The Staircase Pauli Lenticular Truss with a Twist – Problem 1
Kumil Ali
111650455

Objective of Analysis
In our design, we decided to modify a Lenticular Truss by combining its features with a Warren truss. Various elements and features of these 2 varying truss designs were put together to form a unique reverse-stair design. Our overall objective in our design was to try and improve well-known truss designs by introducing different patterns, in our event we utilized double-tiered warren trusses, modified lenticular trusses and created a staircase design, if we were to flip our design, it can be utilized as a scaffold. Given large scale loading conditions, or the placement of a deck on top of the truss, how will our truss react to our loading conditions.

Diagram of Analysis

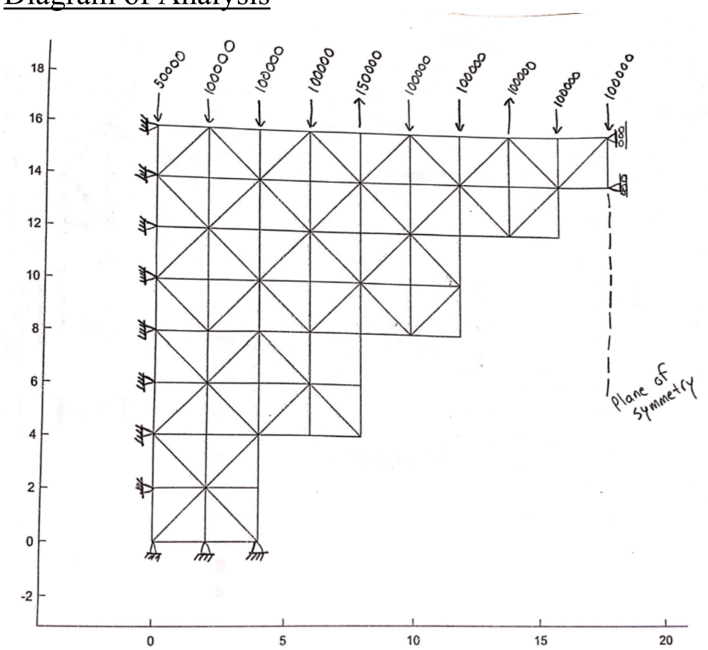


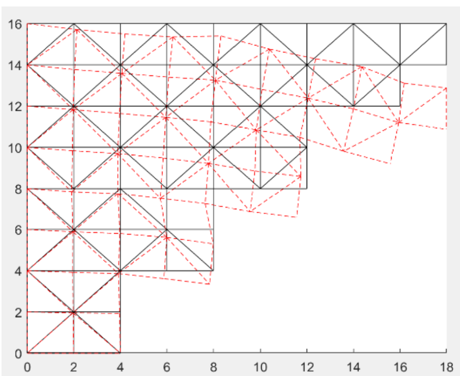
Figure 1: Diagram of Structure under analysis

Given in Figure 1, nodes on the left hand and bottom of the structure were connected via pin supports. Nodes on the right hand of the structure are roller supports.

Design Parameters and features
Modulus of Elasticity (E): 21 x 10^6 psi (Cooper Alloy)
Area of Elements: 10 in^2
Length of Horizontal and Vertical Elements: 2 in
Length of Angled Elements: 2.83 in
Concentrated Loads in units of lbs.
Number of Elements: 140
Number of Nodes: 59

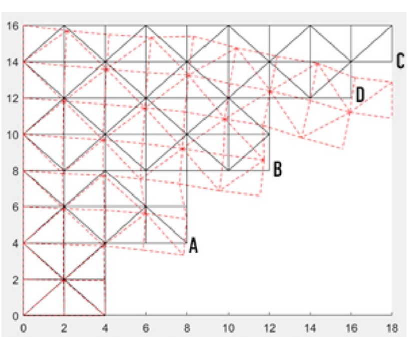
Analysis of Design
The overall design is modeled with concentrated loading conditions to simulate the loads that would be transferred onto a bridge due to the placement of a deck. Although our structure is quite small, we utilized an area of 10 in^2 in order to mimic how our bridge would fare under real-world situations. Most of the loads were applied downwards throughout the truss structure; however, 2 concentrated loads were placed in the form of 150 kips and 100 kips upwards. These loading conditions were enacted to mimic the placement of suspension lines which would alleviate stress within the truss structure. The entire left end of the truss structure was held with pin supports in order to prevent lateral and translational movement; this was considered to mimic

the bridge anchored in place by solid rocks in mountains. Our structure would be meant to cross over a river or a valley.
The bottom end of the structure is connected with pin supports to mimic a pier. All in all, our loading conditions, and our supports were considered to mimic real world conditions and analyze our unique combination design. The design is meshed by combining features relating a Warren Truss to a Lenticular Truss. Warren trusses and Lenticular trusses are known for their emphasis and use of equilateral triangles, our structure makes use of unique patterns of angled cross members.
Symmetry was also applied to our overall structure, in real life conditions depending heavily on the purpose and span of the bridge, symmetry is typically. In our truss structure, we defined a plane of symmetry in order to lower our computational time, we included our plane of symmetry on the right end of the structure which would connect to a similar structure to develop a full span bridge.



Results
The overall deformed configuration of our structure is shown to the right in figure 2. Due to the placement of our boundary conditions, and the various loads applied on the surface of the structure, our results were expected. We expected our structure to behave in a manner like a fixed-end cantilever beam with a deflection at the end of the structure. Due to the presence of the positive loads to mimic a suspension, the deformed shape of the structure developed a slightly morphed shape.

Figure 2: Deformed and undeformed configuration of the structure, structure in black indicates Undeformed configuration, structure in red indicated deformed configuration



Attached in figure 3, are some of the deflections of our structure. Element A displaced an amount 0.0003 in, Element B displaced an amount 0.0004 in, Element C displaced an amount 0.0009 in, Element D displaced an amount 0.0008 in. The overall stresses within each element were also expected. (Attached in Appendix A are a list of all the axial stresses). However, some are included as follows: Element A has an axial stress of -12.74 ksi, Element B has an axial stress of -12.81 ksi, Element C has an axial stress of -2.75 ksi, Element D has an axial stress of -10 ksi.

Conclusion
Altogether our structure acted in a similar fashion to a cantilever beam, which satisfied our initial guess of the overall structure. The Structure deformed heavily at the end and yielded high axial stress results and higher than expected displacement values, to offset, a stronger material can be utilized as well as a material with a greater cross-sectional area.

The H-Beam or Barbell Structure – Problem 2
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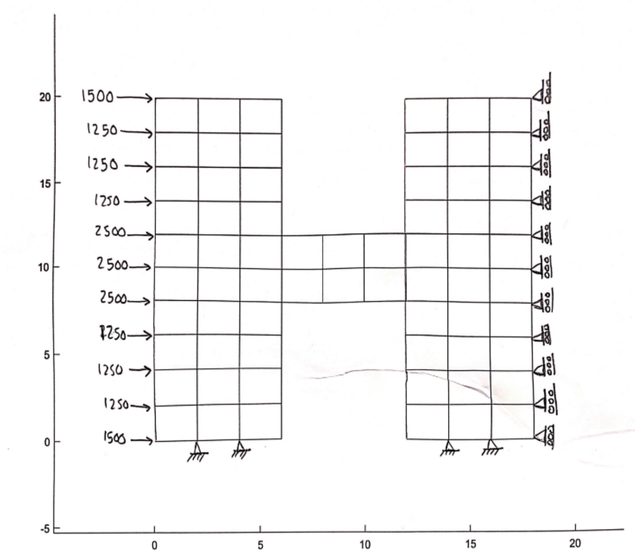
Objective of Analysis

In our design, we decided to modify a create a H-Beam, we decided to model the I- Beam utilizing a Q4 – Quadrilateral Element. Our overall objective of analysis was to determine how an H-Beam would react given one end was fixed and the other end exerted forces against it, how would our H-beam react to compression. In our analysis, we decided to simulate a 2D solid plate in the form of an H-Beam to analyze how well it performs under Compression. (Note, you can also refer as a large barbell structure)

Diagram of Analysis



Given in Figure 1, nodes on the right-hand side of the structure we connected via roller supports, and nodes on the bottom center of the structure were connected via pin supports.

Design Parameters and features

Modulus of Elasticity (E): 21 x 10^6 psi (Cooper Alloy)
Poisson's Ratio: 0.3
Thickness: 0.1 in
Length of Horizontal and Vertical Elements: 2 in
Concentrated Loads in units of lbs.
Number of Elements: 66
Number of Nodes: 94

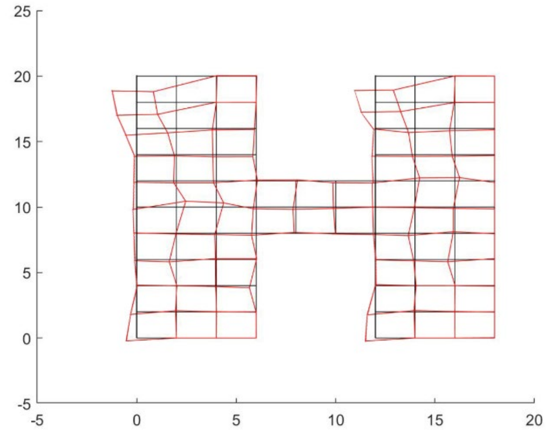
Figure 1: Diagram of Structure under analysis

Analysis of Design

The overall design is modeled with concentrated loading conditions to simulate compression on an H-beam. Our H-Beam was modeled as an 18 in x 18 in. Our Loads were placed on the left-end of the H-Beam with varying loads in units of lbs., with a heavy concentration of loads located near the midspan of the overall structure. The supports were placed on the right end of the structure and as pin supports in order to prevent horizontal movement, roller supports were selected in order to allow vertical translation but prevent horizontal movement. Pin supports were selected on the bottom to provide additional resistance to lateral and translational movement.

The loading conditions were selected due to an H-Beam being able to sustain over 1000 pounds, our loading conditions were heavier to analyze whether the structure would fail due to our compression.

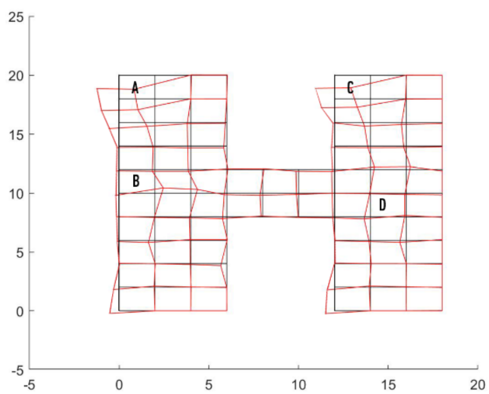
Various steps were taken in order to develop our model, it was decided to utilize Gauss Quadrature in order to lower our computational costs. Our overall structure was meshed utilizing Q4 elements, which was selected in part due to its simplicity and low computational cost.



Results

The overall deformed configuration of our structure is shown to the right in figure 2. Due to the placement of our boundary conditions, and the various loads applied on the surface of the structure, our results were expected. Due to our boundary and loading conditions and our desire to simulate the compression of an H-Beam, our structure deformed accordingly. In areas with higher loads our structure twisted and deformed. Our simulation indicated that under compression, an H-Beam would warp about itself.

Figure 2: Deformed and undeformed configuration of the structure, structure in black indicates Undeformed configuration, structure in red indicated deformed configuration



Attached in figure 3, are some of the displacements of our structure. Element A displaced an amount 0.0125 in, in the horizontal direction and -0.0011 inches in the vertical direction. Element B displaced an amount 0.0075 in in the horizontal direction and displaced an amount -0.0018 inches in the vertical direction. Element C displaced an amount 0.0119 inches in the horizontal direction and -0.0003 inches in the vertical direction. Element D displaced an amount 0.00061 inches in the horizontal direction and -0.0002 inches in the vertical direction. These displacements values for our Q4 elements were expected and yielded sufficiently accurate results within our given parameters. The overall stresses within each element were also expected. (Attached in Appendix B are a list of all the axial and shear stresses). However, some are included as follows: Element A has an shear stress of -6.83 psi, a normal horizontal stress of 3.99 psi, and a normal vertical stress of -3.04 psi. Element B has a shear stress of -2.25 psi, a normal horizontal stress of 4.07 psi, and a normal vertical stress of 0.004 psi. Element C has a shear stress of -0.1208 psi, a normal horizontal stress of -0.1803 psi, and a normal vertical stress of -0.0351 psi. Element D has a shear stress of 0.2379 psi, a normal horizontal stress of 0.5766 psi, and a normal vertical stress of -2.3515 psi. The presence of a negative normal stress values indicate compression, hence our simulation yielded results that we expected.

Conclusion

Our H-Beam simulated using 2-Dimensional Q4 elements to mimic compression yielded results that was expected. Our shear stress and normal stresses values indicated compression throughout the structure, and our displacements yielded a deformed shape that fit given our parameters. Our model could be improved in the following ways: we could utilize Q8 elements, or Q12 elements, we can increase the number of elements, altogether the simulation can be improved significantly by utilizing more nodes and a greater number of elements.

Appendix A
The Staircase Pauli Lenticular Truss with a Twist
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Matlab Code, Displacements, Axial Stress Values and more

```
% Problem 1 MEC 539 - Kumil Ali
% The Staircase Pauli Lenticular Truss with a Twist
clc;clear all;close all;
E=21e6; % Modulus of Elasticity
A=10; % Area
EA=E*A;  % Calculate now, so we dont have to keep on writing E*A

% Define the Number of Elements
numberElements=140;

% Define the number of nodes
numberNodes=59;

% Find and connect nodes, for example node 1 connects to node 2 and so on
elementNodes=[1  2;
2   3;
3   4;
4   5;
5   6;
6   7;
7   8;
8   9;
9   10;
1   11;
2   11;
2   12;
2   13;
3   13;
4   13;
4   14;
4   15;
5   15;
6   15;
6   16;
6   17;
7   17;
8   17;
8   18;
8   19;
9   19;
10   19;
10   20;
11  12;
12  13;
13  14;
14  15;
15  16;
16  17;
17  18;
18  19;
```

```
19  20;
11  21;
11  22;
12  22;
13  22;
13  23;
13  24;
14  24;
15  24;
15  25;
15  26;
16  26;
17  26;
17  27;
17  28;
18  28;
19  28;
19  29;
21  22;
22  23;
23  24;
24  25;
25  26;
26  27;
27  28;
28  29;
21  30;
22  30;
22  31;
22  32;
23  32;
24  32;
24  33;
24  34;
25  34;
26  34;
26  35;
26  36;
27  36;
30  31;
31  32;
32  33;
33  34;
34  35;
35  36;
30  37;
30  38;
31  38;
32  38;
32  39;
```

```
32  40;
33  40;
34  40;
34  41;
34  42;
35  42;
36  42;
36  43;
37  38;
38  39;
39  40;
40  41;
41  42;
42  43;
37  44;
37  45;
38  45;
39  45;
39  46;
39  47;
40  47;
41  48;
44  45;
45  46;
46  47;
47  48;
44  49;
45  49;
45  50;
45  51;
46  51;
47  51;
47  52;
47  53;
48  53;
49  50;
50  51;
51  52;
52  53;
49  54;
49  55;
50  55;
51  55;
51  56;
55  56;
54  55;
55  56;
54  57;
55  57;
55  58;
```

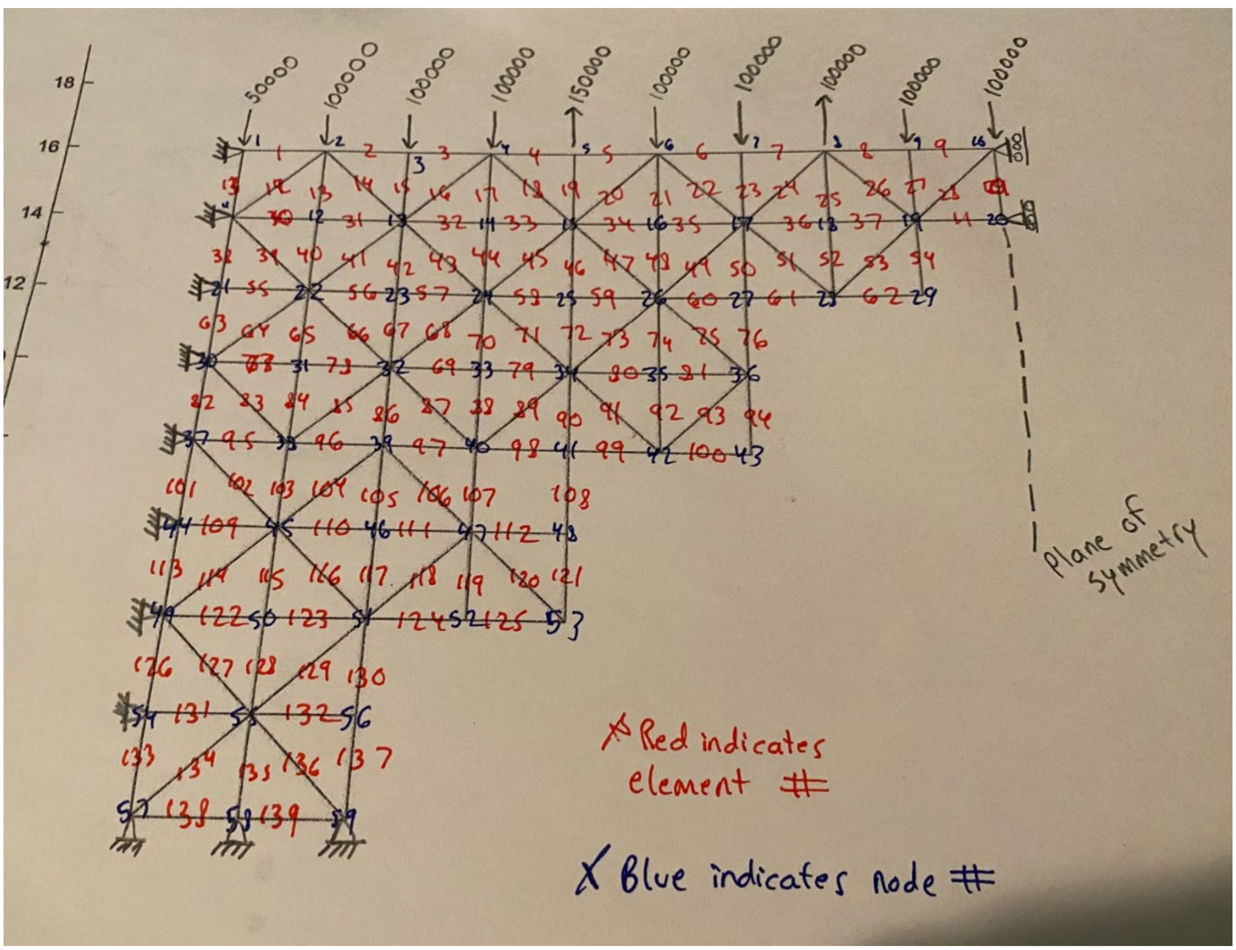
```
55  59;
56  59;
57  58;
58  59;
43  53];

% Location of nodes
nodeCoordinates=[0  16;
2  16;
4  16;
6  16;
8  16;
10  16;
12  16;
14  16;
16  16;
18  16;
0   14;
2  14;
4  14;
6  14;
8  14;
10  14;
12  14;
14  14;
16  14;
18  14;
0   12;
2  12;
4  12;
6  12;
8  12;
10  12;
12  12;
14  12;
16  12;
0  10;
2  10;
4  10;
6  10;
8  10;
10  10;
12  10;
0   8;
2   8;
4   8;
6   8;
8   8;
10  8;
12  8;
```

```
0   6;
2   6;
4   6;
6   6;
8   6;
0   4;
2   4;
4   4;
6   4;
8   4;
0   2;
2   2;
4   2;
0   0;
2   0;
4   0];

xx=nodeCoordinates(:,1);
yy=nodeCoordinates(:,2);
GDof=2*numberNodes; % Global Degrees of Freedom

%%%%%%% Force Vector %%%%%%%%%%%%%%%
Force=zeros(GDof,1);
Force(2) = -50000
Force(4) = -100000
Force(6) = -100000
Force(8) = -100000
Force(10) = 150000
Force(12) = -100000
Force(14) = -100000
Force(16) = 100000
Force(18) = -100000
Force(20) = -100000
Reduced_Force=Force;

% Boundary Conditions, in this event our BCs indicate that the left side of
% the structure has pin supports and right side has roller supports
Fixed_DOF=[1 2 19 21 22 39 41 42 59 60 73 74 87 88 97 98 107 108 113 114 115 116 117 ↙
118];

stiffness=zeros(GDof);
for j=[1:numberElements]
indices=elementNodes(j,:);
DOF_Per_Element=[indices(1)*2-1 indices(1)*2 indices(2)*2-1 indices(2)*2];
Xa=xx(indices(2))-xx(indices(1));
Ya=yy(indices(2))-yy(indices(1));
length_element=sqrt(Xa*Xa+Ya*Ya);
Cos=Xa/length_element;
Sin=Ya/length_element;
k1=EA/length_element*[Cos*Cos Cos*Sin -Cos*Cos -Cos*Sin; Cos*Sin Sin*Sin -Cos*Sin - ↙
```

```
Sin*Sin;-Cos*Cos -Cos*Sin Cos*Cos Cos*Sin;-Cos*Sin -Sin*Sin Cos*Sin Sin*Sin];
stiffness(DOF_Per_Element,DOF_Per_Element)=stiffness(DOF_Per_Element,DOF_Per_Element) ↙
+k1;
Reduced_Stiffness=stiffness;
end


for k=Fixed_DOF
    Reduced_Stiffness(k,:)=3;
    Reduced_Stiffness(:,k)=3;
    Reduced_Force(k)=3;
end
Reduced_Force(Reduced_Force==3) = [];


Reduced_Stiffness(Reduced_Stiffness==3) = [];
Reduced_Stiffness=reshape(Reduced_Stiffness,[94,94]);

% The Prescribed DOFs that we labeled above, we now list each value as 0,
% in that displacement in the rollers in the x are 0, and displacement in
% the pin supports in the x and y are 0
Displacements=zeros(GDof,1); % Displacement Vector
Reduced_Displacement=linsolve(Reduced_Stiffness,Reduced_Force);
k=1;
for e=[1:GDof]
    if e==Fixed_DOF(1)
        Displacements(e)=0;
    elseif e==Fixed_DOF(2)
        Displacements(e)=0;
    elseif e==Fixed_DOF(3)
        Displacements(e)=0;
    elseif e==Fixed_DOF(4)
        Displacements(e)=0;
    elseif e==Fixed_DOF(5)
        Displacements(e)=0;
    elseif e==Fixed_DOF(6)
        Displacements(e)=0;
    elseif e==Fixed_DOF(7)
        Displacements(e)=0;
    elseif e==Fixed_DOF(8)
        Displacements(e)=0;
    elseif e==Fixed_DOF(9)
        Displacements(e)=0;
    elseif e==Fixed_DOF(10)
        Displacements(e)=0;
    elseif e==Fixed_DOF(11)
        Displacements(e)=0;
    elseif e==Fixed_DOF(12)
        Displacements(e)=0;
    elseif e==Fixed_DOF(13)
```

```
        Displacements(e)=0;
    elseif e==Fixed_DOF(14)
        Displacements(e)=0;
    elseif e==Fixed_DOF(15)
        Displacements(e)=0;
    elseif e==Fixed_DOF(16)
        Displacements(e)=0;
    elseif e==Fixed_DOF(17)
        Displacements(e)=0;
    elseif e==Fixed_DOF(18)
        Displacements(e)=0;
    elseif e==Fixed_DOF(19)
        Displacements(e)=0;
    elseif e==Fixed_DOF(20)
        Displacements(e)=0;
    elseif e==Fixed_DOF(21)
        Displacements(e)=0;
    elseif e==Fixed_DOF(22)
        Displacements(e)=0;
    elseif e==Fixed_DOF(23)
        Displacements(e)=0;
    elseif e==Fixed_DOF(24)
        Displacements(e)=0;
    else
        Displacements(e)=Reduced_Displacement(k);
        k=k+1;
    end
end

ScaleFactor = 100;
indexX = (1:2:2*numberNodes-1)';
coordDefX = nodeCoordinates(:,1)+ScaleFactor*Displacements(indexX,1);
indexY = (2:2:2*numberNodes)';
coordDefY = nodeCoordinates(:,2)+ScaleFactor*Displacements(indexY,1);
for iNode = 1:numberNodes
    defPoint(iNode,:) = [coordDefX(iNode) coordDefY(iNode)];
end

% Show Combination of Deformed and Undeformed Shape
figure(1)
hold on
for numberofElements = 1:numberElements
    indexPoint = elementNodes(numberofElements,:);
    plot(nodeCoordinates(indexPoint,1),nodeCoordinates(indexPoint,2),'k')
    plot(defPoint(indexPoint,1),defPoint(indexPoint,2),'red--')
end
hold off

% Show the Undeformed Shape Only
figure(2)
```

```
hold on
for numberofElements = 1:numberElements
    indexPoint = elementNodes(numberofElements,:);
    plot(nodeCoordinates(indexPoint,1),nodeCoordinates(indexPoint,2), 'k')
end
hold off


% Show the Deformed Shape Only
figure(3)
hold on
for numberofElements = 1:numberElements
    indexPoint = elementNodes(numberofElements,:);
    plot(nodeCoordinates(indexPoint,1),nodeCoordinates(indexPoint,2), 'k')
end
hold off

for j=1:numberElements
indices=elementNodes(j,:);
DOF_Per_Element=[indices(1)*2-1 indices(1)*2 indices(2)*2-1 indices(2)*2] ;
Xa=xx(indices(2))-xx(indices(1));
Ya=yy(indices(2))-yy(indices(1));
length_element=sqrt(Xa*Xa+Ya*Ya);
Cos=Xa/length_element;
Sin=Ya/length_element;
Sigma(j)=E/length_element*[-Cos -Sin Cos Sin]*Displacements(DOF_Per_Element);
end

for i=1:numberElements
    disp("Element #")
    disp(i)
    disp("Axial Stress (ksi)")
    disp(Sigma(i)/1000)
    disp("Next")
end
```



Element #
1

Axial Stress (ksi)
14.0441

Next
Element #
2

Axial Stress (ksi)
6.3830

Next
Element #
3

Axial Stress (ksi)
6.3830

Next
Element #
4

Axial Stress (ksi)
7.0828

Next
Element #
5

Axial Stress (ksi)
7.0828

Next
Element #
6

Axial Stress (ksi)
-1.6127

Next
Element #
7

Axial Stress (ksi)

-1.6127

Next
Element #
8

Axial Stress (ksi)
-18.8752

Next
Element #
9

Axial Stress (ksi)
-18.8752

Next
Element #
10

Axial Stress (ksi)
0

Next
Element #
11

Axial Stress (ksi)
-8.0752

Next
Element #
12

Axial Stress (ksi)
-6.2410

Next
Element #
13

Axial Stress (ksi)
2.7592

Next
Element #

14

Axial Stress (ksi)
-10.0000

Next
Element #
15

Axial Stress (ksi)
-2.7485

Next
Element #
16

Axial Stress (ksi)
-5.4132

Next
Element #
17

Axial Stress (ksi)
-3.7382

Next
Element #
18

Axial Stress (ksi)
15

Next
Element #
19

Axial Stress (ksi)
-10.2032

Next
Element #
20

Axial Stress (ksi)
-4.2660

Next
Element #
21

Axial Stress (ksi)
2.0941

Next
Element #
22

Axial Stress (ksi)
-10

Next
Element #
23

Axial Stress (ksi)
-8.9366

Next
Element #
24

Axial Stress (ksi)
5.3757

Next
Element #
25

Axial Stress (ksi)
15.4763

Next
Element #
26

Axial Stress (ksi)
-10

Next
Element #
27

Axial Stress (ksi)
-14.1421

Next
Element #
28

Axial Stress (ksi)
0

Next
Element #
29

Axial Stress (ksi)
3.5389

Next
Element #
30

Axial Stress (ksi)
3.5389

Next
Element #
31

Axial Stress (ksi)
1.1994

Next
Element #
32

Axial Stress (ksi)
1.1994

Next
Element #
33

Axial Stress (ksi)
-1.8211

Next
Element #
34

Axial Stress (ksi)
-1.8211

Next
Element #
35

Axial Stress (ksi)
-5.9070

Next
Element #
36

Axial Stress (ksi)
-5.9070

Next
Element #
37

Axial Stress (ksi)
5.9798

Next
Element #
38

Axial Stress (ksi)
0

Next
Element #
39

Axial Stress (ksi)
7.4706

Next
Element #
40

Axial Stress (ksi)
-6.2410

Next
Element #
41

Axial Stress (ksi)
-7.5588

Next
Element #
42

Axial Stress (ksi)
-5.5368

Next
Element #
43

Axial Stress (ksi)
1.2575

Next
Element #
44

Axial Stress (ksi)
-5.4132

Next
Element #
45

Axial Stress (ksi)
-3.1984

Next
Element #
46

Axial Stress (ksi)
2.0732

Next

Element #
47

Axial Stress (ksi)
7.5383

Next
Element #
48

Axial Stress (ksi)
-4.2660

Next
Element #
49

Axial Stress (ksi)
-11.6035

Next
Element #
50

Axial Stress (ksi)
-10.3144

Next
Element #
51

Axial Stress (ksi)
5.2055

Next
Element #
52

Axial Stress (ksi)
5.3757

Next
Element #
53

Axial Stress (ksi)

-12.8079

Next
Element #
54

Axial Stress (ksi)
5.8208e-14

Next
Element #
55

Axial Stress (ksi)
-2.7713

Next
Element #
56

Axial Stress (ksi)
-1.0195

Next
Element #
57

Axial Stress (ksi)
-1.0195

Next
Element #
58

Axial Stress (ksi)
-7.0051

Next
Element #
59

Axial Stress (ksi)
-7.0051

Next
Element #

60

Axial Stress (ksi)
-12.7374

Next
Element #
61

Axial Stress (ksi)
-12.7374

Next
Element #
62

Axial Stress (ksi)
7.2760e-15

Next
Element #
63

Axial Stress (ksi)
0

Next
Element #
64

Axial Stress (ksi)
-10.2419

Next
Element #
65

Axial Stress (ksi)
-0.6948

Next
Element #
66

Axial Stress (ksi)
2.3101

Next
Element #
67

Axial Stress (ksi)
-5.5368

Next
Element #
68

Axial Stress (ksi)
-9.1213

Next
Element #
69

Axial Stress (ksi)
-3.0225

Next
Element #
70

Axial Stress (ksi)
3.7994

Next
Element #
71

Axial Stress (ksi)
2.0732

Next
Element #
72

Axial Stress (ksi)
-18.0031

Next
Element #
73

Axial Stress (ksi)
-0.9479

Next
Element #
74

Axial Stress (ksi)
9.2454

Next
Element #
75

Axial Stress (ksi)
-10.3144

Next
Element #
76

Axial Stress (ksi)
-6.0221

Next
Element #
77

Axial Stress (ksi)
-6.0221

Next
Element #
78

Axial Stress (ksi)
-4.9987

Next
Element #
79

Axial Stress (ksi)
-4.9987

Next
Element #
80

Axial Stress (ksi)
-2.7606

Next
Element #
81

Axial Stress (ksi)
-2.7606

Next
Element #
82

Axial Stress (ksi)
0

Next
Element #
83

Axial Stress (ksi)
3.2467

Next
Element #
84

Axial Stress (ksi)
-0.6948

Next
Element #
85

Axial Stress (ksi)
-8.7489

Next
Element #
86

Axial Stress (ksi)
-5.0400

Next
Element #
87

Axial Stress (ksi)
1.2352

Next
Element #
88

Axial Stress (ksi)
-3.0225

Next
Element #
89

Axial Stress (ksi)
-11.9555

Next
Element #
90

Axial Stress (ksi)
-4.2413

Next
Element #
91

Axial Stress (ksi)
6.6819

Next
Element #
92

Axial Stress (ksi)
-0.9479

Next

Element #
93

Axial Stress (ksi)
-5.3413

Next
Element #
94

Axial Stress (ksi)
0

Next
Element #
95

Axial Stress (ksi)
-9.8294

Next
Element #
96

Axial Stress (ksi)
-1.3473

Next
Element #
97

Axial Stress (ksi)
-17.8289

Next
Element #
98

Axial Stress (ksi)
-8.5017

Next
Element #
99

Axial Stress (ksi)

-8.5017

Next
Element #
100

Axial Stress (ksi)
-7.2760e-15

Next
Element #
101

Axial Stress (ksi)
0

Next
Element #
102

Axial Stress (ksi)
3.8984

Next
Element #
103

Axial Stress (ksi)
-4.5854

Next
Element #
104

Axial Stress (ksi)
-11.0322

Next
Element #
105

Axial Stress (ksi)
-5.9198

Next
Element #

106

Axial Stress (ksi)
12.2764

Next
Element #
107

Axial Stress (ksi)
-10.6029

Next
Element #
108

Axial Stress (ksi)
-4.2413

Next
Element #
109

Axial Stress (ksi)
-3.9407

Next
Element #
110

Axial Stress (ksi)
1.7240

Next
Element #
111

Axial Stress (ksi)
1.7240

Next
Element #
112

Axial Stress (ksi)
9.6634e-16

Next
Element #
113

Axial Stress (ksi)
0

Next
Element #
114

Axial Stress (ksi)
-7.8390

Next
Element #
115

Axial Stress (ksi)
-3.4366

Next
Element #
116

Axial Stress (ksi)
-0.9195

Next
Element #
117

Axial Stress (ksi)
-5.9198

Next
Element #
118

Axial Stress (ksi)
-8.7164

Next
Element #
119

Axial Stress (ksi)
-7.2760e-15

Next
Element #
120

Axial Stress (ksi)
5.9980

Next
Element #
121

Axial Stress (ksi)
-4.2413

Next
Element #
122

Axial Stress (ksi)
-4.3842

Next
Element #
123

Axial Stress (ksi)
-4.3842

Next
Element #
124

Axial Stress (ksi)
-4.2413

Next
Element #
125

Axial Stress (ksi)
-4.2413

Next
Element #
126

Axial Stress (ksi)
0

Next
Element #
127

Axial Stress (ksi)
0.7117

Next
Element #
128

Axial Stress (ksi)
-3.4366

Next
Element #
129

Axial Stress (ksi)
-7.5948

Next
Element #
130

Axial Stress (ksi)
-7.3631

Next
Element #
131

Axial Stress (ksi)
-4.5475e-16

Next
Element #
132

Axial Stress (ksi)
-3.4407

Next
Element #
133

Axial Stress (ksi)
-4.5475e-16

Next
Element #
134

Axial Stress (ksi)
0

Next
Element #
135

Axial Stress (ksi)
-4.1524

Next
Element #
136

Axial Stress (ksi)
-4.8642

Next
Element #
137

Axial Stress (ksi)
-0.7117

Next
Element #
138

Axial Stress (ksi)
-7.3631

Next

Element #
139

Axial Stress (ksi)
0

Next
Element #
140

Axial Stress (ksi)
0

Displacements =

0

0

0.0013

-0.0029

0.0019

-0.0050

0.0026

-0.0065

0.0032

-0.0060

0.0039

-0.0123

0.0037

-0.0170

0.0036

-0.0208

0.0018

-0.0289

0

-0.0312

0

0

0.0003

-0.0023

0.0007

-0.0041

0.0008

-0.0060

0.0009

-0.0074

0.0007

-0.0119

0.0006

-0.0161

-0.0000

-0.0213

-0.0006

-0.0279

0

-0.0312

0

0

-0.0003

-0.0017

-0.0004

-0.0035

-0.0005
-0.0054
-0.0011
-0.0076
-0.0018
-0.0115
-0.0030
-0.0151
-0.0042
-0.0219
-0.0042
-0.0279
0
0
-0.0006
-0.0016
-0.0011
-0.0030
-0.0016
-0.0051
-0.0021
-0.0078
-0.0024
-0.0114
-0.0026
-0.0141
0
0

-0.0009

-0.0016

-0.0011

-0.0025

-0.0028

-0.0049

-0.0036

-0.0074

-0.0044

-0.0114

-0.0044

-0.0141

0

0

-0.0004

-0.0011

-0.0002

-0.0020

-0.0000

-0.0039

-0.0000

-0.0070

0

0

-0.0004

-0.0008

-0.0008

-0.0014

-0.0012

-0.0039

-0.0016

-0.0066

0

0

-0.0003

-0.0005

-0.0003

-0.0007

0

0

0

0

0

0

Appendix B

H-Beam Analysis
Kumil Ali
111650455

Matlab Code, Displacements, Axial Stress Values and more


```
clear all; clc;

% Define models paramters
E = 21e6; % Modulus of Elasticity
poisson = 0.3;  % Poissons Ratio
thickness = 0.1;  % Thickness

numberElements=66;
numberNodes=94;

% Coordinates of the nodes
nodeCoordinates=[0  20;
2   20;
4   20;
6   20;
12  20;
14  20;
16  20;
18  20;
0   18;
2   18;
4   18;
6   18;
12  18;
14  18;
16  18;
18  18;
0   16;
2   16;
4   16;
6   16;
12  16;
14  16;
16  16;
18  16;
0   14;
2   14;
4   14;
6   14;
12  14;
14  14;
16  14;
18  14;
0   12;
2   12;
4   12;
6   12;
8   12;
10  12;
12  12;
```

```
14  12;
16  12;
18  12;
0   10;
2   10;
4   10;
6   10;
8   10;
10  10;
12  10;
14  10;
16  10;
18  10;
0   8;
2   8;
4   8;
6   8;
8   8;
10  8;
12  8;
14  8;
16  8;
18  8;
0   6;
2   6;
4   6;
6   6;
12  6;
14  6;
16  6;
18  6;
0   4;
2   4;
4   4;
6   4;
12  4;
14  4;
16  4;
18  4;
0   2;
2   2;
4   2;
6   2;
12  2;
14  2;
16  2;
18  2;
0   0;
2   0;
4   0;
```

```
6   0;
12  0;
14  0;
16  0;
18  0];

% Define the Element Nodes, we will be created a Q4 Element, so we define
% all 4 sides of the shape
elementNodes=[1 2 10 9;
2  3  11  10;
3  4  12  11;
5  6  14  13;
6  7  15  14;
7  8  16  15;
9  10  18  17;
10  11  19  18;
11  12  20  19;
13  14  22  21;
14  15  23  22;
15  16  24  23;
17  18  26  25;
18  19  27  26;
19  20  28  27;
21  22  30  29;
22  23  31  30;
23  24  32  31;
25  26  34  33;
26  27  35  34;
27  28  36  35;
29  30  40  39;
30  31  41  40;
31  32  42  41;
33  34  44  43;
34  35  45  44;
35  36  46  45;
36  37  47  46;
37  38  48  47;
38  39  49  48;
39  40  50  49;
40  41  51  50;
41  42  52  51;
43  44  54  53;
44  45  55  54;
45  46  56  55;
46  47  57  56;
47  48  58  57;
48  49  59  58;
49  50  60  59;
50  51  61  60;
51  52  62  61;
```

```
53  54  64  63;
54  55  65  64;
55  56  66  65;
59  60  68  67;
60  61  69  68;
61  62  70  69;
63  64  72  71;
64  65  73  72;
65  66  74  73;
67  68  76  75;
68  69  77  76;
69  70  78  77;
71  72  80  79;
72  73  81  80;
73  74  82  81;
75  76  84  83;
76  77  85  84;
77  78  86  85;
79  80  88  87;
80  81  89  88;
81  82  90  89;
83  84  92  91;
84  85  93  92;
85  86  94  93];

GDof = numberNodes*2;  % Global Degrees of Freedom, we assume 2 per node, one in x ↙
directiona nd one in y direction

% We Assume Plane Stress Conditions
D = E/(1-poisson^2)*[1 poisson 0; poisson 1 0; 0 0 (1-poisson)/2];  % Stress Strain↙
Matrix

Stiffness_K = formStiffness2D(GDof,numberElements,elementNodes,numberNodes, ↙
nodeCoordinates,D,1,thickness);

xx = nodeCoordinates(:,1);
yy = nodeCoordinates(:,2);

force = zeros(GDof,1);

% Define Force Conditions, we apply horizontal forces on the left end of
% the plate
force(1)=1500;
force(17)=1250;
force(33)=1250;
force(49)=1250;
force(65)=2500;
force(85)=2500;
force(105)=2500;
force(125)=1250;
```

```
force(141)=1250;
force(155)=1250;
force(173)=1500;


Reduced_Stiffness = Stiffness_K;
Reduced_Force = force;
displacement_vector = ones(size(Stiffness_K,1),1);

% Define DOF, we define pins on bottom and rollers on right side
Fixed_Dof = [15  31  47  63  83  103  123  139   155  171  175  176   177  178  183 ↙
184   185  186  187];

Reduced_Stiffness(Fixed_Dof,:) = [];
Reduced_Stiffness(:,Fixed_Dof) = [];
Reduced_Force(Fixed_Dof) = [];

% Solve for Displacement Vector, taking into consideration the DOF which we
% must remove that correspond to 0
Displacement_Vector_Reduced=linsolve(Reduced_Stiffness,Reduced_Force);
k=1;
for j=[1:GDof]
    if j==Fixed_Dof(1)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(2)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(3)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(4)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(5)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(6)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(7)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(8)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(9)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(10)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(11)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(12)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(13)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(14)
        displacement_vector(j)=0;
```

```
    elseif j==Fixed_Dof(15)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(16)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(17)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(18)
        displacement_vector(j)=0;
    elseif j==Fixed_Dof(19)
        displacement_vector(j)=0;
    else
        displacement_vector(j)=Displacement_Vector_Reduced(k);
        k=k+1;
    end
end

Uxx = displacement_vector(1:numberNodes);
Uyy = displacement_vector(numberNodes + 1:GDof);
Stress = stresses2D(GDof,numberElements,elementNodes,numberNodes,nodeCoordinates, ↙
displacement_vector,Uxx,Uyy,D,1);

for i=1:numberElements
    disp("Barbell Q4 Element #")
    disp(i)
    disp("Shear Stress (psi):")
    disp(Stress(i,3)/1000)
    disp("Normal Stress - Horizontal (psi):")
    disp(Stress(i,1)/1000)
    disp("Normal Stress - Vertical (psi):")
    disp(Stress(i,2)/1000)
    disp("Next")
end

Scale_Factor = 100;
index_X = (1:2:2*numberNodes-1)';
coordDefX = nodeCoordinates(:,1)+Scale_Factor*displacement_vector(index_X,1);
index_Y = (2:2:2*numberNodes)';
coordDefY = nodeCoordinates(:,2)+Scale_Factor*displacement_vector(index_Y,1);
for numberofNodes = 1:numberNodes
    defPoint(numberofNodes,:) = [coordDefX(numberofNodes) coordDefY(numberofNodes)];
end

% Create a Plot Showing Deformed and Undeformed Configuration
figure(1)
hold on
for numberofElem = 1:numberElements
    index_points = elementNodes(numberofElem,:);
    plot(nodeCoordinates(index_points,1),nodeCoordinates(index_points,2), 'k')
    plot(defPoint(index_points,1),defPoint(index_points,2), 'red')
end
```

```
hold off

% Create a Plot showing undeformed Configuration
figure(2)
hold on
for numberofElem = 1:numberElements
    index_points = elementNodes(numberofElem,:);
    plot(nodeCoordinates(index_points,1),nodeCoordinates(index_points,2), 'k')
end
hold off

% Create a Plot showing Deformed Configuration
figure(3)
hold on
for numberofElem = 1:numberElements
    index_points = elementNodes(numberofElem,:);
    plot(defPoint(index_points,1),defPoint(index_points,2), 'red')
end
hold off
```

Gaussian Quadrature Code

```
% Provided

function [weights,locations]=gaussQuadrature(option)
% Gauss quadrature for Q4 elements
% option 'complete' (2x2)
% option 'reduced'  (1x1)
% locations: Gauss point locations
% weights: Gauss point weights

switch option
    case 'complete'

    locations=...
      [ -0.577350269189626 -0.577350269189626;
         0.577350269189626 -0.577350269189626;
         0.577350269189626  0.577350269189626;
        -0.577350269189626  0.577350269189626];
    weights=[ 1;1;1;1];

    case 'reduced'

    locations=[0 0];
    weights=[4];
end

end  % end function gaussQuadrature
```

Jacobian Matrix Code

```
% Provided

function [JacobianMatrix,invJacobian,XYDerivatives]=...
    Jacobian(nodeCoordinates,naturalDerivatives)

% JacobianMatrix    : Jacobian matrix
% invJacobian : inverse of Jacobian Matrix
% XYDerivatives  : derivatives w.r.t. x and y
% naturalDerivatives  : derivatives w.r.t. xi and eta
% nodeCoordinates  : nodal coordinates at element level

JacobianMatrix=nodeCoordinates'*naturalDerivatives;
invJacobian=inv(JacobianMatrix);
XYDerivatives=naturalDerivatives*invJacobian;

end % end function Jacobian
```

Shape Function Code

```
% Provided
function [shape,naturalDerivatives]=shapeFunctionQ4(xi,eta)

% shape function and derivatives for Q4 elements
% shape : Shape functions
% naturalDerivatives: derivatives w.r.t. xi and eta
% xi, eta: natural coordinates (-1 ... +1)

shape=1/4*[ (1-xi)*(1-eta);(1+xi)*(1-eta);
        (1+xi)*(1+eta);(1-xi)*(1+eta)];
naturalDerivatives=...
       1/4*[-(1-eta), -(1-xi);1-eta,    -(1+xi);
              1+eta,      1+xi;-(1+eta),   1-xi];

end % end function shapeFunctionQ4
```

Stresses2D Code

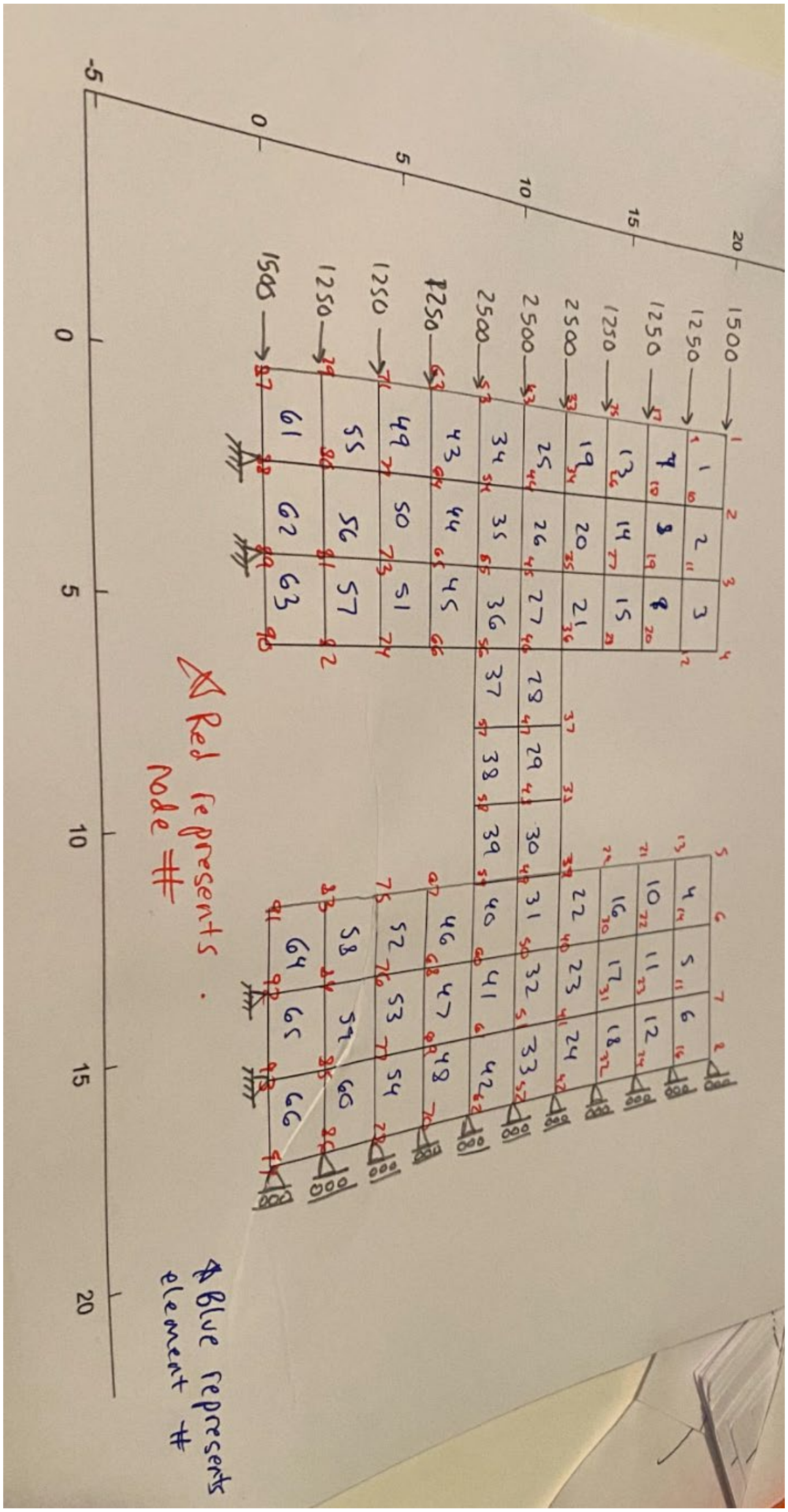
```
% Provided..............................
function [stress] = stresses2D(GDof,numberelements,...
 Q4nodes,numberNodes,CO,...
 displacements,Uxx,Uyy,D,scaleFactor)
% 2 by 2 quadrature
%[gaussWeights,gaussLocations]=gaussQuadrature('complete');
% stresses at nodes
stress=zeros(numberelements,3);
stressPoints=[-1 -1;1 -1;1 1;-1 1];

for e=1:numberelements
 indice=Q4nodes(e,:);
 elementDof=[ indice indice+numberNodes ];
 nn=length(indice);
 %for q=1:size(gaussWeights,1)
 %pt=gaussLocations(q,:);
 %wt=gaussWeights(q);
 xi=0;
 eta=0;
% shape functions and derivatives
 [shapeFunction,naturalDerivatives]=shapeFunctionQ4(xi,eta);
% Jacobian matrix, inverse of Jacobian,
% derivatives w.r.t. x,y
 [Jacob,invJacobian,XYderivatives]=...
 Jacobian(CO(indice,:),naturalDerivatives);
% B matrix
 B=zeros(3,2*nn);
 B(1,1:nn) = XYderivatives(:,1)';
 B(2,nn+1:2*nn) = XYderivatives(:,2)';
 B(3,1:nn) = XYderivatives(:,2)';
 B(3,nn+1:2*nn) = XYderivatives(:,1)';

% element deformation
 strain=B*displacements(elementDof);
 stress(e,:)=D*strain;
 %end

end
```

Form2Stiffness2D code

```
%.................................................................

function [stiffness,mass]=formStiffness2D(GDof,numberelements,...
    Q4nodes,numberNodes,CO,D,rho,thickness)

% compute stiffness matrix (and mass matrix)
% for plane stress Q4 elements

stiffness=zeros(GDof);
mass=zeros(GDof);

% 2 by 2 quadrature
[gaussWeights,gaussLocations]=gaussQuadrature('complete');

for e=1:numberelements
  indice=Q4nodes(e,:);
  elementDof=[ indice indice+numberNodes ];
  ndof=length(indice);

  % cycle for Gauss point
  for q=1:size(gaussWeights,1)
    GaussPoint=gaussLocations(q,:);
    xi=GaussPoint(1);
    eta=GaussPoint(2);

% shape functions and derivatives
    [shapeFunction,naturalDerivatives]=shapeFunctionQ4(xi,eta);

% Jacobian matrix, inverse of Jacobian,
% derivatives w.r.t. x,y
    [Jacob,invJacobian,XYderivatives]=...
        Jacobian(CO(indice,:),naturalDerivatives);
```

```matlab
    % cycle for Gauss point
    for q=1:size(gaussWeights,1)
      GaussPoint=gaussLocations(q,:);
      xi=GaussPoint(1);
      eta=GaussPoint(2);

  % shape functions and derivatives
      [shapeFunction,naturalDerivatives]=shapeFunctionQ4(xi,eta)

  % Jacobian matrix, inverse of Jacobian,
  % derivatives w.r.t. x,y
      [Jacob,invJacobian,XYderivatives]=...
          Jacobian(CO(indice,:),naturalDerivatives);

  %  B matrix
      B=zeros(3,2*ndof);
      B(1,1:ndof)         = XYderivatives(:,1)';
      B(2,ndof+1:2*ndof)   = XYderivatives(:,2)';
      B(3,1:ndof)         = XYderivatives(:,2)';
      B(3,ndof+1:2*ndof)   = XYderivatives(:,1)';

  % stiffness matrix
      stiffness(elementDof,elementDof)=...
          stiffness(elementDof,elementDof)+...
          B'*D*thickness*B*gaussWeights(q)*det(Jacob);
  % mass matrix
      mass(indice,indice)=mass(indice,indice)+...
          shapeFunction*shapeFunction'*...
          rho*thickness*gaussWeights(q)*det(Jacob);
      mass(indice+numberNodes,indice+numberNodes)=...
          mass(indice+numberNodes,indice+numberNodes)+...
          shapeFunction*shapeFunction'*...
          rho*thickness*gaussWeights(q)*det(Jacob);

    end
  end
```

Structure with nodes and elements labeled



Barbell Q4 Element #
1

Shear Stress (psi):
-6.8302

Normal Stress - Horizontal (psi):
3.9901

Normal Stress - Vertical (psi):
-3.0407

Next
Barbell Q4 Element #
2

Shear Stress (psi):
-2.6691

Normal Stress - Horizontal (psi):
0.0910

Normal Stress - Vertical (psi):
3.3729

Next
Barbell Q4 Element #
3

Shear Stress (psi):
1.9993

Normal Stress - Horizontal (psi):
-0.7554

Normal Stress - Vertical (psi):
-0.3321

Next
Barbell Q4 Element #
4

Shear Stress (psi):
-0.1208

Normal Stress - Horizontal (psi):
-0.1803

Normal Stress - Vertical (psi):
-0.0351

Next
Barbell Q4 Element #
5

Shear Stress (psi):
-0.0389

Normal Stress - Horizontal (psi):
-0.5999

Normal Stress - Vertical (psi):
0.0501

Next
Barbell Q4 Element #
6

Shear Stress (psi):
0.1597

Normal Stress - Horizontal (psi):
0.0332

Normal Stress - Vertical (psi):
-0.0149

Next
Barbell Q4 Element #
7

Shear Stress (psi):
-4.3994

Normal Stress - Horizontal (psi):
4.4442

Normal Stress - Vertical (psi):
14.3535

Next
Barbell Q4 Element #
8

Shear Stress (psi):
-4.0823

Normal Stress - Horizontal (psi):
2.5505

Normal Stress - Vertical (psi):
-2.1399

Next
Barbell Q4 Element #
9

Shear Stress (psi):
0.9817

Normal Stress - Horizontal (psi):
0.8843

Normal Stress - Vertical (psi):
-5.6446

Next
Barbell Q4 Element #
10

Shear Stress (psi):
-0.6202

Normal Stress - Horizontal (psi):
-0.0694

Normal Stress - Vertical (psi):
-0.5451

Next
Barbell Q4 Element #
11

Shear Stress (psi):
-0.9628

Normal Stress - Horizontal (psi):
-0.8176

Normal Stress - Vertical (psi):

0.2242

Next
Barbell Q4 Element #
12

Shear Stress (psi):
-0.3769

Normal Stress - Horizontal (psi):
0.1016

Normal Stress - Vertical (psi):
0.3208

Next
Barbell Q4 Element #
13

Shear Stress (psi):
-5.6403

Normal Stress - Horizontal (psi):
3.8167

Normal Stress - Vertical (psi):
7.8840

Next
Barbell Q4 Element #
14

Shear Stress (psi):
-6.0957

Normal Stress - Horizontal (psi):
4.7203

Normal Stress - Vertical (psi):
1.7675

Next
Barbell Q4 Element #
15

Shear Stress (psi):

-2.0140

Normal Stress - Horizontal (psi):
1.1550

Normal Stress - Vertical (psi):
-3.0825

Next
Barbell Q4 Element #
16

Shear Stress (psi):
-0.4175

Normal Stress - Horizontal (psi):
0.1953

Normal Stress - Vertical (psi):
-1.7078

Next
Barbell Q4 Element #
17

Shear Stress (psi):
-1.5420

Normal Stress - Horizontal (psi):
1.1852

Normal Stress - Vertical (psi):
0.7441

Next
Barbell Q4 Element #
18

Shear Stress (psi):
-3.0515e-04

Normal Stress - Horizontal (psi):
-0.4076

Normal Stress - Vertical (psi):
0.9637

Next
Barbell Q4 Element #
19

Shear Stress (psi):
-1.0908

Normal Stress - Horizontal (psi):
3.8650

Normal Stress - Vertical (psi):
2.7633

Next
Barbell Q4 Element #
20

Shear Stress (psi):
-5.4772

Normal Stress - Horizontal (psi):
6.0964

Normal Stress - Vertical (psi):
0.5674

Next
Barbell Q4 Element #
21

Shear Stress (psi):
-7.1821

Normal Stress - Horizontal (psi):
7.3330

Normal Stress - Vertical (psi):
3.2383

Next
Barbell Q4 Element #
22

Shear Stress (psi):
0.3653

Normal Stress - Horizontal (psi):
0.3993

Normal Stress - Vertical (psi):
-1.2874

Next
Barbell Q4 Element #
23

Shear Stress (psi):
0.2823

Normal Stress - Horizontal (psi):
1.2637

Normal Stress - Vertical (psi):
-2.4582

Next
Barbell Q4 Element #
24

Shear Stress (psi):
1.5046

Normal Stress - Horizontal (psi):
-0.2912

Normal Stress - Vertical (psi):
-2.2185

Next
Barbell Q4 Element #
25

Shear Stress (psi):
-2.2484

Normal Stress - Horizontal (psi):
4.0748

Normal Stress - Vertical (psi):
0.0041

Next
Barbell Q4 Element #
26

Shear Stress (psi):
-1.7075

Normal Stress - Horizontal (psi):
6.2124

Normal Stress - Vertical (psi):
-1.1495

Next
Barbell Q4 Element #
27

Shear Stress (psi):
-3.4129

Normal Stress - Horizontal (psi):
10.8030

Normal Stress - Vertical (psi):
0.7837

Next
Barbell Q4 Element #
28

Shear Stress (psi):
-8.6621

Normal Stress - Horizontal (psi):
17.6647

Normal Stress - Vertical (psi):
5.1353

Next
Barbell Q4 Element #
29

Shear Stress (psi):
-3.3168

Normal Stress - Horizontal (psi):
-0.3859

Normal Stress - Vertical (psi):
0.9426

Next
Barbell Q4 Element #
30

Shear Stress (psi):
-0.2073

Normal Stress - Horizontal (psi):
-0.8402

Normal Stress - Vertical (psi):
0.8530

Next
Barbell Q4 Element #
31

Shear Stress (psi):
0.8030

Normal Stress - Horizontal (psi):
1.5645

Normal Stress - Vertical (psi):
-0.6828

Next
Barbell Q4 Element #
32

Shear Stress (psi):
0.5256

Normal Stress - Horizontal (psi):
1.0427

Normal Stress - Vertical (psi):
-2.3232

Next

Barbell Q4 Element #
33

Shear Stress (psi):
0.3787

Normal Stress - Horizontal (psi):
0.6629

Normal Stress - Vertical (psi):
-2.9582

Next
Barbell Q4 Element #
34

Shear Stress (psi):
1.1332

Normal Stress - Horizontal (psi):
0.5974

Normal Stress - Vertical (psi):
-0.8086

Next
Barbell Q4 Element #
35

Shear Stress (psi):
1.6276

Normal Stress - Horizontal (psi):
3.3459

Normal Stress - Vertical (psi):
1.9253

Next
Barbell Q4 Element #
36

Shear Stress (psi):
1.0023

Normal Stress - Horizontal (psi):

5.4952

Normal Stress - Vertical (psi):
2.1511

Next
Barbell Q4 Element #
37

Shear Stress (psi):
1.8432

Normal Stress - Horizontal (psi):
9.5579

Normal Stress - Vertical (psi):
1.1508

Next
Barbell Q4 Element #
38

Shear Stress (psi):
2.7479

Normal Stress - Horizontal (psi):
-3.2773

Normal Stress - Vertical (psi):
-0.3014

Next
Barbell Q4 Element #
39

Shear Stress (psi):
-0.3616

Normal Stress - Horizontal (psi):
-2.8230

Normal Stress - Vertical (psi):
1.0929

Next
Barbell Q4 Element #

40

Shear Stress (psi):
-0.9579

Normal Stress - Horizontal (psi):
1.0495

Normal Stress - Vertical (psi):
-0.2024

Next
Barbell Q4 Element #
41

Shear Stress (psi):
0.2379

Normal Stress - Horizontal (psi):
0.5766

Normal Stress - Vertical (psi):
-2.3515

Next
Barbell Q4 Element #
42

Shear Stress (psi):
-0.4846

Normal Stress - Horizontal (psi):
0.1441

Normal Stress - Vertical (psi):
-3.1445

Next
Barbell Q4 Element #
43

Shear Stress (psi):
0.6701

Normal Stress - Horizontal (psi):
-2.6911

Normal Stress - Vertical (psi):
1.2996

Next
Barbell Q4 Element #
44

Shear Stress (psi):
3.5305

Normal Stress - Horizontal (psi):
-3.2328

Normal Stress - Vertical (psi):
2.0877

Next
Barbell Q4 Element #
45

Shear Stress (psi):
3.0219

Normal Stress - Horizontal (psi):
2.2918

Normal Stress - Vertical (psi):
1.5194

Next
Barbell Q4 Element #
46

Shear Stress (psi):
0.2148

Normal Stress - Horizontal (psi):
-0.2895

Normal Stress - Vertical (psi):
-0.3022

Next
Barbell Q4 Element #
47

Shear Stress (psi):
0.1415

Normal Stress - Horizontal (psi):
0.3246

Normal Stress - Vertical (psi):
-0.3001

Next
Barbell Q4 Element #
48

Shear Stress (psi):
-0.7909

Normal Stress - Horizontal (psi):
0.1181

Normal Stress - Vertical (psi):
-1.0105

Next
Barbell Q4 Element #
49

Shear Stress (psi):
2.5760

Normal Stress - Horizontal (psi):
-2.6821

Normal Stress - Vertical (psi):
3.3089

Next
Barbell Q4 Element #
50

Shear Stress (psi):
-0.1383

Normal Stress - Horizontal (psi):
-2.5692

Normal Stress - Vertical (psi):
1.1377

Next
Barbell Q4 Element #
51

Shear Stress (psi):
-2.4377

Normal Stress - Horizontal (psi):
1.5715

Normal Stress - Vertical (psi):
0.4602

Next
Barbell Q4 Element #
52

Shear Stress (psi):
0.4407

Normal Stress - Horizontal (psi):
0.2807

Normal Stress - Vertical (psi):
-0.0557

Next
Barbell Q4 Element #
53

Shear Stress (psi):
-0.6007

Normal Stress - Horizontal (psi):
-0.8283

Normal Stress - Vertical (psi):
-1.1102

Next
Barbell Q4 Element #
54

Shear Stress (psi):
-0.2745

Normal Stress - Horizontal (psi):
-0.7972

Normal Stress - Vertical (psi):
-0.4469

Next
Barbell Q4 Element #
55

Shear Stress (psi):
2.3822

Normal Stress - Horizontal (psi):
0.9480

Normal Stress - Vertical (psi):
5.6897

Next
Barbell Q4 Element #
56

Shear Stress (psi):
1.3437

Normal Stress - Horizontal (psi):
0.9556

Normal Stress - Vertical (psi):
-3.0968

Next
Barbell Q4 Element #
57

Shear Stress (psi):
-3.7259

Normal Stress - Horizontal (psi):
0.9101

Normal Stress - Vertical (psi):

2.3139

Next
Barbell Q4 Element #
58

Shear Stress (psi):
-2.6401

Normal Stress - Horizontal (psi):
-6.7303

Normal Stress - Vertical (psi):
-0.7894

Next
Barbell Q4 Element #
59

Shear Stress (psi):
0.7374

Normal Stress - Horizontal (psi):
-5.9058

Normal Stress - Vertical (psi):
-0.6858

Next
Barbell Q4 Element #
60

Shear Stress (psi):
1.4680

Normal Stress - Horizontal (psi):
0.5305

Normal Stress - Vertical (psi):
-1.2587

Next
Barbell Q4 Element #
61

Shear Stress (psi):

1.8784

Normal Stress - Horizontal (psi):
-1.6405

Normal Stress - Vertical (psi):
-1.0030

Next
Barbell Q4 Element #
62

Shear Stress (psi):
2.0994

Normal Stress - Horizontal (psi):
-3.4477

Normal Stress - Vertical (psi):
-0.4047

Next
Barbell Q4 Element #
63

Shear Stress (psi):
-3.9778

Normal Stress - Horizontal (psi):
-2.4658

Normal Stress - Vertical (psi):
-0.7397

Next
Barbell Q4 Element #
64

Shear Stress (psi):
2.9486

Normal Stress - Horizontal (psi):
-6.5677

Normal Stress - Vertical (psi):
-1.9703

Next
Barbell Q4 Element #
65

Shear Stress (psi):
-1.3648

Normal Stress - Horizontal (psi):
-6.5892

Normal Stress - Vertical (psi):
-1.7135

Next
Barbell Q4 Element #
66

Shear Stress (psi):
-1.5838

Normal Stress - Horizontal (psi):
-0.0944

Normal Stress - Vertical (psi):
-0.8949

Displacements in X-Direction (units of inches)
Uxx =

-0.0125
-0.0113
-0.0116
-0.0119
0.0003
0.0003
0.0003
0.0003
-0.0107
-0.0111
-0.0109
-0.0107
0.0001
0.0001
0

0.0000
-0.0103
-0.0100
-0.0095
-0.0092
-0.0000
0.0000
-0.0000
-0.0001
-0.0075
-0.0076
-0.0072
-0.0071
-0.0003
-0.0002
0
-0.0001
-0.0059
-0.0052
-0.0045
-0.0033
-0.0020
-0.0011
-0.0008
-0.0008
-0.0006
-0.0005
-0.0032
-0.0031
-0.0026
-0.0017
0
-0.0010
-0.0015
-0.0012
-0.0010
-0.0009
-0.0017
-0.0017
-0.0017
-0.0016
-0.0016
-0.0012
-0.0013
-0.0014
-0.0013

```
   -0.0012
         0
   -0.0006
   -0.0014
   -0.0011
   -0.0015
   -0.0014
   -0.0014
   -0.0014
    0.0006
    0.0006
    0.0008
    0.0007
   -0.0014
   -0.0014
   -0.0015
   -0.0017
    0.0023
    0.0022
    0.0024
    0.0025
         0
   -0.0013
   -0.0022
   -0.0019
    0.0046
    0.0044
    0.0037
    0.0032
   -0.0014
   -0.0013
   -0.0015
   -0.0018
```

Displacements in y-direction (units of inches)

```
>> Uyy

Uyy =

   -0.0011
   -0.0011
   -0.0013
   -0.0001
   -0.0003
   -0.0005
   -0.0008
```

-0.0010
0
-0.0014
-0.0016
0.0002
-0.0003
-0.0005
-0.0008
-0.0010
-0.0023
-0.0016
-0.0009
0.0006
-0.0002
-0.0006
-0.0009
-0.0010
-0.0034
-0.0018
-0.0008
0.0011
0
-0.0004
-0.0011
-0.0010
-0.0037
-0.0018
-0.0005
0.0006
0.0003
0.0006
0.0002
-0.0003
-0.0007
-0.0010
-0.0035
-0.0017
0
0.0006
0.0003
0.0004
0.0002
-0.0001
-0.0004
-0.0007
-0.0034

-0.0017
-0.0002
0.0007
0.0005
0.0000
0.0001
0.0000
0
-0.0005
-0.0035
-0.0020
-0.0005
0.0008
0.0001
0.0001
-0.0000
-0.0003
-0.0040
-0.0023
-0.0005
0.0009
-0.0000
0.0003
0
-0.0002
-0.0051
-0.0022
0
0
0
0
0.0001
-0.0000
-0.0049
-0.0023
0
0
0
0
0
0.0002