Baseline FEM Analysis Report

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Results

Script used for hand calculations

```
%% MAE 3270 - Torque wrench baseline verification
clear; clc;

%% Given (baseline)
T   = 600;
L   = 16;
h   = 0.75;
b   = 0.5;
c   = 1.0;
E   = 32e6;
nu  = 0.29;

su      = 370e3;
KIC     = 15e3;
sfatigue= 115e3;

% Safety factors required
X0_req = 4;    % static
XK_req = 2;    % crack growth
XS_req = 1.5; % fatigue

%% Convert torque to equivalent end force
F = T / L;
fprintf("Equivalent end force F = %.4f lbf\n", F);


I = b*h^3/12;       % in^4
y = h/2;            % distance to outer fiber (in)

fprintf("Section I = %.6f in^4\n", I);


Mmax = F*L;         % in-lbf
sigma_max = Mmax*y/I;  % psi

fprintf("Max normal stress sigma_max = %.3f ksi\n", sigma_max/1000);


delta_tip = F*L^3/(3*E*I);  % in
fprintf("Load point deflection delta = %.4f in\n", delta_tip);


M_c = F*(L - c);
sigma_c = M_c*y/I;
eps_c = sigma_c / E;
eps_micro = eps_c * 1e6;

fprintf("Strain at gauge = %.1f microstrain\n", eps_micro);


GF = 2.0;
Vout_over_Vex = (GF/2) * eps_c;
mV_per_V = Vout_over_Vex * 1000;

fprintf("Half-bridge output = %.3f mV/V (GF=%.1f)\n", mV_per_V, GF);


n_static = su / sigma_max;


n_fatigue = sfatigue / sigma_max;


a = 0.04;
Y = 1.12;
K = Y * sigma_max * sqrt(pi*a);
n_K = KIC / K;

fprintf("\nSafety factor (static)  = %.2f\n", n_static);
fprintf("Safety factor (fatigue) = %.2f\n", n_fatigue);
fprintf("Safety factor (fracture)= %.2f  (a=%.3f in, Y=%.2f)\n", n_K, a, Y);


baseline.delta = 0.091;       % in
baseline.sigma = 12.80;       % ksi
baseline.eps   = 375;         % microstrain
baseline.out   = 0.38;        % mV/V
baseline.n0    = 28.9;
baseline.nK    = 2.95;
baseline.nS    = 8.98;
```

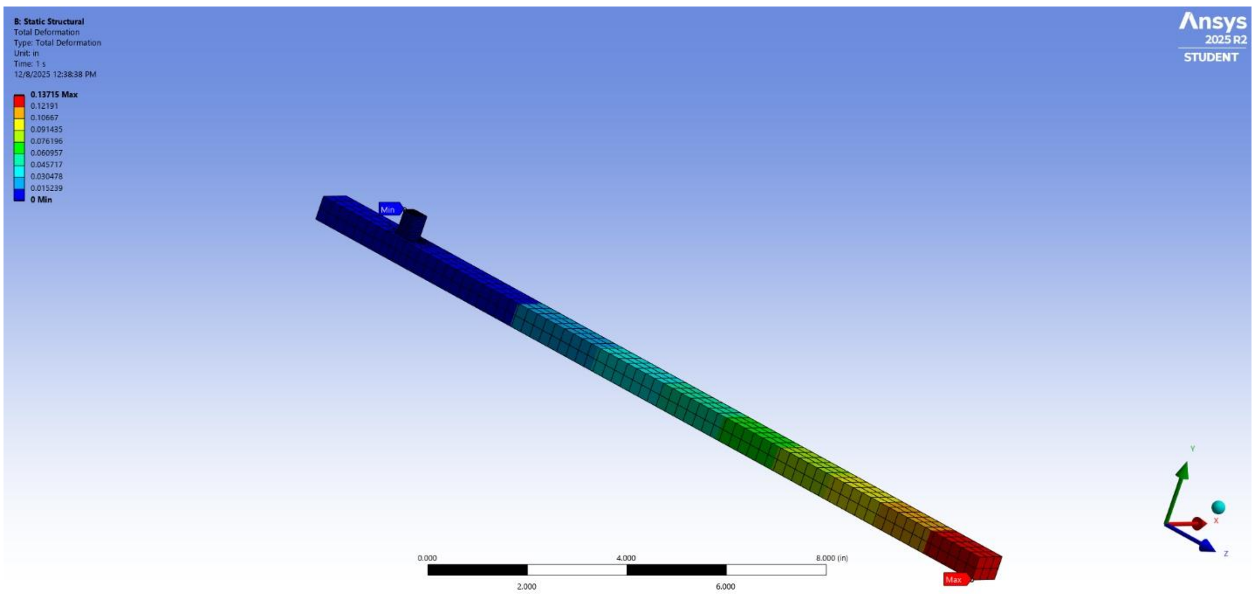
```
Equivalent end force F = 37.5000 lbf
Section I = 0.017578 in^4
Max normal stress sigma_max = 12.800 ksi
Load point deflection delta = 0.0910 in
Strain at gauge = 375.0 microstrain
Half-bridge output = 0.375 mV/V (GF=2.0)
Safety factor (static)  = 28.91
Safety factor (fatigue) = 8.98
Safety factor (fracture)= 2.95  (a=0.040 in, Y=1.12)
```

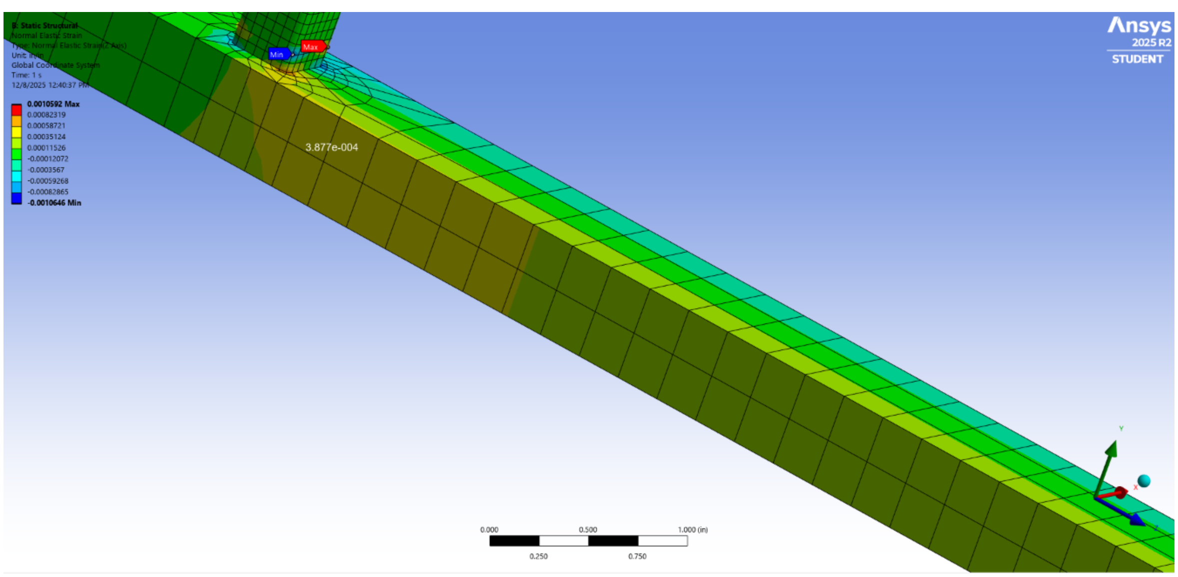
```
fprintf("\n--- Comparison vs provided baseline ---\n");
fprintf("Deflection:  calc %.4f  vs given %.4f\n", delta_tip, baseline.delta);
fprintf("Stress:      calc %.3f ksi vs given %.3f ksi\n", sigma_max/1000, baseline.sigma);
fprintf("Strain:      calc %.1f µε  vs given %.1f µε\n", eps_micro, baseline.eps);
fprintf("Output:      calc %.3f mV/V vs given %.3f mV/V\n", mV_per_V, baseline.out);
fprintf("n_static:    calc %.2f vs given %.2f\n", n_static, baseline.n0);
fprintf("n_fracture:  calc %.2f vs given %.2f\n", n_K, baseline.nK);
fprintf("n_fatigue:   calc %.2f vs given %.2f\n", n_fatigue, baseline.nS);
```

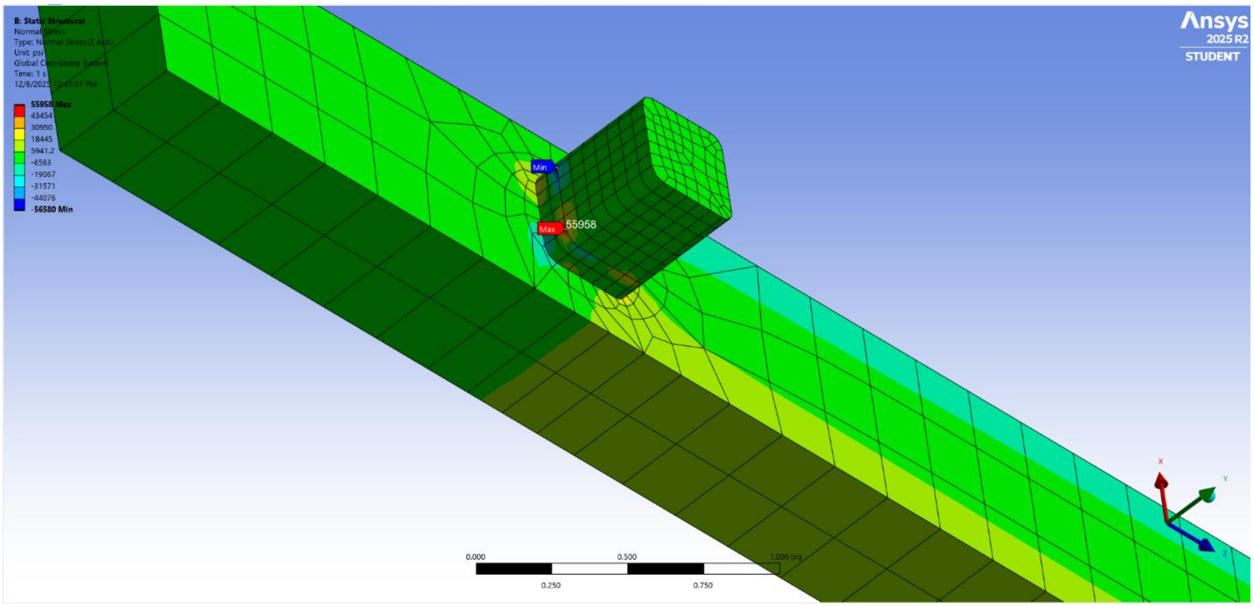
```
--- Comparison vs provided baseline ---
Deflection:   calc 0.0910  vs given 0.0910
Stress:       calc 12.800 ksi vs given 12.800 ksi
Strain:       calc 375.0 µε  vs given 375.0 µε
Output:       calc 0.375 mV/V vs given 0.380 mV/V
n_static:     calc 28.91 vs given 28.90
n_fracture:   calc 2.95 vs given 2.95
n_fatigue:    calc 8.98 vs given 8.98
```

Deflection	0.0910 in
Stress	12.8Ksi
Strain	375με
Output	0.375mV/V
Safety Factor for strength	28.91
Safety Factor for crack growth	2.95
Safety Factor for Fatigue	8.98

FEM Analysis







Deflection	0.13715 in
Strain	387 με
Maximum normal Stress	55.958 ksi

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?

For most of the straight handle region, the deformed mesh lines cutting across the thickness stay almost straight, supporting the Euler-Bernoulli assumption that plan sections remain plane. In that region, the lines do remain straight, showing that beam theory is reasonably accurate for global behavior. The gauge strain matches well between the hand and FEM analysis, therefore supporting that beam theory is good at the gauge location. Approaching the drive region, cross-sections begin to distort, so beam theory is not accurate locally near the drive.

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

Hand – 12.8 ksi

FEM – 55.958 ksi

There is a significant difference between the two, the FEM calculation is 4.4 times higher than the hand calculation. The main reason for this difference is that the hand calculation is a beam-theory nominal bending stress for an ideal prismatic beam and therefore does not include stress concentrations. The FEM reports the true maximum, where sharp corners, fixed/clamped boundaries can create local stress concentrations. As shown in the image captured, the maximum stress for the FEM occurs where the two parts of the drive meet. The FEM measures maximum stress, while the hand value calculates nominal section stress, two different values.

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

Hand Deflection: 0.0910 in

FEM Deflection: 0.13715 in

The FEM deflection is roughly 1.5x the magnitude of the hand deflection. The CAD model includes non-prismatic regions such as the drive head, and transitions that reduce stiffness compared with a simple uniform beam assumption. The Euler-Bernoulli beam theory neglects shear deformation. The 3D solid model includes additional compliance modes that may lead to an increase in deflection.