MAE 3270, Fall 2025, Last HW: Design Project

Part I: Baseline Design

5.1.1- Results

1. Script used for hand calculation.

```
clear; clc;

%initial conditions
M = 600;                  % max torque (in-lbf)
E = 29.5e6;               % Young's Modulus (psi)
nu = 0.29;                % Poisson's ratio
su = 285e3;               % tensile strength (psi)
KIC = 100e3;              % fracture toughness (psi*sqrt(in))
sfatigue= 100e3;          % fatigue strength from 10^6
name= 'Aermet 100';

%dimensions
lengths   = [7,8,9,10,11,12,13,14,15];
heights   = [0.5,0.55,0.6,0.65,0.7, 0.75, 0.8];
thickness = [0.4,0.5,0.6,0.6,0.7,0.8];
c_values  = [1, 1.5, 2, 2.5, 3, 3.5, 4];

found = false;

%loop
for L = lengths
    for h = heights
        for b = thickness
            for c = c_values

                [umax, smax, Xo, Xk, Xs, strain_at_gauge, output] = ...
                     wrench_numbers(M, L, h, b, c, E, su, KIC, sfatigue);

                % Check requirements
                if output > 1 && Xo > 4 && Xk > 2 && Xs > 1.5
                    fprintf('\n=== VALID DIMENSION SET ===\n');
                    fprintf('Length L     = %.2f in\n', L);
                    fprintf('Height h     = %.2f in\n', h);
                    fprintf('Thickness b  = %.2f in\n', b);
                    fprintf('Gauge dist c = %.2f in\n\n', c);

                    fprintf('Results:\n');
                    fprintf('output  = %.3f mV/V\n', output);
                    fprintf('Xo      = %.3f\n', Xo);
                    fprintf('Xk      = %.3f\n', Xk);
                    fprintf('Xs      = %.3f\n\n', Xs);

                    found = true;
                    break;
                end
            end
            if found, break; end
        end
        if found, break; end
    end
end
```

```
if ~found
    disp('No combination of dimensions meets the requirements.');
end



%%function
function [umax, smax, Xo, Xk, Xs,strain_at_gauge, output] =
wrench_numbers(M,L,h,b,c,E,su,KIC,sfatigue)
    I = (b * h^3) / 12;
    umax = (M * L^2)/(3 * E * I);
    smax = (M * h/2)/I * 1e-3;  % ksi

    Xo = (su * I)/((h/2) * M);
    Xk = (KIC* b*h^2)/(M*6*1.12* sqrt(0.04 * pi));
    Xs = (b * h^2 * sfatigue)/(6*M);

    strain_at_gauge = (6*M*(L-c)/(E*L*b*h^2))*1e6;
    output = strain_at_gauge * 1e-3;   % mV/V
end
```

```
=== VALID DIMENSION SET ===
Length L      = 7.00 in
Height h      = 0.50 in
Thickness b   = 0.40 in
Gauge dist c  = 1.00 in

Results:
output   = 1.046 mV/V
Xo       = 7.917
Xk       = 6.996
Xs       = 2.778
```

2. Results from hand calculation of base design.
    a. Maximum normal stress

$$I = \frac{bh^3}{12} = \frac{(0.5)(0.75)^3}{12} = 0.01758\, in^4$$

$$\sigma_{max} = \frac{M(h/2)}{I} = \frac{600(0.75/2)}{0.01758} = \boxed{12.809\, ksi}$$

    b. Strain at strain gauge

gauge @ $L-c=16-1=15\,in$

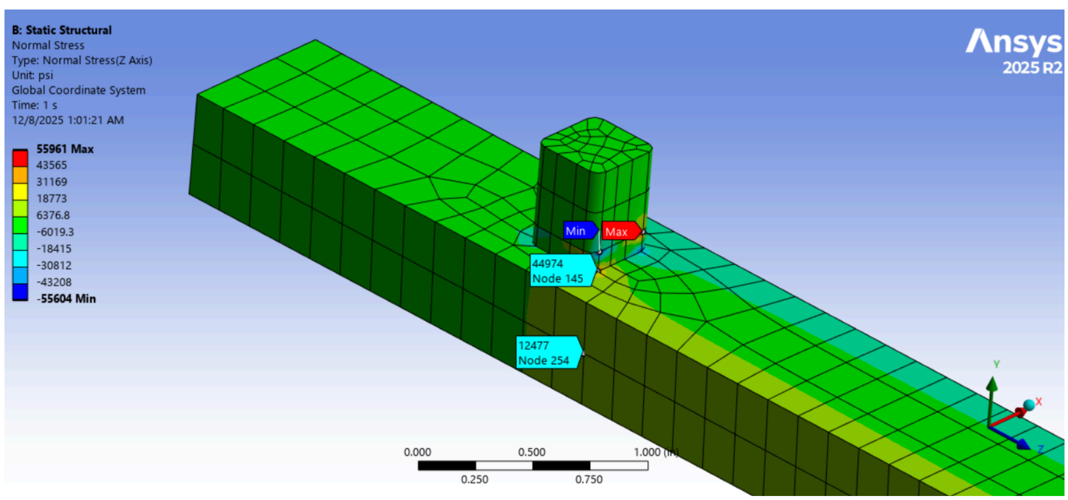
$$\epsilon=\frac{6M(L-c)}{ELbh^2}=\frac{6(600)(15)}{(32\times10^6)(16)(0.5)(0.75)^2}=\boxed{375\,\mu\epsilon}$$

c. Deflection of load point

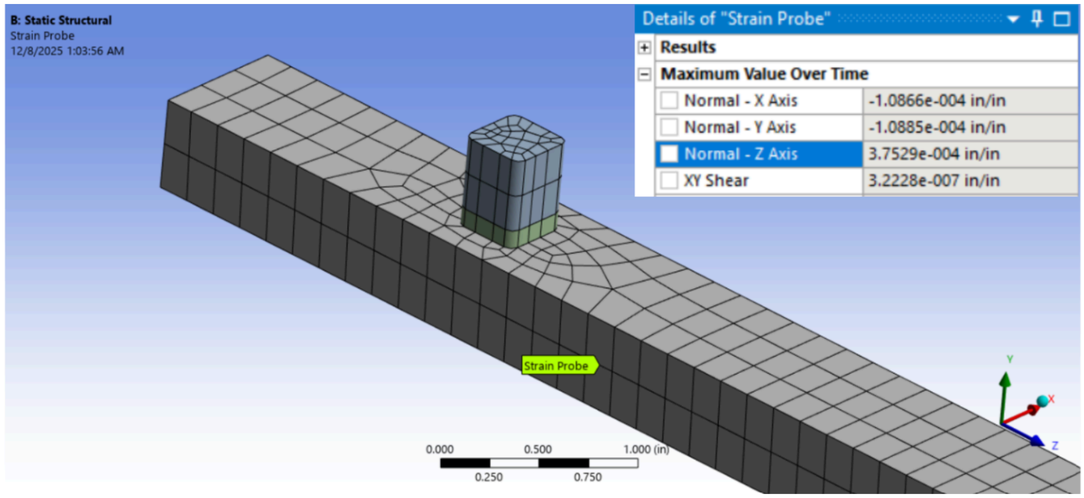
$$F=\frac{M}{L}=\frac{600}{16}=37.5\ lbf$$

$$\delta=\frac{FL^3}{3EI}=\frac{(37.5)(16)^3}{3(32\times10^6)(0.01758)}=\boxed{0.091\ in}$$

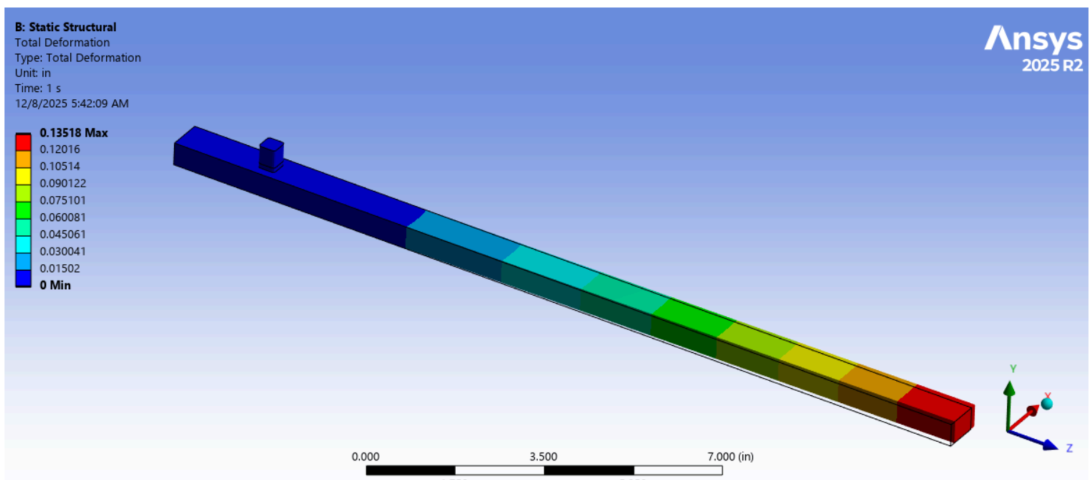
3. Results from FEM calculation of base design
   a. Maximum normal stress 12.477 ksi



   b. Strain at strain gauge 375.29 με

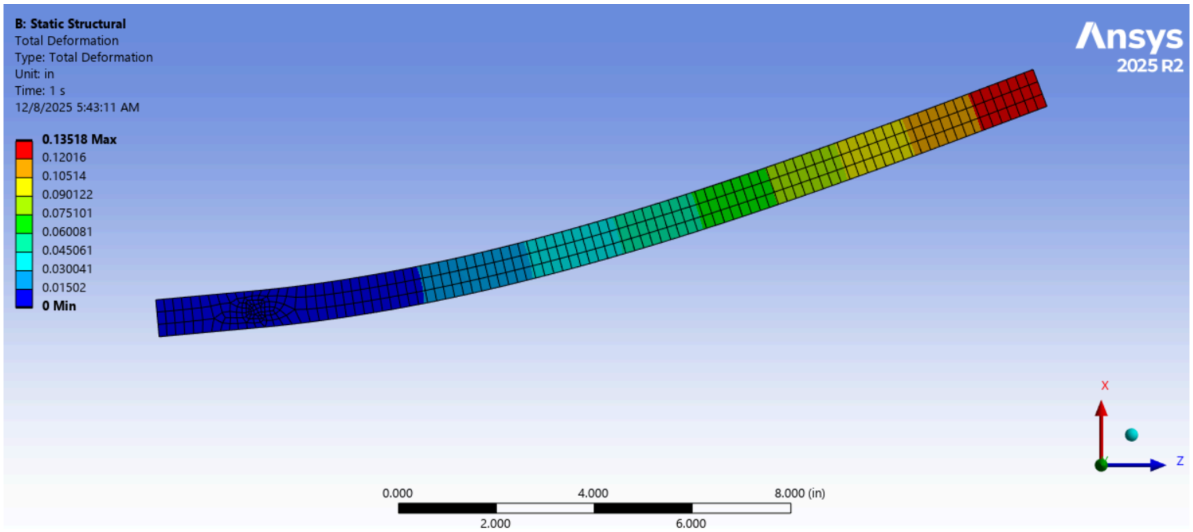


c. Deflection of load point 0.13518 in



5.1.2- 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?



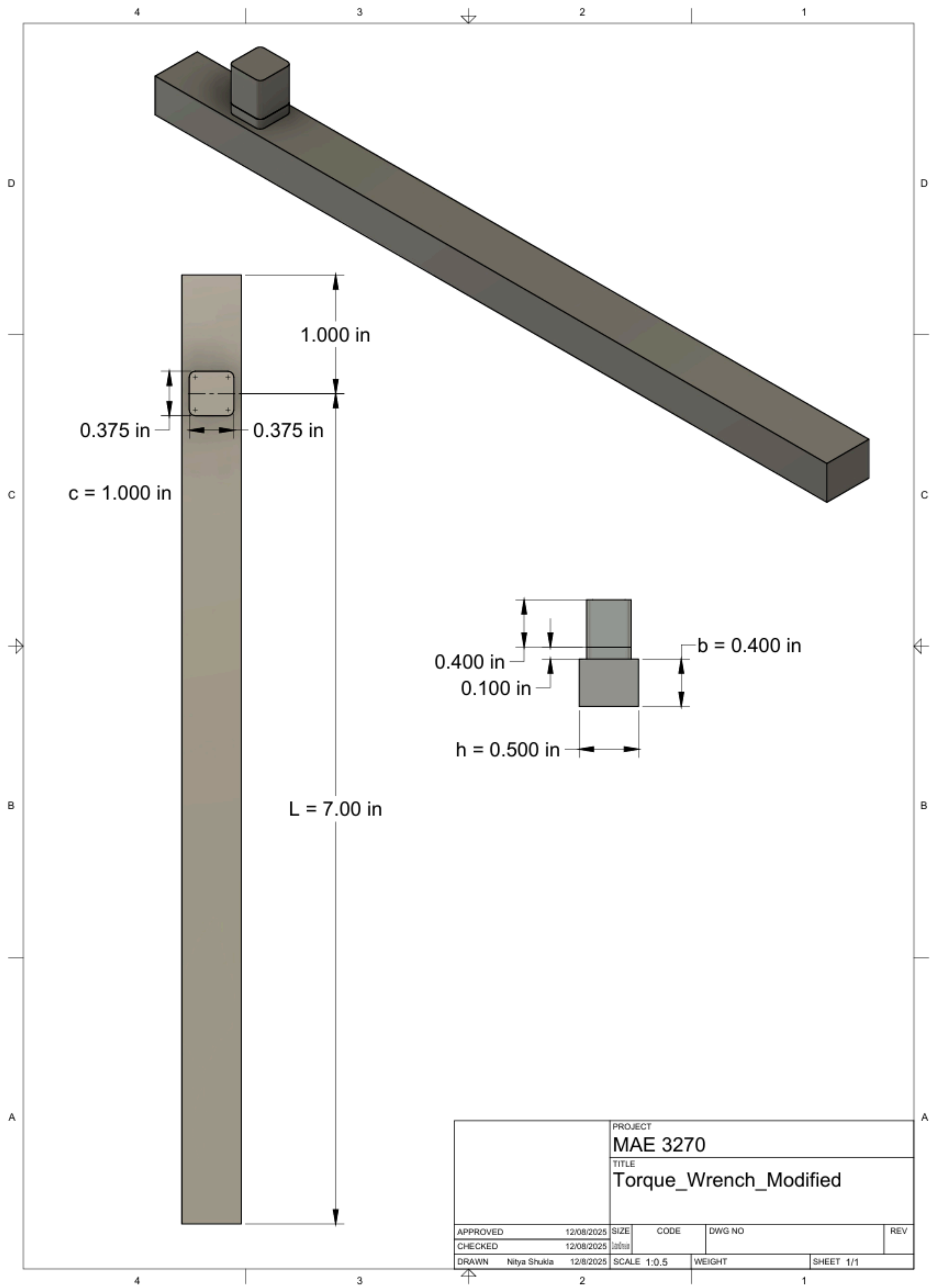
The mesh lines that cut across the beam handle do remain as straight lines when the body is substantially deformed. Thus, the beam theory that assumes that plane sections remain plane does apply to this analysis; the individual mesh components on the torque wrench's handle remain relatively undeformed, despite the scaled deformation displayed in the model above.

2. How do the FEM and hand calculated maximum normal stresses compare? If they differ significantly, why? The FEM maximum normal stress is 12.477 ksi, while the hand calculated maximum normal stress is 12.809; there is a 2.626% error between these two values, meaning that the FEM computation is quite similar to the hand calculation. The FEM analysis reports a maximum stress at the junction between the two driver components. However, this condition does not reflect the behavior of a physical torque wrench; therefore, the maximum normal stress on the plane between the handle and driver is more relevant. The FEM value is compared to the hand calculation, and since the two values are relatively close, the location of the maximum normal stress is effectively validated.
3. How do the FEM and hand calculated displacements compare? If they differ, why? The FEM displacement is 0.13518 in, while the hand calculated displacement is 0.091 in; there is a 39.066% difference between these two values, suggesting that they somewhat differ from one another. It is reasonable to assume that one of the reasons the FEM simulation predicts a higher displacement than the hand calculation is the inclusion of fillets in the CAD model. The rounded edges of the driver are likely to contribute to additional displacement, as they make it more difficult for the torque wrench to remain rotational stationary. Additionally, in the FEM simulation, the entire driver was not clamped still; displacement was only set to zero for the top portion of the driver, potentially resulting in a higher deflection of the load point.

Part II: Improved Design

5.2.1- Results

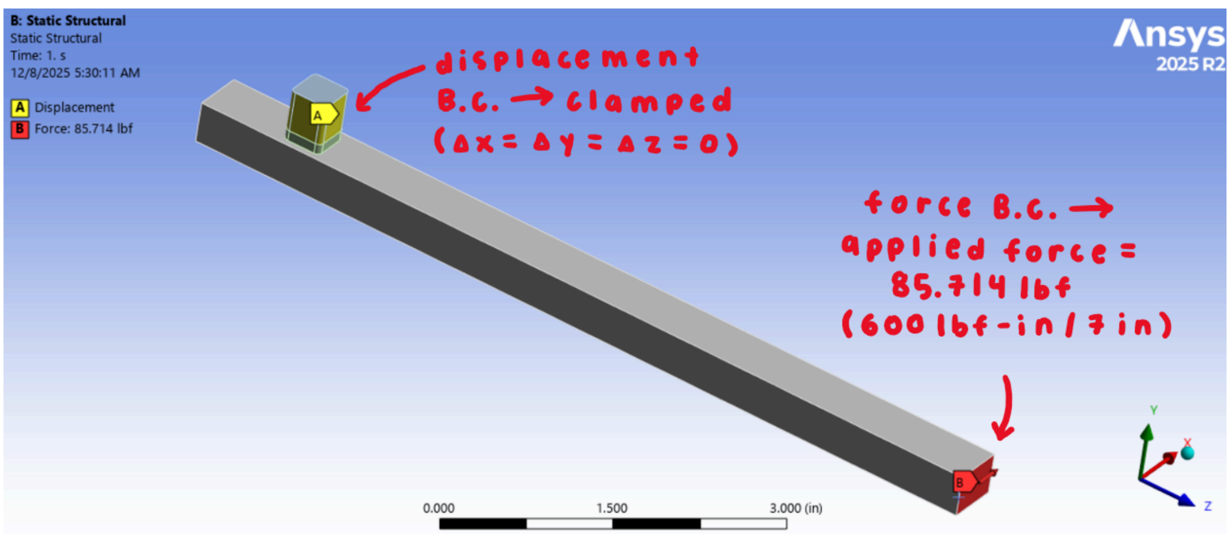
1. Images of CAD model. Must show all key dimensions.



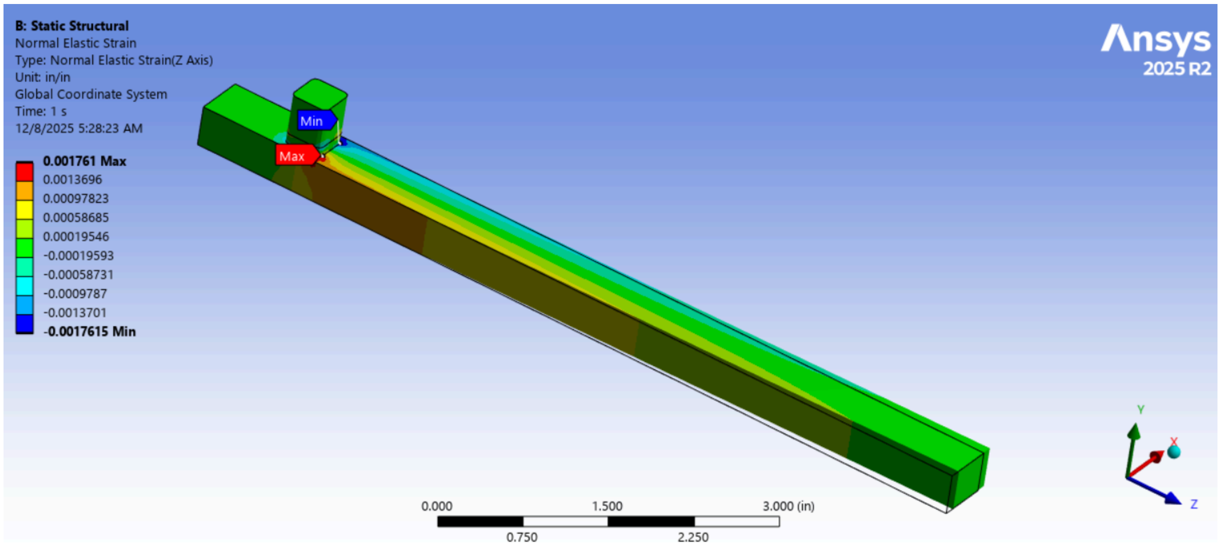
2. Describe material used and its relevant mechanical properties.
   The torque wrench was constructed using AerMet 100, which is a high strength alloy steel used in situations where high strength, high fracture toughness, and high fatigue resistance are necessary. It has a sufficiently high Young's Modulus, ultimate tensile strength, and fracture toughness, giving a range of dimensions that fulfill the requirements. Additionally, AerMet 100 ranks relatively high in the following material indices: $M_1 = \sigma_f/E$, $M_2 = K_{IC}/E$.

```
%initial conditions
M = 600;                  % max torque (in-lbf)
E = 29.5e6;               % Young's Modulus (psi)
nu = 0.29;                % Poisson's ratio
su = 285e3;               % tensile strength (psi)
KIC = 100e3;              % fracture toughness (psi*sqrt(in))
sfatigue= 100e3;          % fatigue strength from 10^6
name= 'Aermet 100';
```

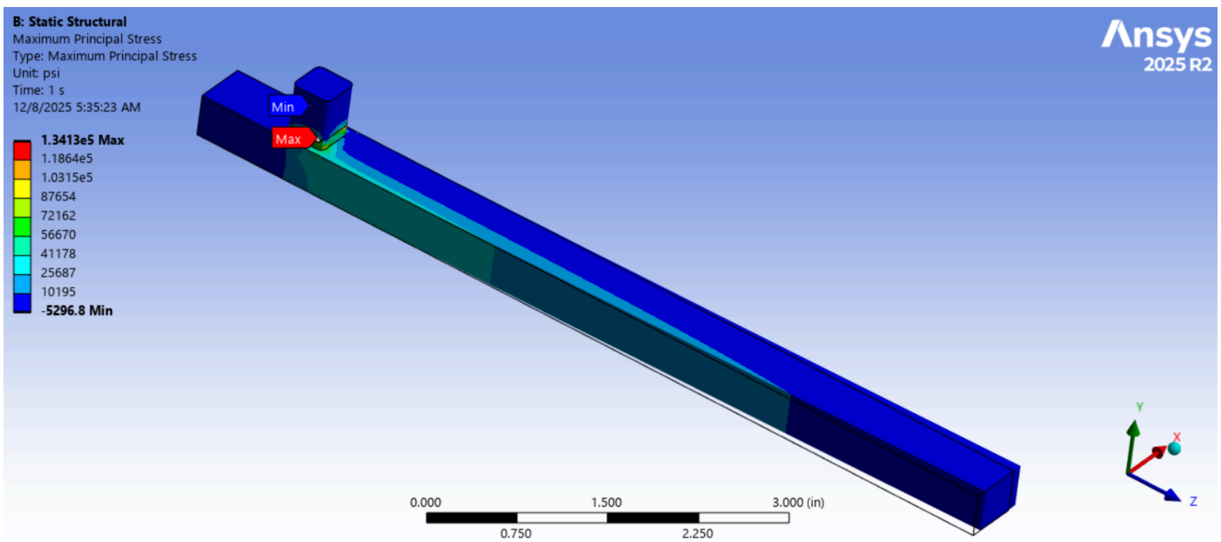
3. Diagram communicating how loads and boundary conditions were applied to your FEM model.



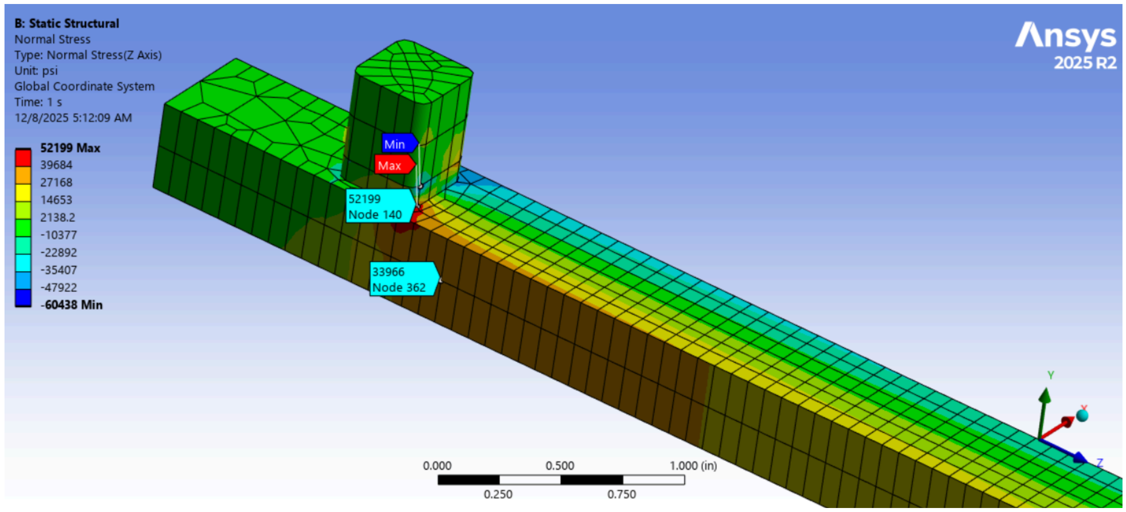
4. Normal strain contours in the strain gauge direction from FEM



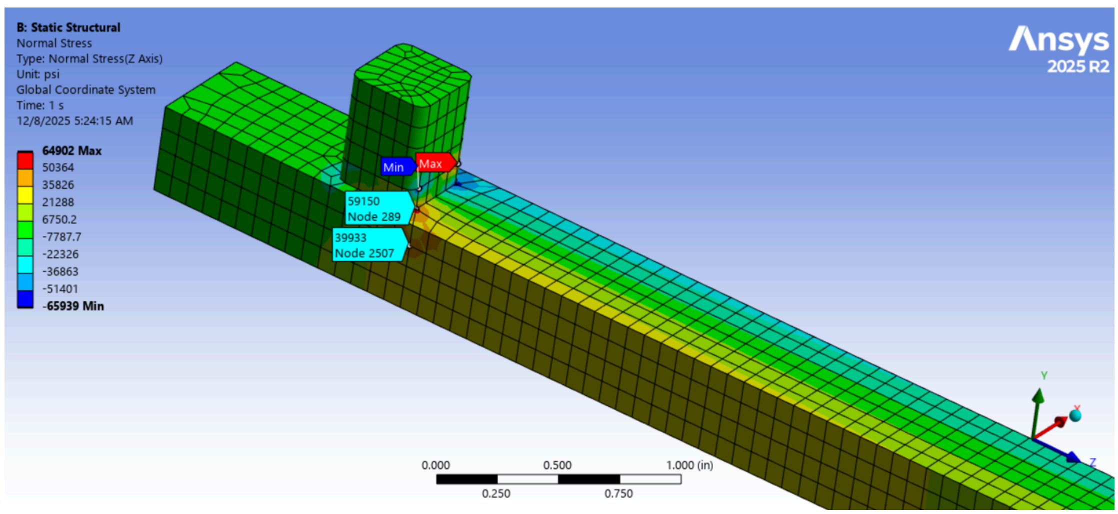
5. Contour plot of maximum principal stress from FEM



6. Summarize results from FEM calculation
    a. Maximum normal stress
       Mesh element size = 0.25 in: 33.966 ksi

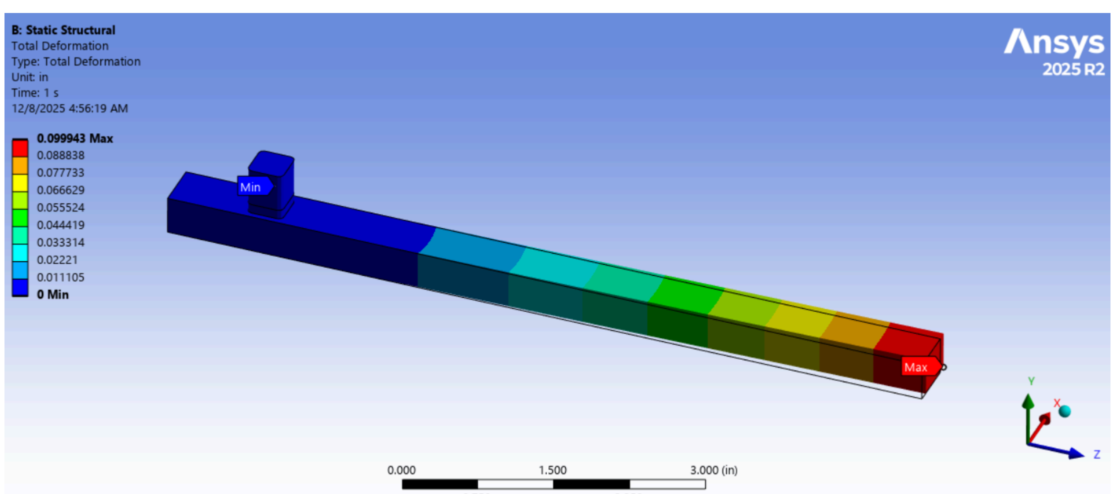


Mesh element size = 0.125 in: 39.933 ksi

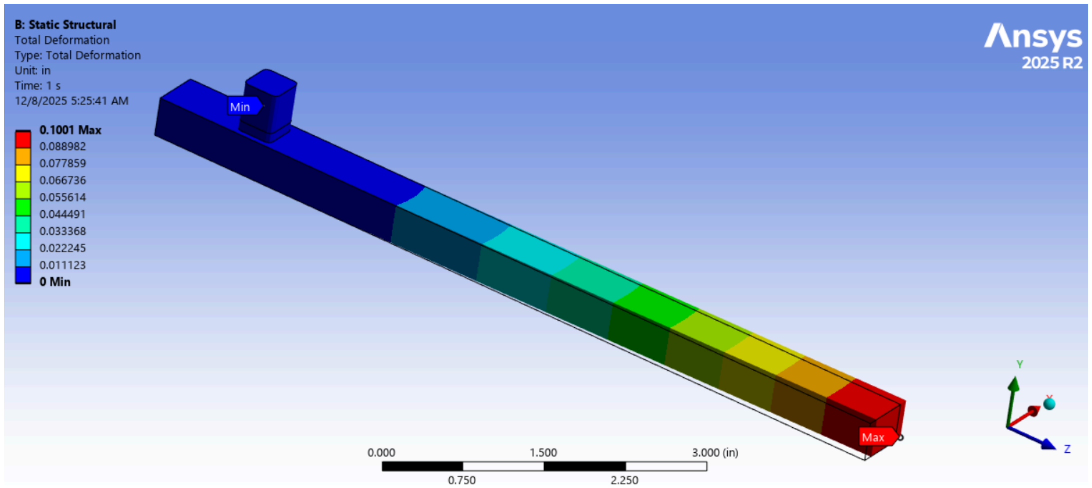


b. Load point deflection

Mesh element size = 0.25 in: 0.099943 in



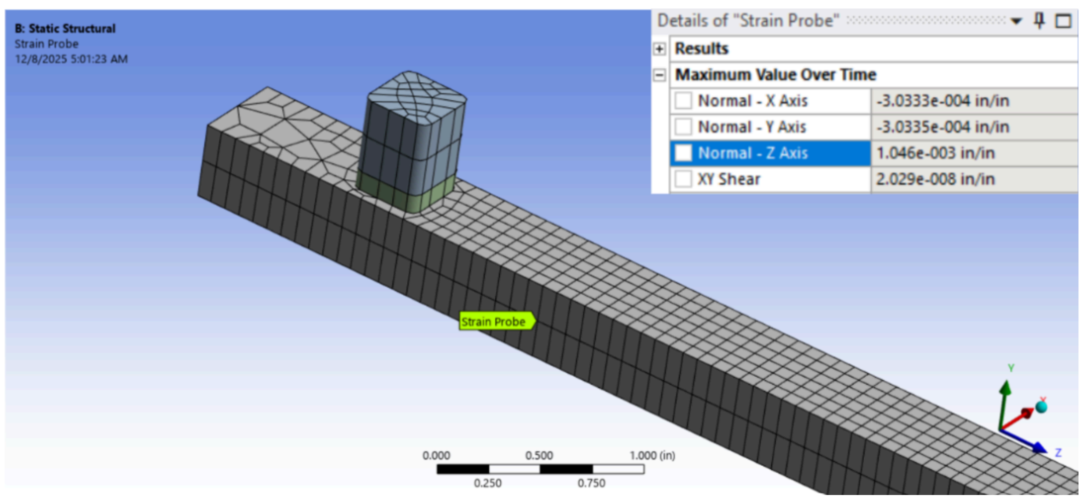
Mesh element size = 0.125 in: 0.1001 in



c. Strain at strain gauge location

Mesh element size = 0.25 in: 1046 με

Mesh element size = 0.125 in: 1046 με



7. Torque wrench sensitivity in mV/V using strains from FEM analysis

$$\frac{V_{out}}{V_{in}} = \frac{GF}{4}(\varepsilon_1 - \varepsilon_2)$$

$$\varepsilon_1 = -\varepsilon_2, \ |\varepsilon_1| = |\varepsilon_2| = \varepsilon \Rightarrow \frac{V_{out}}{V_{in}} = \frac{GF\varepsilon}{2}$$

$$GF = 2 \Rightarrow \frac{V_{out}}{V_{in}} = \varepsilon$$

$$\text{sensitivity (mV/V)} = \varepsilon(\mu\varepsilon) \times 10^3$$

$$= 1046\,\mu\varepsilon \times 10^3 = \boxed{1.046 \text{ mV/V}} > 1.0 \text{ mV/V}$$

8. Strain gauge selected (give type and dimensions): Omega SGD-3/350-LY11

   Type of strain gauge: Half-bridge Wheatstone bridge strain gauge

   - Constraint: half of total length of strain gauge must be smaller than distance from edge of drive to center of gauge
   - If c is location of strain gauge, then → c - (3/16 in) = 0.8125 in = 20.638 mm

   Dimensions:

   - Grid length: 3.2 mm → fits on handle width and within gauge location at c= 0.8125 in
   - Grid width: 2.5 mm
   - Nominal resistance: 350 Ohms
     - High resistance → lower current and heating at high excitations.
   - Gauge factor: 2.0→ this matches the sensitivity requirement where we used a gauge factor of 2
   - Linear orientation: it only measures strain in the bending axis

9. Check: FEM results meet requirements

   The requirements are to:

   - Attain at least 1.0 mV/V output at 600 in-lbf
     - 1.046 mV/V > 1.0 mV/V - **Satisfactory**
   - Safety factor X_o=4 for yield failure
     - 258 ksi/33.966 ksi =7.917 > 4 - **Satisfactory**
   - Fatigue stress safety factor of Xs=1.5
     - 94.36 ksi/33.966 ksi=2.778 > 1.5 - **Satisfactory**
   - Safety factor of X_k = 2 for crack growth from an assumed crack of depth 0.04 inches
     - 6.996 > 2 - **Satisfactory**
   - Material must be steel, aluminum, or titanium alloy
     - The material chosen is a steel alloy (AerMet 100). - **Satisfactory**

10. Observations from mesh refinement study

    The mesh refinement study results in differing maximum normal strength and load point deflection values. As the mesh element size is reduced from 0.25 in to 0.125 in, the maximum normal stress and load point deflection both increase; the strain at the strain gauge location remains roughly the same. The finer mesh is better able to capture sharp changes at geometric features or load application points. Thus, it can detect areas with significant stress concentrations, at which the stress approaches an infinite value. Additionally, the finer mesh is able to more accurately model the deformation of the torque wrench, reporting a more representative load point deflection. Because the strain at the strain gauge location is the same between the two mesh studies, a mesh size of 0.25 in appears adequate for accurately estimating the torque wrench's strain.