PLANNING ADVISORY NOTICE

The Last Piece of the Structural Analysis Puzzle – Mount to Tower Interactions

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The evolution of the telecommunications industry has resulted in the application of effective engineering of towers and mounts to allow for proper risk management and mitigation over the life cycle of telecommunication structures. The impacts of loads caused by mounts on the supporting tower have historically only been considered at a 'global' scale representing how changes impact the overall supporting tower structure versus local impacts at the location of the mount. Generally, minimal attention has been paid to the local antenna mount structure that is transferring the loads back to the tower given that historically, the loads on the equipment and mounts were not very high.

However, increased attention has been applied since 2018, when equipment loading increased substantially with more and larger antennas along with radios being moved from the ground onto the tower near the antennas. This shift has necessitated larger mounts or modifications to existing mounts, as it has been required by the IBC to also evaluate the capacities of the local antenna mount. Practically, the tower and mount analyses are performed by separate engineers due to the ownership of the mount by the Mobile Network Operator (MNO) and the tower by the MNO or other third parties. The provided deliverables are typically a global analysis of the tower (SA) and a localized analysis of the antenna mount (MA). The results of these analyses are compiled and reconciled during the construction drawing and permitting phase of the project.

With the recent publication of ANSI/TIA-222-I, an additional step has been added to ensure the effective management of the loads being applied to the tower from the mount, the analysis of the 'mounting system interface', commonly referred to as MTI (Mount to Tower Interface).

> *The MTI evaluates the impact that the mount will have on the tower at a local level.*

E.g. localized buckling of a tower leg across a single bay or deformation of a monopole shaft at the collar attachment point caused by the force transfer from the mount connection to the supporting tower.

Who does the Analysis?

Given the potential split ownership of the mount by the MNO and the tower by a third party, there are usually two separate structural engineers involved in a project, one for the tower analysis and one for the mount analysis. In all cases there should be an effective sharing of data and information to support the individual engineer's responsibility for their assigned scope of work. The contractual requirements between the mount owner and the structure owner will determine the means in which data is shared.

As written, ANSI/TIA-222-I notes that the *'analysis of a mounting system interface shall be included in the analysis of an appurtenance mounting system'* [§ 16.5.3]. That is, this evaluation shall be performed by the MA engineer as a deliverable, it should be noted that the MA engineer may also be the SA engineer in some cases.

To properly perform this analysis, the MA engineer will need data related to the underlying structure. This localized tower information should include, (but not necessarily be limited to):

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- Leg properties – diameter, thickness, shape, steel grade, etc.
- Tower bay height – distance between tower bracing connection points.
- Monopole shaft properties – diameter, thickness, steel grade, etc.
- Monopole slip joint information – location, length of joint, etc.

It should be noted that this information is generally accessible in past tower analyses or from the mapping of the mount, if performed. Once this information is obtained, the MA engineer can perform a localized mount-to-tower interaction analysis (MTI) utilizing the site-specific reactions required as part of their MA deliverable.

Alternatively, in cases where the SA engineer is requested or required to perform the MTI, the MA engineer or manufacturer should provide batch reaction forces to the SA engineer to perform the MTI evaluation. In the absence of such reactions the SA engineer may need to communicate with the client to procure such information. It should be noted that the Effective Application of TIA-5053-A Planning Advisory Notice (PAN) goes into additional detail on how an engineer may engage the mount manufacturer to determine appropriate reactions for the considered mount.

Clarifying the Calculation Process

The evaluation of the localized tower structure shall be performed in accordance with the ANSI/TIA-222-I standard.

For lattice towers, it is necessary to evaluate the tower leg capacities separately for torsional or twisting forces and for the combination of axial and bending forces. The acting torsion and combined moment and axial forces are then compared against the calculated leg capacities as outlined in ANSI/TIA-222-I Section 4.8.1.1. The MTI should be evaluated with only the forces imparted by the mount connection, without any global forces acting in the leg from loading on the overall tower structure [ANSI/TIA-222-I Section 16.4.i.iii].

For monopole towers, the local impact of the collar to the tower shaft should be evaluated using the formulas included in ANSI/TIA-222-I Section 16.5.1. without global loads from the structural analysis of the supporting structure [ANSI/TIA-222-I Section 16.5.4.ii.ii]. Note that the Cv value in the Moment formula noted in16.5.1.5.v.ii

Figure 1: Example where calculated torsional failure was identified

Figure 2: Installation Fault due to over-tightening of clamp resulting in leg warping

is considered to be interpolative to provide more refined results.

The most effective approach is to evaluate the MTI using 'batch' reactions from the mount analysis. This consists of evaluating the MTI for reactions from each of the various load combinations considered in the mount analysis. While this may be a more rigorous process for the MA engineer, it will ensure that any discovered calculated overstresses are both correct and accurate and not due to overly conservative engineering assumptions and calculations by combining the effects of overall maximum reactions.

It should be noted that for both lattice and monopole towers, ANSI/TIA-222-I allows for the use of more accurate information in lieu of the 'approximate analysis methods' noted in Section 16.5. This would entail the use of a full-scale 3-dimensional finite element analysis software such as ANSYS or equivalent to allow for the more detailed capture of localized impacts to the tower structures. This more detailed analysis can be performed by the mount manufacturers as part of the design process and often can be provided to the EOR directly from the manufacturer when available. The MA EOR should verify that the results provided by the manufacturer capture the site-specific configuration of their analyzed mount.

Mount to Tower Interaction Overstresses – Now What?

When an MTI evaluation results in localized overstresses, there are various options to eliminate the calculated overstress:

1. Verify that the MTI evaluation has been performed correctly and in compliance with ANSI/TIA-222-I

2. *Address Antenna Mount Overstresses* – In cases where the MA reports overstress in the mount structure, trials run by authors of this PAN noted that installing modifications to remediate the mount overstresses provided the additional benefit of redistributing forces at the mount connection and very often resulted in a passing MTI. An example of this is the installation of a V-brace kit for a sector frame or a kicker kit for a monopole-attached mount.

3. *Install 'typical' Antenna Mount Modifications* – In cases where the MA results in a passing mount but there are overstresses in the MTI, traditional mount modification kits (V-kits, kicker kits, etc.) can be proposed. These kits allow for a redistribution of forces at mount connection and subsequently, a passing MTI. An example of this is the installation of a 3rd mounting attachment point for a sector frame or kits as noted in item 2 above.

4. *Reduce and/or Reconfigure Final Loading Configuration* – Removing legacy equipment, proposed future loading, or shifting proposed antennas and radios vertically or horizontally (especially when vertical or horizontal eccentricities are eliminated or mitigated) will result in a redistribution of loads across the antenna mount structure and lead to reduced or changed reactions at the tower interface, which may allow for a passing MTI.

5. *Finite Element Analysis* – Performing a full-scale finite element analysis will likely provide a reduction in usage and may allow for a passing MTI. The MA engineer should communicate with mount manufacturers to obtain analysis or test results where available.

   It should be noted that in trial cases performed by an industry-leading mount manufacturer full-scale finite element analysis resulted in an almost doubling of capacity of an MTI when compared to a mathematical evaluation in accordance with ANSI/TIA-222-I 16.5.

6. *Relocate Mount* – Relocating the existing mount to a different location on the tower having different tower geometry to accommodate the localized mount interactions may allow for a passing MTI.

7. *Replace Mount* – Replacing the mount with a new mount with a different connection configuration, often with larger spacing of connections for lattice tower mounts or different collar geometry for monopole mounts may allow for a passing MTI.

8. *Modify Tower Structure* – In the cases where items 1-7 of this list do not eliminate the calculated MTI overstresses, localized tower modifications may be required to reinforce the tower structure for the applied loads from the mount interface.

Conclusion

The addition of the MTI evaluation now allows for a complete picture of the impacts a loading change will have to the supporting structures, including any localized overstresses, and provide the end user the confidence that their proposed loading changes will not cause detrimental impacts to the supporting structures.

The mount to tower interaction is a critical component of ensuring the overall reliability of the structure and sustained, uninterrupted performance of the supported telecommunications equipment. However, engineers will need to verify they are considering the correct and appropriate tower information and mount reactions during

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their evaluations. When overstresses are discovered, the engineer should perform due diligence in providing the best solution based on cost and timeline constraints provided by the client. Following this process will strike the appropriate balance of code-compliance and optimizing expenditures for the MNO.

This check will support contractors in allowing them to properly plan installations and avoid installation faults that can often happen when installing or modifying existing mounts. The MTI check will not eliminate damage caused due to improper installation. However, an effective PMI process will allow the structure owner, the mount owner, the contractor, and the engineer to all have assurance that the mount, tower, and interface are going to perform as designed.

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Illustrative Examples

Mount to Tower Interaction Calculations and Finite Element Analysis Models

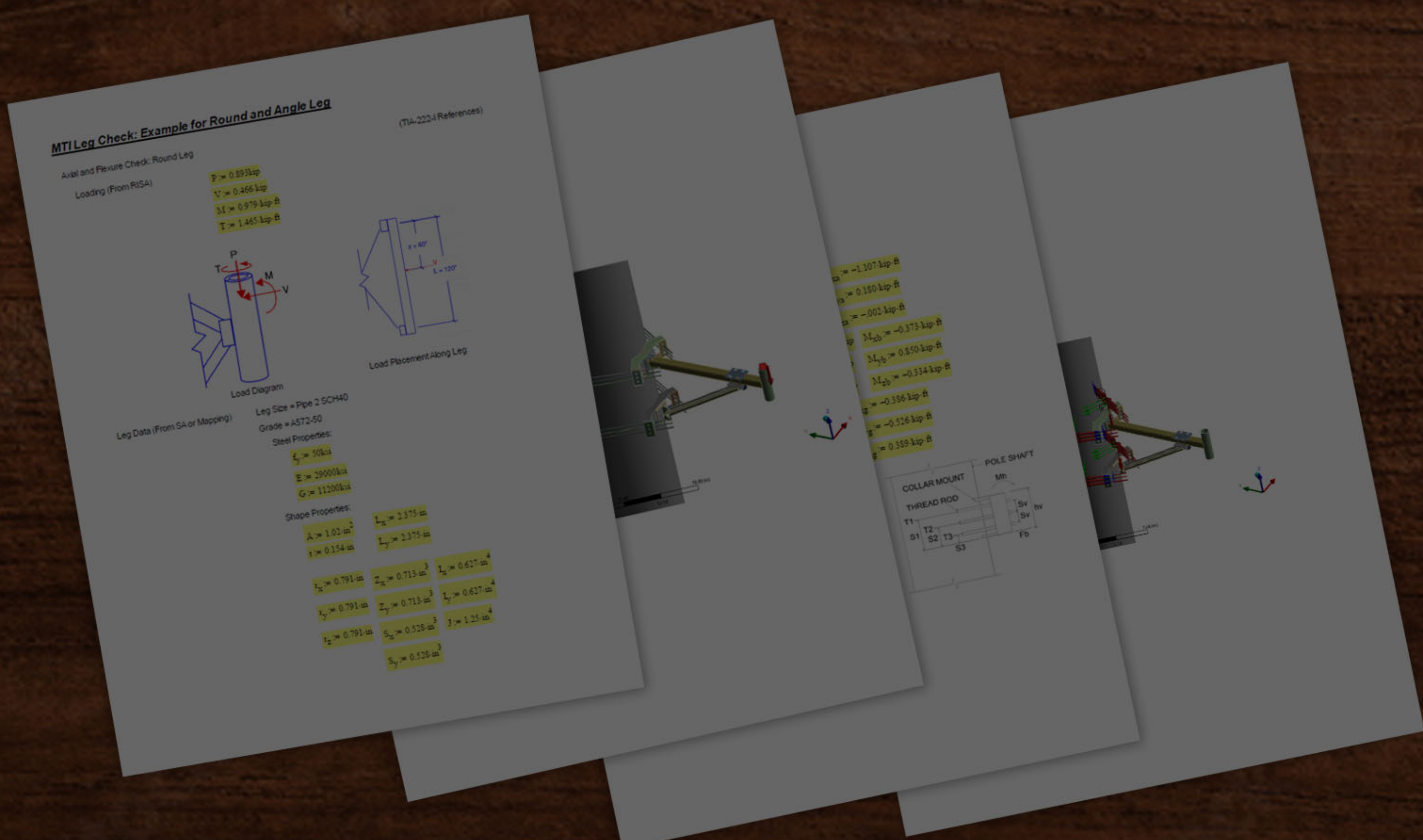

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Exhibit 1

Example calculation of an angle-leg tower analyzed for mount reactions from a sector frame

MTI Leg Check: Example for Round and Angle Leg

Axial and Flexure Check: Round Leg

(TIA-222-I References)

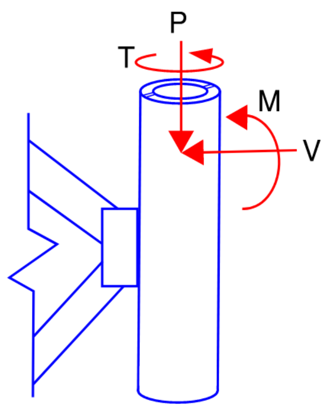
Loading (From RISA)

$P := 0.893 kip$

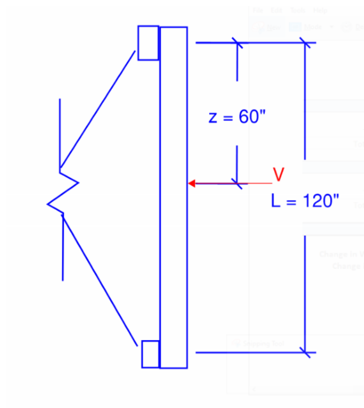
$V := 0.466 \cdot kip$

$M := 0.979 \cdot kip \cdot ft$

$T := 1.465 \cdot kip \cdot ft$



Load Diagram



Load Placement Along Leg

Leg Data (From SA or Mapping)

Leg Size = Pipe 2 SCH40

Grade = A572-50

Steel Properties:

$f_y := 50ksi$

$E := 29000ksi$

$G := 11200ksi$

Shape Properties:

$A := 1.02 \cdot in^2$ $L_x := 2.375 \cdot in$

$t := 0.154 \cdot in$ $L_y := 2.375 \cdot in$

$r_x := 0.791 \cdot in$ $Z_x := 0.713 \cdot in^3$ $I_x := 0.627 \cdot in^4$

$r_y := 0.791 \cdot in$ $Z_y := 0.713 \cdot in^3$ $I_y := 0.627 \cdot in^4$

$r_z := 0.791 \cdot in$ $S_x := 0.528 \cdot in^3$ $J := 1.25 \cdot in^4$

$S_y := 0.528 \cdot in^3$

$K := 1$

$L := 120 \cdot in$

$\phi := 0.9$

$z := 60 \cdot in$

Leg Capacities (Calculated)

$$f_e := \frac{\pi^2 \cdot E}{\left(\frac{K \cdot L}{r_z}\right)^2} = 12.436 \cdot ksi \qquad (4.5.4.2)$$

$$f_{cr} := 0.877 \cdot f_e = 10.907 \cdot ksi \qquad (4.5.4.2)$$

$$Pn := f_{cr} \cdot A = 11.125 \cdot kip \qquad (4.5.4.2)$$

$$Mn := \left(Z_x \cdot f_y\right) = 2.971 \cdot kip \cdot ft \qquad (4.7.2)$$

$$P_e := \frac{\pi^2 \cdot E \cdot I_x}{(K \cdot L)^2} = 12.462 \cdot kip \qquad (4.8.1)$$

$$\beta := \frac{1}{\left(1 - \frac{P}{P_e}\right)} = 1.077 \qquad (4.8.1)$$

Utilization Calculations:

Compression Utilization:

$$Cu := \frac{P}{\phi \cdot Pn} = 0.089$$

Flexure Utilization:

$$Bu := \frac{M + 0.7\left[\frac{2 \cdot V \cdot \left[(L - z)^2\right] \cdot z^2}{L^3}\right]}{\phi \cdot Mn} = 0.519$$

Interaction Utilization:

$$Tu := \frac{Cu}{2} + (\beta \cdot Bu) = 0.603 \qquad (4.8.1.1)$$

Capacity Check:

$$Check := \begin{cases} \text{"OK"} & \text{if } Tu < 1 \\ \text{"No Good"} & \text{otherwise} \end{cases}$$

Check = "OK"

Torsion and Shear Check: Angle Leg

Loading (From RISA)

$P := 0.893\text{kip}$

$V := 0.466\cdot\text{kip}$

$M := 0.979\cdot\text{kip}\cdot\text{ft}$

$T := 1.465\cdot\text{kip}\cdot\text{in}$

Leg Data (From SA)

Leg Size = 60 Degree 4"x4"x1/4"

Grade = A572-50

Steel Properties:

$f_y := 50\text{ksi}$ $\quad K := 1$

$E := 29000\text{ksi}$ $\quad b := 4\cdot\text{in}$

$G := 11200\text{ksi}$

$L := 120\text{in}$ $\quad z := 12\cdot\text{in}$ $\quad t := 0.25\cdot\text{in}$

$A := 1.9375\cdot\text{in}^2$

$J := 0.0404\cdot\text{in}^4$

$C_w := 0.0701\cdot\text{in}^6$

$\alpha := \frac{z}{L} = 0.1$

$$a := \left[\frac{(E\cdot C_w)}{G\cdot J}\right]^{\frac{1}{2}} = 0.177\,\text{ft}$$

(16.5.1-Torsional Stiffness 1)

$$\theta_L := \left(\frac{T\cdot L}{G\cdot J}\right)\cdot(1-\alpha)\cdot\left(\frac{z}{L}\right) + \frac{a}{L}\cdot\left(\frac{\sinh\left(\alpha\cdot\frac{L}{a}\right)}{\tanh\left(\frac{L}{a}\right)} - \cosh\left(\alpha\cdot\frac{L}{a}\right)\right)\cdot\sinh\left(\frac{z}{a}\right) = 0.026\cdot\text{rad}$$

$$\theta_{PL} := \left(\frac{T \cdot L}{G \cdot J}\right) \cdot \left[\left(\frac{1-\alpha}{L}\right) + \frac{\alpha}{L}\left(\frac{\sinh\left(\alpha \cdot \frac{L}{a}\right)}{\tanh\left(\frac{L}{a}\right)} \cdot \cosh\left(\frac{z}{a}\right) - \cosh\left(\frac{\alpha \cdot L}{a}\right) \cdot \cosh\left(\frac{z}{a}\right)\right)\right] = 2.752 \times 10^{-3} \cdot \frac{rad}{in}$$

$$Vut := 1.2 \cdot A \cdot G \cdot t \cdot \theta_{PL} = 17.916 \cdot kip$$

(16.5.1-Torsional Stiffness 2)

$$Vu := Vut + V \cdot \frac{A}{b \cdot t} = 18.819 \cdot kip$$

(16.5.1-Torsional Stiffness 3)

(16.5.1-Torsional Stiffness 4)

$$Vn := 0.6 \cdot f_y \cdot (A) = 58.125 \cdot kip$$

$$\phi := 0.9$$

$$Capacity := \frac{Vu}{\phi \cdot Vn} = 0.36$$

$$Check := \begin{cases} \text{"OK"} & \text{if } \frac{Vu}{\phi \cdot Vn} < 1 \\ \text{"No Good"} & \text{otherwise} \end{cases}$$

$$Check = \text{"OK"}$$

MTI Collar Check

Loading (From RISA)

Alpha

$\theta_a := 180°$

$F_{xa} := -.06318\text{kip}$ $M_{xa} := -1.107\cdot\text{kip}\cdot\text{ft}$

$F_{ya} := -2.67071\text{kip}$ $M_{ya} := 0.180\cdot\text{kip}\cdot\text{ft}$

$F_{za} := 6.42122\text{kip}$ $M_{za} := -.002\cdot\text{kip}\cdot\text{ft}$

Beta

$\theta_b := 60°$

$F_{xb} := -1.25025\text{kip}$ $M_{xb} := -0.373\cdot\text{kip}\cdot\text{ft}$

$F_{yb} := 1.08555\text{kip}$ $M_{yb} := 0.850\cdot\text{kip}\cdot\text{ft}$

$F_{zb} := 1.53866\text{kip}$ $M_{zb} := -0.334\cdot\text{kip}\cdot\text{ft}$

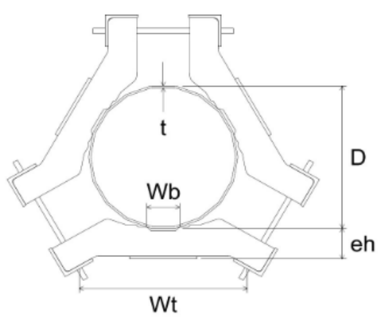
Gamma

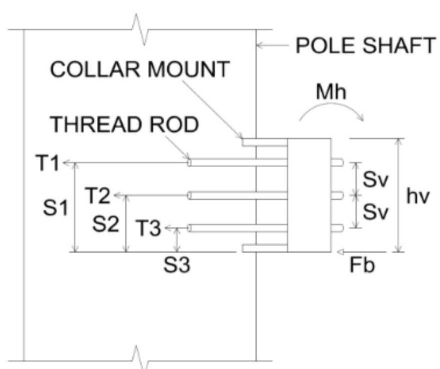
$\theta_g := 300°$

$F_{xg} := 1.36633\text{kip}$ $M_{xg} := -0.386\cdot\text{kip}\cdot\text{ft}$

$F_{yg} := 1.20414\text{kip}$ $M_{yg} := -0.526\cdot\text{kip}\cdot\text{ft}$

$F_{zg} := 1.50055\text{kip}$ $M_{zg} := 0.389\cdot\text{kip}\cdot\text{ft}$





Collar Data:

Threaded Rod Qty: $Q_{tr} := 2$

Collar Height: $h_v := 11.5\text{in}$

Threaded Rod Vertical Spacing: $s_v := 9.5\text{in}$

Threaded Rod Width: $W_t := 23in$

Threaded Rod Considered: 1/2" A307

Diameter: $d_{tr} := 0.5in$

Yield Strength: $f_{ytr} := 36ksi$ $f_{utr} := 60ksi$

Threaded Rod Vertical Height: $s_{v1} := 10.5in$ $s_{v2} := 1in$

Bearing Width: $W_b := 7.5in$

$$R2 := \frac{s_{v2}}{s_{v1}} = 0.095$$ (16.5.1 - Tension Collar 1.i.i)

Pole Data:

Pole Offset: $e_h := 6in$

Pole Diameter: $D := 17.3in$

Pole Thickness: $t := 0.1875in$

Pole Strength: $f_{yp} := 65ksi$

Max Reactions (Calculated):

$M_{ma} := 2.560 \cdot kip \cdot ft$

$M_{mb} := -0.442 \cdot kip \cdot ft$

$M_{mg} := -0.458 \cdot kip \cdot ft$

Max Moment: $M_h := \frac{2.560}{12} \cdot in \cdot kip$

Capacity Calculations:

$$\delta := \frac{6 \cdot M_h}{\left(\cos\left(\frac{\pi}{6}\right)\right)\left[\left[s_{v2} \cdot (R2 - 1)\right] + \frac{\left[(5 - R2) \cdot \left(R2 \cdot s_{v2} + s_{v1}\right)\right]}{1 + R2}\right]} = 0.032 \cdot kip$$ (16.5.1 - Tension Collar 1.i.ii)

$$T1 := \delta \frac{5 - R2}{1 + R2} = 0.142 \cdot kip$$ (16.5.1 - Tension Collar 1.i.iii)

$$T2 := R2 \cdot (T1 + \delta) - \delta = -0.015 \cdot kip$$ (16.5.1 - Tension Collar 1.i.iv)

$\phi := 0.65$ (16.5.4.iii.ii)

$\phi_p := 0.9$ (16.5.1 - Tension Collar 1.iv.ii)

Threaded Rod Capacity:

$$Rn := \phi \cdot f_{utr} \cdot \frac{\pi}{4} \cdot \left(d_{tr} - \frac{0.9743in}{13}\right)^2 = 5.534 \cdot kip$$

Utilization Calculations:

Threaded Rod Utilization:

$$Utr := \frac{T1}{Rn} = 0.026$$

$$Check := \begin{cases} \text{"OK"} & \text{if } Utr < 1 \\ \text{"No Good"} & \text{otherwise} \end{cases}$$

$Check = \text{"OK"}$

Pole Utilization:

$$Bp := 2 \cdot \cos\left(\frac{\pi}{6}\right) \cdot (T1 + T2) = 0.22 \cdot kip$$

$$Rnp := \left[\phi_p \cdot f_{yp} \cdot t^2 \cdot \frac{5.5}{\left(1 - \frac{0.81 \cdot W_b}{D}\right)}\right] = 17.433 \cdot kip$$

(16.5.1 - Tension Collar 1.i.iv)

$$Up := \frac{Bp}{Rnp} = 0.013$$

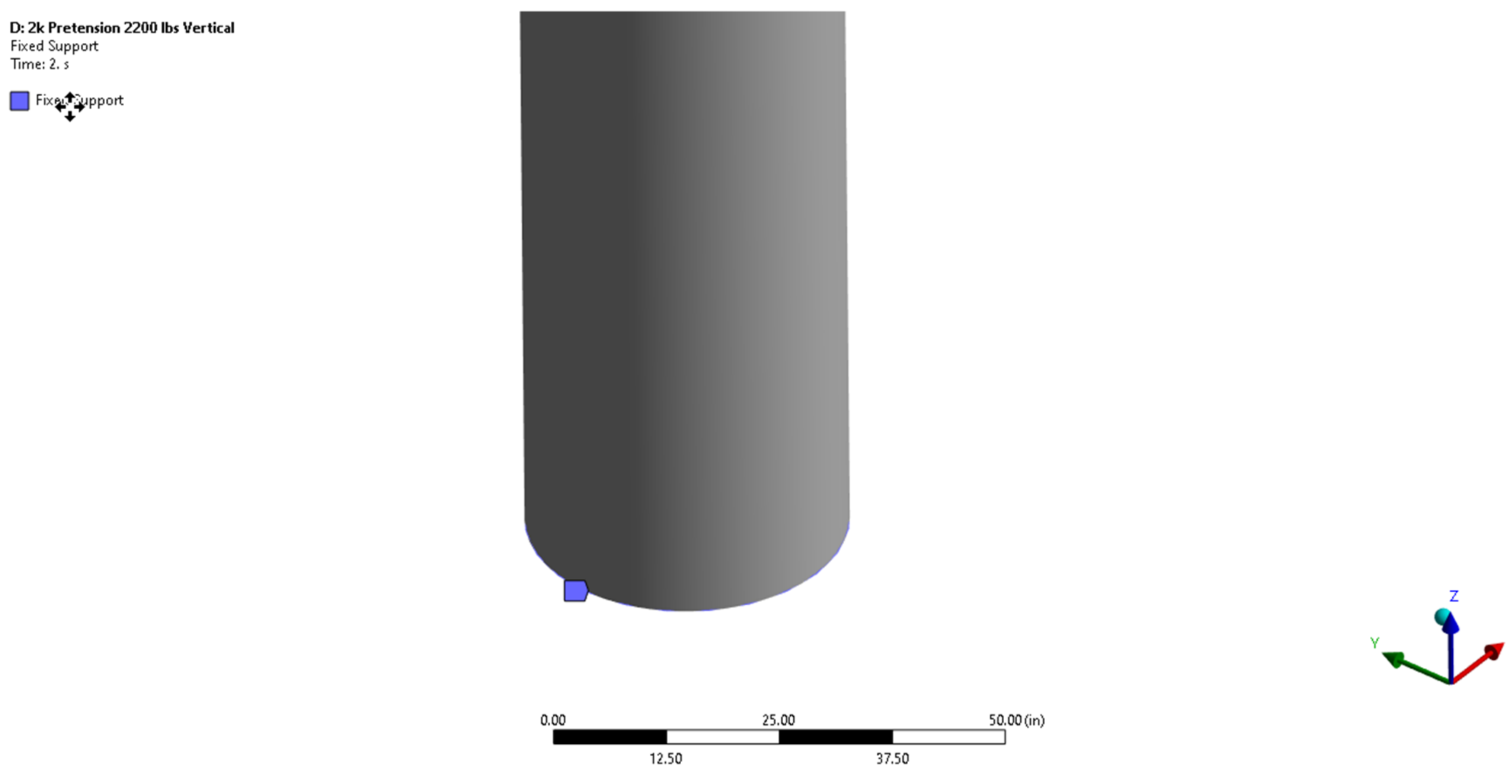
$$Check := \begin{cases} \text{"OK"} & \text{if } Up < 1 \\ \text{"No Good"} & \text{otherwise} \end{cases}$$

$Check = \text{"OK"}$

Exhibit 2

Finite element analysis results showing the reduction of stress in a monopole when a kicker kit is added

4800 pretension. 2200 lbs vertical. Dual Collar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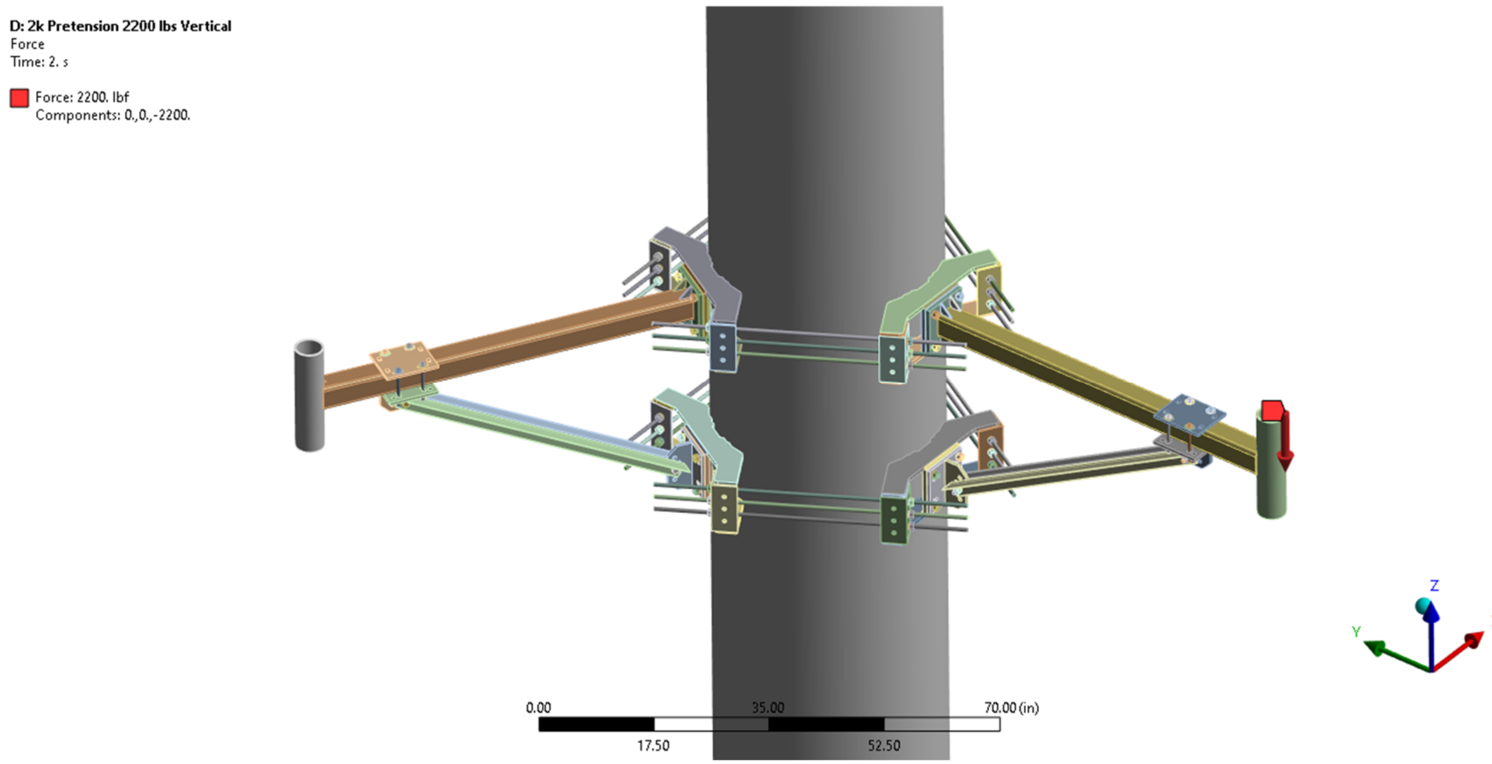
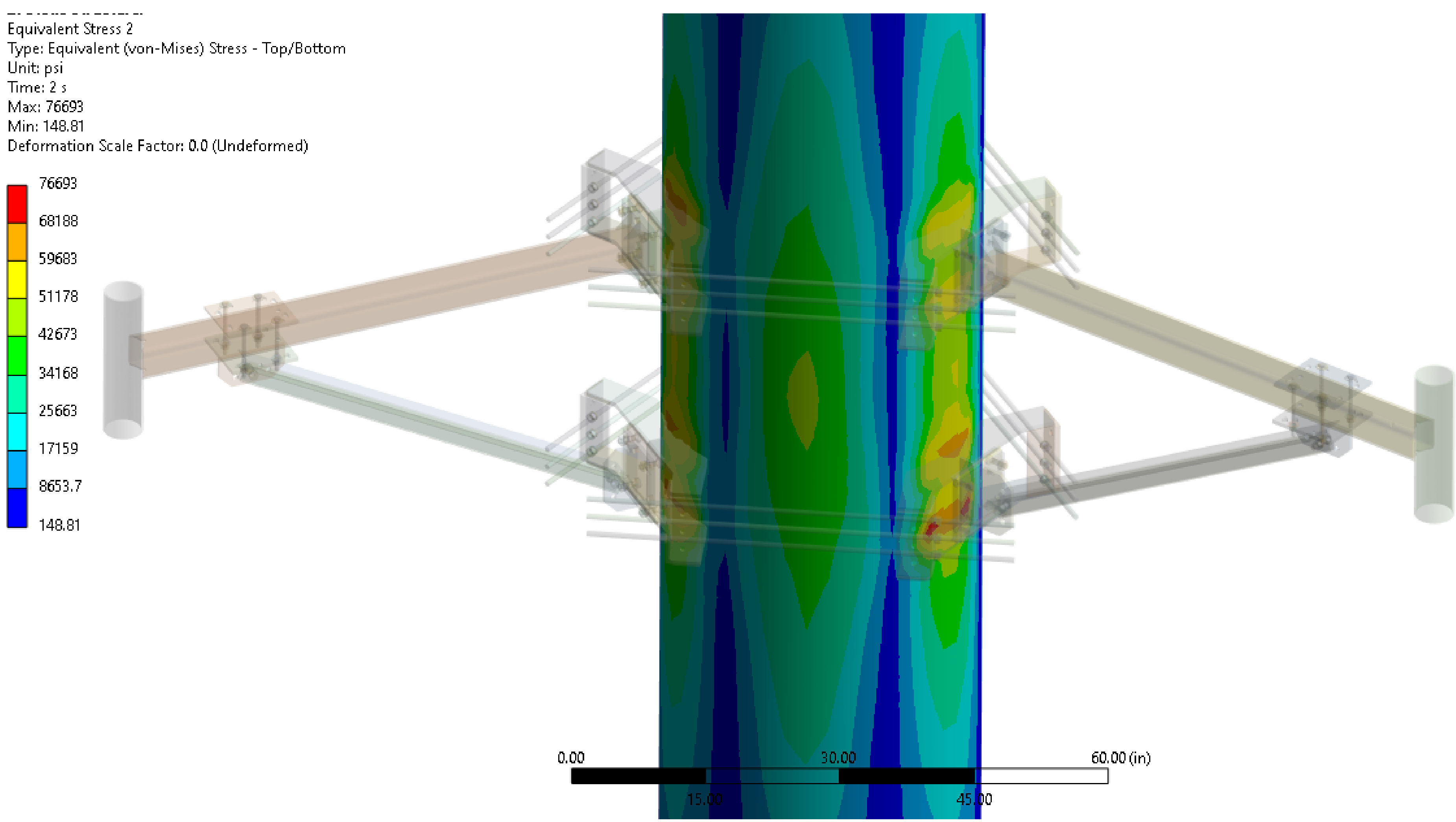
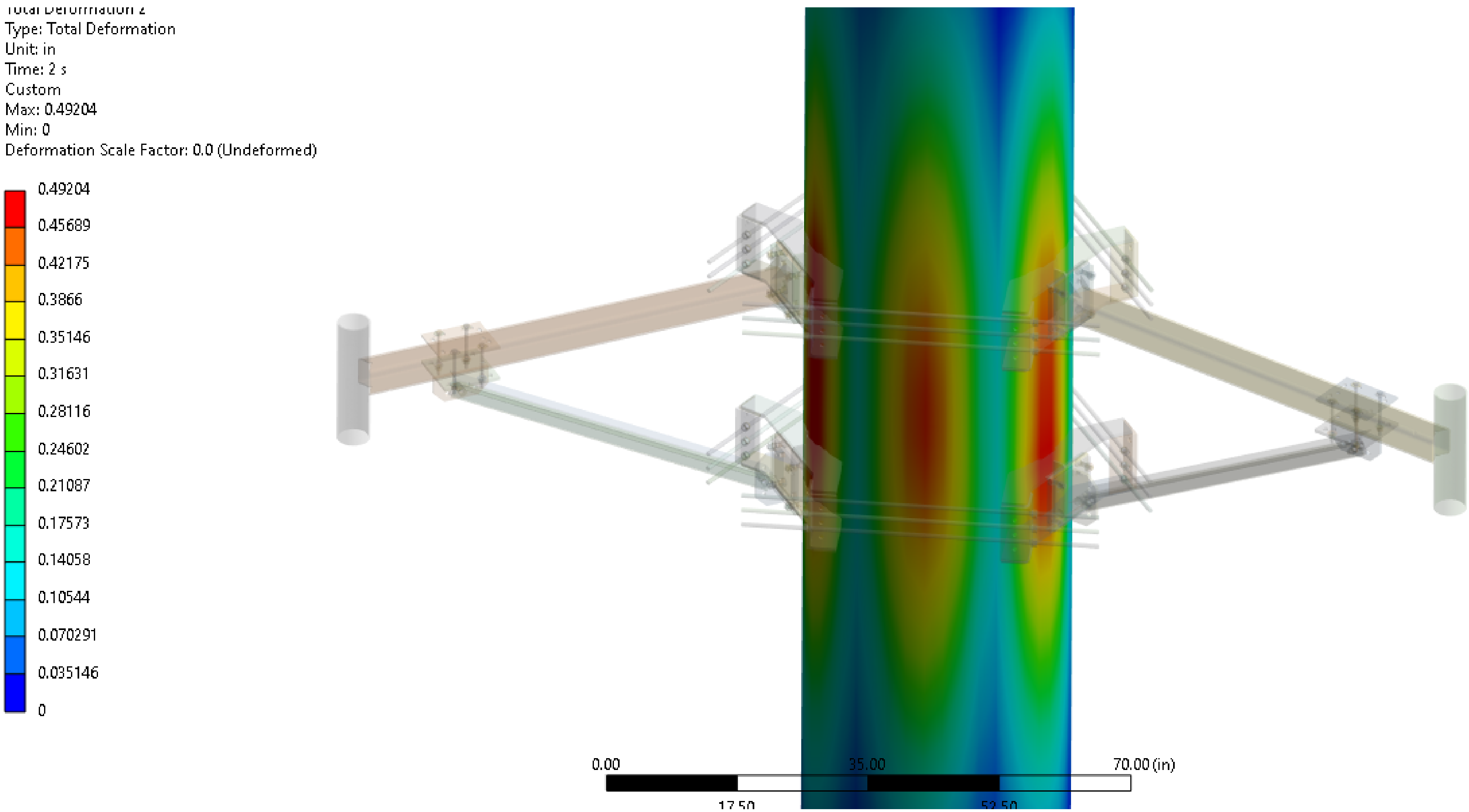
Fixed Support
Time: 2. s
Fixed Support
0.00
25.00
50.00 (in)
12.50
37.50
Z
Y
X

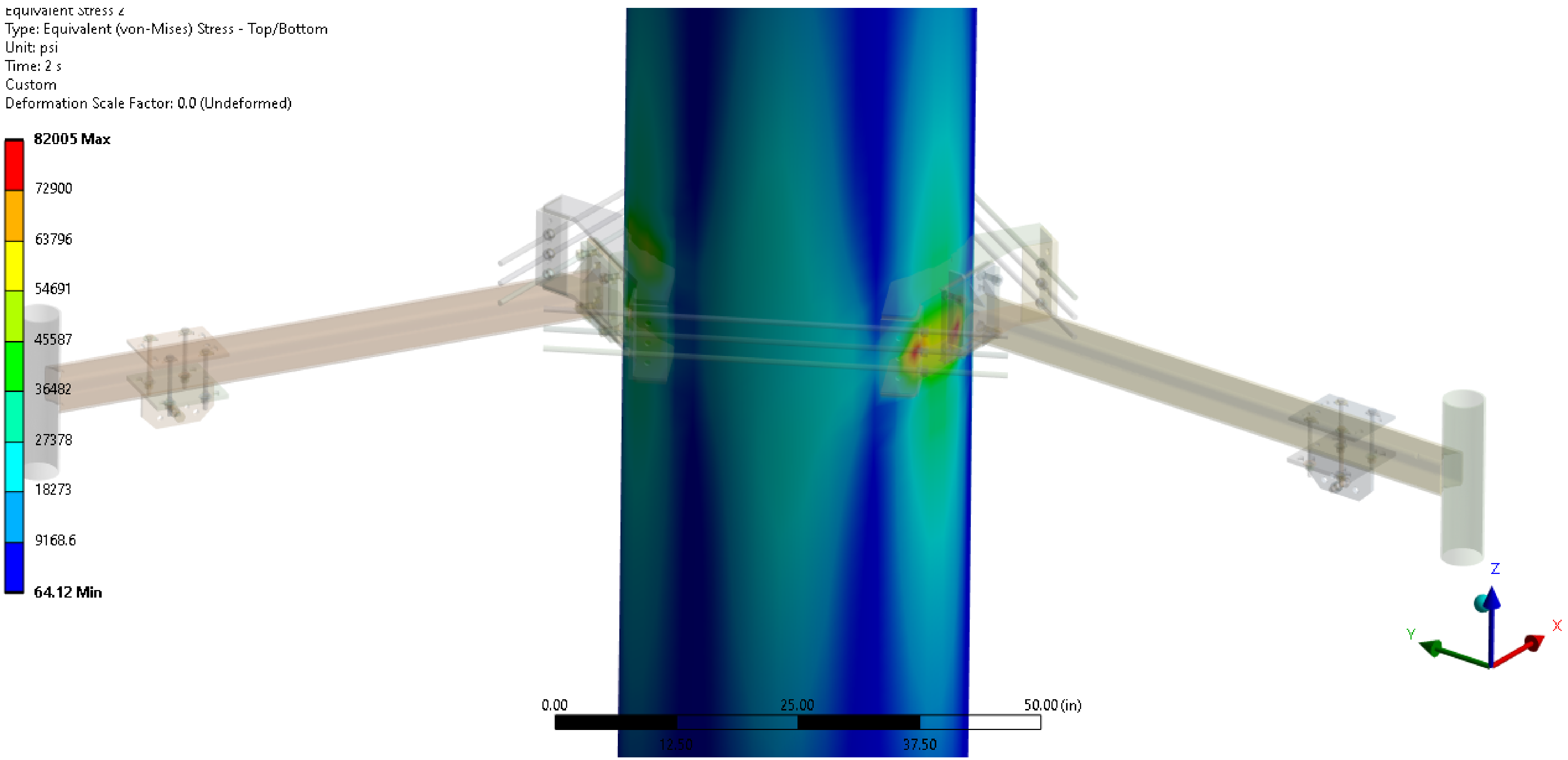
5.Ft standoff arm 2200 lb vertical

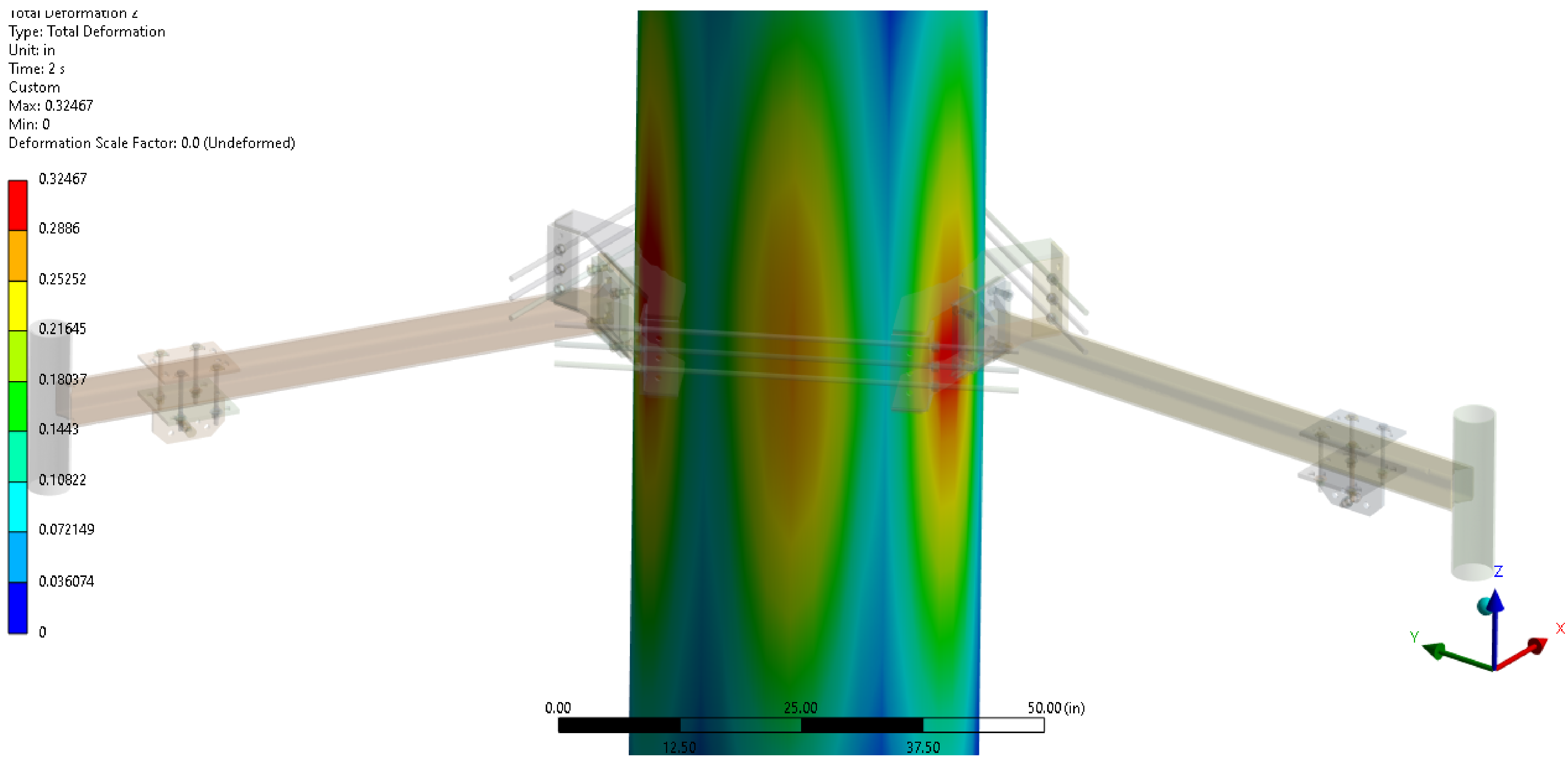



Equivalent Stress 2
Type: Equivalent (von-Mises) Stress - Top/Bottom
Unit: psi
Time: 2 s
Max: 76693
Min: 148.81
Deformation Scale Factor: 0.0 (Undeformed)
76693
68188
59683
51178
42673
34168
25663
17159
8653.7
148.81
0.00
30.00
60.00 (in)
15.00
45.00

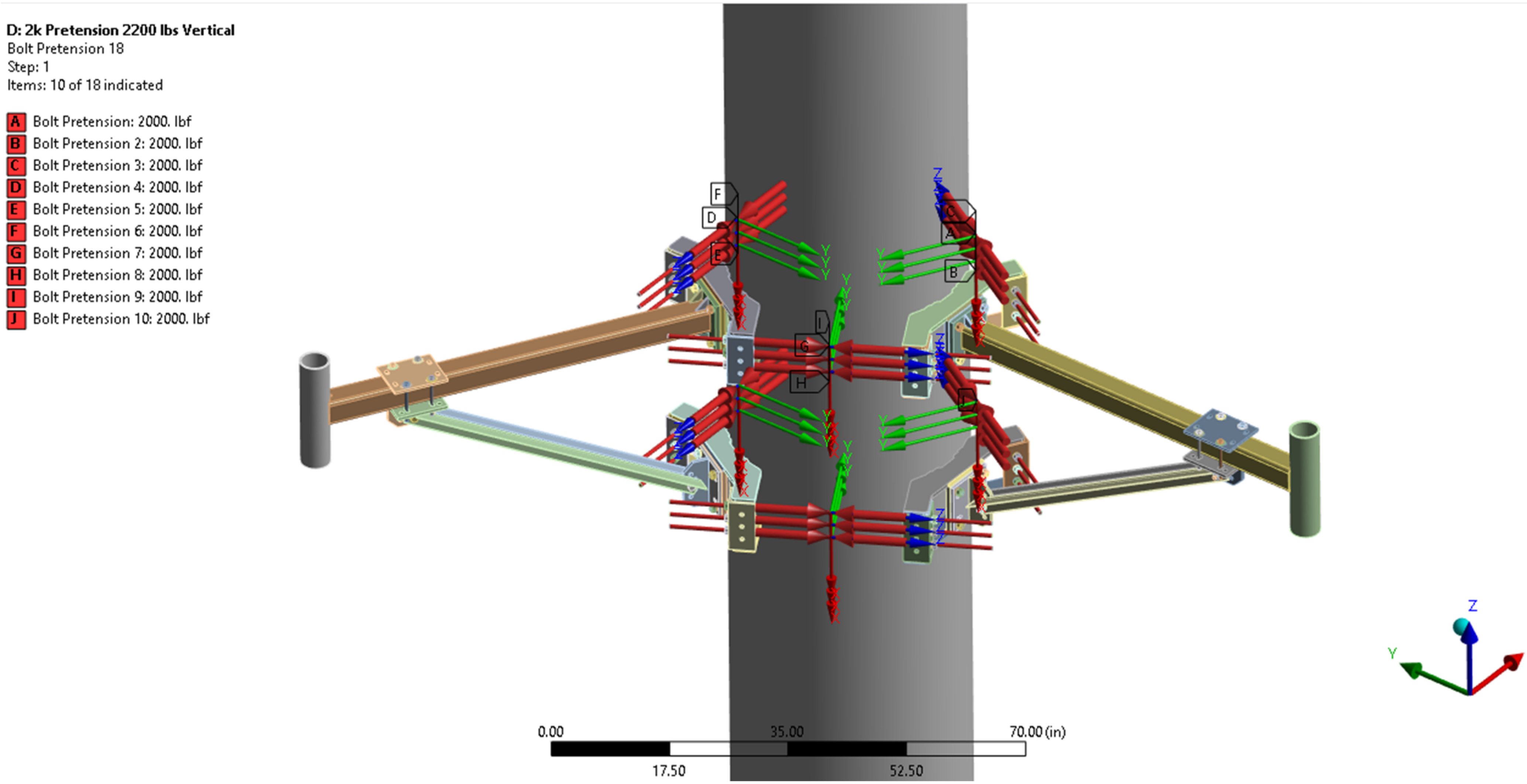

Total Deformation 2
Type: Total Deformation
Unit: in
Time: 2 s
Custom
Max: 0.49204
Min: 0
Deformation Scale Factor: 0.0 (Undeformed)
0.49204
0.45689
0.42175
0.3866
0.35146
0.31631
0.28116
0.24602
0.21087
0.17573
0.14058
0.10544
0.070291
0.035146
0
0.00
35.00
70.00 (in)
17.50
52.50

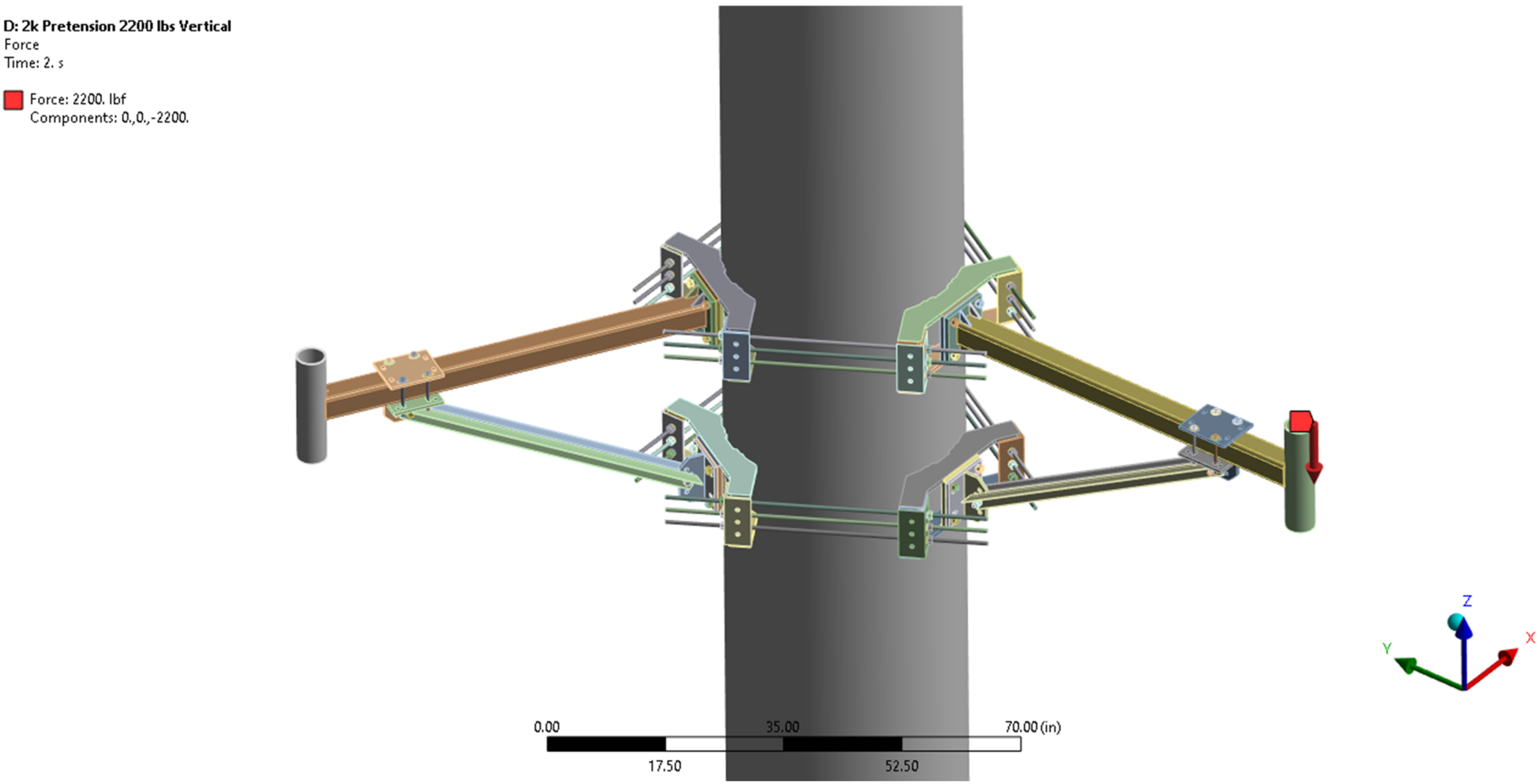
4800 pretension. 2200 lbs vertical. Single collar

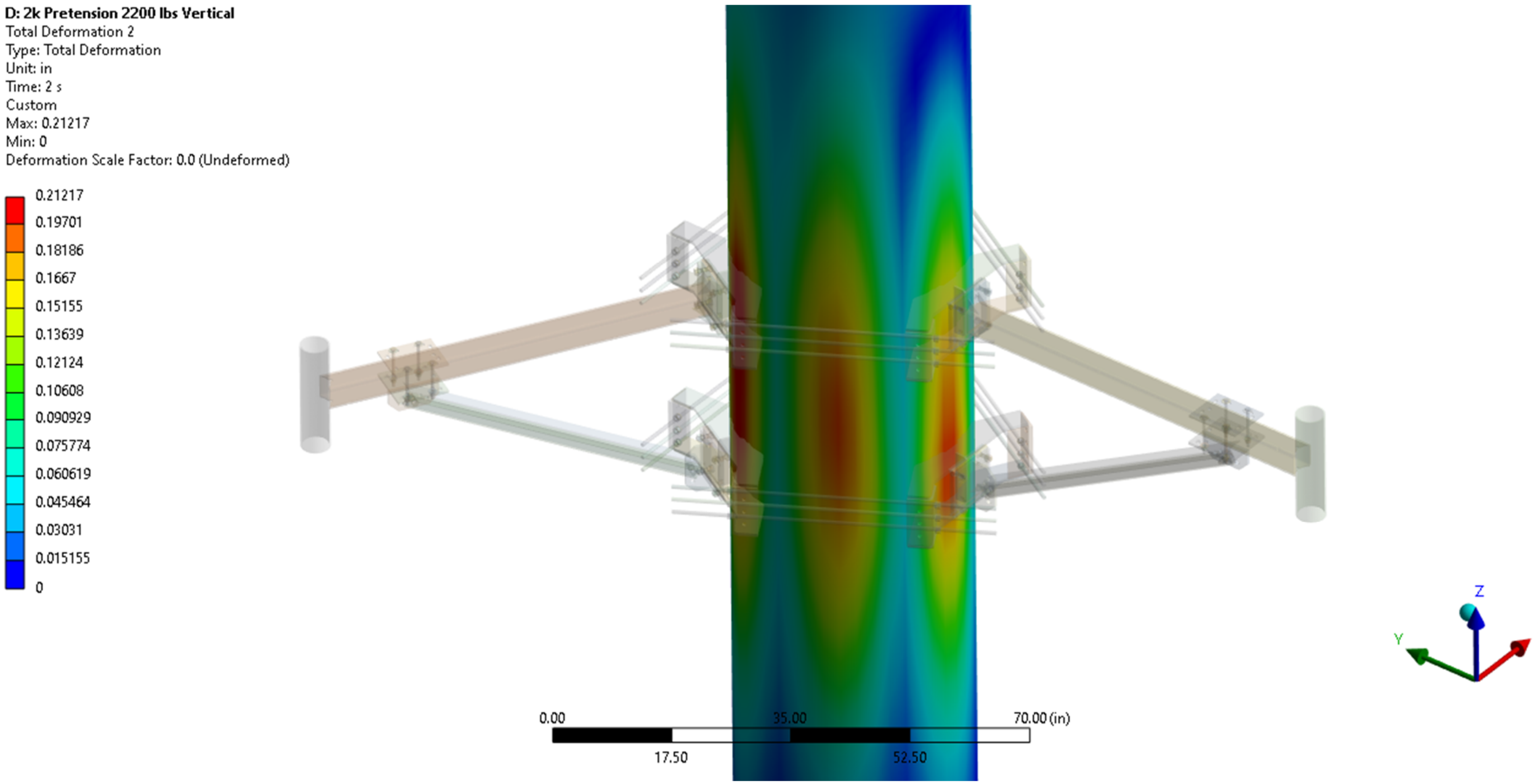

Equivalent Stress 2
Type: Equivalent (von-Mises) Stress - Top/Bottom
Unit: psi
Time: 2 s
Custom
Deformation Scale Factor: 0.0 (Undeformed)
82005 Max
72900
63796
54691
45587
36482
27378
18273
9168.6
64.12 Min
0.00
25.00
50.00 (in)
12.50
37.50
Z
Y
X

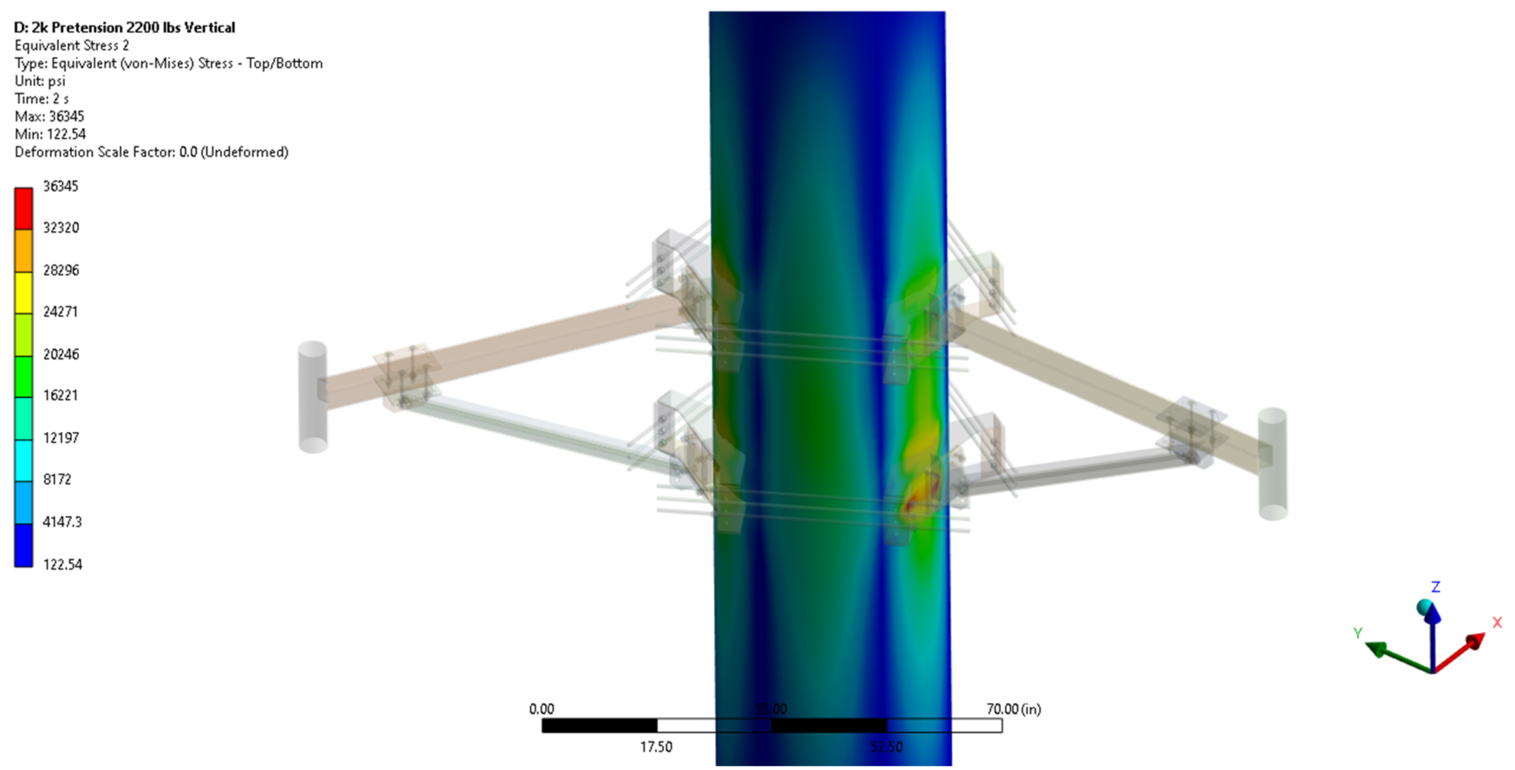

Total Deformation 2
Type: Total Deformation
Unit: in
Time: 2 s
Custom
Max: 0.32467
Min: 0
Deformation Scale Factor: 0.0 (Undeformed)
0.32467
0.2886
0.25252
0.21645
0.18037
0.1443
0.10822
0.072149
0.036074
0
0.00
25.00
50.00 (in)
12.50
37.50
Z
Y
X

2000 pretension. 2200 lbs vertical. Dual collar

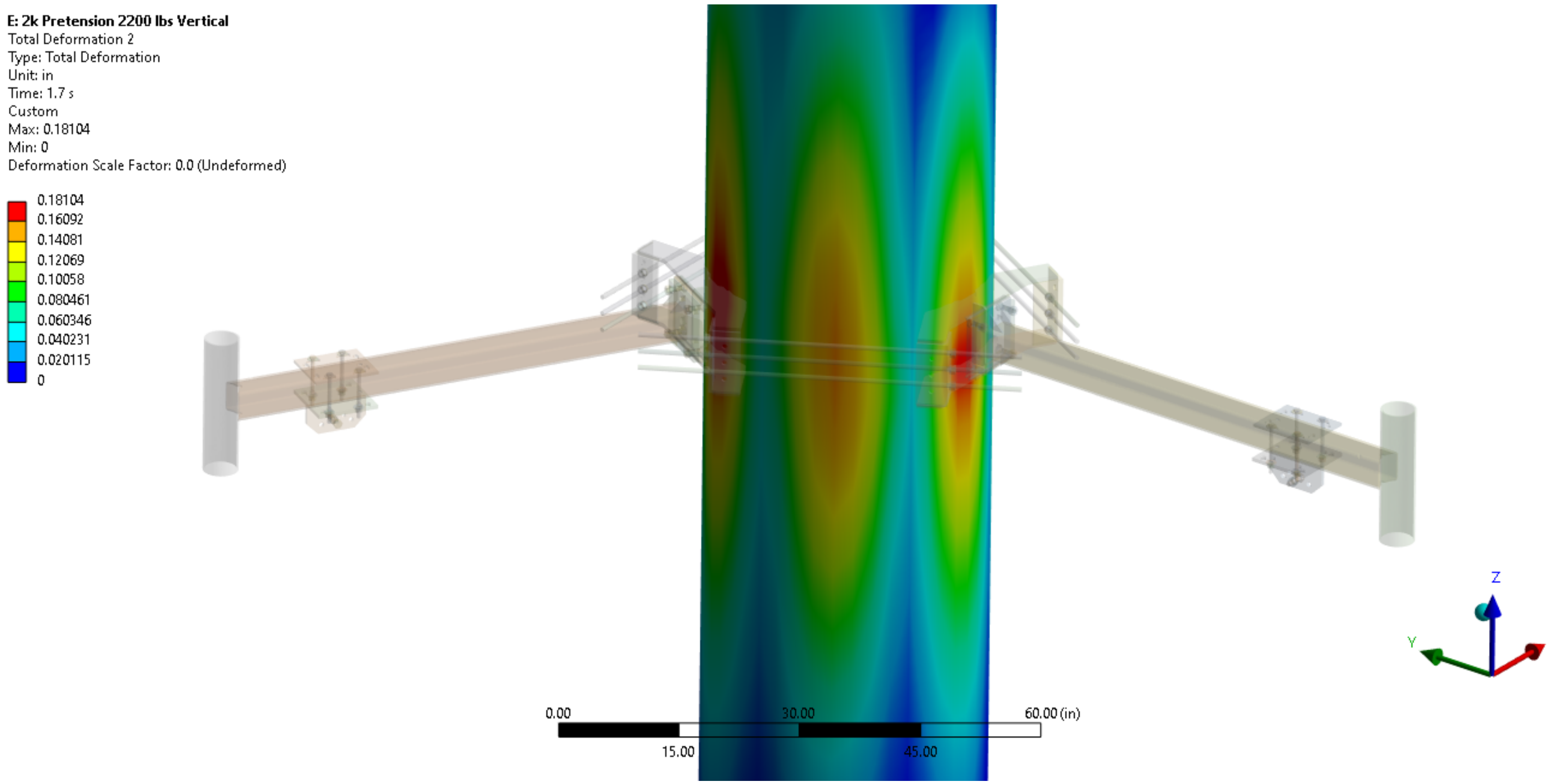

D: 2k Pretension 2200 lbs Vertical
Bolt Pretension 18
Step: 1
Items: 10 of 18 indicated
A Bolt Pretension: 2000. lbf
B Bolt Pretension 2: 2000. lbf
C Bolt Pretension 3: 2000. lbf
D Bolt Pretension 4: 2000. lbf
E Bolt Pretension 5: 2000. lbf
F Bolt Pretension 6: 2000. lbf
G Bolt Pretension 7: 2000. lbf
H Bolt Pretension 8: 2000. lbf
I Bolt Pretension 9: 2000. lbf
J Bolt Pretension 10: 2000. lbf
0.00
35.00
70.00 (in)
17.50
52.50
Z
Y

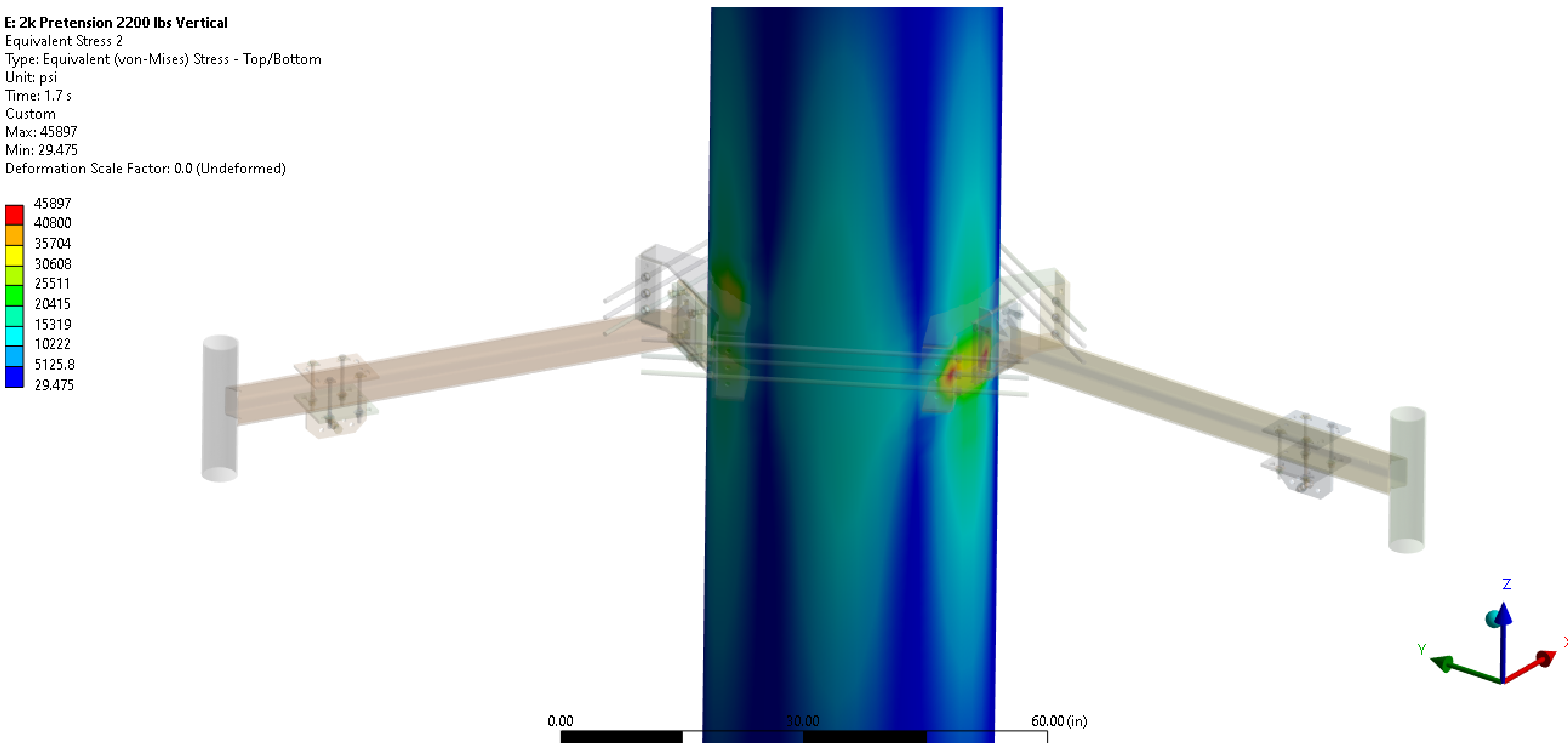

D: 2k Pretension 2200 lbs Vertical
Force
Time: 2. s
Force: 2200. lbf
Components: 0.,0.,-2200.
0.00
35.00
70.00 (in)
17.50
52.50
Z
Y
X


D: 2k Pretension 2200 lbs Vertical
Total Deformation 2
Type: Total Deformation
Unit: in
Time: 2 s
Custom
Max: 0.21217
Min: 0
Deformation Scale Factor: 0.0 (Undeformed)
0.21217
0.19701
0.18186
0.1667
0.15155
0.13639
0.12124
0.10608
0.090929
0.075774
0.060619
0.045464
0.03031
0.015155
0
0.00
35.00
70.00 (in)
17.50
52.50
Z
Y
X


D: 2k Pretension 2200 lbs Vertical
Equivalent Stress 2
Type: Equivalent (von-Mises) Stress - Top/Bottom
Unit: psi
Time: 2 s
Max: 36345
Min: 122.54
Deformation Scale Factor: 0.0 (Undeformed)
36345
32320
28296
24271
20246
16221
12197
8172
4147.3
122.54
0.00
35.00
70.00 (in)
17.50
52.50
Z
Y
X

2000 pretension. 2200 lbs vertical. Single Collar




E: 2k Pretension 2200 lbs Vertical
Equivalent Stress 2
Type: Equivalent (von-Mises) Stress - Top/Bottom
Unit: psi
Time: 1.7 s
Custom
Max: 45897
Min: 29.475
Deformation Scale Factor: 0.0 (Undeformed)
45897
40800
35704
30608
25511
20415
15319
10222
5125.8
29.475
0.00
30.00
60.00 (in)
Z
Y
X