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Project #1

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Introduction

The objective of this project was to develop numerical methods in Matlab to evaluate a two-dimensional truss structure under two concentrated dead loads for the largest tensile and compressive stresses, their locations, the reaction forces at the supports, and the undeformed and deformed shapes of the structure (using a magnification factor to emphasize the displacement). This model was developed using the conceptual framework of the Element-by-Element Stiffness Approach and implemented in Matlab using matrix techniques. Lastly, the model was developed to read truss data in from the user through a text file whose format takes on the form of that presented in the "Results and Discussion" section of the report.

Next, the reader will be informed of the methodology that the author exercised to develop solutions for the project. Before developing any numerical methods in Matlab, the author reproduced the diagram of the truss labeled with element and node number conventions. Then, using the convention of a sample input text file containing properties of a 2-D truss including geometry, node and element numbers, material properties (elastic modulus), and force and displacement boundary conditions, an input text file was developed for the truss in the problem statement using the same convention. It should be noted that this convention was applicable considering that both trusses are 2-D, and subjected to time-invariant, concentrated, loads. After the input text file was created, pseudocode was developed to characterize the framework of the computerized model in a form that was programming language agnostic. The following five figures depict the diagram, text file convention, and pseudocode.

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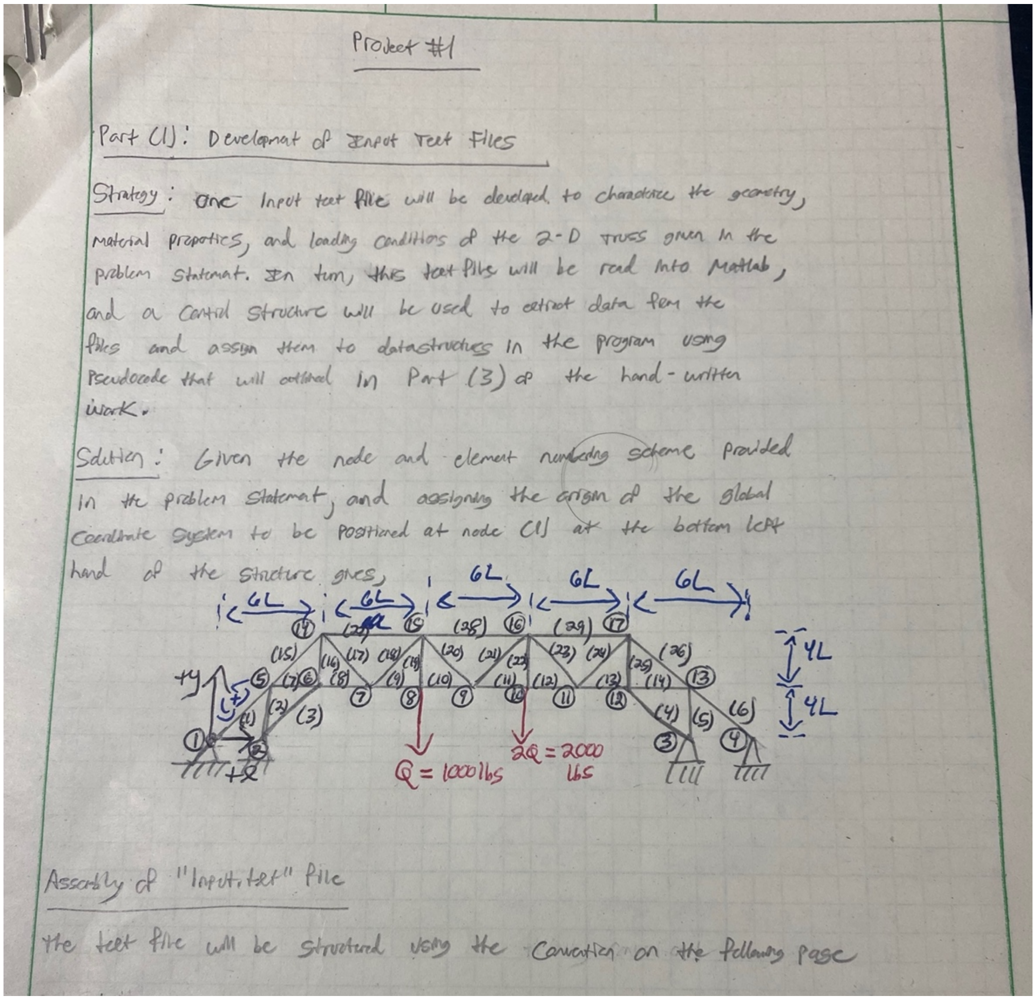

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Part (1): Development of Input Text Files

Strategy: One input text file will be developed to characterize the geometry, material properties, and loading conditions of the 2-D truss given in the problem statement. In turn, this text file will be read into Matlab, and a control structure will be used to extract data from the files and assign them to datastructures in the program using pseudocode that will outlined in Part (3) of the hand-written work.

Solution: Given the node and element numbering scheme provided in the problem statement, and assigning the origin of the global coordinate system to be positioned at node (1) at the bottom left hand of the structure gives,

Assembly of "Input.txt" File

The text file will be structured using the convention on the following page

Figure 1: Problem Statement and Labelled Truss Diagram

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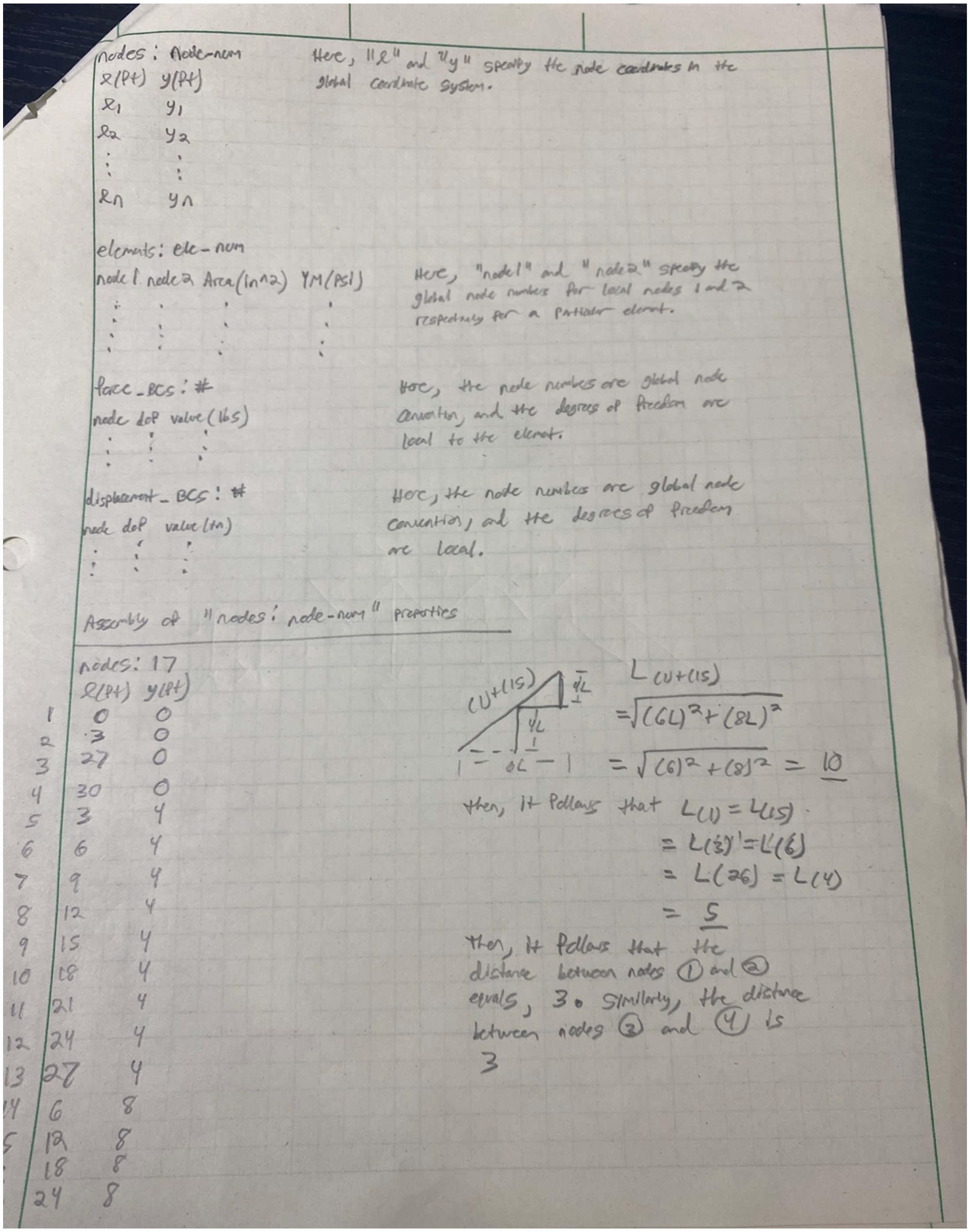

nodes: node-num
x(ft) y(ft)
x_1 y_1
x_2 y_2
⋮ ⋮
x_n y_n

Here, "x" and "y" specify the node coordinates in the global coordinate system.

elements: ele-num
node1 node2 Area(in^2) YM(psi)
⋮ ⋮ ⋮ ⋮

Here, "node1" and "node2" specify the global node numbers for local nodes 1 and 2 respectively for a particular element.

force_BCs: #
node dof value(lbs)
⋮ ⋮ ⋮

Here, the node numbers are global node convention, and the degrees of freedom are local to the element.

displacement_BCs: #
node dof value(in)
⋮ ⋮ ⋮

Here, the node numbers are global node convention, and the degrees of freedom are local.

Assembly of "nodes: node-num" properties

nodes: 17

	x(ft)	y(ft)
1	0	0
2	3	0
3	27	0
4	30	0
5	3	4
6	6	4
7	9	4
8	12	4
9	15	4
10	18	4
11	21	4
12	24	4
13	27	4
14	6	8
15	12	8
	18	8
	24	8

$L_{(1)+(15)}$
$= \sqrt{(6L)^2 + (8L)^2}$
$= \sqrt{(6)^2 + (8)^2} = 10$

then, it follows that $L_{(1)} = L_{(15)}$
$= L_{(3)} = L_{(6)}$
$= L_{(26)} = L_{(4)}$
$= 5$

Then, it follows that the distance between nodes ① and ② equals, 3. Similarly, the distance between nodes ③ and ④ is 3

Figure 2: Assembly of Input Text File (1)

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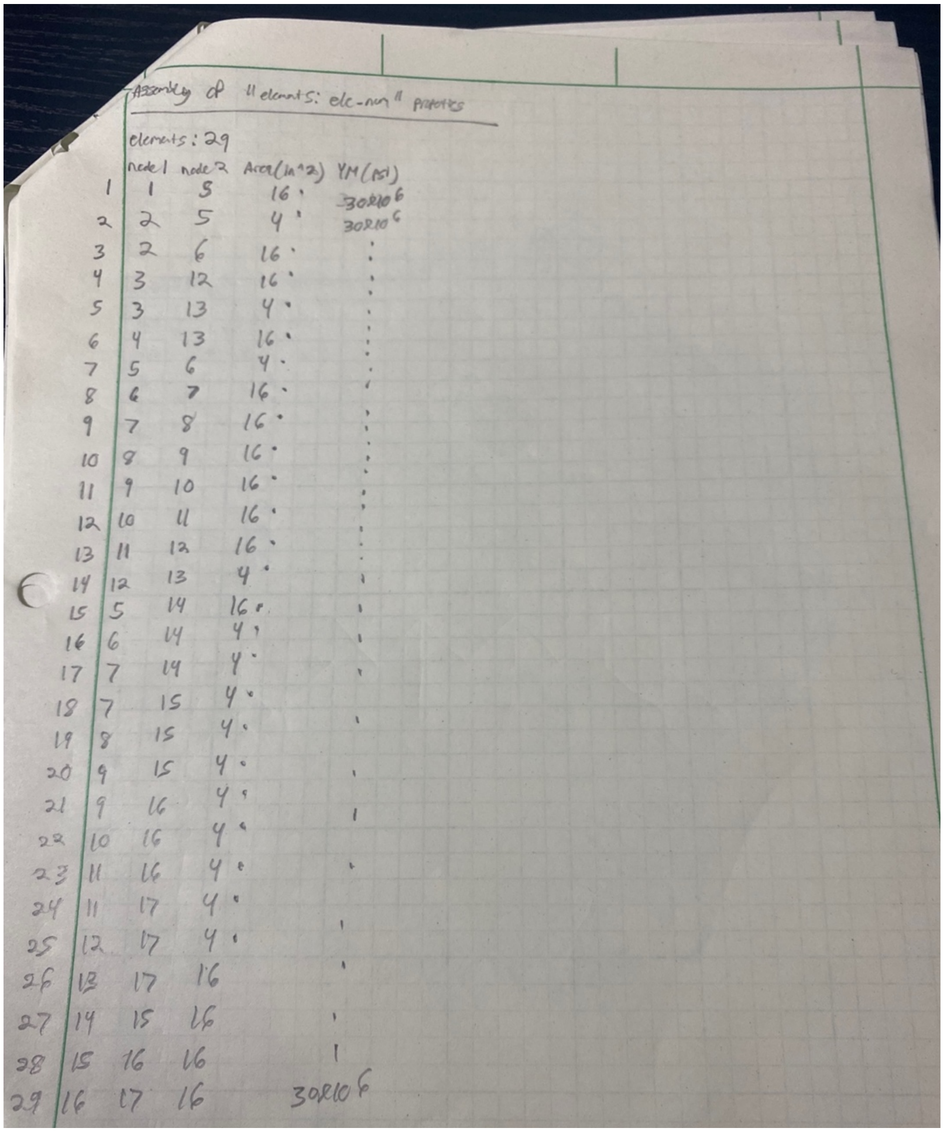

Figure 3: Assembly of Input Text File(2)

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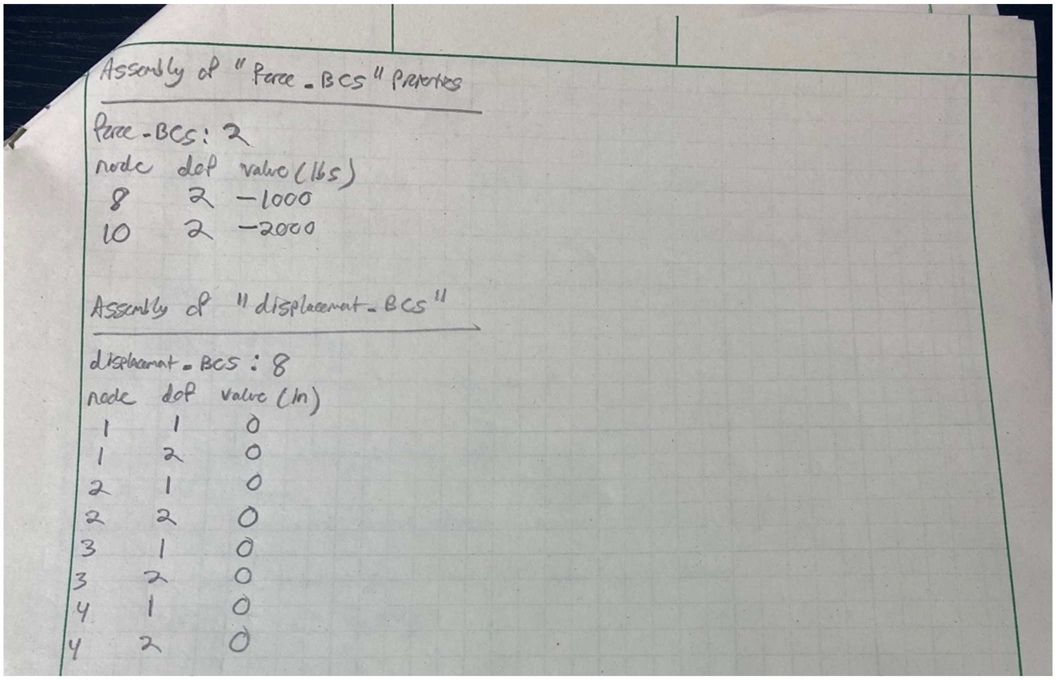

Assembly of "force_BCs" properties

force_BCs: 2

node	dof	value (lbs)
8	2	-1000
10	2	-2000

Assembly of "displacement_BCs"

displacement_BCs: 8

node	dof	value (in)
1	1	0
1	2	0
2	1	0
2	2	0
3	1	0
3	2	0
4	1	0
4	2	0

Figure 4: Assembly of Input Text File (3)

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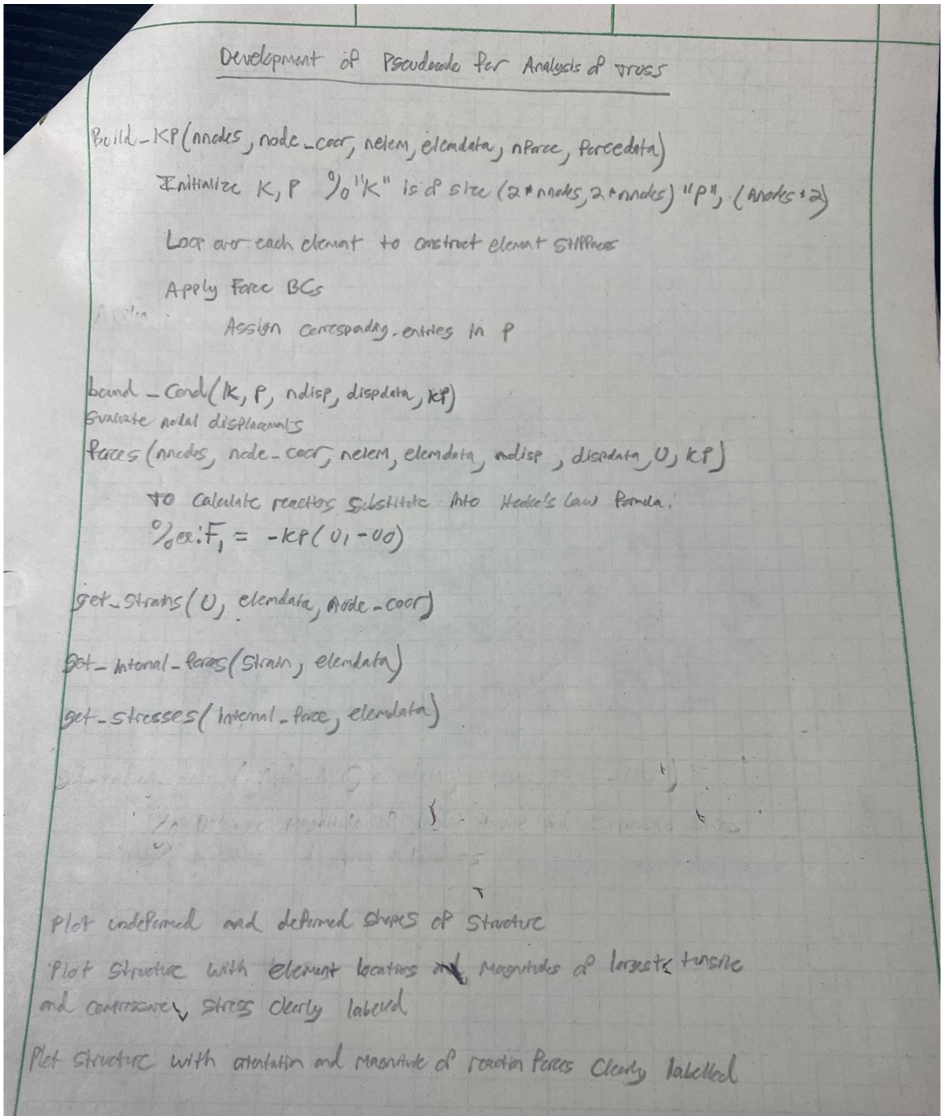

Development of Pseudocode for Analysis of Truss

```
Build_KP(nnodes, node_coor, nelem, elemdata, nForce, forcedata)
    Initialize K, P  %"K" is of size (2*nnodes, 2*nnodes) "P", (nnodes*2)
    Loop over each element to construct element stiffness
    Apply Force BCs
        Assign corresponding entries in P

bound_Cond(K, P, ndisp, dispdata, kp)
Evaluate nodal displacements
forces(nnodes, node_coor, nelem, elemdata, ndisp, dispdata, U, kp)
    To calculate reactions substitute into Hooke's Law formula.
    %ex: F1 = -kp(U1 - U0)

get_strains(U, elemdata, node_coor)

get_internal_forces(strain, elemdata)

get_stresses(internal_force, elemdata)

Plot undeformed and deformed shapes of structure
Plot structure with element locations and magnitudes of largest tensile
and compressive stress clearly labeled
Plot structure with orientation and magnitude of reaction forces clearly labelled
```

Figure 5: Pseudocode of Numerical Model

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Results and Discussion

The author implemented the input text file and pseudocode in Matlab using the skeleton program provided in the problem definition. The three skeleton functions contained within this skeleton "main" program were developed on separate .m files to improve readability of the main program. In evaluating the main program using the constructed input file, the author obtained the following results for the nodal displacements and reaction forces, internal forces and axial stresses as shown in figures 6-8 below. Figure 6 presents the nodal displacements for each of the nodes in the truss. It is important to note that the reason the horizontal and vertical displacements for nodes 1-4 that correspond to the pin-support restrained nodes are non-zero is because the Penalty Method was used as an approximation to the pin-support behavior. In particular, in the Penalty Method, the pin-support is replaced with a spring with a very large stiffness whereby the connected node can be approximated to undergo a displacement that is very small. Effectively the high stiffness of the spring approximates the complete restraint to motion that the pin support provides, and thus, offers a good approximation for the displacement. In referencing figure 7, we have the reaction force values for the eight degrees of freedom that correspond to the restraints at the pin supports for nodes 1-4. Lastly, in referencing figure 8, we have the internal force and axial stress results for each of the members. It is shown that element 24 is the critical tension element, namely, it experienced the largest tensile stress under the given loading configuration with a value of just over 511 psi.

DISPLACEMENT RESULTS (inches)

Node	x-dir(u)	y-dir(v)
1	-1.351E-13	-1.802E-13
2	-2.487E-13	-2.747E-13
3	2.696E-13	-3.929E-13
4	1.142E-13	-1.523E-13
5	-2.318E-04	6.830E-05
6	-2.702E-04	8.367E-06
7	-3.358E-04	-1.919E-03
8	-2.478E-04	-3.703E-03
9	-1.599E-04	-3.773E-03
10	-3.093E-05	-4.751E-03
11	9.803E-05	-2.373E-03
12	4.300E-05	-1.784E-04
13	6.554E-05	-4.007E-05
14	2.824E-04	-3.896E-04
15	8.728E-05	-3.303E-03
16	-3.023E-04	-3.951E-03
17	-5.490E-04	-6.098E-04

Figure 6: Nodal Displacement Results

Conversely, element 23 is the critical compression element, namely, it experienced the largest compression stress under the given loading configuration with a value equal in magnitude to the critical tension element (511 psi). These values and their locations are clearly labelled in the undeformed truss in figure 9.

REACTION RESULTS (lbs)

Node	x-dir(u)	y-dir(v)
1	405.349	540.466
2	746.114	824.080
3	-808.840	1178.624
4	-342.623	456.830
5	0.000	0.000
6	0.000	0.000
7	0.000	0.000
8	0.000	0.000
9	0.000	0.000
10	0.000	0.000
11	0.000	0.000
12	0.000	0.000
13	0.000	0.000
14	0.000	0.000
15	0.000	0.000
16	0.000	0.000
17	0.000	0.000

Figure 7: Reaction Force Results

MEMBER FORCES AND STRESSES

Elem.	Force(lbs)	Stress(psi)
1	-675.582	-42.224
2	170.739	42.685
3	-1243.523	-77.720
4	-1348.067	-84.254
5	-100.170	-25.043
6	-571.038	-35.690
7	-128.054	-32.013
8	-874.168	-54.635
9	1172.650	73.291
10	1172.650	73.291
11	1719.469	107.467
12	1719.469	107.467
13	-733.713	-45.857
14	75.128	18.782
15	-462.159	-28.885
16	-994.819	-248.705
17	1705.682	426.421
18	-1705.682	-426.421
19	1000.000	250.000
20	455.682	113.921
21	-455.682	-113.921
22	2000.000	500.000
23	-2044.318	-511.079
24	2044.318	511.079
25	-1078.454	-269.613
26	-696.251	-43.516
27	-1300.704	-81.294
28	-2597.523	-162.345
29	-1644.341	-102.771

Figure 8: Internal Force and Axial Stress Results

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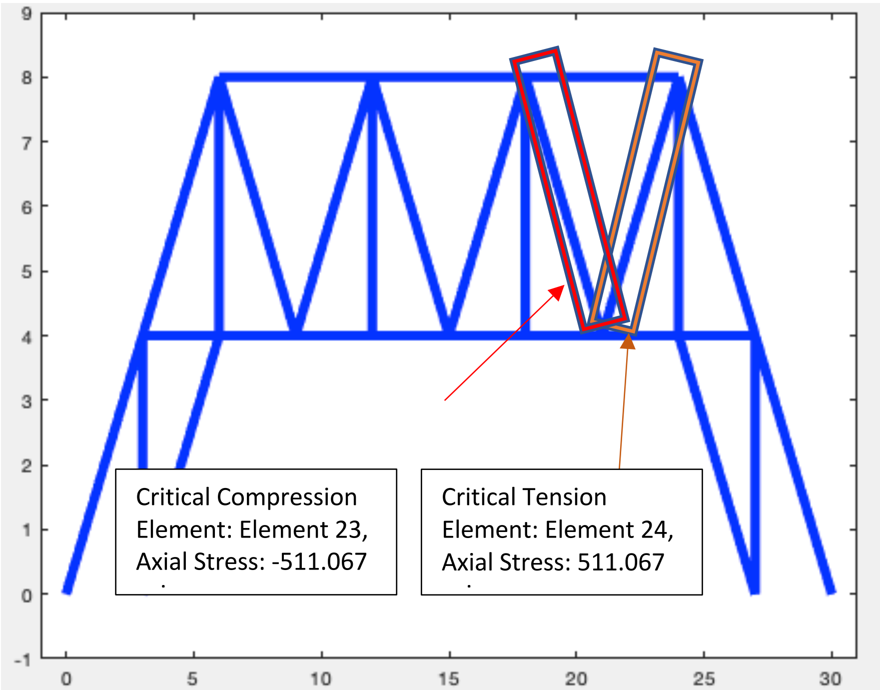

Figure 9: Undeformed Shape of Truss with Critical Tension and Compression Elements

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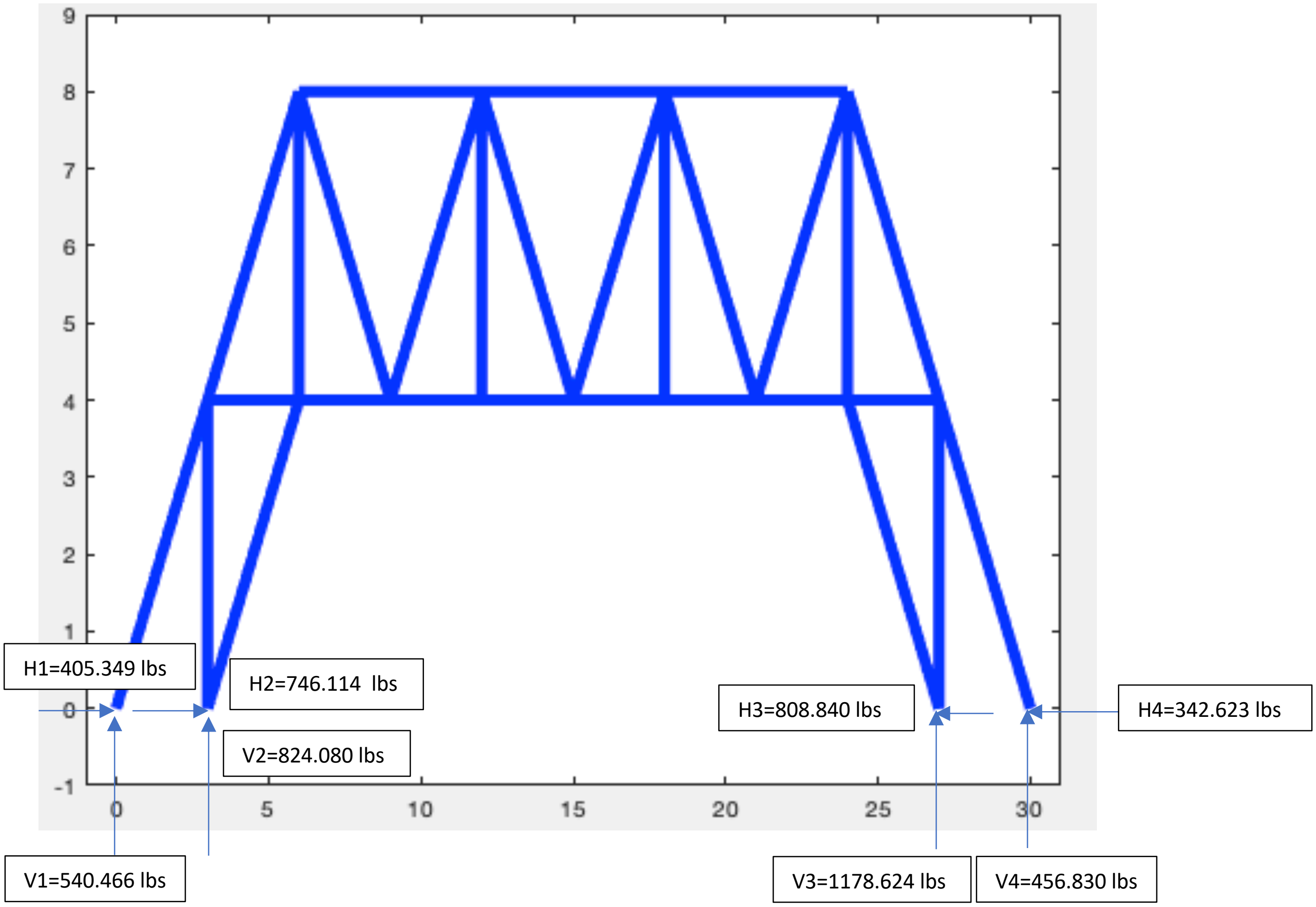

Figure 10: Undeformed Truss with Reaction Forces Labelled

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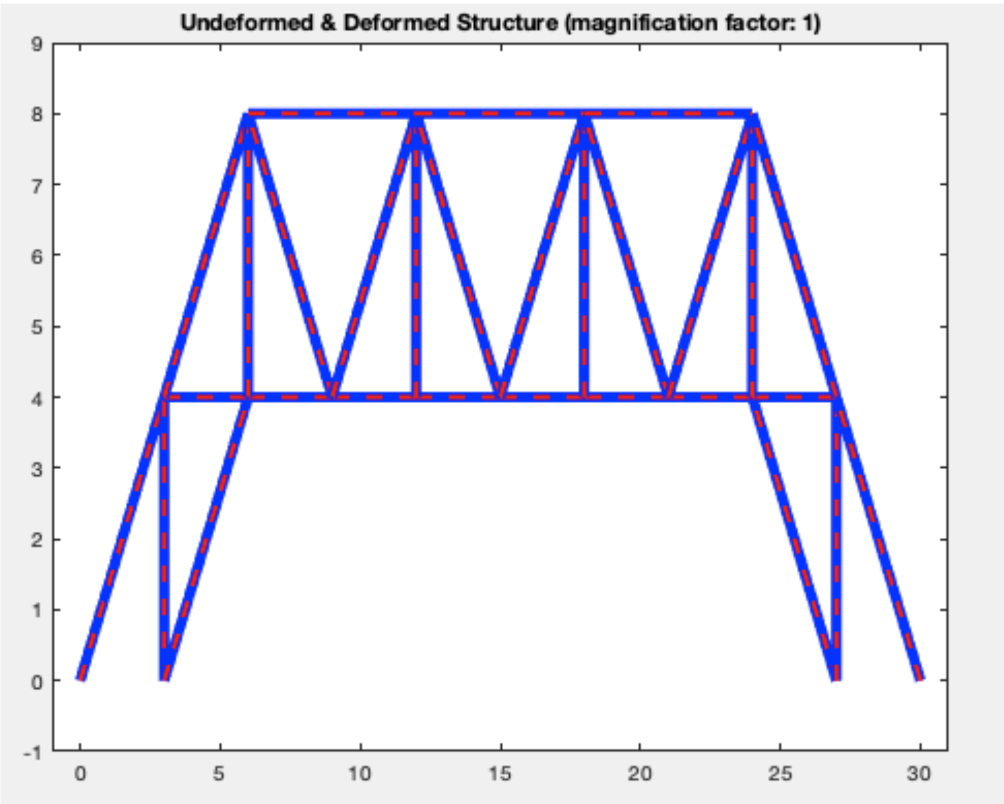

Figure 11: Undeformed and Deformed Structure (Magnification Factor:1)

As shown in figure 11, the deformations of the truss structure under the loading conditions are not recognizable under the default magnification of 1.

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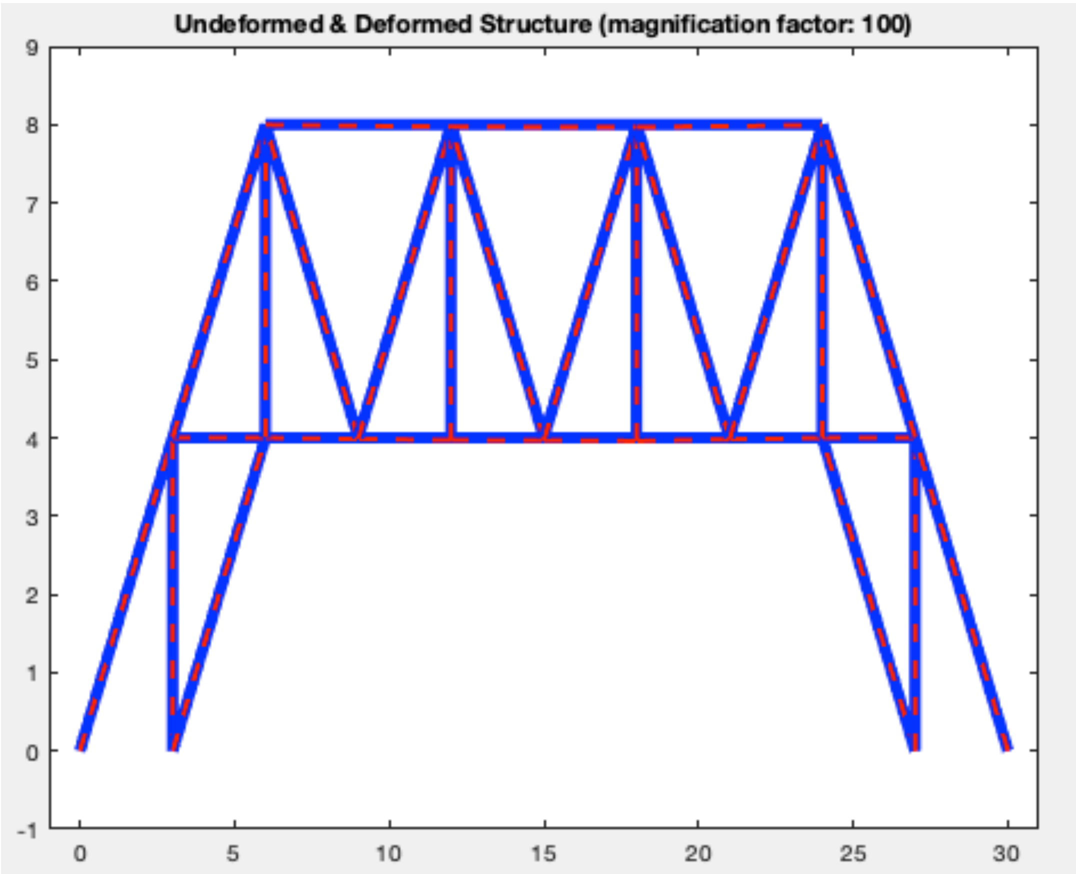

Figure 12: Undeformed and Deformed Structure: Magnification Factor: 100

In increasing the magnification factor from 1 to 100, the deformation becomes somewhat apparent as slight downward deformation along the bottom row of horizontal elements is recognizable. However, this magnification is not clear, so, a magnification of 1000 is used and shown below.

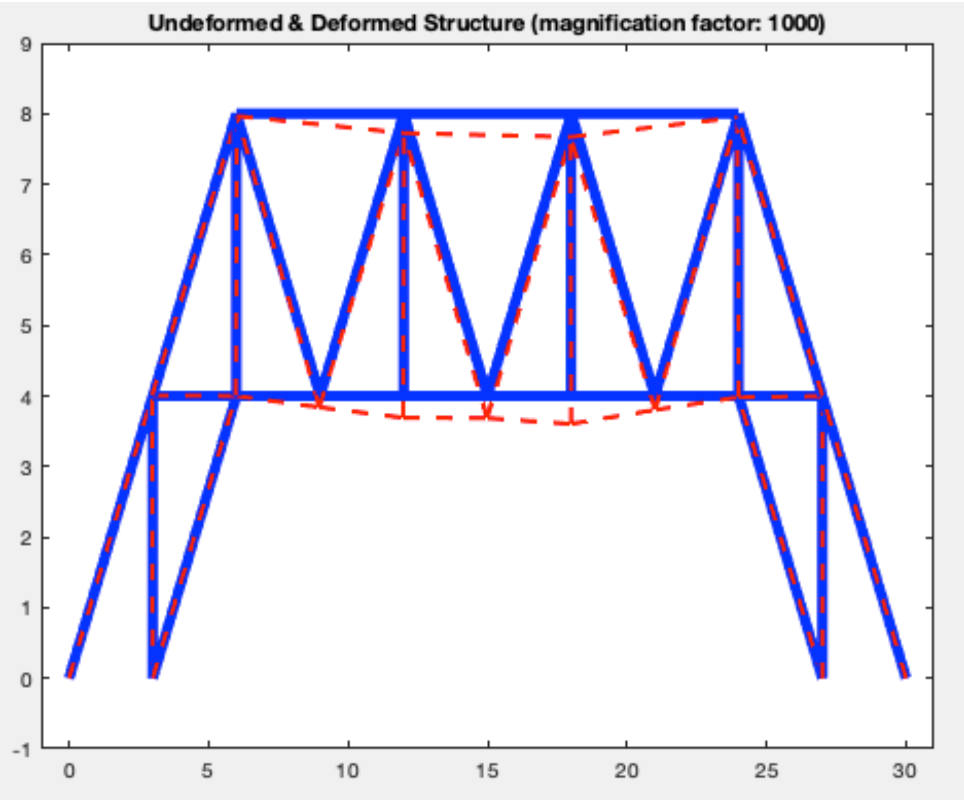

Figure 13: Undeformed and Deformed Structure with Magnification Factor: 1000

As we can see in figure 13, with a magnification factor of 1000, the deformation of the truss is much more pronounced.