Fermilab

Particle Physics Division

Mechanical Department Engineering Note

Number: MD-ENG-551 V2 Date: 10/04/2016

Project: MicroBooNE

Project Internal Reference:

Title: MicroBooNE Top Tagger Panels Support

Author(s): C. M. Lei

Reviewer(s): Erik Voirin ID #15426N

Key Words: strut, Design

Abstract/Summary:

Two layers of muon tagger panels are planned to be installed on the top, bottom, and on the two long sides of the Liquid Argon Time Projection Chamber (LArTPC) within the Liquid Argon Test Facility (LArTF). Commercial items B-line strut and fittings /connectors are selected to form the needed support assembly. The top panel group consists of a set of panels with total weight of roughly 7,500 lbs, being supported by a grid of B-line double channels B22A and C7x14.75'" C-channels. A total of 14 vertical legs and an array of diagonal supports are made from B-line strut as well. This note shows that the support assembly is adequately designed to safely support the load.

1. The top panels design
   The top panels consisting of 16 long modules and 8 small modules, which are supported by a table-top manifold with 14 legs, and diagonal supports as shown in Figure 1.

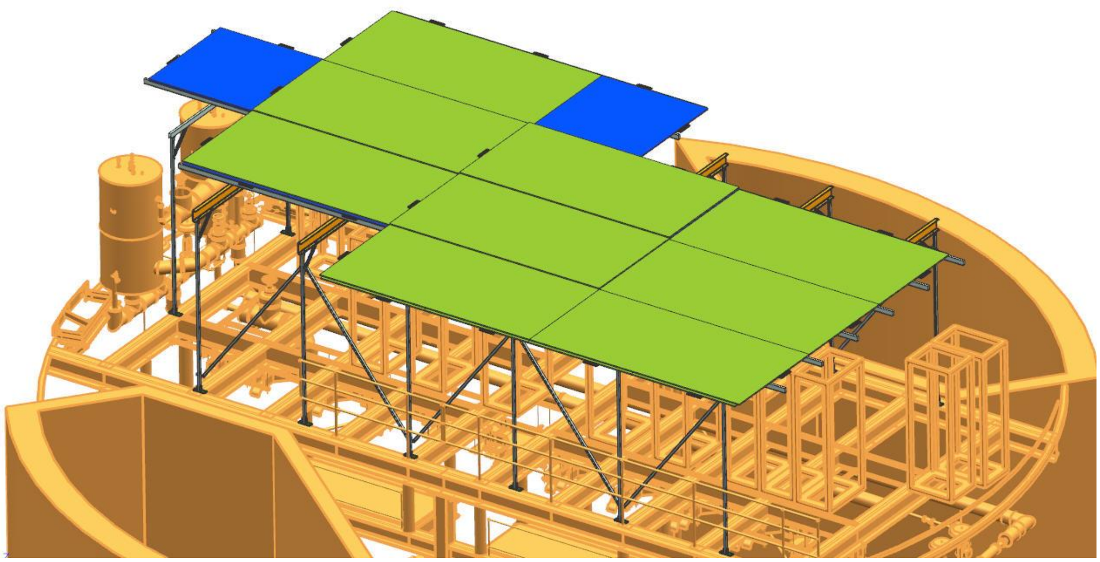


Figure 1. The Top Panels

2. The design of the top panels support

The support assembly is shown in Figure 2. It is made of a set of commercial parts of struts provided by B-line basically. However, since six pieces of long-and-stiff C-channels C7x14.75 are found available, they are set across over the existing cabinets and cable trays properly so that additional posts are not needed to set in the walkway. Some C-channels are revised to set sticking out from the posts so that more additional channel supports can be provided in order to minimize the panel deflection. The panel handling experience that 1 cm is allowed to be deflected within a 1 m span is still observed in this design. Additional B-line parts and braces are added as appropriate so that a robust support table is formed.

B-line channel B22 and post base items are used for the table legs. About 110 inches of space under the table top is thus created and it is clear of any existing hardware in this level of building. The post bases are being mounted to the existing I beams with some proper spacers in between so that no opening of the existing 1.5-inch fiber glass grating will be cut. Wedged washers for fastening parts to the C-channels will be used. Threaded holes are made on these I beams and the hole locations are shown in Figure 3. As this scaffolding-like support structure covers all panel regions very well, and each panel is supported properly with the local supports, any partial loading of the panels will not be an issue.

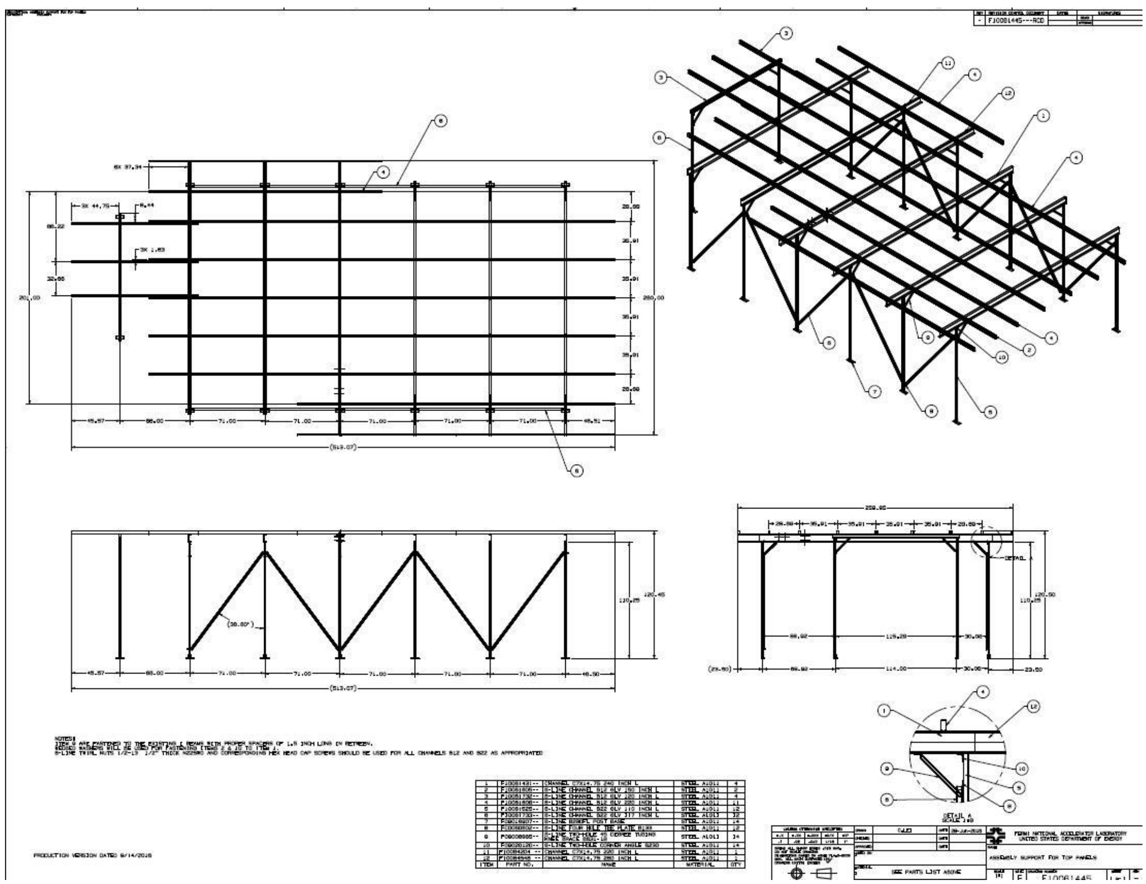


Figure 2. Support Assembly for the Top Panels

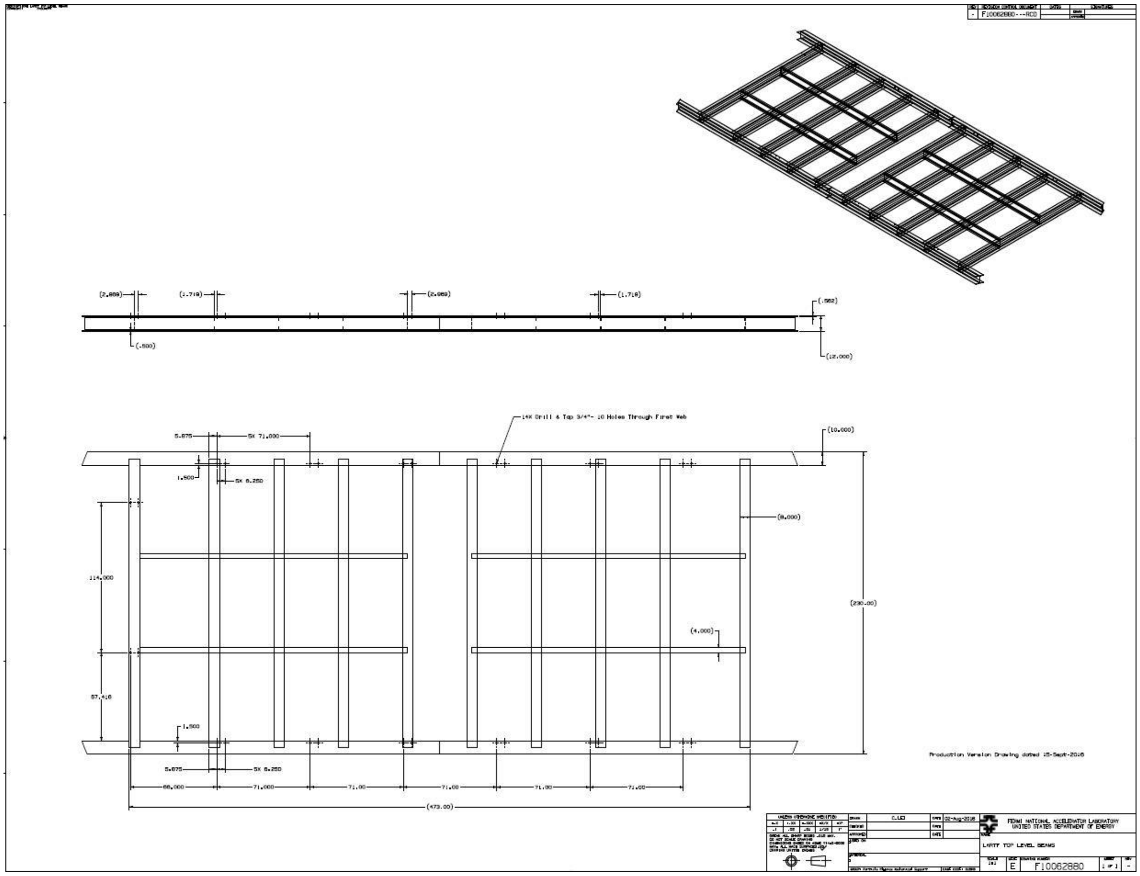


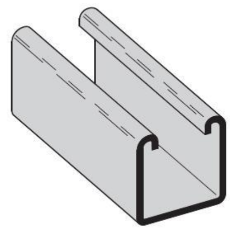
Figure 3. Hole Drilling Locations on the Existing I Beams

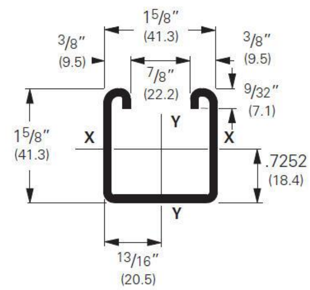
The properties of B-line channels B22 and B22A are shown in Figures 4 and 5 while other parts being used in this support structure are shown in Figures 6, 7, 8 and 9. The property of the non-B-line part C-channel is shown in Figure 10.

B22 Channel

B22
- Thickness: 12 Gauge (2.6 mm)
- Standard lengths: 10′ (3.05 m) & 20′ (6.09 m)
- Standard finishes: Plain, DURA GREEN™, Pre-Galvanized, Hot-Dipped Galvanized, Stainless Steel Type 304 or 316, Aluminum
- Weight: 1.90 Lbs./Ft. (2.83 kg/m)

Note:
Aluminum loading, for B22 & B22A, can be determined by multiplying load data times a factor of 0.38





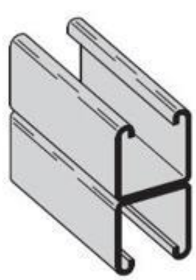
Section Properties			X - X Axis			Y - Y Axis		
Channel	Weight lbs./ft. kg/m	Areas of Section sq. in. cm^2	Moment of Inertia (I) $in.^4$ cm^4	Section Modulus (S) $in.^3$ cm^3	Radius of Gyration (r) in. cm	Moment of Inertia (I) $in.^4$ cm^4	Section Modulus (S) $in.^3$ cm^3	Radius of Gyration (r) in. cm
B22	1.910 (2.84)	.562 (3.62)	.1912 (7.96)	.2125 (3.48)	.583 (1.48)	.2399 (9.99)	.2953 (4.84)	.653 (1.66)
B22A	3.820 (5.69)	1.124 (7.25)	.9732 (40.51)	.5989 (9.81)	.931 (2.36)	.4798 (19.97)	.5905 (9.68)	.653 (1.66)
B22X	6.649 (9.89)	1.956 (12.62)	4.1484(172.67)	1.7019 (27.89)	1.456 (3.70)	1.1023 (45.88)	1.2027 (19.71)	.751 (1.91)

Calculations of section properties are based on metal thicknesses as determined by the AISI Cold-Formed Steel Design Manual.

Figure 4. Properties of Channel B22

Section Properties			X - X Axis			Y - Y Axis		
Channel	Weight lbs./ft. kg/m	Areas of Section sq. in. cm^2	Moment of Inertia (I) $in.^4$ cm^4	Section Modulus (S) $in.^3$ cm^3	Radius of Gyration (r) in. cm	Moment of Inertia (I) $in.^4$ cm^4	Section Modulus (S) $in.^3$ cm^3	Radius of Gyration (r) in. cm
B22	1.910 (2.84)	.562 (3.62)	.1912 (7.96)	.2125 (3.48)	.583 (1.48)	.2399 (9.99)	.2953 (4.84)	.653 (1.66)
B22A	3.820 (5.69)	1.124 (7.25)	.9732 (40.51)	.5989 (9.81)	.931 (2.36)	.4798 (19.97)	.5905 (9.68)	.653 (1.66)
B22X	6.649 (9.89)	1.956 (12.62)	4.1484(172.67)	1.7019 (27.89)	1.456 (3.70)	1.1023 (45.88)	1.2027 (19.71)	.751 (1.91)

Calculations of section properties are based on metal thicknesses as determined by the AISI Cold-Formed Steel Design Manual.



B22A
Wt. 3.80 Lbs./Ft. (5.65 kg/m)

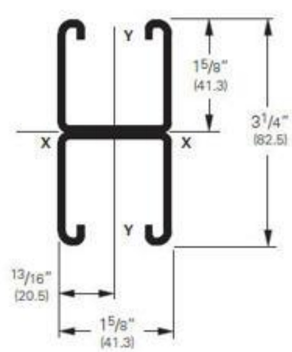


Figure 5. Properties of Channel B22A

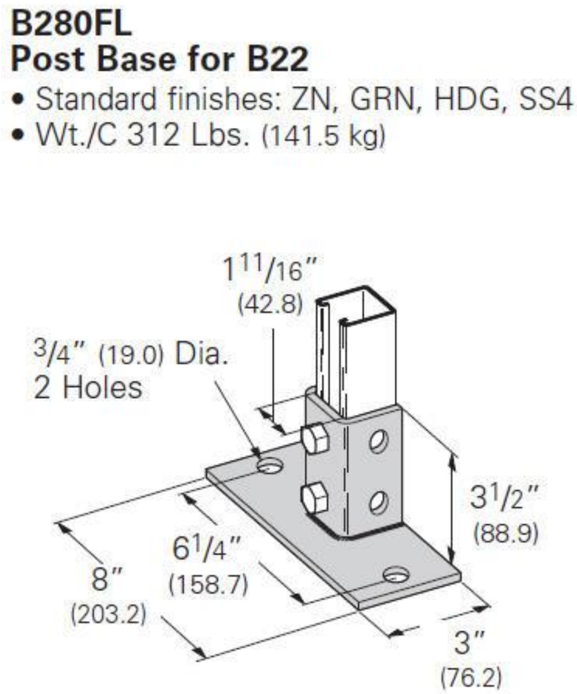


Figure 6. Properties of Post Base B280FL

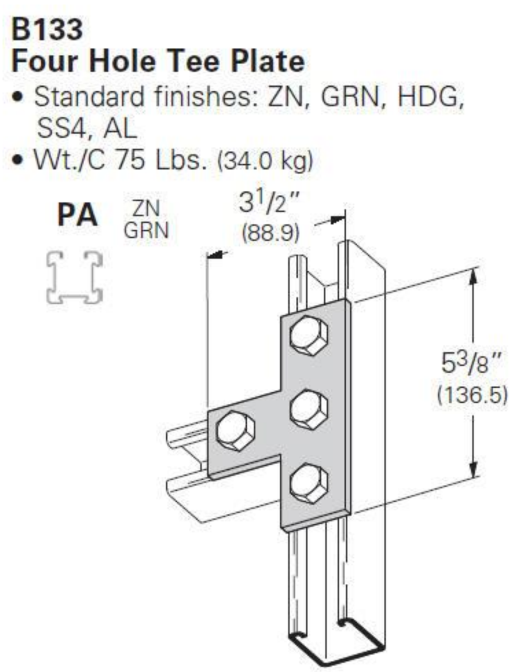


Figure 7. Properties of Four Hole Tee Plate B133

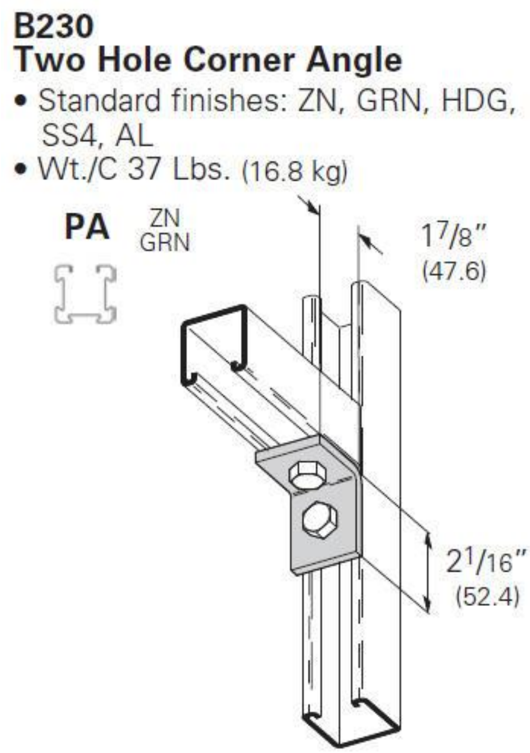


Figure 8 Properties of Two Hole Corner Angle B230

B631 - Two Hole 45° Tubing Knee Brace

- 1" (25.4) Square steel tubing
- Material: ASTM A513
- Standard finishes: ZN, GRN
- Design load determined by testing using a B335 hinged corner connection.
- Load ratings are for brace members only. Do not exceed allowable beam or column loads for strut channels.
- Safety Factor of 3

Part No.	A In.	A mm	Design Load Lbs.	Design Load kN	Wt./C Lbs.	Wt./C kg
B631-18	18"	(457.2)	1500	(6.67)	145	(65.8)
B631-24	24"	(609.6)	1500	(6.67)	186	(84.4)
B631-30	30"	(762.0)	1500	(6.67)	225	(102.0)
B631-36	36"	(914.4)	1500	(6.67)	266	(120.6)
B631-42	42"	(1066.8)	1230	(5.47)	307	(139.2)
B631-48	48"	(1219.2)	940	(4.18)	348	(157.8)
B631-54	54"	(1371.6)	740	(3.29)	389	(176.4)
B631-60	60"	(1524.0)	600	(2.67)	430	(195.0)
B631-72	72"	(1828.8)	420	(1.87)	508	(230.4)
B631-84	84"	(2133.6)	310	(1.38)	589	(267.2)
B631-96	96"	(2438.4)	240	(1.07)	669	(303.5)

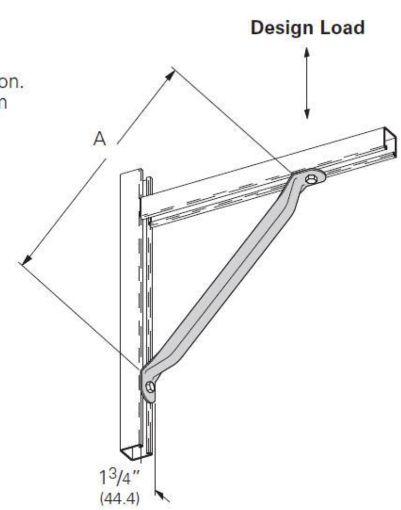
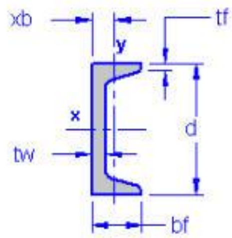


Figure 9. Properties of Two Hole Knee Brace B631-18



in x lb/ft	Area (in^2)	d (in)	bf (in)	tf (in)	tw (in)	Ixx (in^4)	Iyy (in^4)	xb (in)
C15x50	14.7	15	3.716	0.65	0.716	404	11	0.798
C15x40	11.8	15	3.52	0.65	0.52	349	9.23	0.777
C15x33.9	9.96	15	3.4	0.65	0.4	315	8.13	0.787
C12x30	8.82	12	3.17	0.501	0.51	162	5.14	0.674
C12x25	7.35	12	3.047	0.501	0.387	144	4.47	0.674
C12x20.7	6.09	12	2.942	0.501	0.282	129	3.88	0.698
C10x30	8.82	10	3.033	0.436	0.673	103	3.94	0.649
C10x25	7.35	10	2.886	0.436	0.526	91.2	3.36	0.617
C10x20	5.88	10	2.739	0.436	0.379	78.9	2.81	0.606
C10x15.3	4.49	10	2.6	0.436	0.24	67.4	2.28	0.634
C9x20	5.88	9	2.648	0.413	0.448	60.9	2.42	0.583
C9x15	4.41	9	2.485	0.413	0.285	51	1.93	0.586
C9x13.4	3.94	9	2.433	0.413	0.233	47.9	1.76	0.601
C8x13.75	4.04	8	2.343	0.39	0.303	36.1	1.53	0.553
C8x11.5	3.38	8	2.26	0.39	0.22	32.6	1.32	0.571
C7x14.75	4.33	7	2.299	0.366	0.419	27.2	1.38	0.532
C7x12.25	3.6	7	2.194	0.366	0.314	24.2	1.17	0.525

Figure 10. Properties of Steel C-Channels

3. Allowable Load

Referring to the channel information provided by B-line (http://www.cooperindustries.com/content/dam/public/bline/Resources/Library/catalogs/bolted_framing/strut_systems/Channel.pdf), the design loads given for strut beam loads are based on a simple beam condition using an allowable stress of 25,000 psi. This allowable stress results in a safety factor of 1.68.

4. FEA on the Support Design

A Finite Element Analysis (FEA) was performed on the panels and support structure using a decent meshing with beam and shell elements as shown in Figure 11. The result of the resultant stress is shown in Figure 12 and it is basically well under 10,000 psi everywhere. The maximum of 23,000 psi is found at the local contact point between the top of a C-channel beam and the double channel. The maximum deformation is 0.25 inches and occurs at the edges of the small panel at the far end and the result is shown in Figure 13.

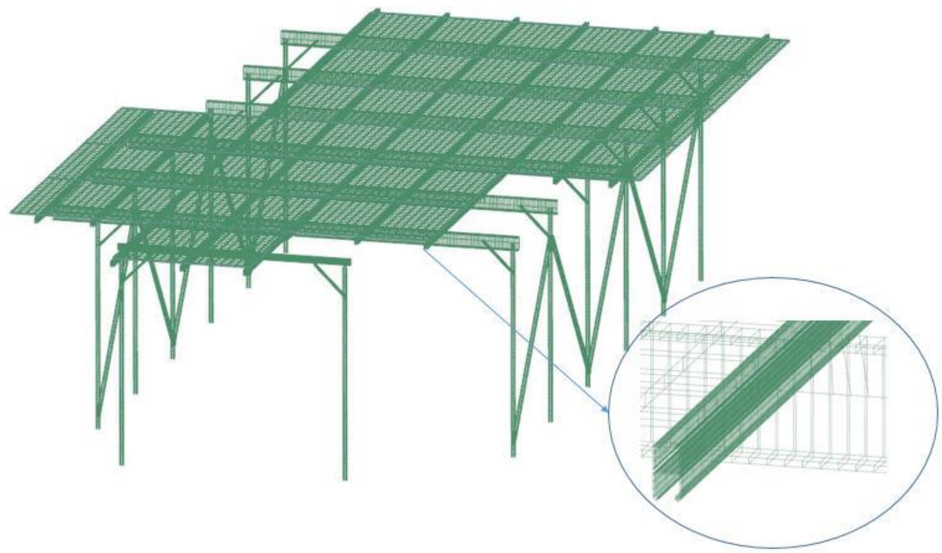


Figure 11. Beam and Shell Element Meshing of Panels and Supports

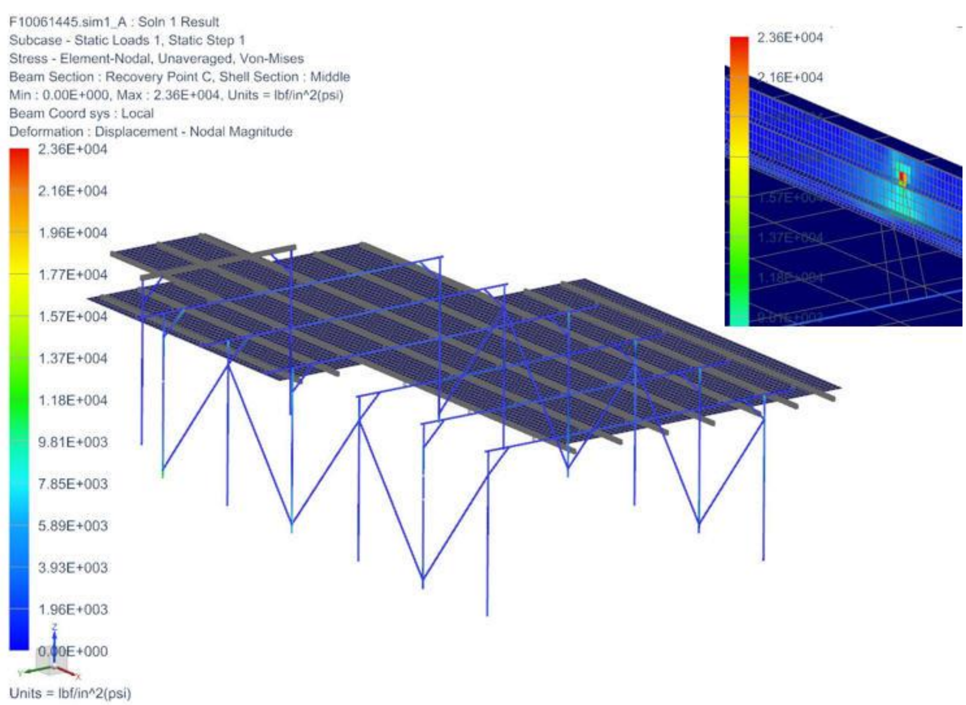


Figure 12. The Resultant Stresses of Panels and Support

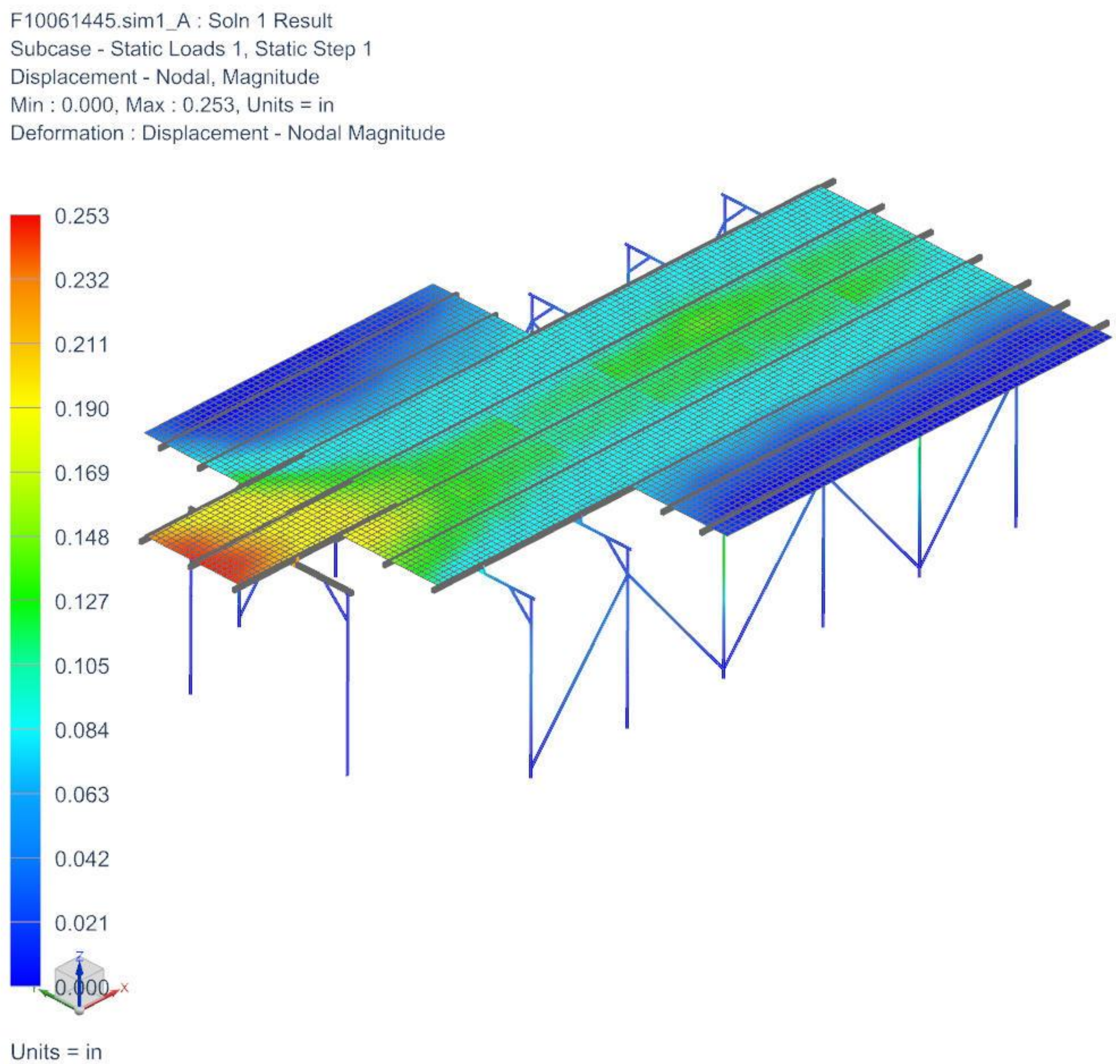


Figure 13. Total Deformation of Panels and Supports (True Scale)

The reaction forces of each vertical support leg were plotted in Figure 14 and the maximum was 1,777 lbf only which is well under the vendor's allowable compressive load of approximately 2,800 pounds as shown in Figure 15. The total of reactional force is about 11,000 lbf, which is the summation of the total panel weight of 7,500 lbs plus 3,500 lbs of supports.

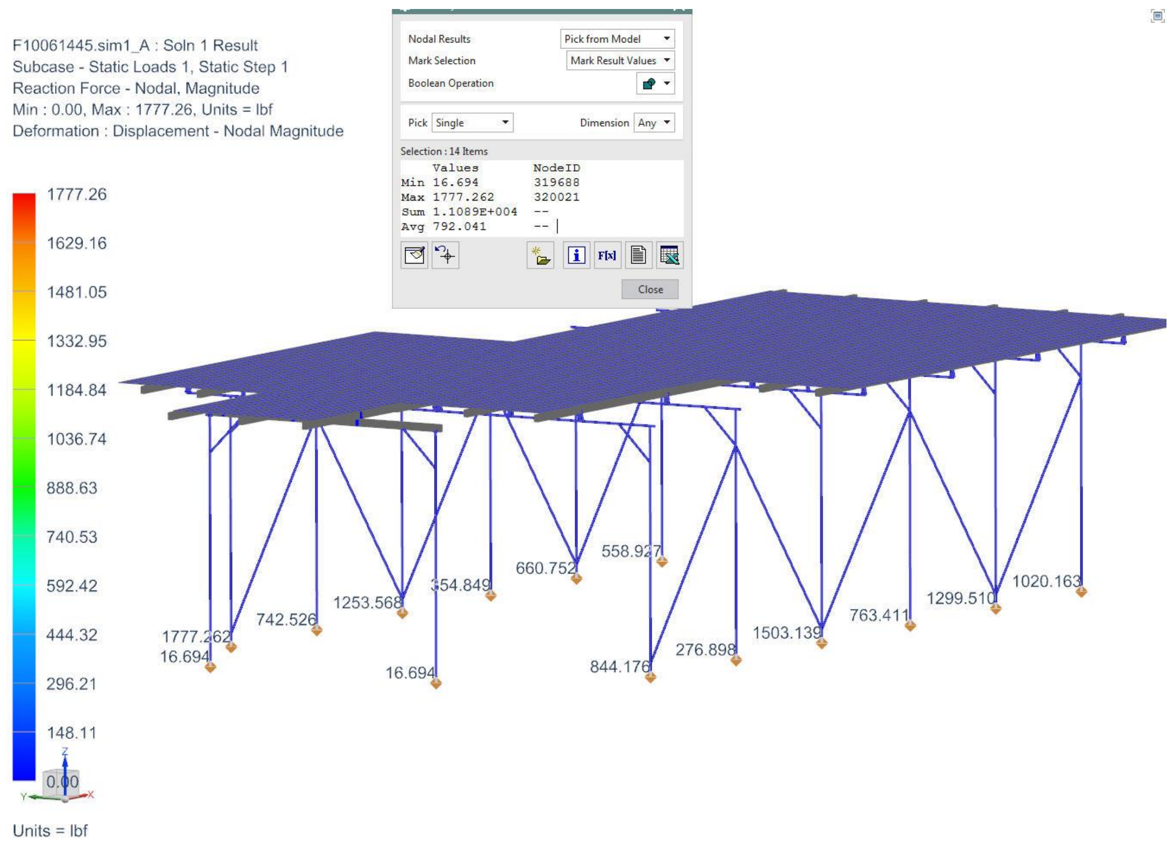


Figure 13. Reaction Forces on Vertical Supports

B22 Column Loading Data

Column Loading

Unbraced Height		Channel Style	Max. Column Loading K = .80				Max. Column Loading (Loaded @ C.G.)					
			Loaded@ C.G.		Loaded@ Slot Face		K = .65		K = 1.0		K = 1.2	
In.	mm		Lbs.	kN	Lbs.	kN	Lbs.	kN	Lbs.	kN	Lbs.	kN
12	(305)	B22	10454	(46.50)	4276	(19.12)	10598	(47.14)	10222	(45.47)	9950	(44.26)
		B22A	21625	(96.19)	7002	(31.14)	21677	(96.42)	21539	(95.81)	21433	(95.34)
		B22X	46948	(208.83)	18975	(84.40)	47061	(209.34)	46761	(208.00)	46531	(206.98)
18	(457)	B22	9950	(44.26)	4153	(18.47)	10253	(45.62)	9481	(42.17)	8955	(39.83)
		B22A	21433	(95.34)	6959	(30.95)	21551	(95.86)	21239	(94.47)	21001	(93.42)
		B22X	46531	(206.98)	18859	(83.90)	46787	(208.12)	46110	(205.11)	45593	(202.81)
24	(609)	B22	9311	(41.42)	3993	(17.76)	9801	(43.60)	8582	(38.17)	7801	(3470)
		B22A	21164	(94.14)	6898	(30.68)	21373	(95.07)	20819	(92.61)	20397	(9073)
		B22X	45947	(204.38)	18693	(84.44)	46401	(206.40)	45198	(201.05)	44282	(196.97)
30	(762)	B22	8582	(38.17)	3802	(16.91)	9268	(41.22)	7601	(33.81)	6595	(29.33)
		B22A	20819	(92.61)	6821	(30.34)	21145	(94.06)	20279	(90.20)	19619	(87.27)
		B22X	45198	(201.05)	18485	(82.22)	45906	(204.20)	44026	(195.84)	42593	(189.46)
36	(914)	B22	7801	(34.70)	3589	(15.96)	8676	(38.59)	6595	(28.33)	5392	(23.98)
		B22A	20397	(90.73)	6728	(29.93)	20866	(92.81)	19619	(87.27)	18669	(83.04)
		B22X	44282	(196.97)	18233	(81.10)	45300	(201.50)	42593	(189.46)	40530	(180.28)
42	(1067)	B22	6998	(31.13)	3360	(14.94)	8048	(35.80)	5595	(24.89)	4444	(19.77)
		B22A	19898	(88.51)	6620	(29.45)	20537	(91.33)	18840	(83.80)	17546	(78.05)
		B22X	43198	(192.15)	17940	(79.80)	44586	(198.33)	40901	(181.94)	38092	(169.44)
48	(1219)	B22	6193	(27.55)	3118	(13.87)	7401	(32.92)	4718	(20.99)	3791	(16.86)
		B22A	19322	(85.95)	6496	(28.89)	20157	(89.66)	17940	(79.80)	16251	(72.29)
		B22X	41948	(186.59)	17604	(78.30)	43761	(194.57)	38948	(173.25)	35281	(156.94)
54	(1371)	B22	5392	(23.98)	2864	(12.74)	6746	(30.01)	4090	(18.19)	3310	(14.72)
		B22A	18669	(83.04)	6263	(27.86)	19276	(87.74)	16920	(75.26)	14782	(65.75)
		B22X	40530	(180.28)	16973	(75.50)	42825	(190.49)	36733	(163.39)	32092	(142.75)
60	(1524)	B22	4718	(20.99)	2631	(11.70)	6093	(27.10)	3616	(16.08)	2936	(13.06)
		B22A	17940	(79.80)	5340	(23.75)	19244	(85.60)	15781	(70.20)	13141	(58.45)
		B22X	38948	(173.25)	14471	(64.37)	41779	(185.84)	34260	(152.39)	28529	(126.90)
66	(1676)	B22	4202	(18.69)	2434	(10.83)	5441	(24.20)	3242	(14.42)	2634	(11.71)
		B22A	17134	(76.21)	4587	(20.40)	18712	(83.23)	14521	(64.59)	11328	(50.39)
		B22X	37198	(165.46)	12431	(55.29)	40624	(180.70)	31525	(140.23)	24593	(109.39)
72	(1829)	B22	3791	(16.86)	2264	(10.07)	4869	(21.66)	2936	(13.06)	2381	(10.59)
		B22A	16251	(72.29)	3968	(17.65)	18129	(80.64)	13141	(58.45)	9524	(42.36)
		B22X	35281	(156.94)	10753	(47.83)	39358	(175.07)	28529	(126.90)	20676	(91.97)
78	(1981)	B22	3456	(15.37)	2116	(9.41)	4412	(19.62)	2680	(11.92)	2166	(9.63)
		B22A	15291	(68.02)	3456	(15.37)	17496	(77.82)	11642	(51.78)	8115	(36.10)
		B22X	33197	(147.67)	9366	(41.66)	37984	(168.96)	25275	(112.43)	17617	(78.36)
84	(2133)	B22	3176	(14.13)	1984	(8.82)	4037	(17.96)	2461	(10.95)	1980	(8.81)
		B22A	14255	(63.41)	3028	(13.47)	16812	(74.78)	10076	(44.82)	6998	(31.13)
		B22X	30947	(137.66)	8206	(36.50)	36499	(162.35)	21875	(97.30)	15192	(67.58)
90	(2286)	B22	2936	(13.06)	1867	(8.30)	3724	(16.56)	2270	(10.10)	1816	(8.08)
		B22A	13141	(58.45)	2667	(11.86)	16077	(71.51)	8778	(39.04)	6096	(27.11)
		B22X	28529	(126.90)	7227	(32.15)	34903	(155.25)	19057	(84.77)	13234	(58.87)
96	(2438)	B22	2728	(16.58)	1761	(7.83)	3456	(15.37)	2101	(9.34)	1671	(7.43)
		B22A	11951	(53.16)	2359	(10.49)	15291	(68.02)	7715	(34.32)	5357	(23.83)
		B22X	25945	(115.41)	6393	(28.44)	33197	(147.67)	16749	(74.50)	11630	(51.73)
102	(2591)	B22	2545	(11.32)	1664	(7.40)	3225	(14.34)	1951	(8.68)	1542**	(6.34)
		B22A	10678	(47.50)	2093	(9.31)	14455	(64.30)	6834	(30.40)	4746	(21.11)
		B22X	23182	(103.12)	5672	(25.23)	31382	(139.59)	14836	(65.99)	10303	(45.83)
108	(2743)	B22	2381	(10.59)	1575	(7.00)	3022	(13.44)	1816	(8.08)	1426**	(68.60)
		B22A	9524	(42.36)	1867	(8.30)	13568	(60.35)	6096	(27.11)	4233	(18.83)
		B22X	20676	(91.97)	5059	(22.50)	29456	(131.03)	13234	(58.87)	9190	(40.88)
114	(2895)	B22	2234	(9.94)	1494	(6.64)	2842	(12.64)	1694	(7.53)	1322**	(5.88)
		B22A	8548	(38.02)	1675	(7.45)	12630	(56.18)	5471	(24.33)	3799**	(16.90)
		B22X	18558	(82.55)	4539	(20.19)	27420	(121.97)	11877	(52.83)	8247	(36.68)

Figure 15. Allowable Loading for Column Post made of Channel B22

A double check on the column support using Euler Buckling calculation is made as well. It is found that each of the support legs can withstand 18 kips before buckling as shown in Figure 16.

Buckling of MicroBooNE Support Structure

The dimensions for a B22 channel support beam are used

Variables

Young Modulus

$E := 200\,GPa$

Moment of Inertia

$I_{xx} := 0.1912\,in^4$

Length of Support Beams

$Length_{support} := 110\,in$

Factor Accounting for End Conditions

$K_{end} := 0.5$ (assume both ends are fixed)

Cross Sectional Area

$area := 0.562\,in^2$

Equations

$$Buckling_{load} := \frac{\left(\pi^2 \cdot E \cdot I_{xx}\right)}{\left(K_{end} \cdot Length_{support}\right)^2}$$

$Buckling_{Load} = 18096\,lbf$

Figure 16. Euler Buckling Calculations for B22 Channel Support Beams

5. Other Calculations

As a general rule, the support structure should be able to withstand a lateral load at least 10% of the overall load which is 10,245 pounds including the weights of the table-top supporting parts in this case. Since one angled support is rated for 1,500 pounds as previously shown in Figure 8, so the total allowable lateral load being applied on the table-top being shared by a set of 14 angled supports is no concern of a failure due to the lateral load.

Calculations for stress in the legs and bolts in the feet from a 10% lateral loading is shown next. They show a safety factor of 1.55 and 5.26 respectively for a 1,025 lb. lateral load on the structure at the top. More lateral loading could be applied to the lower part of the legs, as the resulting moment on the structure is lower, but we show a worst case. More lateral loading could also be applied in the transverse direction, with the large diagonal strut braces, but we analyze the weaker direction which only has a set of small 18-inch long brace supports.

Stesss in Legs from Lateral Loading.

$Total_{load} := 10245lbf$ $Lateral_{Load} := Total_{load} \cdot 10\% = 1024.5\,lbf$

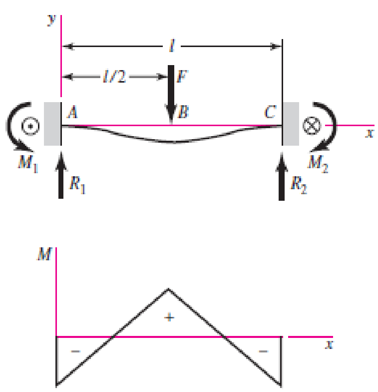
$height_{foot} := 3.75in$ $num_{supports} := 14$

$Length_{staright} := Length_{leg} - Length_{support} - height_{foot} = 93.522\,in$

$Lateral_{LoadPerSupport} := \dfrac{Lateral_{Load}}{num_{supports}}$ $Lateral_{LoadPerSupport} = 73.179\,lbf$

The Shape of these bent legs would be a latertal offset, which would be equal to the fixed support, center load case, where the top of the leg at the angle support location is one end of the beam in the diagram below,, and the bottom of the leg is the center of the beam shown in the diagram below.

14 Fixed supports—center load



$$R_1 = R_2 = \frac{F}{2} \qquad M_1 = M_2 = \frac{Fl}{8}$$

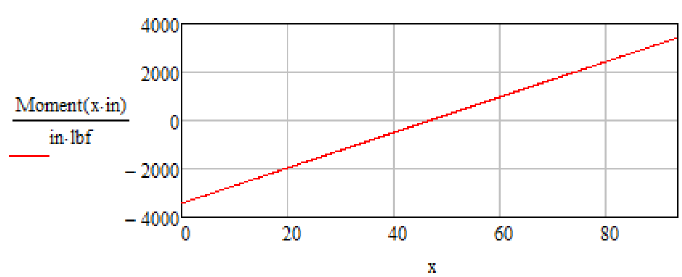
$$V_{AB} = -V_{BC} = \frac{F}{2}$$

$$M_{AB} = \frac{F}{8}(4x - l) \qquad M_{BC} = \frac{F}{8}(3l - 4x)$$

$$y_{AB} = \frac{Fx^2}{48EI}(4x - 3l)$$

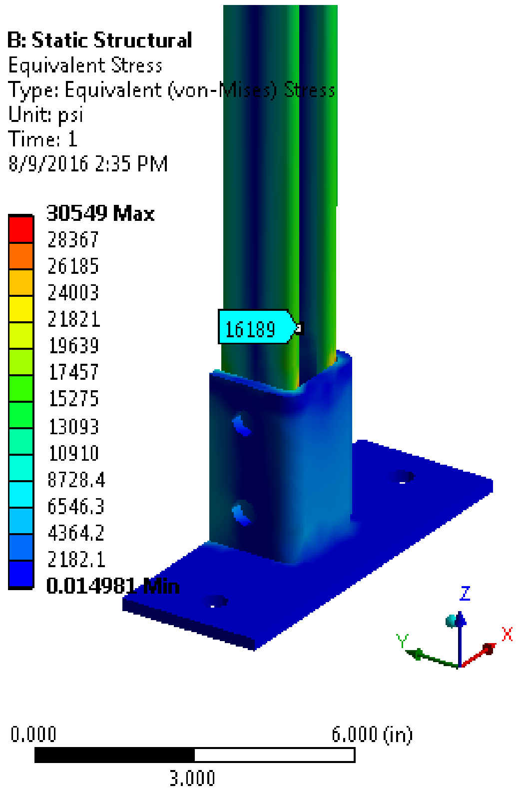
$$y_{max} = -\frac{Fl^3}{192EI}$$

$Moment(x) := \dfrac{Lateral_{LoadPerSupport} \cdot 2 \cdot (4 \cdot x - 2 \cdot Length_{staright})}{8}$ $Lateral_{LoadPerSupport} \cdot 2 = 146.357\,lbf$



$Moment(Length_{staright}) = 3421.906\,in \cdot lbf$

Hand Calculations and FEA results for stress in legs are in agreement, and below the allowable load.



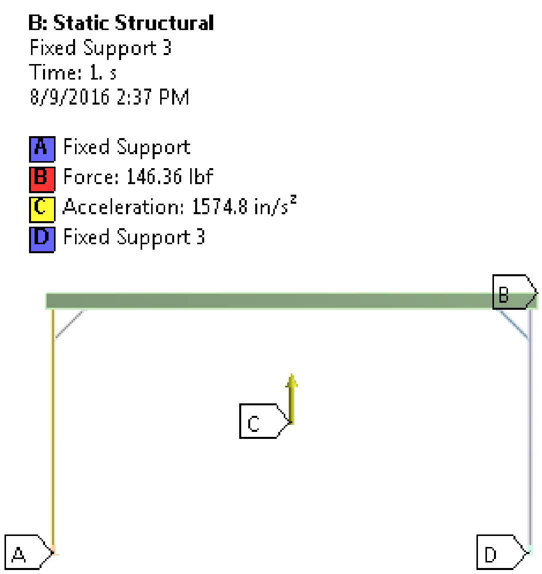
$I_{xx} := 0.1912 in^4 \qquad c_{B22} := (1.625 - 0.7252) in = 0.9 in$

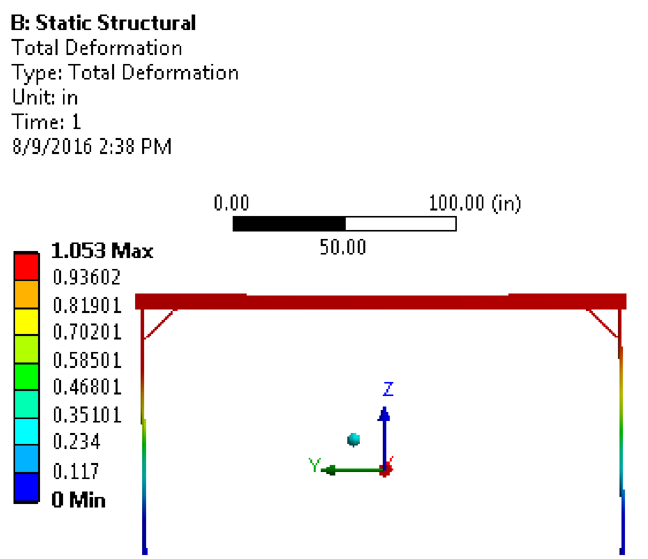
$$\sigma_{bending} := \frac{Moment(Length_{staright}) \cdot (c_{B22})}{I_{xx}} = 16.104 ksi$$

$$\delta_{lateral} := \frac{Lateral_{LoadPerSupport} \cdot 2 \cdot (Length_{staright} \cdot 2)^3}{192 \cdot E_{steel} \cdot I_{xx}} = 0.899 in$$

$\sigma_{allowed} := 25 ksi$

$$Safety_{FactorLegs} := \frac{\sigma_{allowed}}{\sigma_{bending}} = 1.552$$





Bolt Force due to Moment caused by lateral load:

$Moment_{Foot} := 4612 in \cdot lbf$

$length_{BoltToPlateEnd} := 1.5 in \qquad num_{Bolts} := 2$

$$Force_{Bolt} := \frac{Moment_{Foot}}{num_{Bolts} \cdot length_{BoltToPlateEnd}} = 1537.333 \, lbf$$

Half inch by 13 bolt

$area_{bolt} := 0.1419 in^2$

$$\sigma_{bolt} := \frac{Force_{Bolt}}{area_{bolt}} = 10.834 \, ksi$$

$\sigma_{yield.Grade2} := 57 ksi$

$$Safety_{FactorBolts} := \frac{\sigma_{yield.Grade2}}{\sigma_{bolt}} = 5.261$$