PARTNER1 NAME: PARTNER1 **LAB** SECTION:
PARTNER2 NAME: PARTNER2 **LAB** SECTION:

EAS-230 Fall 2019 - Programming Project (PP)

Due Dates:

Hardcopy Submissions: Thursday 11/21/19

Submission to UBlearns: Thursday 11/21/19 up to 11:59 pm.

Directions:

1. This project is recommended to be done in groups of two students at maximum. Your partner can be of section A or B only.
2. If you cannot find a partner you can post a request on *piazza* or contact your instructor no later than a week from posting this document.
3. One copy per a group/team of this project will be submitted as:
   a. A paper copy (the report) including all scripts and functions, the display in the command window, all plots, the results and analysis must be written (a template of the report will be posted on UBlearns). Your report must be turned-in at the start of your lecture on the due dates shown above. Be sure to write your name and lab section on every page. A copy of your report must be saved as a pdf.
   b. A zipped folder by the name of UBitName1_UBitName2 of the 2 partners (to be submitted to UBlearns up to 11:59 pm on 11/21/2019. DO NOT WAIT UNTIL THE LAST MINUTE. Follow the following instructions to create and submit your folder.
      i. Create a folder/directory
      ii. Within this directory, the following files must be saved with the *exact* names as follows:
         a. `F19_PP.m`
         b. `Structure_Analysis.m`
         c. `report.pdf`
         d. `geomtopo1.mat, geomtopo2.mat, geomtopo3.mat`
         e. `materials.dat, pricing.dat`
      iii. This folder/directory must be zipped and uploaded to UBlearns up to the due date. (Do Not include any files ending in ".m~" or ".sav" in your zip file)
4. You must write your own code and follow all instructions to get full credit. You are not allowed to use codes or scripts found on the internet or any other references.
5. You must use good programming practices, including indentation, commenting your functions and/or scripts and choosing descriptive variable names.
6. It is your responsibility to make sure that your functions/scripts work properly and are free of errors by utilizing the resources at your disposal.

1. INTRODUCTION

Assume that you work for a company called "MODULAR STRUCTURES EAS230, Inc. (LLC)" where you are required to design and fabricate small-to-medium scale metal structures. The company produces 3 truss structures, which are 1) a tower structure, 2) a crane or winch structure and 3) a bridge or span structure. Each structure can be fabricated from among 3 possible materials: aluminum, (structural) steel, and titanium. The tower structures can be manufactured in 3 different sizes, while the bridge/span structures can be manufactured to span from 2 meters up to 50 meters distance (up to 25 modular "units", each of which is 2 meters in length); the crane/winch structures are only manufactured in 1 size (see **Figure 1**, **Figure 2** and **Table 1**). As a design engineer, you are asked by your lead to write a MATLAB program to analyze these structures, compute the fabrication cost and produce an estimate for hypothetical clients' interests.

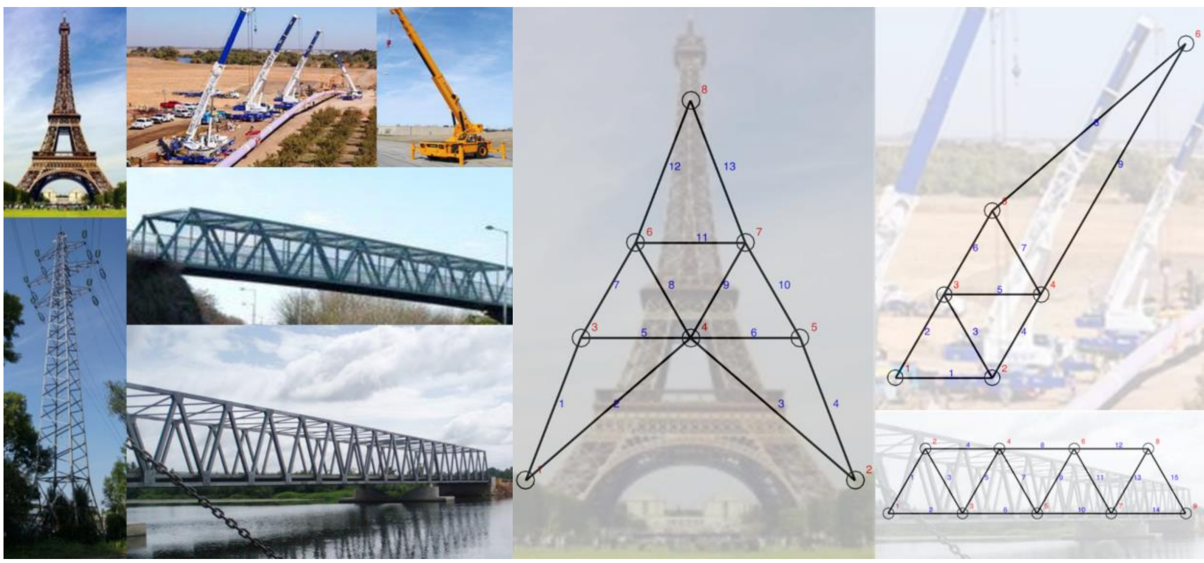

Figure 1 Left: Examples of real-world static truss systems and simple static truss models.

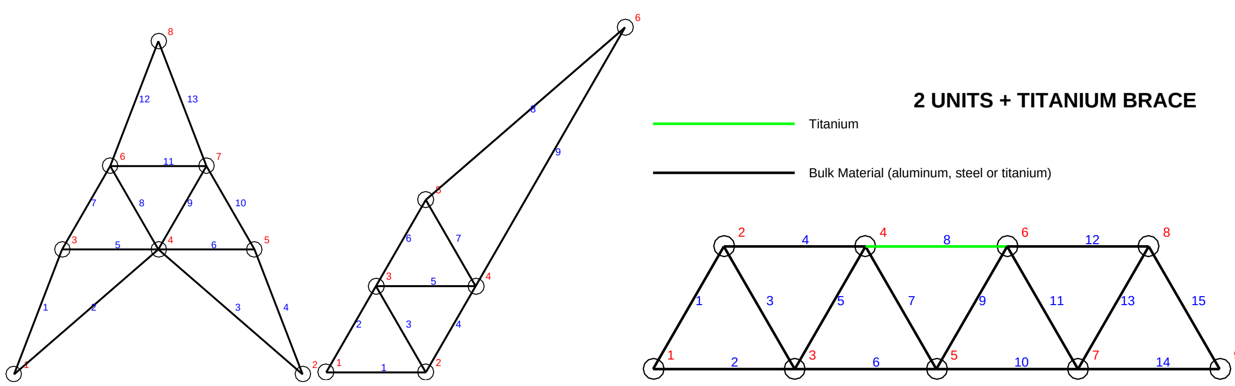

Figure 2 Left: Tower. Center: Crane/Winch. Right: Two-unit bridge/span.
Members are numbered in blue and nodes are numbered in red.

Table 1 Products manufactured by *MODULAR STRUCTURES EAS230, Inc.*

STRUCTURE	MATERIAL	SIZE/DESCRIPTION	# OF PRODUCTS
Tower			
	Aluminum		3
	Steel	1, 2, or 5 m	3
	Titanium		3
			Towers: 9
Crane/Winch			
	Aluminum		1
	Steel	one size only	1
	Titanium		1
			Cranes: 3
Bridge/Span			
	Aluminum		25
	Steel	2, 4, 6, … , 46,48, or 50 m	25
	Titanium		25
			Bridges: 75
			Total: 87

2. SIMPLE TRUSS MODELS

2.1 GEOMETRY AND TOPOLOGY

The 2-dimensional trusses in **Figure 1** and **Figure 2** are constructed using rigid metal bars or "members" connected at joints or "nodes". Each member (marked and numbered in blue) is connected to other members at exactly 2 nodes; each node (marked and numbered in red) connects several members. The nodes are located at the points (x, y) and node 1 is always at the origin (0,0). These data are stored in the files **`geomtopoX.mat`** (**`X=1`** (for towers), **2** (for cranes), and **3** (for bridges)). The variables x and y each contains N entries for the x- and y-coordinates of the N nodes; the data are scaled so that the smallest member of the structure is 1 meter in length. The variable **`memnod`** contains M rows for the M members; the columns are the 2 node numbers associated with that member. The variable **`nodmem`** has N rows for the N nodes; the columns are the member numbers associated with that node. For example, compare the following MATLAB output with the tower structure in **Figure 2**:

```
>> load geomtopo1.mat
>> memnod(9,:)
ans =
     4     7
>> nodmem(4,:)
ans =
     2     5     8     9     6     3
```

2.2 Materials

The ASCII data file **`materials.dat`** contains Young's modulus (E), the yield strength (σ_{yield}) and the ultimate strength ($\sigma_{ultimate}$) for each of the 3 materials available for these structures. The cost to acquire these materials is tabulated (by the linear meter) in the ASCII data file **`pricing.dat`**.

Data Files

materials.dat

material number	Young's Mod. (E, GPa)	Yield Strength (σ_{yield}, MPa)	Ultimate Strength ($\sigma_{ultimate}$, MPa)
1 – aluminum	69	95	110
2 – steel	200	250	400
3 – titanium	112	730	900

pricing.dat

material number	Price ($/meter)
1 – aluminum	33.03
2 – steel	44.48
3 – titanium	206.95

3. CLIENT NEEDS AND QUALITY/SAFETY INFORMATION

3.1 TOWER

The tower can be manufactured in 3 different sizes. The smallest member of the each size can be of length $d = 1$, 2 or 5 meters, respectively, which is selected by the client/user. The clearance (H) and footprint (L), Figure 2, are related to d. Every tower is entirely constructed from a single material.

3.2 CRANE/WINCH

The crane/winch can only be manufactured in one size. The smallest member of the structure is of length $d = 1$ m. The clearance (H) and footprint (L) is related to d. Every crane/winch structure is entirely constructed from a single material. The client/user will supply an estimated working load for the crane/winch, which must not exceed the maximum recommended load.

3.3 BRIDGE/SPAN

The bridge/span structure is manufactured by connecting individual units with a titanium brace (see **Figure 3**). Each member of the units as well as the titanium brace has length $d = 1$. The clearance (H) and footprint (L) is related to d. Each unit is constructed entirely with a single material; two or more units are connected by a titanium brace. The program must ask the client/user about the required length of the bridge to span and then determines the required number of units to cover this span. For safety, the number of units is calculated based on a 10% increase of the requested length. Table 4 shows the relationship between the number of units u, the span L, the number of members M, the number of nodes N and the number of Titanium members.

The safety and quality information for each stucture has been gathered by the company's Quality Assurance (QA) Engineers. This information is summarized in **Table 2**, **Table 3** and **Figure 3**.

Table 2: Clearance and Footprint Data

$h = \sqrt{3}\, d/2$		Tower	Crane	Bridge
Clearance	H	$4h$	$4h$	h
Footprint	L	$3d$	$3d$	$2d, 4d, 6d, \dots, 48d, 50d$

Table 3: Safety and Quality Data

$a = 1 \times 10^{-4}\text{m}^2$ (area factor) $\quad s_f = 2$ (safety factor)		
Maximum load	w_{max}	$\dfrac{a \cdot \sigma_{yield}}{s_f}$
Failure load	w_{fail}	$\dfrac{a \cdot \sigma_{ultimate}}{s_f}$
Maximum deformation	δ_{max} (%)	$\dfrac{w_{max}}{Ea} \times 100\%$

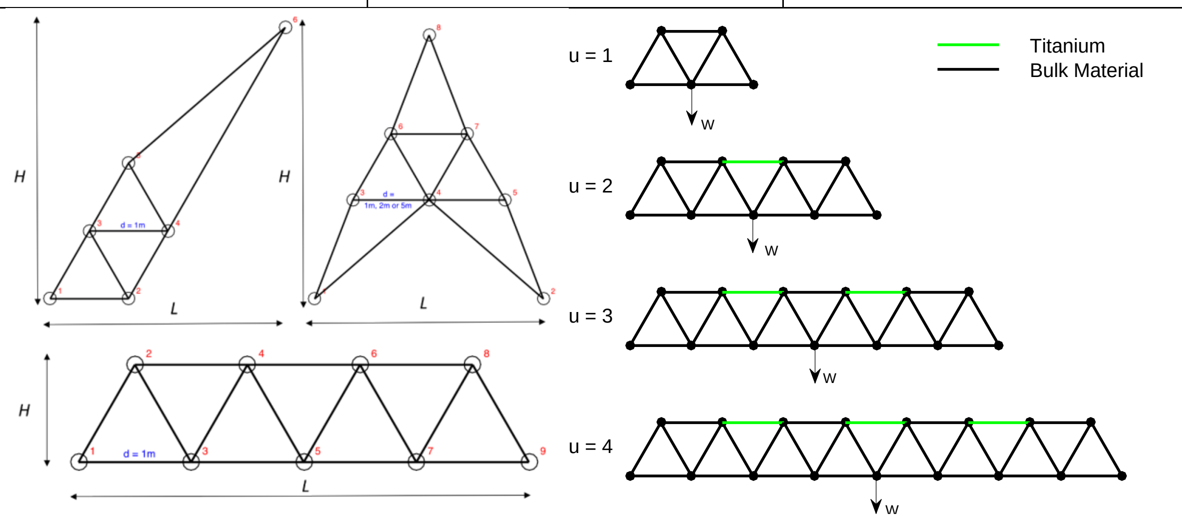

Figure 3 Left: Three structures labeled with node numbers (red), relative sizes (blue) and clearance (H) and footprint (L). Right: Bridge structures fabricated with 1, 2, 3, and 4 units, connected with 0, 1, 2, and 3 titanium braces, respectively.

Table 4: Member and Node Information for BRIDGE/SPAN

Units	Span (meters)	Nodes	Members	Ti - members	Other members
u	L	N	M	t	p
1	2	5	7	0	7
2	4	9	15	1	14
3	6	13	23	2	21
4	8	17	31	3	28
⋮	⋮	⋮	⋮	⋮	⋮
u	$2u$	$4u+1$	$8u-1$	$u-1$	$7u$
⋮	⋮	⋮	⋮	⋮	⋮
25	50	101	199	24	175

You must create a script file **`F19_PP.m`** to perform the following tasks:

INSTRUCTIONS

1) Load **`materials.dat`** and **`pricing.dat`**
2) Prompt the user for the desired structure (1,2 or 3).
3) Prompt the user for the desired material (1 – Aluminum, 2 – Steel, or 3 – Titanium)
4) Based on the choice of materials, the parameter of safety information in Table 3, w_{max}, w_{fail} and δ_{max} can now be calculated and reported to the user in *pounds*.
5) Based on the choice of structure, prompt the user for more information:
   a. TOWER: The length *d = 1, 2* or *5* meters (choose integer 1, 2 or 3). Prompt the user in *feet*; perform calculations in *meters*
   b. CRANE/WINCH: expected working load, *W*. Must be $0 < W < w_{max}$ (from **Table 3**). If the user entered a value outside this interval, the program must prompt the user to enter a value within this interval. Prompt the user in *pounds*; perform calculations in *Newtons.*
   c. BRIDGE/SPAN: distance to span, L. The required number of units u
   Must be enough to span 10% longer than the span requested, or
   $2 < 1.1L < 50$. Prompt the user in *feet*; perform calculations in *meters*
6) Your script must validate all user inputs, using while-loops for input validation.
7) Due to fabrication constraints, the BRIDGE/SPAN is assembled in units of 2 meters in length. If $L > 2$ then every 8th member must be titanium. (See **Table 4**)
8) The program must define the load W (user/client requested for the crane/winch or $W = w_{max}$ otherwise)
9) The program must calculate the footprint and clearance (**Table 2**) and report them to the user in *feet*.
10) Based on the choice of structure, load the geometry and topology for the desired structure: **`geomtopoX.mat`** (three files, **`X=1`**, **`X=2`**, and **`X=3`**).
11) Based on the structure type, determine the number of members, M and the number of Nodes, N.
12) Based on the structure type and size, assign values to the parameters in Table 2.

13) Use a for-loop over all members (1 to M), to compute the length of each member, **`d`** where M is the number of members.
14) Use for-loops over all members (1 to M), and all nodes (1 to N), where N is the number of nodes, in order to plot the desired structure; the figure number should be the structure number from instruction 1) above. Use the **`x`** and **`y`** arrays loaded with the **`geomtopoX.mat`** to determine the coordinates of the points required for plotting.
    a. Plot members with solid black lines, width of 2, no markers
    b. Plot nodes with single dot marker, black, with size large enough to see clearly
    c. Use the **`text()`** function to print the node numbers in red, near the nodes
    d. Use the **`text()`** function to print the member numbers in blue, near the middle of the member
    e. Use **`axis equal`** (see the help topics for explanation)
    f. Turn off the axis with **`axis off`** (see the help topics for explanation)
15) Calculate the material cost for the structure and add the following:
    a. FEES PER STRUCTURE:
        i. TOWER: 50$ for 1 m, 100$ for 2 m, 250$ for 5 m structures
        ii. CRANE: 50$
        iii. BRIDGE: 52$ for 1 unit, 2$ for each additional unit
    b. TAX: 8% of material cost
    c. TOTAL = MATERIAL COST + FEES + TAX

ALL PROMPTS FOR INPUTS MUST BE CONCISE AND EASY TO UNDERSTAND BY THE USER. ALL USER OUTPUTS TO SCREEN MUST BE FULLY DEFINED WITH UNITS, ETC. ALL USER PROMPTS AND OUTPUT MUST BE IN IMPERIAL UNITS (ALL CALCULATIONS IN METRIC)

4. STRUCTURAL ANALYSIS

Your program must now perform a basic structural analysis of the 3 basic truss systems. The program must set-up and solve the system $A\mathbf{x} = \mathbf{b}$ to determine the unknown static forces in the truss systems defined by the various structure geometries, under a simplified concentrated load.

4.1 COEFFICIENT MATRIX

There are 2 equations for each node (static equilibrium in both the x- and y-directions) with a total of 2N equations for N nodes and accordingly the matrix A is $2N \times 2N$. The equations (and therefore the coefficients in A) are given in (**Tables 5, 6**) for the tower and crane structures, respectively. You must notice that, for each of the 3 truss systems, the number of members (M) will always be less than twice the number of nodes ($2N$) by 3, i.e.,

$$M = 2N - 3$$

The span/bridge truss system is user defined and accordingly the number of nodes, members, and equations vary according to the structure. **Table 7** gives the required equations to build the system of equations $A\mathbf{x} = \mathbf{b}$ for the bridge truss system.

4.2 FORCE AND REACTIONS VECTOR

The program must determine the forcein every member of the truss system in addition to the reaction forces at the supporters. There are M member forces, one for each member and there are 3 reaction forces applied at 2 particular nodes. The force vector, **x** is thus $2N \times 1$ column vector:

$$\mathbf{x} = (F_1 \quad F_2 \quad F_3 \quad F_4 \quad \cdots \quad F_m \quad \cdots \quad F_{M-1} \quad F_M \quad R_1 \quad R_2 \quad R_3)^{\mathbf{T}}$$

The population of the coefficient matrix and the force vector is shown in **Table 8**.

4.3 RIGHT-HAND-SIDE VECTOR

For basic analysis of the 3 truss-systems, the load W, requested by the client, will be applied vertically and only at a specific node. The left-hand-sides of the equations, vector **b**, are given by the $x - y$ equations for every node. The $2N \times 1$ column vector **b** for the 3 truss systems can be populated using the following equations:

1) TOWER:

$$b_r = \begin{cases} W \text{ for } r = 2N \\ 0 \text{ for } r \neq 2N \end{cases}, \quad N = 8$$

2) CRANE/WINCH

$$b_r = \begin{cases} W \text{ for } r = 2N \\ 0 \text{ for } r \neq 2N \end{cases}, \quad N = 6$$

3) BRIDGE/SPAN

$$b_r = \begin{cases} W \text{ for } r = N+1 \\ 0 \text{ for } r \neq N+1 \end{cases}, \quad N \text{ user-derived}$$

HINT: pre-allocate the vector **b** with >> b = zeros(2*N,1); then define the only non-zero value according to **Table 9**. Once the matrix A and the right-hand-side **b** are appropriately defined, the solution **x** is determined in MATLAB simply by left division.
The first M elements of **x** will be the member forces and the last 3 elements will be the reaction forces.

5. DEFORMATIONS

The relative deformation(%) in the m^{th} member is calculated as:

$$\delta_m = \frac{F_m}{E_m a} \times 100\%, \qquad m = 1,2,\ldots,M \tag{1}$$

NOTE: Each member may, in principle, be made from a different material and therefore the Young's Modulus (E) must carry the index, m. The area factor a is given in **Table 3**.

Table 5: Equations for the forces in members and reaction forces for a tower:

Row, r	Node, n	Direction	Equation
1	1	x	$F_1\cos\alpha + F_2\cos\beta + R_1 = 0$
2	1	y	$F_1\sin\alpha + F_2\sin\beta + R_2 = 0$
3	2	x	$-F_3\cos\beta - F_4\cos\alpha = 0$
4	2	y	$F_3\sin\beta + F_4\sin\alpha + R_3 = 0$
5	3	x	$-F_1\cos\alpha + F_5 + F_7\cos\theta = 0$
6	3	y	$-F_1\sin\alpha + F_7\sin\theta = 0$
7	4	x	$-F_2\cos\beta + F_3\cos\beta - F_5 + F_6 - F_8\cos\theta + F_9\cos\theta = 0$
8	4	y	$-F_2\sin\beta - F_3\sin\beta + F_8\sin\theta + F_9\sin\theta = 0$
9	5	x	$F_4\cos\alpha - F_6 - F_{10}\cos\theta = 0$
10	5	y	$-F_4\sin\alpha + F_{10}\sin\theta = 0$
11	6	x	$-F_7\cos\theta + F_8\cos\theta + F_{11} + F_{12}\cos\alpha = 0$
12	6	y	$-F_7\sin\theta + F_8\sin\theta + F_{12}\sin\alpha = 0$
13	7	x	$-F_9\cos\theta + F_{10}\cos\theta - F_{11} - F_{13}\cos\alpha = 0$
14	7	y	$-F_9\sin\theta - F_{10}\sin\theta + F_{13}\sin\alpha = 0$
15	8	x	$-F_{12}\cos\alpha + F_{13}\cos\alpha = 0$
16	8	y	$-F_{12}\sin\alpha - F_{13}\sin\alpha = W$

The angles are given by the following:

$$\tan\alpha = \frac{3\sqrt{3}}{2} \qquad \tan\beta = \frac{\sqrt{3}}{2} \qquad \theta = \frac{\pi}{3}$$

Table 6: Equations for the forces in members and reaction forces for a crane:

Row, r	Node, n	Direction	Equation
1	1	x	$F_1 + F_2\cos\theta + R_1 = 0$
2	1	y	$F_2\sin\theta + R_2 = 0$
3	2	x	$-F_1 - F_3\cos\theta + F_4\cos\theta = 0$
4	2	y	$F_3\sin\theta + F_4\sin\theta + R_3 = 0$
5	3	x	$-F_2\cos\theta + F_3\cos\theta + F_5 + F_6\cos\theta = 0$
6	3	y	$-F_2\sin\theta - F_3\sin\theta + F_6\sin\theta = 0$
7	4	x	$-F_4\cos\theta - F_5 - F_7\cos\theta + F_9\cos\theta = 0$
8	4	y	$-F_4\sin\theta + F_7\sin\theta + F_9\sin\theta = 0$
9	5	x	$-F_6\cos\theta + F_7\cos\theta + F_8\cos\gamma = 0$
10	5	y	$-F_6\sin\theta - F_7\sin\theta + F_8\sin\gamma = 0$
11	6	x	$-F_8\cos\gamma - F_9\cos\theta = 0$
12	6	y	$-F_8\sin\gamma - F_9\sin\theta = W$

The angles are given by the following:

$$\tan\gamma = \frac{\sqrt{3}}{2} \qquad \theta = \frac{\pi}{3}$$

Table 7: Equations for the forces in members and reaction forces for a bridge:

Node n	Row r		Equation
1	1		$R_1 + F_1\cos\theta + F_2 = 0$
1	2		$R_2 + F_1\sin\theta = 0$
2	3		$-F_1\cos\theta + F_3\cos\theta + F_4 = 0$
2	4		$-F_1\sin\theta - F_3\sin\theta = 0$
$3 \le n \le N-2$		n EVEN	
	$2n-1$		$-F_{2n-4} - F_{2n-3}\cos\theta + F_{2n-1}\cos\theta + F_{2n} = 0$
	$2n$		$F_{2n-3}\sin\theta + F_{2n-1}\sin\theta = 0$
$3 \le n \le N-2$		n ODD	
	$2n-1$		$-F_{2n-4} - F_{2n-3}\cos\theta + F_{2n-1}\cos\theta + F_{2n} = 0$
	$2n$		$F_{2n-3}\sin\theta + F_{2n-1}\sin\theta = \begin{cases} 0 \text{ if } n \neq \frac{N+1}{2} \\ W \text{ if } n = \frac{N+1}{2} \end{cases}$
$N-1$	$2N-3$		$-F_{2N-6} + F_{2N-5}\cos\theta + F_{2N-3}\cos\theta = 0$
$N-1$	$2N-2$		$-F_{2N-5}\sin\theta - F_{2N-3}\sin\theta = 0$
N	$2N-1$		$-F_{2N-4} - F_{2N-3}\cos\theta = 0$
N	$2N$		$F_{2N-3}\sin\theta + R_3 = 0$

The angle $\theta = \pi/3$

Table 8: Organization of the Left-Hand-Side of $A\mathbf{x} = \mathbf{b}$

ROW # (r)	NODE # (n)	EQUATION	UNKNOWN ($\vec{x}$)
1	1	x-direction	F_1
2	1	y-direction	F_2
3	2	x-direction	F_3
4	2	y-direction	F_4
$\vdots$	$\vdots$	$\vdots$	$\vdots$
r	$n = (r + \text{rem}(r,2))/2$	x-direction	F_m
$r+1$	$n = (r + \text{rem}(r,2))/2$	y-direction	F_{m+1}
$\vdots$	$\vdots$	$\vdots$	$\vdots$
$2N-3$	$N-1$	x-direction	F_M
$2N-2$	$N-1$	y-direction	R_1
$2N-1$	N	x-direction	R_2
$2N$	N	y-direction	R_3

Table 9: Organization of the Right-Hand-Sides $\vec{b}$ for the 3 Truss Systems

ROW # (r)	TOWER	CRANE/WINCH	BRIDGE/SPAN
1	0	0	0
2	0	0	0
3	0	0	0
⋮	⋮	⋮	⋮
12	0	W	0
⋮	⋮	*	⋮
16	W	*	0
⋮	*	*	⋮
$N+1$	*	*	W
⋮	*	*	⋮
$2(N-1)$	*	*	0
$2N-1$	*	*	0
$2N$	*	*	0

INSTRUCTIONS, Cont'd.

16) Create a single function with file name **`Structure_Analysis.m`** to solve for the forces and deformation in each structure. The function must construct the A and $\mathbf{b}$ for every structure and solve for the forces $\mathbf{x}$ using left division.
    - Input Arguments:
        1) Structure ID: When the function is called it must be entered as scalar 1×1 with either 1, 2 or 3 (1 for TOWER, 2 for CRANE/WINCH or 3 for BRIDGE/SPAN).
        2) N the number of nodes (scalar 1×1)
        3) W the estimated load (scalar 1×1)
        4) $M \times 1$ vector with Young's modulus of each member for use in Equation (1)
    - Output Arguments:
        1) $M \times 1$ vector of member forces, $(-)$ compression or $(+)$ tension
        2) $M \times 1$ vector of member deformations, $(-)$ shrinking or $(+)$ stretching
        3) 3×1 vector of reaction forces with R_1, R_2 and R_3, $(+)$ upward or $(-)$ downward
17) Call the function from your **`F19_PP.m`** and save the output with the following variables, in MATLAB (.mat) files named according to the structure number: **`AnalysisX.mat`** (X is 1=TOWER, 2=CRANE/WINCH or 3=BRIDGE/SPAN)
    - $M \times 1$ vector of member forces, F, $(-)$ compression or $(+)$ tension
    - $M \times 1$ vector of member deformations, D, $(-)$ shrinking or $(+)$ stretching
    - 3×1 vector of reaction forces, R, with R_1, R_2 and R_3, $(+)$ upward or $(-)$ downward
18) From the main script **`F19_PP.m`** you must print the force, deformation and reaction data to screen in the following format (using `format short g`):

FORCES, REACTIONS AND DEFORMATIONS:

MEMBER	FORCE(N)	DEFORMATION(%)
1	XX.XX	XX.XX
2	XX.XX	XX.XX
3	XX.XX	XX.XX
.	.	.
.	.	.
.	.	.

REACTIONS(N)

1	XX.XX
2	XX.XX
3	XX.XX

The following section is some test cases which can be used to test your programs. Your program must be developing the following results as it works on each of these cases.

6. TEST CASES

CASE 1: MEDIUM STEEL TOWER

```
********* MENU **********

CHOOSE STRUCTURE:
   1) TOWER
   2) CRANE/WINCH
   3) BRIDGE/SPAN

ENTER A CHOICE: 1

********* MENU **********

CHOOSE MATERIAL:
   1) ALUMINUM
   2) STEEL
   3) TITANIUM

ENTER A CHOICE: 2

********** MENU **********

CHOOSE A SIZE:
   1) small  (3.3 feet)
   2) medium (6.6 feet)
   3) large  (16.4 feet)

ENTER A CHOICE: 2


*****************************************

YOU HAVE CHOSEN:   STEEL      TOWER

   CLEARANCE: 23 ft
   FOOTPRINT: 20 ft
   MAX  LOAD: 2809 lb

 MAX REC'D LOAD: 2809 lb
MAX DEFORMATION: 0.0625%
   FAILURE LOAD: 4495 lb

*****************************************

COST:
MATERIALS:   $  1471.08
     FEES:   $   100.00
      TAX:   $   117.69
----------------------
    TOTAL:   $  1688.77
********************************************
FORCES, REACTIONS AND DEFORMATIONS:

         MEMBER   FORCE(N)  DEFORMATION(%)
           1       2456.6     0.012283
           2        -6253    -0.031265
           3      -104.04  -0.00052019
           4       218.94    0.0010947
           5      -441.22   -0.0022061
           6      -39.322  -0.00019661
           7       2647.3     0.013237
```

8	2647.3	0.013237
9	-7452.8	-0.037264
10	235.93	0.0011797
11	6250	0.03125
12	-6697	-0.033485
13	-6697	-0.033485

REACTION(N)
3844.4
1800.9
-136.22

CASE 2: TITANIUM CRANE, WORKING LOAD 5000 LB

```
********* MENU **********

CHOOSE STRUCTURE:
   1) TOWER
   2) CRANE/WINCH
   3) BRIDGE/SPAN

ENTER A CHOICE: 2

********* MENU **********

CHOOSE MATERIAL:
   1) ALUMINUM
   2) STEEL
   3) TITANIUM

ENTER A CHOICE: 3

********** MENU **********

ENTER YOUR EXPECTED WORKING LOAD (IN LB)
WORKING LOAD (0 < MASS < 8203): 5000


*****************************************

YOU HAVE CHOSEN:  TITANIUM CRANE/WINCH

  CLEARANCE: 11 ft
  FOOTPRINT: 10 ft
  MAX  LOAD: 5000 lb

 MAX REC'D LOAD: 8203 lb
MAX DEFORMATION: 0.3259%
  FAILURE LOAD: 10113 lb

*****************************************


COST:
MATERIALS:   $  2617.04
    FEES:   $    50.00
     TAX:   $   209.36
----------------------
   TOTAL:   $  2876.40

********************************************
FORCES, REACTIONS AND DEFORMATIONS:
```

MEMBER	FORCE(N)	DEFORMATION(%)
1	-25691	-0.22938
2	51381	0.45876
3	-12845	-0.11469
4	-64227	-0.57345
5	12845	0.11469
6	38536	0.34407
7	-12845	-0.11469
8	33985	0.30344
9	-51381	-0.45876

REACTION(N)
1.0494e-11
-44497
66746

CASE 3: ALUMINUM BRIDGE, 40 FOOT SPAN

********* MENU **********

CHOOSE STRUCTURE:
1) TOWER
2) CRANE/WINCH
3) BRIDGE/SPAN

ENTER A CHOICE: 3

********* MENU **********

CHOOSE MATERIAL:
1) ALUMINUM
2) STEEL
3) TITANIUM

ENTER A CHOICE: 1

HOW WIDE DO YOU NEED YOUR BRIDGE/SPAN? (< 164 FEET): 40

****

YOU HAVE CHOSEN: ALUMINUM BRIDGE/SPAN

CLEARANCE: 3 ft
FOOTPRINT: 46 ft
MAX LOAD: 1067 lb

MAX REC'D LOAD: 1067 lb
MAX DEFORMATION: 0.0688%
FAILURE LOAD: 1236 lb

****

COST:
MATERIALS: $ 2860.17
FEES: $ 64.00
TAX: $ 228.81

TOTAL: $ 3152.98

****
FORCES, REACTIONS AND DEFORMATIONS:

MEMBER	FORCE(N)	DEFORMATION(%)
1	-2742.4	-0.039745
2	1371.2	0.019873
3	2742.4	0.039745
4	-2742.4	-0.039745
5	-2742.4	-0.039745
6	4113.6	0.059618
7	2742.4	0.039745
8	-5484.8	-0.048972
9	-2742.4	-0.039745
10	6856	0.099363
11	2742.4	0.039745
12	-8227.2	-0.11924
13	-2742.4	-0.039745
14	9598.4	0.13911
15	2742.4	0.039745
16	-10970	-0.097943
17	-2742.4	-0.039745
18	12341	0.17885
19	2742.4	0.039745
20	-13712	-0.19873
21	-2742.4	-0.039745
22	15083	0.2186
23	2742.4	0.039745
24	-16454	-0.14692
25	-2742.4	-0.039745
26	17826	0.25834
27	2742.4	0.039745
28	-19197	-0.27822
29	2742.4	0.039745
30	17826	0.25834
31	-2742.4	-0.039745
32	-16454	-0.14692
33	2742.4	0.039745
34	15083	0.2186
35	-2742.4	-0.039745
36	-13712	-0.19873
37	2742.4	0.039745
38	12341	0.17885
39	-2742.4	-0.039745
40	-10970	-0.097943
41	2742.4	0.039745
42	9598.4	0.13911
43	-2742.4	-0.039745
44	-8227.2	-0.11924
45	2742.4	0.039745
46	6856	0.099363
47	-2742.4	-0.039745
48	-5484.8	-0.048972
49	2742.4	0.039745
50	4113.6	0.059618
51	-2742.4	-0.039745
52	-2742.4	-0.039745
53	2742.4	0.039745
54	1371.2	0.019873
55	-2742.4	-0.039745

REACTION(N)
2.4533e-12
2375
2375

CASE 4: TITANIUM CRANE, TRY 9000 LB THEN 8000 LB

```
********* MENU **********

CHOOSE STRUCTURE:
   1) TOWER
   2) CRANE/WINCH
   3) BRIDGE/SPAN

ENTER A CHOICE: 2

********* MENU **********

CHOOSE MATERIAL:
   1) ALUMINUM
   2) STEEL
   3) TITANIUM

ENTER A CHOICE: 3

********** MENU **********

ENTER YOUR EXPECTED WORKING LOAD (IN LB)
WORKING LOAD (0 < MASS < 8203): 9000
INVALID ENTRY...
ENTER YOUR EXPECTED WORKING LOAD (IN LB):
WORKING LOAD (0 < MASS < 8203): 8000


*****************************************

YOU HAVE CHOSEN:  TITANIUM CRANE/WINCH

  CLEARANCE: 11 ft
  FOOTPRINT: 10 ft
  MAX  LOAD: 8000 lb

 MAX REC'D LOAD: 8203 lb
MAX DEFORMATION: 0.3259%
  FAILURE LOAD: 10113 lb

*****************************************


COST:
MATERIALS:  $  2617.04
    FEES:  $    50.00
     TAX:  $   209.36
---------------------
   TOTAL:  $  2876.40

********************************************
FORCES, REACTIONS AND DEFORMATIONS:

       MEMBER   FORCE(N)  DEFORMATION(%)
         1      -41105     -0.36701
         2       82210      0.73402
         3      -20552      -0.1835
         4 -1.0276e+05     -0.91752
         5       20552       0.1835
         6       61657      0.55051
         7      -20552      -0.1835
         8       54377      0.48551
```

```
        9      -82210     -0.73402


    REACTION(N)
  8.0591e-12
     -71196
  1.0679e+05
```

CASE 5: ALUMINUM BRIDGE, TRY 170 FEET, DECREASE BY 10 FEET UNTIL ACCEPTED

```
********* MENU **********

CHOOSE STRUCTURE:
   1) TOWER
   2) CRANE/WINCH
   3) BRIDGE/SPAN

ENTER A CHOICE: 3

********* MENU **********

CHOOSE MATERIAL:
   1) ALUMINUM
   2) STEEL
   3) TITANIUM

ENTER A CHOICE: 1

HOW WIDE DO YOU NEED YOUR BRIDGE/SPAN? (< 164 FEET): 170
INVALID ENTRY...
DISTANCE TOO LONG OR TOO SHORT
HOW WIDE DO YOU NEED YOUR BRIDGE/SPAN? (< 164 FEET): 160
INVALID ENTRY...
DISTANCE TOO LONG OR TOO SHORT
HOW WIDE DO YOU NEED YOUR BRIDGE/SPAN? (< 164 FEET): 150
INVALID ENTRY...
DISTANCE TOO LONG OR TOO SHORT
HOW WIDE DO YOU NEED YOUR BRIDGE/SPAN? (< 164 FEET): 140


******************************************

YOU HAVE CHOSEN:  ALUMINUM BRIDGE/SPAN

  CLEARANCE: 3 ft
  FOOTPRINT: 157 ft
  MAX  LOAD: 1067 lb

 MAX REC'D LOAD: 1067 lb
MAX DEFORMATION: 0.0688%
  FAILURE LOAD: 1236 lb

******************************************


COST:
MATERIALS:   $ 10308.89
     FEES:   $    98.00
      TAX:   $   824.71
----------------------
    TOTAL:   $ 11231.60

*********************************************
FORCES, REACTIONS AND DEFORMATIONS:
```

MEMBER	FORCE(N)	DEFORMATION(%)
1	-2742.4	-0.039745
2	1371.2	0.019873
3	2742.4	0.039745
4	-2742.4	-0.039745
5	-2742.4	-0.039745
6	4113.6	0.059618
7	2742.4	0.039745
8	-5484.8	-0.048972
9	-2742.4	-0.039745
10	6856	0.099363
11	2742.4	0.039745
12	-8227.2	-0.11924
13	-2742.4	-0.039745
14	9598.4	0.13911
15	2742.4	0.039745
16	-10970	-0.097943
17	-2742.4	-0.039745
18	12341	0.17885
19	2742.4	0.039745
20	-13712	-0.19873
21	-2742.4	-0.039745
22	15083	0.2186
23	2742.4	0.039745
24	-16454	-0.14692
25	-2742.4	-0.039745
26	17826	0.25834
27	2742.4	0.039745
28	-19197	-0.27822
29	-2742.4	-0.039745
30	20568	0.29809
31	2742.4	0.039745
32	-21939	-0.19589
33	-2742.4	-0.039745
34	23311	0.33783
35	2742.4	0.039745
36	-24682	-0.35771
37	-2742.4	-0.039745
38	26053	0.37758
39	2742.4	0.039745
40	-27424	-0.24486
41	-2742.4	-0.039745
42	28795	0.41732
43	2742.4	0.039745
44	-30167	-0.4372
45	-2742.4	-0.039745
46	31538	0.45707
47	2742.4	0.039745
48	-32909	-0.29383
49	-2742.4	-0.039745
50	34280	0.49681
51	2742.4	0.039745
52	-35651	-0.51669
53	-2742.4	-0.039745
54	37023	0.53656
55	2742.4	0.039745
56	-38394	-0.3428
57	-2742.4	-0.039745
58	39765	0.5763
59	2742.4	0.039745
60	-41136	-0.59618
61	-2742.4	-0.039745

62	42507	0.61605
63	2742.4	0.039745
64	-43879	-0.39177
65	-2742.4	-0.039745
66	45250	0.65579
67	2742.4	0.039745
68	-46621	-0.67567
69	-2742.4	-0.039745
70	47992	0.69554
71	2742.4	0.039745
72	-49363	-0.44075
73	-2742.4	-0.039745
74	50735	0.73528
75	2742.4	0.039745
76	-52106	-0.75516
77	-2742.4	-0.039745
78	53477	0.77503
79	2742.4	0.039745
80	-54848	-0.48972
81	-2742.4	-0.039745
82	56219	0.81478
83	2742.4	0.039745
84	-57591	-0.83465
85	-2742.4	-0.039745
86	58962	0.85452
87	2742.4	0.039745
88	-60333	-0.53869
89	-2742.4	-0.039745
90	61704	0.89427
91	2742.4	0.039745
92	-63076	-0.91414
93	-2742.4	-0.039745
94	64447	0.93401
95	2742.4	0.039745
96	-65818	-0.58766
97	2742.4	0.039745
98	64447	0.93401
99	-2742.4	-0.039745
100	-63076	-0.91414
101	2742.4	0.039745
102	61704	0.89427
103	-2742.4	-0.039745
104	-60333	-0.53869
105	2742.4	0.039745
106	58962	0.85452
107	-2742.4	-0.039745
108	-57591	-0.83465
109	2742.4	0.039745
110	56219	0.81478
111	-2742.4	-0.039745
112	-54848	-0.48972
113	2742.4	0.039745
114	53477	0.77503
115	-2742.4	-0.039745
116	-52106	-0.75516
117	2742.4	0.039745
118	50735	0.73528
119	-2742.4	-0.039745
120	-49363	-0.44075
121	2742.4	0.039745
122	47992	0.69554
123	-2742.4	-0.039745
124	-46621	-0.67567

125	2742.4	0.039745
126	45250	0.65579
127	-2742.4	-0.039745
128	-43879	-0.39177
129	2742.4	0.039745
130	42507	0.61605
131	-2742.4	-0.039745
132	-41136	-0.59618
133	2742.4	0.039745
134	39765	0.5763
135	-2742.4	-0.039745
136	-38394	-0.3428
137	2742.4	0.039745
138	37023	0.53656
139	-2742.4	-0.039745
140	-35651	-0.51669
141	2742.4	0.039745
142	34280	0.49681
143	-2742.4	-0.039745
144	-32909	-0.29383
145	2742.4	0.039745
146	31538	0.45707
147	-2742.4	-0.039745
148	-30167	-0.4372
149	2742.4	0.039745
150	28795	0.41732
151	-2742.4	-0.039745
152	-27424	-0.24486
153	2742.4	0.039745
154	26053	0.37758
155	-2742.4	-0.039745
156	-24682	-0.35771
157	2742.4	0.039745
158	23311	0.33783
159	-2742.4	-0.039745
160	-21939	-0.19589
161	2742.4	0.039745
162	20568	0.29809
163	-2742.4	-0.039745
164	-19197	-0.27822
165	2742.4	0.039745
166	17826	0.25834
167	-2742.4	-0.039745
168	-16454	-0.14692
169	2742.4	0.039745
170	15083	0.2186
171	-2742.4	-0.039745
172	-13712	-0.19873
173	2742.4	0.039745
174	12341	0.17885
175	-2742.4	-0.039745
176	-10970	-0.097943
177	2742.4	0.039745
178	9598.4	0.13911
179	-2742.4	-0.039745
180	-8227.2	-0.11924
181	2742.4	0.039745
182	6856	0.099363
183	-2742.4	-0.039745
184	-5484.8	-0.048972
185	2742.4	0.039745
186	4113.6	0.059618
187	-2742.4	-0.039745

188	-2742.4	-0.039745
189	2742.4	0.039745
190	1371.2	0.019873
191	-2742.4	-0.039745

REACTION(N)
1.5271e-12
2375
2375