   -0.0040   -0.0040         0         0
         0    1.3333         0         0   -1.3333         0         0         0
   -0.0040         0    0.0040    0.0040         0    0.0200         0         0
   -0.0005         0    0.0040    2.5005         0    0.0040   -2.5000         0
         0   -1.3333   -0.0040         0    1.3368    0.0141         0   -0.0035
   -0.0040         0    0.0200    0.0040    0.0141    0.0790         0   -0.0141
         0         0         0   -2.5000         0         0    3.7503    0.7162
         0         0         0         0   -0.0035         0    0.7197    0.4174
         0         0         0         0    0.0141    0.0375   -0.0031    0.0054
         0         0         0         0         0         0   -1.2503   -0.7162
         0         0         0         0         0         0   -0.7162   -0.4174
         0         0         0         0         0         0   -0.0031    0.0054
```

```
  Columns 9 through 12

         0         0         0         0
         0         0         0         0
         0         0         0         0
   -0.0075         0         0         0
    0.0141         0         0         0
    0.0375         0         0         0
   -0.0031   -1.2503   -0.7162   -0.0031
   -0.0054   -0.7162   -0.4174    0.0054
    0.0500    0.0031   -0.0054    0.0250
    0.0031    0.0031   -0.0054    0.0031
   -0.0031    0.7162    0.4174   -0.0054
    0.0250    0.0031   -0.0054    0.0500

>> KR = (10^9)* [ 2.5005 0 0.0040 -2.5000 0 -0.0075; 0 1.3368 0.0141 0 -0.0035
0.0141; 0.0040 0.0141 0.1150 0 -0.0141 0.0375; -2.5000 0 0 3.7503 0.7162 -0.0031;
0 -0.0035 0 0.7162 0.4210 -0.0086; 0 0.0141 0.0375 -0.0031 -0.0086 0.1250]

KR =

   1.0e+09 *

    2.5005         0    0.0040   -2.5000         0   -0.0075
         0    1.3368    0.0141         0   -0.0035    0.0141
    0.0040    0.0141    0.1150         0   -0.0141    0.0375
   -2.5000         0         0    3.7503    0.7162   -0.0031
         0   -0.0035         0    0.7162    0.4210   -0.0086
         0    0.0141    0.0375   -0.0031   -0.0086    0.1250

>> f = (10^3)*[ 0; -120; -160; 0; -220; 160]

f =
           0
     -120000
     -160000
           0
     -220000
      160000

>> u = inv(KR)*f

u =
    0.0120
   -0.0001
   -0.0049
    0.0120
   -0.0209
    0.0016

>> U = [0; 0; 0; 0.0120; -0.0001; -0.0049; 0.0120; -0.0209; 0.0016; 0; 0; 0]

U =
         0
         0
         0
    0.0120
   -0.0001
    0.0049
    0.0120
   -0.0209
    0.0016
         0
         0
         0
```

```
>> F = HT * U

F =

   1.0e+05 *

    0.2000
    1.3333
   -0.5000
   -0.2560
   -1.0706
    0.1418
    0.3006
   -0.9555
   -2.5522
   -0.3006
    1.2430
   -1.1006
```

EJERCICIO 7

Determinar los Desplazamientos y las Cargas generadas en cada nodo, en la estructura mostrada, según la secuencia indicada.



$E = 280GPa$

$I = 6 \times 10^{-6} m^4$

$A = 4 \times 10^{-4} m^2$

$P = 2000N$

$Q = 4000N$

$M = 500Nm$

Nodos: 1 – 2; 2 – 3; 3 – 4; 4 – 5; 2 – 5; 5 – 6; 5 – 7; 7 – 8

A. Resolución

Elemento	Nodo	θ	C	S	C^2	S^2	SC
1	1 – 2	90°	0	1	0	1	0
2	2 – 3	90°	0	1	0	1	0
3	3 – 4	0°	1	0	1	0	0
4	4 – 5	270°	0	–1	0	1	0
5	2 – 5	0°	1	0	1	0	0
6	5 – 6	270°	0	–1	0	1	0
7	5 – 7	0°	1	0	1	0	0
8	7 – 8	270°	0	–1	0	1	0

La matriz para cada elemento estructural es:

$$K=\frac{E}{L}\begin{bmatrix} \left(AC^2+\frac{12I}{L^2}S^2\right) & \left(A-\frac{12I}{L^2}\right)CS & \left(-\frac{6I}{L}\right)S & -\left(AC^2+\frac{12I}{L^2}S^2\right) & -\left(A-\frac{12I}{L^2}\right)CS & \left(-\frac{6I}{L}\right)S \\ \left(A-\frac{12I}{L^2}\right)CS & \left(AS^2+\frac{12I}{L^2}C^2\right) & \left(\frac{6I}{L}\right)C & -\left(A-\frac{12I}{L^2}\right)CS & -\left(AS^2+\frac{12I}{L^2}C^2\right) & \left(\frac{6I}{L}\right)C \\ \left(-\frac{6I}{L}\right)S & \left(\frac{6I}{L}\right)C & 4I & \left(\frac{6I}{L}\right)S & -\left(\frac{6I}{L}\right)C & 2I \\ -\left(AC^2+\frac{12I}{L^2}S^2\right) & -\left(A-\frac{12I}{L^2}\right)CS & \left(\frac{6I}{L}\right)S & \left(AC^2+\frac{12I}{L^2}S^2\right) & \left(A-\frac{12I}{L^2}\right)CS & \left(-\frac{6I}{L}\right)S \\ -\left(A-\frac{12I}{L^2}\right)CS & -\left(AS^2+\frac{12I}{L^2}C^2\right) & -\left(\frac{6I}{L}\right)C & \left(A-\frac{12I}{L^2}\right)CS & \left(AS^2+\frac{12I}{L^2}C^2\right) & -\left(\frac{6I}{L}\right)C \\ \left(-\frac{6I}{L}\right)S & \left(\frac{6I}{L}\right)C & 2I & \left(-\frac{6I}{L}\right)S & -\left(\frac{6I}{L}\right)C & 4I \end{bmatrix}$$

A esta matriz se le denominará matriz "[M]".

$$K_{1-2}=\frac{E}{L}=\frac{\left(280\times10^{9}\right)}{5m}=56000000000[M]$$

$$K_{1-2}=\begin{bmatrix} 161280 & 0 & -403200 & -161280 & 0 & -403200 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 22400000 & 0 & 0 & -22400000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -403200 & 0 & 1344000 & 403200 & 0 & 672000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -161280 & 0 & 403200 & 161280 & 0 & 403200 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -22400000 & 0 & 0 & 22400000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -403200 & 0 & 672000 & 403200 & 0 & 1344000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_{2-3}=\frac{E}{L}=\frac{\left(280\times10^{9}\right)}{5m}=56000000000[M]$$

$$K_{2-3}=\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
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0 & 0 & 0 & -403200 & 0 & 1344000 & 403200 & 0 & 672000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{3-4}=\frac{E}{L}=\frac{\left(280\times10^{9}\right)}{10m}=28000000000[M]$$

$$K_{3-4}=\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 100800 & 672000 & 0 & -100800 & 336000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
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\end{bmatrix}$$

$$K_{4-5} = \frac{E}{L} = \frac{\left(280 \times 10^{9}\right)}{5m} = 56000000000[M]$$

$$K_{4-5} = \left[\begin{array}{cccccccccccccccccccccccc}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 161280 & 0 & 403200 & -161280 & 0 & 403200 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 22400000 & 0 & 0 & -22400000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 403200 & 0 & 1344000 & -403200 & 0 & 672000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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\end{array}\right]$$

$$K_{2-5} = \frac{E}{L} = \frac{\left(280 \times 10^{9}\right)}{10m} = 28000000000[M]$$

$$K_{2-5} = \left[\begin{array}{cccccccccccccccccccccccc}
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0 & 0 & 0 & 11200000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -11200000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 20160 & 100800 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -20160 & 100800 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 100800 & 672000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -100800 & 336000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 100800 & 336000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -100800 & 672000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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\end{array}\right]$$

$$K_{5-6} = \frac{E}{L} = \frac{(280 \times 10^{9})}{5m} = 56000000000[M]$$

$$K_{5-6} = \left[\begin{array}{cccccccccccccccccccccccc}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -22400000 & 0 & 0 & 22400000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -403200 & 0 & 672000 & -403200 & 0 & 1344000 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{array}\right]$$

$$K_{5-7} = \frac{E}{L} = \frac{(280 \times 10^{9})}{6m} = 46666666667[M]$$

$$K_{5-7} = \left[\begin{array}{cccccccccccccccccccccccc}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 18666666.67 & 0 & 0 & 0 & 0 & 0 & -18666666.67 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 93333.33333 & 280000 & 0 & 0 & 0 & 0 & -93333.33333 & 280000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 280000 & 1344000 & 0 & 0 & 0 & 0 & -280000 & 560000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18666666.67 & 0 & 0 & 0 & 0 & 0 & 18666666.67 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -93333.33333 & -280000 & 0 & 0 & 0 & 0 & 93333.33333 & -280000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 280000 & 560000 & 0 & 0 & 0 & 0 & -280000 & 1120000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{array}\right]$$

$$K_{7-8} = \frac{E}{L} = \frac{\left(280 \times 10^9\right)}{5m} = 56000000000[M]$$

$$K_{7-8} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 161280 & 0 & 403200 & -161280 & 0 & 403200 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 22400000 & 0 & 0 & -22400000 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 403200 & 0 & 1344000 & -403200 & 0 & 672000 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -161280 & 0 & -403200 & 161280 & 0 & -403200 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -22400000 & 0 & 0 & 22400000 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 403200 & 0 & 672000 & -403200 & 0 & 1344000
\end{bmatrix}$$

$$K \times U = F$$

$$\begin{bmatrix}
161280 & 0 & -403200 & -161280 & 0 & -403200 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 22400000 & 0 & 0 & -22400000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-403200 & 0 & 1344000 & 403200 & 0 & 672000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-161280 & 0 & 403200 & 11522560 & 0 & 0 & -161280 & 0 & -403200 & 0 & 0 & 0 & -11200000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -22400000 & 0 & 0 & 44820160 & 100800 & 0 & -22400000 & 0 & 0 & 0 & 0 & 0 & -20160 & 100800 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-403200 & 0 & 672000 & 0 & 100800 & 3360000 & 403200 & 0 & 672000 & 0 & 0 & 0 & 0 & -100800 & 336000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -161280 & 0 & 403200 & 11361280 & 0 & 403200 & -11200000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -22400000 & 0 & 0 & 22420160 & 100800 & 0 & -20160 & 100800 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -403200 & 0 & 672000 & 403200 & 100800 & 2016000 & 0 & -100800 & 336000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -11200000 & 0 & 0 & 11361280 & 0 & 403200 & -161280 & 0 & 403200 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -20160 & -100800 & 0 & 22420160 & -100800 & 0 & -224000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 100800 & 336000 & 403200 & -100800 & 2016000 & -403200 & 0 & 672000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -11200000 & 0 & 0 & 0 & 0 & 0 & -161280 & 0 & -403200 & 30189226.67 & 0 & 0 & -161280 & 0 & 403200 & -18666666.67 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -20160 & 100800 & 0 & 0 & 0 & 0 & -22400000 & 0 & 0 & 44913493.33 & 179200 & 0 & -22400000 & 0 & 0 & -93333.33333 & 280000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 100800 & 336000 & 0 & 0 & 0 & 403200 & 0 & 672000 & 0 & 179200 & 4480000 & -403200 & 0 & 672000 & 0 & 280000 & 560000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -161280 & 0 & -403200 & 161280 & 0 & -403200 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -224000000 & 0 & 0 & 22400000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 403200 & 0 & 672000 & -403200 & 0 & 1344000 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18666666.67 & 0 & 0 & 0 & 0 & 0 & 18827946.67 & 0 & 403200 & -161280 & 0 & 403200 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -93333.33333 & -280000 & 0 & 0 & 0 & 0 & 22493333.33 & -280000 & 0 & -22400000 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 280000 & 560000 & 0 & 0 & 0 & 403200 & -280000 & 2464000 & -403200 & 0 & 672000 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -161280 & 0 & -403200 & 161280 & 0 & -403200 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -22400000 & 0 & 0 & 2240000 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 403200 & 0 & 672000 & -403200 & 0 & 1344000
\end{bmatrix}
\begin{bmatrix} u_1 \\ v_1 \\ \theta_1 \\ u_2 \\ v_2 \\ \theta_2 \\ u_3 \\ v_3 \\ \theta_3 \\ u_4 \\ v_4 \\ \theta_4 \\ u_5 \\ v_5 \\ \theta_5 \\ u_6 \\ v_6 \\ \theta_6 \\ u_7 \\ v_7 \\ \theta_7 \\ v_8 \\ u_8 \\ \theta_8 \end{bmatrix}
=
\begin{bmatrix} F_{1x} \\ F_{1x} \\ M_1 \\ 0 \\ 0 \\ 0 \\ 0 \\ -4000 \\ 0 \\ 0 \\ 0 \\ 500 \\ 0 \\ 0 \\ 0 \\ F_{6x} \\ F_{6y} \\ M_6 \\ 2000 \\ 0 \\ 0 \\ F_{8x} \\ F_{8y} \\ M_8 \end{bmatrix}$$

Eliminando las filas y columnas respectivas 1, 6 y 8:

$$\begin{bmatrix}
11522560 & 0 & 0 & -161280 & 0 & -403200 & 0 & 0 & 0 & -11200000 & 0 & 0 & 0 & 0 & 0 \\
0 & 44820160 & 100800 & 0 & -22400000 & 0 & 0 & 0 & 0 & 0 & -20160 & 100800 & 0 & 0 & 0 \\
0 & 100800 & 3360000 & 403200 & 0 & 672000 & 0 & 0 & 0 & 0 & -100800 & 336000 & 0 & 0 & 0 \\
-161280 & 0 & 403200 & 11361280 & 0 & 403200 & -11200000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -22400000 & 0 & 0 & 22420160 & 100800 & 0 & -20160 & 100800 & 0 & 0 & 0 & 0 & 0 & 0 \\
-403200 & 0 & 672000 & 403200 & 100800 & 2016000 & 0 & -100800 & 336000 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -11200000 & 0 & 0 & 11361280 & 0 & 403200 & -161280 & 0 & 403200 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -20160 & -100800 & 0 & 22420160 & -100800 & 0 & -224000000 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 100800 & 336000 & 403200 & -100800 & 2016000 & -403200 & 0 & 672000 & 0 & 0 & 0 \\
-11200000 & 0 & 0 & 0 & 0 & 0 & -161280 & 0 & -403200 & 30189226.67 & 0 & 0 & -18666666.67 & 0 & 0 \\
0 & -20160 & 100800 & 0 & 0 & 0 & 0 & -22400000 & 0 & 0 & 44913493.33 & 179200 & 0 & -93333.33333 & 280000 \\
0 & 100800 & 336000 & 0 & 0 & 0 & 403200 & 0 & 672000 & 0 & 179200 & 4480000 & 0 & -280000 & 560000 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -18666666.67 & 0 & 0 & 18827946.67 & 0 & 403200 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -93333.33333 & -280000 & 0 & 22493333.33 & -280000 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 280000 & 560000 & 403200 & -280000 & 2464000
\end{bmatrix}
\begin{bmatrix} u_2 \\ v_2 \\ \theta_2 \\ u_3 \\ v_3 \\ \theta_3 \\ u_4 \\ v_4 \\ \theta_4 \\ u_5 \\ v_5 \\ \theta_5 \\ u_7 \\ v_7 \\ \theta_7 \end{bmatrix}
=
\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ -4000 \\ 0 \\ 0 \\ 0 \\ 500 \\ 0 \\ 0 \\ 0 \\ 2000 \\ 0 \\ 0 \end{bmatrix}$$

B. Resolución con MATLAB

```
>> K = [11522560 0 0 -161280 0 -403200 0 0 0 -11200000 0 0 0 0 0; 0 44820160 100800
0 -22400000 0 0 0 0 0 -20160 100800 0 0 0; 0 100800 3360000 403200 0 672000 0 0 0 0
-100800 336000 0 0 0; -161280 0 403200 11361280 0 403200 -11200000 0 0 0 0 0 0 0 0;
0 -22400000 0 0 22420160 100800 0 -20160 100800 0 0 0 0 0 0; -403200 0 672000 403200
100800 2016000 0 -100800 336000 0 0 0 0 0 0; 0 0 0 -11200000 0 0 11361280 0 403200
-161280 0 403200 0 0 0; 0 0 0 0 -20160 -100800 0 22420160 -100800 0 -2240000 0 0 0
0; 0 0 0 0 100800 336000 403200 -100800 2016000 -403200 0 672000 0 0 0; -11200000
0 0 0 0 0 -161280 0 -403200 30189226.67 0 0 -18666666.67 0 0; 0 -20160 100800 0 0
0 0 -22400000 0 0 4491349.33 179200 0 -93333.33333 280000; 0 100800 336000 0 0 0
403200 0 672000 0 179200 4480000 0 -280000 560000; 0 0 0 0 0 0 0 0 0 -18666666.67
0 0 18827946.67 0 403200; 0 0 0 0 0 0 0 0 0 0 -93333.33333 -280000 0 22493333.33
-280000; 0 0 0 0 0 0 0 0 0 0 280000 560000 403200 -280000 2464000}

K =

  1.0e+007 *

  Columns 1 through 12

  1.1523        0        0  -0.0161        0  -0.0403        0        0        0  -1.1200        0        0
       0   4.4820   0.0101        0  -2.2400        0        0        0        0        0  -0.0020   0.0101
       0   0.0101   0.3360   0.0403        0   0.0672        0        0        0        0  -0.0101   0.0336
 -0.0161        0   0.0403   1.1361        0   0.0403  -1.1200        0        0        0        0        0
       0  -2.2400        0        0   2.2420   0.0101        0  -0.0020   0.0101        0        0        0
 -0.0403        0   0.0672   0.0403   0.0101   0.2016        0  -0.0101   0.0336        0        0        0
       0        0        0  -1.1200        0        0   1.1361        0   0.0403  -0.0161        0   0.0403
       0        0        0        0  -0.0020  -0.0101        0   2.2420  -0.0101        0  -0.2240        0
       0        0        0        0   0.0101   0.0336   0.0403  -0.0101   0.2016  -0.0403        0   0.0672
 -1.1200        0        0        0        0        0  -0.0161        0  -0.0403   3.0189        0        0
       0  -0.0020   0.0101        0        0        0        0  -2.2400        0        0   0.4491   0.0179
       0   0.0101   0.0336        0        0        0   0.0403        0   0.0672        0   0.0179   0.4480
       0        0        0        0        0        0        0        0        0  -1.8667        0        0
       0        0        0        0        0        0        0        0        0        0  -0.0093  -0.0280
       0        0        0        0        0        0        0        0        0        0   0.0280   0.0560

  Columns 13 through 15

        0         0         0         0
        0         0         0         0
        0         0         0         0
        0         0         0         0
        0         0         0         0
        0         0         0         0
        0         0         0         0
        0         0         0         0
        0         0         0         0
  -1.8667         0         0         0
        0   -0.0093    0.0280         0
        0   -0.0280    0.0560         0
   1.8828         0    0.0403
        0    2.2493   -0.0280
   0.0403   -0.0280    0.2464
```

```
F =
           0
           0
           0
           0
        -400
           0
           0
           0
         500
           0
           0
           0
        2000
           0
           0

>> U = inv(K)*F

U =
    0.0060
   -0.0000
   -0.0008
    0.0077
   -0.0000
   -0.0001
    0.0077
    0.0000
    0.0001
    0.0060
    0.0002
   -0.0005
    0.0061
   -0.0000
   -0.0009

>> KT = [ 161280 0 -403200 -161280 0 -403200 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0
22400000 0 0 -22400000 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; -403200 0 1344000 403200
0 672000 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; -161280 0 403200 11522560 0 0 -161280
0 -403200 0 0 0 -11200000 0 0 0 0 0 0 0 0 0 0; 0 -22400000 0 0 44820160 100800
0 -22400000 0 0 0 0 0 -20160 100800 0 0 0 0 0 0 0 0 0; -403200 0 672000 0 100800
3360000 403200 0 672000 0 0 0 0 -100800 336000 0 0 0 0 0 0 0 0 0; 0 0 0 -1612280 0
403200 11361280 0 403200 -11200000 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 -22400000 0 0
22420160 100800 0 -20160 100800 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 -403200 0 672000 403200
100800 2016000 0 -100800 336000 0 0 0 0 0 0 0 0 0 0 0, 0 0 0 0 0 0 -11200000 0 0
11361280 0 403200 -161280 0 403200 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 -20160 -100800
0 22420160 -100800 0 -224000000 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 100800 336000
403200 -100800 2016000 -403200 0 672000 0 0 0 0 0 0 0 0 0; 0 0 0 -11200000 0 0 0 0 0
-161280 0 -403200 30189226.67 0 0 -161280 0 403200 -18666666.67 0 0 0 0 0; 0 0 0 0
-20160 100800 0 0 0 0 -22400000 0 0 44913493.33 179200 0 -22400000 0 0 93333.33333
280000 0 0 0; 0 0 0 0 100800 336000 0 0 0 403200 0 672000 0 179200 4480000 -403200
0 672000 0 -280000 560000 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 -161280 0 -403200 161280
0 –403200 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 -224000000 0 0 22400000 0 0 0 0 0
0 0; 0 0 0 0 0 0 0 0 0 0 0 0 403200 0 672000 -403200 0 1344000 0 0 0 0 0 0; 0 0 0 0
0 0 0 0 0 0 0 0 -18666666.67 0 0 0 0 0 18827946.67 0 403200 -161280 0 403200; 0 0
0 0 0 0 0 0 0 0 0 0 0 -93333.33333 -280000 0 0 0 0 22493333.33 -280000 0 -22400000
0; 0 0 0 0 0 0 0 0 0 0 0 0 0 280000 560000 0 0 0 403200 -280000 2464000 -403200 0
672000; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -161280 0 -403200 161280 0 -403200; 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -22400000 0 0 22400000 0; 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 103200 0 672000 -403200 0 1344000]
```

```
KT =

   1.0e+008 *

  Columns 1 through 12

    0.0016         0   -0.0040   -0.0016         0   -0.0040         0         0         0         0         0         0
         0    0.2240         0         0   -0.2240         0         0         0         0         0         0         0
   -0.0040         0    0.0134    0.0040         0    0.0067         0         0         0         0         0         0
   -0.0016         0    0.0040    0.1152         0         0   -0.0016         0   -0.0040         0         0         0
         0   -0.2240         0         0    0.4482    0.0010         0   -0.2240         0         0         0         0
   -0.0040         0    0.0067         0    0.0010    0.0336    0.0040         0    0.0067         0         0         0
         0         0         0   -0.0161         0    0.0040    0.1136         0    0.0040   -0.1120         0         0
         0         0         0         0   -0.2240         0         0    0.2242   -0.0010         0   -0.0002    0.0010
         0         0         0   -0.0040         0    0.0067    0.0040    0.0010    0.0202         0   -0.0010    0.0034
         0         0         0         0         0         0   -0.1120         0         0    0.1136         0    0.0040
         0         0         0         0         0         0         0   -0.0002   -0.0010         0    0.2242   -0.0010
         0         0         0         0         0         0         0    0.0010    0.0034    0.0040   -0.0010    0.0202
         0         0         0   -0.1120         0         0         0         0         0   -0.0016         0   -0.0040
         0         0         0         0   -0.0002    0.0010         0         0         0         0   -0.2240         0
         0         0         0         0    0.0010    0.0034         0         0         0    0.0040         0    0.0067
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0

  Columns 13 through 24

         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
   -0.1120         0         0         0         0         0         0         0         0         0         0         0
         0   -0.0002    0.0010         0         0         0         0         0         0         0         0         0
         0   -0.0010    0.0034         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
   -0.0016         0    0.0040         0         0         0         0         0         0         0         0         0
         0   -2.2400         0         0         0         0         0         0         0         0         0         0
   -0.0040         0    0.0067         0         0         0         0         0         0         0         0         0
    0.3019         0         0   -0.0016         0    0.0040   -0.1867         0         0         0         0         0
         0    0.4491    0.0018         0   -0.2240         0         0    0.0009    0.0028         0         0         0
         0    0.0018    0.0448   -0.0040         0    0.0067         0   -0.0028    0.0056         0         0         0
   -0.0016         0   -0.0040    0.0016         0   -0.0040         0         0         0         0         0         0
         0   -2.2400         0         0    0.2240         0         0         0         0         0         0         0
    0.0040         0    0.0067   -0.0040         0    0.0134         0         0         0         0         0         0
   -0.1867         0         0         0         0         0    0.1883         0    0.0040   -0.0016         0    0.0040
         0   -0.0009   -0.0028         0         0         0         0    0.2249   -0.0028         0   -0.2240         0
         0    0.0028    0.0056         0         0         0    0.0040   -0.0028    0.0246   -0.0040         0    0.0067
         0         0         0         0         0         0   -0.0016         0   -0.0040    0.0016         0   -0.0040
         0         0         0         0         0         0         0   -0.2240         0         0    0.2240         0
         0         0         0         0         0         0    0.0010         0    0.0067   -0.0040         0    0.0134
```

```
>> U = [ 0; 0; 0; 0.0060; -0.000172309; -0.0008; 0.0077; -0.00350935; -0.0001;
0.0077; 0.0000112; 0.0001; 0.0060; 0.0002; -0.0005; 0; 0; 0; 0.0061; -0.0000174;
-0.0009; 0; 0; 0]

U =
         0
         0
         0
    0.0060
   -0.0002
   -0.0008
    0.0077
   -0.0035
   -0.0001
    0.0077
    0.0000
    0.0001
    0.0060
    0.0002
   -0.0005
         0
         0
         0
    0.0061
   -0.0000
   -0.0009
         0
         0
         0

>> F = KT * U

F =

  1.0e+004 *

   -0.0645
    0.3860
    0.1882
    0.0734
    7.0751
    0.0144
   -0.8795
   -7.4821
   -0.0375
    0.0113
   -4.4478
    0.0163
   -0.1213
    0.8311
    0.0182
   -0.0766
   -4.4800
    0.2083
    0.2488
   -0.0018
    0.0023
   -0.0621
    0.0390
    0.0025
```

Desplazamientos Nodales:

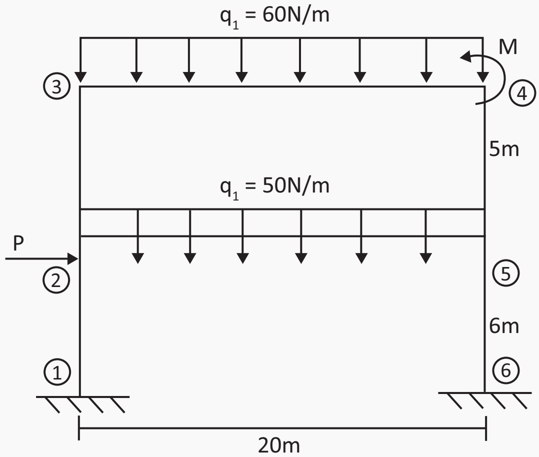
$u_1 = 0m$
$v_1 = 0m$
$\theta_1 = 0rad$
$u_2 = 0.005937122m$
$v_2 = -0.000172309m$
$\theta_2 = -0.00084053rad$
$u_3 = 0.007576456m$
$v_3 = -0.000350935m$
$\theta_3 = -5.24127E-05rad$
$u_4 = 0.007567916m$
$v_4 = 1.1225E-05m$
$\theta_4 = 0.000136983rad$
$u_5 = 0.006000897m$
$v_5 = 1.11704E-05m$
$\theta_5 = -0.000526852rad$
$u_6 = 0m$
$v_6 = 0m$
$\theta_6 = 0rad$
$u_7 = 0.006074512m$
$v_7 = -1.74329E-05m$
$\theta_7 = -0.000877584rad$
$u_8 = 0m$
$v_8 = 0m$
$\theta_8 = 0rad$

Fuerzas:

$F_{1x} = -765.062808N$
$F_{1y} = -1325.5109N$
$M_1 = 16.65567789Nm$
$F_{2x} = 5000N$
$F_{2y} = -3.69482E-13N$
$M_2 = 2.84217E-14Nm$
$F_{3x} = 0N$
$F_{3y} = 7.10543E-15N$
$M_3 = 600Nm$
$F_{4x} = -4233.09764N$
$F_{4y} = -55.44773342N$
$M_4 = 145.7337248Nm$
$F_{5x} = -1.839551812N$
$F_{5y} = 1380.958634N$
$M_5 = 29.83718616Nm$
$F_{6x} = -1.839551812N$
$F_{6y} = 1380.958634N$
$M_6 = 29.83718616Nm$
$F_{7x} = -1.839551812N$
$F_{7y} = 1380.958634N$
$M_7 = 29.83718616Nm$
$F_{8x} = -1.839551812N$
$F_{8y} = 1380.958634N$
$M_8 = 29.83718616Nm$

EJERCICIO 8

Determinar los Desplazamientos y las Cargas generadas en cada nodo, en la estructura mostrada, según la secuencia indicada.



$E = 300GPa$

$I = 8 \times 10^{-6} m^4$

$A = 4 \times 10^{-4} m^2$

$P = 5000N$

$M = 800NM$

Nodos: 1 – 2; 2 – 3; 3 – 4; 4 – 5; 5 – 6; 2 – 5

A. Resolución

Elemento	Nodo	θ	C	S	C²	S²	SC
1	1 – 2	90°	0	1	0	1	0
2	2 – 3	90°	0	1	0	1	0
3	3 – 4	0°	1	0	1	0	0
4	4 – 5	270°	0	–1	0	1	0
5	5 – 6	270°	0	–1	0	1	0
6	2 – 5	0°	1	0	1	0	0

$$K_{1-2} = \frac{E}{L} = \frac{(300 \times 10^9)}{6m} = 50000000000[M]$$

$$K_{1-2} = \begin{bmatrix}
133333.3385 & 0 & -400000 & -133333.3385 & 0 & -400000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 20000000 & 0 & 0 & -20000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-400000 & 0 & 1600000 & 400000 & 0 & 800000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-133333.3385 & 0 & 400000 & 133333.3385 & 0 & 400000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -20000000 & 0 & 0 & 20000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-400000 & 0 & 800000 & 400000 & 0 & 1600000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{2-3} = \frac{E}{L} = \frac{\left(300\times10^{9}\right)}{5m} = 60000000000000$$

$$K_{2-3} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 230400 & 0 & -576000 & -230400 & 0 & -576000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 24000000 & 0 & 0 & -24000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -576000 & 0 & 1920000 & 576000 & 0 & 960000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -230400 & 0 & 576000 & 2304000 & 0 & 576000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -24000000 & 0 & 0 & 24000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -576000 & 0 & 960000 & 576000 & 0 & 1920000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{3-4} = \frac{E}{L} = \frac{\left(280\times10^{9}\right)}{12m} = 25000000000000$$

$$K_{3-4} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 10000000 & 0 & 0 & -10000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 16666.66667 & 100000 & 0 & -16666.66667 & 100000 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 100000 & 800000 & 0 & -100000 & 4000000 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -10000000 & 0 & 0 & 10000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -16666.66667 & -100000 & 0 & 16666.66667 & 100000 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 100000 & 400000 & 0 & -100000 & 800000 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{4-5} = \frac{E}{L} = \frac{\left(300 \times 10^{9}\right)}{5\text{m}} = 60000000000$$

$$K_{4-5} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 230400 & 0 & 576000 & -230400 & 0 & 576000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 24000000 & 0 & 0 & -24000000 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 576000 & 0 & 1920000 & -576000 & 0 & 960000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -230400 & 0 & -576000 & 230400 & 0 & -576000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -24000000 & 0 & 0 & 24000000 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 576000 & 0 & 960000 & -576000 & 0 & 1920000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{2-5} = \frac{E}{L} = \frac{\left(300 \times 10^{9}\right)}{12\text{m}} = 25000000000$$

$$K_{2-5} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 10000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -10000000 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 16666.66667 & 100000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -16666.66667 & 100000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 100000 & 800000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -100000 & 400000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -10000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 10000000 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -16666.66667 & -100000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 16666.66667 & -100000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 100000 & 400000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -100000 & 800000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{5-6} = \frac{E}{L} = \frac{\left(300 \times 10^{9}\right)}{6\text{m}} = 50000000000$$

$$K_{5-6} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 133333.3333 & 0 & 400000 & -133333.3333 & 0 & 400000 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 20000000 & 0 & 0 & -20000000 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 400000 & 0 & 1600000 & -400000 & 0 & 800000 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -133333.3333 & 0 & -400000 & 133333.3333 & 0 & -400000 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -20000000 & 0 & 0 & 20000000 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -400000 & 0 & 800000 & -400000 & 0 & 1600000
\end{bmatrix}$$

B. Resolución con MATLAB

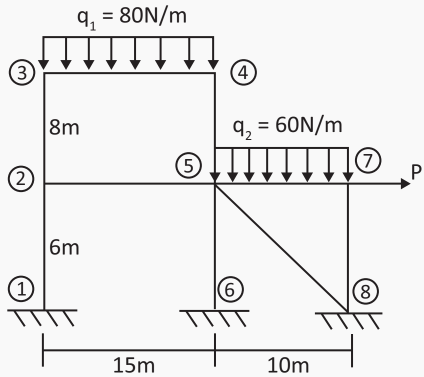
```
>> KT = [ 133333.3333 0 -400000 -133333.3333 0 -400000 0 0 0 0 0 0 0 0 0 0 0 0; 0 20000000
0 0 -20000000 0 0 0 0 0 0 0 0 0 0 0 0 0; -400000 0 1600000 400000 0 800000 0 0 0 0 0 0 0
0 0 0 0 0; -133333.3333 0 400000 10363733.34 0 -176000 -2304400 0 -576000 0 0 0 -10000000
0 0 0 0 0; 0 -20000000 0 0 44016666.67 100000 0 -24000000 0 0 0 0 0 -16666.66667 100000 0
0 0; -400000 0 800000 -176000 100000 4320000 576000 0 960000 0 0 0 0 -100000 400000 0 0 0;
0 0 0 -230400 0 576000 10230400 0 576000 -10000000 0 0 0 0 0 0 0 0; 0 0 0 0 -24000000 0 0
24016666.67 100000 0 -16666.66667 100000 0 0 0 0 0 0; 0 0 0 -576000 0 960000 576000 100000
2720000 0 -100000 400000 0 0 0 0 0 0; 0 0 0 0 0 0 -10000000 0 0 10230400 0 576000 -230400
0 576000 0 0 0; 0 0 0 0 0 0 0 -16666.66667 -100000 0 24016666.67 -100000 0 -24000000 0
0 0 0; 0 0 0 0 0 0 0 100000 400000 576000 -100000 2720000 -576000 0 960000 0 0 0; 0 0
0 -10000000 0 0 0 0 0 -230400 0 -576000 10363733.33 0 -176000 -133333.3333 0 400000; 0
0 0 0 -16666.66667 -100000 0 0 0 0 -24000000 0 0 44016666.67 -100000 0 -20000000 0; 0 0
0 0 100000 400000 0 0 0 576000 0 960000 -176000 -100000 4320000 -400000 0 800000; 0 0 0
0 0 0 0 0 0 0 0 0 –133333.3333 0 -400000 133333.3333 0 -400000; 0 0 0 0 0 0 0 0 0 0 0 0
0 -20000000 0 0 20000000 0; 0 0 0 0 0 0 0 0 0 0 0 0 -400000 0 800000 -400000 0 1600000]

KT =

  1.0e+007 *

  Columns 1 through 12

   0.0133         0   -0.0400   -0.0133         0   -0.0400         0         0         0         0         0         0
        0    2.0000         0         0   -2.0000         0         0         0         0         0         0         0
  -0.0400         0    0.1600    0.0400         0    0.0800         0         0         0         0         0         0
  -0.0133         0    0.0400    1.0364         0   -0.0176   -0.2304         0   -0.0576         0         0         0
        0   -2.0000         0         0    4.4017    0.0100         0   -2.4000         0         0         0         0
  -0.0400         0    0.0800   -0.0176    0.0100    0.4320    0.0576         0    0.0960         0         0         0
        0         0         0   -0.0230         0    0.0576    1.0230         0    0.0576   -1.0000         0         0
        0         0         0         0   -2.4000         0         0    2.4017    0.0100         0   -0.0017    0.0100
        0         0         0   -0.0576         0    0.0960    0.0576    0.0100    0.2720         0   -0.0100    0.0400
        0         0         0         0         0         0   -1.0000         0         0    1.0230         0    0.0576
        0         0         0         0         0         0         0   -0.0017   -0.0100         0    2.4017   -0.0100
        0         0         0         0         0         0         0    0.0100    0.0400    0.0576   -0.0100    0.2720
        0         0         0   -1.0000         0         0         0         0         0   -0.0230         0   -0.0576
        0         0         0         0   -0.0017   -0.0100         0         0         0         0   -2.4000         0
        0         0         0         0    0.0100    0.0400         0         0         0    0.0576         0    0.0960
        0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0
```

```
Columns 13 through 18

        0         0         0         0         0         0
        0         0         0         0         0         0
        0         0         0         0         0         0
  -1.0000         0         0         0         0         0
        0   -0.0017    0.0100         0         0         0
        0   -0.0100    0.0400         0         0         0
        0         0         0         0         0         0
        0         0         0         0         0         0
        0         0         0         0         0         0
  -0.0230         0    0.0576         0         0         0
        0   -2.4000         0         0         0         0
  -0.0576         0    0.0960         0         0         0
   1.0364         0   -0.0176   -0.0133         0    0.0400
        0    4.4017   -0.0100         0   -2.0000         0
  -0.0176   -0.0100    0.4320   -0.0400         0    0.0800
  -0.0133         0   -0.0400    0.0133         0   -0.0400
        0   -2.0000         0         0    2.0000         0
  -0.0400         0    0.0800   -0.0400         0    0.1600

>> KR = [10363733.34 0 -176000 -230400 0 -576000 0 0 0 -10000000 0 0; 0 44016666.67
100000 0 -24000000 0 0 0 0 0 -16666.66667 100000; -176000 100000 4320000 576000 0
960000 0 0 0 0 –100000 400000; -230400 0 576000 10230400 0 576000 –10000000 0 0 0 0
0; 0 -24000000 0 0 24016666.67 100000 0 -16666.66667 100000 0 0 0; -576000 0 960000
576000 100000 2720000 0 -100000 400000 0 0 0; 0 0 0 -10000000 0 0 10230400 0 576000
-230400 0 576000; 0 0 0 0 -16666.66667 -100000 0 24016666.67 -100000 0 -240000000 0;
0 0 0 0 100000 400000 576000 -100000 2720000 -576000 0 960000; -10000000 0 0 0 0 0
-230400 0 -576000 10363733.33 0 -176000; 0 -16666.66667 -100000 0 0 0 0 -24000000 0 0
44016666.67 -100000; 0 100000 400000 0 0 0 576000 0 960000 -176000 -100000 4320000]

KR =

  1.0e+008 *

   0.1036         0   -0.0018   -0.0023         0   -0.0058         0         0         0   -0.1000         0         0
        0    0.4402    0.0010         0   -0.2400         0         0         0         0         0   -0.0002    0.0010
  -0.0018    0.0010    0.0432    0.0058         0    0.0096         0         0         0         0   -0.0010    0.0040
  -0.0023         0    0.0058    0.1023         0    0.0058   -0.1000         0         0         0         0         0
        0   -0.2400         0         0    0.2402    0.0010         0   -0.0002    0.0010         0         0         0
  -0.0058         0    0.0096    0.0058    0.0010    0.0272         0   -0.0010    0.0040         0         0         0
        0         0         0   -0.1000         0         0    0.1023         0    0.0058   -0.0023         0    0.0058
        0         0         0         0   -0.0002   -0.0010         0    0.2402   -0.0010         0   -2.4000         0
        0         0         0         0    0.0010    0.0040    0.0058   -0.0010    0.0272   -0.0058         0    0.0096
  -0.1000         0         0         0         0         0   -0.0023         0   -0.0058    0.1036         0   -0.0018
        0   -0.0002   -0.0010         0         0         0         0   -0.2400         0         0    0.4402   -0.0010
        0    0.0010    0.0040         0         0         0    0.0058         0    0.0096   -0.0018   -0.0010    0.0432

>> f = [5000; -300; -600; 0; -360; -720; 0; -360; 1520; 0; -300; 600]

f =
        5000
        -300
        -600
           0
        -360
        -720
           0
        -360
        1520
           0
        -300
         600
```

```
>> u = inv(KR)*f

u =
    0.0303
    0.0000
   -0.0038
    0.0418
    0.0000
   -0.0013
    0.0418
    0.0001
   -0.0004
    0.0300
    0.0000
   -0.0038

>>  U  =  [0;  0;  0;  0.0303;  -0.0000134;  0.0418;  0.00000553;  -0.0013;  0.0418;
-0.0001015; -0.000414511; -0.004; 0.0300; -0.0000794; -0.0038; 0; 0; 0]

U =
         0
         0
         0
    0.0303
   -0.0000
    0.0418
    0.0000
   -0.0013
    0.0418
   -0.0001
   -0.0004
   -0.0040
    0.0300
   -0.0001
   -0.0038
         0
         0
         0

>> F = KT * U

F =

  1.0e+005 *

   -0.2076
    0.0027
    0.4556
   -0.1743
    0.3441
    2.1386
    0.4224
   -0.2711
    1.3469
   -0.1250
   -0.1181
   -0.1524
    0.1091
    0.0265
   -0.0887
   -0.0248
    0.0159
   -0.1504
```

EJERCICIO 9

Determinar los Desplazamientos y las Cargas generadas en cada nodo, en la estructura mostrada, según la secuencia indicada.



$E = 250GPa$

$I = 8 \times 10^{-6} m^4$

$A = 4 \times 10^{-4} m^2$

$P = 2500N$

Nodos: 1 – 2; 2 – 3; 3 – 4; 4 – 5; 5 – 6; 2 – 5; 5 – 7; 5 – 8; 7 – 8

A. Resolución

Elemento	Nodo	θ	C	S	C²	S²	SC
1	1 – 2	90°	0	1	0	1	0
2	2 – 3	90°	0	1	0	1	0
3	3 – 4	0°	1	0	1	0	0
4	4 – 5	270°	0	–1	0	1	0
5	2 – 5	270°	0	–1	0	1	0
6	5 – 6	0°	1	0	1	0	0
7	5 – 7	0°	1	0	1	0	0
8	7 – 8	270°	0	–1	0	1	0
9	5 – 8	315°	0.707	–0.707	0.499	0.499	–0.499

$$K_{1-2} = \frac{E}{L} = \frac{(250 \times 10^9)}{6m} = 41666666667[M]$$

$$K_{1-2} = 10^7 \begin{bmatrix}
-0.03330 & 0.0111 & 0 & 0 & -0.01110 & -0.0333 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1.6667 & 0 & 0 & -1.66670 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0.1333 & 0.0333 & 0 & 0 & 0.0667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0.0333 & 0.0111 & 0 & 0 & 0.0333 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -1.6667 & 0 & 0 & 1.6667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.0333 & 0 & 0.0667 & 0.0333 & 0 & 0.1333 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{2-3} = \frac{E}{L} = \frac{\left(250 \times 10^{9}\right)}{8\text{m}} = 31250000000[\text{M}]$$

$$K_{2-3} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -187500 & -46875 & 0 & -187500 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 12500000 & 0 & 0 & -12500000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -187500 & 0 & 1000000 & 187500 & 0 & 500000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -46875 & 0 & 187500 & 46875 & 0 & 187500 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -12500000 & 0 & 0 & 12500000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -187500 & 0 & 500000 & 187500 & 0 & 1000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{3-4} = \frac{E}{L} = \frac{\left(250 \times 10^{9}\right)}{15\text{m}} = 16666666667[\text{M}]$$

$$K_{3-4} = 10^{6}\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 6.6667 & 0 & 0 & -0.6667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0071 & 0.0533 & 0 & -0.0071 & 0.0533 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0533 & 0.5333 & 0 & -0.0533 & 0.2667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -6.6667 & 0 & 0 & 6.6667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0071 & -0.0533 & 0 & 0.0071 & -0.0533 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0533 & 0.2667 & 0 & -0.0533 & 0.5333 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{4-5} = \frac{E}{L} = \frac{(250\times10^{9})}{8\text{m}} = 31250000000[\text{M}]$$

$$K_{4-5} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 187500 & -46875 & 0 & 187500 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 12500000 & 0 & 0 & -12500000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 187500 & 0 & 1000000 & -187500 & 0 & 500000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -46875 & 0 & -187500 & 46875 & 0 & -187500 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -12500000 & 0 & 0 & 12500000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 187500 & 0 & 500000 & -187500 & 0 & 1000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{2-5} = \frac{E}{L} = \frac{(250\times10^{9})}{15\text{m}} = 16666666667[\text{M}]$$

$$K_{2-5} = 10^{6}\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 6.6667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -6.6667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0.0071 & 0.0533 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0071 & 0.0533 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0.0533 & 0.5333 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0533 & 0.2667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -6.6667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 6.6667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -0.0071 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0071 & -0.0533 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0.0533 & 0.2667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0533 & 0.5333 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{5-6} = \frac{E}{L} = \frac{(250 \times 10^9)}{6m} = 41666666667[M]$$

$$K_{5-6} = 10^7 \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0333 & -0.0111 & 0 & 0.0333 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.6667 & 0 & 0 & -1.6667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0333 & 0 & 0.1333 & -0.0333 & 0 & 0.0667 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0111 & 0 & -.0333 & 0.0111 & 0 & -0.0333 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.6667 & 0 & 0 & 1.6667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0333 & 0 & 0.0667 & -0.0333 & 0 & 0.1333 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{5-7} = \frac{E}{L} = \frac{(250 \times 10^9)}{10m} = 25000000000[M]$$

$$K_{5-7} = 10^7 \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0024 & 0.0120 & 0 & 0 & 0 & 0 & -0.0024 & 0.0120 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0120 & 0.0800 & 0 & 0 & 0 & 0 & -0.0120 & 0.0400 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0.0024 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0024 & -0.0120 & 0 & 0 & 0 & 0 & -0.0120 & -0.0120 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0120 & 0.0400 & 0 & 0 & 0 & 0 & 0 & 0.0800 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{7-8} = \frac{E}{L} = \frac{(250 \times 10^9)}{6m} = 41666666667[M]$$

$$K_{7-8} = 10^7 \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0333 & -0.0111 & 0 & 0.0333 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.6667 & 0 & 0 & -1.6667 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0333 & 0 & 0.1333 & -0.0333 & 0 & 0.0667 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0111 & 0 & -0.0333 & 0.0111 & 0 & -0.0333 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.6667 & 0 & 0 & 1.6667 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0333 & 0 & 0.0667 & -0.0333 & 0 & 0.1333
\end{bmatrix}$$

$$K_{5-8} = \frac{E}{L} = \frac{(250 \times 10^9)}{11.66m} = 17680339463[M]$$

$$K_{5-8} = 10^6 \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3.5350 & -3.5308 & 0.0424 & 0 & 0 & 0 & 0 & 0 & 0 & -3.5393 & 3.5308 & 0.0424 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3.5308 & 3.5393 & 0.0424 & 0 & 0 & 0 & 0 & 0 & 0 & 3.5308 & -3.5393 & 0.0424 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0424 & 0.0424 & 0.5658 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0424 & -0.0424 & 0.2829 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -3.5393 & 3.5308 & -0.0424 & 0 & 0 & 0 & 0 & 0 & 0 & 3.5393 & -3.5308 & -0.0424 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3.5308 & -3.5393 & -0.0424 & 0 & 0 & 0 & 0 & 0 & 0 & -3.5308 & 3.5393 & -0.0424 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0424 & 0.0424 & 0.2829 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0424 & -0.0424 & 0.5658
\end{bmatrix}$$

B. Resolución con MATLAB

```
>> KT = (10^7)*[ 0 0 -0.0333 -0.0111 0 -0.0333 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0; 0 1.6667 0 0 -1.6667 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; -0.0333 0 0.1333
0.0333 0 0.0667 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; -0.0111 0 0.0333 0.6778 0
0.0146 -0.0047 0 -0.0187 0 0 0 -0.6667 0 0 0 0 0 0 0 0 0 0; 0 -1.6667 0 0 2.9174
0.0053 0 -1.2500 0 0 0 0 0 -0.00007 0.0053 0 0 0 0 0 0 0 0 0; -0.0333 0 0.0667
0.0146 0.0053 0.2867 0.0187 0 0.0500 0 0 0 0 -0.0053 0.0267 0 0 0 0 0 0 0 0 0;
0 0 0 -0.0047 0 0.0187 0 0 0.0187 -0.6667 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0
-1.2500 0 0.6714 1.2507 0.0053 0 -0.0007 0.0053 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
-0.01787 0 0.0500 0 0.0053 0.1533 0 -0.0053 0.0267 0 0 0.0187 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0.0187 0 0 0.6667 0 0.0187 -0.0047 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0
-0.6667 -0.0007 -0.0053 0 1.2507 -0.0053 0 -1.2500 0 0 0 0 0 0 0 0 0; 0 0 0 0 0
0 0 0.0053 0.0267 0.00187 -0.0053 -0.1533 -0.0187 0 0.0500 0 0 0 0 0 0 0 0; 0 0
0 -0.6667 0 0 0 0 0 -0.0047 0 -0.0187 1.3582 0.3136 0.0188 0.0111 0 0.0300 -1 0 0
-0.3539 0.3531 0.0042; 0 0 0 0 -0.0007 -0.0053 0 0 0 0 -1.2500 0 -0.3531 3.2737
0.0109 0 -1.6667 0 0 -0.0024 0.0120 0.3531 -0.3539 0.0042; 0 0 0 0 0.0053 0.0267 0
0 0 0.0187 0 0.0500 0.0188 0.0109 0.4232 -0.0333 0 0.0667 0 -0.0120 0.0400 -0.0042
-0.0042 0.0283; 0 0 0 0 0 0 0 0 0 0 0 0 0 -0.0111 0 -0.0333 0.0111 0 -0.0333 0 0 0 0
0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 -1.6667 0 0 1.6667 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0
0 0 0 0.0333 0 0.0667 -0.0333 0 0.1333 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 -1 0 0
0 0 0 1 0 0.0333 -0.0111 0 0.0333; 0 0 0 0 0 0 0 0 0 0 0 0 0 -0.0024 -0.0120 0 0 0
0 1.6691 -0.0120 0 -1.6667 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 -0.3539 0.3531 -0.0042 0 0 0
-0.0111 0 -0.0333 0.3650 -0.3531 -0.0376; 0 0 0 0 0 0 0 0 0 0 0 0 0 0.3531 -0.3539
-0.0042 0 0 0 0 -1.6667 0 -0.3531 2.0206 -0.0042; 0 0 0 0 0 0 0 0 0 0 0 0 0 0.0042
0.0042 0.0283 0 0 0 0.0333 0 0.0667 -0.0376 -0.0042 0.1899]

KT =

  1.0e+007 *

  Columns 1 through 12

         0         0   -0.0333   -0.0111         0   -0.0333         0         0         0         0         0         0
         0    1.6667         0         0   -1.6667         0         0         0         0         0         0         0
   -0.0333         0    0.1333    0.0333         0    0.0667         0         0         0         0         0         0
   -0.0111         0    0.0333    0.6778         0    0.0146   -0.0047         0   -0.0187         0         0         0
         0   -1.6667         0         0    2.9174    0.0053         0   -1.2500         0         0         0         0
   -0.0333         0    0.0667    0.0146    0.0053    0.2867    0.0187         0    0.0500         0         0         0
         0         0         0   -0.0047         0    0.0187         0         0    0.0187   -0.6667         0         0
         0         0         0         0   -1.2500         0    0.6714    1.2507    0.0053         0   -0.0007    0.0053
         0         0         0   -0.0179         0    0.0500         0    0.0053    0.1533         0   -0.0053    0.0267
         0         0         0         0         0         0    0.0187         0         0    0.6667         0    0.0187
         0         0         0         0         0         0   -0.6667   -0.0007   -0.0053         0    1.2507   -0.0053
         0         0         0         0         0         0         0    0.0053    0.0267    0.0019   -0.0053   -0.1533
         0         0         0   -0.6667         0         0         0         0         0   -0.0047         0   -0.0187
         0         0         0         0   -0.0007   -0.0053         0         0         0         0   -1.2500         0
         0         0         0         0    0.0053    0.0267         0         0         0    0.0187         0    0.0500
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0
```

```
Columns 13 through 24

       0         0         0         0         0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0         0         0         0         0
 -0.6667         0         0         0         0         0         0         0         0         0         0         0
       0   -0.0001    0.0053         0         0         0         0         0         0         0         0         0
       0   -0.0053    0.0267         0         0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0         0         0         0         0
       0         0    0.0187         0         0         0         0         0         0         0         0         0
 -0.0047         0         0         0         0         0         0         0         0         0         0         0
       0   -1.2500         0         0         0         0         0         0         0         0         0         0
 -0.0187         0    0.0500         0         0         0         0         0         0         0         0         0
  1.3582    0.3136    0.0188    0.0111         0    0.0300   -1.0000         0         0   -0.3539    0.3531    0.0042
 -0.3531    3.2737    0.0109         0   -1.6667         0         0   -0.0024    0.0120    0.3531   -0.3539    0.0042
  0.0188    0.0109    0.4232   -0.0333         0    0.0667         0   -0.0120    0.0400   -0.0042   -0.0042    0.0283
 -0.0111         0   -0.0333    0.0111         0   -0.0333         0         0         0         0         0         0
       0   -1.6667         0         0    1.6667         0         0         0         0         0         0         0
  0.0333         0    0.0667   -0.0333         0    0.1333         0         0         0         0         0         0
 -1.0000         0         0         0         0         0    1.0000         0    0.0333   -0.0111         0    0.0333
       0   -0.0024   -0.0120         0         0         0         0    1.6691   -0.0120         0   -1.6667         0
 -0.3539    0.3531   -0.0042         0         0         0   -0.0111         0   -0.0333    0.3650   -0.3531   -0.0376
  0.3531   -0.3539   -0.0042         0         0         0         0   -1.6667         0   -0.3531    2.0206   -0.0042
  0.0042    0.0042    0.0283         0         0         0    0.0333         0    0.0667   -0.0376   -0.0042    0.1899

>> KR = (10^7)*[ 0.6778 0 0.0146 -0.0047 0 -0.0187 0 0 0 -0.6667 0 0 0 0 0; 0
2.9174 0.0053 0 -1.2500 0 0 0 0 0 -0.0007 0.0053 0 0 0; 0.0146 0.0053 0.2867 0.0187
0 0.0500 0 0 0 0 -0.0053 0.0267 0 0 0; -0.0047 0 0.0187 0 0 0.0187 -0.6667 0 0 0
0 0 0 0 0; 0 -1.2500 0 0.6714 1.2507 0.0053 0 -0.0007 0.0053 0 0 0 0 0 0; -0.0187
0 0.0500 0 0.0053 0.1533 0 -0.0053 0.0267 0 0 0.0187 0 0 0; 0 0 0 0.0187 0 0
0.6667 0 0.0187 -0.0047 0 0 0 0 0; 0 0 0 -0.6667 -0.0007 -0.0053 0 1.2507 -0.0053
0 -1.2500 0 0 0 0; 0 0 0 0 0.0053 0.0267 0.0187 -0.0053 0.1533 -0.0187 0 0.0500 0
0 0; -0.6667 0 0 0 0 0 -0.0047 0 -0.0187 1.3582 0.3136 0.0188 -1 0 0; 0 -0.0007
-0.0053 0 0 0 0 -1.2500 0 -0.3531 3.2737 0.0109 0 -0.0024 0.0120; 0 0.0053 0.0267
0 0 0 0.0187 0 0.0500 0.0188 0.0109 0.4232 0 -0.0120 0.0400; 0 0 0 0 0 0 0 0 0 -1
0 0 1 0 0.0333; 0 0 0 0 0 0 0 0 0 0 -0.0024 -0.0120 0 1.6691 -0.0120; 0 0 0 0 0 0
0 0 0 0 0.0120 0.0400 0.0333 -0.0120 0.2133]

KR =

  1.0e+007 *

  Columns 1 through 12

  0.6778         0    0.0146   -0.0047         0   -0.0187         0         0         0   -0.6667         0         0
       0    2.9174    0.0053         0   -1.2500         0         0         0         0         0   -0.0007    0.0053
  0.0146    0.0053    0.2867    0.0187         0    0.0500         0         0         0         0   -0.0053    0.0267
 -0.0047         0    0.0187         0         0    0.0187   -0.6667         0         0         0         0         0
       0   -1.2500         0    0.6714    1.2507    0.0053         0   -0.0007    0.0053         0         0         0
 -0.0187         0    0.0500         0    0.0053    0.1533         0   -0.0053    0.0267         0         0    0.0187
       0         0         0    0.0187         0         0    0.6667         0    0.0187   -0.0047         0         0
       0         0         0   -0.6667   -0.0007   -0.0053         0    1.2507   -0.0053         0   -1.2500         0
       0         0         0         0    0.0053    0.0267    0.0187   -0.0053    0.1533   -0.0187         0    0.0500
 -0.6667         0         0         0         0         0   -0.0047         0   -0.0187    1.3582    0.3136    0.0188
       0   -0.0007   -0.0053         0         0         0         0   -1.2500         0   -0.3531    3.2737    0.0109
       0    0.0053    0.0267         0         0         0    0.0187         0    0.0500    0.0188    0.0109    0.4232
       0         0         0         0         0         0         0         0         0   -1.0000         0         0
       0         0         0         0         0         0         0         0         0         0   -0.0024   -0.0120
       0         0         0         0         0         0         0         0         0         0    0.0120    0.0400
```

```
Columns 13 through 15

       0         0         0
       0         0         0
       0         0         0
       0         0         0
       0         0         0
       0         0         0
       0         0         0
       0         0         0
       0         0         0
 -1.0000         0         0
       0   -0.0024    0.0120
       0   -0.0120    0.0400
  1.0000         0    0.0333
       0    1.6691   -0.0120
  0.0333   -0.0120    0.2133

>> f = [ 0; 0; 0; -600; 0; -1500; -600; 0; 1500; -300; 0; -500; -300; 2500; 500]

f =

           0
           0
           0
        -600
           0
       -1500
        -600
           0
        1500
        -300
           0
        -500
        -300
        2500
         500

>> U = inv(KR)*f

U =

   -0.0024
    0.0028
    0.0009
   -0.0070
    0.0066
   -0.0021
    0.0001
   -0.0065
    0.0007
   -0.0024
   -0.0027
   -0.0002
   -0.0024
    0.0002
    0.0008
```

Desplazamientos Nodales:

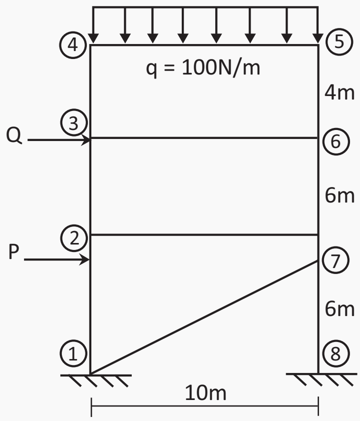
$$u_1 = 0m$$
$$v_1 = 0m$$
$$\theta_1 = 0rad$$
$$u_2 = 0.0028m$$
$$v_2 = -0.0003m$$
$$\theta_2 = 0.0202rad$$
$$u_3 = -0.3941m$$
$$v_3 = -0.0006m$$
$$\theta_3 = 0.0330rad$$
$$u_4 = -0.3953m$$
$$v_4 = 0.0010m$$
$$\theta_4 = 0.0454rad$$
$$u_5 = 0.0051m$$
$$v_5 = 0.0006m$$
$$\theta_5 = -0.0040rad$$
$$u_6 = 0m$$
$$v_6 = 0m$$
$$\theta_6 = 0rad$$
$$u_7 = 0.0062m$$
$$v_7 = -0.6290m$$
$$\theta_7 = -0.0354rad$$
$$u_8 = 0m$$
$$v_8 = 0m$$
$$\theta_8 = 0rad$$

Fuerzas:

$$F_{1x} = -0.0007KN$$
$$F_{1y} = 0.0005KN$$
$$M_1 = 0.0014KNm$$
$$F_{2x} = 0KN$$
$$F_{2y} = 0KN$$
$$M_2 = 0KNm$$
$$F_{3x} = -0.5271KN$$
$$F_{3y} = 0KN$$
$$M_3 = -0.0002KNm$$
$$F_{4x} = 0.5270N$$
$$F_{4y} = 0.0001KN$$
$$M_4 = 0.0149Nm$$
$$F_{5x} = -0.0037KN$$
$$F_{5y} = -0.0037KN$$
$$M_5 = 0.0148KNm$$
$$F_{6x} = 0.0001KN$$
$$F_{6y} = -0.0010KN$$
$$M_6 = -0.0001KNm$$
$$F_{7x} = -0.0001KN$$
$$F_{7y} = -1.0494KN$$
$$M_7 = 0KNm$$
$$F_{8x} = -0.0005KN$$
$$F_{8y} = 1.0499KN$$
$$M_8 = -0.0022KNm$$

Ejercicio 10

Determinar los Desplazamientos y las Cargas generadas en cada nodo, en la estructura mostrada, según la secuencia indicada.



$E = 300GPa$

$I = 6 \times 10^{-6} m^4$

$A = 5 \times 10^{-4} m^2$

$P = 3000N$

$Q = 5000N$

Nodos: 1 – 2; 2 – 3; 3 – 4; 4 – 5; 5 – 6; 6 – 7; 7 – 8; 3 – 6; 2 – 7; 1 – 7

A. Resolución

Elemento	Nodo	θ	C	S	C^2	S^2	SC
1	1 – 2	90°	0	1	0	1	0
2	2 – 3	90°	0	1	0	1	0
3	3 – 4	90°	0	1	0	1	0
4	4 – 5	0°	0	1	0	1	0
5	5 – 6	270°	0	–1	0	1	0
6	6 – 7	270°	0	–1	0	1	0
7	7 – 8	270°	0	–1	0	1	0
8	3 – 6	0°	0	1	0	1	0
9	2 – 7	0°	0	1	0	1	0
10	1 – 7	30.96°					

$$K_{1-2} = \frac{E}{L} = \frac{\left(300 \times 10^{9}\right)}{6m} = 5 \times 10^{10}\,[M]$$

$$K_{1-2} = \begin{bmatrix}
100000 & 0 & -300000 & -100000 & 0 & -300000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 25000000 & 0 & 0 & -250000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-300000 & 0 & 1200000 & 300000 & 0 & 600000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-100000 & 0 & 300000 & 100000 & 0 & 300000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -25000000 & 0 & 0 & 25000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-300000 & 0 & 600000 & 300000 & 0 & 1200000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{2-3} = \frac{E}{L} = \frac{\left(300 \times 10^{9}\right)}{6m} = 5 \times 10^{10}\,[M]$$

$$K_{1-3} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 100000 & 0 & -300000 & -100000 & 0 & -300000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 25000000 & 0 & 0 & -25000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -300000 & 0 & 1200000 & 300000 & 0 & 600000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -100000 & 0 & 300000 & 100000 & 0 & 300000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -25000000 & 0 & 0 & 25000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -300000 & 0 & 600000 & 300000 & 0 & 1200000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{3-4} = \frac{E}{L} = \frac{\left(3000 \times 10^{9}\right)}{4m} = 75000000000\,[M]$$

$$K_{3-4} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 337500 & 0 & -168750 & -337500 & 0 & -168750 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 37500000 & 0 & 0 & -37500000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -168750 & 0 & 1800000 & 168750 & 0 & 900000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -337500 & 0 & 168750 & 337500 & 0 & 168750 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -37500000 & 0 & 0 & 37500000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -168750 & 0 & 900000 & 168750 & 0 & 1800000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{4-5} = \frac{E}{L} = \frac{(300 \times 10^9)}{10m} = 30000000000[M]$$

$$K_{4-5} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 15000000 & 0 & 0 & -15000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 21600 & 108000 & 0 & -21600 & 108000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 108000 & 720000 & 0 & -108000 & 360000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -15000000 & 0 & 0 & 15000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -21600 & -108000 & 0 & 21600 & -108000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 108000 & 360000 & 0 & -108000 & 720000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{5-6} = \frac{E}{L} = \frac{(3000 \times 10^9)}{4m} = 75000000000[M]$$

$$K_{5-6} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 33750 & 0 & -168750 & -337500 & 0 & -168750 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 37500000 & 0 & 0 & -37500000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -168750 & 0 & 1800000 & 168750 & 0 & 900000 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -337500 & 0 & 168750 & 337500 & 0 & 168750 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -37500000 & 0 & 0 & 37500000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -168750 & 0 & 900000 & 168750 & 0 & 1800000 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{6-7} = \frac{E}{L} = \frac{\left(300 \times 10^{9}\right)}{6m} = 5 \times 10^{10}\,[M]$$

$$K_{6-7} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 100000 & 0 & -300000 & -100000 & 0 & -300000 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 25000000 & 0 & 0 & -25000000 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -300000 & 0 & 1200000 & 300000 & 0 & 600000 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -100000 & 0 & 300000 & 100000 & 0 & 300000 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -25000000 & 0 & 0 & 25000000 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -300000 & 0 & 600000 & 300000 & 0 & 1200000 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{7-8} = \frac{E}{L} = \frac{\left(300 \times 10^{9}\right)}{6m} = 5 \times 10^{10}\,[M]$$

$$K_{3-4} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 100000 & 0 & -300000 & -100000 & 0 & -300000 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 25000000 & 0 & 0 & -25000000 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -300000 & 0 & 1200000 & 300000 & 0 & 600000 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -100000 & 0 & 300000 & 100000 & 0 & 300000 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -25000000 & 0 & 0 & 25000000 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -300000 & 0 & 600000 & 300000 & 0 & 1200000
\end{bmatrix}$$

$$K_{3-6} = \frac{E}{L} = \frac{\left(300 \times 10^{9}\right)}{10\text{m}} = 30000000000\left[\text{M}\right]$$

$$K_{3-6} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 15000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -15000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 21600 & 108000 & 0 & 0 & 0 & 0 & 0 & 0 & -21600 & 108000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 108000 & 720000 & 0 & 0 & 0 & 0 & 0 & 0 & -108000 & 360000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -15000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 15000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -21600 & -108000 & 0 & 0 & 0 & 0 & 0 & 0 & 21600 & -108000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 108000 & 360000 & 0 & 0 & 0 & 0 & 0 & 0 & -108000 & 720000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{2-7} = \frac{E}{L} = \frac{\left(300 \times 10^{9}\right)}{10\text{m}} = 30000000000\left[\text{M}\right]$$

$$K_{2-7} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 15000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -15000000 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 21600 & 108000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -21600 & 108000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 108000 & 720000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 108000 & 360000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -15000000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 15000000 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -21600 & -108000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 21600 & -108000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 108000 & 360000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 108000 & 720000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_{1-7} = \frac{E}{L} = \frac{\left(280 \times 10^{9}\right)}{5m} = 56000000000\left[M\right]$$

$$K_{1-7} = \begin{bmatrix}
11067007 & 5654382 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -11067007 & -5654382.06 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
5654382.06 & 3354851 & 68316.42 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -5654382.06 & -3354851 & 68316.42 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 68316.42 & 617495.7118 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -68316.42 & 308747.8559 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11067007 & 5654382.06 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-11067007 & -5654382 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 5654382.06 & 3354851 & -68316.42 & 0 & 0 & 0 & 0 & 0 & 0 \\
5654382.06 & -3354851 & -68316.42 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 68316.42 & 308747.8559 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 68316.42 & 308747.8559 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

B. Resolución con MATLAB

```
>> KT = [ 100000 0 -300000 -100000 0 -300000 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0; 0 25000000 0 0 -25000000 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; -300000 0
1200000 300000 0 600000 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; -100000 0 300000
15200000 0 0 -100000 0 -300000 0 0 0 0 0 0 0 0 –15000000 0 0 0 0 0; 0 -25000000
0 0 50021600 108000 0 -25000000 0 0 0 0 0 0 0 0 0 0 0 -21600 108000 0 0 0;
-300000 0 600000 0 108000 3120000 300000 0 600000 0 0 0 0 0 0 0 0 0 0 –108000
360000 0 0 0; 0 0 0 -100000 0 300000 15437500 0 131250 -337500 0 -168750 0 0 0
-15000000 0 0 0 0 0 0 0 0; 0 0 0 0 -25000000 0 0 6251600 108000 0 -37500000 0 0
0 0 0 -21600 1080000 0 0 0 0 0 0; 0 0 0 -300000 0 600000 131250 108000 3720000
168750 0 90000 0 0 0 0 -108000 360000 0 0 0 0 0 0; 0 0 0 0 0 0 -337500 0 168750
15337500 0 168750 -15000000 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 -37500000 0
0 37521600 108000 0 -24600 1080000 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 -168750 0
900000 168750 108000 2520000 0 –108000 360000 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0
0 0 -15000000 0 0 15337500 0 –168750 -337500 0 -168750 0 0 0 0 0 0; 0 0 0 0 0
0 0 0 0 0 -21600 108000 0 375216000 1080000 0 -37500000 0 0 0 0 0 0 0; 0 0 0 0
0 0 0 0 0 0 108000 360000 -168750 -1080000 2520000 168750 0 9000000 0 0 0 0 0
0; 0 0 0 0 0 0 -15000000 0 0 0 0 0 -337500 0 168750 15537500 0 -431250 -200000
0 -600000 0 0 0; 0 0 0 0 0 0 0 -21600 -108000 0 0 0 0 -37500000 0 0 87521600
-108000 0 -50000000 0 0 0 0; 0 0 0 0 0 0 0 108000 360000 0 0 0 -168750 0 900000
-432150 -108000 4920000 600000 0 1200000 0 0 0; 0 0 0 -15000000 0 0 0 0 0 0 0
0 0 0 0 -200000 0 600000 15200000 0 600000 0 0 0; 0 0 0 0 -21600 -108000 0 0 0
0 0 0 0 0 0 0 -50000000 0 0 50021600 –108000 0 0 0; 0 0 0 0 108000 360000 0 0
0 0 0 0 0 0 0 -600000 0 1200000 600000 -1080000 3120000 0 0 0; 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
```

```
KT =

  Columns 1 through 10

     100000          0    -300000    -100000          0    -300000          0          0          0          0
          0   25000000          0          0  -25000000          0          0          0          0          0
    -300000          0    1200000     300000          0     600000          0          0          0          0
    -100000          0     300000   15200000          0          0    -100000          0    -300000          0
          0  -25000000          0          0   50021600     108000          0  -25000000          0          0
    -300000          0     600000          0     108000    3120000     300000          0     600000          0
          0          0          0    -100000          0     300000   15437500          0     131250    -337500
          0          0          0          0  -25000000          0          0    6251600     108000          0
          0          0          0    -300000          0     600000     131250     108000    3720000     168750
          0          0          0          0          0          0    -337500          0     168750   15337500
          0          0          0          0          0          0          0  -37500000          0          0
          0          0          0          0          0          0    -168750          0     900000     168750
          0          0          0          0          0          0          0          0          0  -15000000
          0          0          0          0          0          0          0          0          0          0
          0          0          0          0          0          0          0          0          0          0
          0          0          0          0          0          0  -15000000          0          0          0
          0          0          0          0          0          0          0     -21600    -108000          0
          0          0          0          0          0          0          0     108000     360000          0
          0          0          0  -15000000          0          0          0          0          0          0
          0          0          0          0     -21600    -108000          0          0          0          0
          0          0          0          0     108000     360000          0          0          0          0
          0          0          0          0          0          0          0          0          0          0
          0          0          0          0          0          0          0          0          0          0
          0          0          0          0          0          0          0          0          0          0

  Columns 11 through 20

          0          0          0          0          0          0          0          0          0          0
          0          0          0          0          0          0          0          0          0          0
          0          0          0          0          0          0          0          0          0          0
          0          0          0          0          0          0          0          0  -15000000          0
          0          0          0          0          0          0          0          0          0     -21600
          0          0          0          0          0          0          0          0          0    -108000
          0    -168750          0          0          0  -15000000          0          0          0          0
  -37500000          0          0          0          0          0     -21600    1080000          0          0
          0      90000          0          0          0          0    -108000     360000          0          0
          0     168750  -15000000          0          0          0          0          0          0          0
   37521600     108000          0     -24600    1080000          0          0          0          0          0
     108000    2520000          0    -108000     360000          0          0          0          0          0
          0          0   15337500          0    -168750    -337500          0    -168750          0          0
     -21600     108000          0  375216000    1080000          0  -37500000          0          0          0
     108000     360000    -168750   -1080000    2520000     168750          0    9000000          0          0
          0          0    -337500          0     168750   15537500          0    -431250    -200000          0
          0          0          0  -37500000          0          0   87521600    -108000          0  -50000000
          0          0    -168750          0     900000    -432150    -108000    4920000     600000          0
          0          0          0          0          0    -200000          0     600000   15200000          0
          0          0          0          0          0          0  -50000000          0          0   50021600
          0          0          0          0          0    -600000          0    1200000     600000   -1080000
          0          0          0          0          0          0          0          0          0          0
          0          0          0          0          0          0          0          0          0          0
          0          0          0          0          0          0          0          0          0          0
```

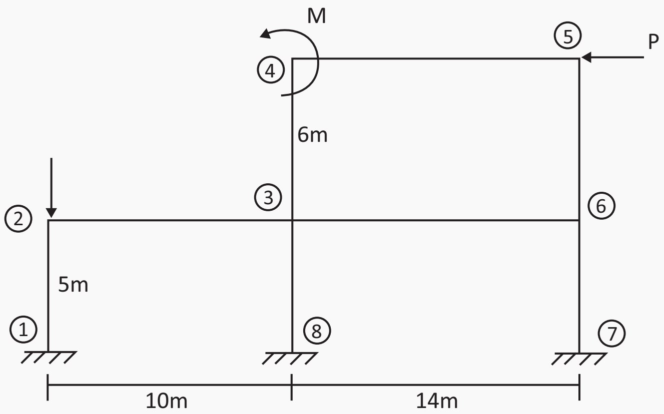
```
Columns 21 through 24

         0           0           0           0
         0           0           0           0
         0           0           0           0
         0           0           0           0
    108000           0           0           0
    360000           0           0           0
         0           0           0           0
         0           0           0           0
         0           0           0           0
         0           0           0           0
         0           0           0           0
         0           0           0           0
         0           0           0           0
         0           0           0           0
         0           0           0           0
   -600000           0           0           0
         0           0           0           0
   1200000           0           0           0
    600000           0           0           0
   -108000           0           0           0
   3120000           0           0           0
         0           0           0           0
         0           0           0           0
         0           0           0           0

>> KR = [ 15200000 0 0 -100000 0 -300000 0 0 0 0 0 0 0 0 -15000000 0 0; 0 50021600
108000 0 -25000000 0 0 0 0 0 0 0 0 0 0 -21600 108000; 0 108000 3120000 300000 0
600000 0 0 0 0 0 0 0 0 0 –108000 360000; -100000 0 300000 15437500 0 131250 -337500
0 -168750 0 0 0 -15000000 0 0 0 0 0; 0 -25000000 0 0 62521600 108000 0 -37500000 0
0 0 0 0 -21600 108000 0 0 0; -300000 0 600000 131250 108000 3720000 168750 0 900000
0 0 0 0 -108000 360000 0 0 0; 0 0 0 -337500 0 168750 15337500 0 168750 -15000000 0
0 0 0 0 0 0 0; 0 0 0 0 -37500000 0 0 37521600 108000 0 -21600 1080000 0 0 0 0 0 0;
0 0 0 -168750 0 900000 168750 108000 2520000 0 -108000 360000 0 0 0 0 0 0; 0 0 0 0
0 0 -15000000 0 0 15337500 0 -168750 -337500 0 -168750 0 0 0; 0 0 0 0 0 0 0 -21600
-108000 0 375216000 -1080000 0 -37500000 0 0 0 0; 0 0 0 0 0 0 0 108000 360000 -168750
-108000 2520000 168750 0 9000000 0 0 0; 0 0 0 -15000000 0 0 0 0 0 -337500 0 168750
15537500 0 -431250 -20000 0 -600000; 0 0 0 0 -21600 -108000 0 0 0 0 -37500000 0 0
87521600 -108000 0 -50000000 0; 0 0 0 0 108000 360000 0 0 0 -168750 0 900000 -431250
-108000 4920000 600000 0 1200000; -185000000 0 0 0 0 0 0 0 0 0 0 0 -200000 0 600000
15200000 0 600000; 0 -21600 -108000 0 0 0 0 0 0 0 0 0 0 -50000000 0 0 50021600
-108000; 0 108000 360000 0 0 0 0 0 0 0 0 0 -600000 0 1200000 600000 -108000 3120000]

KR =

  Columns 1 through 10

   15200000          0          0    -100000          0    -300000          0          0          0          0
          0   50021600     108000          0  -25000000          0          0          0          0          0
          0     108000    3120000     300000          0     600000          0          0          0          0
    -100000          0     300000   15437500          0     131250    -337500          0    -168750          0
          0  -25000000          0          0   62521600     108000          0  -37500000          0          0
    -300000          0     600000     131250     108000    3720000     168750          0     900000          0
          0          0          0    -337500          0     168750   15337500          0     168750  -15000000
          0          0          0          0  -37500000          0          0   37521600     108000          0
          0          0          0    -168750          0     900000     168750     108000    2520000          0
          0          0          0          0          0          0  -15000000          0          0   15337500
          0          0          0          0          0          0          0     -21600    -108000          0
          0          0          0          0          0          0          0     108000     360000    -168750
          0          0          0  -15000000          0          0          0          0          0    -337500
          0          0          0          0     -21600    -108000          0          0          0          0
          0          0          0          0     108000     360000          0          0          0    -168750
 -185000000          0          0          0          0          0          0          0          0          0
          0     -21600    -108000          0          0          0          0          0          0          0
          0     108000     360000          0          0          0          0          0          0          0
```

```
  Columns 11 through 18

         0          0          0          0          0  -15000000          0          0
         0          0          0          0          0          0     -21600     108000
         0          0          0          0          0          0    -108000     360000
         0          0  -15000000          0          0          0          0          0
         0          0          0     -21600     108000          0          0          0
         0          0          0    -108000     360000          0          0          0
         0          0          0          0          0          0          0          0
    -21600    1080000          0          0          0          0          0          0
   -108000     360000          0          0          0          0          0          0
         0    -168750    -337500          0    -168750          0          0          0
 375216000   -1080000          0  -37500000          0          0          0          0
   -108000    2520000     168750          0    9000000          0          0          0
         0     168750   15537500          0    -431250     -20000          0    -600000
 -37500000          0          0   87521600    -108000          0  -50000000          0
         0     900000    -431250    -108000    4920000     600000          0    1200000
         0          0    -200000          0     600000   15200000          0     600000
         0          0          0  -50000000          0          0   50021600    -108000
         0          0    -600000          0    1200000     600000    -108000    3120000

>> f = [ 3000; 0; 0; 5000; 0; 0; 0; 500; 833.33; 0; -500; 833.33; 5000; 0; 0; 3000; 0; 0]

f =

  1.0e+003 *

    3.0000
         0
         0
    5.0000
         0
         0
         0
    0.5000
    0.8333
         0
   -0.5000
    0.8333
    5.0000
         0
         0
    3.0000
         0
         0

>> u = inv(KR)*f

u =
    0.0000
   -0.0450
    0.0668
   -0.8637
   -0.0900
    0.1307
   -0.6503
   -0.1205
   -0.2102
   -0.6464
    0.0033
    1.0837
   -0.8698
    0.0028
   -0.2893
    0.0030
    0.0028
   -0.0626
```

```
>> U = [ 0; 0; 0; 0; -0.0450; 0.0668; -0.8637; -0.0900; 0.1307; -0.6503; -0.1205;
-0.2102;  -0.6464;  0.0033;  1.0837;  -0.8698;  0.0028;  -0.2893;  0.0030;  0.0028;
-0.0626; 0; 0; 0]

U =
         0
         0
         0
         0
   -0.0450
    0.0668
   -0.8637
   -0.0900
    0.1307
   -0.6503
   -0.1205
   -0.2102
   -0.6464
    0.0033
    1.0837
   -0.8698
    0.0028
   -0.2893
    0.0030
    0.0028
   -0.0626
         0
         0
         0

>> F = KT * U

F =

  1.0e+006 *

   -0.0200
    1.1250
    0.0401
    0.0022
   -0.0006
    0.0000
    0.0058
    4.7827
    0.1701
    0.0001
    0.0013
    0.0007
   -0.0002
    2.2835
   -0.0027
    0.0037
    0.0004
    0.0006
    0.0084
    0.0006
   -0.0026
         0
         0
         0
```

Ejercicio 11

Determinar los Desplazamientos y las Cargas generadas en cada nodo, en la estructura mostrada, según la secuencia indicada.



$E = 250GPa$

$I = 5 \times 10^{-6} m^4$

$A = 4 \times 10^{-4} m^2$

$P = 2000N$

$Q = 3000N$

$M = 400Nm$

Nodos: 1 – 2; 2 – 3; 3 – 4; 4 – 5; 5 – 6; 3 – 6; 7 – 8

A. Resolución

Nodo	θ	C	S	C^2	S^2
1 – 2	90º	0	1	0	1
2 – 3	0º	1	0	1	0
3 – 4	90º	0	1	0	1
4 – 5	0º	1	0	1	0
5 – 6	270º	0	–1	0	1
3 – 6	0º	1	0	1	0
7 – 8	180º	–1	0	1	0

B. Resolución con MATLAB

```
>> K1 =(5*10^10)* [2.4*10^-6 0  -0.000006 -0.0000024 0  -0.000006 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0; 0   4*10^-4 0   0   -0.0004 0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0; -0.000006   0   2*10^-5 6*10^-6 0   1*10^-5 0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0; -0.0000024  0   6*10^-6 2.4*10^-6
0   6*10^-6 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0
-0.0004 0   0   4*10^-4 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0; -0.000006   0   1*10^-5 6*10^-6 0   2*10^-5 0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0;
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0]
```

```
K1 =

  1.0e+007 *

  Columns 1 through 17

   0.0120        0  -0.0300  -0.0120        0  -0.0300        0        0        0        0        0        0        0        0        0        0        0
        0   2.0000        0        0  -2.0000        0        0        0        0        0        0        0        0        0        0        0        0
  -0.0300        0   0.1000   0.0300        0   0.0500        0        0        0        0        0        0        0        0        0        0        0
  -0.0120        0   0.0300   0.0120        0   0.0300        0        0        0        0        0        0        0        0        0        0        0
        0  -2.0000        0        0   2.0000        0        0        0        0        0        0        0        0        0        0        0        0
  -0.0300        0   0.0500   0.0300        0   0.1000        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0

Columns 18 through 24

        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
```

```
>> K2 = (2.5*10^10)*[0  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   4*10^-4 0   0
-0.0004 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0
0   6*10^-7 3*10^-6 0   -0.0000006  3*10^-6 0   0   0   0   0   0   0   0   0   0
0   0   0   0   0; 0   0   0   0   3*10^-6 2*10^-5 0   3*10^-6 1*10^-5 0   0   0
0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   -0.0004 0   0   4*10^-4
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0
-0 0000006  -0.000003   0   6*10^-7 -0.000003   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0; 0   0   0   0   3*10^-6 1*10^-5 0   3*10^-6 2*10^-5 0   0
0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0]

K2 =

  1.0e+007 *

  Columns 1 through 17

        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0   1.0000        0        0  -1.0000        0        0        0        0        0        0        0        0        0        0
        0        0        0        0   0.0015   0.0075        0  -0.0015   0.0075        0        0        0        0        0        0        0        0
        0        0        0        0   0.0075   0.0500        0   0.0075   0.0250        0        0        0        0        0        0        0        0
        0        0        0  -1.0000        0        0   1.0000        0        0        0        0        0        0        0        0        0        0
        0        0        0        0  -0.0015  -0.0075        0   0.0015  -0.0075        0        0        0        0        0        0        0        0
        0        0        0        0   0.0075   0.0250        0   0.0075   0.0500        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
```

```
Columns 18 through 24

       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0

>> K3 = (4.166*10^10)*[0    0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0; 0   0   0   0   0   0   1.67*10^-6  0   -0.000005   -0.00000167 0
-0.000005   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0
4*10^-4 0   0   -0.0004 0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0
0   0   0   0   -0.000005   0   2*10^-5 5*10^-6 0   1*10^-6 0   0   0   0   0   0
0   0   0   0   0   0; 0   0   0   0   0   0   -0.00000167  0  5*10^-6 1.67*10^-6
0    5*10^-6 0   0   0   0   0   0   0   0   0   0   0 0; 0   0   0   0   0   0   0
-0.0004 0   0   4*10^-4 0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0
0   0   0   0   -0.000005   0   1*10^-6 5*10^-6 0   2*10^-5 0   0   0   0   0   0
0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0;
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0]
```

```
K3 =

  1.0e+007 *

  Columns 1 through 17

         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0    0.0070         0   -0.0208   -0.0070         0   -0.0208         0         0         0         0         0
         0         0         0         0         0         0         0    1.6664         0         0   -1.6664         0         0         0         0         0         0
         0         0         0         0         0         0   -0.0208         0    0.0833    0.0208         0    0.0042         0         0         0         0         0
         0         0         0         0         0         0   -0.0070         0    0.0208    0.0070         0    0.0208         0         0         0         0         0
         0         0         0         0         0         0         0   -1.6664         0         0    1.6664         0         0         0         0         0         0
         0         0         0         0         0         0   -0.0208         0    0.0042    0.0208         0    0.0833         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0

Columns 18 through 24

         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
```

```
>> K4 = (1.79*10^10)*[0 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   4*10^-4
0   0   -0.0004 0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0
0   0   0   0   4.29*10^-6  2.14*10^-6  0   -0.00000429 2.14*10^-6  0   0   0   0
0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   2.14*10^-6  2*10^-5 0
2.14*10^-6  1*10^-5 0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0
0   0   -0.0004 0   0   4*10^-4 0   0   0   0   0   0   0   0   0   0   0; 0   0   0
0   0   0   0   0   0   0   -0.00000429 -0.00000214 0   4.29*10^-6  -0.00000214 0
0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   2.14*10^-6
1*10^-5 0   2.14*10^-6  2*10^-5 0   0   0   0   0   0   0   0   0; 0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0;
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0]

K4 =

  1.0e+006 *

  Columns 1 through 17

        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0   7.1600        0        0  -7.1600        0        0        0        0
        0        0        0        0        0        0        0        0        0        0   0.0768   0.0383        0  -0.0768   0.0383        0        0
        0        0        0        0        0        0        0        0        0        0   0.0383   0.3500        0   0.0383   0.1790        0        0
        0        0        0        0        0        0        0        0        0  -7.1600        0        0   7.1600        0        0        0        0
        0        0        0        0        0        0        0        0        0        0  -0.0768  -0.0383        0   0.0768  -0.0383        0        0
        0        0        0        0        0        0        0        0        0        0   0.0383   0.1790        0   0.0383   0.3580        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
```

```
Columns 18 through 24

         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0

>> K5 = (4.17*10^10)*[0 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0
0   0   0   0   0   0   0   0   0   0   0   1.67*10^-6  0   5*10^-6 -0.00000167
0   5*10^-6 0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0
0   4*10^-4 0   0   -0.0004 0   0   0   0   0   0   0; 0   0   0   0   0   0   0
0   0   0   0   0   5*10^-6 0   2*10^-5 -0.000005   0   1*10^-5 0   0   0   0   0
0; 0   0   0   0   0   0   0   0   0   0   0   0   -0.00000167 0   0   1.67*10^-6
0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0
-0.0004 0   0   4*10^-4 0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0
0   0   0   0   -0.000005   0   1*10^-5 5*10^-6 0   2*10^-5 0   0   0   0   0   0;
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0]
```

```
K5 =

  1.0e+007 *

  Columns 1 through 17

         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0    0.0070         0    0.0208   -0.0070         0
         0         0         0         0         0         0         0         0         0         0         0         0         0    1.6680         0         0   -1.6680
         0         0         0         0         0         0         0         0         0         0         0         0    0.0280         0    0.0834   -0.0209         0
         0         0         0         0         0         0         0         0         0         0         0         0   -0.0070         0         0    0.0070         0
         0         0         0         0         0         0         0         0         0         0         0         0         0   -1.6680         0         0    1.6680
         0         0         0         0         0         0         0         0         0         0         0         0   -0.0209         0    0.0417    0.0208         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0

Columns 18 through 24

         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
    0.0208         0         0         0         0         0         0
         0         0         0         0         0         0         0
    0.0417         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
    0.0834         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
```

```
>> K6 = (1.79*10^10)*[0 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0;
0   0   0   0   0   0   4*10^-4 0   0   0   0   0   0   0   0   -0.0004 0   0   0
0   0   0   0   0; 0   0   0   0   0   0   0   3.06*10^-7  2.14*10^-6  0   0   0
0   0   0   0   -3.06E-07   2.14*10^-6  0   0   0   0   0   0; 0   0   0   0   0   0
0   2.14*10^-6  2*10^-5 0   0   0   0   0   0   0   2.14*10^-6  1*10^-5 0   0   0
0   0   0; 0   0   0   0   0   0   4*10^-4 0   0   0   0   0   0   0   0   4*10^-4
0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   -3.06E-07   -0.00000214
0   0   0   0   0   0   0   3.06*10^-7  -0.00000214 0   0   0   0   0   0; 0   0   0
0   0   0   0   2.14*10^-6  1*10^-5 0   0   0   0   0   0   0   2.14*10^-6  2*10^-5
0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0;
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0]

K6 =

  1.0e+006 *

  Columns 1 through 17

      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0   7.1600        0        0        0        0        0        0        0        0  -7.1600        0
      0        0        0        0        0        0        0   0.0055   0.0383        0        0        0        0        0        0        0  -0.0055
      0        0        0        0        0        0        0   0.0383   0.3580        0        0        0        0        0        0        0   0.0383
      0        0        0        0        0        0   7.1600        0        0        0        0        0        0        0        0   7.1600        0
      0        0        0        0        0        0        0  -0.0055  -0.0383        0        0        0        0        0        0        0   0.0055
      0        0        0        0        0        0        0   0.0383   0.1790        0        0        0        0        0        0        0   0.0383
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
      0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
```

```
Columns 18 through 24

       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
  0.0383         0         0         0         0         0         0
  0.1790         0         0         0         0         0         0
       0         0         0         0         0         0         0
 -0.0383         0         0         0         0         0         0
  0.3580         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0

>> K7 = (1.79*10^10)*[0 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0; 0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   4*10^-4 0   0   -4*10^-4
0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
3.06*10^-7  -2.14*10^-6 0   -3.06*10^-7 -2.14*10^-6; 0   0   0   0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   -2.14*10^-6 2*10^-5 0   -2.14*10^-6 0;
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   -4*10^-4
0   0   4*10^-4 0   0; 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
0   0   0   0   -3.06*10^-7 2.14*10^-6  0   0   2.14*10^-6; 0   0   0   0   0
0   0   0   0   0   0   0   0   0   0   0   0   0   0   -2.14*10^-6 1*10^-5 0
-2.14*10^-6 2*10^-5]
```

```
K7 =

  1.0e+006 *

  Columns 1 through 17

     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

Columns 18 through 24

        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0    7.1600         0         0   -7.1600         0         0
        0         0    0.0055   -0.0383         0   -0.0055   -0.0383
        0         0   -0.0383    0.3580         0   -0.0383         0
        0   -7.1600         0         0    7.1600         0         0
        0         0   -0.0055    0.0383         0         0    0.0383
        0         0   -0.0383    0.1790         0   -0.0383    0.3580
```

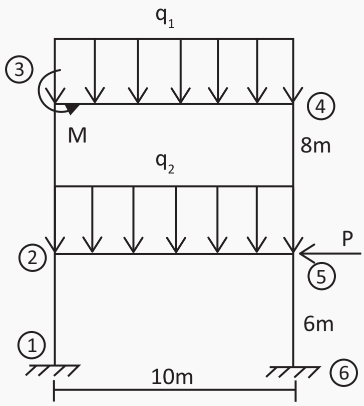
```
>> KT = K1 + K2 + K3 + K4 + K5 + K6 + K7

KT =

  1.0e+007 *

  Columns 1 through 17

    0.0120         0   -0.0300   -0.0120         0   -0.0300         0         0         0         0         0         0         0         0         0         0         0
         0    2.0000         0         0   -2.0000         0         0         0         0         0         0         0         0         0         0         0         0
   -0.0300         0    0.1000    0.0300         0    0.0500         0         0         0         0         0         0         0         0         0         0         0
   -0.0120         0    0.0300    1.0120         0    0.0300   -1.0000         0         0         0         0         0         0         0         0         0         0
         0   -2.0000         0         0    2.0015    0.0075         0   -0.0015    0.0075         0         0         0         0         0         0         0         0
   -0.0300         0    0.0500    0.0300    0.0075    0.1500         0    0.0075    0.0250         0         0         0         0         0         0         0         0
         0         0         0   -1.0000         0         0    1.7230         0   -0.0208   -0.0070         0   -0.0208         0         0         0   -0.7160         0
         0         0         0         0   -0.0015   -0.0075         0    1.6684   -0.0037         0   -1.6664         0         0         0         0         0   -0.0005
         0         0         0         0    0.0075    0.0250   -0.0208    0.0113    0.1691    0.0208         0    0.0042         0         0         0         0    0.0038
         0         0         0         0         0         0    0.7090         0    0.0208    0.7230         0    0.0208   -0.7160         0         0    0.7160         0
         0         0         0         0         0         0         0   -1.6669   -0.0038         0    1.6741    0.0038         0   -0.0077    0.0038         0    0.0005
         0         0         0         0         0         0   -0.0208    0.0038    0.0221    0.0208    0.0038    0.1191         0    0.0038    0.0179         0    0.0038
         0         0         0         0         0         0         0         0         0   -0.7160         0         0    0.7230         0    0.0208   -0.0070         0
         0         0         0         0         0         0         0         0         0         0   -0.0077   -0.0038         0    1.6757   -0.0038         0   -1.6680
         0         0         0         0         0         0         0         0         0         0    0.0038    0.0179    0.0208    0.0038    0.1192   -0.0209         0
         0         0         0         0         0         0         0         0         0         0         0         0   -0.0070         0         0    0.0070         0
         0         0         0         0         0         0         0         0         0         0         0         0         0   -1.6680         0         0    1.6680
         0         0         0         0         0         0         0         0         0         0         0         0   -0.0209         0    0.0417    0.0208         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0         0

Columns 18 through 24

         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
    0.0038         0         0         0         0         0         0
    0.0179         0         0         0         0         0         0
         0         0         0         0         0         0         0
   -0.0038         0         0         0         0         0         0
    0.0358         0         0         0         0         0         0
    0.0208         0         0         0         0         0         0
         0         0         0         0         0         0         0
    0.0417         0         0         0         0         0         0
         0         0         0         0         0         0         0
         0         0         0         0         0         0         0
    0.0834         0         0         0         0         0         0
         0    0.7160         0         0   -0.7160         0         0
         0         0    0.0005   -0.0038         0   -0.0005   -0.0038
         0         0   -0.0038    0.0358         0   -0.0038         0
         0   -0.7160         0         0    0.7160         0         0
         0         0   -0.0005    0.0038         0         0    0.0038
         0         0   -0.0038    0.0179         0   -0.0038    0.0358
```

```
>> kr = (10^7)*[1.0120 0 0.0300 -1.0000 0 0 0 0 0 0 0 0 0 0 0; 0 2.0015 0.0075 0
-0.0015 0.0075 0  0  0  0 0 0 0 0 0 0; 0.0300  0.0075 0.1500 0 0.0075 0.0250  0  0
0  0  0  0  0 0  0; -1.0000     0  0 1.7230  0  -0.0208   -0.0070  0  -0.0208 0 0
0 -0.7160 0 0; 0  -0.0015 -0.0075  0 1.6684 -0.0037 0 -1.6664  0 0 0 0 0 -0.0005
0.0038; 0  0.0075 0.0250  -0.0208 0.0113 0.1691 0.0208 0 0.0042 0 0 0 0 0.0038
0.0179; 0  0 0 -0.7090  0 0.0208  0.7230 0 0.0208 -0.7160  0 0 0.7160 0 0; 0  0
0 0 -1.6669 -0.0038  0 1.6741  0.0038 0 -0.0077 0.0038 0 0.0005 -0.0038; 0  0 0
-0.0208  0.0038 0.0221 0.0208 0.0038  0.1191  0 0.0038 0.0179 0 0.0038 0.0358; 0
0 0 0 0 0 -0.7160  0 0 0.7230 0 0.0208   -0.0070 0 0.0208; 0  0 0 0 0 0 0 -0.0077
-0.0038 0 1.6757 -0.0038 0   -1.6680 0; 0  0 0 0 0 0 0 0.0038 0.0179  0.0208 0.0038
0.1192 0 0 0.0417; 0  0 0 0 0 0 0 0 0 -0.0070 0 0 -0.0209 0 0; 0  0 0 0 0 0 0 0
0 0 -1.6680 0  0.0070 1.6680 0; 0  0 0 0 0 0 0 0 0 -0.0209 0 0.0417 0 0 0.0834]

kr =

  1.0e+007 *

   1.0120        0   0.0300  -1.0000        0        0        0        0        0        0        0        0        0        0        0
        0   2.0015   0.0075        0  -0.0015   0.0075        0        0        0        0        0        0        0        0        0
   0.0300   0.0075   0.1500        0   0.0075   0.0250        0        0        0        0        0        0        0        0        0
  -1.0000        0        0   1.7230        0  -0.0208  -0.0070        0  -0.0208        0        0        0  -0.7160        0        0
        0  -0.0015  -0.0075        0   1.6684  -0.0037        0  -1.6664        0        0        0        0        0  -0.0005   0.0038
        0   0.0075   0.0250  -0.0208   0.0113   0.1691   0.0208        0   0.0042        0        0        0        0   0.0038   0.0179
        0        0        0  -0.7090        0   0.0208   0.7230        0   0.0208  -0.7160        0        0   0.7160        0        0
        0        0        0        0  -1.6669  -0.0038        0   1.6741   0.0038        0  -0.0077   0.0038        0   0.0005  -0.0038
        0        0        0  -0.0208   0.0038   0.0221   0.0208   0.0038   0.1191        0   0.0038   0.0179        0   0.0038   0.0358
        0        0        0        0        0        0  -0.7160        0        0   0.7230        0   0.0208  -0.0070        0   0.0208
        0        0        0        0        0        0        0  -0.0077  -0.0038        0   1.6757  -0.0038        0  -1.6680        0
        0        0        0        0        0        0        0   0.0038   0.0179   0.0208   0.0038   0.1192        0        0   0.0417
        0        0        0        0        0        0        0        0        0  -0.0070        0        0  -0.0209        0        0
        0        0        0        0        0        0        0        0        0        0  -1.6680        0   0.0070   1.6680        0
        0        0        0        0        0        0        0        0        0  -0.0209        0   0.0417        0        0   0.0834

>> F=[-3000; 0; 0; 0; 0; 0; -4000; 0; 0; -2000; 0; 0; 0; 0; 0]

F =
       -3000
           0
           0
           0
           0
           0
       -4000
           0
           0
       -2000
           0
           0
           0
           0
           0

>> u = inv(kr)*F

u =
    0.0583
   -0.0002
   -0.0140
    0.0588
   -0.1098
    0.0470
   -0.1783
   -0.1101
    0.0598
   -0.1757
   -0.1077
    0.0534
    0.0589
   -0.1080
   -0.0707
```

```
>> ut = [0; 0; 0; 0.0583; -0.0002; -0.0140; 0.0588; -0.1098;0.0470;  -0.1783; -0.1101;
0.0598; -0.1757; -0.1077; 0.0534; 0.0589; -0.1080; -0.0707; 0; 0; 0; 0; 0; 0]

ut =

         0
         0
         0
    0.0583
   -0.0002
   -0.0140
    0.0588
   -0.1098
    0.0470
   -0.1783
   -0.1101
    0.0598
   -0.1757
   -0.1077
    0.0534
    0.0589
   -0.1080
   -0.0707
         0
         0
         0
         0
         0
         0

>> FT = KT*ut

FT =

  1.0e+005 *

   -0.0280
    0.0400
    0.1049
   -0.0220
    0.0012
   -0.0001
   -0.0147
   -0.0004
   -0.0016
    8.2987
    0.0007
   -0.0022
   -0.0133
    0.0085
   -0.1238
    0.1634
   -0.0500
    0.1222
         0
         0
         0
         0
         0
         0
```

EJERCICIO 12

Determinar los Desplazamientos y las Cargas generadas en cada nodo, en la estructura mostrada, según la secuencia indicada.



$E = 280GPa$

$I = 5 \times 10^{-6} m^4$

$A = 6 \times 10^{-4} m^2$

$P = 3000N$

$q_1 = 80N/m$

$q_2 = 600N/m$

$M = 600Nm$

Nodos: 1 – 2; 2 – 3; 3 – 4;
4 – 5; 5 – 6; 2 – 5

A. Resolución

Nodo	θ	C	S	C²	S²	SC
1 – 2	90º	0	1	0	1	0
2 – 3	90º	0	1	0	1	0
3 – 4	0º	1	0	1	0	0
4 – 5	270º	0	–1	0	1	0
5 – 6	270º	0	–1	0	1	0
2 – 5	0º	1	0	1	0	0

$$K_1 = \left(4.67x10^{10}\right)\begin{bmatrix} 0.0078 & 0 & -0.0233 & -0.0078 & 0 & -0.0233 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2.8020 & 0 & 0 & -2.8020 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.0233 & 0 & 0.0934 & 0.0233 & 0 & 0.0700 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.0078 & 0 & 0.0233 & 0.0078 & 0 & 0.0233 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -2.8020 & 0 & 0 & 2.8020 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.0233 & 0 & 0.0700 & 0.0233 & 0 & 0.0934 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} 10^{-12}$$

$$K_2 = \left(3.5\times10^{10}\right)\begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0.0003&0&-0.0131&-0.0003&0&-0.0131&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0.2100&0&0&-0.2100&0&0&0&0&0&0&0&0&0&0\\
0&0&0&-0.0131&0&0.0070&0.0131&0&0.0052&0&0&0&0&0&0&0&0&0\\
0&0&0&-0.0003&0&0.0131&0.0003&0&0.0131&0&0&0&0&0&0&0&0&0\\
0&0&0&0&-0.2100&0&0&0.2100&0&0&0&0&0&0&0&0&0&0\\
0&0&0&-0.0131&0&0.0052&0.01&0&0.0070&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{bmatrix}10^{-12}$$

$$K_3 = \left(2.8\times10^{10}\right)\begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&1680000&0&0&-16800000&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&1680000&84000&0&-1680000&84000&0&0&0&0&0&0\\
0&0&0&0&0&0&0&84000&560000&0&-84000&420000&0&0&0&0&0&0\\
0&0&0&0&0&0&-16800000&0&0&16800000&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&-1680000&-84000&0&1680000&-84000&0&0&0&0&0&0\\
0&0&0&0&0&0&0&84000&420000&0&-84000&560000&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{bmatrix}$$

$$K_4 = \left(3.5\times10^{10}\right)\begin{bmatrix}
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0.0262&0&0.0131&-0.0262&0&0.0131&0&0&0\\
0&0&0&0&0&0&0&0&0&0&2.1000&0&0&-2.1000&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0.0131&0&0.0700&-0.0131&0&0.0525&0&0&0\\
0&0&0&0&0&0&0&0&0&-0.0262&0&-0.0131&0.0262&0&-0.0131&0&0&0\\
0&0&0&0&0&0&0&0&0&0&-2.1000&0&0&2.1000&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0.0131&0&0.0525&-0.0131&0&0.0700&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{bmatrix}10^{7}$$

$$
K_5 = \left(4.67 \times 10^{10}\right) \left[\begin{array}{cccccccccccccccccccccccc}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0079 & 0 & 2.3350 & -0.0079 & 0 & 2.3350 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.8020 & 0 & 0 & -2.8020 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.3350 & 0 & 0.0934 & -2.3350 & 0 & 0.0700 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0079 & 0 & -2.3350 & 0.0079 & 0 & -2.3350 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -2.8020 & 0 & 0 & 2.820 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.3350 & 0 & 0.0700 & -2.3350 & 0 & 0.0934
\end{array}\right] 10^{7}
$$

$$
K_6 = \left(2.8 \times 10^{10}\right) \left[\begin{array}{cccccccccccccccccccccccc}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 16800000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -16800000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 16800000 & 8400000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -16800000 & 8400000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 8400000 & 560000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -8400000 & 420000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -16800000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 16800000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -16800000 & -8400000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 16800000 & -8400000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 8400000 & 420000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -8400000 & 560000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{array}\right] 10^{7}
$$

$$
KT = 10^{7} \left[\begin{array}{cccccccccccccccccc}
0.0078 & 0 & -0.0233 & -0.0078 & 0 & -0.0233 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 2.8020 & 0 & 0 & -2.8020 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.0233 & 0 & 0.0934 & 0.0233 & 0 & 0.0700 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.0078 & 0 & 0.0233 & 1.6878 & 0 & 0.0233 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -2.8020 & 0 & 0 & 4.4820 & 0.8400 & 0 & 0 & 0 & 0 & 0 & 0 & -1.6800 & 0 & 0 & 0 & 0 & 0 \\
-0.0233 & 0 & 0.0700 & 0.0233 & 0.8400 & 0.1494 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.6800 & 0.8400 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1.6800 & 0 & 0 & -1.6800 & 0 & 0 & 0 & -0.8400 & 0.0420 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.1680 & 0.0084 & 0 & -0.1680 & 0.0084 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0084 & 0.0560 & 0 & -0.0084 & 0.0420 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -1.6800 & 0 & 0 & 1.7063 & 0 & 0.0131 & -0.0262 & 0 & 0.0131 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.1680 & -0.0084 & 0 & 2.2680 & -0.0084 & 0 & -2.1000 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0084 & 0.0420 & 0.0131 & -0.0084 & 0.1260 & -0.0131 & 0 & 0.0525 & 0 & 0 & 0 \\
0 & 0 & 0 & -1.6800 & 0 & 0 & 0 & 0 & 0 & -0.0262 & 0 & -0.0131 & 1.7142 & 0 & 2.3219 & -0.0079 & 0 & 2.3350 \\
0 & 0 & 0 & 0 & -1.6800 & -0.8400 & 0 & 0 & 0 & 0 & -2.1000 & 0 & 0 & 6.5820 & -0.8400 & 0 & -2.8020 & 0 \\
0 & 0 & 0 & 0 & 0.8400 & 0.0420 & 0 & 0 & 0 & 0.0131 & 0 & 0.0525 & 2.3219 & -0.8400 & 0.2194 & -2.3350 & 0 & 0.0700 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0079 & 0 & -2.3350 & 0.0079 & 0 & -2.3350 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -2.8020 & 0 & 0 & 2.8020 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.3350 & 0 & 0.0700 & -2.3350 & 0 & 0.0934
\end{array}\right]
\begin{bmatrix} \gamma_1 \\ \mu_1 \\ \theta_1 \\ \gamma_2 \\ \mu_2 \\ \theta_2 \\ \gamma_3 \\ \mu_3 \\ \theta_3 \\ \gamma_4 \\ \mu_4 \\ \theta_4 \\ \gamma_5 \\ \mu_5 \\ \theta_5 \\ \gamma_6 \\ \mu_6 \\ \theta_6 \end{bmatrix}
=
\begin{bmatrix} F_{1x} \\ F_{1y} \\ M_1 \\ F_{2x} \\ F_{2y} \\ M_2 \\ F_{3x} \\ F_{3y} \\ M_3 \\ F_{4x} \\ F_{4y} \\ M_4 \\ F_{5x} \\ F_{5y} \\ M_5 \\ F_{6x} \\ F_{6y} \\ M_6 \end{bmatrix}
$$

Eliminando Filas y Columnas:

$$
KTR = \begin{bmatrix}
1.6878 & 0 & 0.233 & 0 & 0 & 0 & 0 & 0 & 0 & -1.6800 & 0 & 0 \\
0 & 4.4820 & 0.8400 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.6800 & 0.8400 \\
0.0233 & 0.8400 & 0.1494 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.8400 & 0.0420 \\
0 & 0 & 0 & 1.6800 & 0 & 0 & -1.6800 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0.1680 & 0.0084 & 0 & -0.1680 & 0.0084 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0.0084 & 0.0560 & 0 & -0.0084 & 0.0420 & 0 & 0 & 0 \\
0 & 0 & 0 & -1.6800 & 0 & 0 & 1.7063 & 0 & 0.0131 & -0.0262 & 0 & 0.0131 \\
0 & 0 & 0 & 0 & -0.1680 & -0.0084 & 0 & 2.2680 & -0.0084 & 0 & -2.1000 & 0 \\
0 & 0 & 0 & 0 & 0.0084 & 0.0420 & 0.0131 & -0.0084 & 0.1260 & -0.0131 & 0 & 0.0525 \\
-1.6800 & 0 & 0 & 0 & 0 & 0 & -0.0262 & 0 & -0.0131 & 1.7142 & 0 & 2.3219 \\
0 & -1.6800 & -0.8400 & 0 & 0 & 0 & 0 & -2.1000 & 0 & 0 & 6.5820 & -0.8400 \\
0 & 0.8400 & 0.0420 & 0 & 0 & 0 & 0.0131 & 0 & 0.0525 & 2.3219 & -0.8400 & 0.2194
\end{bmatrix}
\begin{bmatrix} \gamma_2 \\ \mu_2 \\ \theta_2 \\ \gamma_3 \\ \mu_3 \\ \theta_3 \\ \gamma_4 \\ \mu_4 \\ \theta_4 \\ \gamma_5 \\ \mu_5 \\ \theta_5 \end{bmatrix}
=
\begin{bmatrix} -650 \\ -3000 \\ -416.67 \\ -400 \\ 0 \\ -66.67 \\ -400 \\ 0 \\ 666.67 \\ -650 \\ -3000 \\ 416.67 \end{bmatrix}
$$

B. Resolución con MATLAB

```
>> K1 = (10^7)*{0.0078 0 -0.0233 -0.0078 0 -0.0233 0 0 0 0 0 0 0 0 0 0 0; 0
2.8020 0 0 -2.8020 0 0 0 0 0 0 0 0 0 0 0 0; -0.0233 0 0.0934 0.0233 0 0.0700 0
0 0 0 0 0 0 0 0 0 0 0; -0.0078 0 0.0233 1.6878 0 0.0233 0 0 0 0 0 0 -1.6800 0 0
0 0 0; 0 -2.8020 0 0 4.4820 0.8400 0 0 0 0 0 0 0 -1.6800 0.8400 0 0 0; -0.0233 0
0.0700 0.0233 0.8400 0.1494 0 0 0 0 0 0 0 -0.8400 0.0420 0 0 0; 0 0 0 0 0 0 1.6800
0 0 -1.6800 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0.1680 0.0084 0 -0.1680 0.0084 0 0 0 0
0 0; 0 0 0 0 0 0 0 0.0084 0.0560 0 -0.0084 0.0420 0 0 0 0 0 0; 0 0 0 0 0 0 -1.6800
0 0 1.7063 0 0.0131 -0.0262 0 0.0131 0 0 0; 0 0 0 0 0 0 0 -0.1680 -0.0084 0 2.2680
-0.0084 0 -2.1000 0 0 0 0; 0 0 0 0 0 0 0 0.0084 0.0420 0.0131 -0.0084 0.1260 -0.0131
0 0.0525 0 0 0; 0 0 0 -1.6800 0 0 0 0 0 -0.0262 0 -0.0131 1.7142 0 2.3219 -0.0079 0
2.3350; 0 0 0 0 -1.6800 -0.8400 0 0 0 0 -2.1000 0 0 6.5820 -0.8400 0 -2.8020 0; 0 0
0 0 0.8400 0.0420 0 0 0 0.0131 0 0.0525 2.3219 -0.8400 0.2194 -2.3350 0 0.0700; 0
0 0 0 0 0 0 0 0 0 0 0 -0.0079 0 -2.3350 0.0079 0 -2.3350; 0 0 0 0 0 0 0 0 0 0 0 0
0 -2.8020 0 0 2.8020 0; 0 0 0 0 0 0 0 0 0 0 0 0 2.3350 0 0.0700 -2.3350 0 0.0930]

K1 =

   1.0e+007 *

   Columns 1 throguh 17

    0.0078         0   -0.0233   -0.0078         0   -0.0233         0         0         0         0         0         0         0         0         0         0         0
         0    2.8020         0         0   -2.8020         0         0         0         0         0         0         0         0         0         0         0         0
   -0.0233         0    0.0934    0.0233         0    0.0700         0         0         0         0         0         0         0         0         0         0         0
   -0.0078         0    0.0233    1.6878         0    0.0233         0         0         0         0         0         0   -1.6800         0         0         0         0
         0   -2.8020         0         0    4.4820    0.8400         0         0         0         0         0         0         0   -1.6800    0.8400         0         0
   -0.0233         0    0.0700    0.0233    0.8400    0.1494         0         0         0         0         0         0         0   -0.8400    0.0420         0         0
         0         0         0         0         0         0    1.6800         0         0   -1.6800         0         0         0         0         0         0         0
         0         0         0         0         0         0         0    0.1680    0.0084         0   -0.1680    0.0084         0         0         0         0         0
         0         0         0         0         0         0         0    0.0084    0.0560         0   -0.0084    0.0420         0         0         0         0         0
         0         0         0         0         0         0   -1.6800         0         0    1.7063         0    0.0131   -0.0262         0    0.0131         0         0
         0         0         0         0         0         0         0   -0.1680   -0.0084         0    2.2680   -0.0084         0   -2.1000         0         0         0
         0         0         0         0         0         0         0    0.0084    0.0420    0.0131   -0.0084    0.1260   -0.0131         0    0.0525         0         0
         0         0         0   -1.6800         0         0         0         0         0   -0.0262         0   -0.0131    1.7442         0    2.3219   -0.0079         0
         0         0         0         0   -1.6800   -8.0400         0         0         0         0   -2.1000         0         0    6.5820   -0.8400         0   -2.8020
         0         0         0         0    0.8400    0.0420         0         0         0    0.0131         0    0.0525    2.3219   -0.8400    0.2194   -2.3350         0
         0         0         0         0         0         0         0         0         0         0         0         0   -0.0079         0   -2.3350    0.0079         0
         0         0         0         0         0         0         0         0         0         0         0         0         0   -2.8020         0         0    2.8020
         0         0         0         0         0         0         0         0         0         0         0         0    2.3350         0    0.0700   -2.3350         0
```

```
Column 18

         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
         0
    2.3350
         0
    0.0700
   -2.3350
         0
    0.0930

>> KRD =[(10^7)*[ 1.6878 0 0.0233 0 0 0 0 0 0 -1.6800 0 0; 0 4.4820 0.8400 0 0 0
0 0 0 0 -1.6800 0.8400; 0.0233 0.8400 0.1494 0 0 0 0 0 0 -0.8400 0.0420; 0 0 0
1.6800 0 0 -1.6800 0 0 0 0 0; 0 0 0 0 0.1680 0.0084 0 -0.1680 0.0084 0 0 0; 0 0 0
0 0.0084 0.0560 0 -0.0084 0.0420 0 0 0; 0 0 0 -1.6800 0 0 1.7063 0 0.0131 -0.0262
0 0.0131; 0 0 0 0 -0.1680 -0.0084 0 2.2680 -0.0084 0 -2.1000 0; 0 0 0 0 0.0084
0.0420 0.0131 -0.0084 0.1260 -0.0131 0 0.0525; -1.6800 0 0 0 0 0 -0.0262 0 -0.0131
1.7142 0 2.3219; 0 -1.6800 -0.8400 0 0 0 0 -2.1000 0 0 6.5820 -0.8400; 0 0.8400
0.0420 0 0 0 0.0131 0 0.0525 2.3219 -0.8400 0.2194]]

KRD =

  1.0e+007 *

    1.6878         0    0.0233         0         0         0         0         0         0   -1.6800         0         0
         0    4.4820    0.8400         0         0         0         0         0         0         0   -1.6800    0.8400
    0.0233    0.8400    0.1494         0         0         0         0         0         0         0   -0.8400    0.0420
         0         0         0    1.6800         0         0   -1.6800         0         0         0         0         0
         0         0         0         0    0.1680    0.0084         0   -0.1680    0.0084         0         0         0
         0         0         0         0    0.0084    0.0560         0   -0.0084    0.0420         0         0         0
         0         0         0   -1.6800         0         0    1.7063         0    0.0131   -0.0262         0    0.0131
         0         0         0         0   -0.1680   -0.0084         0    2.2680   -0.0084         0   -2.1000         0
         0         0         0         0    0.0084    0.0420    0.0131   -0.0084    0.1260   -0.0131         0    0.0525
   -1.6800         0         0         0         0         0   -0.0262         0   -0.0131    1.7142         0    2.3219
         0   -1.6800   -0.8400         0         0         0         0   -2.1000         0         0    6.5820   -0.8400
         0    0.8400    0.0420         0         0         0    0.0131         0    0.0525    2.3219   -0.8400    0.2194

>> f = [-650; -3000; -416.67; -400; 0; -66.67; -400; 0; 667.67; -650; -3000; 416.67]

f =

  1.0e+003 *

   -0.6500
   -3.0000
   -0.4167
   -0.4000
         0
   -0.0667
   -0.4000
         0
    0.6677
   -0.6500
   -3.0000
    0.4167
```

```
>> u = inv(KRD)*f

u =
    0.0000
   -0.0002
    0.0008
   -0.0036
   -0.0000
   -0.0011
   -0.0036
   -0.0000
    0.0013
    0.0001
   -0.0000
   -0.0001

>> U = [ 0; 0; 0; 0; -0.0002; 0.0008; -0.0036; 0; -0.0011; -0.0036; 0; 0.0013;
0.0001; 0; -0.0001; 0; 0; 0]

U =
         0
         0
         0
         0
   -0.0002
    0.0008
   -0.0036
         0
   -0.0011
   -0.0036
         0
    0.0013
    0.0001
         0
   -0.0001
         0
         0
         0

>> F = K1 * U

F =

  1.0e+003 *

   -0.1864
    5.6040
    0.5600
   -1.4936
   -3.0840
   -0.5268
         0
    0.0168
   -0.0700
   -0.8158
   -0.0168
    0.6388
    0.1652
   -2.5200
    0.9694
    2.3271
         0
    2.2650
```

Por lo tanto:

$\gamma_1 = 0$	$\mu_1 = 0$	$\theta_1 = 0$
$\gamma_2 = 0$	$\mu_2 = -0.0002\text{ m}$	$\theta_2 = 0.0008\text{ rad}$
$\gamma_3 = -0.0036\text{ m}$	$\mu_3 = 0$	$\theta_3 = -0.0011\text{ rad}$
$\gamma_4 = -0.0036\text{ m}$	$\mu_4 = 0$	$\theta_4 = 0.0013\text{ rad}$
$\gamma_5 = 0.0001\text{ m}$	$\mu_5 = 0$	$\theta_5 = -0.0001\text{ rad}$
$\gamma_6 = 0$	$\mu_6 = 0$	$\theta_6 = 0$

Fuerzas:

$$\left(-0.007\times10^7\right)(0)+\left(-0.0233\times10^7\right)(0.0008)=F_{1x}-650$$
$$F_{1x}=463.6\text{ N}$$

$$\left(-2.8020\times10^7\right)(-0.0002)=F_{1y}$$
$$F_{1y}=5604\text{ N}$$

$$\left(0.0233\times10^7\right)(0)+\left(0.0700\times10^7\right)(0.0008)=M_1$$
$$M_1=560\text{ Nm}$$

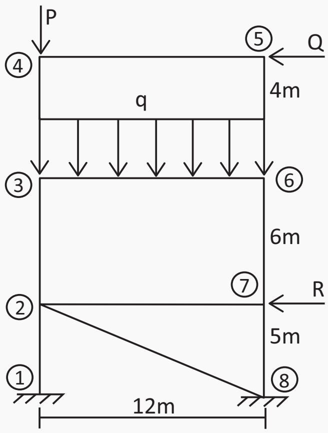
$$\left(0.0079\times10^7\right)(0.0001)+\left(-2.3350\times10^7\right)(0.0001)=F_{5x}-650$$
$$F_{5x}=2992.9\text{ N}$$

$$\left(-2.8020\times10^7\right)(0)=F_{5y}$$
$$F_{5y}=0$$

$$\left(2.3350\times10^7\right)(0.0001)+\left(0.0700\times10^7\right)(0.0001)=M_5$$
$$M_5=2265\text{ Nm}$$

EJERCICIO 13

Determinar los Desplazamientos y las Cargas generadas en cada nodo, en la estructura mostrada, según la secuencia indicada.



$E = 250 GPa$

$I = 4 \times 10^{-6} m^4$

$A = 2 \times 10^{-4} m^2$

$P = 3000 N$

$Q = 4000 N$

$R = 5000 N$

$q = 60 N/m$

Nodos: 1 – 2; 2 – 3; 3 – 4; 4 – 5; 5 – 6;
6 – 7; 7 – 8; 3 – 6; 2 – 8; 1 – 7

A. Resolución

Nodo	θ	C	S	C^2	S^2	SC
1 – 2	90°	0	1	0	1	0
2 – 3	90°	0	1	0	1	0
3 – 4	90°	0	1	0	1	0
4 – 5	0°	1	0	1	0	0
5 – 6	270°	0	–1	0	1	0
6 – 7	270°	0	–1	0	1	0
7 – 8	270°	0	–1	0	1	0
3 – 6	0°	1	0	1	0	0
2 – 8	308.66°	0.62	–0.78	0.39	0.61	–0.49
1 – 7	51.34°	0.62	0.78	0.39	0.61	0.49

$$K_1 = 10^7 \left[\begin{array}{cccccccccccccccccccccccc}
0.0096 & 0 & -0.0240 & -0.0096 & 0 & -0.0240 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0096 & 0 & 0.0240 & -0.0096 & 0 & 0.0240 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.0000 & 0 & 0 & -1.0000 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0240 & 0 & 0.0800 & -0.0240 & 0 & 0.0400 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0096 & 0 & -0.0240 & 0.0096 & 0 & -0.0240 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.0000 & 0.0240 & 0 & 1.0000 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0240 & 0 & 0.0400 & -0.0240 & 0 & 0.0800
\end{bmatrix}
$$

$$K_8 = 10^6 \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 4.1667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -4.1667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0069 & 0.0417 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0069 & 0.0417 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0417 & 0.3333 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0417 & 0.1667 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -4.1667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 4.1667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0069 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0069 & -0.0417 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0417 & 0.1667 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0417 & 0.3333 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$K_9 = 10^6 \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1.0161 & -1.2745 & 0.0127 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.0161 & 1.2745 & 0.0127 \\
0 & 0 & 0 & -1.2745 & 1.5884 & 0.0101 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.2745 & -1.5884 & 0.0101 \\
0 & 0 & 0 & 0.0127 & 0.0101 & 0.2082 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -1.0161 & 1.2745 & -0.0127 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.0161 & -1.2745 & -0.0127 \\
0 & 0 & 0 & 1.2745 & -1.5884 & 0.0127 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.2745 & 1.5884 & -0.0101 \\
0 & 0 & 0 & 0.0127 & 0.0101 & 0.1041 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0127 & -0.0101 & 0.2082
\end{bmatrix}$$

$$K_{10} = 10^6 \begin{bmatrix}
0.0161 & 1.2745 & -0.0127 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.0161 & -1.2745 & -0.0127 & 0 & 0 & 0 \\
1.2745 & 1.5884 & 0.0101 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.2745 & -1.5884 & 0.0101 & 0 & 0 & 0 \\
-0.0127 & 0.0101 & 0.2082 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0127 & -0.0101 & 0.1041 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-1.0161 & -1.2745 & 0.0127 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.0161 & 1.2745 & 0.0127 & 0 & 0 & 0 \\
-1.2745 & -1.5884 & -0.0101 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.2745 & 1.5884 & -0.0101 & 0 & 0 & 0 \\
-0.0127 & 0.0101 & 0.1041 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0127 & -0.0101 & 0.2082 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

B. Resolución con MATLAB

```
>> P= (250*10^9/5);
>> a= (2*10^-4*0)+ 12*(4*10^-6*1/5^2);
>> b= (2*10^-4-12*4*10^-6/5^2)*0;
>> c= 6*(4*10^-6*1/5);
>> d= (2*10^-4*1)+ 12*(4*10^-6*0/5^2);
>> e= 6*(4*10^-6*1/5);
>> f= 4*(4*10^-6);
>> g= 2*(4*10^-6);
>> k1= P* [a b -c -a -b -c 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; b d e -b -d e 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; -c e f c -e g 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0; -a -b c a b c 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; -b -d -e b d -e 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0; -c e g c -e f 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
```

```
k1 =

  1.0e+007 *

  Columns 1 through 17

  0.0096        0  -0.0240  -0.0096        0  -0.0240        0        0        0        0        0        0        0        0        0        0        0
       0   1.0000   0.0240        0  -1.0000   0.0240        0        0        0        0        0        0        0        0        0        0        0
 -0.0240   0.0240   0.0800   0.0240  -0.0240   0.0400        0        0        0        0        0        0        0        0        0        0        0
 -0.0096        0   0.0240   0.0096        0   0.0240        0        0        0        0        0        0        0        0        0        0        0
       0  -1.0000  -0.0240        0   1.0000  -0.0240        0        0        0        0        0        0        0        0        0        0        0
 -0.0240   0.0240   0.0400   0.0240  -0.0240   0.0800        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
       0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0

Columns 18 through 24

       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
       0        0        0        0        0        0        0
```

```
>> P= (250*10^9/5);

>> a2= (2*10^-4*0)+ 12*(4*10^-6*1/6^2);

>> b2= (2*10^-4-12*4*10^-6*0/6^2)*0;

>> c2= 6*(4*10^-6*1/6);

>> d2= (2*10^-4*1)+ 12*(4*10^-6*0/6^2);

>> e2= 6*(4*10^-6*0/6);

>> f2= 4*(4*10^-6);

>> g2= 2*(4*10^-6);

>>  k2= P* [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0
0 a b -c -a -b -c 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 b d e -b -d e 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0; 0 0 0 -c e f c -e g 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 -a -b
c a b c 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 -b -d -e b d -e 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 -c e g c -e f 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]

k2 =

  1.0e+006 *

  Columns 1 through 17

      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0  0.0800       0 -0.2000 -0.0800       0 -0.2000       0       0       0       0       0       0       0       0
      0       0       0       0  8.3333  0.2000       0 -8.3333  0.2000       0       0       0       0       0       0       0       0
      0       0       0 -0.2000  0.2000  0.6667  0.2000 -0.2000  0.3333       0       0       0       0       0       0       0       0
      0       0       0 -0.0800       0  0.2000  0.0800       0  0.2000       0       0       0       0       0       0       0       0
      0       0       0       0 -8.3333 -0.2000       0  8.3333 -0.2000       0       0       0       0       0       0       0       0
      0       0       0 -0.2000  0.2000  0.3333  0.2000 -0.2000  0.6667       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0
```

```
Columns 18 through 24

       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0

>> P= (250*10^9/4);
>> a3= (2*10^-4*0)+ 12*(4*10^-6*1/4^2);
>> b3= (2*10^-4-12*4*10^-6*0/4^2)*0;
>> c3= 6*(4*10^-6*1/4);
>> d3= (2*10^-4*1)+ 12*(4*10^-6*0/4^2);
>> e3= 6*(4*10^-6*0/4);
>> f3= 4*(4*10^-6);
>> g3= 2*(4*10^-6);
>> k3= P* [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 a3 b3 -c3
-a3 -b3 -c3 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 b3 d3 e3 -b3 -d3 e3 0 0 0 0 0 0
0 0 0 0 0 0; 0 0 0 0 0 0 -c3 e3 f3 c3 -e3 g3 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0
0 -a3 -b3 c3 a3 b3 c3 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 -b3 -d3 -e3 b3 d3 -e3
0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 -c3 e3 g3 c3 -e3 f3 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0]
```

```
k3 =

  Columns 1 through 14

        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0    187500         0   -375000   -187500         0   -375000         0         0
        0         0         0         0         0         0         0  12500000         0         0 -12500000         0         0         0
        0         0         0         0         0         0   -375000         0   1000000    375000         0    500000         0         0
        0         0         0         0         0         0   -187500         0    375000    187500         0    375000         0         0
        0         0         0         0         0         0         0 -12500000         0         0  12500000         0         0         0
        0         0         0         0         0         0   -375000         0    500000    375000         0   1000000         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0         0         0         0         0

Columns 18 through 24

        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
        0         0         0         0         0         0         0         0         0         0
```

```
>> P= (250*10^9/4.99);

>> a4= (2*10^-4*1)+ 12*(4*10^-6*0/4.99^2);

>> b4= (2*10^-4-12*4*10^-6*0/4.99^2)*1;

>> c4= 6*(4*10^-6*0/4.99);

>> d4= (2*10^-4*0)+ 12*(4*10^-6*1/4.99^2);

>> e4= 6*(4*10^-6*1/4.99);

>> f4= 4*(4*10^-6);

>> g4= 2*(4*10^-6);

>> k4= P* [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 a4 b4 -c4 -a4 -b4
-c4 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 b4 d4 e4 -b4 -d4 e4 0 0 0 0;0 0 0 0 0; 0
0 0 0 0 0 0 0 0 -c4 e4 f4 c4 -e4 g4 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 -a4 -b4
c4 a4 b4 c4 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 -b4 -d4 -e4 b4 d4 -e4 0 0 0 0 0
0 0 0 0; 0 0 0 0 0 0 0 0 0 -c4 e4 g4 c4 -c4 f4 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0]

k4 =

  1.0e+007 *

  Columns 1 through 14

      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0 1.0020 1.0020      0 -1.0020 -1.0020     0      0      0
      0      0      0      0      0      0      0      0      0 1.0020 0.0097 0.0241 -1.0020 -0.0097 0.0241     0      0
      0      0      0      0      0      0      0      0      0      0 0.0241 0.0802      0 -0.0241 0.0401      0      0
      0      0      0      0      0      0      0      0      0 -1.0020 -1.0020     0 1.0020 1.0020      0      0      0
      0      0      0      0      0      0      0      0      0 -1.0020 -0.0097 -0.0241 1.0020 0.0097 -0.0241    0      0
      0      0      0      0      0      0      0      0      0      0 0.0241 0.0401      0 -0.0241 0.0802      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0
```

```
Columns 18 through 24

     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0
     0     0     0     0     0     0     0

>> P= (250*10^9/4);
>> a5= (2*10^-4*0)+ 12*(4*10^-6*1/5^2);
>> b5= (2*10^-4- 12*4*10^-6/4^2)*0;
>> c5= 6*(4*10^-6*-1/4);
>> d5= (2*10^-4*1)+ 12*(4*10^-6*0/4^2);
>> e5= 6*(4*10^-6*0/4);
>> f5= 4*(4*10^-6);
>> g5= 2*(4*10^-6);
>> k5= P* [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 a5 b5 -c5 -a5 -b5 -c5 0 0 0 0
0 0; 0 0 0 0 0 0 0 0 0 0 0 0 b5 d5 e5 -b5 -d5 e5 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0
0 0 -c5 e5 f5 c5 -e5 g5 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 -a5 -b5 c5 a5 b5 c5
0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 -b5 -d5 -e5 b5 d5 -e5 0 0 0 0 0 0; 0 0 0 0
0 0 0 0 0 0 0 0 -c5 e5 g5 c5 -e5 f5 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0]
```

```
k5 =

  1.0e+007 *

  Columns 1 through 17

        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0   0.0120        0   0.0375  -0.0120        0
        0        0        0        0        0        0        0        0        0        0        0        0        0   1.2500        0        0  -1.2500
        0        0        0        0        0        0        0        0        0        0        0        0   0.0375        0   0.1000  -0.0375        0
        0        0        0        0        0        0        0        0        0        0        0        0  -0.0120        0  -0.0375   0.0120        0
        0        0        0        0        0        0        0        0        0        0        0        0        0  -1.2500        0        0   1.2500
        0        0        0        0        0        0        0        0        0        0        0        0   0.0375        0   0.0500  -0.0375        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0

Columns 18 through 24

        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
   0.0375        0        0        0        0        0        0
        0        0        0        0        0        0        0
   0.0500        0        0        0        0        0        0
  -0.0375        0        0        0        0        0        0
        0        0        0        0        0        0        0
   0.1000        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
```

```
>> P= (250*10^9/6);
>> a6= (2*10^-4*0)+ 12*(4*10^-6*1/6^2);
>> b6= (2*10^-4- 12*4*10^-6/6^2)*0;
>> c6= 6*(4*10^-6*-1/6);
>> d6= (2*10^-4*1)+ 12*(4*10^-6*0/6^2);
>> e6= 6*(4*10^-6*0/6);
>> f6= 4*(4*10^-6);
>> g6= 2*(4*10^-6);
>> k6= P* [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 a6 b6 -c6 -a6 -b6 -c6 0 0 0; 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 b6 d6 e6 -b6 -d6 e6 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -c6
e6 f6 c6 -e6 g6 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -a6 -b6 c6 a6 b6 c6 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -b6 -d6 -e6 b6 d6 -e6 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 -c6 e6 g6 c6 -e6 f6 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0]

k6 =

  1.0e+006 *


  Columns 1 through 17

     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0  0.0556       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0  8.3333
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0  0.1667       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0 -0.0556       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0 -8.3333
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0  0.1667       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0       0       0
```

```
Columns 18 through 24

        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
   0.1667   -0.0556         0    0.1667         0         0         0
        0         0   -8.3333         0         0         0         0
   0.6667   -0.1667         0    0.3333         0         0         0
  -0.1667    0.0556         0   -0.1667         0         0         0
        0         0    8.3333         0         0         0         0
   0.3333   -0.1667         0    0.6667         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0

>> P= (250*10^9/5);
>> a7= (2*10^-4*0)+ 12*(4*10^-6*1/5^2);
>> b7= (2*10^-4- 12*4*10^-6/5^2)*0;
>> c7= 6*(4*10^-6*-1/5);
>> d7= (2*10^-4*1)+ 12*(4*10^-6*0/5^2);
>> e7= 6*(4*10^-6*0/5);
>> f7= 4*(4*10^-6);
>> g7= 2*(4*10^-6);
>> k7= P* [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 a6 b6 -c7 -a7 -b7 -c7; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 b7 d7 e7 -b7 -d7 e7; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -c7 e7 f7
c7 -e7 g7; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -a7 -b7 c7 a7 b7 c7; 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 -b7 -d7 -e7 b7 d7 -e7; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 -c7 e7 g7 c7 -e7 f7]
```

```
k7 =

  1.0e+007 *

  Columns 1 through 17

     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

Columns 18 through 24

       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0    0.0067         0    0.0240   -0.0096         0    0.0240
       0         0    1.0000         0         0   -1.0000         0
       0    0.0240         0    0.0800   -0.0240         0    0.0400
       0   -0.0096         0   -0.0240    0.0096         0   -0.0240
       0         0   -1.0000         0         0    1.0000         0
       0    0.0240         0    0.0400   -0.0240         0    0.0800
```

```
>> P= (250*10^9/4.99);

>> a8= (2*10^-4*1)+ 12*(4*10^-6*0/4.99^2);

>> b8= (2*10^-4- 12*4*10^-6/4.99^2)*1;

>> c8= 6*(4*10^-6*0/4.99);

>> d8= (2*10^-4*0)+ 12*(4*10^-6*1/4.99^2);

>> e8= 6*(4*10^-6*1/4.99);

>> f8= 4*(4*10^-6);

>> g8= 2*(4*10^-6);

>> k8= P* [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 a8 b8 -c8
0 0 0 0 0 0 -a8 -b8 -c8 0 0 0 0 0 0; 0 0 0 0 0 0 b8 d8 e8 0 0 0 0 0 0 -b8 -d8 -e8
0 0 0 0 0 0; 0 0 0 0 0 0 -c8 e8 f8 0 0 0 0 0 0 c8 -e8 g8 0 0 0 0 0 0; 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 -a8 -b8 c8 0 0 0 0 0 0 a8 b8 c8
0 0 0 0 0 0; 0 0 0 0 0 0 -b8 -d8 -e8 0 0 0 0 0 0 b8 d8 -e8 0 0 0 0 0 0; 0 0 0 0
0 0 -c8 e8 g8 0 0 0 0 0 0 c8 -e8 f8 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0]

k8 =

  1.0e+007 *

Columns 1 through 17

     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0  1.0020  0.9923       0     0     0     0     0     0     0 -1.0020 -0.9923
     0     0     0     0     0     0  0.9923  0.0097  0.0241     0     0     0     0     0     0 -0.9923 -0.0097
     0     0     0     0     0     0       0  0.0241  0.0802     0     0     0     0     0     0       0 -0.0241
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0 -1.0020 -0.9923       0     0     0     0     0     0     0  1.0020  0.9923
     0     0     0     0     0     0 -0.9923 -0.0097 -0.0241     0     0     0     0     0     0  0.9923  0.0097
     0     0     0     0     0     0       0  0.0241  0.0401     0     0     0     0     0     0       0 -0.0241
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
     0     0     0     0     0     0       0       0       0     0     0     0     0     0     0       0       0
```

```
Columns 18 through 24

        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
  -0.0241         0         0         0         0         0         0
   0.0401         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
  -0.0241         0         0         0         0         0         0
   0.0802         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0
        0         0         0         0         0         0         0

>> P= (250*10^9/7.07);

>> a9= (2*10^-4*0.499)+ 12*(4*10^-6*0.499/7.07^2);

>> b9= (2*10^-4- 12*4*10^-6/7.07^2)*-0.499;

>> c9= 6*(4*10^-6*-0.707/7.07);

>> d9= (2*10^-4*0.499)+ 12*(4*10^-6*0.499/7.07^2);

>> e9= 6*(4*10^-6*0.707/7.07);

>> f9= 4*(4*10^-6);

>> g9= 2*(4*10^-6);

>> k9= P* [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
a9 b9 -c9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 -a9 -b9 -c9; 0 0 0 b9 d9 e9 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 -b9 -d9 e9; 0 0 0 -c9 e9 f9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 c9 -e9
g9; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0; 0 0 0 -a9 -b9 c9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 a9 b9 c9; 0 0 0 -b9 -d9 -e9
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;b9 d9 -e9; 0 0 0 -c9 e9 g9 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 c9 -e9 f9]
```

```
k9 =

  1.0e+006 *

  Columns 1 through 17

     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0  3.5459 -3.5121  0.0849      0      0      0      0      0      0      0      0      0      0      0
     0      0      0 -3.5121  3.5459  0.0849      0      0      0      0      0      0      0      0      0      0      0
     0      0      0  0.0849  0.0849  0.5658      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0       0       0       0      0      0      0      0      0      0      0      0      0      0      0
     0      0      0 -3.5459  3.5121 -0.0849      0      0      0      0      0      0      0      0      0      0      0
     0      0      0  3.5121 -3.5459 -0.0849      0      0      0      0      0      0      0      0      0      0      0
     0      0      0  0.0849  0.0849  0.2829      0      0      0      0      0      0      0      0      0      0      0

Columns 18 through 24

       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0   -3.5459    3.5121    0.0849
       0         0         0         0    3.5121   -3.5459    0.0849
       0         0         0         0   -0.0849   -0.0849    0.2829
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0         0         0         0
       0         0         0         0    3.5459   -3.5121   -0.0849
       0         0         0         0   -3.5121    3.5459   -0.0849
       0         0         0         0   -0.0849   -0.0849    0.5658
```

```
>> KT = k1 + k2 + k3 + k4 + k5 + k6 + k7 + k8 + k9

KT =

  1.0e+007 *

  Columns 1 through 17

   0.0096        0  -0.0240  -0.0096        0  -0.0240        0        0        0        0        0        0        0        0        0        0        0
        0   1.0000   0.0240        0  -1.0000   0.0240        0        0        0        0        0        0        0        0        0        0        0
  -0.0240   0.0240   0.0800   0.0240  -0.0240   0.0400        0        0        0        0        0        0        0        0        0        0        0
  -0.0096        0   0.0240   0.3722  -0.3512   0.0125  -0.0080        0  -0.0200        0        0        0        0        0        0        0        0
        0  -1.0000  -0.0240  -0.3512   2.1879  -0.0045        0  -0.8333   0.0200        0        0        0        0        0        0        0        0
  -0.0240   0.0240   0.0400   0.0125   0.0045   0.2032   0.0200  -0.0200   0.0333        0        0        0        0        0        0        0        0
        0        0        0  -0.0080        0   0.0200   1.0288   0.9923  -0.0175  -0.0187        0  -0.0375        0        0        0  -1.0020  -0.9923
        0        0        0        0  -0.8333  -0.0200   0.9923   2.0930   0.0041        0  -1.2500        0        0        0        0  -0.9923  -0.0097
        0        0        0  -0.0200   0.0200   0.0333  -0.0175   0.0041   0.2468   0.0375        0   0.0500        0        0        0        0  -0.0241
        0        0        0        0        0        0  -0.0187        0   0.0375   1.0208   1.0020   0.0375  -1.0020  -1.0020        0        0        0
        0        0        0        0        0        0        0  -1.2500        0   1.0020   1.2597   0.0241  -1.0020  -0.0097   0.0241        0        0
        0        0        0        0        0        0  -0.0375        0   0.0500   0.0375   0.0241   0.1802        0  -0.0241   0.0401        0        0
        0        0        0        0        0        0        0        0        0  -1.0020  -1.0020        0   1.0140   1.0020   0.0375  -0.0120        0
        0        0        0        0        0        0        0        0        0  -1.0020  -0.0097  -0.0241   1.0020   1.2597  -0.0241        0  -1.2500
        0        0        0        0        0        0        0        0        0        0   0.0241   0.0401   0.0375  -0.0241   0.1802  -0.0375        0
        0        0        0        0        0        0  -1.0020  -0.9923        0        0        0        0  -0.0120        0  -0.0375   1.0196   0.9923
        0        0        0        0        0        0  -0.9923  -0.0097  -0.0241        0        0        0        0  -1.2500        0   0.9923   2.0930
        0        0        0        0        0        0        0   0.0241   0.0401        0        0        0   0.0375        0   0.0500  -0.0208  -0.0241
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0  -0.0056        0
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0  -0.8333
        0        0        0        0        0        0        0        0        0        0        0        0        0        0        0   0.0167        0
        0        0        0  -0.3546   0.3512  -0.0085        0        0        0        0        0        0        0        0        0        0        0
        0        0        0   0.3512  -0.3546  -0.0085        0        0        0        0        0        0        0        0        0        0        0
        0        0        0   0.0085   0.0085   0.0283        0        0        0        0        0        0        0        0        0        0        0

 Columns 18 through 24

        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0  -0.3546   0.3512   0.0085
        0        0        0        0   0.3512  -0.3546   0.0085
        0        0        0        0  -0.0085  -0.0085   0.0283
        0        0        0        0        0        0        0
  -0.0241        0        0        0        0        0        0
   0.0401        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
        0        0        0        0        0        0        0
   0.0375        0        0        0        0        0        0
        0        0        0        0        0        0        0
   0.0500        0        0        0        0        0        0
  -0.0208  -0.0056        0   0.0167        0        0        0
  -0.0241        0  -0.8333        0        0        0        0
   0.2468  -0.0167        0   0.0333        0        0        0
  -0.0167   0.0122        0   0.0073  -0.0096        0   0.0240
        0        0   1.8333        0        0  -1.0000        0
   0.0333   0.0073        0   0.1467  -0.0240        0   0.0400
        0  -0.0096        0  -0.0240   0.3642  -0.3512  -0.0325
        0        0  -1.0000        0  -0.3512   1.3546  -0.0085
        0   0.0240        0   0.0400  -0.0325  -0.0085   0.1366
```

Desplazamientos:

$$u = inv(k) * F$$

$$u = \begin{bmatrix} -0.0005m \\ -0.0004m \\ 0.0002rad \\ -0.0003m \\ -0.0008m \\ -0.0006rad \\ 0.0010m \\ -0.0010m \\ -0.0000rad \\ 0.0010m \\ 0.0005m \\ -0.0004rad \\ -0.0003m \\ 0.0005m \\ -0.0001rad \\ -0.0049m \\ 0.0005m \\ 0.0003rad \end{bmatrix}$$

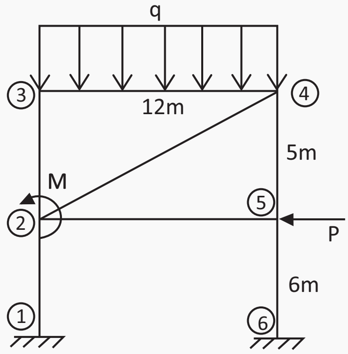
Fuerzas:

$$F = K * u$$

$$F = 10^3 \begin{bmatrix} 4.3380N \\ 9.4541N \\ -0.0759Nm \\ 0.0798N \\ -0.6627N \\ 0.0379Nm \\ -0.0743N \\ -0.9049N \\ -0.6833Nm \\ -0.0187N \\ -2.3021N \\ 0.0583Nm \\ -4.0479N \\ 0.0271N \\ 0.0646Nm \\ 0.0368N \\ -0.3326N \\ 0.8000Nm \\ -5.0252N \\ -0.4708N \\ -0.0074Nm \\ 0.3941N \\ -4.9274N \\ -1.0456Nm \end{bmatrix}$$

EJERCICIO 14

Determinar los Desplazamientos y las Cargas generadas en cada nodo, en la estructura mostrada, según la secuencia indicada.



$E = 180\,GPa$

$I = 6 \times 10^{-6} m^4$

$A = 4 \times 10^{-4} m^2$

$P = 5000N$

$M = 6000N$

$q = 80N/m$

A. Resolución

$$K_1 = 10^4 \begin{bmatrix} 1000000 & 0 & -18 & -1000000 & 0 & -18 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1200 & 0 & 0 & -1200 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -18 & 0 & 72 & 18 & 0 & 36 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1000000 & 0 & 18 & 1000000 & 0 & 18 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1200 & 0 & 0 & 1200 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -18 & 0 & 36 & 18 & 0 & 72 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K_2 = 10^5 \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1.0368 & 0 & -2.592 & -1.368 & 0 & -2.592 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 144 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -2.592 & 0 & 8.64 & 2.592 & -144 & 4.32 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1.0368 & 0 & 2.592 & 1.0368 & 0 & 2.592 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -144 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -2.592 & 0 & 4.32 & 2.592 & 144 & 8.64 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$
K_3 = 10^2 \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 60000 & 0 & 0 & -60000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 75 & 450 & 0 & -75 & 4500 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 450 & 3600 & 0 & -450 & 180 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -60000 & 0 & 0 & 60000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -75 & -450 & 0 & 75 & -450 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 450 & 1800 & 0 & 450 & 36000 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
$$

$$
K_4 = 10^4 \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 6 & 0 & 18 & -16 & 0 & 18 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1200 & 0 & 0 & -1200 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 18 & 0 & 72 & -18 & 0 & 36 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -6 & 0 & -18 & 6 & 0 & -18 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1200 & 0 & 0 & 1200 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 18 & 0 & 36 & -18 & 0 & 72
\end{bmatrix}
$$

$$K_5 = \left[\begin{array}{cccccccccccccccccc}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1746735.2 & 2505153.8 & 29504.1 & 0 & 0 & 0 & -1746735.2 & -2505153.8 & 29504.1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 2505153.8 & 3609253.3 & -20509.01 & 0 & 0 & 0 & -2505153.8 & -3609253.3 & -20509.01 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 29504.1 & -20509.01 & 321907.6 & 0 & 0 & 0 & -29504.1 & 20509.01 & 160953.8 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -1746735.2 & -2505153.8 & -29504.1 & 0 & 0 & 0 & 0 & 0 & -29504.1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -2505153.8 & -3609253.3 & 20509.01 & 0 & 0 & 0 & 0 & 0 & 20509.01 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 29504.1 & -20509.01 & 160953.8 & 0 & 0 & 0 & 0 & 0 & 321907.6 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{array}\right]$$

$$K_6 = 10^4 \left[\begin{array}{cccccccccccccccccccccccc}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 6 & 0 & 18 & -6 & 0 & 18 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1200 & 0 & 0 & -1200 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 18 & 0 & 72 & -18 & 0 & 36 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -6 & 0 & -18 & 6 & 0 & -18 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1200 & 0 & 0 & 1200 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 18 & 0 & 36 & -18 & 0 & 72
\end{array}\right]$$

B. Resolución con MATLAB

```
>> K1 = (10^4)*[1000000 0 -18 -1000000 0 -18 0 0 0 0 0 0 0 0 0 0 0 0; 0 1200
0 0 -1200 0 0 0 0 0 0 0 0 0 0 0 0 0; -18 0 72 18 0 36 0 0 0 0 0 0 0 0 0 0 0 0;
-1000000 0 18 1000000 0 18 0 0 0 0 0 0 0 0 0 0 0 0; 0 -1200 0 0 1200 0 0 0 0 0
0 0 0 0 0 0 0 0; -18 0 36 18 0 72 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0]

K1 =

  1.0e+010 *

  Columns 1 through 8

    1.0000         0   -0.0000   -1.0000         0   -0.0000         0         0
         0    0.0012         0         0   -0.0012         0         0         0
   -0.0000         0    0.0001    0.0000         0    0.0000         0         0
   -1.0000         0    0.0000    1.0000         0    0.0000         0         0
         0   -0.0012         0         0    0.0012         0         0         0
   -0.0000         0    0.0000    0.0000         0    0.0001         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0

Columns 9 through 16

       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
```

```
Columns 17 through 18

       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0

>> K2 = (10^5)*[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 1.0368 0 -2.592 -1.368 0
-2.592 0 0 0 0 0 0 0 0 0; 0 0 0 0 144 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 -2.592 0
8.64 2.592 -144 4.32 0 0 0 0 0 0 0 0 0; 0 0 0 -1.0368 0 2.592 1.0368 0 2.592 0 0
0 0 0 0 0 0 0; 0 0 0 0 -144 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 -2.592 0 4.32 2.592
144 8.64 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]

K2 =

  Columns 1 through 6

           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0      103680           0     -259200
           0           0           0           0    14400000           0
           0           0           0     -259200           0      864000
           0           0           0     -103680           0      259200
           0           0           0           0   -14400000           0
           0           0           0     -259200           0      432000
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
```

```
  Columns 7 through 12

         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
   -136800           0     -259200           0           0           0
         0           0           0           0           0           0
    259200   -14400000      432000           0           0           0
    103680           0      259200           0           0           0
         0           0           0           0           0           0
    259200    14400000      864000           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0

Columns 13 through 18

         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0

>> K3 = (10^2)*[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 60000 0 0 -60000 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 75 450 0 -75 4500 0
0 0 0 0 0; 0 0 0 0 0 0 0 450 3600 0 -450 180 0 0 0 0 0 0; 0 0 0 0 0 0 -60000 0
0 60000 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 -75 -450 0 75 -450 0 0 0 0 0 0; 0 0 0 0
0 0 0 450 1800 0 450 36000 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0]
```

```
K3 =

  Columns 1 through 6

           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0

Columns 7 through 12

         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
   6000000           0           0    -6000000           0           0
         0        7500       45000           0       -7500      450000
         0       45000      360000           0      -45000       18000
  -6000000           0           0     6000000           0           0
         0       -7500      -45000           0        7500      -45000
         0       45000      180000           0       45000     3600000
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0

Columns 13 through 18

         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
```

```
>> K4 = (10^4)*[ 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 6 0 18
-6 0 18; 0 0 0 0 0 0 0 0 0 0 0 0 0 1200 0 0 -1200 0; 0 0 0 0 0 0 0 0 0 0 0 18 0
72 -18 0 36; 0 0 0 0 0 0 0 0 0 0 0 0 -6 0 -18 6 0 -18; 0 0 0 0 0 0 0 0 0 0 0 0 0
-1200 0 0 1200 0; 0 0 0 0 0 0 0 0 0 0 0 0 18 0 36 -18 0 72]

K4 =

  Columns 1 through 6

           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0

Columns 7 through 12

         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
```

```
Columns 13 through 18

         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
         0          0          0          0          0          0
     60000          0     180000     -60000          0     180000
         0   12000000          0          0  -12000000          0
    180000          0     720000    -180000          0     360000
    -60000          0    -180000      60000          0    -180000
         0  -12000000          0          0   12000000          0
    180000          0     360000    -180000          0     720000

>> K5 = [ 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 1746735.2 2505153.8 29504.1 0 0 0
-1746735.2 -2505153.8 29504.1 0 0 0 0 0 0; 0 0 0 2505153.8 3609253.3 -20509.01 0 0
0 -2505153.3 -3609253.3 -20509.01 0 0 0 0 0 0;  0 0 0 29504.1 -20509.01 321907.6
0 0 0 -29504.1 20509.01 160953.8 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0
0 -1746735.2 -2505153.8 -29504.1 0 0 0 0 0 -29504.1 0 0 0 0 0 0; 0 0 0 -2505153.8
-3609253.3 20509.01 0 0 0 0 0 20509.01 0 0 0 0 0 0; 0 0 0 29504.1 -20509.01 160953.8
0 0 0 0 0 321907.6 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0]

K5 =

  1.0e+006 *

  Columns 1 through 8

         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0    1.7467    2.5052    0.0295         0         0
         0         0         0    2.5052    3.6093   -0.0205         0         0
         0         0         0    0.0295   -0.0205    0.3219         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0   -1.7467   -2.5052   -0.0295         0         0
         0         0         0   -2.5052   -3.6093    0.0205         0         0
         0         0         0    0.0295   -0.0205    0.1610         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
```

```
Columns 9 through 16

       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0   -1.7467   -2.5052    0.0295         0         0         0         0
       0   -2.5052   -3.6093   -0.0205         0         0         0         0
       0   -0.0295    0.0205    0.1610         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0   -0.0295         0         0         0         0
       0         0         0    0.0205         0         0         0         0
       0         0         0    0.3219         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0
       0         0         0         0         0         0         0         0

Columns 17 through 18

       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0
       0         0

>> K6 = (10^4)*[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0; 0 0 0 0 0 0 0 0 0 0 0 0 6 0 18
-6 0 18; 0 0 0 0 0 0 0 0 0 0 0 0 0 1200 0 0 -1200 0; 0 0 0 0 0 0 0 0 0 0 0 0 18 0
72 -18 0 36; 0 0 0 0 0 0 0 0 0 0 0 0 -6 0 -18 6 0 -18; 0 0 0 0 0 0 0 0 0 0 0 0 0
-1200 0 0 1200 0; 0 0 0 0 0 0 0 0 0 0 0 0 18 0 36 -18 0 72]
```

```
K6 =

  Columns 1 through 6

           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0
           0           0           0           0           0           0

Columns 7 through 12

         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0

Columns 13 through 18

         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
         0           0           0           0           0           0
     60000           0      180000      -60000           0      180000
         0    12000000           0           0   -12000000           0
    180000           0      720000     -180000           0      360000
    -60000           0     -180000       60000           0     -180000
         0   -12000000           0           0    12000000           0
    180000           0      360000     -180000           0      720000
```

```
>> KT = K1 + K2 + K3 + K4 + K5 + K6

KT =

  1.0e+010 *

  Columns 1 through 8

    1.0000         0   -0.0000   -1.0000         0   -0.0000         0         0
         0    0.0012         0         0   -0.0012         0         0         0
   -0.0000         0    0.0001    0.0000         0    0.0000         0         0
   -1.0000         0    0.0000    1.0002    0.0003   -0.0000   -0.0000         0
         0   -0.0012         0    0.0003    0.0030   -0.0000         0         0
   -0.0000         0    0.0000   -0.0000   -0.0000    0.0002    0.0000   -0.0014
         0         0         0   -0.0000         0    0.0000    0.0006         0
         0         0         0         0   -0.0014         0         0    0.0000
         0         0         0   -0.0000         0    0.0000    0.0000    0.0014
         0         0         0   -0.0002   -0.0003   -0.0000   -0.0006         0
         0         0         0   -0.0003   -0.0004    0.0000         0   -0.0000
         0         0         0    0.0000   -0.0000    0.0000         0    0.0000
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0

Columns 9 through 16

         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
         0         0         0         0         0         0         0         0
   -0.0000   -0.0002   -0.0003    0.0000         0         0         0         0
         0   -0.0003   -0.0004   -0.0000         0         0         0         0
    0.0000   -0.0000    0.0000    0.0000         0         0         0         0
    0.0000   -0.0006         0         0         0         0         0         0
    0.0000         0   -0.0000    0.0000         0         0         0         0
    0.0001         0   -0.0000    0.0000         0         0         0         0
         0    0.0006         0   -0.0000         0         0         0         0
   -0.0000         0    0.0000   -0.0000         0         0         0         0
    0.0000         0    0.0000    0.0004         0         0         0         0
         0         0         0         0    0.0000         0    0.0000   -0.0000
         0         0         0         0         0    0.0024         0         0
         0         0         0         0    0.0000         0    0.0001   -0.0000
         0         0         0         0   -0.0000         0   -0.0000    0.0000
         0         0         0         0         0   -0.0024         0         0
         0         0         0         0    0.0000         0    0.0001   -0.0000

Columns 17 through 18

         0         0
         0         0
         0         0
         0         0
         0         0
         0         0
         0         0
         0         0
         0         0
         0         0
         0         0
         0         0
         0    0.0000
   -0.0024         0
         0    0.0001
         0   -0.0000
    0.0024         0
         0    0.0001
```

```
>> KR = [10001850415 2505153.891 -49695.80114 -103680 0 -259200 -1746735.237
-2505153.891 29504.19886 0 0 0; 2505153.891 30009253.37 -20509.01628 0 -14400000
0 -2505153.891 -3609253.374 -20509.01628 0 0 0; -49695.80114 -20509.01628
1905907.601 259200 0 432000 29504.19886 20509.01628 160953.8003 0 0 0; -103680
0 259200 6103680 0 259200 -6000000 0 0 0 0 0; 0 -14400000 0 0 14407500 45000
0 -7500 45000 0 0 0; -259200 0 432000 259200 45000 1224000 0 -45000 180000 0 0
0; -1746735237 -2505153.891 -29504.19886 -6000000 0 0 7850415.237 2505153.891
229695.8011 -103680 0 259200; 29504.19886 -3609253.374 20509.01628 0 -7500 -45000
-2505153.891 18016753.37 -24490.98372 0 -14400000 0; 0 -20509.01628 160953.8003
0 4500 180000 229695.8011 20509.01628 1545907.601 -259200 0 432000; 0 0 0 0 0 0
-103680 0 -259200 163680 0 -75200; 0 0 0 0 0 0 -14400000 0 0 26400000 0; 0 0 0
0 0 0 259200 0 432000 -79200 0 1584000]

KR =

  1.0e+010 *

  Columns 1 through 8

    1.0002    0.0003   -0.0000   -0.0000         0   -0.0000   -0.0002   -0.0003
    0.0003    0.0030   -0.0000         0   -0.0014         0   -0.0003   -0.0004
   -0.0000   -0.0000    0.0002    0.0000         0    0.0000    0.0000    0.0000
   -0.0000         0    0.0000    0.0006         0    0.0000   -0.0006         0
         0   -0.0014         0         0    0.0014    0.0000         0   -0.0000
   -0.0000         0    0.0000    0.0000    0.0000    0.0001         0   -0.0000
   -0.1747   -0.0003   -0.0000   -0.0006         0         0    0.0008    0.0003
    0.0000   -0.0004    0.0000         0   -0.0000   -0.0000   -0.0003    0.0018
         0   -0.0000    0.0000         0    0.0000    0.0000    0.0000    0.0000
         0         0         0         0         0         0   -0.0000         0
         0         0         0         0         0         0         0   -0.0014
         0         0         0         0         0         0    0.0000         0

Columns 9 through 12

  0.0000         0         0         0
 -0.0000         0         0         0
  0.0000         0         0         0
       0         0         0         0
  0.0000         0         0         0
  0.0000         0         0         0
  0.0000   -0.0000         0    0.0000
 -0.0000         0   -0.0014         0
  0.0002   -0.0000         0    0.0000
 -0.0000    0.0000         0   -0.0000
       0         0    0.0026         0
  0.0000   -0.0000         0    0.0002
```

Desplazamientos:

$$u = inv(k) * F$$

$$u = \begin{bmatrix} 0m \\ 0m \\ -2.676 \times 10^{7} rad \\ -0.0003m \\ 0.00108m \\ -0.002rad \\ 0.0010m \\ -0.0010m \\ -0.0000rad \\ 0.0010m \\ 0.0005m \\ -0.0004rad \\ -0.0003m \\ 0.0005m \\ -0.0001rad \\ -0.0049m \\ 0.0005m \\ 0.0003rad \end{bmatrix}$$

Fuerzas:

$$F = K \times u$$

$$F = 10^{3} \begin{bmatrix} 4.3380N \\ 9.4541N \\ -0.0759Nm \\ 0.0798N \\ -0.6627N \\ 0.0379Nm \\ -0.0743N \\ -0.9049N \\ -0.6833Nm \\ -0.0187N \\ -2.3021N \\ 0.0583Nm \\ -4.0479N \\ 0.0271N \\ 0.0646Nm \\ 0.0368N \\ -0.3326N \\ 0.8000Nm \\ -5.0252N \\ -0.4708N \\ -0.0074Nm \\ 0.3941N \\ -4.9274N \\ -1.0456Nm \end{bmatrix}$$

CAPÍTULO

8

APLICACIONES EN LA INGENIERÍA

TRABAJO DE APLICACIÓN EN INGENIERÍA: ANÁLISIS MATRICIAL DE UN TRAMO DEL MUELLE DE PIMENTEL, CHICLAYO

Introducción

El presente proyecto se desarrollará en la región de Lambayeque, distrito de Pimentel el cual dicho muelle tiene más de 90 años de función de los pobladores del distrito y turistas en general. Hoy en día este muelle se ha deteriorado debido a los años que esta estructura tiene, habiendo sufrido maltrato por parte de la naturaleza encontrándose en desuso por inactividad por carecer de operación y mantenimiento.

Debido a esta necesidad, es básica la implementación de un nuevo muelle con mayores beneficios tantos turísticos como para el traslado de las personas el cual requiere de un estudio. Motivo por el cual se desarrollará este trabajo, estudiando el periodo de las vigas del muelle para así reducir y controlar el peligro y deterioro que puede causar un mal estudio de la estructura del muelle de Pimentel.

El objetivo es realizar un estudio sobre las diversas deformaciones de vigas existentes tomando como base en un tramo del muelle de Pimentel.

Por medio de los conocimientos obtenidos en la asignatura, se estudiará la resistencia de cada uno de los materiales empleados, en este caso, el acero, la madera solo para el revestimiento; hallando así los momentos, reacciones, fuerzas y esfuerzos utilizando el método matricial con el cual se obtendrán los desplazamientos, momentos y las fuerzas, tanto internas como externas en cada nodo establecido de acuerdo con lo tomado en la investigación.

Sobre la base de los resultados analizados, se espera que pueda ser de gran apoyo a la región, para que así se pueda implementar dicho muelle con una mejor tecnología el cual obtendrá mayores beneficios tanto económicos como turísticos.

1. DISEÑO DE LA INVESTIGACIÓN

1.1. Situación problemática

Se sabe que el muelle de Pimentel tiene más de 90 años en función de los pobladores del distrito y turistas en general. Sin embargo, hoy en día este muelle se ha deteriorado debido a los años que esta estructura tiene; además de no haber tenido un adecuado mantenimiento.

Esta es la preocupación por la cual se desarrollará este trabajo; estudiar el periodo de las vigas del muelle para así reducir y controlar el peligro y el deterioro que puede ocasionar un mal estudio de la estructura del muelle de Pimentel.

1.2. Antecedentes

El muelle de Pimentel cuya construcción se realizó en el año 1913 (I tramo), 1915 (II tramo) y 1961 (III tramo) que ha sufrido a través del tiempo el desgaste de sus estructuras que la han deteriorado lo cual ha originado que los pobladores de distrito de Pimentel y visitantes nacionales y extranjeros quienes son los que hacen uso de ella a través de sus representantes han venido solicitando se les incluya en el financiamiento de la rehabilitación del muelle de Pimentel al Gobierno Regional de Lambayeque, así como entidades públicas que han priorizado dentro de su presupuesto participativo el proyecto.

1.3. Objetivos

1.3.1. Objetivo general

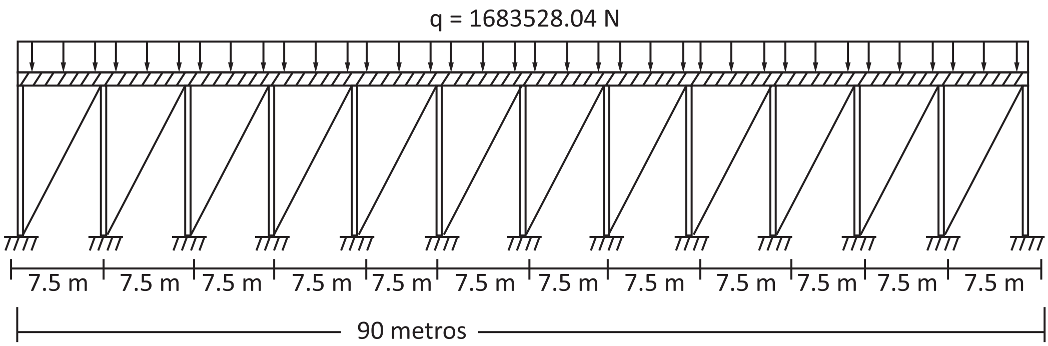
Realizar un estudio sobre las diversas deformaciones de vigas existentes, tomando como base en un tramo del muelle de Pimentel; aplicando los conocimientos obtenidos en la asignatura, mediante un análisis estructural de vigas en el muelle de Pimentel.

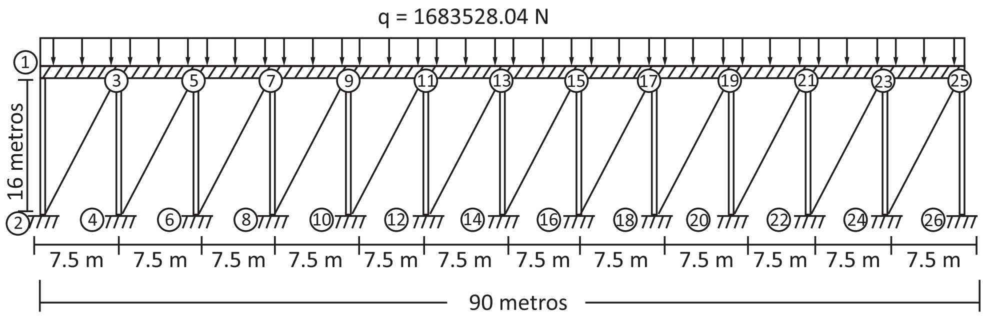
1.3.2. Objetivos específicos

- Realizar el modelo matemático de la estructura.
- Plantear la ecuación matricial.
- Resolver la matriz ensamblada obtenida a través del software MATLAB.
- Interpretar los resultados de manera que sea un aporte para la continuación de este proyecto.

2. ANÁLISIS ESTRUCTURAL

2.1. Modelo matemático

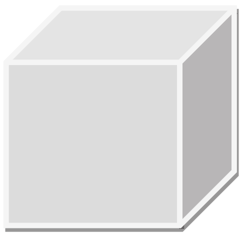




2.2 Análisis de fuerzas y momentos

Para hallar los desplazamientos correspondientes, se necesita primero hallar la carga y la matriz K (se halla momento de inercia, elasticidad y las distancias de cada tramo).

2.3. Cálculo del área



A = 2 × (ab + ac + cb)

A = 2 × (1.34 + 1440 + 201.6)

A = 5551.2 m^2

2.4. Módulo de elasticidad del acero

$$E = 2100000 \text{ Kg/cm}^2 = 2.1 \times 1010$$

Calcule la cantidad máxima de personas que pueden estar en el tramo del muelle evaluado al mismo tiempo.

$$\text{PESO} = 20\,400 \text{ visitas} \times 65 \text{ Kg} = 1132600 \text{ Kg} \times 9.81 \text{ m}^2/\text{s} = 13\,008\,060 \text{ N}$$

La carga generada en toda la longitud del muelle es 13008.060 KN. Siendo el análisis de un tramo del muelle entonces:

695.40 m ——— 13008060 N

90 m ——— X

$$X = 1683528.041 \text{ N}$$

Por tanto, la carga generada en el tramo del muelle evaluado será 1683.528KN.

Momento de inercia

$$I_{total} = \frac{b \times h^2}{12}$$

$$I_{total} = \frac{90 \times 16^2}{12}$$

$$I_{total} = 30720 \text{ m}^4$$

Momento de inercia de cada tramo

$$I = \frac{7.5 \times 16^2}{12}$$

$$I = 2560\ m^4$$

2.7. Análisis de los ángulos respectivos

Elemento viga	θ	Coseno	Seno
1-2	270°	0	–1
1-3	45°	0.7071	0.7071
2-3	0°	1	0
3-4	270°	0	–1
3-5	45°	0.7071	0.7071
4-5	0°	1	0
5-6	270°	0	–1
5-7	45°	0.7071	0.7071
6-7	0°	1	0
7-8	270°	0	–1
7-9	45°	0.7071	0.7071
8-9	0°	1	0
10-11	270°	0	–1
10-12	45°	0.7071	0.7071
11-12	0°	1	0
13-14	270°	0	–1
13-15	45°	0.7071	0.7071
14-15	0°	1	0
16-17	270°	0	–1
16-18	45°	0.7071	0.7071
17-18	0°	1	0
19-20	270°	0	–1
19-21	45°	0.7071	0.7071
20-21	0°	1	0
22-23	270°	0	–1
22-24	45°	0.7071	0.7071
23-24	0°	1	0
23-25	270°	0	–1
24-25	45°	0.7071	0.7071
25-26	0°	1	0

Determinaciòn de las constantes

K_1 (1-2)

A	C	I	L	S	E
5551.2	0	2560	16	–1	2.10E+10

$$K_1 = \begin{pmatrix} 158E+11 & 0 & 126E+12 & -1.575E+11 & 0 & 126E+12 \\ 0 & 7.28595E+12 & 0 & 0 & -7.28595E+12 & 0 \\ 126E+12 & 0 & 1.344E+13 & -1.26E+12 & 0 & 6.72E+12 \\ -1.575E+11 & 0 & -1.26E+12 & 1.575E+11 & 0 & -1.26E+12 \\ 0 & -7.28595E+12 & 0 & 0 & 7.28595E+12 & 0 \\ 1.26E+12 & 0 & 6.72E+12 & -1.26E+12 & 0 & 1.344E+13 \end{pmatrix}$$

K_2 (1-3)

A	C	I	L	S	E
5551.2	0.7071	2560	7.5	0.7071	2.10E+10

$$K_2 = \begin{pmatrix} 8.536E+12 & 7.007E+12 & -4.05E+12 & -8.54E+12 & -7.01E+12 & -4.05E+12 \\ 7.007E+12 & 8.536E+12 & 4.055E+12 & -7.01E+12 & -8.54E+12 & 4.055E+12 \\ -4.05E+12 & 4.055E+12 & 2.867E+13 & 4.055E+12 & -4.05E+12 & 1.434E+13 \\ -8.54E+12 & -7.01E+12 & 4.055E+12 & 8.536E+12 & 7.007E+12 & 4.055E+12 \\ -7.01E+12 & -8.54E+12 & -4.05E+12 & 7.007E+12 & 8.536E+12 & -4.05E+12 \\ -4.05E+12 & 4.055E+12 & 1.434E+13 & 4.055E+12 & -4.05E+12 & 2.867E+13 \end{pmatrix}$$

K_3 (2-3)

A	C	I	L	S	E
5551.2	1	2560	17.67	0	2.10E+10

$$K_3 = \begin{pmatrix} 6.5974E+12 & 0 & 0 & -6.5974E+12 & 0 & 0 \\ 0 & 1.1693E+11 & 1.0331E+12 & 0 & -1.1693E+11 & 1.0331E+12 \\ 0 & 1.0331E+12 & 1.217E+13 & 0 & -1.0331E+12 & 6.0849E+12 \\ -6.5974E+12 & 0 & 0 & 6.59735E+12 & 0 & 0 \\ 0 & -1.1693E+11 & -1.0331E+12 & 0 & 1.16931E+11 & -1.0331E+12 \\ 0 & 1.0331E+12 & 6.0849E+12 & 0 & -1.0331E+12 & 1.217E+13 \end{pmatrix}$$

K_4 (3-4)

A	C	I	L	S	E
5551.2	0	2560	16	-1	2.10E+10

$$K_4 = \begin{pmatrix} 1.575E+11 & 0 & 1.26E+12 & -1.575E+11 & 0 & 1.26E+12 \\ 0 & 7.28595E+12 & 0 & 0 & -7.28595E+12 & 0 \\ 1.26E+12 & 0 & 1.344E+13 & -1.26E+12 & 0 & 6.72E+12 \\ -1.575E+11 & 0 & -1.26E+12 & 1.575E+11 & 0 & -1.26E+12 \\ 0 & -7.28595E+12 & 0 & 0 & 7.28595E+12 & 0 \\ 1.26E+12 & 0 & 6.72E+12 & -1.26E+12 & 0 & 1.344E+13 \end{pmatrix}$$

K_5 (3-5)

A	C	I	L	S	E
5551.2	0.7071	2560	7.5	0.7071	2.10E+10

K_6 (4-5)

A	C	I	L	S	E
5551.2	1	2560	17.67	0	2.10E+10

$$K_6 = \begin{pmatrix} 6.5974E+12 & 0 & 0 & -6.5974E+12 & 0 & 0 \\ 0 & 1.1693E+11 & 1.0331E+12 & 0 & -1.1693E+11 & 1.0331E+12 \\ 0 & 1.0331E+12 & 1.217E+13 & 0 & -1.0331E+12 & 6.0849E+12 \\ -6.5974E+12 & 0 & 0 & 6.59735E+12 & 0 & 0 \\ 0 & -1.1693E+11 & -1.0331E+12 & 0 & 1.16931E+11 & -1.0331E+12 \\ 0 & 1.0331E+12 & 6.0849E+12 & 0 & -1.0331E+12 & 1.217E+13 \end{pmatrix}$$

K_7 (5-6)

A	C	I	L	S	E
5551.2	0	2560	16	-1	2.10E+10

$$K_7 = \begin{pmatrix} 1.575E+11 & 0 & 1.26E+12 & -1.575E+11 & 0 & 1.26E+12 \\ 0 & 7.28595E+12 & 0 & 0 & -7.28595E+12 & 0 \\ 1.26E+12 & 0 & 1.344E+13 & -1.26E+12 & 0 & 6.72E+12 \\ -1.575E+11 & 0 & -1.26E+12 & 1.575E+11 & 0 & -1.26E+12 \\ 0 & -7.28595E+12 & 0 & 0 & 7.28595E+12 & 0 \\ 1.26E+12 & 0 & 6.72E+12 & -1.26E+12 & 0 & 1.344E+13 \end{pmatrix}$$

K_8 (5-7)

A	C	I	L	S	E
5551.2	0.7071	2560	7.5	0.7071	2.10E+10

$$K_8 = \begin{pmatrix} 8.536E+12 & 7.007E+12 & -4.05E+12 & -8.54E+12 & -7.01E+12 & -4.05E+12 \\ 7.007E+12 & 8.536E+12 & 4.055E+12 & -7.01E+12 & -8.54E+12 & 4.055E+12 \\ -4.05E+12 & 4.055E+12 & 2.867E+13 & 4.055E+12 & -4.05E+12 & 1.434E+13 \\ -8.54E+12 & -7.01E+12 & 4.055E+12 & 8.536E+12 & 7.007E+12 & 4.055E+12 \\ -7.01E+12 & -8.54E+12 & -4.05E+12 & 7.007E+12 & 8.536E+12 & -4.05E+12 \\ -4.05E+12 & 4.055E+12 & 1.434E+13 & 4.055E+12 & -4.05E+12 & 2.867E+13 \end{pmatrix}$$

K_9 (6-7)

A	C	I	L	S	E
5551.2	1	2560	17.67	0	2.10E+10

$$K_9 = \begin{pmatrix} 6.5974E+12 & 0 & 0 & -6.5974E+12 & 0 & 0 \\ 0 & 1.1693E+11 & 1.0331E+12 & 0 & -1.1693E+11 & 1.0331E+12 \\ 0 & 1.0331E+12 & 1.217E+13 & 0 & -1.0331E+12 & 6.0849E+12 \\ -6.5974E+12 & 0 & 0 & 6.59735E+12 & 0 & 0 \\ 0 & -1.1693E+11 & -1.0331E+12 & 0 & 1.16931E+11 & -1.0331E+12 \\ 0 & 1.0331E+12 & 6.0849E+12 & 0 & -1.0331E+12 & 1.217E+13 \end{pmatrix}$$

K_{10} (7-8)

A	C	I	L	S	E
5551.2	0	2560	16	–1	2.10E+10

$$K_{10} = \begin{pmatrix} 1.575E+11 & 0 & 1.26E+12 & -1.575E+11 & 0 & 1.26E+12 \\ 0 & 7.28595E+12 & 0 & 0 & -7.28595E+12 & 0 \\ 1.26E+12 & 0 & 1.344E+13 & -1.26E+12 & 0 & 6.72E+12 \\ -1.575E+11 & 0 & -1.26E+12 & 1.575E+11 & 0 & -1.26E+12 \\ 0 & -7.28595E+12 & 0 & 0 & 7.28595E+12 & 0 \\ 1.26E+12 & 0 & 6.72E+12 & -1.26E+12 & 0 & 1.344E+13 \end{pmatrix}$$

K_{11} (7-9)

A	C	I	L	S	E
5551.2	0.7071	2560	7.5	0.7071	2.10E+10

$$K_{11} = \begin{pmatrix} 8.536E+12 & 7.007E+12 & -4.05E+12 & -8.54E+12 & -7.01E+12 & -4.05E+12 \\ 7.007E+12 & 8.536E+12 & 4.055E+12 & -7.01E+12 & -8.54E+12 & 4.055E+12 \\ -4.05E+12 & 4.055E+12 & 2.867E+13 & 4.055E+12 & -4.05E+12 & 1.434E+13 \\ -8.54E+12 & -7.01E+12 & 4.055E+12 & 8.536E+12 & 7.007E+12 & 4.055E+12 \\ -7.01E+12 & -8.54E+12 & -4.05E+12 & 7.007E+12 & 8.536E+12 & -4.05E+12 \\ -4.05E+12 & 4.055E+12 & 1.434E+13 & 4.055E+12 & -4.05E+12 & 2.867E+13 \end{pmatrix}$$

K_{12} (8-9)

A	C	I	L	S	E
5551.2	1	2560	17.67	0	2.10E+10

$$K_{12} = \begin{pmatrix} 6.5974E+12 & 0 & 0 & -6.5974E+12 & 0 & 0 \\ 0 & 1.1693E+11 & 1.0331E+12 & 0 & -1.1693E+11 & 1.0331E+12 \\ 0 & 1.0331E+12 & 1.217E+13 & 0 & -1.0331E+12 & 6.0849E+12 \\ -6.5974E+12 & 0 & 0 & 6.59735E+12 & 0 & 0 \\ 0 & -1.1693E+11 & -1.0331E+12 & 0 & 1.16931E+11 & -1.0331E+12 \\ 0 & 1.0331E+12 & 6.0849E+12 & 0 & -1.0331E+12 & 1.217E+13 \end{pmatrix}$$

K_{13} (9-10)

A	C	I	L	S	E
5551.2	0	2560	16	−1	2.10E+10

$$K_{13} = \begin{pmatrix} 1.575E+11 & 0 & 1.26E+12 & -1.575E+11 & 0 & 1.26E+12 \\ 0 & 7.28595E+12 & 0 & 0 & -7.28595E+12 & 0 \\ 1.26E+12 & 0 & 1.344E+13 & -1.26E+12 & 0 & 6.72E+12 \\ -1.575E+11 & 0 & -1.26E+12 & 1.575E+11 & 0 & -1.26E+12 \\ 0 & -7.28595E+12 & 0 & 0 & 7.28595E+12 & 0 \\ 1.26E+12 & 0 & 6.72E+12 & -1.26E+12 & 0 & 1.344E+13 \end{pmatrix}$$

K_{14} (9-11)

A	C	I	L	S	E
5551.2	0.7071	2560	7.5	0.7071	2.10E+10

$$K_{14} = \begin{pmatrix} 8.536E+12 & 7.007E+12 & -4.05E+12 & -8.54E+12 & -7.01E+12 & -4.05E+12 \\ 7.007E+12 & 8.536E+12 & 4.055E+12 & -7.01E+12 & -8.54E+12 & 4.055E+12 \\ -4.05E+12 & 4.055E+12 & 2.867E+13 & 4.055E+12 & -4.05E+12 & 1.434E+13 \\ -8.54E+12 & -7.01E+12 & 4.055E+12 & 8.536E+12 & 7.007E+12 & 4.055E+12 \\ -7.01E+12 & -8.54E+12 & -4.05E+12 & 7.007E+12 & 8.536E+12 & -4.05E+12 \\ -4.05E+12 & 4.055E+12 & 1.434E+13 & 4.055E+12 & -4.05E+12 & 2.867E+13 \end{pmatrix}$$

K_{15} (10-11)

A	C	I	L	S	E
5551.2	1	2560	17.67	0	2.10E+10

$$K_{15} = \begin{pmatrix} 6.5974E+12 & 0 & 0 & -6.5974E+12 & 0 & 0 \\ 0 & 1.1693E+11 & 1.0331E+12 & 0 & -1.1693E+11 & 1.0331E+12 \\ 0 & 1.0331E+12 & 1.217E+13 & 0 & -1.0331E+12 & 6.0849E+12 \\ -6.5974E+12 & 0 & 0 & 6.59735E+12 & 0 & 0 \\ 0 & -1.1693E+11 & -1.0331E+12 & 0 & 1.16931E+11 & -1.0331E+12 \\ 0 & 1.0331E+12 & 6.0849E+12 & 0 & -1.0331E+12 & 1.217E+13 \end{pmatrix}$$

K_{16} (11-12)

A	C	I	L	S	E
5551.2	0	2560	16	–1	2.10E+10

$$K_{16} = \begin{pmatrix} 1.575E+11 & 0 & 1.26E+12 & -1.575E+11 & 0 & 1.26E+12 \\ 0 & 7.28595E+12 & 0 & 0 & -7.28595E+12 & 0 \\ 1.26E+12 & 0 & 1.344E+13 & -1.26E+12 & 0 & 6.72E+12 \\ -1.575E+11 & 0 & -1.26E+12 & 1.575E+11 & 0 & -1.26E+12 \\ 0 & -7.28595E+12 & 0 & 0 & 7.28595E+12 & 0 \\ 1.26E+12 & 0 & 6.72E+12 & -1.26E+12 & 0 & 1.344E+13 \end{pmatrix}$$

K_{17} (11-13)

A	C	I	L	S	E
5551.2	0.7071	2560	7.5	0.7071	2.10E+10

$$K_{17}=\begin{pmatrix} 8.536E+12 & 7.007E+12 & -4.05E+12 & -8.54E+12 & -7.01E+12 & -4.05E+12 \\ 7.007E+12 & 8.536E+12 & 4.055E+12 & -7.01E+12 & -8.54E+12 & 4.055E+12 \\ -4.05E+12 & 4.055E+12 & 2.867E+13 & 4.055E+12 & -4.05E+12 & 1.434E+13 \\ -8.54E+12 & -7.01E+12 & 4.055E+12 & 8.536E+12 & 7.007E+12 & 4.055E+12 \\ -7.01E+12 & -8.54E+12 & -4.05E+12 & 7.007E+12 & 8.536E+12 & -4.05E+12 \\ -4.05E+12 & 4.055E+12 & 1.434E+13 & 4.055E+12 & -4.05E+12 & 2.867E+13 \end{pmatrix}$$

K_{18} (12-13)

A	C	I	L	S	E
5551.2	1	2560	17.67	0	2.10E+10

$$K_{18}=\begin{pmatrix} 6.5974E+12 & 0 & 0 & -6.5974E+12 & 0 & 0 \\ 0 & 1.1693E+11 & 1.0331E+12 & 0 & -1.1693E+11 & 1.0331E+12 \\ 0 & 1.0331E+12 & 1.217E+13 & 0 & -1.0331E+12 & 6.0849E+12 \\ -6.5974E+12 & 0 & 0 & 6.59735E+12 & 0 & 0 \\ 0 & -1.1693E+11 & -1.0331E+12 & 0 & 1.16931E+11 & -1.0331E+12 \\ 0 & 1.0331E+12 & 6.0849E+12 & 0 & -1.0331E+12 & 1.217E+13 \end{pmatrix}$$

K_{19} (13-14)

A	C	I	L	S	E
5551.2	0	2560	16	–1	2.10E+10

$$K_{19}=\begin{pmatrix} 1.575E+11 & 0 & 1.26E+12 & -1.575E+11 & 0 & 1.26E+12 \\ 0 & 7.28595E+12 & 0 & 0 & -7.28595E+12 & 0 \\ 1.26E+12 & 0 & 1.344E+13 & -1.26E+12 & 0 & 6.72E+12 \\ -1.575E+11 & 0 & -1.26E+12 & 1.575E+11 & 0 & -1.26E+12 \\ 0 & -7.28595E+12 & 0 & 0 & 7.28595E+12 & 0 \\ 1.26E+12 & 0 & 6.72E+12 & -1.26E+12 & 0 & 1.344E+13 \end{pmatrix}$$

K_{20} (13-15)

A	C	I	L	S	E
5551.2	0.7071	2560	7.5	0.7071	2.10E+10

$$K_{20} = \begin{pmatrix} 8.536E+12 & 7.007E+12 & -4.05E+12 & -8.54E+12 & -7.01E+12 & -4.05E+12 \\ 7.007E+12 & 8.536E+12 & 4.055E+12 & -7.01E+12 & -8.54E+12 & 4.055E+12 \\ -4.05E+12 & 4.055E+12 & 2.867E+13 & 4.055E+12 & -4.05E+12 & 1.434E+13 \\ -8.54E+12 & -7.01E+12 & 4.055E+12 & 8.536E+12 & 7.007E+12 & 4.055E+12 \\ -7.01E+12 & -8.54E+12 & -4.05E+12 & 7.007E+12 & 8.536E+12 & -4.05E+12 \\ -4.05E+12 & 4.055E+12 & 1.434E+13 & 4.055E+12 & -4.05E+12 & 2.867E+13 \end{pmatrix}$$

K_{21} (14-15)

A	C	I	L	S	E
5551.2	1	2560	17.67	0	2.10E+10

$$K_{21} = \begin{pmatrix} 6.5974E+12 & 0 & 0 & -6.5974E+12 & 0 & 0 \\ 0 & 1.1693E+11 & 1.0331E+12 & 0 & -1.1693E+11 & 1.0331E+12 \\ 0 & 1.0331E+12 & 1.217E+13 & 0 & -1.0331E+12 & 6.0849E+12 \\ -6.5974E+12 & 0 & 0 & 6.59735E+12 & 0 & 0 \\ 0 & -1.1693E+11 & -1.0331E+12 & 0 & 1.16931E+11 & -1.0331E+12 \\ 0 & 1.0331E+12 & 6.0849E+12 & 0 & -1.0331E+12 & 1.217E+13 \end{pmatrix}$$

K_{22} (15-16)

A	C	I	L	S	E
5551.2	0	2560	16	–1	2.10E+10

$$K_{22} = \begin{pmatrix} 1.575E+11 & 0 & 1.26E+12 & -1.575E+11 & 0 & 1.26E+12 \\ 0 & 7.28595E+12 & 0 & 0 & -7.28595E+12 & 0 \\ 1.26E+12 & 0 & 1.344E+13 & -1.26E+12 & 0 & 6.72E+12 \\ -1.575E+11 & 0 & -1.26E+12 & 1.575E+11 & 0 & -1.26E+12 \\ 0 & -7.28595E+12 & 0 & 0 & 7.28595E+12 & 0 \\ 1.26E+12 & 0 & 6.72E+12 & -1.26E+12 & 0 & 1.344E+13 \end{pmatrix}$$

K_{23} (15-17)

A	C	I	L	S	E
5551.2	0.7071	2560	7.5	0.7071	2.10E+10

$$K_{23} = \begin{pmatrix} 8.536E+12 & 7.007E+12 & -4.05E+12 & -8.54E+12 & -7.01E+12 & -4.05E+12 \\ 7.007E+12 & 8.536E+12 & 4.055E+12 & -7.01E+12 & -8.54E+12 & 4.055E+12 \\ -4.05E+12 & 4.055E+12 & 2.867E+13 & 4.055E+12 & -4.05E+12 & 1.434E+13 \\ -8.54E+12 & -7.01E+12 & 4.055E+12 & 8.536E+12 & 7.007E+12 & 4.055E+12 \\ -7.01E+12 & -8.54E+12 & -4.05E+12 & 7.007E+12 & 8.536E+12 & -4.05E+12 \\ -4.05E+12 & 4.055E+12 & 1.434E+13 & 4.055E+12 & -4.05E+12 & 2.867E+13 \end{pmatrix}$$

K_{24} (16-17)

A	C	I	L	S	E
5551.2	1	2560	17.67	0	2.10E+10

$$K_{24} = \begin{pmatrix} 6.5974E+12 & 0 & 0 & -6.5974E+12 & 0 & 0 \\ 0 & 1.1693E+11 & 1.0331E+12 & 0 & -1.1693E+11 & 1.0331E+12 \\ 0 & 1.0331E+12 & 1.217E+13 & 0 & -1.0331E+12 & 6.0849E+12 \\ -6.5974E+12 & 0 & 0 & 6.59735E+12 & 0 & 0 \\ 0 & -1.1693E+11 & -1.0331E+12 & 0 & 1.16931E+11 & -1.0331E+12 \\ 0 & 1.0331E+12 & 6.0849E+12 & 0 & -1.0331E+12 & 1.217E+13 \end{pmatrix}$$

K_{25} (17-18)

A	C	I	L	S	E
5551.2	0	2560	16	–1	2.10E+10

$$K_{25} = \begin{pmatrix} 1.575E+11 & 0 & 1.26E+12 & -1.575E+11 & 0 & 1.26E+12 \\ 0 & 7.28595E+12 & 0 & 0 & -7.28595E+12 & 0 \\ 1.26E+12 & 0 & 1.344E+13 & -1.26E+12 & 0 & 6.72E+12 \\ -1.575E+11 & 0 & -1.26E+12 & 1.575E+11 & 0 & -1.26E+12 \\ 0 & -7.28595E+12 & 0 & 0 & 7.28595E+12 & 0 \\ 1.26E+12 & 0 & 6.72E+12 & -1.26E+12 & 0 & 1.344E+13 \end{pmatrix}$$

K_{26} (17-19)

A	C	I	L	S	E
5551.2	0.7071	2560	7.5	0.7071	2.10E+10

$$K_{26} = \begin{pmatrix} 8.536E+12 & 7.007E+12 & -4.05E+12 & -8.54E+12 & -7.01E+12 & -4.05E+12 \\ 7.007E+12 & 8.536E+12 & 4.055E+12 & -7.01E+12 & -8.54E+12 & 4.055E+12 \\ -4.05E+12 & 4.055E+12 & 2.867E+13 & 4.055E+12 & -4.05E+12 & 1.434E+13 \\ -8.54E+12 & -7.01E+12 & 4.055E+12 & 8.536E+12 & 7.007E+12 & 4.055E+12 \\ -7.01E+12 & -8.54E+12 & -4.05E+12 & 7.007E+12 & 8.536E+12 & -4.05E+12 \\ -4.05E+12 & 4.055E+12 & 1.434E+13 & 4.055E+12 & -4.05E+12 & 2.867E+13 \end{pmatrix}$$

K_{27} (18-19)

A	C	I	L	S	E
5551.2	1	2560	17.67	0	2.10E+10

$$K_{27} = \begin{pmatrix} 6.5974E+12 & 0 & 0 & -6.5974E+12 & 0 & 0 \\ 0 & 1.1693E+11 & 1.0331E+12 & 0 & -1.1693E+11 & 1.0331E+12 \\ 0 & 1.0331E+12 & 1.217E+13 & 0 & -1.0331E+12 & 6.0849E+12 \\ -6.5974E+12 & 0 & 0 & 6.59735E+12 & 0 & 0 \\ 0 & -1.1693E+11 & -1.0331E+12 & 0 & 1.16931E+11 & -1.0331E+12 \\ 0 & 1.0331E+12 & 6.0849E+12 & 0 & -1.0331E+12 & 1.217E+13 \end{pmatrix}$$

K_{28} (19-20)

A	C	I	L	S	E
5551.2	0	2560	16	–1	2.10E+10

$$K_{28} = \begin{pmatrix} 1.575E+11 & 0 & 1.26E+12 & -1.575E+11 & 0 & 1.26E+12 \\ 0 & 7.28595E+12 & 0 & 0 & -7.28595E+12 & 0 \\ 1.26E+12 & 0 & 1.344E+13 & -1.26E+12 & 0 & 6.72E+12 \\ -1.575E+11 & 0 & -1.26E+12 & 1.575E+11 & 0 & -1.26E+12 \\ 0 & -7.28595E+12 & 0 & 0 & 7.28595E+12 & 0 \\ 1.26E+12 & 0 & 6.72E+12 & -1.26E+12 & 0 & 1.344E+13 \end{pmatrix}$$

K_{29} (19-21)

A	C	I	L	S	E
5551.2	0.7071	2560	7.5	0.7071	2.10E+10

$$K_{29}=\begin{pmatrix} 8.536E+12 & 7.007E+12 & -4.05E+12 & -8.54E+12 & -7.01E+12 & -4.05E+12\\ 7.007E+12 & 8.536E+12 & 4.055E+12 & -7.01E+12 & -8.54E+12 & 4.055E+12\\ -4.05E+12 & 4.055E+12 & 2.867E+13 & 4.055E+12 & -4.05E+12 & 1.434E+13\\ -8.54E+12 & -7.01E+12 & 4.055E+12 & 8.536E+12 & 7.007E+12 & 4.055E+12\\ -7.01E+12 & -8.54E+12 & -4.05E+12 & 7.007E+12 & 8.536E+12 & -4.05E+12\\ -4.05E+12 & 4.055E+12 & 1.434E+13 & 4.055E+12 & -4.05E+12 & 2.867E+13 \end{pmatrix}$$

K_{30} (20-21)

A	C	I	L	S	E
5551.2	1	2560	17.67	0	2.10E+10

$$K_{30}=\begin{pmatrix} 6.5974E+12 & 0 & 0 & -6.5974E+12 & 0 & 0\\ 0 & 1.1693E+11 & 1.0331E+12 & 0 & -1.1693E+11 & 1.0331E+12\\ 0 & 1.0331E+12 & 1.217E+13 & 0 & -1.0331E+12 & 6.0849E+12\\ -6.5974E+12 & 0 & 0 & 6.59735E+12 & 0 & 0\\ 0 & -1.1693E+11 & -1.0331E+12 & 0 & 1.16931E+11 & -1.0331E+12\\ 0 & 1.0331E+12 & 6.0849E+12 & 0 & -1.0331E+12 & 1.217E+13 \end{pmatrix}$$

K_{31} (21-22)

A	C	I	L	S	E
5551.2	0	2560	16	–1	2.10E+10

$$K_{31}=\begin{pmatrix} 1.575E+11 & 0 & 1.26E+12 & -1.575E+11 & 0 & 1.26E+12\\ 0 & 7.28595E+12 & 0 & 0 & -7.28595E+12 & 0\\ 1.26E+12 & 0 & 1.344E+13 & -1.26E+12 & 0 & 6.72E+12\\ -1.575E+11 & 0 & -1.26E+12 & 1.575E+11 & 0 & -1.26E+12\\ 0 & -7.28595E+12 & 0 & 0 & 7.28595E+12 & 0\\ 1.26E+12 & 0 & 6.72E+12 & -1.26E+12 & 0 & 1.344E+13 \end{pmatrix}$$

K_{32} (21-23)

A	C	I	L	S	E
5551.2	0.7071	2560	7.5	0.7071	2.10E+10

$$K_{32} = \begin{pmatrix} 8.536E+12 & 7.007E+12 & -4.05E+12 & -8.54E+12 & -7.01E+12 & -4.05E+12 \\ 7.007E+12 & 8.536E+12 & 4.055E+12 & -7.01E+12 & -8.54E+12 & 4.055E+12 \\ -4.05E+12 & 4.055E+12 & 2.867E+13 & 4.055E+12 & -4.05E+12 & 1.434E+13 \\ -8.54E+12 & -7.01E+12 & 4.055E+12 & 8.536E+12 & 7.007E+12 & 4.055E+12 \\ -7.01E+12 & -8.54E+12 & -4.05E+12 & 7.007E+12 & 8.536E+12 & -4.05E+12 \\ -4.05E+12 & 4.055E+12 & 1.434E+13 & 4.055E+12 & -4.05E+12 & 2.867E+13 \end{pmatrix}$$

K_{33} (22-23)

A	C	I	L	S	E
5551.2	1	2560	17.67	0	2.10E+10

$$K_{33} = \begin{pmatrix} 6.5974E+12 & 0 & 0 & -6.5974E+12 & 0 & 0 \\ 0 & 1.1693E+11 & 1.0331E+12 & 0 & -1.1693E+11 & 1.0331E+12 \\ 0 & 1.0331E+12 & 1.217E+13 & 0 & -1.0331E+12 & 6.0849E+12 \\ -6.5974E+12 & 0 & 0 & 6.59735E+12 & 0 & 0 \\ 0 & -1.1693E+11 & -1.0331E+12 & 0 & 1.16931E+11 & -1.0331E+12 \\ 0 & 1.0331E+12 & 6.0849E+12 & 0 & -1.0331E+12 & 1.217E+13 \end{pmatrix}$$

K_{34} (23-24)

A	C	I	L	S	E
5551.2	0	2560	16	–1	2.10E+10

$$K_{34} = \begin{pmatrix} 1.575E+11 & 0 & 1.26E+12 & -1.575E+11 & 0 & 1.26E+12 \\ 0 & 7.28595E+12 & 0 & 0 & -7.28595E+12 & 0 \\ 1.26E+12 & 0 & 1.344E+13 & -1.26E+12 & 0 & 6.72E+12 \\ -1.575E+11 & 0 & -1.26E+12 & 1.575E+11 & 0 & -1.26E+12 \\ 0 & -7.28595E+12 & 0 & 0 & 7.28595E+12 & 0 \\ 1.26E+12 & 0 & 6.72E+12 & -1.26E+12 & 0 & 1.344E+13 \end{pmatrix}$$

K_{35} (23-25)

A	C	I	L	S	E
5551.2	0.7071	2560	7.5	0.7071	2.10E+10

$$K_{35}=\begin{pmatrix} 8.536E+12 & 7.007E+12 & -4.05E+12 & -8.54E+12 & -7.01E+12 & -4.05E+12 \\ 7.007E+12 & 8.536E+12 & 4.055E+12 & -7.01E+12 & -8.54E+12 & 4.055E+12 \\ -4.05E+12 & 4.055E+12 & 2.867E+13 & 4.055E+12 & -4.05E+12 & 1.434E+13 \\ -8.54E+12 & -7.01E+12 & 4.055E+12 & 8.536E+12 & 7.007E+12 & 4.055E+12 \\ -7.01E+12 & -8.54E+12 & -4.05E+12 & 7.007E+12 & 8.536E+12 & -4.05E+12 \\ -4.05E+12 & 4.055E+12 & 1.434E+13 & 4.055E+12 & -4.05E+12 & 2.867E+13 \end{pmatrix}$$

K_{36} (24-25)

A	C	I	L	S	E
5551.2	1	2560	17.67	0	2.10E+10

$$K_{36}=\begin{pmatrix} 6.5974E+12 & 0 & 0 & -6.5974E+12 & 0 & 0 \\ 0 & 1.1693E+11 & 1.0331E+12 & 0 & -1.1693E+11 & 1.0331E+12 \\ 0 & 1.0331E+12 & 1.217E+13 & 0 & -1.0331E+12 & 6.0849E+12 \\ -6.5974E+12 & 0 & 0 & 6.59735E+12 & 0 & 0 \\ 0 & -1.1693E+11 & -1.0331E+12 & 0 & 1.16931E+11 & -1.0331E+12 \\ 0 & 1.0331E+12 & 6.0849E+12 & 0 & -1.0331E+12 & 1.217E+13 \end{pmatrix}$$

K_{37} (25-26)

A	C	I	L	S	E
5551.2	1	2560	17.67	0	2.10E+10

$$K_{37}=\begin{pmatrix} 1.575E+11 & 0 & 1.26E+12 & -1.575E+11 & 0 & 1.26E+12 \\ 0 & 7.28595E+12 & 0 & 0 & -7.28595E+12 & 0 \\ 1.26E+12 & 0 & 1.344E+13 & -1.26E+12 & 0 & 6.72E+12 \\ -1.575E+11 & 0 & -1.26E+12 & 1.575E+11 & 0 & -1.26E+12 \\ 0 & -7.28595E+12 & 0 & 0 & 7.28595E+12 & 0 \\ 1.26E+12 & 0 & 6.72E+12 & -1.26E+12 & 0 & 1.344E+13 \end{pmatrix}$$

2.8 Resultados en MATLAB

	X 10^{-6} (m)
δ_{2x}	0.0334m
δ_{2y}	0.8214m
θ_{2}	0.2463rad
δ_{4x}	–0.0155m
δ_{4y}	0.8695m
θ_{4}	–0.1486 rad
δ_{6x}	–0.0120m
δ_{6y}	0.8645m
θ_{6}	0.1525 rad
δ_{8x}	0.0125m
δ_{8y}	0.8409m
θ_{8}	–0.1376 rad
δ_{10x}	–0.0144m
δ_{10y}	0.8664m
θ_{10}	0.1538 rad
δ_{12x}	0.0115m
δ_{12y}	0.8416m
θ_{12}	–0.1380 rad
δ_{14x}	–0.0145m
δ_{14y}	0.8663m

	X 10^{-6} (m)
θ_{14}	0.1538 rad
δ_{16x}	0.0115m
δ_{16y}	0.8415m
θ_{16}	–0.1380 rad
δ_{18x}	–0.0145m
δ_{18y}	0.8662m
θ_{18}	0.1538 rad
δ_{20x}	0.0110m
δ_{20y}	0.8416m
θ_{20}	–0.1379 rad
δ_{22x}	–0.0147m
δ_{22y}	0.8658m
θ_{22}	0.1531 rad
δ_{24x}	0.0300m
δ_{24y}	0.8216m
θ_{24}	–0.1448 rad
δ_{26x}	–0.0588m
δ_{26y}	0.9070m
θ_{26}	0.2153 rad

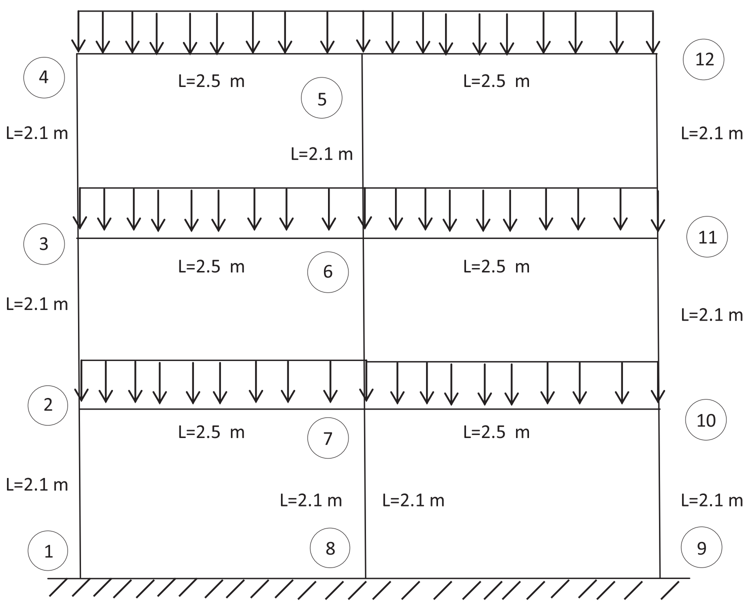
2.9 Cálculo de fuerzas y momentos

Fuerzas y momentos	
F_{2x}	–8.47E+04 KN
F_{2y}	6.34E+06KN
M_{2}	7.11E+06 KNm
F_{5x}	8.25E+04 KN
F_{5y}	–6.25E+06 KN
M_{5}	1.03E+06 KNm
F_{8x}	2.58E+05 KN
F_{8y}	6.08E+06 KN
M_{8}	–2.67E+06 KNm
F_{11x}	–8.07E+04 KN
F_{11y}	–6.39E+06 KN
M_{11}	8.89E+05 KNm
F_{14x}	–2.92E+05 KN
F_{14y}	–6.31E+06 KN

Fuerzas y momentos	
M_{14}	4.85E+06 KNm
F_{17x}	1.20E+05 KN
F_{17y}	–6.27E+06 KN
M_{17}	1.08E+06 KNm
F_{20x}	2.48E+05 KN
F_{20y}	6.09E+06 KN
M_{20}	–2.68E+06 KNm
F_{23x}	–9.02E+04 KN
F_{23y}	–6.25E+06 KN
M_{23}	8.15E+05 KNm
F_{26x}	–2.81E+05 KN
F_{26y}	6.61E+06 KN
M_{26}	2.97E+06 KNm

DISEÑO ESTRUCTURAL DE UN SISTEMA DE PLATAFORMA DE ELEVACIÓN DE AUTOMÓVILES A TRAVÉS DEL MÉTODO MATRICIAL EN UNA PLAYA DE ESTACIONAMIENTO

Modelamiento del sistema estructural del elevador de automóviles:



$I_1 = 1.6222 \times 10^{-4}\, m^4$

$I_2 = 3.645 \times 10^{-8}\, m^4$

$E = 210$ GPa

$A = 0.0019\ m^2$

$q = 8240.4\ N/m$

Análisis matricial:

$$K = E/L \times \begin{bmatrix} A\times c1+12\times I\times s1/L1\hat{}2 & (A-12\times I/L1\hat{}2)\times CS1 & -6\times I\times S1/L1 & -A\times c1+12\times I\times s1/L1\hat{}2 & -(A-12\times I/L1\hat{}2)\times CS1 & -6\times I\times S1/L1 \\ (A-12\times I/L1\hat{}2)\times CS1 & A\times s1+12\times I\times c1/L1\hat{}2 & 6\times I\times C1/L1 & -(A-12\times I/L1^2)\times CS1 & -(A\times s1+12\times I\times c1/L1\hat{}2) & 6\times I\times C1/L1 \\ -6\times I\times S1/L1 & 6\times I\times C1/L1 & 4\times I & 6\times I\times S1/L1 & -6\times I\times C1/L1 & 2\times I \\ -(A\times c1+12\times I\times s1/L1\hat{}2) & -(A-12\times I/L1\hat{}2)\times CS1 & 6\times I\times S1/L1 & A\times c1+12\times I\times s1/L1\hat{}2 & (A-12\times I/L1\hat{}2)\times CS1 & 6\times I\times S1/L1 \\ -(A-12\times I/L1\hat{}2)\times CS1 & -(A\times s1+12\times I\times c1/L1\hat{}2) & -6\times I\times C1/L1 & (A-12\times I/L1\hat{}2)\times CS1 & (A\times s1+12\times I\times c1/L1\hat{}2) & -6\times I\times C1/L1 \\ -6\times I\times S1/L1 & 6\times I\times C1/L1 & 2\times I & 6\times I\times S1/L1 & -6\times I\times C1/L1 & 4\times I \end{bmatrix}$$

Reemplazando valores:

$$\begin{bmatrix} 44141496.6 & 8.93492E-09 & -46348571.4 & -4.41415E+18 & -893.4916004 & -4.63486E+18 & 0 & \cdots 30\text{ veces}\cdots & 0 \\ 893.4916004 & 0.0019 & 2.8392E-09 & -8.93492E+13 & -190000000 & 283.9194034 & & \vdots & \vdots \\ -4.63486E+18 & 283.9194034 & 64888000 & 4.63486E+18 & -2.83919E+13 & 32444000 & & \vdots & \vdots \\ -4.41415E+29 & -8.93492E+24 & 4.6349E+29 & 4.41415E+18 & 8.93492E+13 & 4.63486E+29 & & \vdots & \vdots \\ -8.93492E+13 & -1.9E+19 & -2.8392E+24 & 8.93492E+24 & 190000000 & -2.83919E+13 & & \vdots & \vdots \\ -4.63486E+29 & 2.83919E+13 & 3.2444E+18 & 4.63486E+40 & -2.83919E+24 & 6.4888E+18 & & \vdots & 36\text{ veces} \\ 0 & 0 & 0 & 0 & 0 & 0 & & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & & \vdots & \vdots \\ 30\text{ veces} & 30\text{ veces} & 30\text{ veces} & 30\text{ veces} & 30\text{ veces} & 30\text{ veces} & & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & & \vdots & \vdots \\ 0 & \cdots & \cdots & 36\text{ veces} & \cdots & \cdots & & \cdots & 0 \end{bmatrix}$$

$$\begin{bmatrix} 0 & \cdots & \cdots & \cdots & \cdots & 36\text{ veces} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\ \vdots & \cdots & \cdots & \cdots & \cdots & 36\text{ veces} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ \vdots & \cdots & \cdots & \cdots & \cdots & 36\text{ veces} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ \vdots & \vdots & \vdots & 44141496.6 & 8.93492E-09 & -46348571.43 & -4.41415E+18 & -893.4916004 & -4.63486E+18 & 0 & 25\text{ veces} & & & \vdots \\ \vdots & \vdots & \vdots & 893.4916004 & 0.0019 & 2.83919E-09 & -8.93492E+13 & -190000000 & 283.9194034 & 0 & 25\text{ veces} & & & \vdots \\ \vdots & \vdots & \vdots & -4.63486E+18 & 283.9194034 & 64888000 & 4.63486E+18 & -2.83919E+13 & 32444000 & 0 & 25\text{ veces} & & & \vdots \\ \vdots & \vdots & \vdots & -4.41415E+29 & -8.93492E+24 & 4.63486E+29 & 4.41415E+18 & 8.93492E+13 & 4.63486E+29 & 0 & 25\text{ veces} & & & \vdots \\ \vdots & \vdots & \vdots & -8.93492E+13 & -1.9E+19 & -2.83919E+24 & 8.93492E+24 & 190000000 & -2.83919E+13 & 0 & 25\text{ veces} & & & \vdots \\ \vdots & \vdots & \vdots & -4.63486E+29 & 2.83919E+13 & 3.2444E+18 & 4.63486E+40 & -2.83919E+24 & 6.4888E+18 & 0 & 25\text{ veces} & & & \vdots \\ \vdots & \vdots & \vdots & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & 0 & 0 & & 36\text{ veces} & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & 0 & 0 & & \vdots & \vdots \\ 36\text{ veces} & \vdots & \vdots & 25\text{ veces} & 25\text{ veces} & 25\text{ veces} & 25\text{ veces} & 25\text{ veces} & 25\text{ veces} & 0 & 0 & & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & 0 & 0 & & 36\text{ veces} & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & 0 & 0 & & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & 0 & 0 & & 0 & \vdots \\ 0 & \cdots & \cdots & \cdots & \cdots & 36\text{ veces} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \end{bmatrix}$$

$$\begin{bmatrix} 0 & \cdots & \cdots & \cdots & \cdots & 36\text{ veces} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\ \vdots & \cdots & \cdots & \cdots & \cdots & 36\text{ veces} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ \vdots & \cdots & \cdots & \cdots & \cdots & 36\text{ veces} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ \vdots & \cdots & \cdots & \cdots & \cdots & 36\text{ veces} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ \vdots & \cdots & \cdots & \cdots & \cdots & 36\text{ veces} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ \vdots & \cdots & \cdots & \cdots & \cdots & 36\text{ veces} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\ \vdots & 0 & 0 & 0 & 4.41E+07 & 8.93E-09 & -4.63E+07 & -4.41E+18 & -8.93E+02 & -4.63E+18 & 0 & 30\text{ veces} & \vdots \\ \vdots & 0 & 0 & 0 & 8.93E+02 & 1.90E-03 & 2.84E-09 & -8.93E+13 & -1.90E+08 & 2.84E+02 & 0 & 30\text{ veces} & \vdots \\ \vdots & 0 & 0 & 0 & -4.63E+18 & 2.84E+02 & 6.49E+07 & 4.63E+18 & -2.84E+13 & 3.24E+07 & 0 & 30\text{ veces} & \vdots \\ \vdots & 0 & 0 & 0 & -4.41E+29 & -8.93E+24 & 4.63E+29 & 4.41E+18 & 8.93E+13 & 4.63E+29 & 0 & 30\text{ veces} & \vdots \\ \vdots & 0 & 0 & 0 & -8.93E+13 & -1.90E+19 & -2.84E+24 & 8.93E+24 & 1.90E+08 & -2.84E+13 & 0 & 30\text{ veces} & \vdots \\ \vdots & 0 & 0 & 0 & -4.63E+29 & 2.84E+13 & 3.24E+18 & 4.63E+40 & -2.84E+24 & 6.49E+18 & 0 & 30\text{ veces} & \vdots \\ 36\text{ veces} & \vdots & \vdots & \vdots & 0 & 0 & 0 & 0 & 0 & 0 & \vdots & \vdots & 36\text{ veces} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & 24\text{ veces} & 24\text{ veces} & 24\text{ veces} & 24\text{ veces} & 24\text{ veces} & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & 24\text{ veces} & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & 36\text{ veces} & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$
\begin{bmatrix}
0 & \cdots & \cdots & \cdots & \cdots & 36\ \text{veces} & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & 9\ \text{veces} & 9\ \text{veces} & 9\ \text{veces} & 9\ \text{veces} & 9\ \text{veces} & 9\ \text{veces} & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & 8\ \text{veces} & 0 & 1.90\text{E}-03 & 0.00\text{E}+00 & 0.00\text{E}+00 & -1.60\text{E}+08 & 0.00\text{E}+00 & 0.00\text{E}+00 & 0 & 21\ \text{veces} & \vdots \\
\vdots & 8\ \text{veces} & 0 & 0.00\text{E}+00 & 2.62\text{E}+07 & 3.27\text{E}+07 & 0.00\text{E}+00 & 2.20\text{E}+18 & 2.75\text{E}+18 & 0 & 21\ \text{veces} & \vdots \\
\vdots & 8\ \text{veces} & 0 & 0.00\text{E}+00 & 2.75\text{E}+18 & 5.45\text{E}+07 & 0.00\text{E}+00 & 2.31\text{E}+29 & 2.73\text{E}+07 & 0 & 21\ \text{veces} & \vdots \\
\vdots & 8\ \text{veces} & 0 & 1.34\text{E}+19 & 0.00\text{E}+00 & 0.00\text{E}+00 & 1.60\text{E}+08 & 0.00\text{E}+00 & 0.00\text{E}+00 & 0 & 21\ \text{veces} & \vdots \\
\vdots & 8\ \text{veces} & 0 & 0.00\text{E}+00 & 1.85\text{E}+29 & -1.94\text{E}+40 & 0.00\text{E}+00 & 2.20\text{E}+18 & 2.31\text{E}+29 & 0 & 21\ \text{veces} & \vdots \\
\vdots & 8\ \text{veces} & 0 & 0.00\text{E}+00 & 2.31\text{E}+29 & 2.29\text{E}+18 & 0.00\text{E}+00 & 1.94\text{E}+40 & 4.58\text{E}+18 & 0 & 21\ \text{veces} & \vdots \\
36\ \text{veces} & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & 36\ \text{veces} \\
\vdots & \vdots & \vdots & 42\ \text{veces} & 42\ \text{veces} & 42\ \text{veces} & 42\ \text{veces} & 42\ \text{veces} & 42\ \text{veces} & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
0 & \cdots & \cdots & \cdots & \cdots & 36\ \text{veces} & \cdots & \cdots & \cdots & \cdots & \cdots & 0
\end{bmatrix}
$$

$$
\begin{bmatrix}
0 & \cdots & \cdots & \cdots & \cdots & 36\ \text{veces} & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\
\vdots & \cdots & \cdots & \cdots & \cdots & 36\ \text{veces} & \cdots & \cdots & \cdots & \cdots & \cdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & 12\ \text{veces} & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
0 & 12\ \text{veces} & 0 & 4.41\text{E}+07 & 2.68\text{E}-08 & 4.63\text{E}+07 & -4.41\text{E}+18 & -2.68\text{E}+03 & 4.63\text{E}+18 & 0 & 18\ \text{veces} & 0 \\
0 & 12\ \text{veces} & 0 & 2.68\text{E}+03 & 1.90\text{E}-03 & -8.52\text{E}-09 & -2.68\text{E}+14 & -1.90\text{E}+08 & -8.52\text{E}+02 & 0 & 18\ \text{veces} & 0 \\
0 & 12\ \text{veces} & 0 & 4.63\text{E}+18 & -8.52\text{E}+02 & 6.49\text{E}+07 & -4.63\text{E}+18 & 8.52\text{E}+13 & -8.52\text{E}+02 & 0 & 18\ \text{veces} & 0 \\
0 & 12\ \text{veces} & 0 & -4.41\text{E}+29 & -2.68\text{E}+25 & -4.63\text{E}+29 & 4.41\text{E}+18 & 2.68\text{E}+14 & -4.63\text{E}+29 & 0 & 18\ \text{veces} & 0 \\
0 & 12\ \text{veces} & 0 & -2.68\text{E}+14 & -1.90\text{E}+19 & 8.52\text{E}+24 & 2.68\text{E}+25 & 1.90\text{E}+08 & 8.52\text{E}+13 & 0 & 18\ \text{veces} & 0 \\
0 & 12\ \text{veces} & 0 & 4.63\text{E}+29 & -8.52\text{E}+13 & 3.24\text{E}+18 & -4.63\text{E}+40 & 8.52\text{E}+24 & 6.49\text{E}+18 & 0 & 18\ \text{veces} & 0 \\
\vdots & \vdots & \vdots & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \vdots & 0 \\
36\ \text{veces} & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & 36\ \text{veces} \\
\vdots & \vdots & \vdots & 18\ \text{veces} & 18\ \text{veces} & 18\ \text{veces} & 18\ \text{veces} & 18\ \text{veces} & 18\ \text{veces} & 18\ \text{veces} & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
$$

$$
\begin{bmatrix}
0 & \cdots & \cdots & \cdots & \cdots & 36\ \text{veces} & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & 15\ \text{veces} & 15\ \text{veces} & 15\ \text{veces} & 15\ \text{veces} & 15\ \text{veces} & 15\ \text{veces} & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & 15\ \text{veces} & 0 & 4.41\text{E}+07 & 2.68\text{E}-08 & 4.63\text{E}+07 & -4.41\text{E}+18 & -2.68\text{E}+03 & 4.63\text{E}+18 & 0 & 15\ \text{veces} & \vdots \\
\vdots & 15\ \text{veces} & 0 & 2.68\text{E}+03 & 1.90\text{E}-03 & -8.52\text{E}-09 & -2.68\text{E}+14 & -1.90\text{E}+08 & -8.52\text{E}+02 & 0 & 15\ \text{veces} & \vdots \\
\vdots & 15\ \text{veces} & 0 & 4.63\text{E}+18 & -8.52\text{E}+02 & 6.49\text{E}+07 & -4.63\text{E}+18 & 8.52\text{E}+13 & 3.24\text{E}+07 & 0 & 15\ \text{veces} & \vdots \\
\vdots & 15\ \text{veces} & 0 & -4.41\text{E}+29 & -2.68\text{E}+25 & -4.63\text{E}+29 & 4.41\text{E}+18 & 2.68\text{E}+14 & -4.63\text{E}+29 & 0 & 15\ \text{veces} & \vdots \\
\vdots & 15\ \text{veces} & 0 & -2.68\text{E}+14 & -1.90\text{E}+19 & 8.52\text{E}+24 & 2.68\text{E}+25 & 1.90\text{E}+08 & 8.52\text{E}+13 & 0 & 15\ \text{veces} & \vdots \\
\vdots & 15\ \text{veces} & 0 & 4.63\text{E}+29 & -8.52\text{E}+13 & 3.24\text{E}+18 & -4.63\text{E}+40 & 8.52\text{E}+24 & 6.49\text{E}+18 & 0 & 15\ \text{veces} & \vdots \\
\vdots & \vdots & \vdots & 0 & 0 & 0 & 0 & 0 & 0 & \vdots & \vdots & \vdots \\
36\ \text{veces} & \vdots & \vdots & 15\ \text{veces} & 15\ \text{veces} & 15\ \text{veces} & 15\ \text{veces} & 15\ \text{veces} & 15\ \text{veces} & \vdots & \vdots & 36\ \text{veces} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
0 & \cdots & \cdots & \cdots & \cdots & 36\ \text{veces} & \cdots & \cdots & \cdots & \cdots & \cdots & 0
\end{bmatrix}
$$

$$
\begin{bmatrix}
0 & \cdots & \cdots & \cdots & \cdots & 36\text{ veces} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & 0 & 0 & \vdots \\
\vdots & \vdots & \vdots & \vdots & 18\text{ veces} & 18\text{ veces} & 18\text{ veces} & 18\text{ veces} & 18\text{ veces} & 18\text{ veces} & 0 & 0 & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & 0 & 0 & \vdots \\
\vdots & 12\text{ veces} & \vdots & 0 & 4.41E+07 & 2.68E-08 & 4.63E+07 & -4.41E+18 & -2.68E+03 & 4.63E+18 & 0 & 30\text{ veces} & \vdots \\
\vdots & 12\text{ veces} & \vdots & 0 & 2.68E+03 & 1.90E-03 & -8.52E-09 & -2.68E+14 & -1.90E+08 & -8.52E+02 & 0 & 30\text{ veces} & \vdots \\
\vdots & 12\text{ veces} & \vdots & 0 & 4.63E+18 & -8.52E+02 & 6.49E+07 & -4.63E+18 & 8.52E+13 & 3.24E+07 & 0 & 30\text{ veces} & \vdots \\
\vdots & 12\text{ veces} & \vdots & 0 & -4.41E+29 & -2.68E+25 & -4.63E+29 & 4.41E+18 & 2.68E+14 & -4.63E+29 & 0 & 30\text{ veces} & \vdots \\
\vdots & 12\text{ veces} & \vdots & 0 & -2.68E+14 & -1.90E+19 & 8.52E+24 & 2.68E+25 & 1.90E+08 & 8.52E+13 & 0 & 30\text{ veces} & \vdots \\
\vdots & 12\text{ veces} & \vdots & 0 & 4.63E+29 & -8.52E+13 & 3.24E+18 & -4.63E+40 & 8.52E+24 & 6.49E+18 & 0 & 30\text{ veces} & \vdots \\
36\text{ veces} & \vdots & \vdots & \vdots & 0 & 0 & 0 & 0 & 0 & 0 & \vdots & \vdots & 36\text{ veces} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & 30\text{ veces} & 30\text{ veces} & 30\text{ veces} & 30\text{ veces} & 30\text{ veces} & 30\text{ veces} & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
0 & \cdots & \cdots & \cdots & \cdots & 36\text{ veces} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0
\end{bmatrix}
$$

$$
\begin{bmatrix}
0 & \cdots & \cdots & \cdots & \cdots & 36\text{ veces} & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\
\vdots & 0 & 0 & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & 0 & 0 & \vdots \\
\vdots & 0 & 0 & 24\text{ veces} & 24\text{ veces} & 24\text{ veces} & 24\text{ veces} & 24\text{ veces} & 24\text{ veces} & 0 & 0 & \vdots \\
\vdots & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \vdots \\
\vdots & 24\text{ veces} & 0 & 4.41E+07 & 8.93E-09 & -4.63E+07 & -4.41E+18 & -8.93E+02 & 4.63E+18 & 0 & 6\text{ veces} & \vdots \\
\vdots & 24\text{ veces} & 0 & 8.93E+02 & 1.90E-03 & 2.84E-09 & -8.93E+13 & -1.90E+08 & 2.84E+02 & 0 & 6\text{ veces} & \vdots \\
\vdots & 24\text{ veces} & 0 & -4.63E+18 & 2.84E+02 & 6.49E+07 & 4.63E+18 & -2.84E+13 & 3.24E+07 & 0 & 6\text{ veces} & \vdots \\
\vdots & 24\text{ veces} & 0 & -4.41E+29 & -8.93E+24 & 4.63E+29 & 4.41E+18 & 8.93E+13 & 4.63E+29 & 0 & 6\text{ veces} & \vdots \\
\vdots & 24\text{ veces} & 0 & -8.93E+13 & -1.90E+19 & -2.84E+24 & 8.93E+24 & 1.90E+08 & -2.84E+13 & 0 & 6\text{ veces} & \vdots \\
\vdots & 24\text{ veces} & 0 & -4.63E+29 & 2.84E+13 & 3.24E+18 & 4.63E+40 & -2.84E+24 & 6.49E+18 & 0 & 6\text{ veces} & \vdots \\
36\text{ veces} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 36\text{ veces} \\
\vdots & 0 & 0 & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & 0 & 0 & \vdots \\
\vdots & 0 & 0 & 6\text{ veces} & 6\text{ veces} & 6\text{ veces} & 6\text{ veces} & 6\text{ veces} & 6\text{ veces} & 0 & 0 & \vdots \\
0 & \cdots & \cdots & \cdots & \cdots & 36\text{ veces} & \cdots & \cdots & \cdots & \cdots & \cdots & 0
\end{bmatrix}
$$

$$
\begin{bmatrix}
0 & \cdots & \cdots & \cdots & \cdots & 36\text{ veces} & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & 27\text{ veces} & 27\text{ veces} & 27\text{ veces} & 27\text{ veces} & 27\text{ veces} & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & 0 & 0 & 0 & 0 & 0 & \vdots & \vdots & \vdots \\
\vdots & 30\text{ veces} & 0 & 4.41E+07 & 8.93E-09 & -4.63E+07 & -4.41E+18 & -8.93E+02 & -4.63E+18 & 0 & 0 & \vdots \\
\vdots & 30\text{ veces} & 0 & 8.93E+02 & 1.90E-03 & 2.84E-09 & -8.93E+13 & -1.90E+08 & 2.84E+02 & 0 & 0 & \vdots \\
\vdots & 30\text{ veces} & 0 & -4.63E+18 & 2.84E+02 & 6.49E+07 & 4.63E+18 & -2.84E+13 & 3.24E+07 & 0 & 0 & \vdots \\
36\text{ veces} & 30\text{ veces} & 0 & -4.41E+29 & -8.93E+24 & 4.63E+29 & 4.41E+18 & 8.93E+13 & 4.63E+29 & 0 & 0 & 36\text{ veces} \\
\vdots & 30\text{ veces} & 0 & -8.93E+13 & -1.90E+19 & -2.84E+24 & 8.93E+24 & 1.90E+08 & -2.84E+13 & 0 & 0 & \vdots \\
\vdots & 30\text{ veces} & 0 & -4.63E+29 & 2.84E+13 & 3.24E+18 & 4.63E+40 & -2.84E+24 & 6.49E+18 & 0 & 0 & \vdots \\
\vdots & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \vdots \\
\vdots & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \vdots \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
$$

$$\begin{bmatrix}
0 & \cdots & \cdots & \cdots & \text{36 veces} & \cdots & \cdots & \cdots & \cdots \\
\vdots & 0 & 0 & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & 0 & 0 & \text{30 veces} & \text{30 veces} & \text{30 veces} & \text{30 veces} & \text{30 veces} & \text{30 veces} \\
\vdots & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\vdots & \text{30 veces} & 0 & 4.41E+07 & 8.93E-09 & -4.63E+07 & -4.41E+18 & -8.93E+02 & -4.63E+18 \\
\vdots & \text{30 veces} & 0 & 8.93E+02 & 1.90E-03 & 2.84E-09 & -8.93E+13 & -1.90E+08 & 2.84E+02 \\
\vdots & \text{30 veces} & 0 & -4.63E+18 & 2.84E+02 & 6.49E+07 & 4.63E+18 & -2.84E+13 & 3.24E+07 \\
\vdots & \text{30 veces} & 0 & -4.41E+29 & -8.93E+24 & 4.63E+29 & 4.41E+18 & 8.93E+13 & 4.63E+29 \\
\text{36 veces} & \text{30 veces} & 0 & -8.93E+13 & -1.90E+19 & -2.84E+24 & 8.93E+24 & 1.90E+08 & -2.84E+13 \\
0 & \text{30 veces} & 0 & -4.63E+29 & 2.84E+13 & 3.24E+18 & 4.63E+40 & -2.84E+24 & 6.49E+18
\end{bmatrix}$$

$$\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \text{9 veces} & \text{9 veces} & \text{9 veces} & \text{9 veces} & \text{9 veces} & \text{9 veces} & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \text{9 veces} & 0 & 1.90E-03 & 0.00E+00 & 0.00E+00 & -1.60E+08 & 0.00E+00 & 0.00E+00 & 0 & \text{21 veces} & \vdots \\
\vdots & \text{9 veces} & 0 & 0.00E+00 & 5.88E+03 & 7.35E+03 & 0.00E+00 & -4.94E+14 & 6.17E+14 & 0 & \text{21 veces} & \vdots \\
\vdots & \text{9 veces} & 0 & 0.00E+00 & 6.17E+14 & 1.22E+04 & 0.00E+00 & -5.18E+25 & 6.12E+03 & 0 & \text{21 veces} & \vdots \\
\vdots & \text{9 veces} & 0 & -1.34E+19 & 0.00E+00 & 0.00E+00 & 1.60E+08 & 0.00E+00 & 0.00E+00 & 0 & \text{21 veces} & \vdots \\
\vdots & \text{9 veces} & 0 & 0.00E+00 & -4.15E+25 & -4.36E+36 & 0.00E+00 & 4.94E+14 & -5.18E+25 & 0 & \text{21 veces} & \vdots \\
\text{36 veces} & \text{9 veces} & 0 & 0.00E+00 & 5.18E+25 & 5.14E+14 & 0.00E+00 & -4.36E+36 & 1.03E+15 & 0 & \text{21 veces} & \text{36 veces} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \text{21 veces} & \text{21 veces} & \text{21 veces} & \text{21 veces} & \text{21 veces} & \text{21 veces} & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

$$\begin{bmatrix}
0 & \cdots & \cdots & \cdots & \cdots & \text{36 veces} & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & \text{12 veces} & \text{12 veces} & \text{12 veces} & & \text{12 veces} & \text{12 veces} & \text{12 veces} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & 0 & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \text{9 veces} & 0 & 0 & 0.0019 & 0 & 0 & \vdots & -159600000 & 0 & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & 0 & \vdots & 7348.32 & \vdots & 0 & -4.9381E+14 & 6.1726E+14 \\
\vdots & \vdots & \vdots & \vdots & \vdots & 0 & \vdots & 12247.2 & \vdots & 0 & -5.185E+25 & 6123.6 \\
\vdots & \vdots & \vdots & \vdots & \vdots & 0 & \vdots & 0 & \vdots & 0 & 0 & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\text{36 veces} & \vdots & \vdots & \vdots & \vdots & \text{18 veces} & \vdots & \text{18 veces} & \vdots & \text{18 veces} & \text{18 veces} & \text{18 veces} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & \vdots & \vdots & 0 & 0 & 0 & \vdots & 0 & 0 & 0 \\
\vdots & \vdots & \text{9 veces} & 0 & 0 & -1.34064E+19 & 0 & 0 & \vdots & 159600000 & 0 & 0 \\
\vdots & \vdots & \text{9 veces} & 0 & 0 & 0 & -4.148E+25 & 4.3554E+36 & \vdots & 0 & 4.9381E+14 & -5.185E+25 \\
0 & 0 & \text{9 veces} & 0 & 0 & 0 & 5.185E+25 & 5.1438E+14 & \vdots & 0 & -4.3554E+36 & 1.0288E+15
\end{bmatrix}$$

KT =

4.41E+07	8.93E−09	−4.63E+07	−4.41E+18	−8.93E+02	−4.63E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8.93E+02	1.90E−03	2.84E−09	−8.93E+13	−1.90E+08	2.84E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
−4.63E+18	2.84E+02	6.29E+07	4.63E+18	−2.84E+13	3.24E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
−4.41E+29	−8.9E+24	4.63E+29	4.41E+18	8.93E+13	4.63E+29	−4.41E+18	−8.93E+02	−4.63E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.60E+08
−8.93E+13	−1.90E+19	−2.84E+24	8.93E+24	1.90E+08	−2.84E+13	−8.93E+13	−1.90E+08	2.84E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
−4.63E+29	2.84E+13	3.24E+18	4.63E+40	−2.84E+24	6.49E+18	4.63E+18	−2.84E+13	3.24E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	−4.41E+29	−8.93E+24	4.63E+29	4.41E+18	8.93E+13	4.63E+29	−4.41E+18	−8.93E+02	−4.63E+18	0.00E+00	0.00E+00	0.00E+00	−1.60E+08	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	−8.93E+13	−1.90E+19	−2.84E+24	8.93E+24	1.90E+08	−2.84E+13	−8.93E+13	−1.90E+08	2.84E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.94E+14	6.17E+14	0.00E+00
0.00E+00	0.00E+00	0.00E+00	−4.63E+29	2.84E+13	3.24+18	4.63E+40	−2.84E+24	6.49E+18	4.63E+18	−2.84E+13	3.24E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−5.18E+25	6.12E+03	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.41E+29	−8.93E+24	4.63E+29	4.41E+18	8.93E+13	4.63E+29	−1.60E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−8.93E+13	−1.90E+19	−2.84E+24	8.93E+24	1.90E+08	−2.84E+13	0.00E+00	−4.94E+14	6.17E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.63E+29	2.84E+13	3.24E+18	4.63E+40	−2.84E+24	6.49E+18	0.00E+00	−5.18E+25	6.12E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.34E+19	0.00E+00	0.00E+00	2.04E+08	2.68E−08	4.63E+07	−4.41E+18	−2.68E+03	4.63E+18	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.15E+25	−4.36E+36	2.68E+03	4.94E+14	−5.18E+25	−2.68E+14	−1.90E+08	−8.52E+02	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.18E+25	5.14E+14	4.63E+18	−4.36E+36	1.03E+15	−4.63E+18	8.52E+13	3.24E+07	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.34E+19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.41E+29	−2.68E+25	−4.63E+29	4.41E+18	2.68E+14	−4.63E+29	−4.41E+18
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.15E+25	−4.36E+36	0.00E+00	0.00E+00	0.00E+00	−4.41E+29	−1.90E+19	8.52E+24	2.68E+25	4.94E+14	−5.18E+25	−2.68E+14
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.18E+25	5.14E+14	0.00E+00	0.00E+00	0.00E+00	2.68E+14	−8.52E+13	3.24E+18	−4.63E+40	−4.36E+36	6.49E+18	−4.63E+18
0.00E+00	0.00E+00	0.00E+00	−1.34E+19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.63E+29	0.00E+00	0.00E+00	−4.41E+29	−2.68E+25	−4.63E+29	4.41E+18
0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.15E+25	−4.36E+36	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−2.68E+14	−1.90E+19	8.52E+24	2.68E+25
0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.18E+25	5.14E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.63E+29	−8.52E+13	3.24E+18	−4.63E+40
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.41E+29
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−2.68E+14
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.34E+19
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.34E+19	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.15E+25	−4.36E+36	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.18E+25	5.14E+14	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.34E+19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.15E+25	−4.36E+36	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.18E+25	5.14E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00

0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		u_1		0
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		v_1		0
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		θ_1		0
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		u_2		0
−4.94E+14	6.17E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		v_2		10300.5
−5.18E+25	6.12E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		θ_2		−4291.9
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		u_3		0
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		v_3		10300.5
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		θ_3		−4291.9
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		u_4		0
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		v_4		10300.5
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		θ_4		−4291.9
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.60E+08	0.00E+00	0.00E+00		u_5		0
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.94E+14	6.17E+14		v_5		20601
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−5.18E+25	6.12E+03		θ_5		0
−2.68E+03	4.63E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.60E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		u_6		0
−1.90E+08	−8.52E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.94E+14	6.17E+14	0.00E+00	0.00E+00	0.00E+00		v_6		20601
8.52E+13	3.24E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−5.18E+25	6.12E+03	0.00E+00	0.00E+00	0.00E+00	×	θ_6	=	0
2.68E+14	−4.63E+29	−4.41E+18	−2.68E+03	4.63E+18	0.00E+00	0.00E+00	0.00E+00	−1.60E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		u_7		0
4.94E+14	−5.18E+25	−2.68E+14	−1.90E+08	−8.52E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.94E+14	6.17E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		v_7		20601
−4.36E+36	6.49E+18	−4.63E+18	8.52E+13	3.24E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−5.18E+25	6.12E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		θ_7		0
−2.68E+25	−4.63E+29	4.41E+18	2.68E+14	−4.63E+29	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		u_8		0
−1.90E+19	8.52E+24	2.68E+25	1.90E+08	8.52E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		v_8		0
−8.52E+13	3.24E+18	−4.63E+40	8.52E+24	6.49E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		θ_8		0
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.41E+07	8.93E−09	−4.63E+07	−4.41E+18	−8.93E+02	−4.63E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		u_9		0
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.93E+02	1.90E−03	2.84E−09	−8.93E+13	−1.90E+08	2.84E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		v_9		0
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.63E+18	2.84E+02	6.49E+07	4.63E+18	−2.84E+13	3.24E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		θ_9		0
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.41E+29	−8.93E+24	4.63E+29	4.41E+18	8.93E+13	4.63E+29	−4.41E+18	−8.93E+02	−4.63E+18	0.00E+00	0.00E+00	0.00E+00		u_{10}		0
−4.15E+25	−4.36E+36	0.00E+00	0.00E+00	0.00E+00	−8.93E+13	−1.90E+19	−2.84E+24	8.93E+24	4.94E+14	−5.18E+25	−8.93E+13	−1.90E+08	2.84E+02	0.00E+00	0.00E+00	0.00E+00		v_{10}		10300.5
5.18E+25	5.14E+14	0.00E+00	0.00E+00	0.00E+00	−4.63E+29	2.84E+13	3.24E+18	4.63E+40	−4.63E+36	6.49E+18	4.63E+18	−2.84E+13	3324E+07	0.00E+00	0.00E+00	0.00E+00		θ_{10}		4291.88
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.41E+29	−8.93E+24	4.63E+29	4.41E+18	8.93E+13	4.63E+29	−4.41E+18	−8.93E+02	−4.63E+18		u_{11}		0
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−8.93E+13	−1.90E+19	−2.84E+24	8.93E+24	4.94E+14	−5.18E+25	−8.93E+13	−1.90E+08	2.84E+02		v_{11}		10300.5
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.63E+29	2.84E+13	3.24E+18	4.63E+40	−4.36E+36	6.49E+18	4.63E+18	−2.84E+13	3.24E+07		θ_{11}		4291.88
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.41E+29	−8.93E+24	4.63E+29	4.41E+18	8.93E+13	4.63E+29		u_{12}		0
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−8.93E+13	−1.90E+19	−2.84E+24	8.93E+24	4.94E+14	−5.18E+25		v_{12}		10300.5
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.63E+29	2.84E+13	3.24E+18	4.63E+40	−4.36E+36	6.49E+18		θ_{12}		4291.88

Matriz reducida

4.41E+18	8.93E+13	4.63E+29	−4.41E+18	−8.93E+02	−4.63E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.60E+08	0.00E+00
8.93E+24	2.16E+08	2.84E+13	−8.93E+13	−1.90E+08	2.84E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−2.20E+18
4.63E+40	−2.84E+24	6.49E+18	4.63E+18	−2.84E+13	3.24E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−2.31E+29
−4.41E+29	−8.93E+24	4.63E+29	4.41E+18	8.93E+13	4.63E+29	−4.41E+18	−8.93E+02	−4.63E+18	0.00E+00	0.00E+00	0.00E+00	−1.60E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00
−8.93E+13	−1.90E+19	−2.84E+24	8.93E+24	2.16E+08	−2.84E+13	−8.93E+13	−1.90E+08	2.84E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−2.20E+18	2.75E+18	0.00E+00	0.00E+00
−4.63E+29	2.84E+13	3.24E+18	4.63E+40	−2.84E+24	6.49E+18	4.63E+18	−2.84E+13	3.24E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−2.31E+29	2.73E+07	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	−4.41E+29	−8.93E+24	4.63E+29	4.41E+18	8.93E+13	4.63E+29	−1.60E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	−8.93E+13	−1.90E+19	−2.84E+24	8.93E+24	2.16E+08	−2.84E+13	0.00E+00	−2.20E+18	2.75E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	−4.63E+29	2.84E+13	3.24E+18	4.63E+40	−2.84E+24	6.49E+18	0.00E+00	−2.31E+29	2.73E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.34E+19	0.00E+00	0.00E+00	2.04E+08	2.68E−08	4.63E+07	−4.41E+18	−2.68E+03	4.63E+18	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.85E+29	−1.94E+40	2.68E+03	2.20E+18	−2.31E+29	−2.68E+14	−1.90E+08	−8.52E+02	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.31E+29	2.29E+18	4.63E+18	−1.94E+40	4.58E+18	−4.63E+18	8.52E+13	3.24E+07	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	−1.34E+19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.41E+29	−2.68E+25	−4.63E+29	4.41E+18	2.68E+14	−4.63E+29	−4.41E+18	−2.68E+03
0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.85E+29	−1.94E+40	0.00E+00	0.00E+00	0.00E+00	−2.68E+14	−1.90E+19	8.52E+24	2.68E+25	2.20E+18	−2.31E+29	−2.68E+14	−1.90E+08
0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.31E+29	2.29E+18	0.00E+00	0.00E+00	0.00E+00	4.63E+29	−8.52E+13	3.24E+18	−4.63E+40	−1.94E+40	1.11E+19	−4.63E+18	8.52E+13
−1.34E+19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−4.41E+29	−2.68E+25	−4.63E+29	4.41E+18	2.68E+14
0.00E+00	−1.85E+29	−1.94E+40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−2.68E+14	−1.90E+19	8.52E+24	2.68E+25	2.20E+18
0.00E+00	2.31E+29	2.29E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.63E+29	−8.52E+13	3.24E+18	−4.63E+40	−1.94E+40
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.34E+19	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.85E+29
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.31E+29
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.34E+19	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.85E29	−1.94E+40	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.31E+29	2.29E+18	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.34E+19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	−1.85E+29	−1.94E+40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.31E+29	2.29E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

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\left.\begin{matrix}
0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
2.75E+18 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
2.73E+07 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & -1.60E+08 & 0.00E+00 & 0.00E+00 \\
0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & -2.20E+18 & 2.75E+18 \\
0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & -2.31E+29 & 2.73E+07 \\
4.63E+18 & 0.00E+00 & 0.00E+00 & 0.00E+00 & -1.60E+08 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
-8.52E+02 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & -2.20E+18 & 2.75E+18 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
3.24E+07 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & -2.31E+29 & 2.73E+07 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
-4.63E+29 & -1.60E+08 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
-2.31E+29 & 0.00E+00 & -2.20E+18 & 2.75E+18 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
1.11E+19 & 0.00E+00 & -2.31E+29 & 2.73E+07 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
0.00E+00 & 4.41E+18 & 8.93E+13 & 4.63E+29 & -4.41E+18 & -8.93E+02 & -4.63E+18 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
-1.94E+40 & 8.93E+24 & 2.20E+18 & -2.31E+29 & -8.93E+13 & -1.90E+08 & 2.84E+02 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
2.29E+18 & 4.63E+40 & -1.94E+40 & 1.11E+19 & 4.63E+18 & -2.84E+13 & 3.24E+07 & 0.00E+00 & 0.00E+00 & 0.00E+00 \\
0.00E+00 & -4.41E+29 & -8.93E+24 & 4.63E+29 & 4.41E+18 & 8.93E+13 & 4.63E+29 & -4.41E+18 & -8.93E+02 & -4.63E+18 \\
0.00E+00 & -8.93E+13 & -1.90E+19 & -2.84E+24 & 8.93E+24 & 2.20E+18 & -2.31E+29 & -8.93E+13 & -1.90E+08 & 2.84E+02 \\
0.00E+00 & -4.63E+29 & 2.84E+13 & 3.24E+18 & 4.63E+40 & -1.94E+40 & 1.11E+19 & 4.63E+18 & -2.84E+13 & 3.24E+07 \\
0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & -4.41E+29 & -8.93E+24 & 4.63E+29 & 4.41E+18 & 8.93E+13 & 4.63E+29 \\
0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & -8.93E+13 & -1.90E+19 & -2.84E+24 & 8.93E+24 & 2.20E+18 & -2.31E+29 \\
0.00E+00 & 0.00E+00 & 0.00E+00 & 0.00E+00 & -4.63E+29 & 2.84E+13 & 3.24E+18 & 4.63E+40 & -1.94E+40 & 1.11+19
\end{matrix}\right]
$$

Matriz inversa

$$
\left[\begin{matrix}
8.27E-37 & -1.19E-29 & 2.19E-41 & 2.32E-32 & -2.58E-38 & 4.21E-44 & -1.10E-38 & -7.24E-34 & -1.03E-47 & -1.21E-26 & 6.61E-59 & -1.17E-64 & -1.03E-47 & 6.74E-43E & 3.09E-60 & 2.02E-46 & -1.41E-36 \\
1.44E-20 & -3.02E-23 & -1.40E-39 & -6.08E-26 & -4.25E-22 & 5.58E-37 & 5.73E-32 & 1.95E-27 & -2.33E-40 & -9.32E-19 & 1.08E-42 & -1.91E-48 & -1.18E-40 & -2.60E-36 & 5.07E-44 & 3.53E-30 & -2.88E-30 \\
-3.58E-32 & 1.87E-33 & -4.60E-47 & -2.94E-36 & 3.56E-33 & -1.08E-47 & 1.13E-42 & 7.78E-38 & 3.62E-51 & 1.04E-29 & -9.81E-54 & 1.80E-59 & 2.15E-51 & -7.97E-47 & -4.26E-55 & -3.39E-41 & 1.38E-40 \\
4.00E-31 & 3.86E-35 & 8.80E-49 & 1.34E-37 & -5.10E-32 & 2.16E-41 & -7.50E-42 & -2.83E-36 & -2.31E-52 & -1.00E-30 & -4.85E-53 & 1.87E-58 & 1.46E-51 & 1.23E-48 & -2.58E-52 & 2.71E-41 & 5.19E-42 \\
6.66E-15 & 4.99E-19 & 1.02E-32 & 2.87E-21 & -8.37E-16 & -4.85E-32 & -1.22E-25 & -4.62E-20 & -3.88E-36 & -1.68E-14 & -7.89E-37 & 3.06E-42 & 3.21E-36 & 1.51E-32 & -1.56E-38 & 9.45E-26 & 5.15E-26 \\
-6.34E-26 & -4.75E-30 & -9.72E-44 & -2.73E-32 & 7.97E-27 & 4.62E-43 & 1.16E-36 & 4.40E-31 & 3.69E-47 & 1.60E-25 & 7.52E-48 & -2.91E-53 & -3.06E-47 & -5.17E-41 & 1.49E-49 & -9.00E-37 & -4.90E-37 \\
-8.26E-25 & -6.19E-29 & -1.27E-42 & -3.55E-31 & 1.04E-25 & 6.02E-42 & 1.24E-36 & 5.72E-30 & 2.16E-41 & 2.08E-24 & -2.34E-49 & -6.36E-52 & -3.99E-46 & -1.87E-42 & 1.94E-48 & -1.17E-35 & -6.38E-36 \\
-1.35E-08 & -1.01E-12 & -2.07E-42 & -5.80E-15 & 1.69E-09 & 9.82E-26 & 2.06E-20 & 9.35E-14 & 7.85E-30 & 3.39E-08 & -3.82E-30 & -6.18E-36 & -6.51E-30 & -3.06E-26 & 3.16E-32 & -1.91E-19 & -1.04E-19 \\
1.28E-19 & 9.62E-24 & 1.97E-37 & 5.52E-26 & -1.61E-20 & -9.36E-37 & -1.93E-31 & -8.90E-25 & -7.48E-41 & -3.23E-19 & -1.52E-41 & 5.89E-47 & 6.20E-41 & 2.91E-37 & -3.01E-43 & 1.82E-30 & 9.92E-31 \\
9.70E-24 & 7.28E-28 & 1.54E-41 & 4.24E-30 & -1.22E-24 & -7.10E-41 & -1.47E-35 & -6.76E-29 & -5.74E-45 & -2.47E-23 & 2.76E-45 & 3.13E-45 & -2.27E-30 & 2.32E-41 & -2.29E-47 & 1.40E-34 & 7.30E-35 \\
-1.61E-19 & -1.20E-23 & -2.46E-37 & -6.90E-26 & 2.02E-20 & 1.17E-36 & 2.42E-31 & 1.11E-24 & 9.35E-41 & 4.04E-19 & -4.55E-41 & -5.16E-41 & -7.74E-41 & -3.646E-37 & 3.77E-43 & -2.28E-30 & -1.24E-30 \\
-4.24E-21 & 6.76E-25 & 1.94E-38 & 2.05E-27 & 2.07-23 & -3.99E-39 & -8.92E-34 & -5.70E-29 & -3.20E-43 & -1.14E-21 & -2.13E-44 & 6.95E-51 & -5.30E-43 & 4.90E-38 & 2.37E-45 & 1.17E-32 & -1.01E-31 \\
6.43E-22 & -7.62E-25 & -2.13E-38 & 3.45E-27 & -2.59E-23 & -6.73E-39 & 2.04E-33 & -3.84E-29 & -5.39E-43 & -1.93E-21 & 1.56E-44 & 1.09E-50 & -1.29E-40 & -2.54E-38 & 3.15E-45 & -1.79E-30 & -1.71E-31 \\
-1.54E-21 & 1.82E-24 & 5.10E-38 & -8.26E-27 & 6.20E-23 & 1.61E-38 & -4.87E-33 & 9.12E-29 & 1.29E-42 & 4.61E-21 & -3.73E-44 & -2.61E-50 & 2.54E-40 & 6.08E-38 & -5.16E-41 & 4.29E-30 & 4.08E-31 \\
4.24E-21 & -6.76E-25 & -1.94E-38 & -2.05E-27 & -2.07E-23 & 3.99E-39 & 8.92E-34 & 5.70E-29 & 3.20E-43 & 1.14E-21 & 2.13E-44 & -6.46E-51 & 5.30E-43 & -4.90E-38 & 2.37E-45 & -1.17E-32 & 1.01E-31 \\
4.45E-21 & 9.96E-19 & -2.83E-32 & -1.95E-21 & -2.18E-23 & -3.54E-33 & 9.28E-28 & 6.08E-23 & 8.64E-37 & 1.02E-15 & 2.24E-44 & -6.78E-51 & 8.64E-37 & -5.66E-32 & 2.48E-45 & -1.23E-32 & 1.19E-25 \\
-1.10E-26 & -2.38E-18 & 6.77E-32 & 4.65E-21 & 5.40E-29 & 8.46E-33 & -2.22E-27 & -1.45E-22 & -2.07E-36 & -2.44E-15 & -5.74E-50 & 1.21E-56 & -2.07E-36 & 1.35E-31 & -2.33E-51 & -2.77E-36 & -2.84E-25 \\
-1.16E-25 & 2.84E-29 & 4.03E-43 & 5.54E-32 & 9.08E-28 & -2.02E-43 & -2.64E-38 & 1.57E-44 & 6.15E-48 & -2.90E-26 & -7.69-49 & 3.67E-55 & -1.23E-47 & -1.37E-53 & -9.61E-50 & 4.23E-37 & 2.83E-47 \\
-3.74E-10 & 5.96E-14 & 1.71E-27 & 1.81E-16 & 1.83E-12 & -3.52E-28 & -7.86E-23 & -5.02E-18 & -2.82E-32 & -1.01E-10 & -1.88E-33 & 5.70E-40 & -4.68E-32 & 4.32E-27 & -2.09E-34 & 1.03E-21 & -8.94E-21 \\
-8.94E-10 & 1.43E-13 & 4.09E-27 & 4.32E-16 & 4.37E-12 & -8.42E-28 & -1.88E-22 & -1.20E-17 & -6.75E-32 & -2.41E-10 & -4.50E-33 & 1.36E-39 & -1.12E-31 & 1.03E-26 & -4.99E-34 & 2.46E-21 & -2.14E-20 \\
-9.05E-26 & 1.99E-29 & 4.13E-43 & 4.37E-32 & 4.42E-28 & -8.52E-44 & -1.90E-38 & -1.23E-33 & -4.52E-47 & -1.57E-25 & -4.54E-49 & 1.40E-55 & -7.26E-47 & 1.05E-42 & -5.23E-50 & 1.58E-36 & -2.16E-36 \\
5.47E-16 & -8.73E-20 & -2.50E-33 & -2.65E-22 & -2.69E-18 & 5.24E-34 & 1.19E-28 & 5.68E-24 & -3.99E-36 & -1.38E-14 & 2.86E-39 & -6.02E-46 & -6.36E-36 & -6.33E-33 & 1.16E-40 & 1.38E-25 & 1.31E-26 \\
1.31E-15 & -2.09E-19 & -5.99E-33 & -6.33E-22 & -6.43E-18 & 1.25E-33 & 2.85E-28 & 1.36E-23 & -9.54E-36 & -3.30E-14 & 6.83E-39 & -1.44E-45 & -1.52E-35 & -1.51E-32 & 2.78E-40 & 3.30E-25 & 3.13E-26 \\
-3.56E-10 & 5.68E-14 & 1.63E-27 & 1.72E-16 & 1.74E-12 & -3.36E-28 & -7.49E-23 & -4.78E-18 & -2.69E-32 & -9.61E-11 & -1.79E-33 & 5.43E-40 & -4.46E-32 & 4.12E-27 & -1.99E-34 & 9.82E-22 & -8.51E-21 \\
-3.71E-15 & 7.19E-19 & 3.70E-32 & 3.90E-21 & -9.72E-16 & 1.87E-31 & 4.18E-26 & -2.06E-20 & 7.65E-36 & 1.27E-14 & 1.00E-36 & 2.33E-42 & 5.99E-36 & 9.33E-32 & 1.10E-37 & -1.39E-25 & -8.88E-26 \\
-8.88E-15 & 1.72E-18 & 8.85E-32 & 9.33E-21 & -2.32E-15 & 4.48E-31 & 1.00E-25 & -4.92E-20 & 1.83E-35 & 3.05E-14 & 2.39E-36 & 5.58E-42 & 1.43E-35 & 2.23E-31 & 2.64E-37 & -3.32E-25 & -2.12E-25 \\
3.56E-10 & -5.68E-14 & -1.63E-27 & -1.72E-16 & -1.74E-12 & 3.36E-28 & 7.49E-23 & 4.78E-18 & 2.69E-32 & 9.61E-11 & 1.79E-33 & -5.43E-40 & 4.45E-32 & -4.12E-27 & 1.99E-34 & -9.82E-22 & 8.51E-21
\end{matrix}\right.
$$

$$
\left.\begin{matrix}
1.26E-51 & -5.15E-52 & 2.06E-47 & -1.92E-56 & 5.14E-48 & 1.03E-47 & 1.57E-52 & -4.43E-65 & 8.79E-85 & 8.54E-64 \\
4.56E-45 & 8.98E-41 & 9.01E-41 & 2.66E-50 & -1.18E-40 & -1.73E-40 & -6.36E-46 & -7.67E-49 & 1.44E-48 & 1.40E-47 \\
-2.25E-55 & 4.17E-52 & -2.74E-51 & 2.58E-60 & 5.09E-52 & 1.18E-52 & -1.59E-56 & 2.19E-60 & -1.35E-59 & -1.23E-58 \\
1.08E-56 & 7.13E-52 & -1.15E-52 & 9.93E-62 & -6.46E-52 & -1.12E-51 & -1.36E-57 & 3.76E-58 & -5.66E-58 & -2.51E-57 \\
1.73E-40 & 1.47E-35 & -1.57E-36 & 1.86E-45 & -2.23E-36 & 1.97E-36 & -6.60E-43 & 6.13E-42 & -9.25E-42 & -4.12E-41 \\
-1.65E-51 & -1.40E-46 & 1.49E-47 & -1.78E-56 & 2.12E-47 & -1.88E-47 & 6.29E-54 & -5.84E-53 & 8.80E-53 & 3.92E-52 \\
-2.15E-50 & -1.82E-45 & 1.94E-46 & -2.31E-55 & 2.76E-46 & -2.44E-46 & 8.19E-53 & -7.61-52 & 1.15E-51 & 5.11E-51 \\
-3.51E-34 & -2.97E-29 & 3.17E-30 & -3.77E-39 & 4.51E-30 & -3.99E30 & 1.34E-36 & -1.24E-35 & 1.87E-35 & 8.34E-35 \\
3.34E-45 & 2.83E-40 & -3.02E-41 & 3.59E-50 & -4.30E-41 & 3.80E-41 & -1.27E-47 & 1.18E-46 & -1.78E-46 & -7.94E-46 \\
2.54E-49 & 2.12E-44 & -2.31E-45 & 2.70E-54 & -2.97E-45 & 5.42E-41 & -5.47E-52 & 2.70E-41 & 5.42E-41 & -6.03E-50 \\
-4.18E-45 & -3.54E-40 & 3.78E-41 & -4.49E-50 & 5.37E-41 & -4.75E-41 & 1.59E-47 & -1.48E-46 & 2.23E-46 & 9.93E-46 \\
-6.79E-47 & -5.33E-41 & 9.27E-43 & -1.08E-51 & 2.54E-41 & -5.50E-43 & 6.20E-48 & -2.57E-41 & -5.16E-41 & -4.47E-49 \\
-1.39E-47 & 1.57E-41 & 1.56E-42 & 1.25E-51 & 4.28E-41 & 1.05E-40 & 1.11E-46 & -3.18E-50 & -7.95E-52 & -7.54E-49 \\
3.31E-47 & -3.76E-41 & -3.74E-42 & -2.99E-51 & -1.02E-40 & -2.50E-40 & -2.66E-46 & 7.68E-50 & 3.09E-51 & 1.08E-48 \\
6.79E-47 & 5.33E-41 & -9.27E-43 & 1.08E-51 & -2.54E-41 & -5.10E-41 & -6.20E-48 & -2.14E-49 & 8.04E-51 & 4.47E-49 \\
-1.27E-40 & 7.23E-41 & -1.73E-36 & 1.61E-45 & -4.32E-37 & -8.64E-37 & -1.32E-41 & -2.24E-49 & 8.44E-51 & 4.70E-49 \\
2.52E-40 & -1.03E-40 & 4.13E-36 & -3.85E-45 & 1.03E-36 & 2.07E-36 & 3.15E-41 & 5.35E-55 & -1.75E-56 & -1.16E-54 \\
-3.00E-51 & -2.57E-41 & -5.16E-41 & 3.54E-67 & -1.23E-47 & -2.46E-47 & -3.10E-64 & 5.87E-54 & -3.67E-55 & -2.35E-53 \\
-5.99E-36 & -2.43E-30 & 8.18E-32 & -9.54E-41 & -2.42E-32 & -4.85E-32 & 5.47E-37 & 1.89E-38 & -7.09E-40 & -3.95E-38 \\
-1.43E-35 & -5.82E-30 & 1.96E-31 & -2.80E-40 & -5.78E-32 & -1.16E-31 & 1.31E-36 & 4.51E-38 & -1.70E-39 & -9.44E-38 \\
-2.07E-51 & 2.16E-30 & -1.19E-47 & -2.75E-56 & 2.16E-41 & -7.52E-47 & 3.06E-52 & 2.20E-52 & -1.73E-55 & -9.55E-54 \\
8.77E-42 & 5.22E-36 & -3.45E-36 & 1.40E-46 & -3.28E-36 & -6.59E-36 & 1.74E-41 & -2.67E-44 & 8.69E-46 & 5.79E-44 \\
2.10E-41 & 1.25E-35 & -8.25E-36 & 3.34E-46 & -7.85E-36 & -1.58E-35 & -9.97E-42 & -6.37E-44 & 2.08E-45 & 1.38E-43 \\
-5.71E-36 & -4.48E-30 & 7.79E-32 & -9.08E-41 & 2.13E-30 & -4.62E-32 & 5.21E-37 & 1.80E-38 & -6.75E-40 & -3.76E-38 \\
-8.51E-41 & -2.44E-35 & 4.38E-36 & -1.02E-45 & 3.10E-36 & 6.23E-36 & 2.38E-42 & 5.85E-42 & -2.92E-42 & 1.25E-41 \\
-2.04E-40 & -5.84E-35 & 1.05E-35 & -2.43E-45 & 7.42E-36 & 1.49E-35 & 5.64E-42 & 1.40E-41 & -6.97E-42 & -2.17E-41 \\
5.71E-36 & 4.48E-30 & -7.79E-32 & 9.08E-41 & -2.1E-30 & 4.62E-32 & -5.21E-37 & 2.16E-30 & 6.75E-40 & 3.76E-38
\end{matrix}\right]
\times
\begin{bmatrix}
0.00E+00 \\ 1.03E+04 \\ 4.29E+03 \\ 0.00E+00 \\ 1.03E+04 \\ 4.29E+03 \\ 0.00E+00 \\ 1.03E+04 \\ 4.29E+03 \\ 0.00E+00 \\ 2.06E+04 \\ 0.00E+00 \\ 0.00E+00 \\ 2.06E+04 \\ 0.00E+00 \\ 0.00E+00 \\ 2.06E+04 \\ 0.00E+00 \\ 0.00E+00 \\ 0.00E+00 \\ 0.00E+00 \\ 0.00E+00 \\ 1.03E+04 \\ 4.29E+03 \\ 0.00E+00 \\ 1.03E+04 \\ 4.29E+03
\end{bmatrix}
=
\begin{bmatrix}
-1.22E-25 \\ -4.69E-18 \\ 5.59E-29 \\ -5.25E-28 \\ -8.62E-12 \\ 8.21E-23 \\ 1.07E-21 \\ 1.74E-05 \\ -1.66E-16 \\ -1.26E-20 \\ 2.08E-16 \\ 2.20E-19 \\ -2.75E-19 \\ 6.57E-19 \\ -2.20E-19 \\ 1.03E-14 \\ -2.45E-14 \\ 9.64E-24 \\ 1.94E-08 \\ 4.65E-08 \\ 4.76E-24 \\ -2.86E-14 \\ -6.84E-14 \\ 1.85E-08 \\ -1.00E-11 \\ -2.39E-11 \\ -1.85E-08
\end{bmatrix}
\begin{matrix}
\mathrm{m} \\ \mathrm{m} \\ \mathrm{rad} \\ \mathrm{m} \\ \mathrm{m} \\ \mathrm{rad} \\ \mathrm{m} \\ \mathrm{m} \\ \mathrm{rad} \\ \mathrm{m} \\ \mathrm{m} \\ \mathrm{rad} \\ \mathrm{m} \\ \mathrm{m} \\ \mathrm{rad} \\ \mathrm{m} \\ \mathrm{m} \\ \mathrm{rad} \\ \mathrm{m} \\ \mathrm{m} \\ \mathrm{rad} \\ \mathrm{m} \\ \mathrm{m} \\ \mathrm{rad} \\ \mathrm{m} \\ \mathrm{m} \\ \mathrm{rad}
\end{matrix}
$$

DISEÑO ESTRUCTURAL A TRAVÉS DEL ANÁLISIS MATRICIAL DE UNA TRIBUNA EN LA CANCHA DEPORTIVA EN UNA UNIVERSIDAD

Introducción

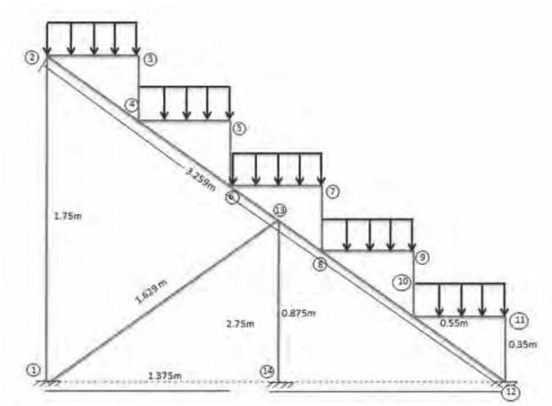
En la actualidad muchas universidades no cuenta con una tribuna segura y estable en sus canchas deportivas de futbol que poseen, debido a esto cada vez que se presenta un evento deportivo o social en estas, se arman y se colocan tribunas temporales que ponen en peligro la seguridad de los estudiantes y docentes, aparte de generar gastos innecesarios para el alquiler del equipo para su construcción; razón por la cual se hace necesario construir una tribuna.

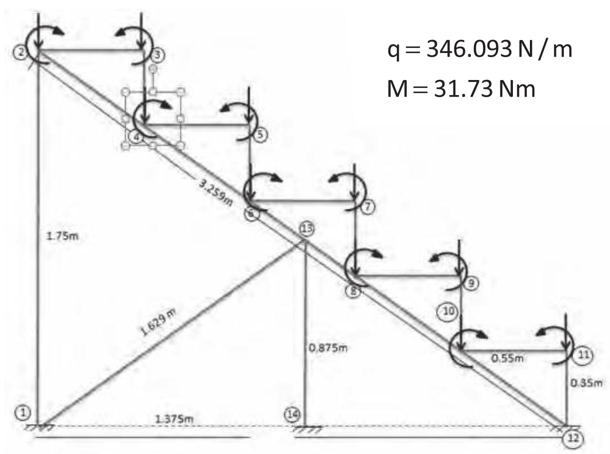
El presente trabajo a desarrollar tiene como objetivo diseñar dos tribunas estables y resistentes para 200 personas.

Para el desarrollo del modelo matemático de este diseño se utilizara las matrices de rigidez las cuales serán resueltas a través del software MATLAB.

Se espera que los desplazamientos nodales estén dentro de un rango permisible para la construcción de la tribuna, ofreciendo la seguridad y comodidad.

Aplicación:





$$q = 346.093\ N/m$$
$$M = 31.73\ Nm$$

$$K=\frac{E}{L}\times\begin{bmatrix} AC^2+\frac{12IS^2}{L^2} & \left(A-\frac{12I}{L^2}\right)CS & -\frac{6I}{L}S & -\left(AC^2+\frac{12I}{L^2}S^2\right) & -\left(A-\frac{12I}{L^2}\right)CS & -\frac{6I}{L}S \\ \left(A-\frac{12I}{L^2}\right)CS & AS^2+\frac{12I}{L^2}C^2 & \frac{6I}{L}C & -\left(A-\frac{12I}{L^2}\right)CS & -\left(AS^2+\frac{12I}{L^2}C^2\right) & \frac{6I}{L}C \\ -\frac{6I}{L}S & \frac{6I}{L}C & 4I & \frac{6I}{L}S & & 2I \\ -\left(AC^2+\frac{12IS^{2}{}^{2}}{L^2}\right) & -\left(A-\frac{12I}{L^2}\right)CS & \frac{6I}{L}S & AC^2+\frac{12IS^2}{L^2} & \left(A-\frac{12I}{L^2}\right)CS & \frac{6I}{L}S \\ -\left(A-\frac{12I}{L^2}\right)CS & -\left(AS^2+\frac{12I}{L^2}C^2\right) & -\frac{6I}{L}C & \left(A-\frac{12I}{L^2}\right)CS & AS^2+\frac{12I}{L^2}C^2 & -\frac{6I}{L}C \\ -\frac{6I}{L}S & \frac{6I}{L}C & 2I & \frac{6I}{L}S & -\frac{6I}{L}C & 4I \end{bmatrix}$$

$$K=\frac{E}{L}\times\begin{bmatrix} a & b & -c & -a & -b & -c \\ b & d & e & -b & -d & e \\ -c & e & f & c & -e & g \\ -a & -b & c & a & b & c \\ -b & -d & -e & b & d & -e \\ -c & e & g & c & -e & f \end{bmatrix}$$

$$a=AC^2+\frac{12IS^2}{L^2}$$

$$b=\left(A-\frac{12I}{L^2}\right)CS$$

$$c=\frac{6IS}{L}$$

$$d=AS^2+\frac{12IC^2}{L^2}$$

$$e=\frac{6IC}{L}$$

$$f=4I$$

$$g=2I$$

$$K_1 = 10^{12} \times \begin{bmatrix}
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K_6 = 10^{11} \times \begin{bmatrix}
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K_T = 10^{12} \times \begin{bmatrix}
0.5393 & 0.1707 & -0.2454 & -0.2776 & 0 & -0.2429 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.1707 & 0.3895 & 0.0038 & 0 & -0.2780 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.2454 & 0.0038 & 0.2884 & 0.2429 & 0 & 0.1417 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.2776 & 0 & 0.2429 & 1.1465 & -0.7109 & 0.2736 & -0.4553 & 0 & 0 & -0.4136 & 0.7109 & 0.0307 & 0 & 0 \\
0 & -0.2780 & -0.2429 & -0.7109 & 1.5530 & 0.0504 & 0 & -0.0096 & 0.0026 & 0 & -0.7464 & 0 & 0 & 0 \\
-0.2429 & 0 & 0.1417 & 0.2736 & 0.0504 & 0.3091 & 0 & -0.0026 & 0.0005 & -0.0307 & -0.0478 & 0.0124 & 0 & 0 \\
0 & 0 & 0 & -0.4553 & 0 & 0 & 3.5851 & 0 & 0.5477 & -3.1298 & 0 & 0.5477 & 0 & 0 \\
0 & 0 & 0 & 0 & -0.0096 & 0 & 0 & 2.4244 & -0.0026 & 0 & -0.0151 & 0.0042 & 0 & 0 \\
0 & 0 & 0 & 0 & 0.0026 & 0.0005 & 0.5477 & -0.0026 & 0.1288 & -0.5477 & 0 & 0.0639 & 0 & 0 \\
0 & 0 & 0 & -0.4136 & 0.7109 & -0.0307 & -3.1298 & 0 & -0.5477 & 4.5071 & -0.9969 & -0.5970 & -0.4553 & 0 \\
0 & 0 & 0 & 0.7109 & -1.2653 & 0.0307 & 0 & -2.4148 & 0.5477 & -0.9969 & 3.9333 & -0.0271 & 0 & -0.0096 \\
0 & 0 & 0 & 0.0307 & 0.0478 & 0.0124 & 0.5477 & 0 & 0.0639 & -0.5670 & -0.0271 & 0.1627 & 0 & -0.0026 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.4553 & 0 & 0 & 3.5851 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0096 & 0 & 0 & 2.4244 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0026 & 0.0005 & 0.5477 & -0.0026 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.5084 & 0.2860 & -0.0114 & -3.1298 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.2860 & -0.2436 & -0.0180 & 0 & -2.4148 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0114 & 0.0180 & 0.0046 & -0.5477 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.2617 & -0.1707 & 0.0025 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.1707 & -0.1115 & -0.0038 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.0025 & 0.0038 & 0.0025 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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\end{bmatrix}
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0 & -0.5084 & 0.2860 & 0.0114 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.0026 & 0.2860 & -0.2436 & 0.0180 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.0005 & -0.0114 & -0.0180 & 0.0046 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.5477 & -3.1298 & 0 & 0.5447 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.0026 & 0 & -0.5719 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.1288 & -0.5477 & 2.9116 & 0.0639 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.5477 & 4.6019 & 0.0026 & -0.5477 & -0.4553 & 0 & 0 & -0.5084 & 0.2860 & 0.0114 & 0 & 0 & 0 & 0 \\
-0.5477 & -0.5719 & 0 & 0.0026 & 0 & -0.0096 & 0.0026 & 0.2860 & -0.2436 & 0.0180 & 0 & 0 & 0 & 0 \\
0.0639 & -0.5477 & -0.0096 & 0.1472 & 0 & -0.0026 & 0.0005 & -0.0114 & -0.0180 & 0.0046 & 0 & 0 & 0 & 0 \\
0 & -0.4553 & 0.0026 & 0 & 0.7967 & 0 & 0.0597 & -0.3414 & 0 & 0.0597 & 0 & 0 & 0 & 0 \\
0 & 0 & 0.2860 & 0 & 0 & 0.8146 & -0.0026 & 0 & -0.8049 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -0.2436 & 0.0005 & -0.1350 & -0.0026 & 0.1584 & 0.1350 & 0 & 0.0787 & 0 & 0 & 0 & 0 \\
0 & -0.5084 & 0.0180 & -0.0114 & -0.1542 & 0 & 0.1350 & 2.0372 & -1.0537 & 0.1542 & -0.0096 & 0 & 0 & -1.3649 \\
0 & 0.2860 & 0 & -0.0180 & 0 & 0.8146 & -0.1350 & -1.0537 & 0.8227 & 2.6772 & 0 & -0.4553 & 2.6469 & 0.7678 \\
0 & 0.0114 & 0 & 0.0046 & -0.1350 & -0.0026 & 0.0787 & 0.1542 & 2.6772 & 0.1923 & 0 & -2.6469 & 0.0005 & -0.0307 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0096 & 0 & 0 & 0.3510 & 0 & 0.0597 & -0.3414 \\
0 & 0 & 0 & 0 & 0 & -0.1545 & 0 & 0 & -0.4553 & 0 & 0 & 1.2602 & -2.6469 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.6469 & 0.005 & 0.0597 & -2.6469 & 0.0149 & -0.0597 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.3649 & 0.7678 & -0.307 & -0.3414 & 0 & -0.0597 & 3.0809 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.7678 & 0.0307 & -0.0483 & 0 & -0.8049 & 0.0597 & -1.5355 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0307 & 0.0483 & 0.0124 & 0.0597 & 0 & 0.0070 & -0.0597 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0096 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.3649 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.7678 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0307 \\
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\end{bmatrix}
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.7678 & 0.0307 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.0307 & 0.0483 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.0483 & 0.0124 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0.0597 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.8049 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0.0070 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-1.5355 & -0.0597 & -0.0096 & 0 & 0 & -1.3649 & 0.7678 & 0.0307 & 0 & 0 & 0 & 0 & 0 & 0 \\
1.8836 & 2.6469 & 0 & -0.4553 & 2.6469 & 0.7678 & -0.6540 & 0.0483 & 0 & 0 & 0 & 0 & 0 & 0 \\
2.6469 & 0.0643 & 0 & -2.6469 & 0.0005 & -0.0307 & -0.0483 & 0.0124 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0.3510 & 0 & 0.0597 & -0.3414 & 0 & 0.0597 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.4553 & 0 & 0 & 1.2602 & -2.6469 & 0 & -0.8049 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
2.6469 & 0.0005 & 0.0597 & -2.6469 & 0.0149 & -0.0597 & 0 & 0.0070 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.7978 & -0.0307 & -0.1542 & 0 & 0.1350 & 1.5192 & -0.7678 & 0.1043 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.6540 & -0.0483 & 0 & -0.8049 & 0.0597 & -0.7678 & 1.4590 & -0.0483 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.0483 & 0.0124 & 0.0597 & 0 & 0.0070 & -0.0905 & -0.0483 & 0.0387 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.2811 & 0.1707 & -0.0006 & -0.0194 & -0.0194 & -0.0085 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.1707 & 0.4822 & -0.0038 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0060 & -0.0038 & 0.0099 & 0.0085 & 0.0085 & 0.0025 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0194 & 0 & 0.0085 & 0.0194 & 0.0194 & 0.0085 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.3708 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0085 & 0 & 0.0025 & 0.0085 & 0.0085 & 0.0049
\end{bmatrix}
\times
\begin{bmatrix}
0 \\ 0 \\ 0 \\ u_2 \\ v_2 \\ \theta_2 \\ u_3 \\ v_3 \\ \theta_3 \\ u_4 \\ v_4 \\ \theta_4 \\ u_5 \\ v_5 \\ \theta_5 \\ u_6 \\ v_6 \\ \theta_6 \\ u_7 \\ v_7 \\ \theta_7 \\ u_8 \\ v_8 \\ \theta_8 \\ u_9 \\ v_9 \\ \theta_9 \\ u_{10} \\ v_{10} \\ \theta_{10} \\ u_{11} \\ v_{11} \\ \theta_{11} \\ 0 \\ 0 \\ 0 \\ u_{13} \\ v_{13} \\ \theta_{13} \\ 0 \\ 0 \\ 0
\end{bmatrix}
=
\begin{bmatrix}
F_{1x} \\ F_{1y} \\ M_1 \\ -346.093 \\ 0 \\ -31.73 \\ -346.093 \\ 0 \\ 31.73 \\ -346.093 \\ 0 \\ -31.73 \\ -346.093 \\ 0 \\ 31.73 \\ -346.093 \\ 0 \\ -31.73 \\ -346.093 \\ 0 \\ 31.73 \\ -346.093 \\ 0 \\ -31.73 \\ -346.093 \\ 0 \\ 31.73 \\ -346.093 \\ 0 \\ -31.73 \\ -346.093 \\ 0 \\ 31.73 \\ F_{12x} \\ F_{12y} \\ M_{12} \\ 0 \\ 0 \\ 0 \\ F_{14} \\ F_{14} \\ M_{14}
\end{bmatrix}
$$

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K = 10^{12} \times \begin{bmatrix}
1.1465 & -0.7109 & 0.2736 & -0.4553 & 0 & 0 & -0.4136 & 0.7109 & 0.0307 & 0 & 0 \\
-0.7109 & 1.5530 & 0.0504 & 0 & -0.0096 & 0.0026 & 0 & -0.7464 & 0 & 0 & 0 \\
0.2736 & 0.0504 & 0.3091 & 0 & -0.0026 & 0.0005 & -0.0307 & -0.0478 & 0.0124 & 0 & 0 \\
-0.4553 & 0 & 0 & 3.5851 & 0 & 0.5477 & -3.1298 & 0 & 0.5477 & 0 & 0 \\
0 & -0.0096 & 0 & 0 & 2.4244 & -0.0026 & 0 & -0.0151 & 0.0042 & 0 & 0 \\
0 & 0.0026 & 0.0005 & 0.5477 & -0.0026 & 0.1288 & -0.5477 & 0 & 0.0639 & 0 & 0 \\
-0.4136 & 0.7109 & -0.0307 & -3.1298 & 0 & -0.5477 & 4.5071 & -0.9969 & -0.5670 & -0.4553 & 0 \\
0.7109 & -1.2653 & 0.0307 & 0 & -2.4148 & 0.5477 & -0.0969 & 3.9333 & -0.0271 & 0 & -0.0026 \\
0.0307 & 0.0478 & 0.0124 & 0.5477 & 0 & 0.0639 & -0.5670 & -0.0271 & 0.1627 & 0 & -0.0026 \\
0 & 0 & 0 & 0 & 0 & 0 & -0.4553 & 0 & 0 & 3.5851 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0096 & 0 & 0 & 2.4244 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0026 & 0.0005 & 0.5477 & -0.0026 \\
0 & 0 & 0 & 0 & 0 & 0 & -0.5084 & 0.2860 & -0.0114 & -3.1298 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0.2860 & -0.2436 & -0.0180 & 0 & -2.4148 \\
0 & 0 & 0 & 0 & 0 & 0 & 0.0114 & 0.0180 & 0.0046 & -0.5477 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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\end{bmatrix}
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$$\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -0.5084 & 0.2860 & 0.0114 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.0026 & 0.2860 & -0.2436 & 0.0180 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.0005 & -0.0114 & -0.0180 & 0.0046 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.5477 & -3.1298 & 0 & 0.5477 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.0026 & 0 & -2.4148 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.1288 & -0.5477 & 0 & 0.0639 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-0.5477 & 4.6019 & -0.5719 & -0.5477 & -0.4553 & 0 & 0 & -0.5084 & 0.2860 & 0.0114 & 0 \\
-0.5477 & -0.5719 & 2.9116 & 0.0026 & 0 & -0.0096 & 0.0026 & 0.2860 & -0.2436 & 0.0180 & 0 \\
0.0639 & -0.5477 & 0.0026 & 0.1472 & 0 & -0.0026 & 0.0005 & -0.0114 & -0.0180 & 0.0046 & 0 \\
0 & -0.4553 & 0 & 0 & 0.7967 & 0 & 0.0597 & -0.3414 & 0 & 0.0597 & 0 \\
0 & 0 & -0.0096 & 0 & 0 & 0.8146 & -0.0026 & 0 & -0.8049 & 0 & 0 \\
0 & 0 & 0 & 0 & 0.0026 & 0.0005 & -0.1350 & -0.0026 & 0.1584 & 0.1350 & 0 \\
0 & 0 & 0 & -0.5084 & 0.2860 & -0.0114 & -0.1542 & 0 & 0.1350 & 2.0372 & -1.0537 \\
0 & 0 & 0 & 0.2860 & -0.2436 & -0.0180 & 0 & -0.1545 & -0.1350 & -1.0537 & 0.0827 \\
0 & 0 & 0 & 0.0114 & 0.0180 & 0.0046 & -0.1350 & 0 & 0.0787 & 0.1542 & 2.6772 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0096 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.4553 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2.6469 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.3649 & 0.7678 & -0.0307 & -0.3414 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.7678 & 0.0307 & -0.0483 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0307 & 0.0483 & 0.0124 & 0.0597 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

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\begin{bmatrix}
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0.0787 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.1542 & -0.0096 & 0 & 0 & -1.3649 & 0.7678 & 0.0307 & 0 & 0 & 0 & 0 \\
2.6772 & 0 & -0.4553 & 2.6469 & 0.7678 & 0.0307 & 0.0483 & 0 & 0 & 0 & 0 \\
0.1923 & 0 & -2.6469 & 0.0005 & -0.0307 & -0.0483 & 0.0124 & 0 & 0 & 0 & 0 \\
0 & 0.3510 & 0 & 0.0597 & -0.3414 & 0 & 0.0597 & 0 & 0 & 0 & 0 \\
0 & 0 & 1.2602 & -2.6469 & 0 & -0.8049 & 0 & 0 & 0 & 0 & 0 \\
0.0005 & 0.0597 & -2.6469 & 0.0149 & -0.0597 & 0 & 0.0070 & 0 & 0 & 0 & 0 \\
0 & -0.0597 & 3.0809 & -1.5355 & -0.0597 & -0.0096 & 0 & 0 & 0 & 0 & 0 \\
-0.8049 & 0.0597 & -1.5355 & 1.8836 & 2.6469 & 0 & -0.4553 & 2.6469 & 0 & 0 & 0 \\
0 & 0.0070 & -0.0597 & 2.6469 & 0.0643 & 0 & -2.6469 & 0.0005 & 0 & 0 & 0 \\
0 & 0 & -0.0096 & 0 & 0 & 0.3510 & 0 & 0.0597 & 0 & 0 & 0 \\
0 & 0 & 0 & -0.4553 & 0 & 0 & 1.2602 & -2.6469 & 0 & 0 & 0 \\
0 & 0 & 0 & 2.6469 & 0.0005 & 0.0597 & -2.6469 & 0.0149 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.2811 & 0.1707 & -0.0060 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.1707 & 0.4822 & -0.0038 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.0060 & -0.0038 & 0.0099
\end{bmatrix}
\begin{bmatrix}
u_2 \\ v_2 \\ \theta_2 \\ u_3 \\ v_3 \\ \theta_3 \\ u_4 \\ v_4 \\ \theta_4 \\ u_5 \\ v_5 \\ \theta_5 \\ u_6 \\ v_6 \\ \theta_6 \\ u_7 \\ v_7 \\ \theta_7 \\ u_8 \\ v_8 \\ \theta_8 \\ u_9 \\ v_9 \\ \theta_9 \\ u_{10} \\ v_{10} \\ \theta_{10} \\ u_{11} \\ v_{11} \\ \theta_{11} \\ u_{13} \\ v_{13} \\ \theta_{13}
\end{bmatrix}
=
\begin{bmatrix}
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\end{bmatrix}
$$

Desplazamientos Nodales:

$$u = inv(k) \times F$$

$$U = 10^{-7}\begin{bmatrix} 0\,m \\ 0\,m \\ 0\,rad \\ -0.1167\,m \\ -0.0758\,m \\ 0.0959\,rad \\ -0.1182\,m \\ -0.0006\,m \\ 0.2203\,rad \\ -0.0442\,m \\ -0.0392\,m \\ 0.1973\,rad \\ -0.0077\,m \\ 0.0785\,m \\ 0.0516\,rad \\ -0.0051\,m \\ 0.0789\,m \\ -0.0730\,rad \\ -0.0150\,m \\ -0.0004\,m \\ -0.0281\,rad \\ -0.0273\,m \\ -0.0012\,m \\ -0.0242\,rad \\ -0.0157\,m \\ -0.0006\,m \\ -0.0099\,rad \\ -0.0160\,m \\ -0.0018\,m \\ -0.0001\,rad \\ -0.0102\,m \\ -0.0022\,m \\ -0.0007\,rad \\ 0\,m \\ 0\,m \\ 0\,rad \\ 0\,m \\ 0\,m \\ 0\,rad \\ 0\,m \\ 0\,m \\ 0\,rad \end{bmatrix}$$

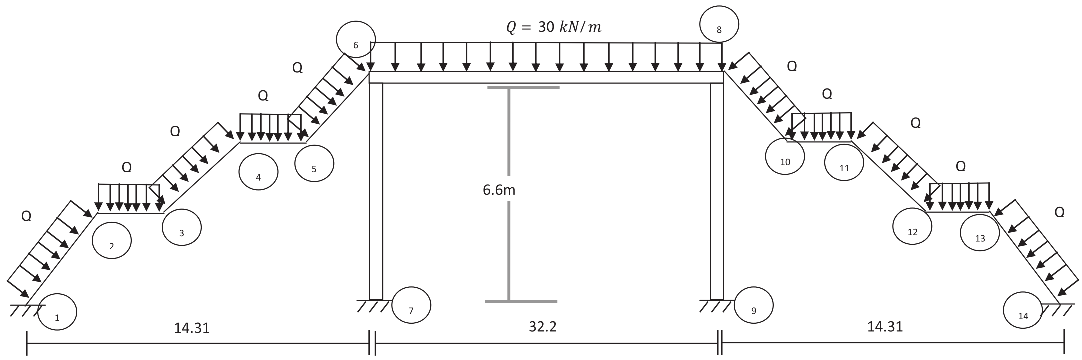
Fuerzas:

$$F = K \times u$$

$$F = 10^3 \begin{bmatrix} 0.9103\,N \\ 2.1074\,N \\ -1.4760\,Nm \\ -0.3383\,N \\ -0.0070\,N \\ -0.0336\,Nm \\ -0.3562\,N \\ 0.0105\,N \\ 0.0292\,Nm \\ -0.3460\,N \\ -0.0081\,N \\ -0.0342\,Nm \\ -0.3240\,N \\ 0.0030\,N \\ 0.0340\,Nm \\ -0.3682\,N \\ -0.0037\,N \\ -0.0321\,Nm \\ -0.3433\,N \\ -0.0045\,N \\ -0.7843\,Nm \\ -1.2966\,N \\ -9.0794\,N \\ -0.9079\,Nm \\ -0.0383\,N \\ 2.7443\,N \\ -0.1730\,Nm \\ -0.3390\,N \\ 0.0127\,N \\ -0.0195\,Nm \\ -0.3468\,N \\ -0.0100\,N \\ 0.0439\,Nm \\ 2.1939\,N \\ -0.9373\,N \\ -0.1194\,Nm \\ 0\,N \\ 0\,N \\ 0\,Nm \\ 0\,m \\ 0\,N \\ 0\,Nm \end{bmatrix}$$

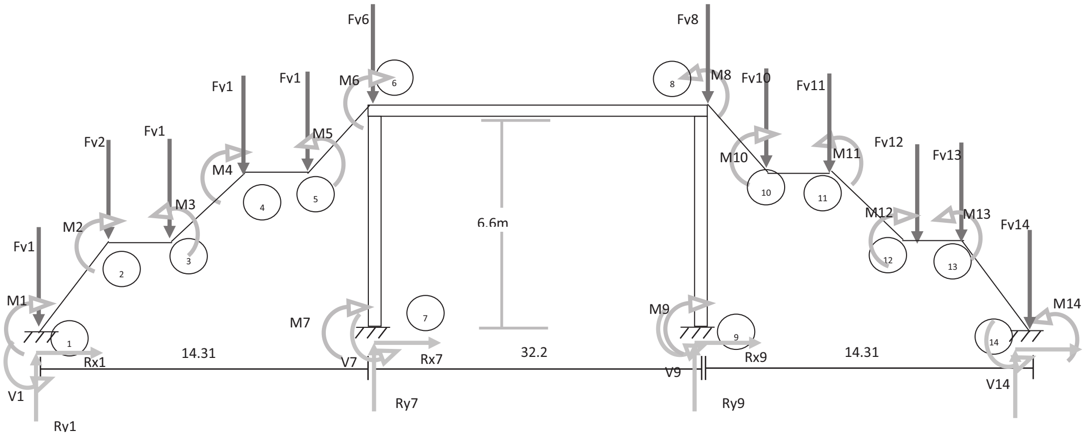
DISEÑO DE UN PUENTE PEATONAL

Modelo matemático:



nodos	ángulo	radianes	c	s	C^2	s^2	cs	A	I	E	L	L
1--2	30	0.523599	0.8660254	0.5	0.75	0.25	0.4330127	7.48	4.437E+09	2100000000	4.16	17.3056
2--3	0	0.008727	0.9999619	0.00872654	0.99992385	7.615E-05	0.0087262	4.16	4.437E+09	2100000000	2	4
3--4	30	0.523599	0.8660254	0.5	0.75	0.25	0.4330127	7.48	4.437E+09	2100000000	4.16	17.3056
4--5	0	0.008727	0.9999619	0.00872654	0.99992385	7.615E-05	0.0087262	8.32	4.437E+09	2100000000	2	4
5--6	30	0.5235988	0.8660254	0.5	0.75	0.25	0.4330127	3.79	4.437E+09	2100000000	3.6	12.96
6--7	270	4.712389	-1.84E-16	-1	3.3772E-32	1	1.8377E-16	10.56	4.437E+09	2100000000	6.6	43.56
6--8	0	0.0087266	0.9999619	0.00872654	0.99992385	7.615E-05	0.0087262	212.52	4.437E+09	2100000000	32.2	1036.84
8--9	270	4.712389	-1.84E-16	-1	3.3772E-32	1	1.8377E-16	10.56	4.437E+09	2100000000	6.6	43.56
8--10	330	5.7595865	0.8660254	-0.5	0.75	0.25	-0.4330127	3.79	4.437E+09	2100000000	3.6	12.96
10--11	0	0.0087266	0.9999619	0.00872654	0.99992385	7.615E-05	0.0087262	8.32	4.437E+09	2100000000	2	4
11--12	330	5.7595865	0.8660254	-0.5	0.75	0.25	-0.4330127	7.48	4.437E+09	2100000000	4.16	17.3056
12--13	0	0.0087266	0.9999619	0.00872654	0.99992385	7.615E-05	0.0087262	4.16	4.437E+09	2100000000	2	4
13--14	330	5.7595865	0.8660254	-0.5	0.75	0.25	-0.4330127	7.48	4.437E+09	2100000000	4.16	17.3056

Análisis de las cargas:



Nodos	Fxi(N)	Fyi(N)	Mi(Nm)
1	Fx1	–62400+A	–43264+A
2	0	–30000	–10000
3	13000	30000	10000
4	0	–62400	–43264
5	20000	30000	10000
6	0	–54000	–32400
7	F7x	99000+B	108900+B
8	–10000	–99000	–108900
9	F9x	99000+M	108900+M
10	0	54000	32400
11	40000	–62400	–43264
12	0	30000	10000
13	0	–62400	–43264
14	F14x	–62400+C	43264+C

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\begin{bmatrix}
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\left[\begin{matrix}
3.88311E+17 & -6.726E+17 & -1.6154E+18 & -3.883E+17 & 6.7257E+17 & -1.6154E+18 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-6.72574E+17 & 1.1649E+18 & 2.79791E+18 & 6.7257E+17 & -1.1649E+18 & 2.7979E+18 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-1.61537E+18 & 2.7979E+18 & 8.95993E+18 & 1.6154E+18 & -2.7979E+18 & 4.48E+18 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-3.88311E+17 & 6.7257E+17 & 1.61537E+18 & 3.8938E+17 & -7.9454E+17 & 1.4934E+18 & -1.064E+15 & 1.2197E+17 & -1.22E+17 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
6.72574E+17 & -1.165E+18 & -2.7979E+18 & -7.945E+17 & 1.5141E+19 & 1.1179E+19 & 1.2197E+17 & -1.3976E+19 & 1.3977E+19 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
-1.61537E+18 & 2.7979E+18 & 4.47997E+18 & 1.4934E+18 & 1.1179E+19 & 2.7597E+19 & 1.2198E+17 & -1.3977E+19 & 9.3183E+18 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -1.064E+15 & 1.2197E+17 & 1.2198E+17 & 3.8938E+17 & -7.9454E+17 & -1.493E+18 & -3.883E+17 & 6.7257E+17 & -1.615E+18 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1.2197E+17 & -1.3976E+19 & -1.3977E+19 & -7.945E+17 & 1.5141E+19 & -1.118E+19 & 6.7257E+17 & -1.165E+18 & 2.798E+18 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -1.22E+17 & 1.3977E+19 & 9.3183E+18 & -1.493E+18 & -1.1179E+19 & 2.7597E+19 & 1.6154E+18 & -2.798E+18 & 4.48E+18 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -3.883E+17 & 6.7257E+17 & 1.6154E+18 & 3.8938E+17 & -7.945E+17 & 1.493E+18 & -1.064E+15 & 1.2197E+17 & -1.22E+17 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & -1.615E+18 & 2.7979E+18 & 4.48E+18 & 1.4934E+18 & 1.1179E+19 & 2.76E+19 & 1.2198E+17 & -1.398E+19 & 9.3183E+18 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.064E+15 & 1.2197E+17 & 1.22E+17 & 6.0024E+17 & -1.16E+18 & -2.035E+18 & -5.9917E+17 & 1.0378E+18 & -2.157E+18 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.2197E+17 & -1.398E+19 & -1.398E+19 & -1.16E+18 & 1.5774E+19 & -1.024E+19 & 1.0378E+18 & -1.7975E+18 & 3.7361E+18 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.22E+17 & 1.3977E+19 & 9.318E+18 & -2.035E+18 & -1.024E+19 & 2.899E+19 & 2.15702E+18 & -3.7361E+18 & 5.1769E+18 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -5.992E+17 & 1.0378E+18 & 2.157E+18 & 9.88117E+17 & -1.0378E+18 & 3.4401E+18 & -3.889E+17 & 71.47719449 \\
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1.2835E+18	-2.68915E+11	2.92264E+13	-4.706E+14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-235.874744	2.92264E+13	-3.34903E+15	5.3921E+16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.8237E+18	4.70565E+14	-5.39214E+16	5.7878E+17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1.2835E+18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
235.874744	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.6475E+18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	9.88117E+17	1.03777E+18	3.441E+18	-3.88944E+17	71.47719449	1.28352E+18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1.03777E+18	1.80087E+18	3.6821E+18	71.47719449	-3360000000	-235.8747438	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	3.44101E+18	3.68215E+18	1.7159E+19	-1.28352E+18	235.8747438	2.82374E+18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	-3.88944E+17	71.47719449	-1.284E+18	3.88944E+17	-71.4771945	-1.28352E+18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	71.47719449	-3360000000	235.874744	-71.47719449	3360000000	235.8747438	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1.28352E+18	-235.8747438	2.8237E+18	-1.28352E+18	235.8747438	5.64747E+18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	-5.99172E+17	-1.0378E+18	-2.157E+18	0	0	0	6.00237E+17	9.15827E+17	-2.279E+18	-1.064E+15	1.2197E+17	-1.2198E+17	0	0	0	0	0	0	0	0	0
0	-1.0378E+18	-1.79752E+18	-3.736E+18	0	0	0	9.15827E+17	1.57739E+19	1.02409E+19	1.2197E+17	-1.39764E+19	1.3977E+19	0	0	0	0	0	0	0	0	0
0	2.15702E+18	3.73607E+18	5.1769E+18	0	0	0	-2.279E+18	1.02409E+19	2.89904E+19	1.2198E+17	-1.3977E+19	9.31833E+18	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	-1.06443E+15	1.2197E+17	1.21975E+17	3.8938E+17	5.50603E+17	1.73735E+18	4.47997E+18	-6.726E+17	1.61537E+18	0	0	0	0	0	0
0	0	0	0	0	0	0	1.2197E+17	-1.3976E+19	-1.3977E+19	5.506E+17	1.51414E+19	-1.1179E+19	-6.7257E+17	-1.165E+18	2.79791E+18	0	0	0	0	0	0
0	0	0	0	0	0	0	-1.21975E+17	1.3977E+19	9.31833E+18	1.7373E+18	-1.11791E+19	2.75966E+19	-1.6154E+18	-2.798E+18	4.47997E+18	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	-3.883E+17	-6.72574E+17	-1.6154E+18	3.88311E+17	6.7257E+17	-1.6154E+18	-1013736.6	116162345	-116166768	0	0	0
0	0	0	0	0	0	0	0	0	0	-6.726E+17	-1.16493E+18	-2.7979E+18	6.72574E+17	1.1649E+18	-2.7979E+18	116162345	-1.3311E+10	1.3311E+10	0	0	0
0	0	0	0	0	0	0	0	0	0	1.6154E+18	2.79791E+18	4.47997E+18	-1.6154E+18	-2.798E+18	8.95993E+18	116166768	-1.3311E+10	8874600000	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	-1013736.57	116162345	116166767.9	1013736.6	-116162345	116166768	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	116162344.6	-1.331E+10	-1.3311E+10	-116162345	1.3311E+10	-1.3311E+10	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	-116166768	1.3311E+10	8874600000	116166768	-1.3311E+10	1.7749E+10	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

3.89E+17	-7.95E+17	1.49E+18	-1.06E+15	1.22E+17	-1.22E+17	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
-7.95E+17	1.51E+19	1.12E+19	1.22E+17	-1.40E+19	1.40E+19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.49E+18	1.12E+19	2.76E+19	1.22E+17	-1.40E+19	9.32E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
-1.06E+15	1.22E+17	1.22E+17	3.89E+17	-7.95E+17	-1.49E+18	-3.88E+17	6.73E+17	-1.62E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.22E+17	-1.40E+19	-1.40E+19	-7.95E+17	1.51E+19	-1.12E+19	6.73E+17	-1.16E+18	2.80E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
-1.22E+17	1.40E+19	9.32E+18	-1.49E+18	-1.12E+19	2.76E+19	1.62E+18	-2.80E+18	4.48E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	-3.88E+17	6.73E+17	1.62E+18	3.89E+17	-7.95E+17	1.49E+18	-1.06E+15	1.22E+17	-1.22E+17	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	6.73E+17	-1.16E+18	-2.80E+18	-7.95E+17	1.51E+19	1.12E+19	1.22E+17	-1.40E+19	1.40E+19	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	-1.62E+18	2.80E+18	4.48E+18	1.49E+18	1.12E+19	2.76E+19	1.22E+17	-1.40E+19	9.32E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.06E+15	1.22E+17	1.22E+17	6.00E+17	-1.16E+18	-2.04E+18	-5.99E+17	1.04E+18	-2.16E+18	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.22E+17	-1.40E+19	-1.40E+19	-1.16E+18	1.58E+19	-1.02E+19	1.04E+18	-1.80E+18	3.74E+18	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.22E+17	1.40E+19	9.32E+18	-2.04E+18	-1.02E+19	2.90E+19	2.16E+18	-3.74E+18	5.18E+18	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-5.99E+17	1.04E+18	2.16E+18	9.88E+17	-1.04E+18	3.44E+18	-2.69E+11
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.04E+18	-1.80E+18	-3.74E+18	-1.04E+18	1.80E+18	-3.68E+18	2.92E+13
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.16E+18	3.74E+18	5.18E+18	3.44E+18	-3.68E+18	1.72E+19	4.71E+14
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.69E+11	2.92E+13	4.71E+14	9.88E+17
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.92E+13	-3.35E+15	-5.39E+16	1.04E+18
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-4.71E+14	5.39E+16	5.79E+17	3.44E+18
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-5.99E+17
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.04E+18
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.16E+18
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.92E+13	-4.71E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
-3.35E+15	5.39E+16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
-5.39E+16	5.79E+17	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.04E+18	3.44E+18	-5.99E+17	-1.04E+18	2.16E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.80E+18	3.68E+18	-1.04E+18	-1.80E+18	3.74E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.68E+18	1.72E+19	-2.16E+18	-3.74E+18	5.18E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
-1.04E+18	-2.16E+18	6.00E+17	9.16E+17	-2.28E+18	-1.06E+15	1.22E+17	-1.22E+17	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
-1.80E+18	-3.74E+18	9.16E+17	1.58E+19	1.02E+19	1.22E+17	-1.40E+19	1.40E+19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.74E+18	5.18E+18	-2.28E+18	1.02E+19	2.90E+19	1.22E+17	-1.40E+19	9.32E+18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	-1.06E+15	1.22E+17	1.22E+17	3.89E+17	5.51E+17	1.74E+18	-3.88E+17	-6.73E+17	1.62E+18	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	1.22E+17	-1.40E+19	-1.40E+19	5.51E+17	1.51E+19	-1.12E+19	-6.73E+17	-1.16E+18	2.80E+18	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	-1.22E+17	1.40E+19	9.32E+18	1.74E+18	-1.12E+19	2.76E+19	-1.62E+18	-2.80E+18	4.48E+18	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-3.88E+17	-6.73E+17	-1.62E+18	3.88E+17	6.73E+17	-1.62E+18	-1.01E+06	1.16E+08	-1.16E+08
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-6.73E+17	-1.16E+18	-2.80E+18	6.73E+17	1.16E+18	-2.80E+18	1.16E+08	-1.33E+10	1.33E+10
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.62E+18	2.80E+18	4.48E+18	-1.62E+18	-2.80E+18	8.96E+18	1.16E+08	-1.33E+10	8.87E+09
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.01E+06	1.16E+08	1.16E+08	1.01E+06	-1.16E+08	1.16E+08
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.16E+08	-1.33E+10	-1.33E+10	-1.16E+08	1.33E+10	-1.33E+10
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.16E+08	1.33E+10	8.87E+09	1.16E+08	-1.33E+10	1.77E+10

x

U1		F1x
V1		F1y
θ1		M1
U2		F2x
V2		F2y
θ2		M2
U3		F3x
V3		F3y
θ3		M3
U4		F4x
V4		F4y
θ4		M4
U5		F5x
V5		F5y
θ5		M5
U6		F6x
V6		F6y
θ6		M6
U7		F7x
V7		F7y
θ7	=	M7
U8		F8x
V8		F8y
θ8		M8
U9		F9x
V9		F9y
θ9		M9
U10		F10x
V10		F10y
θ10		M10
U11		F11x
V11		F11y
θ11		M11
U12		F12x
V12		F12y
θ12		M12
U13		F13x
V13		F13y
θ13		M13
U14		F14x
V14		F14y
θ14		M14

Aplicando la opción inversa de la matriz se obtiene los desplazamientos y fuerzas en cada nodo:

	DESPLAZAMIENTOS	UNIDADES		FUERZAS	UNIDADES
U1	0	m	F1x	-49756.52	N
V1	0	m	F1y	104934.06	N
θ1	0	rad	M1	1155574.04	N/m
U2	-2.15055E-06	m	F2x	0.00	N
V2	-1.24162E-06	m	F2y	-30000.00	N
θ2	-4.08399E-13	rad	M2	-10000.00	N/m
U3	9.09003E-06	m	F3x	13000.00	N
V3	-1.14353E-06	m	F3y	29999.99	N
θ3	-5.34746E-13	rad	M3	10000.01	N/m
U4	4.35736E-06	m	F4x	0.00	N
V4	-3.87594E-06	mF	4y	-62399.94	N
θ4	-6.66916E-13	rad	M4	43264.03	N/m
U5	8.52203E-06	m	F5x	20000.00	N
V5	-3.83959E-06	m	F5y	29999.96	N
θ5	-6.81773E-13	rad	M5	10000.02	N/m
U6	2.09083E-12	m	F6x	0.00	N
V6	-8.75979E-06	m	F6y	-53999.99	N
θ6	-6.46315E-13	rad	M6	-32400.00	N/m
U7	0	m	F7x	16337.94	N
V7	0	m	F7y	29432.90	N
θ7	0	rad	M7	858596.52	N/m
U8	1.38476E-12	m	F8x	-10000.02	N
V8	-8.75982E-06	m	F8y	-98999.99	N
θ8	-4.45193E-13	rad	M8	108900.02	N/m
U9	0	m	F9x	32818.62	N
V9	0	m	F9y	29433.01	N
θ9	0	rad	M9	520252.18	N/m
U10	-1.18295E-05	m	F10x	0.00	N
V10	-1.93005E-06	m	F10y	53999.96	N
θ10	-4.56306E-13	rad	M10	32399.96	N/m
U11	-1.44258E-05	m	F11x	39999.99	N
V11	-1.95271E-06	m	F11y	-62399.97	N
θ11	-4.65422E-13	rad	M11	43263.95	N/m
U12	-3.02603E-05	m	F12x	0.00	N
V12	7.18933E-06	m	F12y	30000.01	N
θ12	-4.84475E-13	rad	M12	9999.98	N/m
U13	-19858.53189	m	F13x	-62400.00	N
V13	-173.3027844	m	F13y	0.00	N
θ13	-9.58761E-06	rad	M13	-43264.00	N/m
U14	0	m	F14x	0.00	N
V14	0	m	F14y	0.00	N
θ14	0	rad	M14	0.00	N/m

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