Particle Physics Division

# Mechanical Department Engineering Note

Number: MD-ENG-549 Date: 08/17/2016

Project: MicroBooNE

Project Internal Reference:

Title: MicroBooNE Muon Tagger Panels Framing Supports

Author(s): C. M. Lei

Reviewer(s): Erik Voirin ID#15426N

Key Words: Unistrut, 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 assemblies. This side panel group consists of five separate support assemblies with the largest load about 2,900 lbs. The design of the support assemblies is similar and works like a shower curtain. This note shows that the side support assemblies are adequately designed to safely support the load.

1. **The side panels design:**

Similar to the shower curtain, the panels are carried by a set of B-Line bearing trolleys B376 rolling along the double channel B22A as shown in Figure 1. There are five sets of separate trolley assemblies for the sides, each attached to the large I beams using beam clamps. They are named below, and their support designs are shown in Figures 2, 3, 4, 5 and 6.

- Feed-Through Horizontal
- Feed-Through Vertical
- Pipe Horizontal
- Pipe Vertical, and
- Pipe Combined which has three horizontal and seven vertical panels.

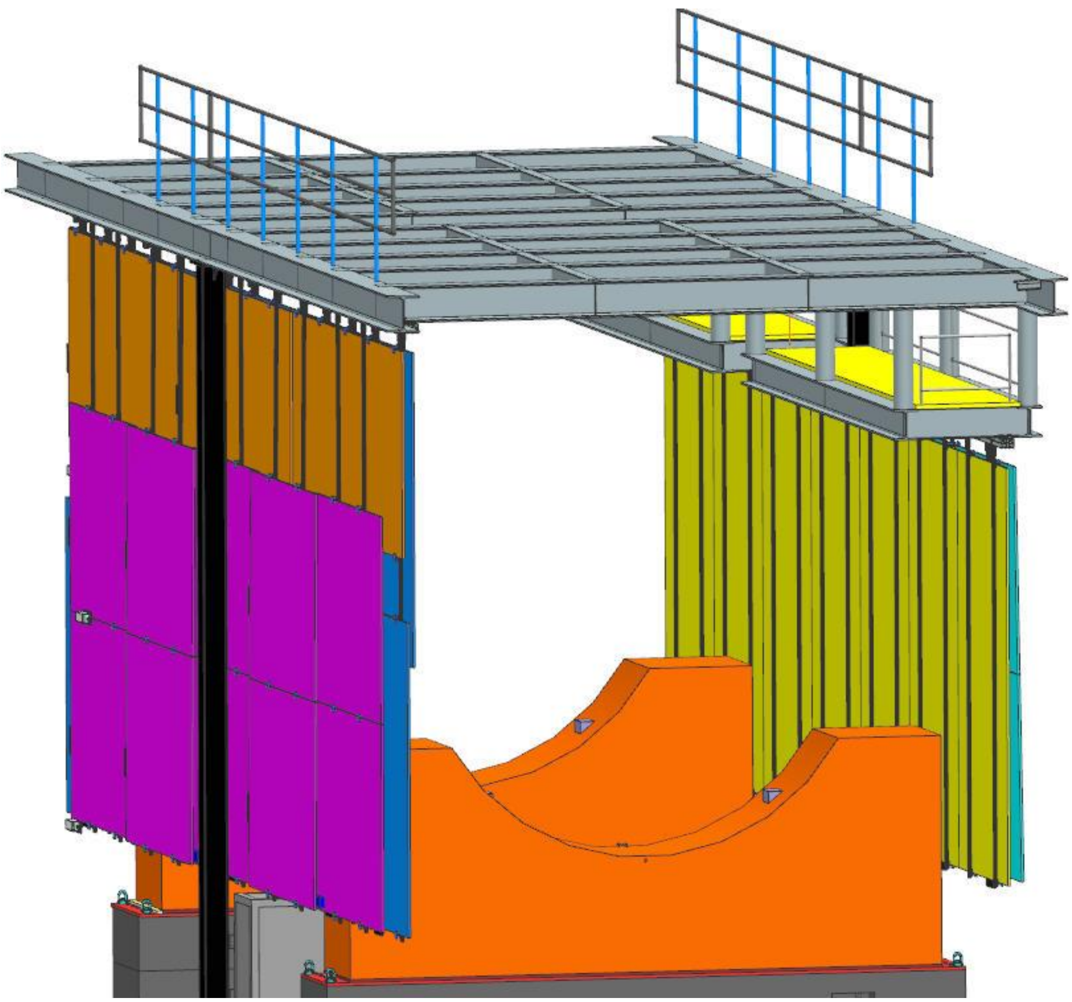


Figure 1. Side Panels Layout

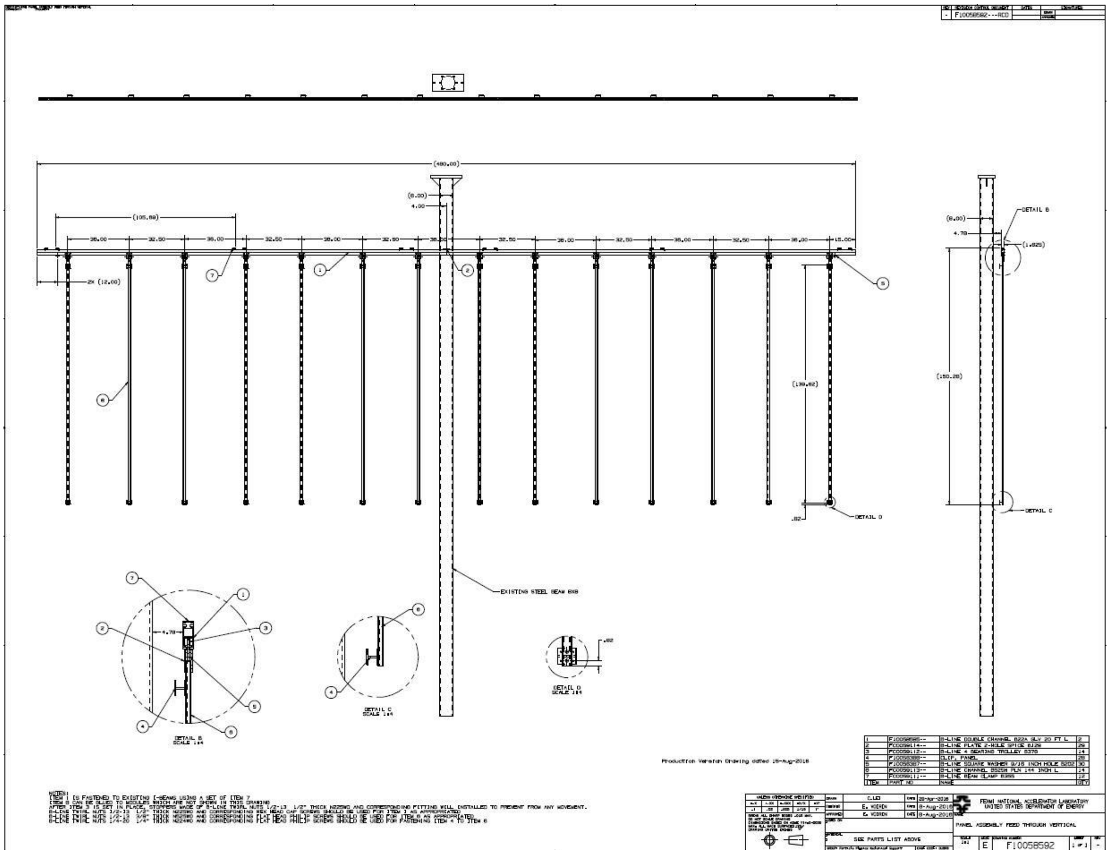



Figure 2. Support Design for Feed-Through Vertical Side Panels

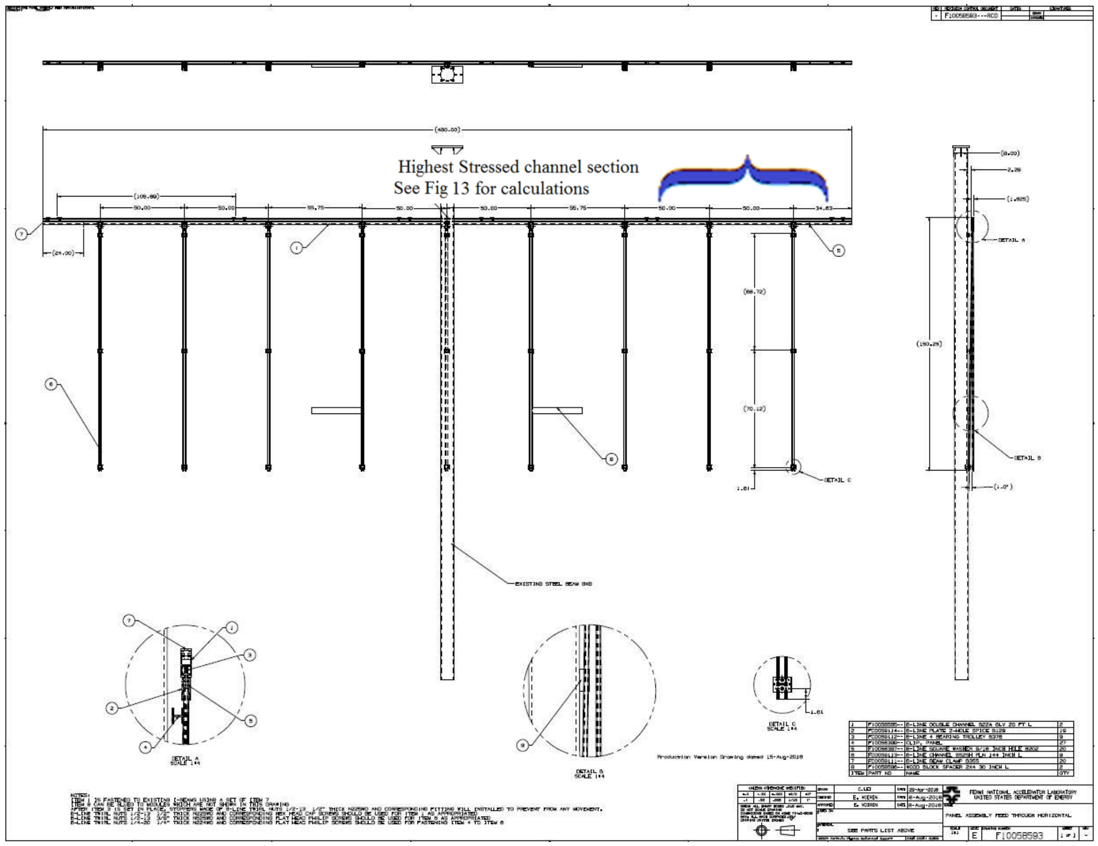



Figure 3. Support Design for Feed-Through Horizontal Side Panels

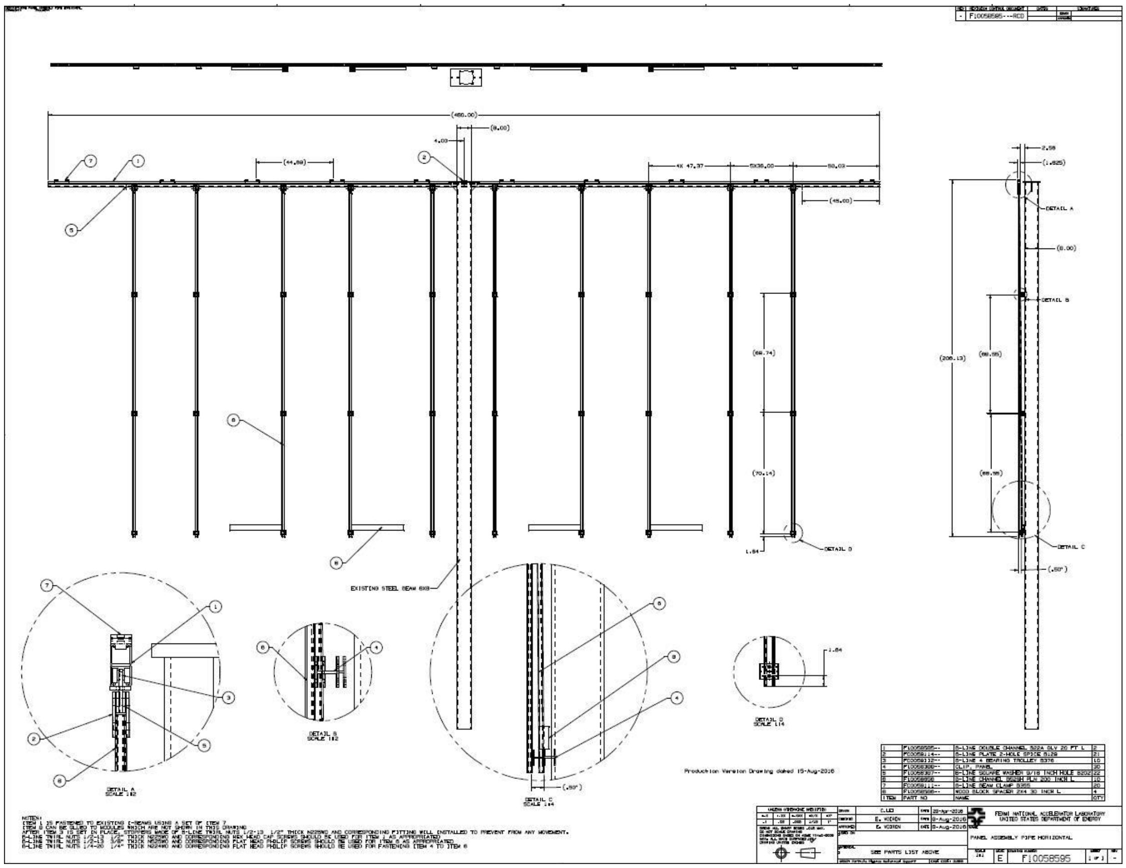


Figure 4. Support Design for Pipe Horizontal Side Panels

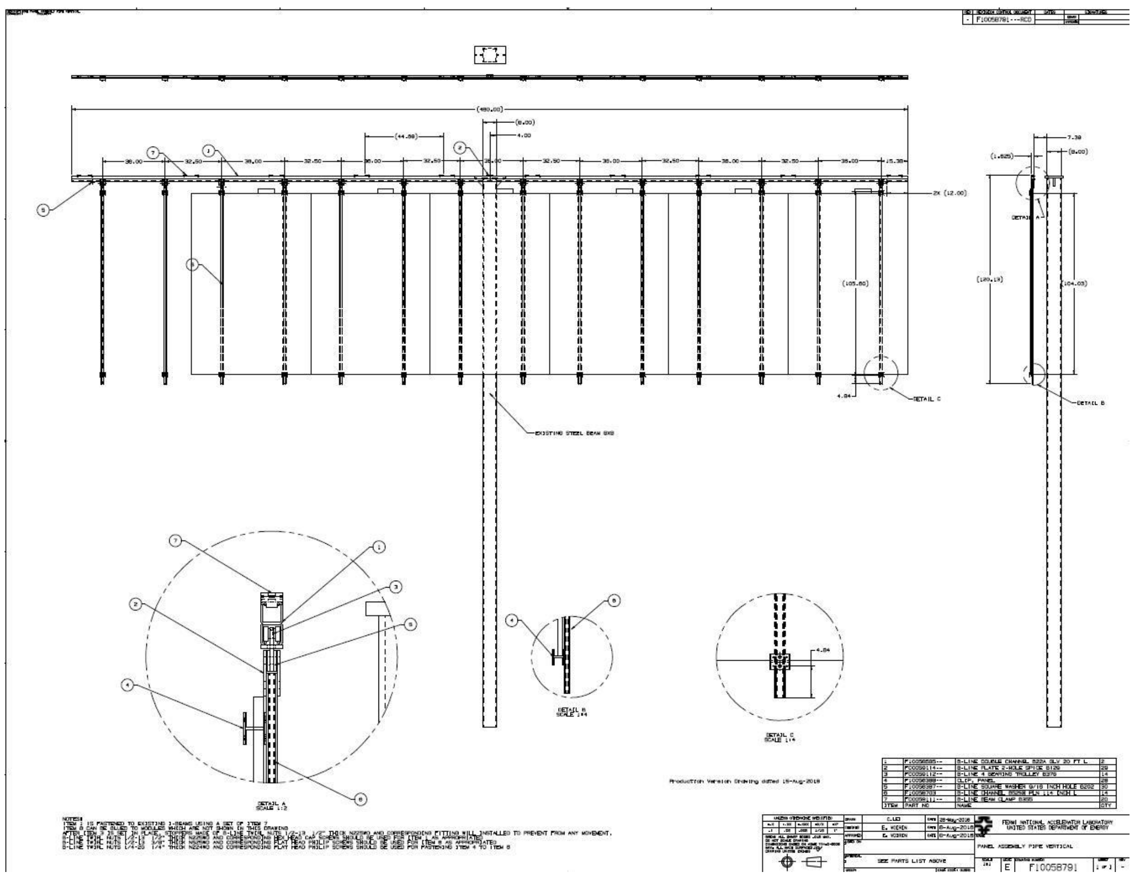


Figure 5. Support Design for Pipe Vertical Side Panels

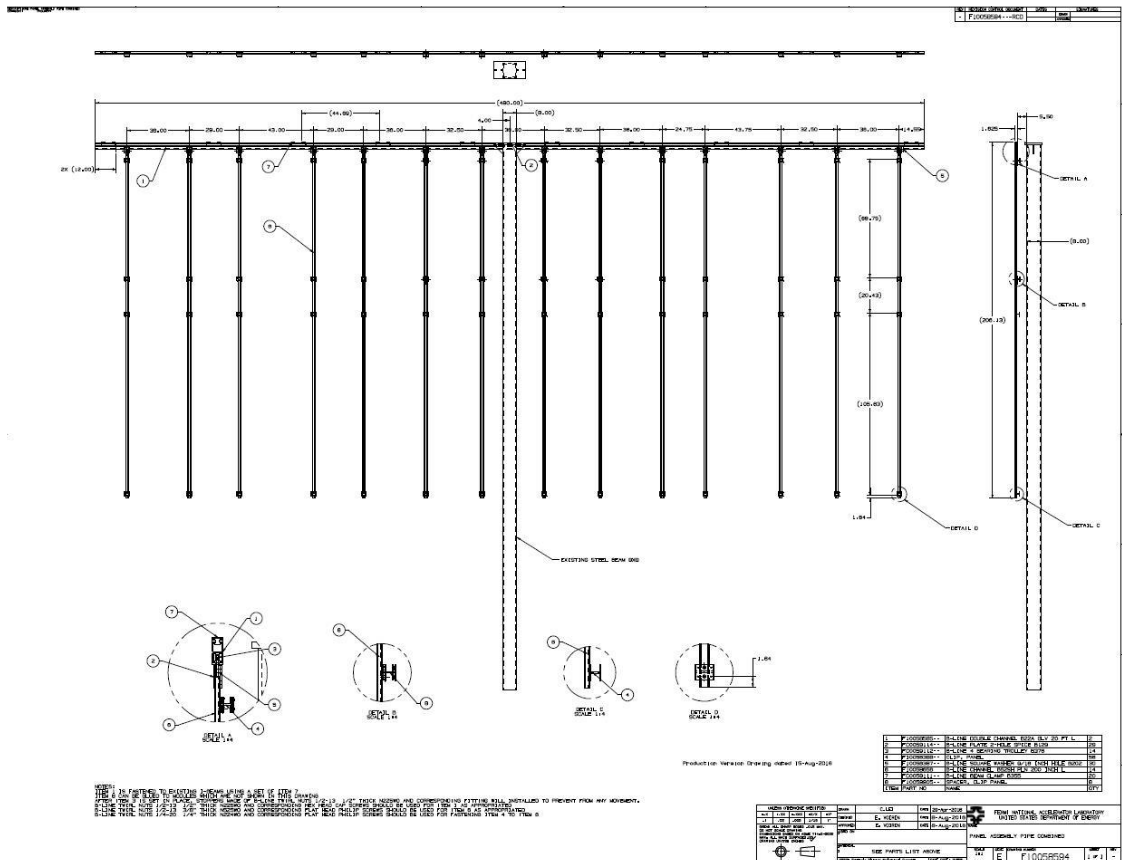


Figure 6. Support Design for Pipe Combined Side Panels

2. **Allowable Load**

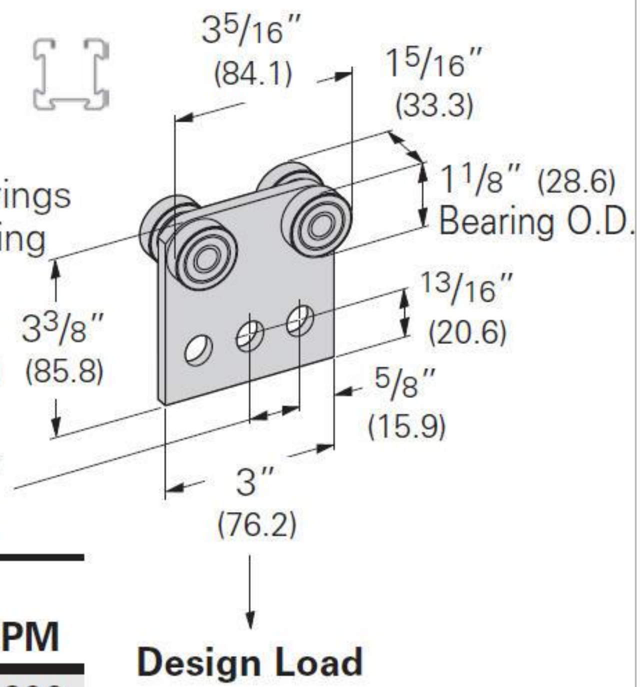
Referring to the channel information provided by B-line (http://www.cooperindustries.com/content/dam/public/bline/Resources/Library/catalogs/bolted_framing/strut_systems/Channel.pdf), the design loads given for strut beam loads are based on a simple beam condition using an allowable stress of 25,000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

3. **Load Capacity Check**

Referring to Figure 7, the load capacity of each bearing trolley with a safety factor of 2.5 can be taken as 600 lbs as the available worst-case rating. The actual rolling speed during the installation phase will be much slower than 100 RPM.

**B376**
**Four Bearing Trolley Assembly**

- Safety Factor of 2.5
- Stainless steel ball bearings
- Not for continuous cycling applications
- Standard finishes: ZN
- Wt./C 110 Lbs. (49.9 kg)

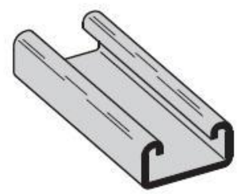


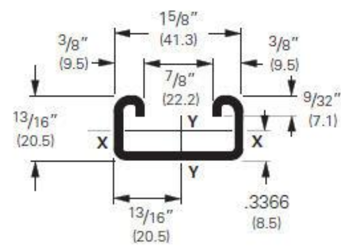

| Design Load in B22 | | RPM |
|---|---|---|
| Lbs. | kN | |
| 300 | (1.33) | @600 |
| 450 | (2.00) | @300 |
| 600 | (2.67) | @100 |

Figure 7. Bearing Trolley Load Capacity

## B52 Channel & Combinations

**B52**
- Thickness: 12 Gauge (2.6 mm)
- Standard lengths: 10′ (3.05 m) & 20′ (6.09 m)
- Standard finishes: Plain, DURA GREEN™, Pre-Galvanized, Stainless Steel Type 304 or 316, Hot-Dipped Galvanized
- Weight: 1.27 Lbs./Ft. (1.89 kg/m)






| Section Properties | | | X - X Axis | | | Y - Y Axis | | |
|---|---|---|---|---|---|---|---|---|
| Channel | Weight lbs./ft. kg/m | Areas of Section sq. in. cm² | Momentof Inertia (I) in.⁴ cm⁴ | Section Modulus (S) in.³ cm³ | Radius of Gyration (r) in. cm | Moment of Inertia (I) in.⁴ cm⁴ | Section Modulus (S) in.³ cm³ | Radius of Gyration (r) in. cm |
| **B52** | 1.313 (1.95) | .386 (2.49) | .0320 (1.33) | .0673 (1.10) | .288 (.73) | .1404 (5.84) | .1728 (2.83) | .603 (1.53) |
| **B52A** | 2.627 (3.91) | .773 (4.99) | .1517 (6.31) | .1868 (3.06) | .443 (1.13) | .2809 (11.69) | .3457 (5.67) | .603 (1.53) |

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

Figure 8. Properties of B52 Channel

The total load capacity provided by the bearing trolleys is then checked against all the weights they carry. The results are shown in Figure 9 with the maximum load to be carried by one bearing trolley is about 274 lbs only, the selection of using this bearing trolley is thus adequate.

| | Panel Q'ty | Total Panel Wt, lbs | Channel B52 Q'ty | Channel B52 Wt, lbs | Total Channel Wt, lbs | Total Wt, lbs | Trolley Q'ty | Load per channel | Total Trolley capacity, lbs | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| Feed through Horizontal, lbs | 6 | 2322 | 9 | 16 | 144 | **2466** | 9 | **274** | 5400 | OK |
| Feed through Vertical, lbs | 7 | 2338 | 14 | 16 | 224 | **2562** | 14 | **183** | 8400 | OK |
| Pipe Horizontal, lbs | 10 | 2220 | 10 | 13 | 130 | **2350** | 10 | **235** | 6000 | OK |
| Pipe Vertical, lbs | 7 | 1771 | 14 | 22 | 308 | **2079** | 14 | **149** | 8400 | OK |
| Pipe Combined, Lbs | 3 + 7 | 2911 | 14 | 22 | 308 | **3219** | 14 | **230** | 8400 | OK |

Figure 9. Load Capacity Check of Bearing Trolleys

B-line channel B52 will be used and hanging from the bearing trolley. With some proper fitting, these channels will be carrying the side panels. Hex head cap screws ½-13 will be used for fastening parts of the bearing trolley assembly. The shear load on screw

= Load that carries by the bearing trolley/cross-sectional area of ½-13 screw
= 274 lb. / 0.1419 $in^2$ (minor diameter of screw thread used.)
= 1,931 psi

Which is very small and any grade of steel screw can be selected without any problems.

Aluminum H clips are used to hold the panels. They are fastened to the pre-galvanized non-painted channel B52, which is made of 12 gauge steel, with ¼" flat head Philip screws together with B-line twirl nuts 1/4-20 1/4" thick N224WO as shown in Figure 10. Two screws should be used for the H clips in the bottom which support the panel basically while one screw is used for the top as it is simply captured the panel without falling only. As the resistance to slip of 300 lbs of these channel nuts as shown in Figure 11 is greater than the maximum weight of each channel to be carried, the design for this support is thus adequate. And regarding the shear load on screw

= Load that holds the H-clip held with one ¼-20 screw as the worst case
= 274 lb. / 0.0318 $in^2$ (minor diameter of screw thread used.)
= 8,616 psi

Alloy steel flat head socket head screws as provided by McMaster Carr (item# 91263559) can be selected for this application. This screw meets the ASTM F835 standard and it has a minimum tensile strength of 145,000 psi as shown in Figure 13. Referring to document Design of Below-the-Hook Lifting Devices ASME BTH-1-2005, the allowable shear stress $F_v$ of the screw is

$F_v = (0.62*F_u)/(1.2*N_d)$

Where $F_u$ = 145,000 psi, and $N_d$ = 2, a nominal design factor for general lifter

$F_v = (0.62*145{,}000)/(1.2*2)$
$= 37{,}460$ psi

Which is much higher than the shear stress of the ¼" screws and the selection of this screw is thus acceptable.

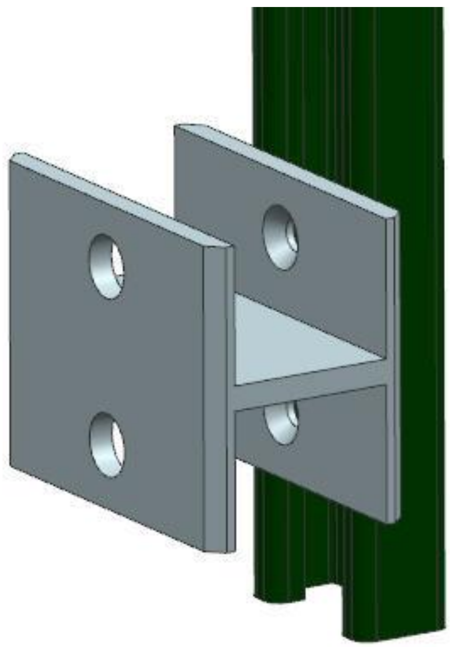


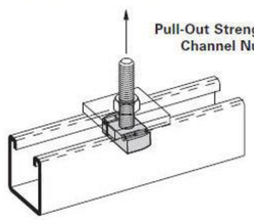
Figure 10.   The H Clip fastened to Channel

**Pull-Out Strength**
- With Safety Factor of 3
- Maximum pullout strength for B11 & B12 channels is limited to 1500 lbs. (6670 N).

| Thread Size | Nut Part Numbers | Pull-Out Strength 12 ga. Channel Lbs. | 12 ga. Channel N | 14 ga. Channel Lbs. | 14 ga. Channel N | 16 ga. Channel Lbs. | 16 ga. Channel N |
|---|---|---|---|---|---|---|---|
| #8-32 | N221, N221WO,N521, N721, TN221 | 200 | 890 | 200 | 890 | 200 | 890 |
| #10-24 | N222, N222WO, N522, N722, TN222 | 250 | 1110 | 250 | 1110 | 250 | 1110 |
| #10-32 | N227, N227WO, N527, N727, TN227 | 250 | 1110 | 250 | 1110 | 250 | 1110 |
| 1/4"-20 | NW524*, N224,N224WO, N524, N724, TN224, STN224, SN224WO, SN224, SN524, SN724 | 450 | 2000 | 450 | 2000 | 450 | 2000 |
| 5/16"-18 | N223, N223WO, N523, N723, TN223 | 750 | 3330 | 750 | 3330 | 750 | 3330 |
| 3/8"-16 | NW528*, N228, N228WO, N528, N728 TN228, STN228, SN228WO, SN228, SN528, SN728 | 1100 | 4890 | 1000 | 4450 | 1000 | 4450 |
| 7/16"-14 | N226, N226WO, N526, N726, TN226 | 1500 | 6670 | 1200 | 5340 | 1000 | 4450 |
| 1/2"-13 | N225, N225WO, N725, TN225, STN225, SN225WO, SN225, SN725 | 2000 | 8900 | 1400 | 6230 | 1000 | 4450 |
| | NW525*, N525, N525WO, TN525, STN525, SN525WO, SN525 | 1500 | 6670 | 1400 | 6230 | 1000 | 4450 |

**Resistance To Slip**
- With Safety Factor of 3

| Thread Size | Nut Part Numbers | Resistance to Slip 12 ga. Channel Lbs. | 12 ga. Channel N | 14 ga. Channel Lbs. | 14 ga. Channel N | 16 ga. Channel Lbs. | 16 ga. Channel N |
|---|---|---|---|---|---|---|---|
| #8-32 | N221, N221WO,N521, N721, TN221 | 50 | 220 | 50 | 220 | 50 | 220 |
| #10-24 | N222, N222WO, N522, N722, TN222 | 100 | 440 | 100 | 440 | 100 | 440 |
| #10-32 | N227, N227WO, N527, N727, TN227 | 100 | 440 | 100 | 440 | 100 | 440 |
| 1/4"-20 | NW524*, N224, N224WO, N524, N724, TN224, STN224, SN224WO, SN224, SN524, SN724 | 300 | 1330 | 300 | 1330 | 300 | 1330 |
| 5/16"-18 | N223, N223WO, N523, N723, TN223 | 450 | 2000 | 450 | 2000 | 450 | 2000 |
| 3/8"-16 | NW528*, N228, N228WO, N528, N728 TN228, STN228, SN228WO, SN228, SN528, SN728 | 800 | 3560 | 600 | 2670 | 600 | 2670 |
| 7/16"-14 | N226, N226WO, N526, N726, TN226 | 1000 | 4450 | 800 | 3560 | 800 | 3560 |
| 1/2"-13 | N225, N225WO, N725, TN225, STN225, SN225WO, SN225, SN725 | 1500 | 6670 | 1000 | 4450 | 1000 | 4450 |
| | NW525*, N525, N525WO, TN525, STN525, SN525WO, SN525 | 1500 | 6670 | 1000 | 4450 | 1000 | 4450 |



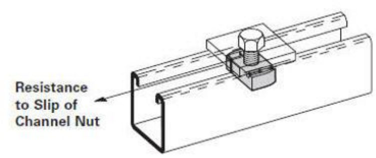




Figure 11. Properties of B-line Channel Nuts

**Mechanical Properties of Externally Threaded Fasteners**

| Specification | Material | Size Range (in.) | Min. Proof Strength (psi) | Min. Tensile Strength (psi) | Core Hardness Rockwell Min. | Core Hardness Rockwell Max. | Min. Yield Strength (psi) | Grade Identification Marking | Compatible Nuts |
|---|---|---|---|---|---|---|---|---|---|
| ASTM F835 Socket Button & Flat Countersunk Head Cap Screw | Medium carbon alloy steel: quenched & tempered | #0 - 1/2 | | 145,000 | C39 | C44 | | | |
| | | over 1/2 | | 135,000 | C37 | C44 | | | |

Figure 12. The Properties of ASTM F835 Screws

Double channel B22A is used as the rail for the bearing trolleys. These channels are clamped on the existing I-beams with the longest span about 106 inches for Feed-through Side and 44 inches for Pipe Side. As by observation, the most severe loading scenario is occurred on the 106-inch beam span in which two concentrated loads of 274 lb each, are acting on the double channel B22A as sketched in Figure 13 in which a worst-case end condition of simple support is analyzed. See Figure 3 for the beam section we are analyzing, which has the highest bending stress of any section of strut channel.

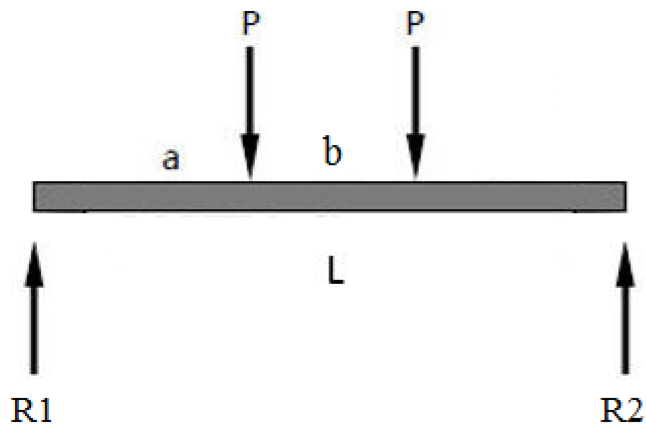



Figure 13. Schematic Loading Scenario of Double Channel B22A between Beam Clamps taken as Simple Support Ends

Where L = 106"; a = worst case of 35.3", b=50" and P = 274 lbs each.

The corresponding calculations and bending moment diagram along the double channel is then shown in Figure 14 in which the maximum bending moment of 8,480 in*lbs is resulted. The moment of inertia, I, as provided in Figure 20 is 0.9732 in^4. Therefore, the maximum bending stress, S, on the double channel is:

S = M*y/I where y = 1.625" for double channel B22A
= 8,480*1.625/0.9732
= 14,159 psi

As the allowable stress with a safety factor of 1.68 is equal to 25,000 psi, the double channel B22A is thus OK for being used in this loading scenario.

$length := 106in \qquad length_b(l_a) := length - l_a \qquad dist_{between} := 50in \qquad Force := 274lbf = 1218.813\,N$

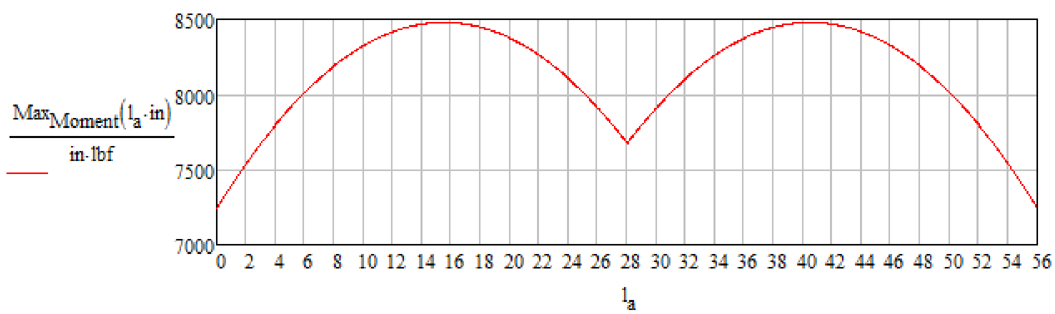
$$Moment1(x, l_a) := \begin{cases} \left(\dfrac{Force \cdot length_b(l_a) \cdot x}{length}\right) & \text{if } x \le l_a \\ \left[\left(\dfrac{Force \cdot l_a}{length}\right)(length - x)\right] & \text{otherwise} \end{cases}$$

$l_{a2}(l_a) := l_a + dist_{between} \qquad length_{b2}(l_a) := length - l_{a2}(l_a)$

$$Moment2(x, l_a) := \begin{cases} \left(\dfrac{Force \cdot length_{b2}(l_a) \cdot x}{length}\right) & \text{if } x \le l_{a2}(l_a) \\ \left[\left(\dfrac{Force \cdot l_{a2}(l_a)}{length}\right)(length - x)\right] & \text{otherwise} \end{cases}$$

$Moment(x, l_a) := Moment1(x, l_a) + Moment2(x, l_a) \qquad y_c := 1.625in \qquad I_{B22A} := 0.9732in^4$

$Max_{Moment}(l_a) := \max\left(\left|Moment(l_a, l_a)\right|, \left|Moment(l_{a2}(l_a), l_a)\right|\right)$




$length_a := 15.5in \qquad Max_{Moment} := Moment(l_{a2}(length_a), length_a) = 8479.783\,in \cdot lbf$

$$Max_{BendingStress} := \frac{Moment(l_{a2}(length_a), length_a) \cdot y_c}{I_{B22A}} = 14.159\,ksi$$

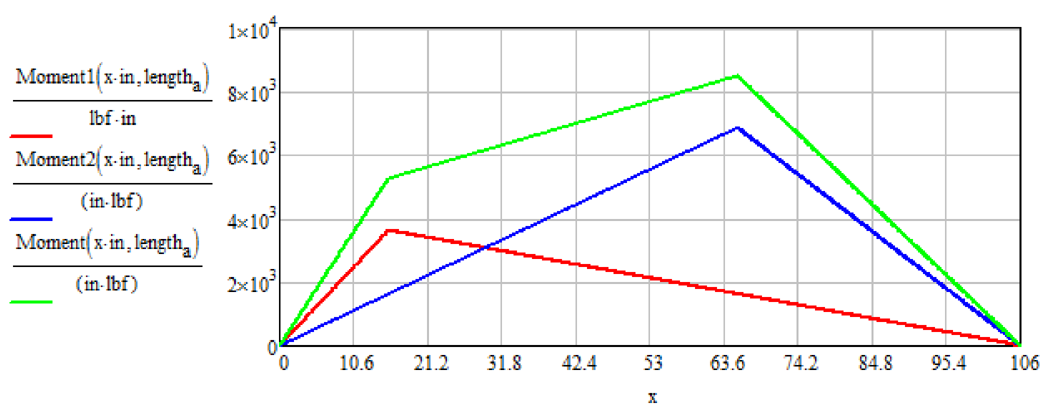



Figure 14. Calculations and Bending Moment Diagram of Double Channel B22A between Beam Clamps

## **Stress on Strut Channel Welds**

We perform an FEA on the above beam, modeling the welds, which are ½" diameter spot welds along the center of the strut every 3". Quad Symmetry is used, and the boundary conditions are shown in Figure 15, results are shown in Figures 16-19. Stress values are below the allowable 25ksi, and bending stress of the strut itself, away from the welds is the highest, making it a worse case than any stresses seen as the welds.

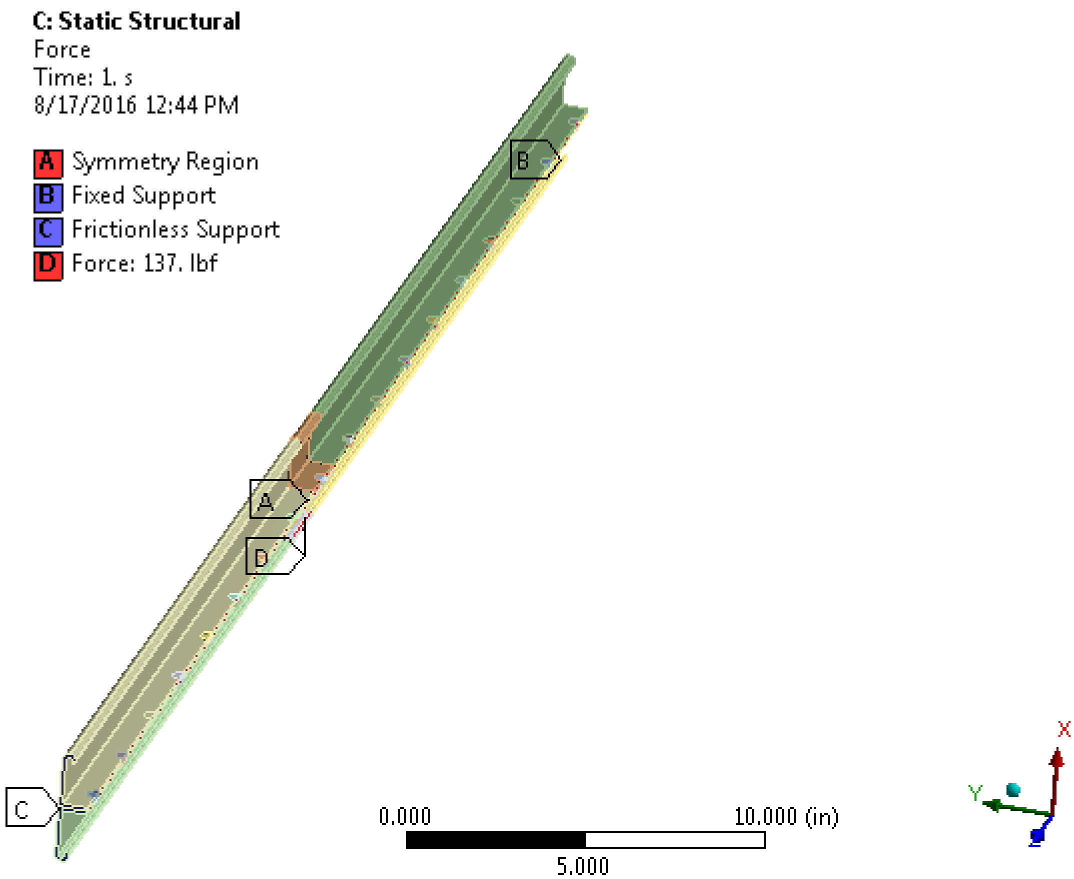



Figure 15: Boundary Conditions for weld stress model.
Quarter symmetry used.

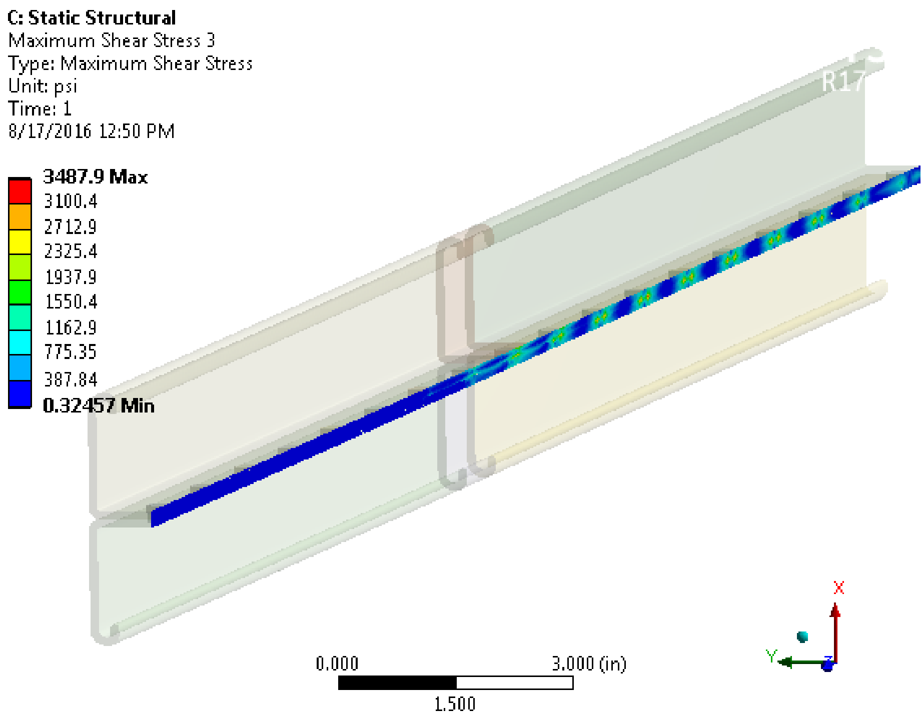



Figure 16. Maximum shear stress down centerline of B22A strut.

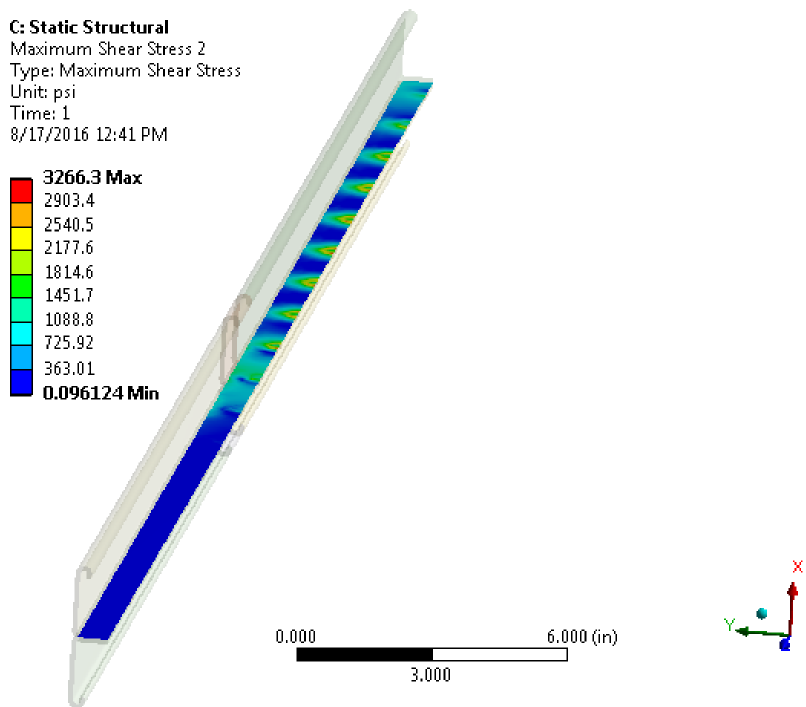



Figure 17. Maximum shear stress across interface with welds.

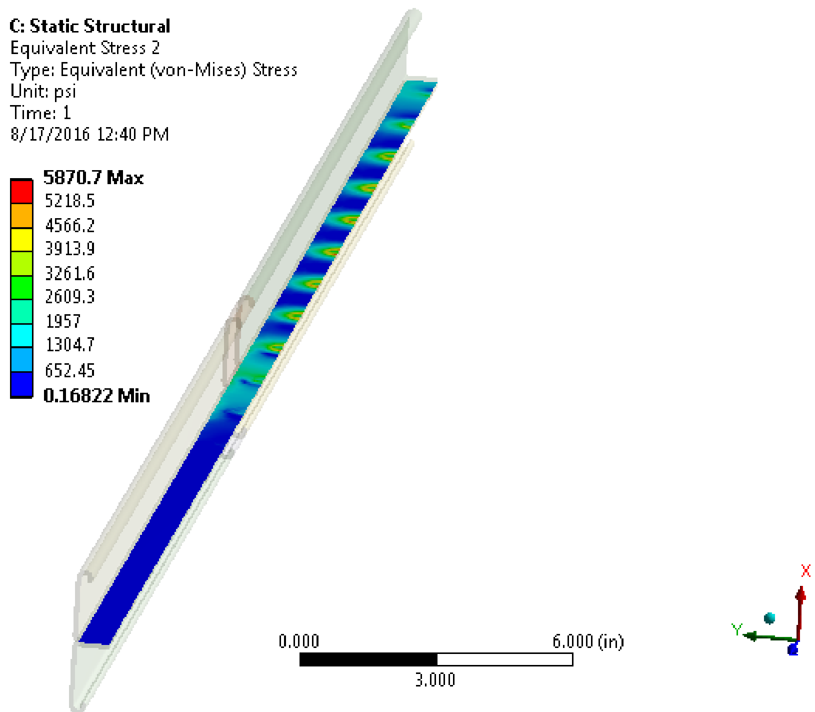



Figure 18. von-Mises stress across interface with welds.

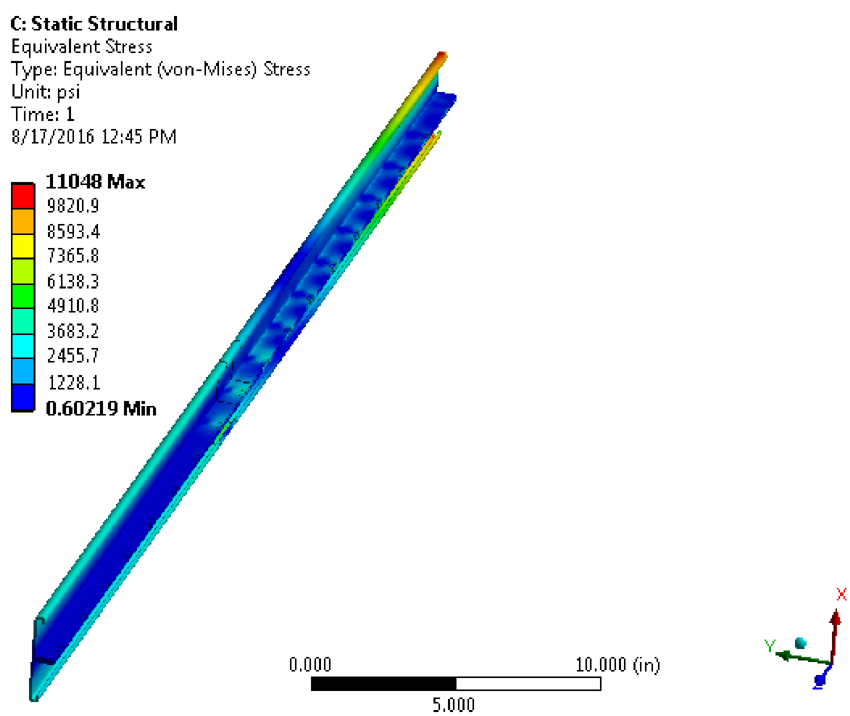
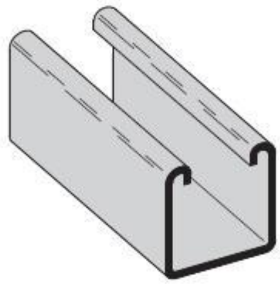


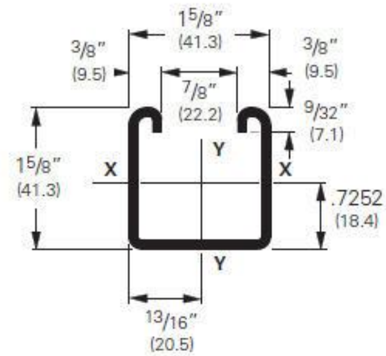

Figure 19. von-Mises stress of entire beam (maximum is due to bending and not near the welded area.)

# 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)

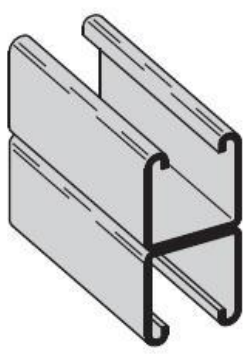
Note:
Aluminum loading, for B22 & B22A, can be determined by multiplying load data times a factor of 0.38






| Section Properties | | | X - X Axis | | | Y - Y Axis | | |
|---|---|---|---|---|---|---|---|---|
| Channel | Weight | Areas of Section | Momentof Inertia (I) | Section Modulus (S) | Radius of Gyration (r) | Moment of Inertia (I) | Section Modulus (S) | Radius of Gyration (r) |
| | lbs./ft. kg/m | sq. in. cm² | in.⁴ cm⁴ | in.³ cm³ | in. cm | in.⁴ cm⁴ | in.³ cm³ | 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)

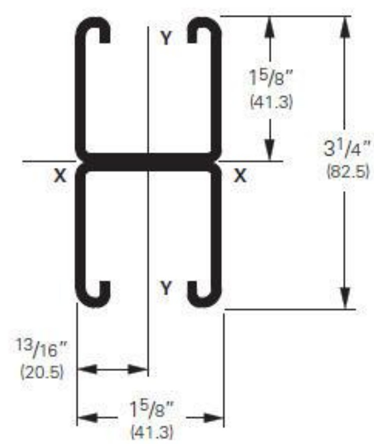



Figure 20. Properties of Channel B22 and Double Channel B22A

Two beam clamps B355 will be used to secure the B22A double channel to each of the existing I-beam. As shown in Figure 21, the load capacity of one pair of beam clamps is rated at 1,200 lbs each with a safety factor of 5. As there are at least 6 I-beams totally and hence 6 pairs of beam clamps will be used for each rail assembly, therefore, the total load capacity provided by the beam clamps is 7,200 lbs and it is much higher than the weight of any load that any of the side panel will carry. (The maximum load carried by the Pipe Combined group is of 3,219 lbs.) The selection of this beam clamp is thus OK.

## B355 Beam Clamp

- Design Load 1200 Lbs. (5.34 kN) when used in pairs
- Safety Factor of 5
- 5/8″ (15.9) Max. Flange Thickness
- Sold in pieces
- Order 1/2″-13 x 1 1/2″ HHCS and Channel Nut separately
- Standard finishes: ZN, GRN, HDG, SS4
- Wt./C 30 Lbs. (13.6 kg)

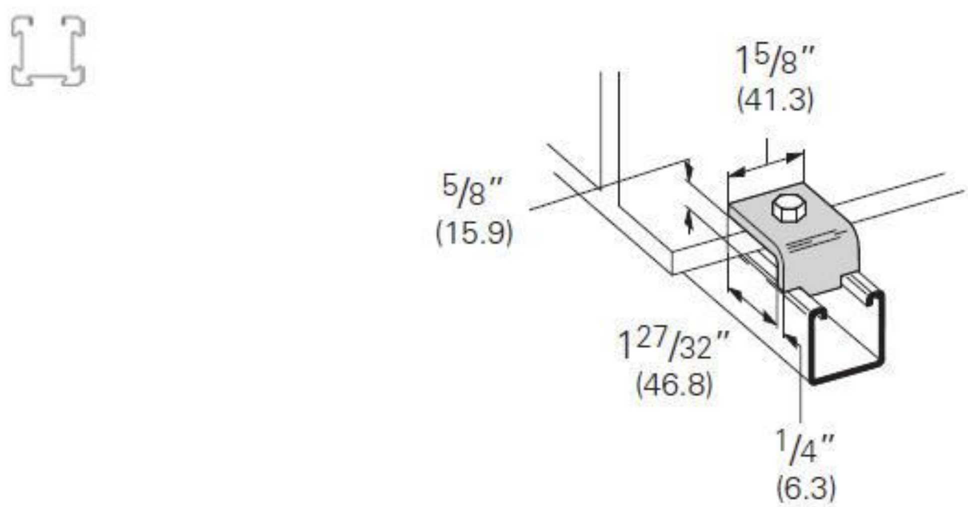



Figure 21. Properties of Beam Clamp B355

To prevent the bearing trolley from rolling off the channel ends, a stopper plate should be mounted as shown in Figure 22.

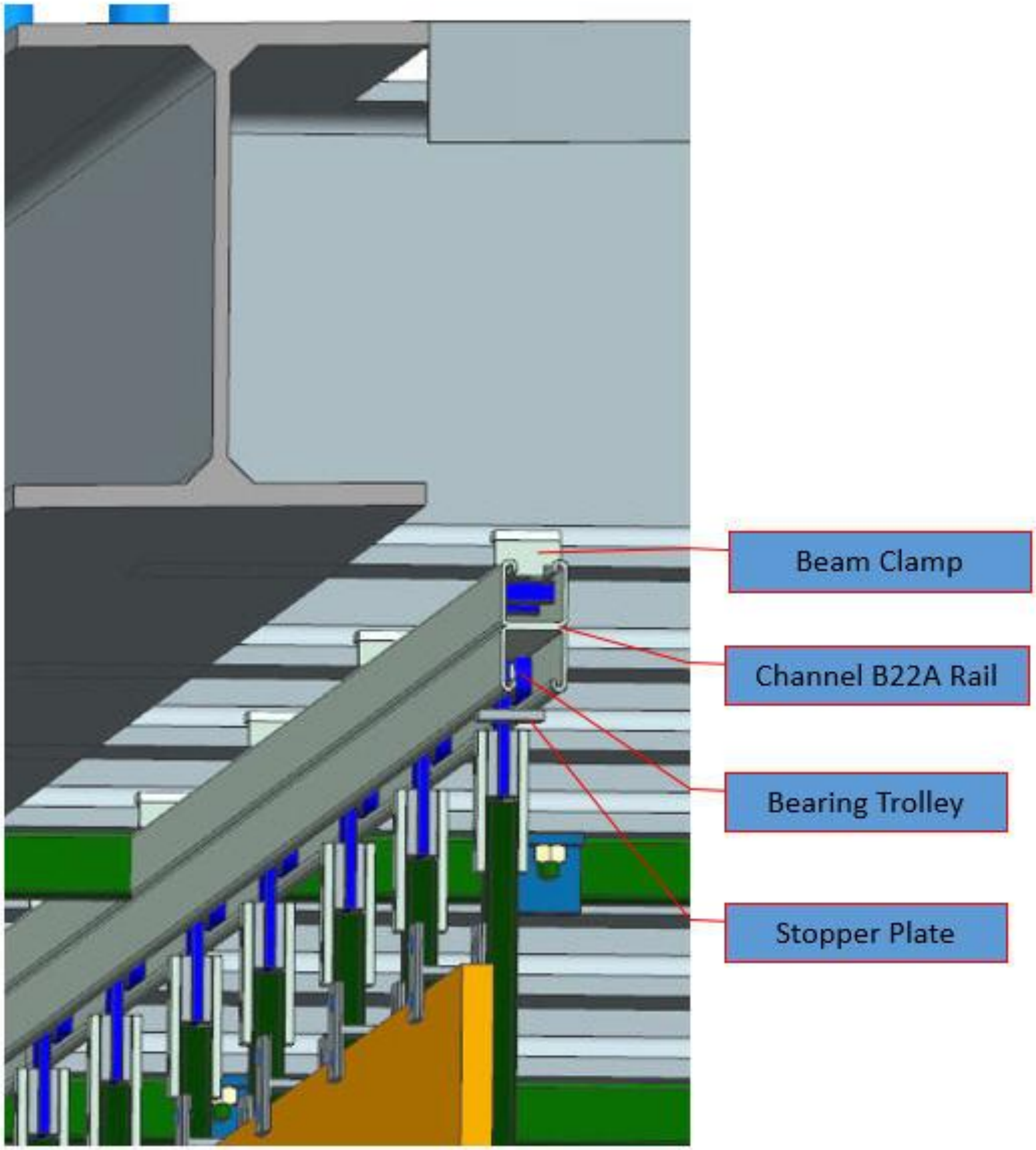



Figure 22. A Stopper Plate being mounted at the end of Rail

Two double channels B22A are needed to make up the long rail, a two-hole plate provided by B-line B129 can be used to help aligning these two channels properly as shown in Figure 23. When fastening, extra angle or straight ruler edges can be used to confirm the alignment of the channels are properly well set. The distance between the I-beams there is just 42 inches, so the worst cantilever loading case on the double channel, even when there is no such alignment-aid two-hole plate, can be calculated as shown below.

Bending moment, M = 274 lbs* 21”
= 5,754 in-lbs

The maximum bending stress, S, on the double channel is:

S = M*y/I where y = 1.625” for double channel B22A
= 5,754 *1.625/0.9732
= 9,607 psi

As the allowable stress with a safety factor of 1.68 is equal to 25,000 psi, the double channel B22A is OK in this loading scenario even without the splice plate connection. This splice plate can thus be taken as an alignment tool and can be removed when done.

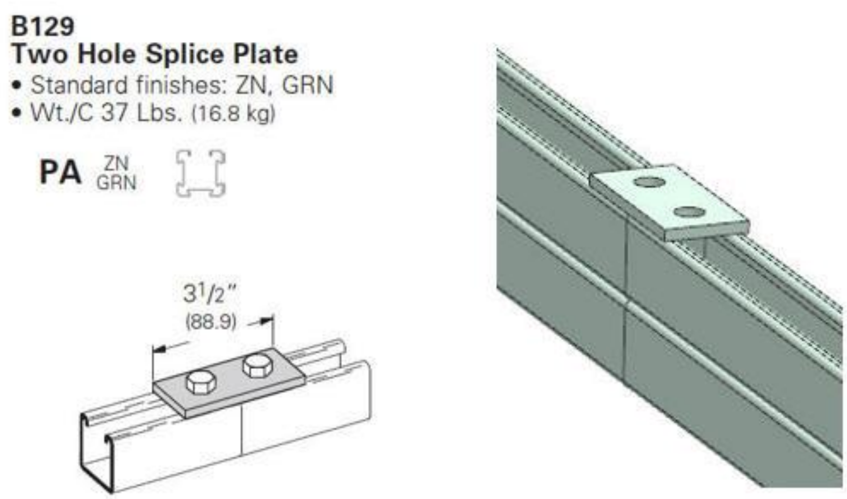



Figure 23. B-line Plate B129 for aligning two Channels

4. **Pre-installation Work**

There are a few items that need to be removed or relocated basically on the pipe side because of interference with the panel support hardware.

- Three electrical boxes clamped to the platform need to move about 6”. Electricians have looked at this and this is easily accomplished.
- Unistrut support frames supporting a cryo line need to be replaced with the hangers below.
- Some unistrut arms are too long and need to be shortened on the feed through side.

Steel Hinged Loop Hanger

8-5/8" ID, 2000 lb. Capacity


Each

ADD TO ORDER

In stock
$12.15 Each
3037T34

| | |
|---|---|
| Material | Steel |
| ID | 8 5/8" |
| For Pipe Size | 8 |
| For Rigid Conduit Trade Size | 8 |
| Capacity | 2,000 lbs. |
| Width | 1 3/4" |
| Height | 12 9/16" |
| Thickness | 11/64" |
| Mounting Hole Diameter | 13/16" |

Also known as clevis hangers, these hangers include a bolt that can be adjusted to compensate for line movement and vibration. Hangers have an unthreaded hole on top to mount using a threaded rod or fastener (not included). They meet Fed. Spec. WW-H-171, Type 1 and Manufacturers' Standardization Society SP-69 and SP-58, Type 1.

Steel—1 1/16" to 12 3/4" ID hangers are UL listed.

Figure 24. Steel Hinged Loop Hanger