

Stress and Deflection Analysis of the LCLS Gun Laser Transport Line

1.0 ABSTRACT

The goal of this memo is to seek the approval of the SLAC Earthquake Committee, for the design of the LCLS Gun Laser Transport Line.

The Laser Transport Line provides an optical path for the gun drive laser, from the future, above ground, LCLS laser hut at SLAC Linac sector 20, through a Linac roof penetration, to the under ground LCLS Gun vault, also located at sector 20.

The LCLS Gun Laser Transport Line consists of six 25' long, 2.5" diameter aluminum tubes symmetrically distributed around an aluminum center strong-back. Each tube is capped top and bottom with a vacuum tight optical quality window. The tubes are welded to a 2" thick, aluminum, upper support plate at ground level. The upper support plate is resting on three, 1" diameter, vertical, steel, threaded rods embedded in the concrete floor of the LCLS Gun laser hut. The strong-back is welded to this support plate as well. The six aluminum tubes are welded to an additional Al plate at the roof penetration entrance at the LCLS Gun Vault. The bottom end of the strong-back is welded to this plate as well. To prevent the Al tubes from twisting and flexing there are three spacer plates equally spaced between the support plate at ground level and the plate at the roof penetration entrance at the LCLS Gun Vault. These spacer plates are welded to the Al tubes as well as the strong-back.

To prevent radiation from penetrating up through the Linac roof penetration there is a lead plug at the very end of the Laser Transport Line assembly. The lead plug is held in place by a basket that is welded to the strongback. The space between the Linac roof penetration and the basket will be sealed with foam after the installation and alignment of the assembly has taken place.

In case of strongback failure the whole laser transport line is prevented from falling through the Linac roof penetration by a steel plate ring (lower support plate) that is mounted in the ceiling of the LCLS gun vault.

During the operation of the LCLS Gun Laser Transport Line the six Al tubes will be pumped down to approximately $1\text{E}-3$ torr. Each tube is equipped with a vacuum pump-down valve which will be closed after the initial pump down. The pressure will then be allowed to rise to an equilibrium of approximately $1\text{E}-1$ torr.

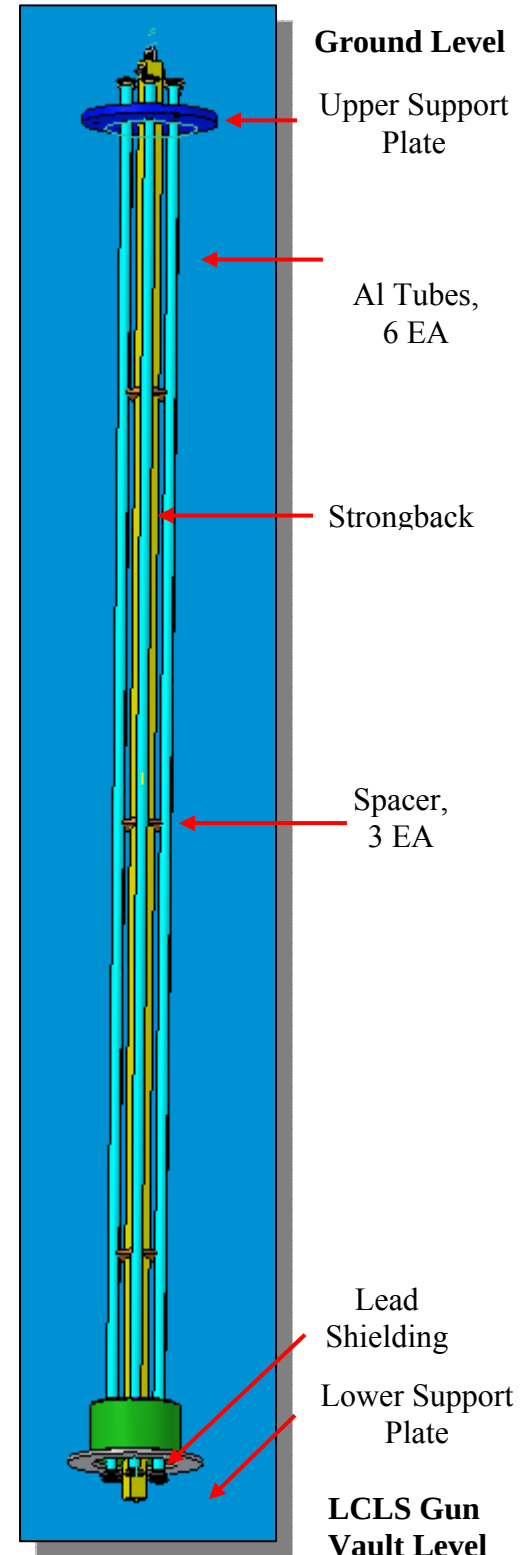


Fig. 1 LCLS Gun Laser Transport Line Assembly

This memo intends to show the mechanical design of the LCLS Gun laser transport line assembly, as well as stress and deflection calculations for the components in this assembly.

2.0 WEIGHTS

PART NO.	DESCRIPTION	WEIGHT (LBS)	QTY	TOTAL WEIGHT (LBS)
PF-380-902-02	TUBE SUPPORT PLATE	8	3	24
PF-380-902-28	LIFTING TUBE	118.4	1	118.4
PF-380-902-35	LIFT BOLT	3.1	1	3.1
PF-380-902-29	LIGHT TRANSPORT TUBE	28.3	6	169.8
PF-380-902-36	EYE LIFT	5.4	1	5.4
PF-380-902-34	SPACER	0.68	2	1.36
PF-380-902-30	LEAD CONTAINER	76.2	1	76.2
PF-380-902-32	COVER	0.96	6	5.76
MO38090231-0	LEAD	902.7	1	902.7
PF-380-902-10	HANGER PLATE	128.3	1	128.3
	ATLAS_FLANGE	2.3	12	27.6
PF-380-902-39	BOTTOM TUBE SUPPORT	41.2	1	41.2
	MDC REDUCING TEE	5.9	4	23.6
PF-380-902-40	SPACER	0.28	2	0.56
TOTAL=				1527.42

Data from Machinery's handbook page 356

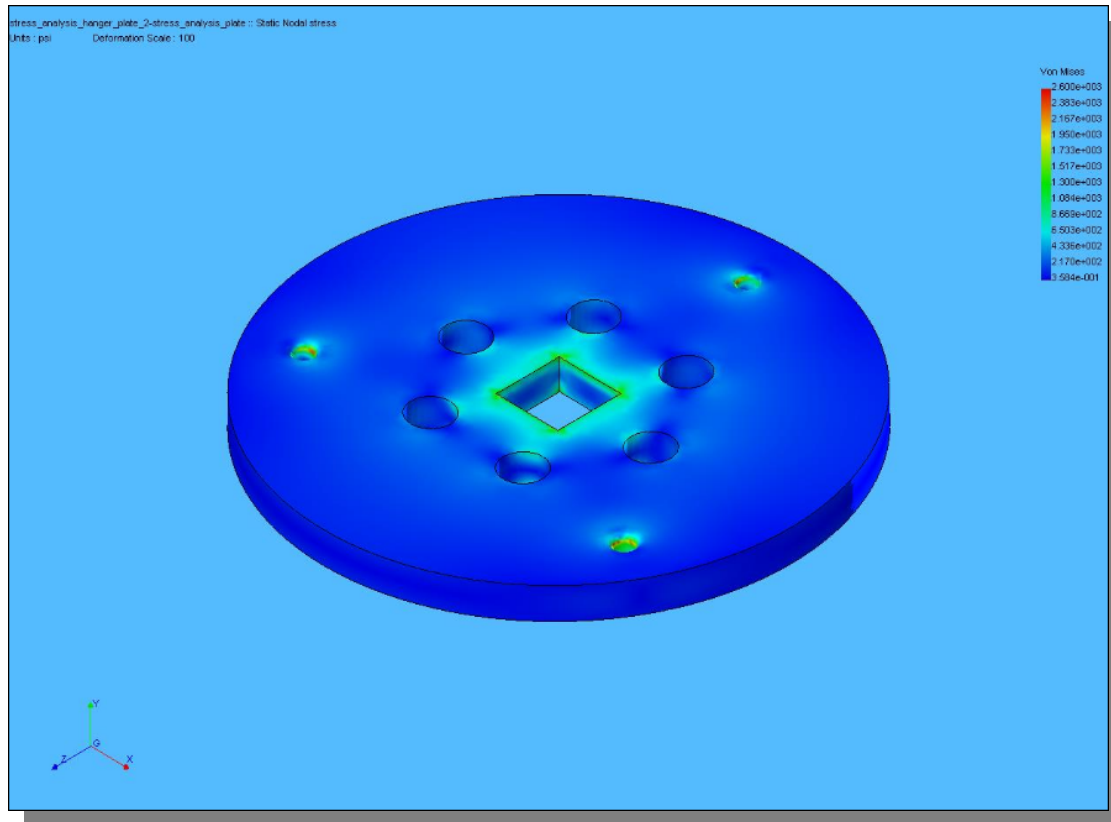
Alum Density= .093 lb/in³

Steel Density= .283 lb/in³

Lead Density= .397 lb/in³

3.0 STRESS CALCULATIONS

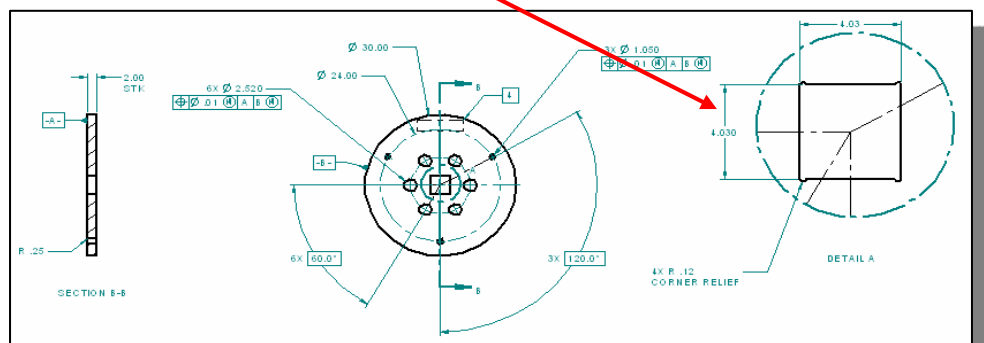
3.1 Upper support plate



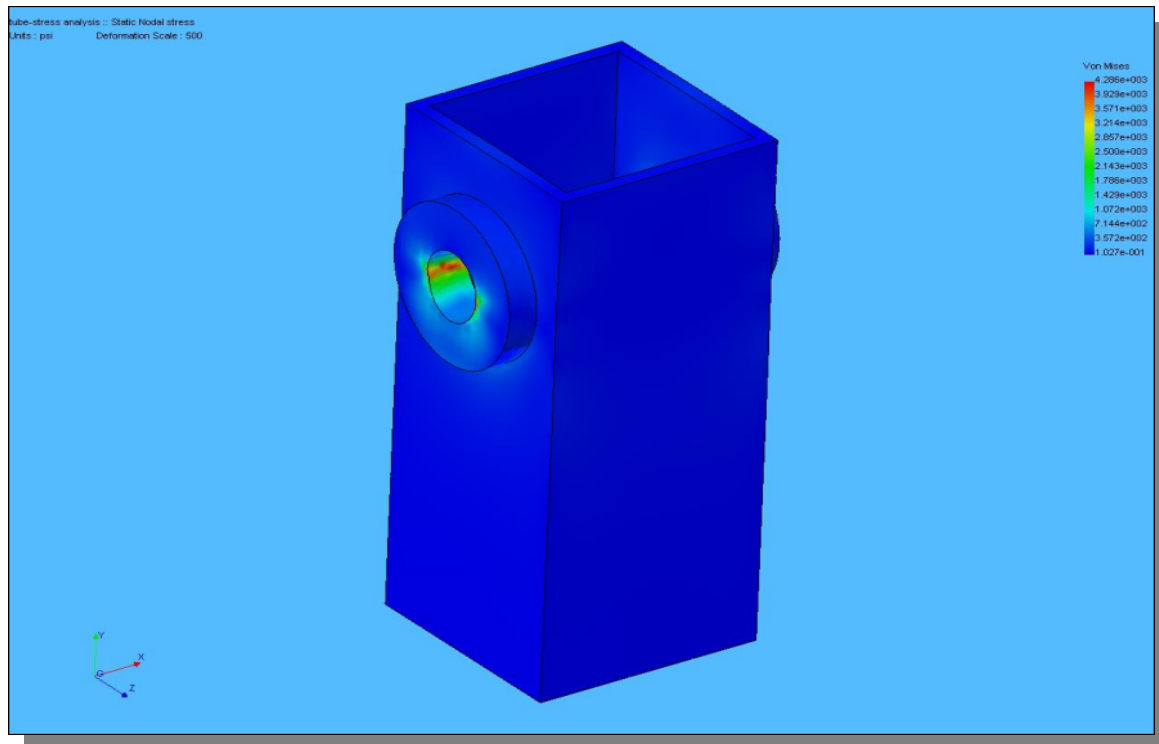
CONCLUSION: The calculated static stresses on the upper support plate are well below the yield strength for aluminum. The maximum static stress of the upper support plate is calculated to be between 1000 and 1300 psi. The maximum stresses occur at the corners where the strong-back is welded to the upper support plate, as well as at the holes where the vertical threaded rods attach to the upper support plate. Assuming these calculated values for the stresses and comparing them to the yield strength of aluminum, (approximately 10,000 psi), gives a safety factor of $10000/1300 = 7.69$

To minimize the effects of the stresses at the corners where the strong-back attaches to the upper support plate, the corners have been notched out.

To minimize the effects of the stresses where the vertical threaded rods attach to the upper support plate the holes have been counter sunk to avoid any sharp corners.

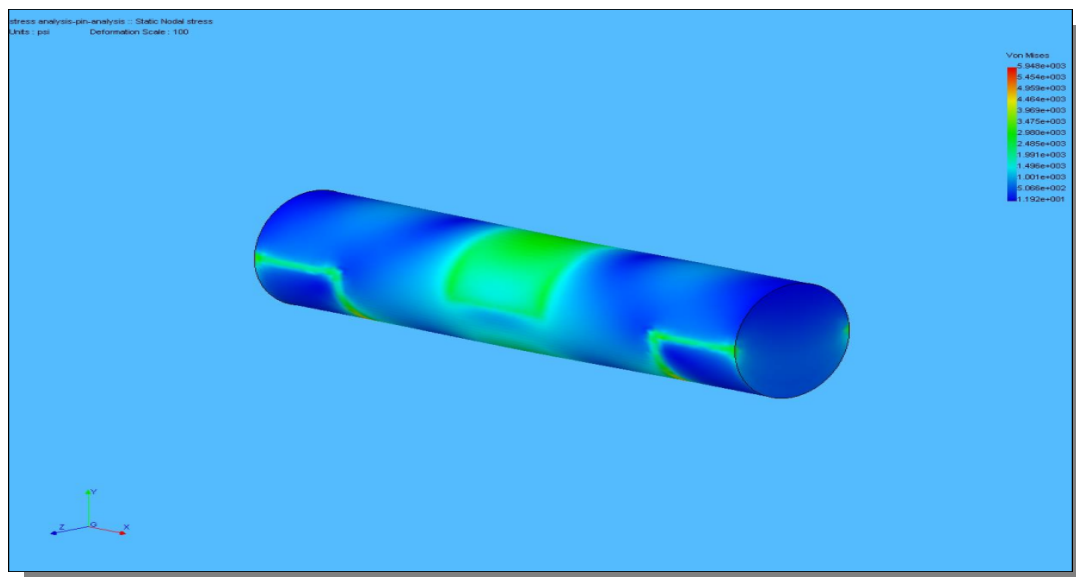


3.2 Strongback



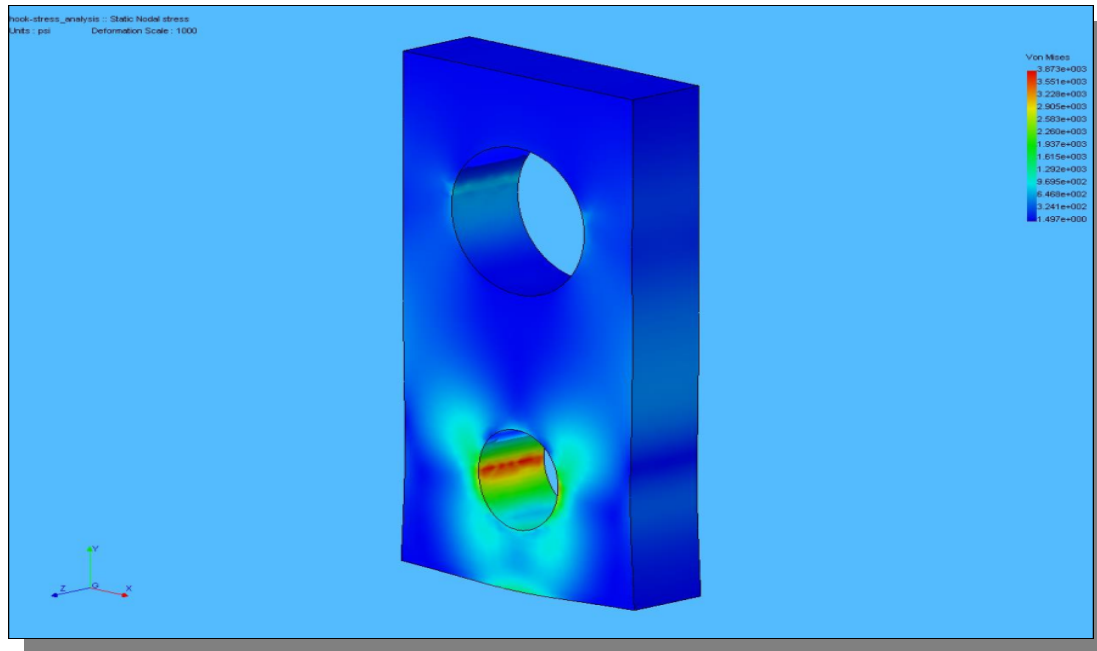
CONCLUSION: The calculated maximum static stresses on the Strongback are well below the yield strength for aluminum. The maximum static stress on the strongback is calculated to be between 3500 and 4000 psi. Assuming these calculated values for the stresses and comparing them to the yield strength of aluminum, (approximately 10,000 psi), gives a safety factor of $20000/4000 = 5$

3.3 Lifting bolt



CONCLUSION: The calculated maximum static stresses on the Lifting Bolt are well below the yield strength of steel. The maximum static stress on the lifting bolt is calculated to be between 2000 and 2500 psi. Assuming these calculated values for the stresses and comparing them to the yield strength of steel, (approximately 60,000 psi), gives a safety factor of $60000/2500 = 24$

3.4 Lifting connector



CONCLUSION: The calculated maximum static stresses on the Lifting Connector are well below the yield strength for steel. The maximum static stress on the lifting connector is calculated to be between 3000 and 3500 psi. Assuming these calculated values for the stresses and comparing them to the yield strength of steel, (approximately 10,000 psi), gives a safety factor of $60000/3500 = 17.14$

3.5 Stress/Strip force calculation for vertical threaded rods

Hex nut height (12 threads per inch, 1 inch) = 0.86 in

Minor Diameter: 0.9"

Picth Diameter: 0.946"

Major Diameter: 1.0"

Thread Pitch Circle Diameter, $d_p = D - 0.64952 \times p$

[http://www.engineersedge.com/thread_strength/thread_bolt_stress.htm, 12/09/04]

where

D_p = Pitch Circel Diameter of Thread

$D =$ Major Diameter

$p =$ 1/Number of Threads Per Inch (n)

$$d_p = 1.000 - 0.64952 \times 1/12 = 0.946''$$

Thread Shear Area, $A_{th} = 0.5 \times \pi \times d_p \times L_e = 0.5 \times \pi \times L_e \times (D - 0.64952 \times p)$

[http://www.engineersedge.com/thread_strength/thread_bolt_stress.htm, 12/09/04]

where

$A_{th} =$ Thread Shear Area

$L_e =$ Thread Engagement Length $= \pi \times D_p \times n$

$D_p =$ Pitch Circle Diameter of Thread

$D =$ Major Diameter

$p =$ 1/Number of Threads Per Inch (n)

$$L_e = \pi \times 0.946 \times 12 = 35.641''$$

$$A_{th} = 0.5 \times \pi \times 0.946 \times 35.641 = 52.934 \text{ in.}^2$$

$$\text{Load on each vertical threaded rod} = 1527.420/3 = 509.140 \text{ lb}$$

$$\text{Actual shear stress on thread} = \text{Load}/A_{th}$$

$$\text{Actual shear stress} = 509.140/52.934 = 9.618 \text{ psi}$$

Allowable shear stress = 50% of tensile strength

Ultimate tensile strength for steel, 73000 psi

[Machinery's handbook page 356, 24th ed]

$$\text{Allowable shear stress} = 73000 \times 0.5 = 36500 \text{ psi}$$

CONCLUSION: Thread stripping is not an issue for this design. The vertical threaded rods are over-sized compared to the relatively small load.

3.6 Critical buckling force of vertical threaded rods

$$P_{cr} = (4 \times \pi^2 \times E \times I)/L^2 \quad [\text{Roark's Formulas for Stress and Strain}]$$

Where

$P_{cr} =$ Critical load for buckling

$E =$ Modulus of elasticity, 30E6 psi [Machinery's Handbook, 1959 ed., p. 425]

$I =$ Moment of inertia $= (\pi d^4)/64$ [Machinery's Handbook, 1959 ed., p. 360]

$$\rightarrow (3.14 \times 1^4)/64 = 0.049$$

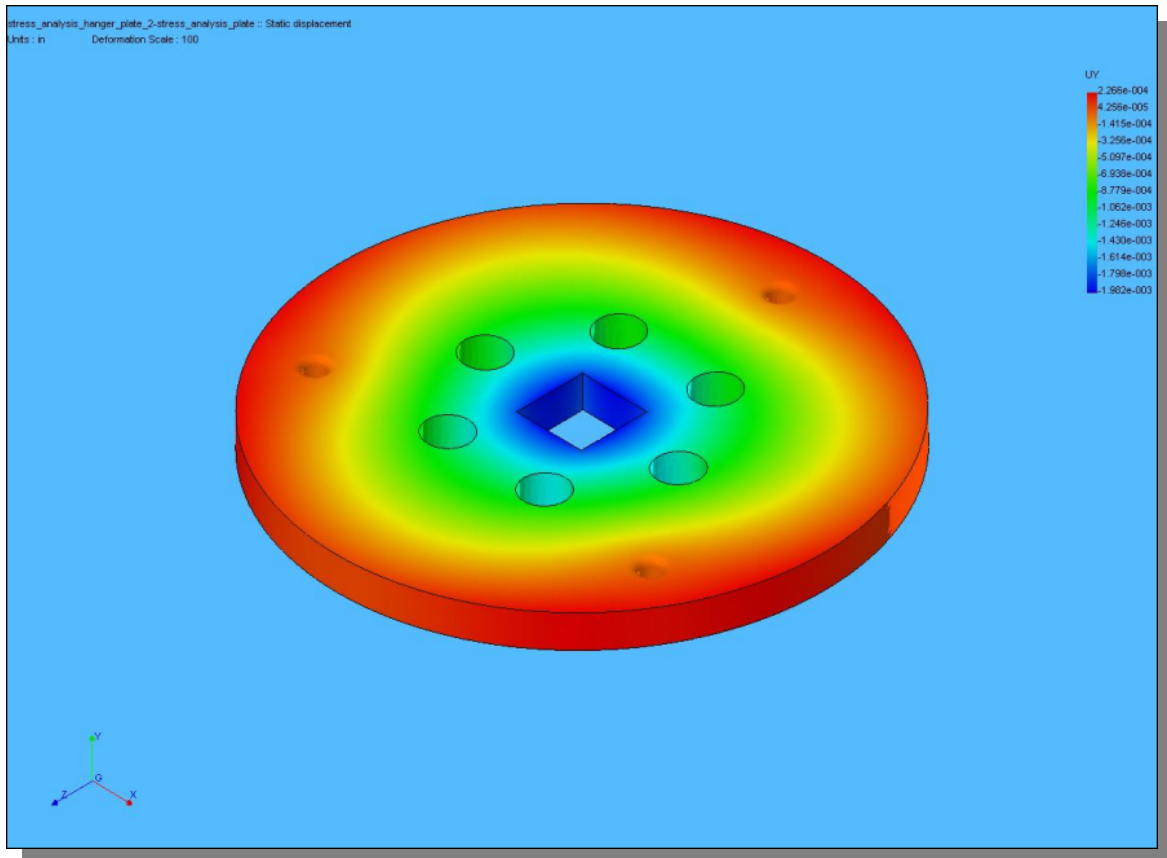
$L =$ Length of beam under load $\rightarrow 24''$

$$P_{cr} = (4 \times \pi^2 \times 30E6 \times 0.049)/24^2 = 100650 \text{ lb}$$

CONCLUSION: The buckling load for one vertical threaded rod is 100650 lb. The actual load for each vertical threaded rod in this design is approximately 600 lb. Buckling is therefore not an issue for this design.

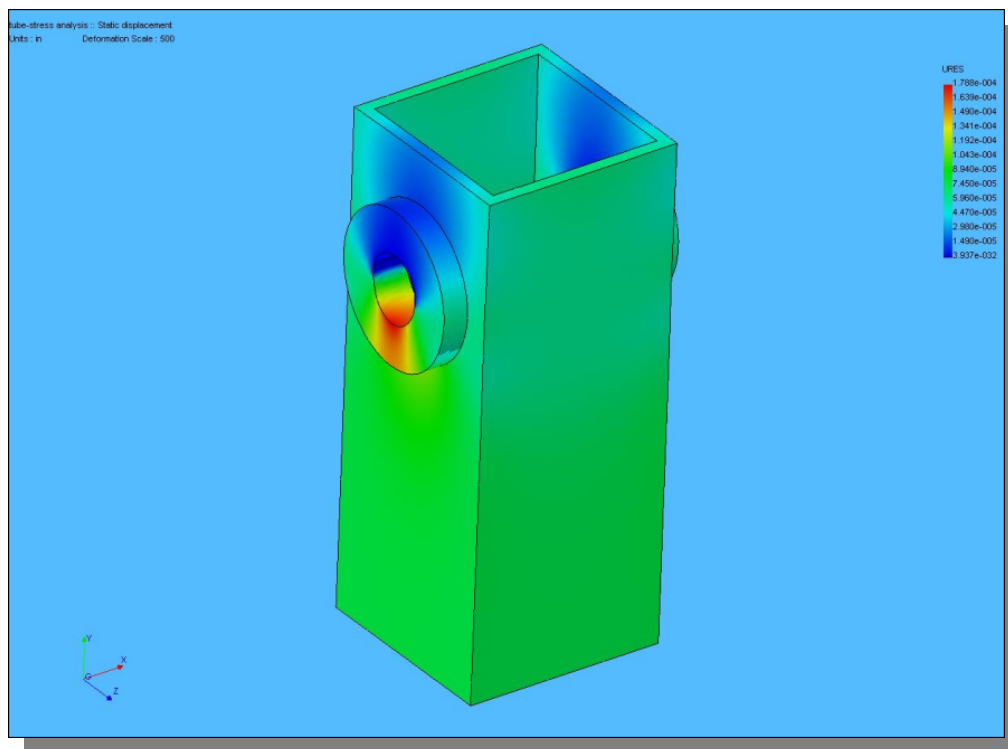
4.0 DEFLECTION CALCULATIONS

4.1 Upper support plate



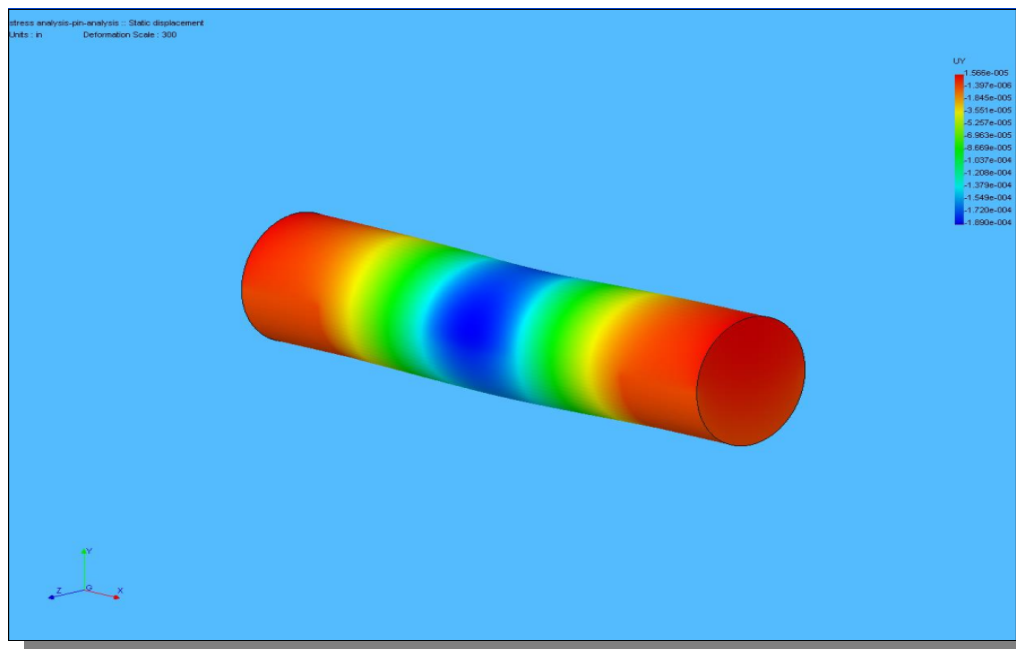
Conclusion: The calculated maximum deflection on the Upper Support Plate is 2.266E-4 inches = 0.0058 mm. This deflection is very small and will not pose a problem for this design.

4.2 Strongback



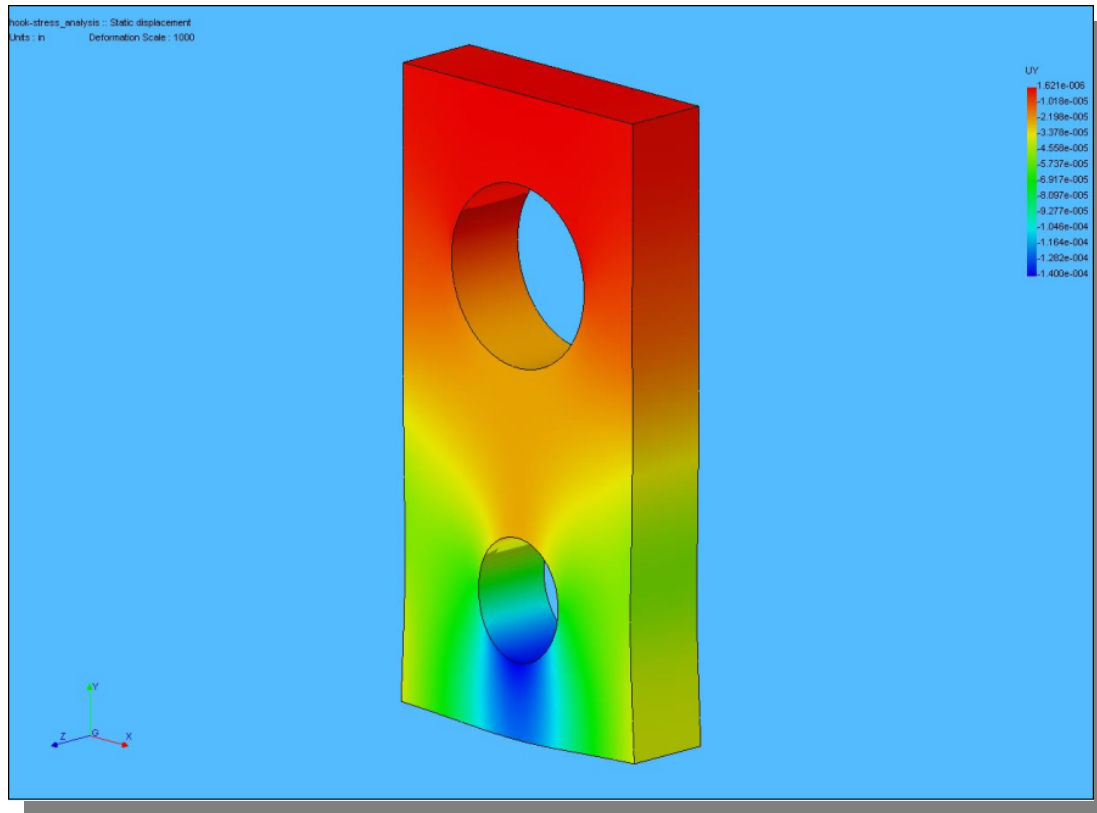
Conclusion: The calculated maximum deflection on the Strongback is 1.788E-4 inches = 0.0045 mm. This deflection is very small and will not pose a problem for this design.

4.3 Lifting bolt



Conclusion: The calculated maximum deflection on the Lifting Bolt is 1.566E-5 inches = 0.00042 mm. This deflection is very small and will not pose a problem for this design.

4.4 Lifting connector



Conclusion: The calculated maximum deflection on the Lifting Connector is 1.400E-4 inches = 0.0036 mm. This deflection is very small and will not pose a problem for this design.

5.0 Summary

	Max Stress [psi]	Max. Deflection [inches]	Comments
Upper Support Plate	1000 - 1300	2.27E-04	Safety factor = 7.690 for max. stress
Strongback	3500 - 4000	1.79E-04	Safety factor = 5.000 for max. stress
Lifting Bolt	2000 - 2500	1.57E-05	Safety factor = 24 for max. stress
Lifting Connector	3000 - 3500	1.40E-04	Safety factor = 17.14 for max. stress
Thread Stripping	36500	N/A	Actual force = 9.618 psi
Buckling	100650.083	N/A	Actual Load = approximately 600 lb

The calculated stresses for the above listed parts are well below the yield strength of the respective materials they are made from.

The calculated deflections for the above listed parts are too small to have a negative impact on the design.