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MAE 3270 Final Homework Part 1

Analysis

1. Script used for hand calculation.

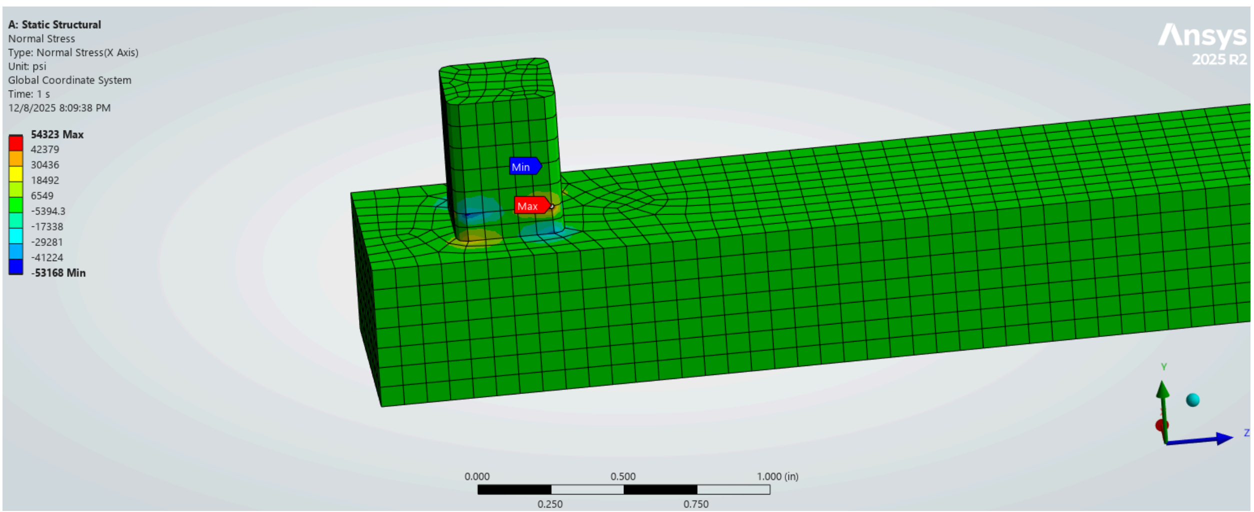
```
%% Input
M = 600; %Max torque (in-lbf)
L = 16; %Length (in)
h = 0.75; %Width (in)
b = 0.5; %Thickness (in)
D = 1; %Dist to --> sg (in)
E = 32*(10^6); %Young's modulus (psi)
v = 0.29; %Poisson's ratio,
y = 370*(10^3); %Yield Strength,
k = 15 * 10^3; %Fracture Toughness
f = 115 * 10^3; %Fatigue Strength, 10^6 cycles
c = 1;
P = M/L;
%% Equations
I = 1/12 * (h^3) * b;
a = 0.04; %Assumed crack 0.04" in size
Crack = (1.12*(sqrt(pi*a)))*((M*(h/2))/I); %Stress, crack. From HW12 Q5
FOScrack = k/Crack; %FOS, crack, needs to be at least 2
Yield = (M*(h/2))/I; %Stress, yield. From HW11 Q5
FOSyield = y/Yield; %FOS, yield, needs to be at least 4
FOSfatigue = f/Yield; %FOS, fatigue, needs to be at least 1.5. Stress eq is the same as yield
Deflection = (P*(L^3))/(3*E*I); %Max deflection
StressG = ((M/L)*(L-c)*(h/2))/I; %gauge stress
StrainG = (StressG/E)*(10^6); %gauge microstrain
output = StrainG/1000; %needs to be at least 1
%% Printing
disp([ 'FOS to brittle failure = ' mat2str(FOScrack)]);
disp([ 'FOS to yield = ' mat2str(FOSyield)]);
disp([ 'FOS to fatigue = ' mat2str(FOSfatigue)]);
disp([ 'Strain gauge output = ' mat2str(output)]);
disp([ 'Deflection at load point = ' mat2str(Deflection) ' in']);
disp([ 'Strain at gauge = ' mat2str(StrainG) ' microstrain']);
disp([ 'Maximum stress = ' mat2str(Yield) ' psi']);
```

2. Results from hand calculation of base design showing maximum normal stress (anywhere), strains at the strain gauge locations and deflection of the load point.

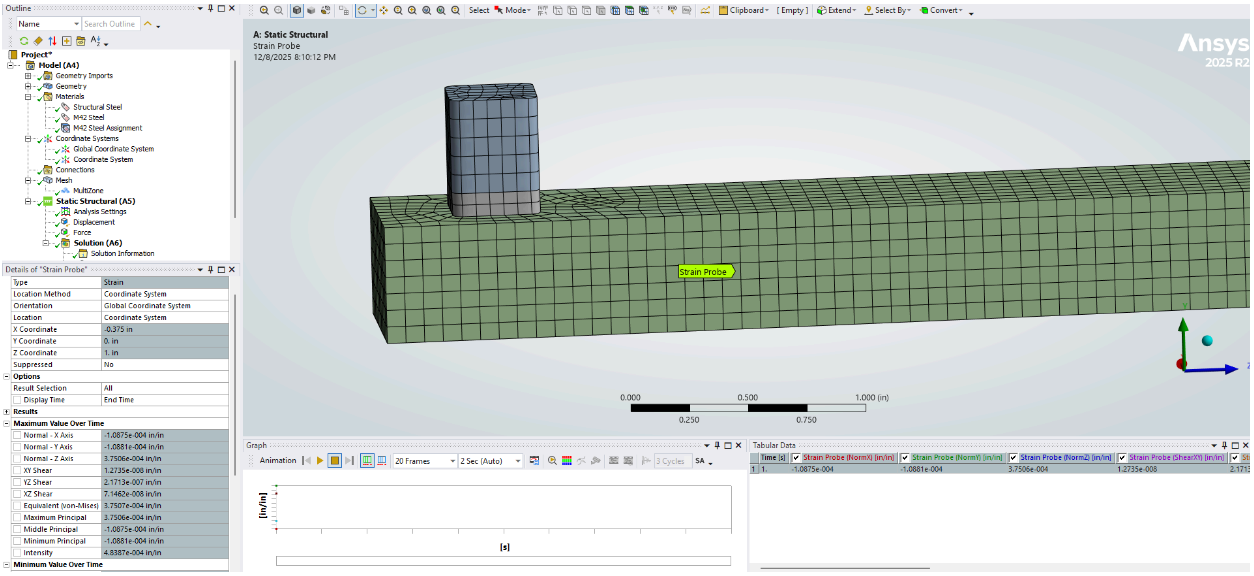
```
FOS to brittle failure = 2.95160566169655
FOS to yield = 28.90625
FOS to fatigue = 8.984375
Strain gauge output = 0.375
Deflection at load point = 0.0910222222222222 in
Strain at gauge = 375 microstrain
Maximum stress = 12800 psi
```

3. Results from FEM calculation of base design. From the FEM find the maximum normal stress (anywhere), strains at the strain gauge locations and deflection of the load point.

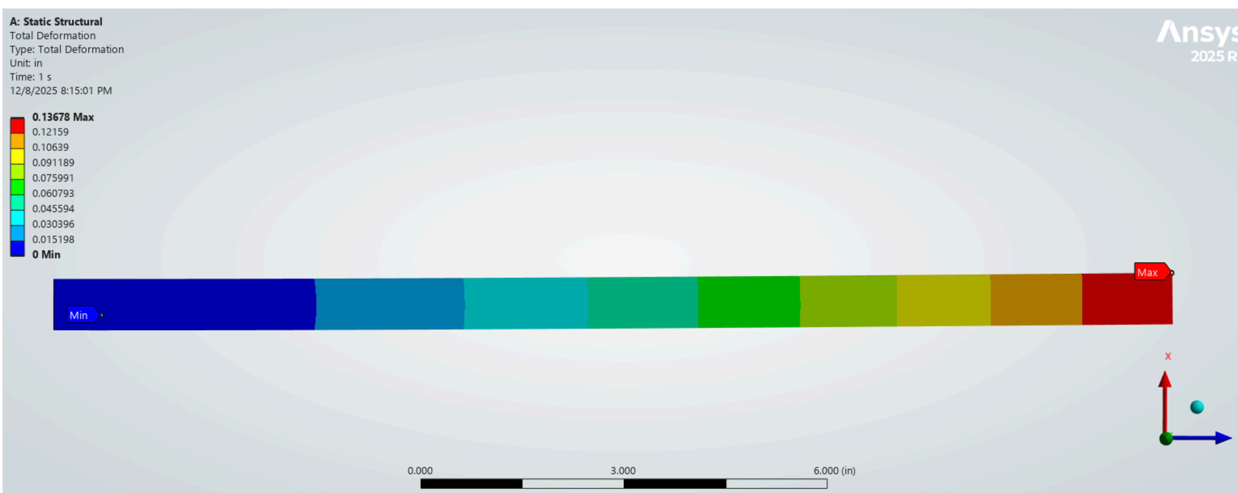
Maximum normal stress: 54323 psi



Strains at gauge location:
Normal strain in the x direction = -1.0875e-004 in/in = -0.00010875 in/in
Normal strain in the y direction = -1.0881e-004 in/in = -0.00010881 in/in
Normal strain in the z direction = 3.7506e-004 in/in = **0.00037506 in/in**



Deflection at load point: 0.13678 in



Reflections

1. Beam theory assumes that plane sections remain plane. View the deformed mesh and check if mesh lines that cut across the beam handle remain as straight lines. Do you think that beam theory is reasonably accurate?

   Looking at our mesh, we can see that the lines do remain straight, so beam theory does seem to be reasonably accurate. The only place where the mesh starts to deform is around the drive, which is also where our stress results start to deviate from our hand calculations.

2. How do the FEM and hand calculated maximum normal stresses compare? If they differ significantly, why?

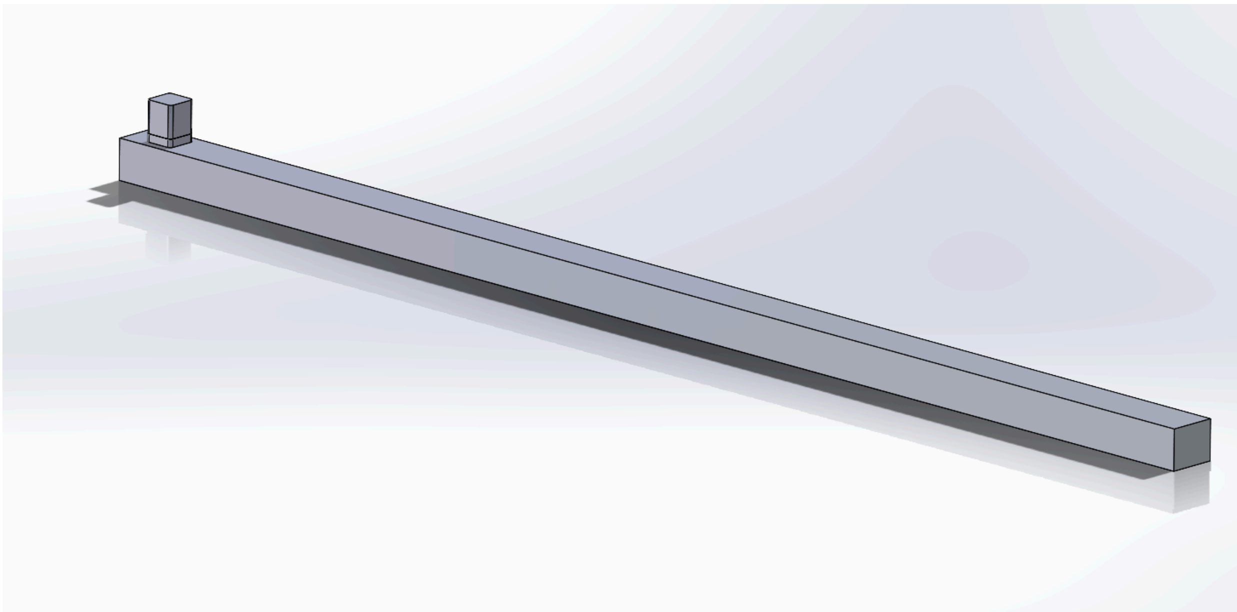
   The FEM value for maximum stress is 54323 psi, which is higher than the hand calculated maximum stress value, which is 12800 psi. This is a very significant difference. This is likely because we calculated the maximum stress in a beam of the dimensions of the handle, not accounting for how the drive factors into the situation. Since the drive has a much smaller cross sectional area, it will have a higher stress when reacting the same load. An additional consideration for the max stress being so high is that it is a stress concentration due to the torque wrench being cadded as 3 separate bodies.

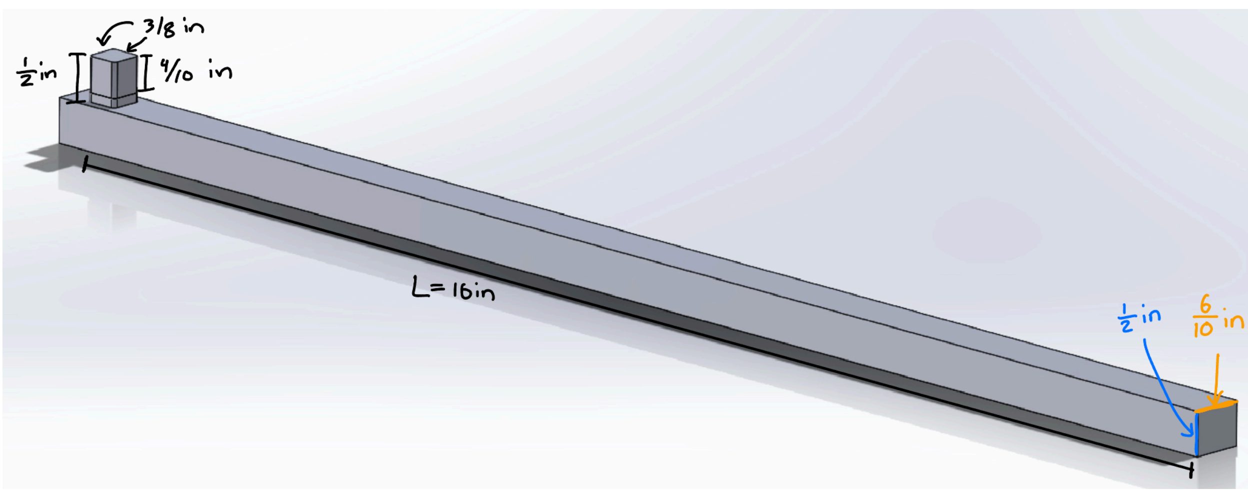
3. How do the FEM and hand calculated displacements compare? If they differ, why?

   The FEM value for maximum displacement is 0.14 inches, which is different from the hand-calculated maximum displacement, which was 0.13678 inches. This difference is not very large, and therefore could be accounted for by the stiffness of the drive of the wrench, which is not accounted for in our hand calculations. In the FEM, the stiffness of the drive prevents the end of the wrench from deflecting more, which explains why the deflection in the FEM is smaller than the hand calculations.

Your Design

1. Image(s) of CAD model. Must show all key dimensions.

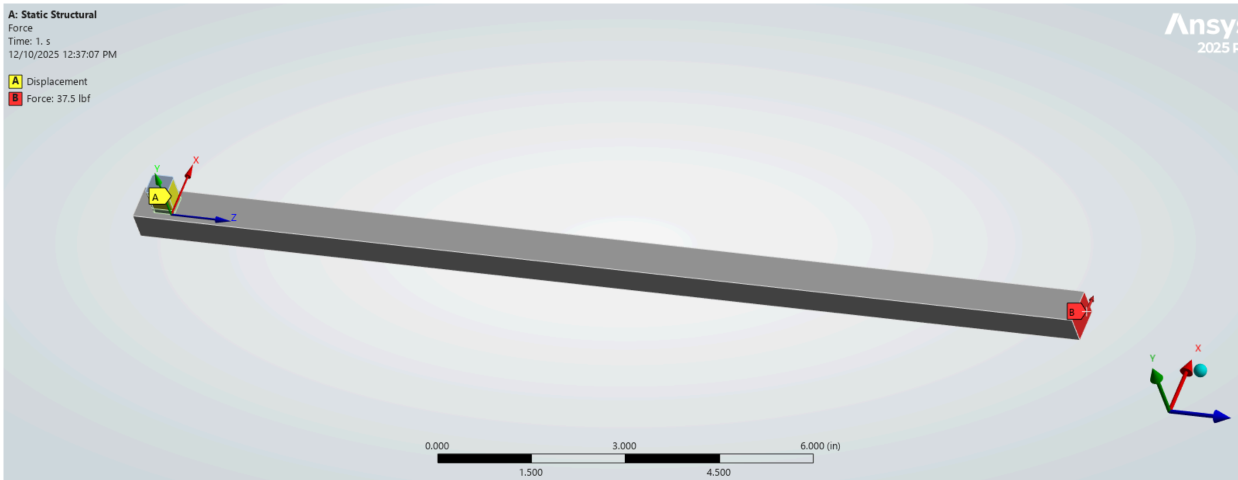




2. Describe material used and its relevant mechanical properties.

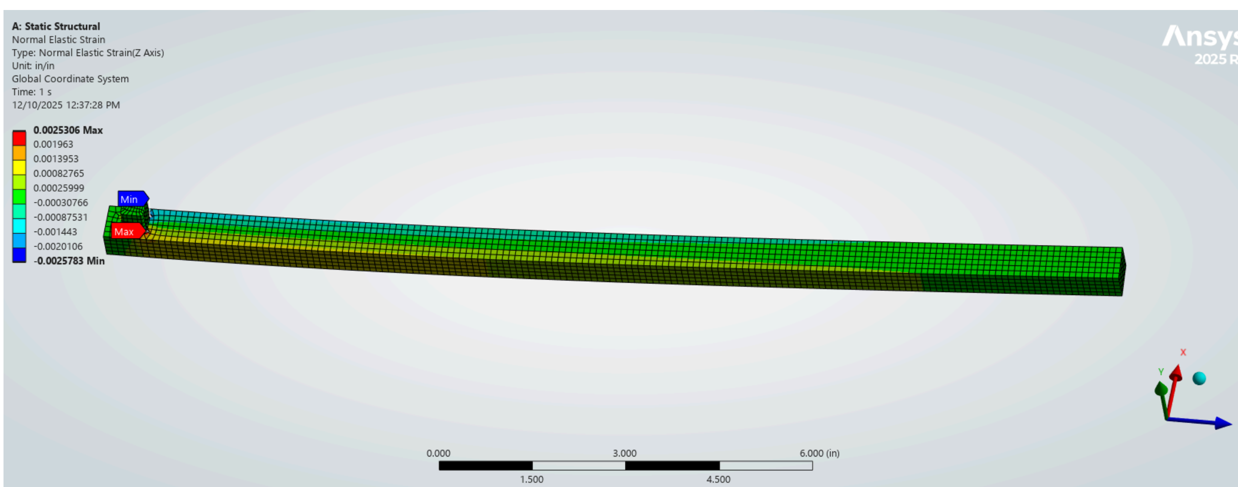
   The material we selected is Titanium, specifically, Ti-6Al-4V. One reason we selected this material is because it has a very high strength to weight ratio. This is optimal for a tool that someone may need to carry around because it will be light enough to carry but still offer the strength required of a tool under high loads. Another reason we chose this material is because it has a high fatigue life as compared to aluminum, which is also light. This is also important for our application because the torque wrench will be used over and over again, so it needs to have a high fatigue life. Titanium is also less stiff than steel, which helps us meet our sensitivity goal.

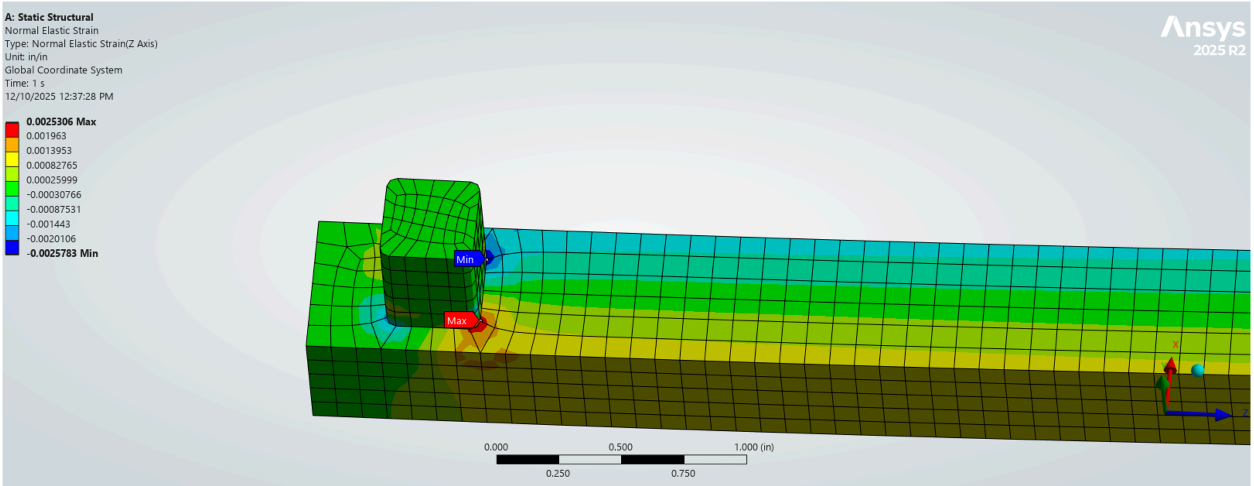
3. Diagram communicating how loads and boundary conditions were applied to your FEM Model.



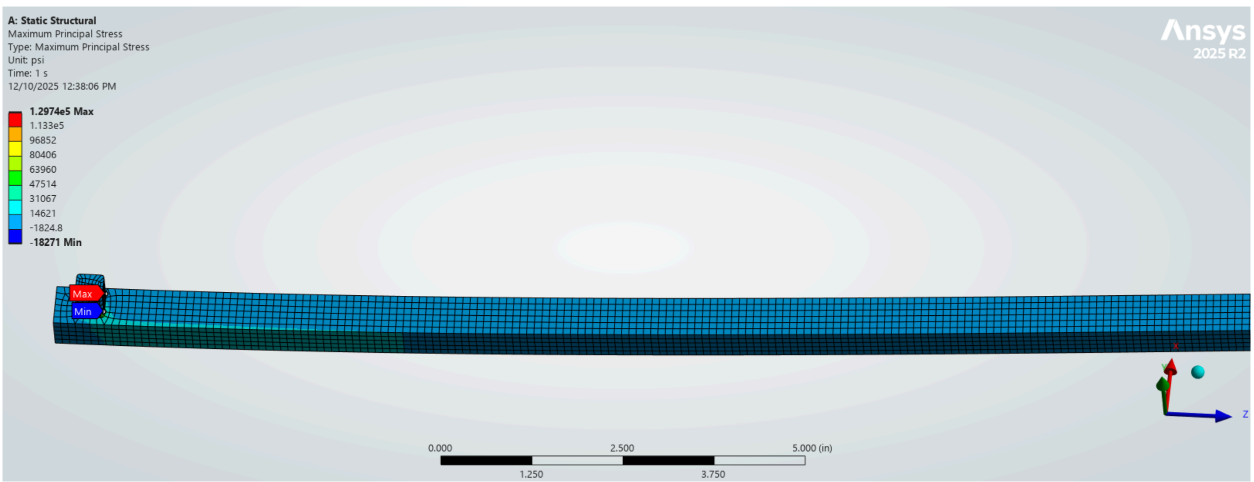
We applied zero displacement supports to the 4 sides of the drive. We applied the force of 37.5 lbs (equal to the moment = 600 in-lbs divided by the length from the end to the center of the drive) to the end of the torque wrench.

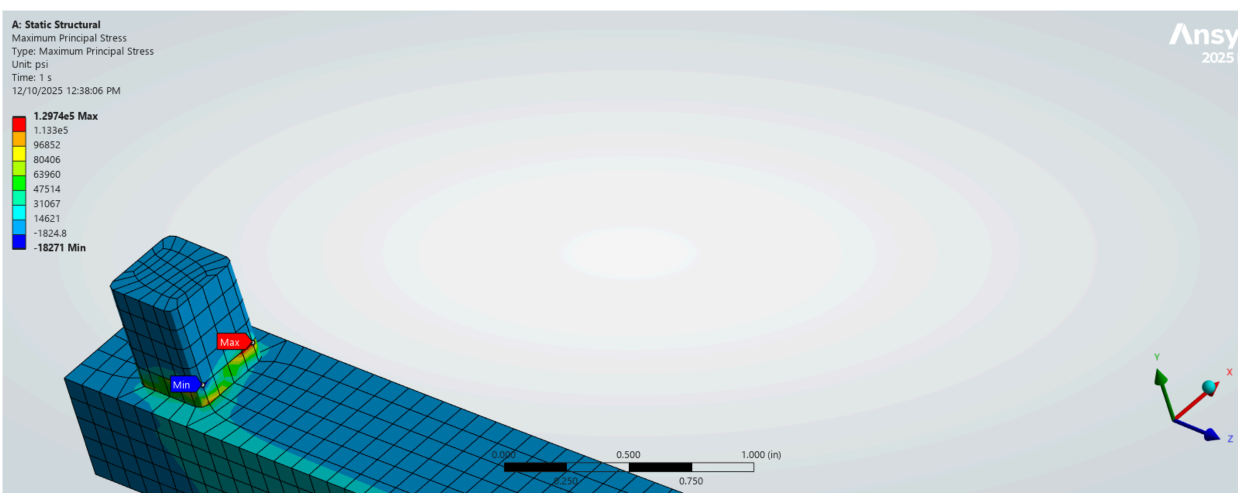
4. Normal strain contours (in the strain gauge direction) from FEM





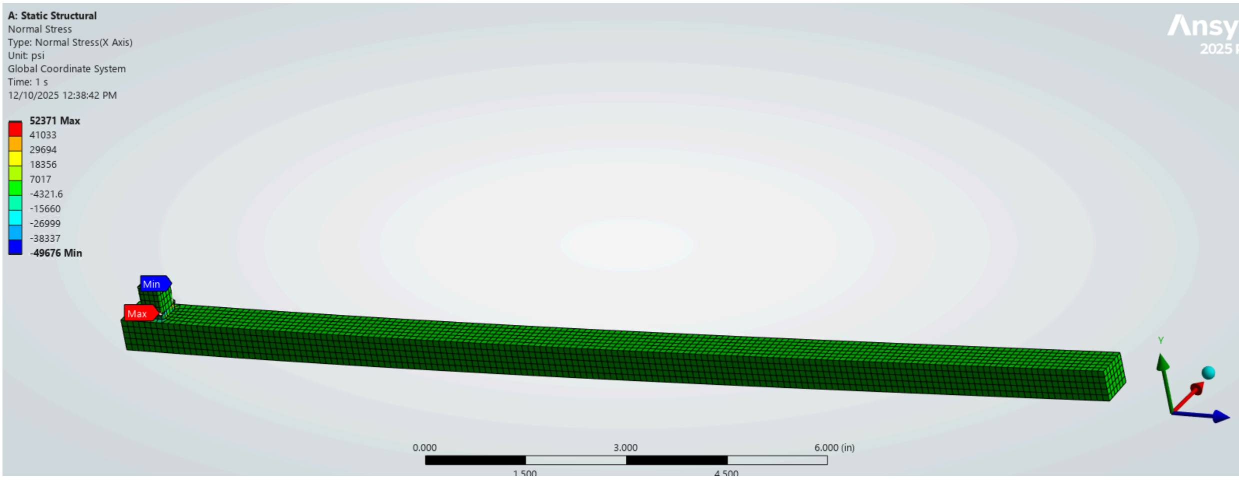
5. Contour plot of maximum principal stress from FEM

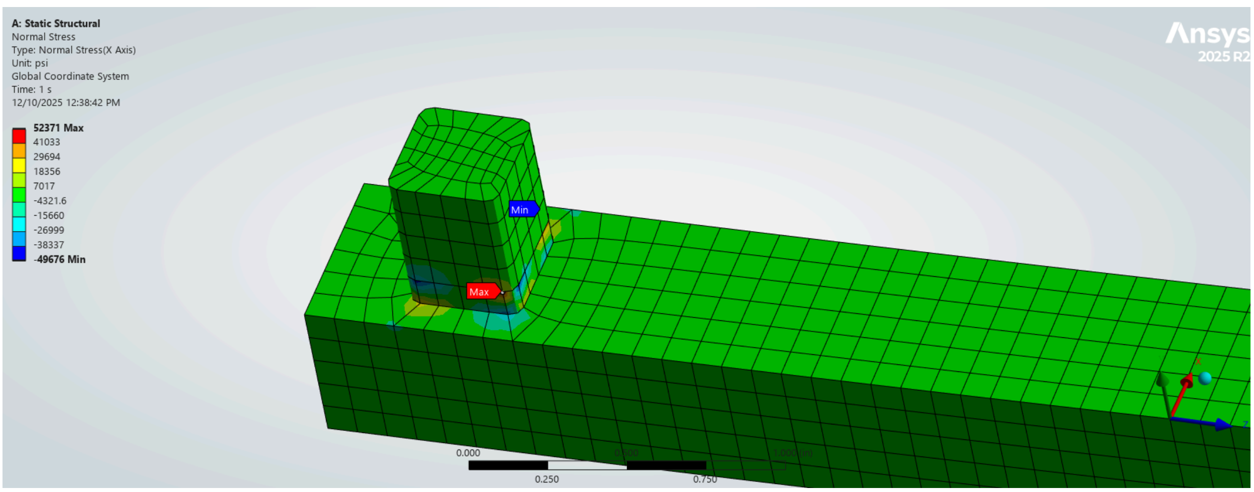




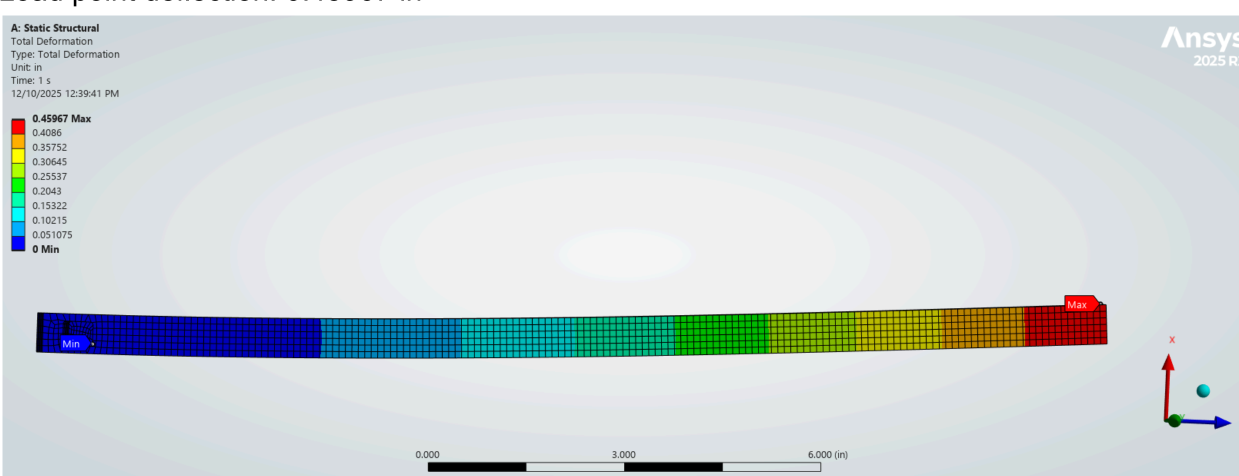
6. Summarize results from FEM calculation showing maximum normal stress (anywhere), load point deflection, strains at the strain gauge locations

Max normal stress: 52371 psi

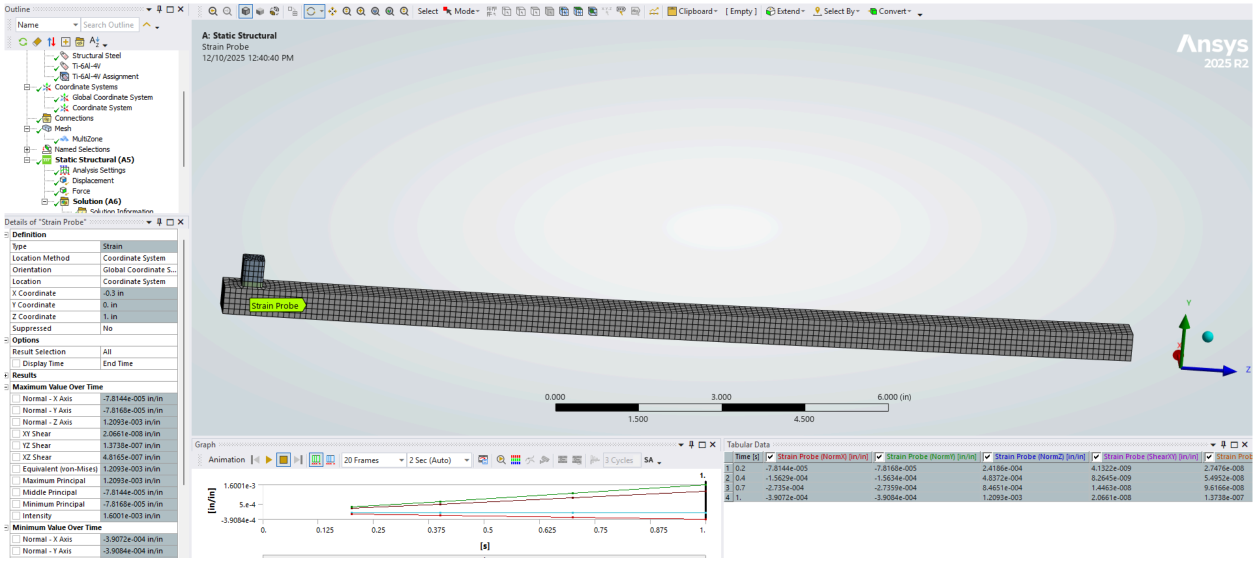




Load point deflection: 0.45967 in



Strains at strain gauge:



7. Torque wrench sensitivity in mV/V using strains from the FEM analysis
Our FEM analysis showed a maximum strain (which occurs along the z axis as expected) of $1.2093*10^{-3}$ in/in, which is equal to 1209.4 microstrain, and a sensitivity of 1.209 mV/V. This is reasonably close to our calculated sensitivity of 1.17 mV/V, and is likely a little bit larger due to the fact that our code assumed that it could only deform axially, however that's not entirely true in real life.

8. Strain gauge selected (give type and dimensions). Note that design must physically have enough space to bond the gauges.

We have selected to use a double linear strain gauge, which is most commonly used to measure bending. It is 0.354" x 0.354" so it should have no trouble fitting on our torque wrench.

UPDATED MATLAB SCRIPT WITH NEW MATERIAL PROPERTIES AND DIMENSIONS TO PASS REQUIREMENTS:

```
%% Input
M = 600; %Max torque (in-lbf)
L = 16; %Length (in)
h = 0.6; %Width (in)
b = 0.5; %Thickness (in)
D = 1; %Dist to --> sg (in)
E = 16*(10^6); %Young's modulus (psi) 16-17.4 PSI range
v = 5.51; %Poisson's ratio, 5.51-6.53 range
y = 102*(10^3); %Yield Strength, 102-158 KSI range
k = 46.7 * 10^3; %Fracture Toughness, 46.7-78.4 KSI range
f = 59.8 * 10^3; %Fatigue Strength, 10^6 cycles, 59.8-92.2 KSI range for 10^7
```

```
c = 1;
P = M/L;
%% Equations
I = 1/12 * (h^3) * b;
a = 0.04; %Assumed crack 0.04" in size
Crack = (1.12*(sqrt(pi*a)))*((M*(h/2))/I); %Stress, crack. From HW12 Q5
FOScrack = k/Crack; %FOS, crack, needs to be at least 2
Yield = (M*(h/2))/I; %Stress, yield. From HW11 Q5
FOSyield = y/Yield; %FOS, yield, needs to be at least 4
FOSfatigue = f/Yield; %FOS, fatigue, needs to be at least 1.5. Stress eq is the same as yield
Deflection = (P*(L^3))/(3*E*I); %Max deflection
StressG = ((M/L)*(L-c)*(h/2))/I; %gauge stress
StrainG = (StressG/E)*(10^6); %gauge microstrain
output = StrainG/1000; %needs to be at least 1
%% Printing
disp([ 'FOS to brittle failure = ' mat2str(FOScrack)]);
disp([ 'FOS to yield = ' mat2str(FOSyield)]);
disp([ 'FOS to fatigue = ' mat2str(FOSfatigue)]);
disp([ 'Strain gauge output = ' mat2str(output)]);
disp([ 'Deflection at load point = ' mat2str(Deflection) ' in']);
disp([ 'Strain at gauge = ' mat2str(StrainG) ' microstrain']);
disp([ 'Maximum stress = ' mat2str(Yield) ' psi']);
```

RESULTS:
FOS to brittle failure = 5.88117266778576
FOS to yield = 5.1
FOS to fatigue = 2.99
Strain gauge output = 1.171875
Deflection at load point = 0.355555555555556 in
Strain at gauge = 1171.875 microstrain
Maximum stress = 20000 psi