Results:

1. Script for hand calculations

```
M = 600; % max torque (in-lbf)
L = 16; % length from drive to where load applied (inches)
h = 0.58; % width
b = 0.32; % thickness
c = 1.0; % distance from center of drive to center of strain gauge
E = 30.E6; % Young's modulus (psi)
nu = 0.29; % Poisson's ratio
su = 210.E3; % tensile strength use yield or ultimate depending on material (psi)
KIC = 77.E3; % fracture toughness (psi sqrt(in))
sfatigue = 95.e3; % fatigue strength from Granta for 10^6 cycles
name = 'AISI 4340, QT 409'; % material name


I=b*h^3/12;
F=M/L;
c_calc=h/2;
load_point_deflection=M*L^2/(3*E*I)
max_normal_stress=M*c_calc/I

a=0.04; %assignment says crack size of 0.04 in
x = a/h;
%Y = 1.12 - 0.23*x + 10.6*x.^2 - 21.7*x.^3 + 30.4*x.^4;
Y=1.12;
Kmax = Y*max_normal_stress*sqrt(pi*a);
safety_factor_for_strength=su/max_normal_stress
safety_factor_for_crack_growth=KIC/Kmax
safety_factor_for_fatigue=sfatigue/max_normal_stress

M_bend=F*(L-c);
sigma_bend=M_bend*c_calc/I;
strain_at_guage=sigma_bend/E
output=strain_at_guage*1000 %for half-bridge
```

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.

load_point_deflection = 0.3280
max_normal_stress = 3.3442e+04
safety_factor_for_strength = 6.2795
safety_factor_for_crack_growth = 5.7992
safety_factor_for_fatigue = 2.8407
strain_at_guage = 0.0010
output = 1.0451

Maximum normal stress = 33.442 ksi
Strain at gauge = 1000 microstrain
Deflection at load point = 0.3280 in.

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 = 40.972 ksi
Strain at gauge = 1060 microstrain
Deflection at load point = 0.36641 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?

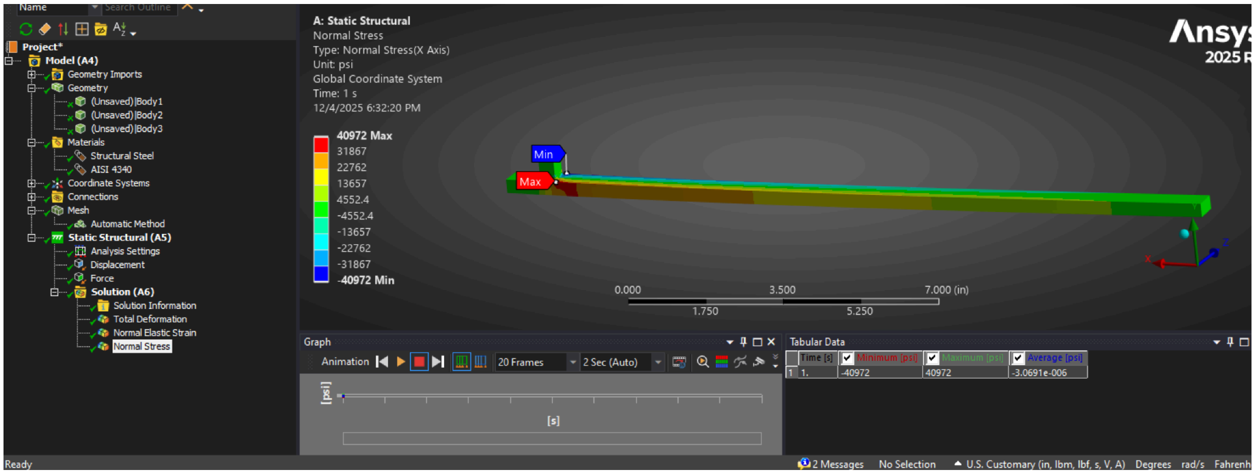
The mesh lines that cut across the beam handle remain as straight lines, which implies that beam theory is followed and the plane sections remain plane even under stress. Because the wrench follows the assumption that there is no cross-sectional warping, beam theory here is accurate.

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

The hand calculated maximum normal stress is less than the FEM by about 17%, which isn't a significant difference per say, but surely notable. The hand calculations include several assumptions that simplify the model in ways that the FEM software doesn't. The FEM investigates boundary conditions and accounts for the 3D shape of the wrench, resulting in a more accurate stress reading and a higher overall maximum normal stress.

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

The FEM and hand-calculated displacements are very similar, differing by less than 10%. This difference is small and can be attributed to boundary conditions and assumptions made in the hand calculations. This is less significant of a difference than the maximum normal stress, which implies that displacement is a less simplified equation when solving by hand.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Normal Stress
Type: Normal Stress(X Axis)
Unit: psi
Global Coordinate System
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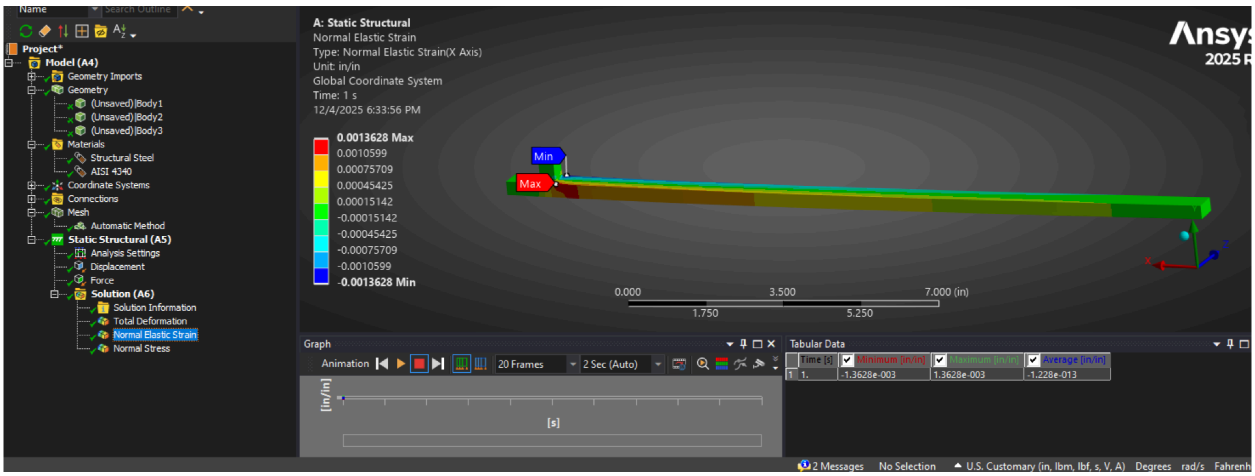
12/4/2025 6:32:20 PM
40972 Max
31867
22762
13657
4552.4
-4552.4
-13657
-22762
-31867
-40972 Min
Min
Max
0.000
3.500
7.000 (in)
1.750
5.250
Graph
Animation
20 Frames
2 Sec (Auto)
Tabular Data
Time [s]
Minimum [psi]
Maximum [psi]
Average [psi]
1.
-40972
40972
-3.0691e-006
Project*
Model (A4)
Geometry Imports
Geometry
(Unsaved)|Body1
(Unsaved)|Body2
(Unsaved)|Body3
Materials
Structural Steel
AISI 4340
Coordinate Systems
Connections
Mesh
Automatic Method
Static Structural (A5)
Analysis Settings
Displacement
Force
Solution (A6)
Solution Information
Total Deformation
Normal Elastic Strain
Normal Stress
Ready
2 Messages
No Selection
U.S. Customary (in, lbm, lbf, s, V, A)
Degrees
rad/s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Type: Normal Elastic Strain(X Axis)
Unit: in/in
Global Coordinate System
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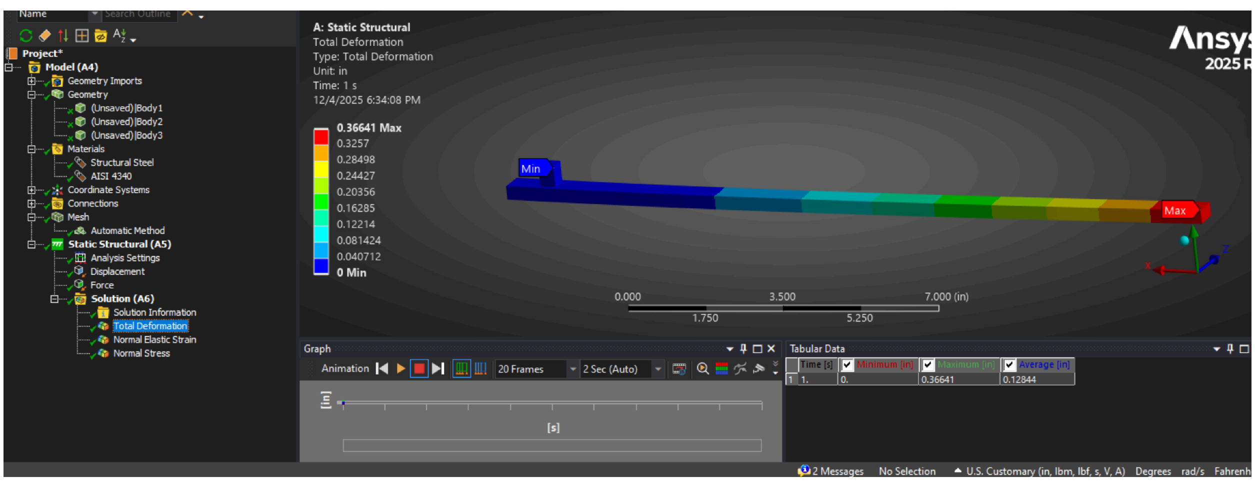
0.00075709
0.00045425
0.00015142
-0.00015142
-0.00045425
-0.00075709
-0.0010599
-0.0013628 Min
Min
Max
0.000
3.500
7.000 (in)
1.750
5.250
Graph
Animation
20 Frames
2 Sec (Auto)
Tabular Data
Time [s]
Minimum [in/in]
Maximum [in/in]
Average [in/in]
1.
-1.3628e-003
1.3628e-003
-1.228e-013
2 Messages
No Selection
U.S. Customary (in, lbm, lbf, s, V, A)
Degrees
rad/s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Total Deformation
Type: Total Deformation
Unit: in
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12/4/2025 6:34:08 PM
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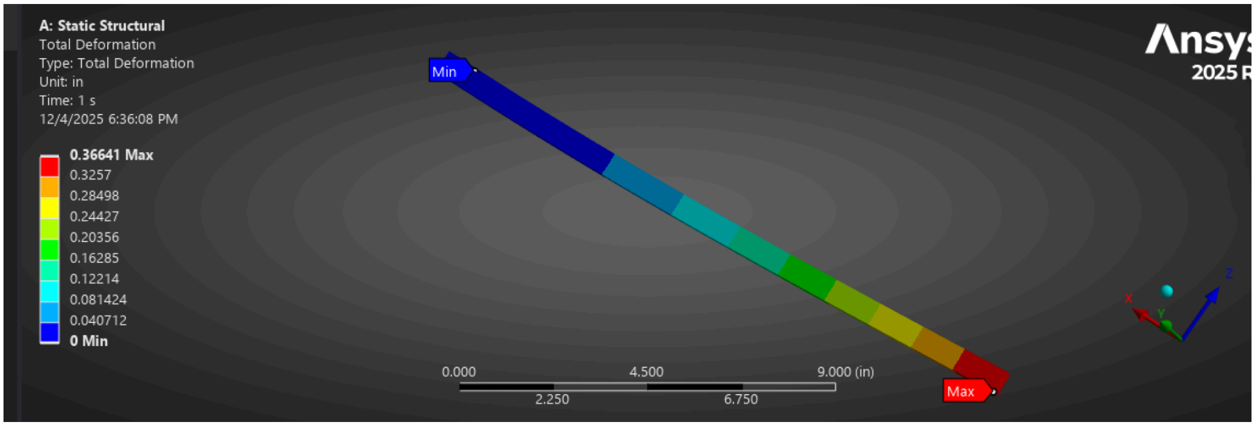
0.28498
0.24427
0.20356
0.16285
0.12214
0.081424
0.040712
0 Min
Min
Max
0.000
3.500
7.000 (in)
1.750
5.250
Graph
Animation
20 Frames
2 Sec (Auto)
Tabular Data
Time [s]
Minimum [in]
Maximum [in]
Average [in]
1.
0.
0.36641
0.12844
2 Messages
No Selection
U.S. Customary (in, lbm, lbf, s, V, A)
Degrees
rad/s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Total Deformation
Type: Total Deformation
Unit: in
Time: 1 s
12/4/2025 6:36:08 PM
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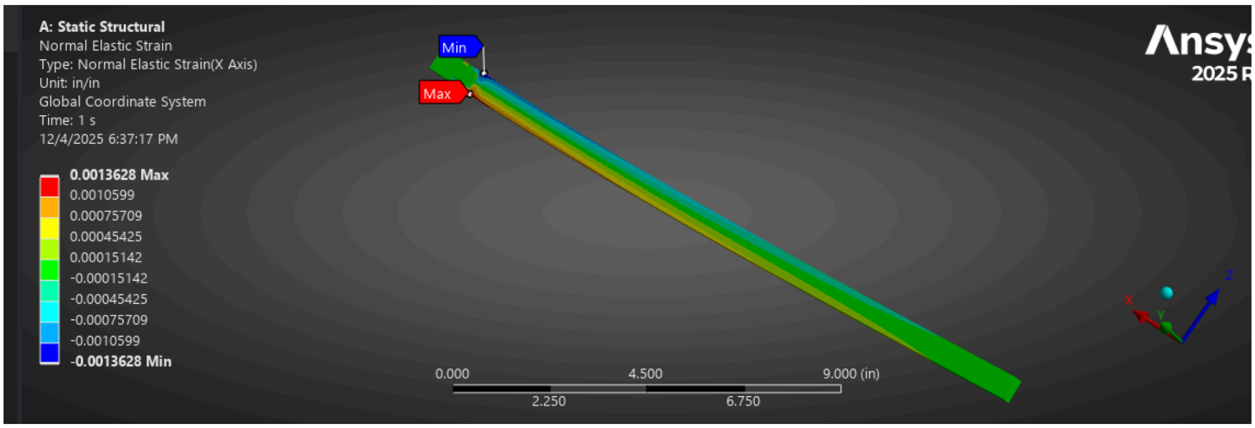
0.3257
0.28498
0.24427
0.20356
0.16285
0.12214
0.081424
0.040712
0 Min
Min
Max
0.000
4.500
9.000 (in)
2.250
6.750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Normal Elastic Strain
Type: Normal Elastic Strain(X Axis)
Unit: in/in
Global Coordinate System
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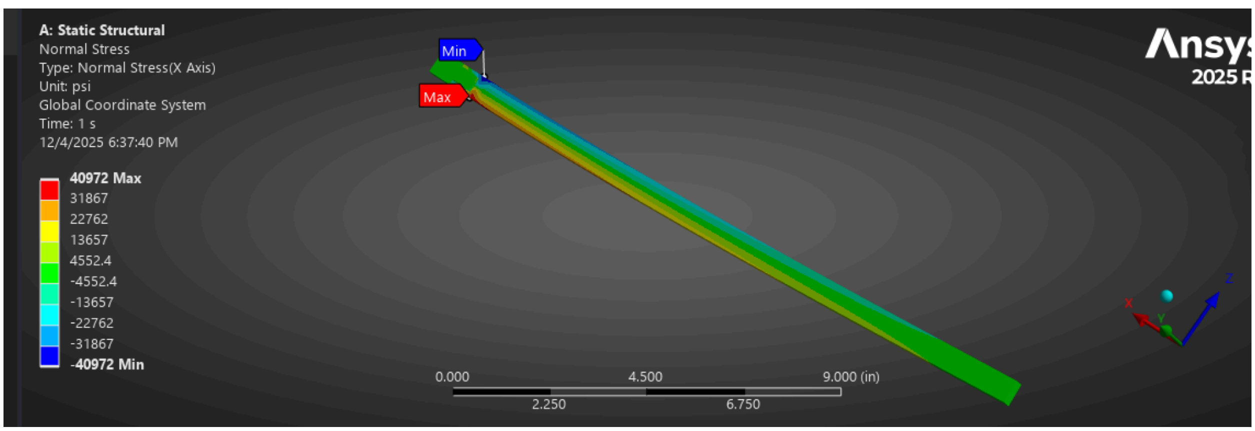
12/4/2025 6:37:17 PM
0.0013628 Max
0.0010599
0.00075709
0.00045425
0.00015142
-0.00015142
-0.00045425
-0.00075709
-0.0010599
-0.0013628 Min
Min
Max
0.000
4.500
9.000 (in)
2.250
6.750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Normal Stress
Type: Normal Stress(X Axis)
Unit: psi
Global Coordinate System
Time: 1 s
12/4/2025 6:37:40 PM
40972 Max
31867
22762
13657
4552.4
-4552.4
-13657
-22762
-31867
-40972 Min
Min
Max
0.000
4.500
9.000 (in)
2.250
6.750