HydraSafe

10” Structural Steel Crosshead FEA

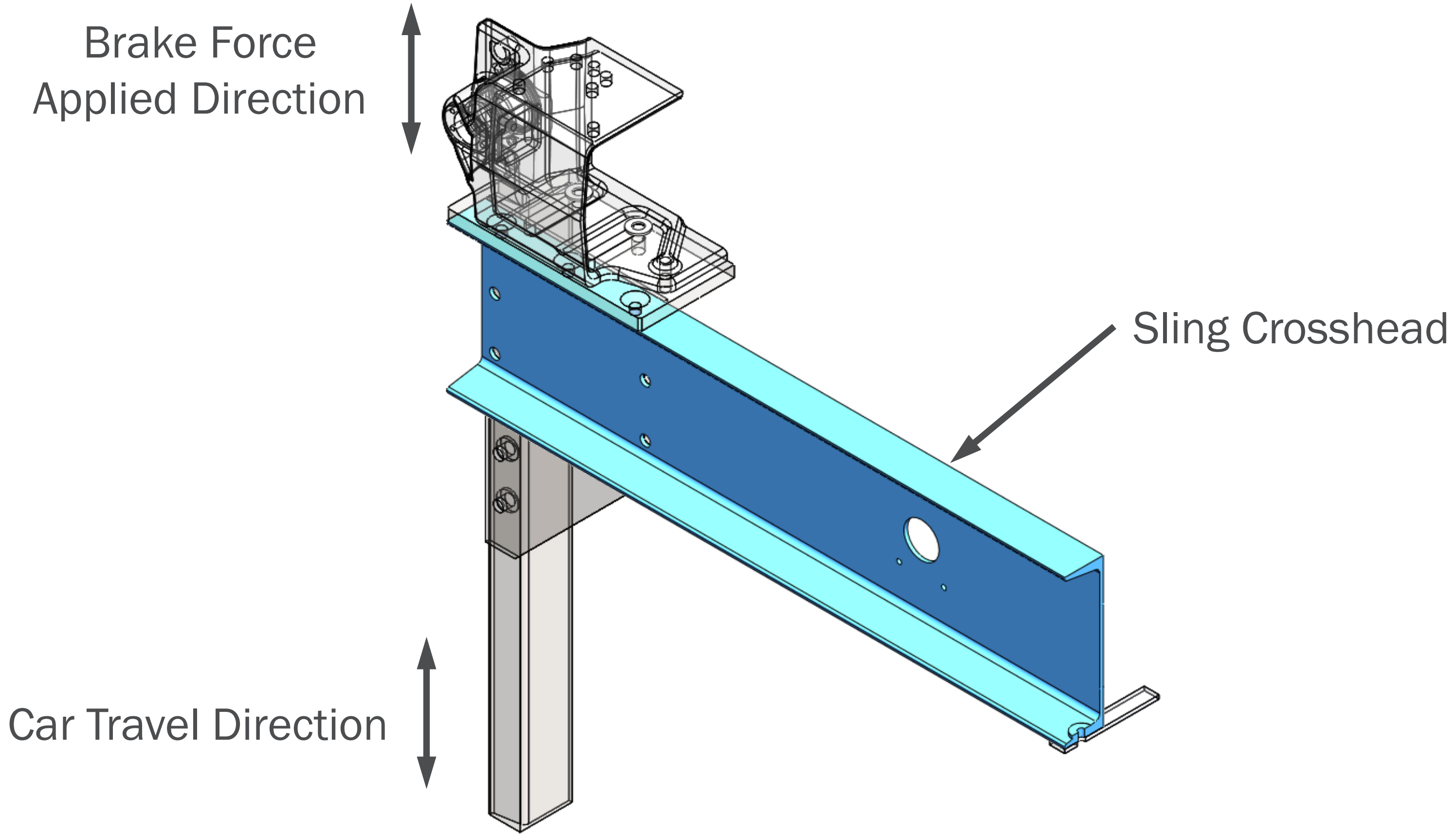
2024/03/15

Purpose of Sling Crosshead FEA

The purpose of the FEA is to show the Stress, Displacement and FOS for the structural steel crosshead.

When the car is travelling in the upward direction, a downward force is applied at the caliper housing.

When the car is travelling in a downward direction, and upward force is applied at the caliper housing.



Required FOS for crosshead

Per ASME A17.1-2016/CSA B44-16 2.24.3

FOS for the brake and its components is 3.5x

Required max stress for the crosshead is 27,500 psi (~1.3x FOS)

2.19.3 Emergency Brake (See Nonmandatory Appendix F)

2.19.3.1 Where Required

2.19.3.2 Requirements. The emergency brake is permitted to consist of one or more devices and shall

(i) be designed so that the factors of safety based on the maximum stresses developed in the parts subject to load during the operation of the emergency brake shall comply with the following:

(1) Where an emergency brake is applied only when protecting against either an ascending car overspeed condition or unintended car movement with the car and hoistway doors open, the minimum factors of safety, when applied during the retardation phase of emergency braking, shall be not less than those specified in 2.17.12.1.

2.17.12 Minimum Factors of Safety and Stresses of Safety Parts and Rope Connections

2.17.12.1 Parts of safeties, except springs, safety-rope drums, leading sheaves, and their supporting brackets and safety-jaw gibs, shall have a factor of safety of not less than 3.5, and the materials used shall have an elongation of not less than 15% in a length of 50 mm (2 in.) when tested in accordance with ASTM E8. Forged, cast, or welded parts shall be stress relieved.

2.19.4 Emergency Brake Supports

All components and structural members, including their fastenings, subjected to forces due to the application of the emergency brake shall be designed to withstand the maximum forces developed during the retardation phase of the emergency braking so that the resulting stresses shall not exceed those permitted for the applicable type of equipment as follows:

(a) machinery and sheave beams (see 2.9.6)

(b) guide rails and their supports (see 2.23.5.3)

(c) counterweight frames (see 2.21.2.3.3)

(d) car frames (see 2.15.10.2)

(e) machines, sheaves, and bedplates (see 2.24.3.2)

2.15.10.2 Car frame members, brackets, and their connections subject to forces due to the application of the emergency brake (see 2.19.4) shall be designed to withstand the maximum forces developed during the retardation phase of the emergency braking so that the resulting stresses due to the emergency braking and all other loading acting simultaneously, if applicable, shall not exceed 190 MPa (27,500 psi).

Structural steel and caliper casting materials

Channel and Beam Materials are made from hot roll material. These materials are most commonly A572, A588 and A36 steel. For this FEA, A36 steel was chosen as it has the lowest yield strength.
The caliper casting is made from A352 LC2-1 steel.

Different Steel Compositions

In addition to choosing the right shape for your steel beams, it's important to consider the material itself. Most commonly, steel beams come in A572, A588, and A36.

Source: www.bushwickmetals.com

Structural Steel Components

A36 Yield Strength: 36,000psi

Caliper Casting Component

A352 LC2-1 Yield Strength: 105,000psi

Source: www.makeitfrom.com

Bolt Material, Strength and Torque

For the purposes of fastener strength simulations, the yield strength is used.

Grade 8 Bolts

A **grade 8 bolt** is the highest grade SAE bolt. Grade 8 bolts have a minimum tensile strength of 150,000 PSI. As a comparison, the ASTM A325 bolt is roughly equivalent to the SAE grade 5. A grade 8 bolt would be one that meets ASTM A490 standards.

[Source: www.tfgusa.com](http://www.tfgusa.com)

US Bolts					
Head Marking	Grade and Material	Nominal Size Range (inches)	Mechanical Properties		
			Proof Load (psi)	Min. Yield Strength (psi)	Min. Tensile Strength (psi)
 6 Radial Lines	**Grade 8** Medium carbon alloy steel, quenched and tempered	1/4" thru 1-1/2"	120,000	130,000	150,000

[Source: www.boltdepot.com](http://www.boltdepot.com)

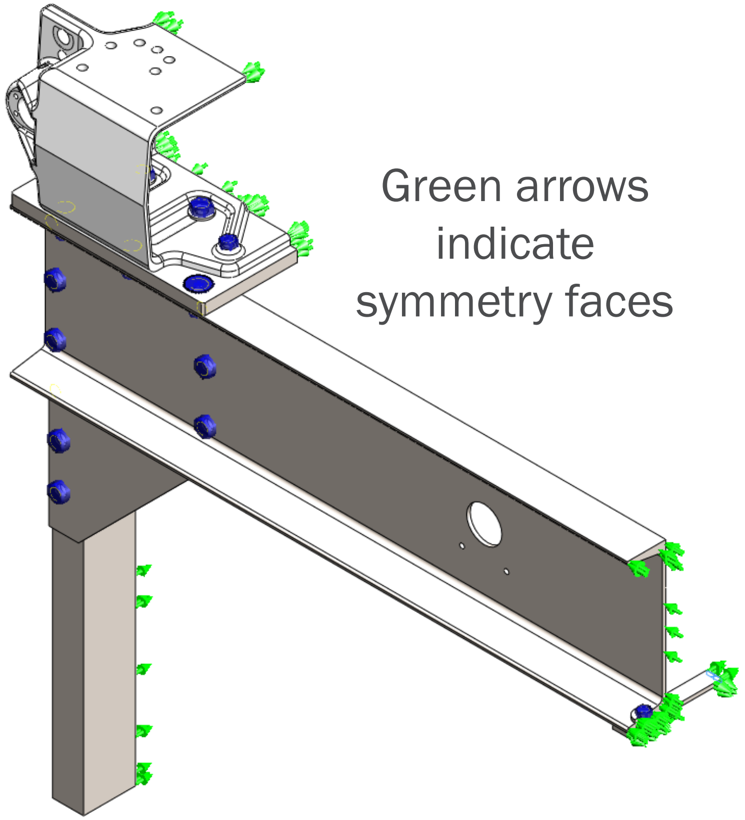
This is not an installation torque spec. This is the highest expected torque spec used to confirm our bolt tension is safe.

GRADE 8 Coarse Thread			
Size	Clamp Load	Plain (ft. lbs.)	Plated (ft. lbs.)
1/4-20 (.250)	2850	12	9
5/16-18 (.3125)	4725	25	18
3/8-16 (.375)	6975	44	33
7/16-14 (.4375)	9600	70	52
1/2-13 (.500)	12750	106	80
9/16-12 (.5625)	16350	153	115
5/8-11 (.625)	20325	212	159
3/4-10 (.750)	30075	376	282
7/8-9 (.875)	41550	606	454
1-8 (1.000)	54525	909	682
1 1/8-7 (1.125)	68700	1288	966
1 1/4-7 (1.250)	87225	1817	1363
1 3/8-6 (1.375)	103950	2382	1787
1 1/2-6 (1.500)	126450	3161	2371

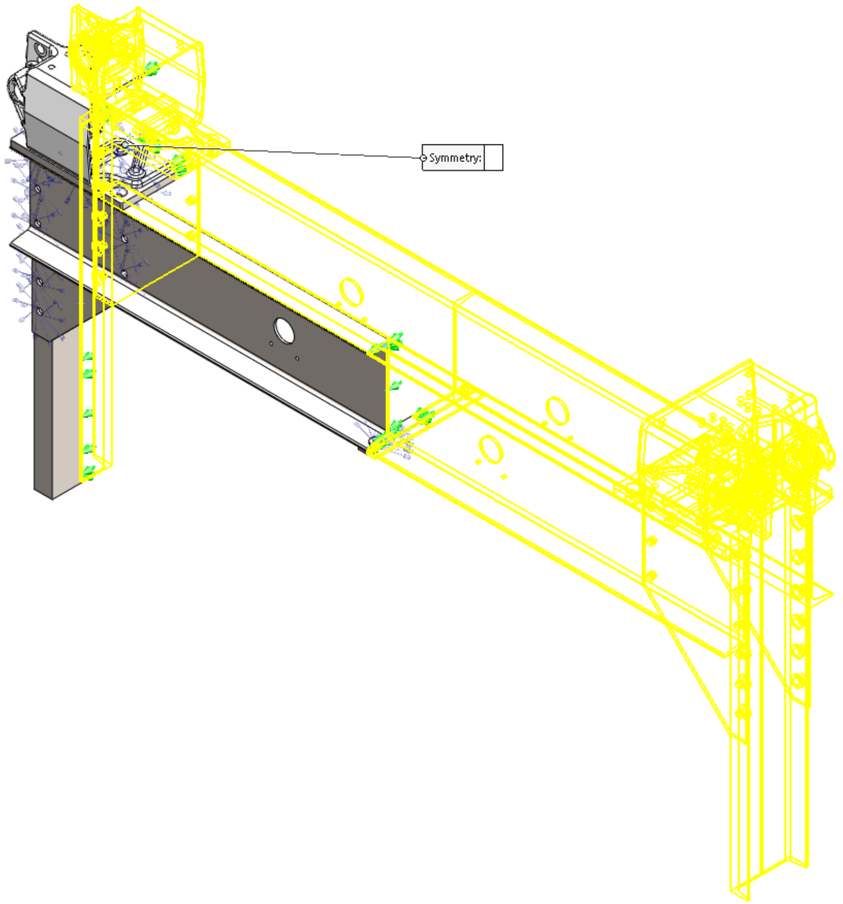
Source: www.almabolt.com

FEA Setup - Model

The FEA model was set up using ¼ of the actual assembly, and then applying symmetry fixtures in the front and right planes.



Green arrows indicate symmetry faces



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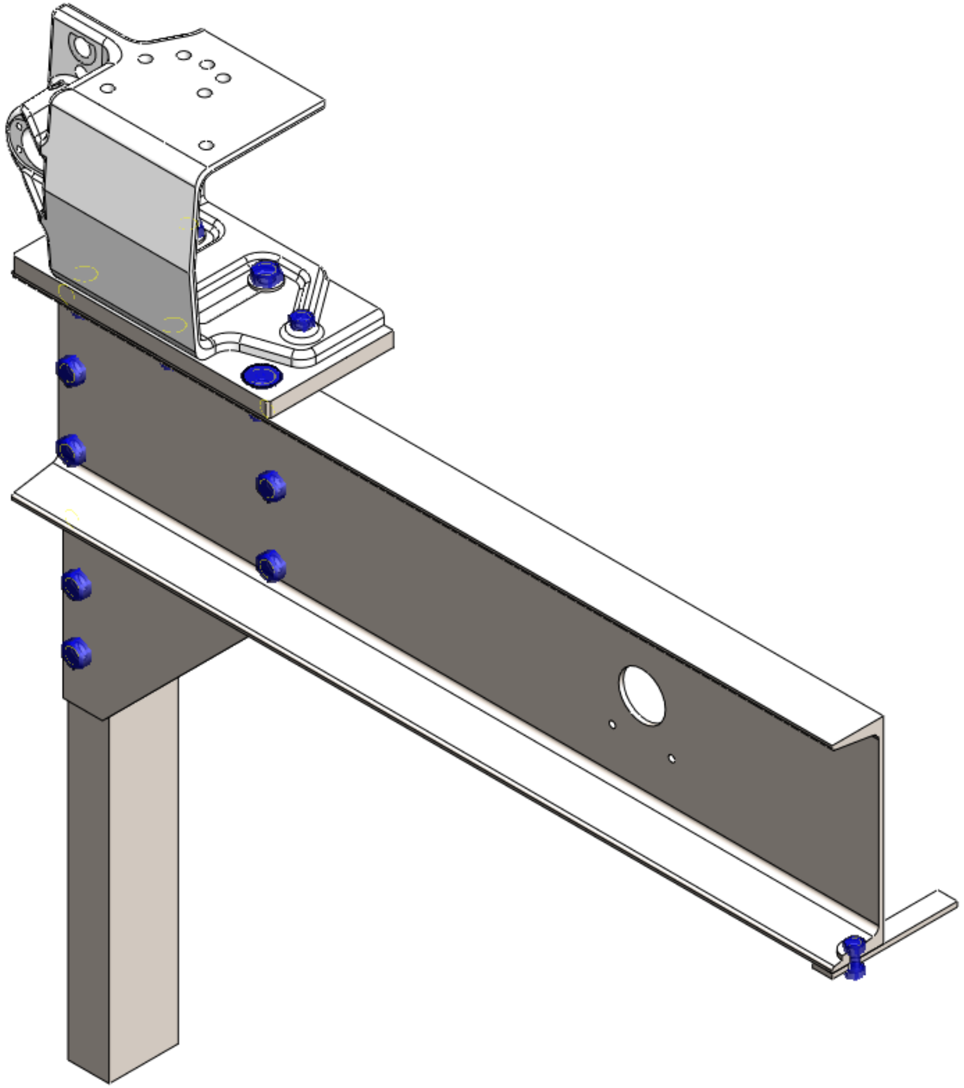
FEA Setup - Connectors

Grade 8 fasteners are used at all bolt locations.



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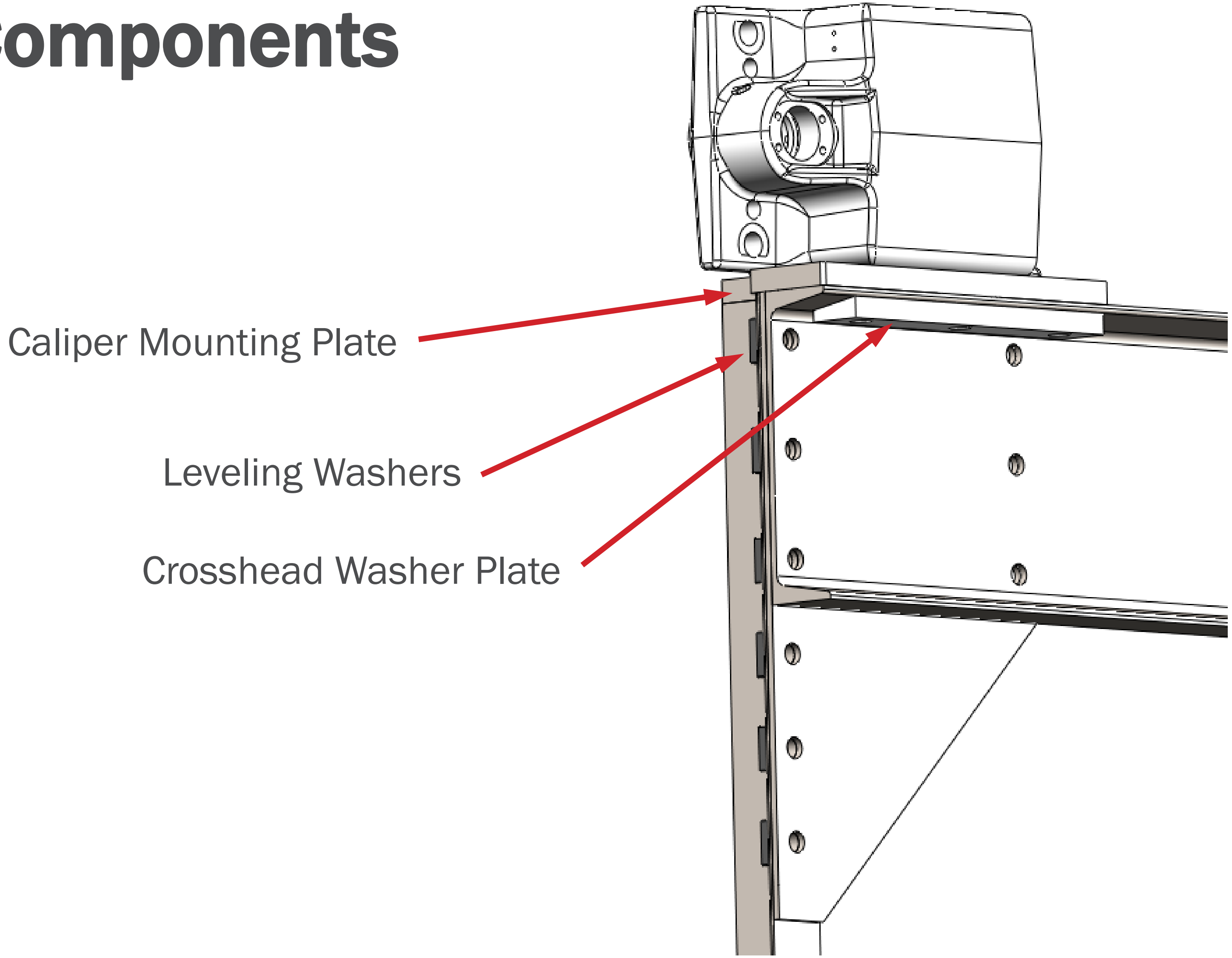
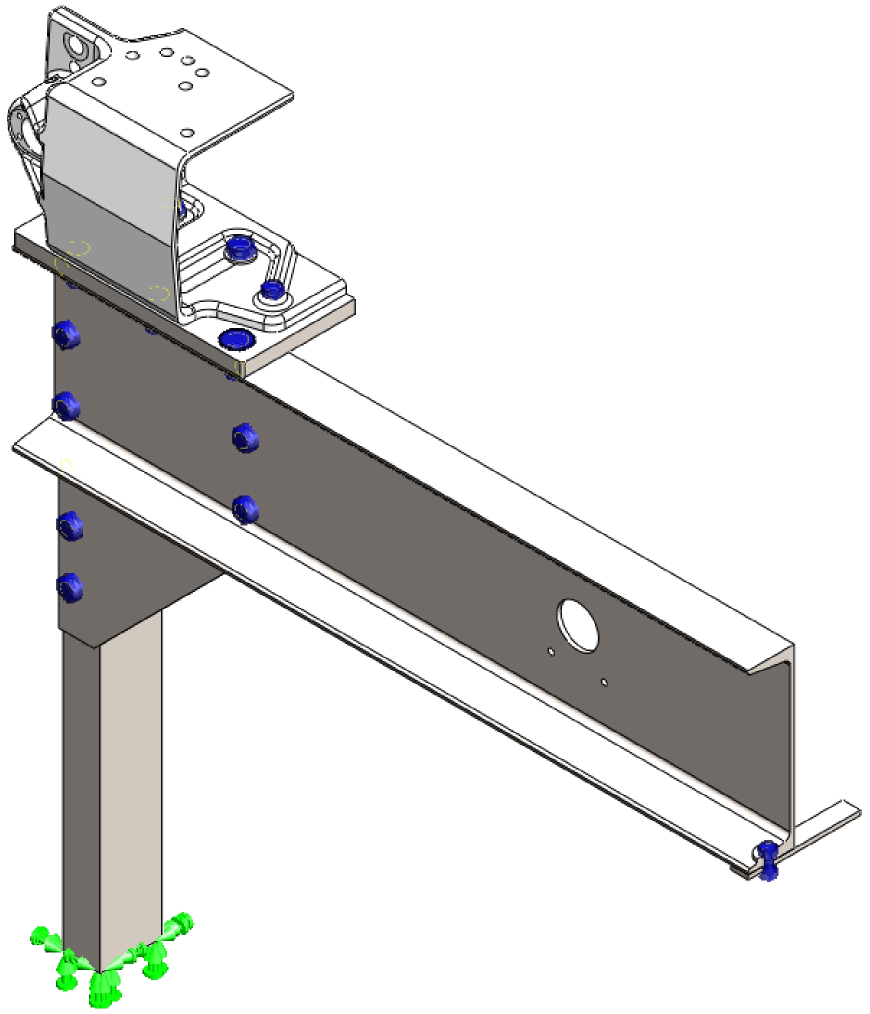
Updated Mounting Components

An update to the FEA was made to strengthen areas of stress.
Leveling washers were added and are made from ductile iron.
A crosshead washer plate was added and is made from A36 steel.



FEA Setup – Fixed Component

The stile was cut at 3' from the top and fixed at the base surface.



Green arrows indicate fixed face

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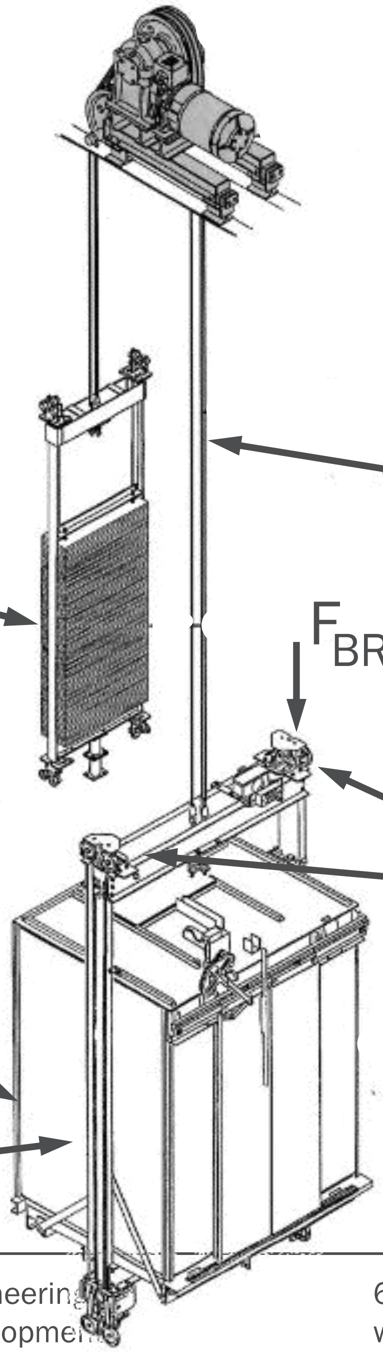
FEA Masses 10” Crosshead Car Travelling Upward (Downward Brake Force)

Braking load:

Car and Sling Empty Weight
+ Load Inside Car
+ Counterweight
+ Ropes & Cables
= 22,720 lbs

0.5g Stopping Force
Used For FEA = 22,720 LBS X 0.5
= 11,360 lbs



Sling Crosshead FEA Brake Downward Forces

The 11,360 lb mass used in the FEA was calculated using an 22,720 lb moving mass and a 0.5 stopping reaction force.

Speed (ft/min)	Stopping distance (ft) at acceleration (g)										
	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
50	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.9	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
200	3.5	1.7	0.9	0.6	0.4	0.3	0.3	0.2	0.2	0.2	0.2
500	21.6	10.8	5.4	3.6	2.7	2.2	1.8	1.5	1.3	1.2	1.1
1000	86.3	43.1	21.6	14.4	10.8	8.6	7.2	6.2	5.4	4.8	4.3
1500	194.1	97.0	48.5	32.3	24.3	19.4	16.2	13.9	12.1	10.8	9.7
2000	345.1	172.5	86.3	57.5	43.1	34.5	28.8	24.6	21.6	19.2	17.3

$$v^2 = u^2 + 2as$$

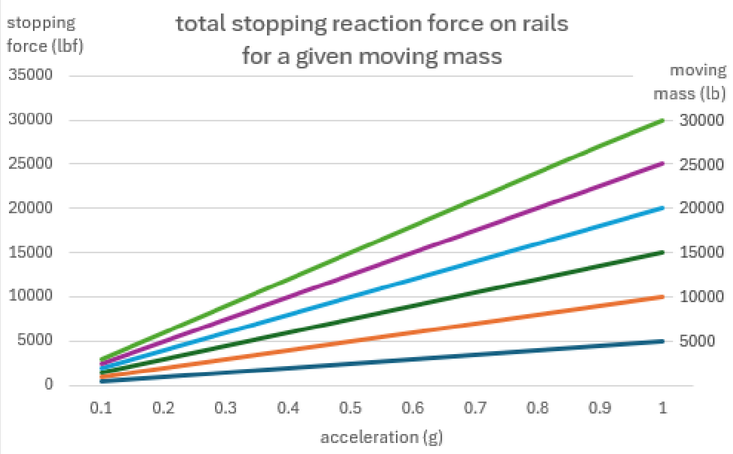
where:

- v is the final velocity,
- u is the initial velocity,
- a is the acceleration,
- s is the displacement.

"Total Gross Load"

F = ma mass = 22720 lb

Moving Mass (lb)	Stopping reaction force (lbf) at acceleration (g)										
	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
5000	250	500	1000	1500	2000	2500	3000	3500	4000	4500	5000
10000	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
15000	750	1500	3000	4500	6000	7500	9000	10500	12000	13500	15000
20000	1000	2000	4000	6000	8000	10000	12000	14000	16000	18000	20000
25000	1250	2500	5000	7500	10000	12500	15000	17500	20000	22500	25000
30000	1500	3000	6000	9000	12000	15000	18000	21000	24000	27000	30000
22720	1136	2272	4544	6816	9088	11360	13632	15904	18176	20448	22720

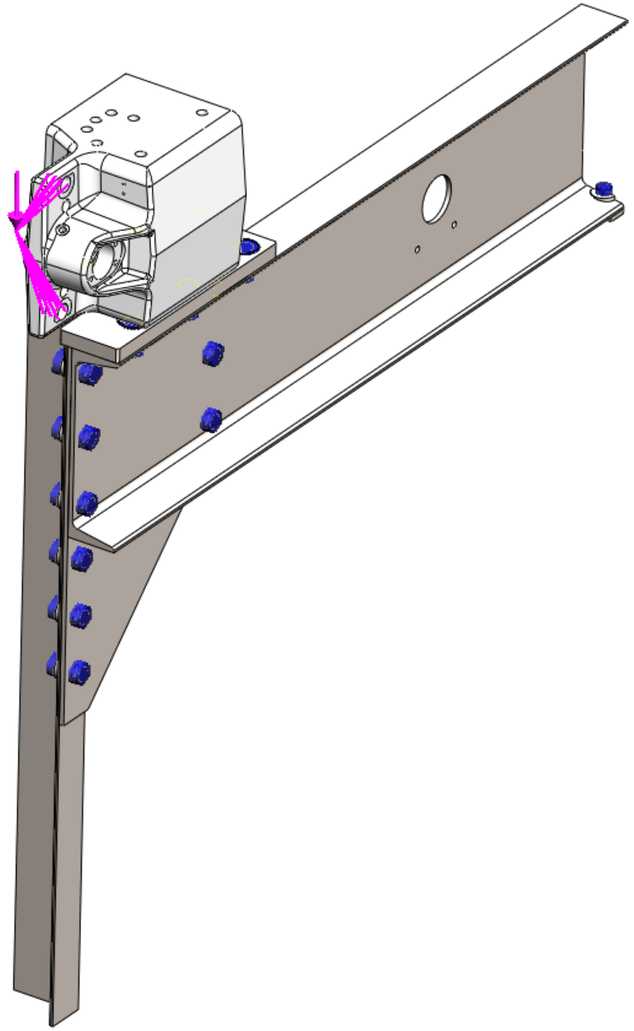


Setup – Downward Load

A braking load of 22,720 lb is used. A multiplier for 0.5g was added for an FEA load of 11,360 lbs. Since the model is in a ¼ section, ¼ of the 11,360 lb was used.

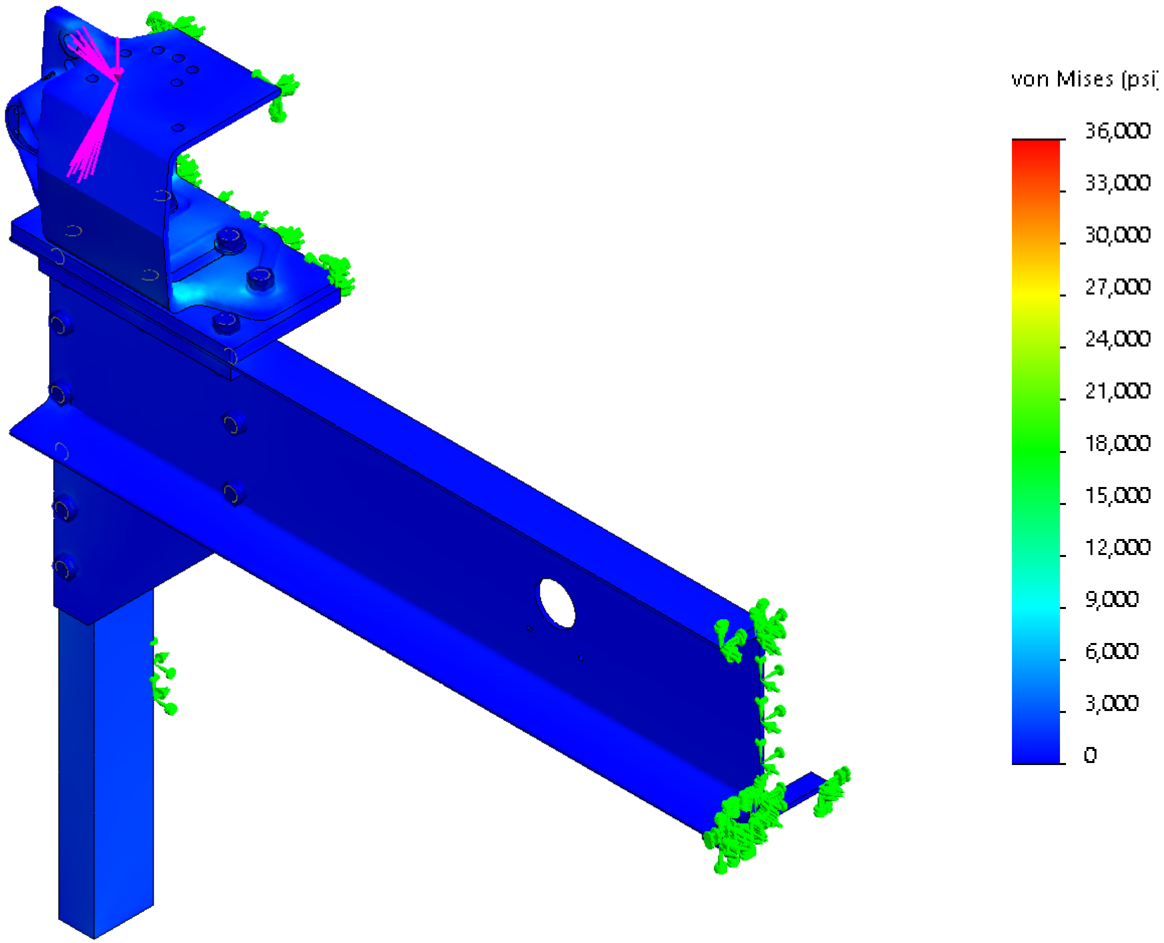
A 2,840 lb load was applied in a Downward direction at the brake pad clamping location and transferred to the brake pad bolt holes in the caliper casting.

The Downward force is used to simulate the car travelling in an Upward direction.



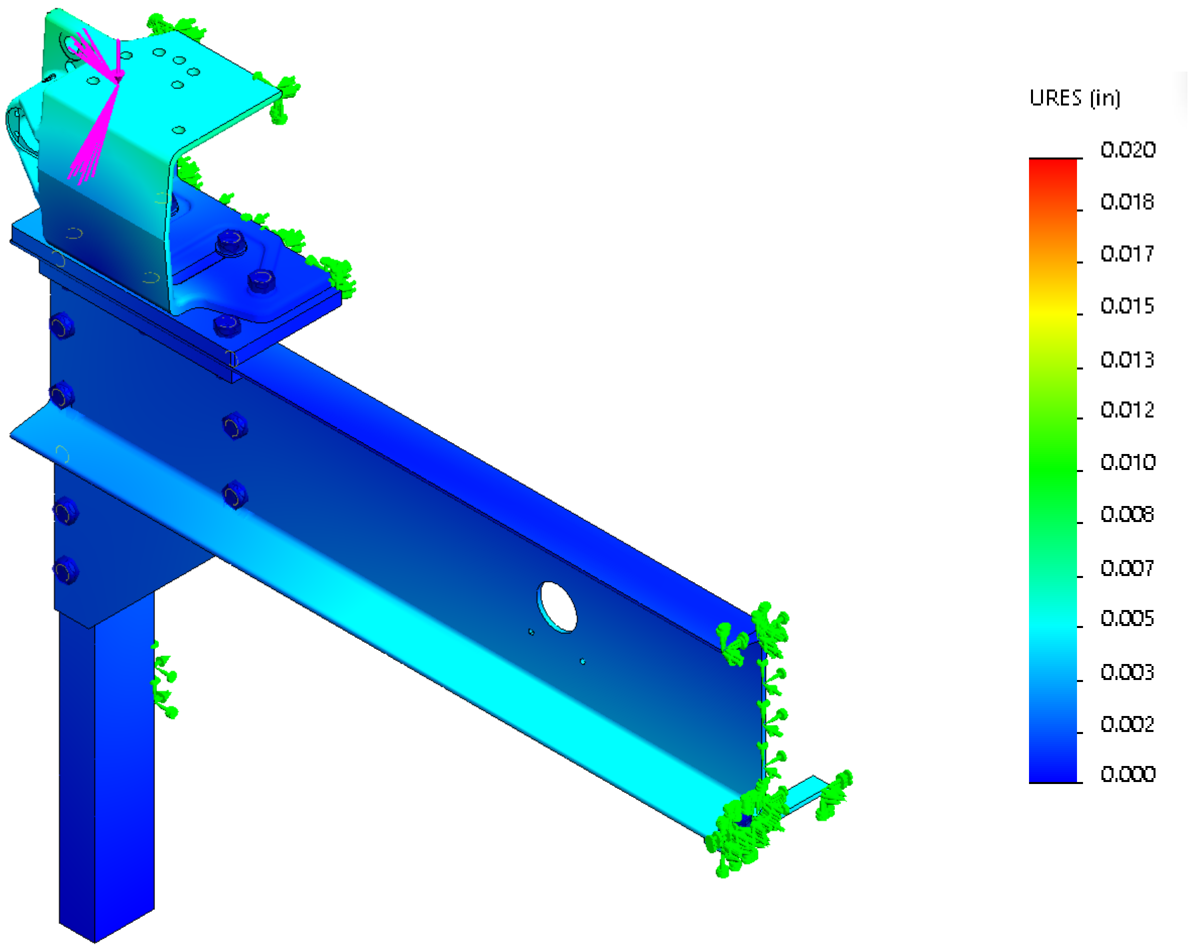
Stress Results – Crosshead Downward Load

Crosshead stress is ~6,000psi.



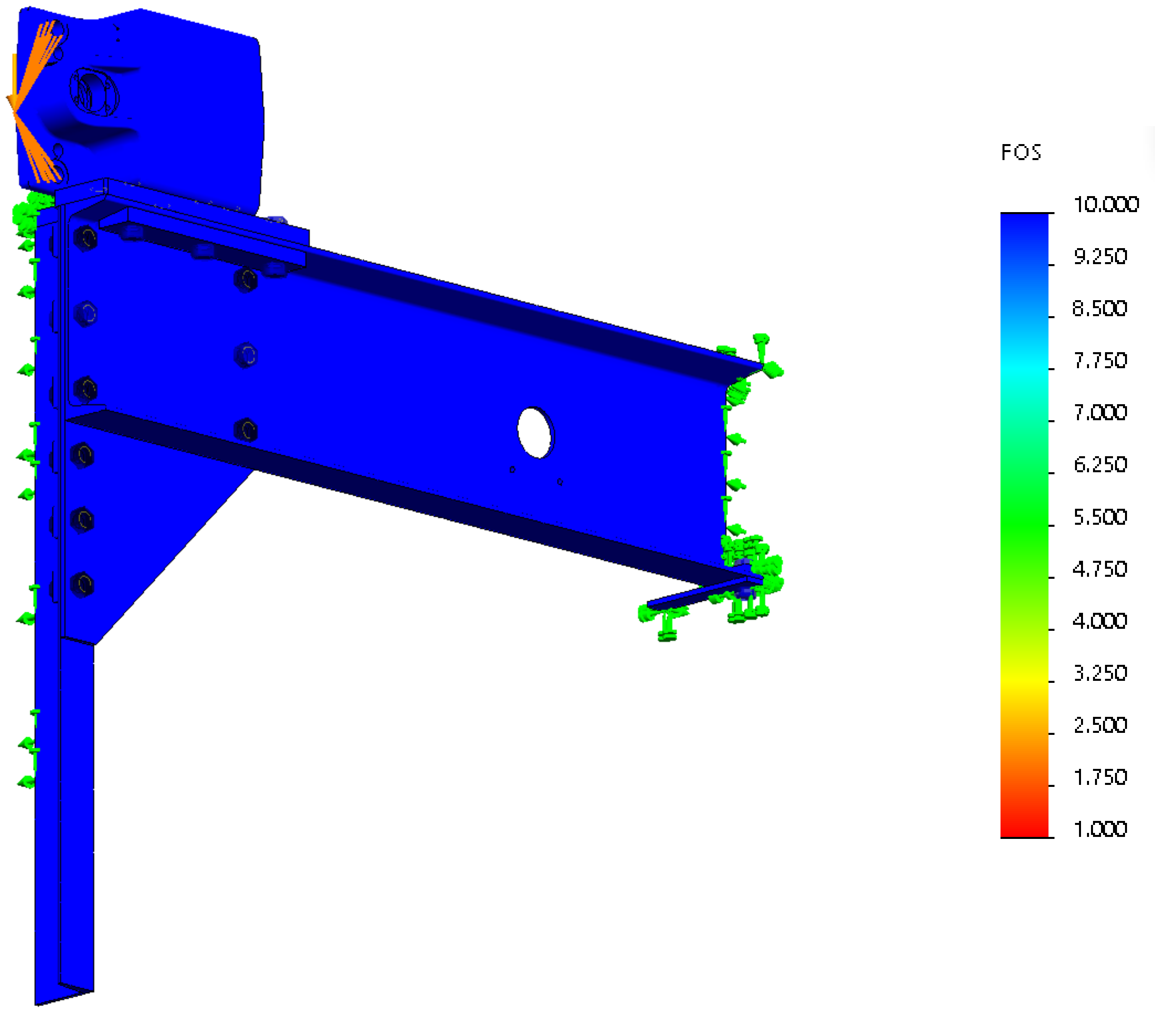
Displacement Results – Crosshead Downward Load

Crosshead displacement is ~0.002”



Factor of Safety Results – Crosshead Downward Load

Crosshead FOS is over 3.5X.



Factor of Safety Results – Bolts Downward Load

Applied appropriate preload to all bolts (e.g. 212 ft-lbs torque for 5/8”)

Increase load to 3.5x (9940 lbs downward) since we need a 3.5x FOS

- We’re increasing load because factor-of-safety plots would incorrectly show an unloaded bolt failing due to installation torque alone

No bolts yield with 3.5x applied load

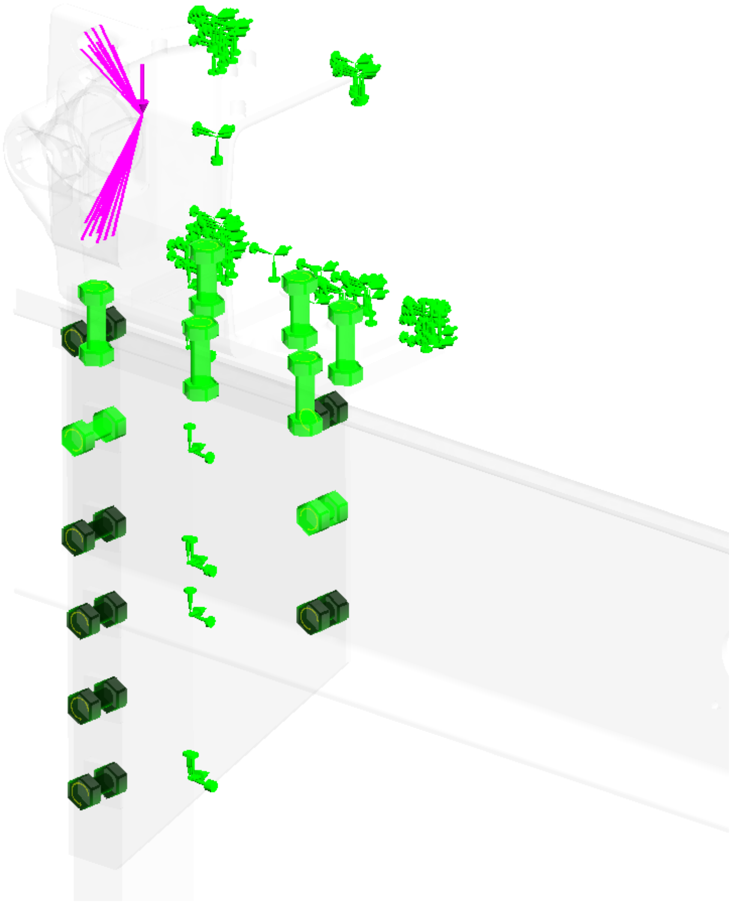
Highest load thru any bolt is 20,645 lbs (77,613 psi) which is well below the yield strength of 130,000 psi for a grade 8 bolt

Study name: DOWN - PRELOAD- 3_5FOS - A36

Connector: All bolts Units: English (IPS)

Connector type: Bolt <-- -->

Type	X-Component	Y-Component	Z-Component	Resultant	Connector
Axial Force (lbf)	0	0	20,645	20,645	Counterbore with Nut-4
Axial Force (lbf)	0	0	20,625	20,625	Counterbore with Nut-5
Axial Force (lbf)	0	0	20,619	20,619	Counterbore with Nut-6
Axial Force (lbf)	0	0	20,611	20,611	Counterbore with Nut-3
Axial Force (lbf)	0	0	20,604	20,604	Counterbore with Nut-2
Axial Force (lbf)	0	0	20,598	20,598	Counterbore with Nut-1
Axial Force (lbf)	0	0	20,507	20,507	Counterbore with Nut-9
Axial Force (lbf)	0	0	20,486	20,486	Counterbore with Nut-8
Axial Force (lbf)	0	0	20,449	20,449	Counterbore with Nut-7
Axial Force (lbf)	0	20,441	0	20,441	Counterbore with Nut-14
Axial Force (lbf)	0	20,403	0	20,403	Counterbore with Nut-13
Axial Force (lbf)	0	20,376	0	20,376	Counterbore with Nut-15
Axial Force (lbf)	0	20,370	0	20,370	Counterbore with Nut-11
Axial Force (lbf)	0	20,365	0	20,365	Counterbore with Nut-12
Axial Force (lbf)	0	-12,882	0	12,882	Counterbore with Nut-10
Axial Force (lbf)	0	10,281	0	10,281	Counterbore with Nut-16
Shear Force (lbf)	175.32	2,026	0	2,033.6	Counterbore with Nut-6



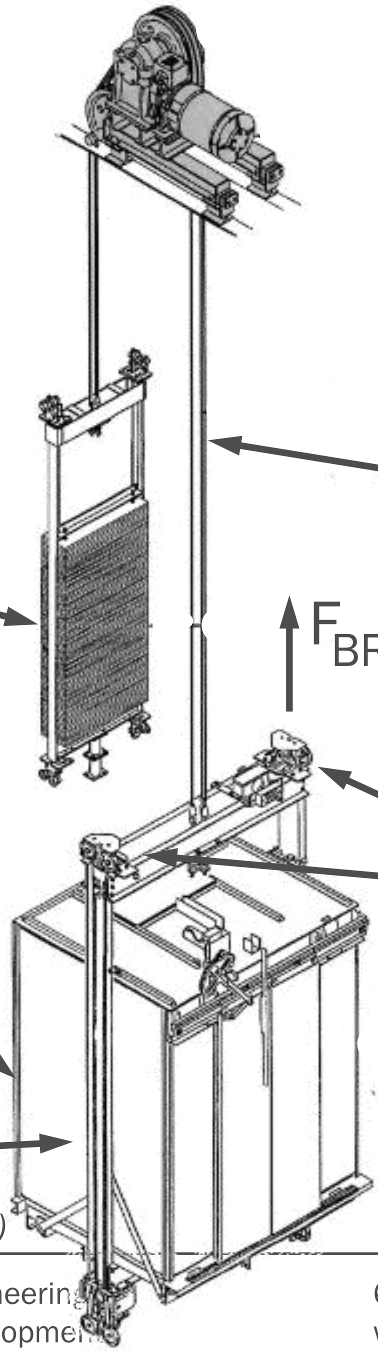
FEA Masses 10” Crosshead Car Travelling Downward (Upward Brake Force)

NOTE: Guide-rails not shown

Braking load:

Car and Sling Empty Weight
+ Load Inside Car
+ Ropes & Cables
= 12,205 lbs

0.5g Stopping Force
Used For FEA = 12,205 lbs X 0.5
= 6,102.5 lbs



Sling Crosshead FEA Brake Upward Forces

The 6,102.5 lb mass used in the FEA was calculated using an 12,205 lb moving mass and a 0.5 stopping reaction force.

Speed (ft/min)	Stopping distance (ft) at acceleration (g)										
	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
50	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.9	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
200	3.5	1.7	0.9	0.6	0.4	0.3	0.3	0.2	0.2	0.2	0.2
500	21.6	10.8	5.4	3.6	2.7	2.2	1.8	1.5	1.3	1.2	1.1
1000	86.3	43.1	21.6	14.4	10.8	8.6	7.2	6.2	5.4	4.8	4.3
1500	194.1	97.0	48.5	32.3	24.3	19.4	16.2	13.9	12.1	10.8	9.7
2000	345.1	172.5	86.3	57.5	43.1	34.5	28.8	24.6	21.6	19.2	17.3

$$v^2 = u^2 + 2as$$

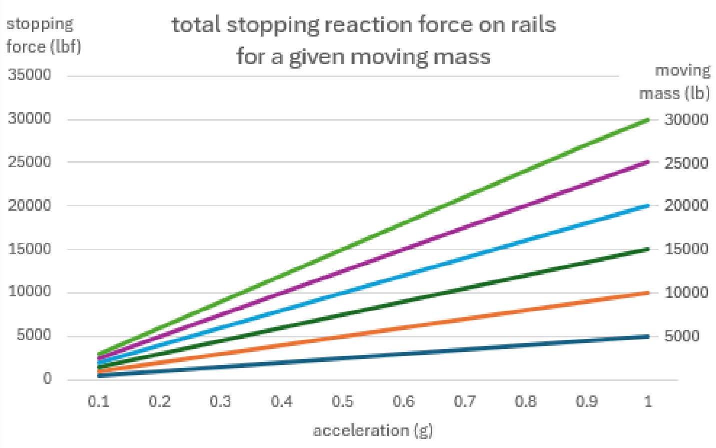
where:

- v is the final velocity,
- u is the initial velocity,
- a is the acceleration,
- s is the displacement.

"Total Gross Load"

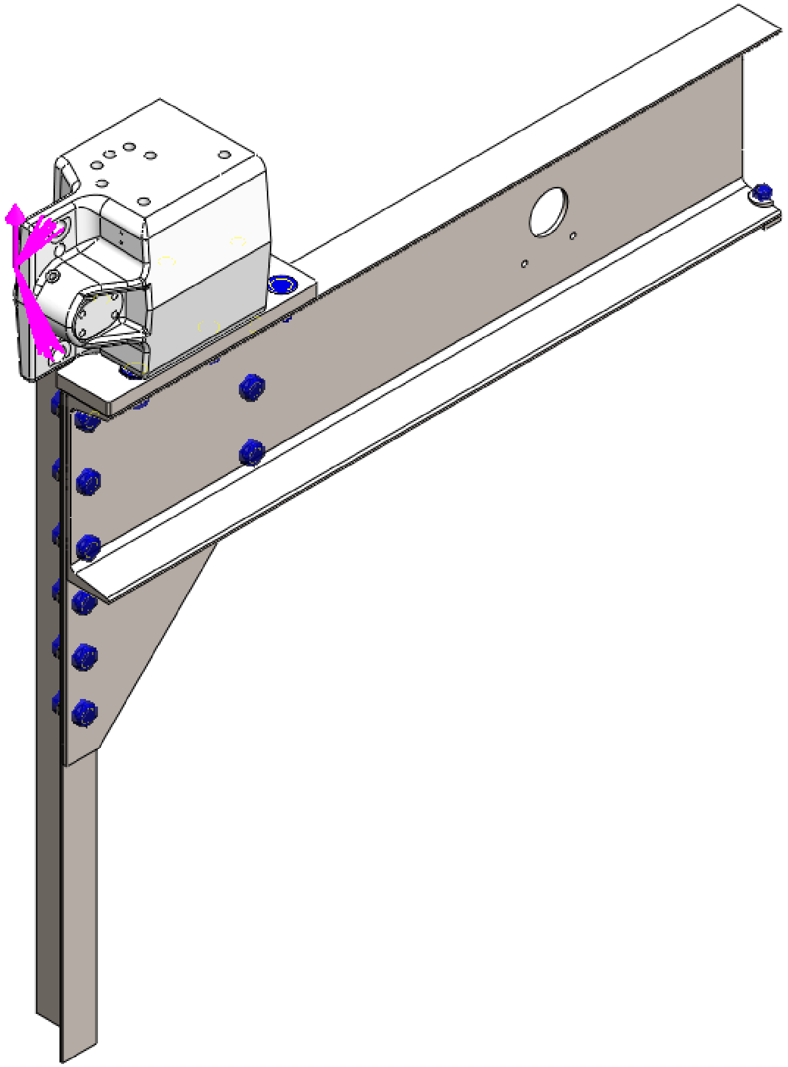
F = ma   mass = 12205 lb

Moving Mass (lb)	Stopping reaction force (lbf) at acceleration (g)										
	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
5000	250	500	1000	1500	2000	2500	3000	3500	4000	4500	5000
10000	500	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
15000	750	1500	3000	4500	6000	7500	9000	10500	12000	13500	15000
20000	1000	2000	4000	6000	8000	10000	12000	14000	16000	18000	20000
25000	1250	2500	5000	7500	10000	12500	15000	17500	20000	22500	25000
30000	1500	3000	6000	9000	12000	15000	18000	21000	24000	27000	30000
12205	610.25	1220.5	2441	3661.5	48[illegible]2	6102.5	7323	8543.5	9764	10985	12205



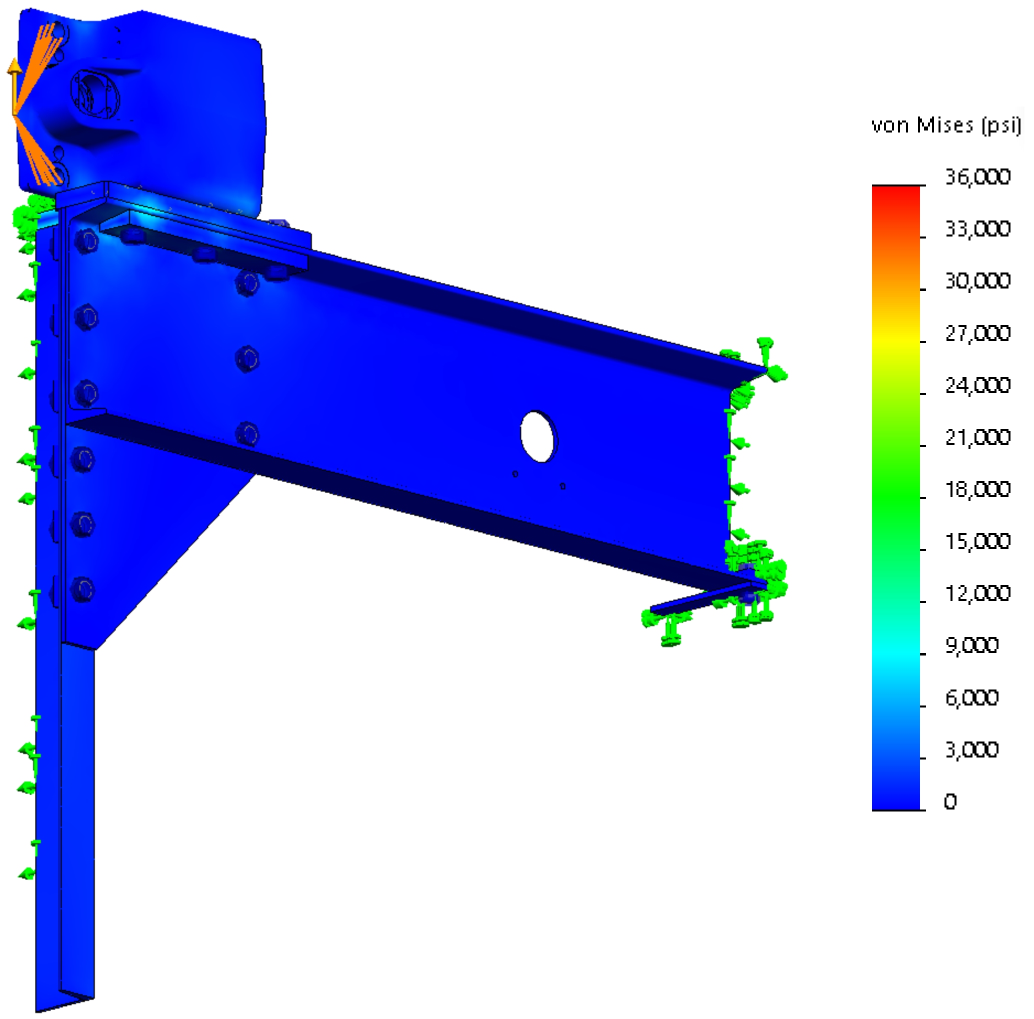
Setup – Upward Load

A braking load of 12,205 lb is used. A multiplier for 0.5g was added for an FEA load of 6,102.5 lbs.
Since the model is in a ¼ section, ¼ of the 6,102.5 lb was used.
A 1,526 lb load was applied in a Downward direction at the brake pad clamping location and transferred to the brake pad bolt holes in the caliper casting.
The Downward force is used to simulate the car travelling in an Upward direction.



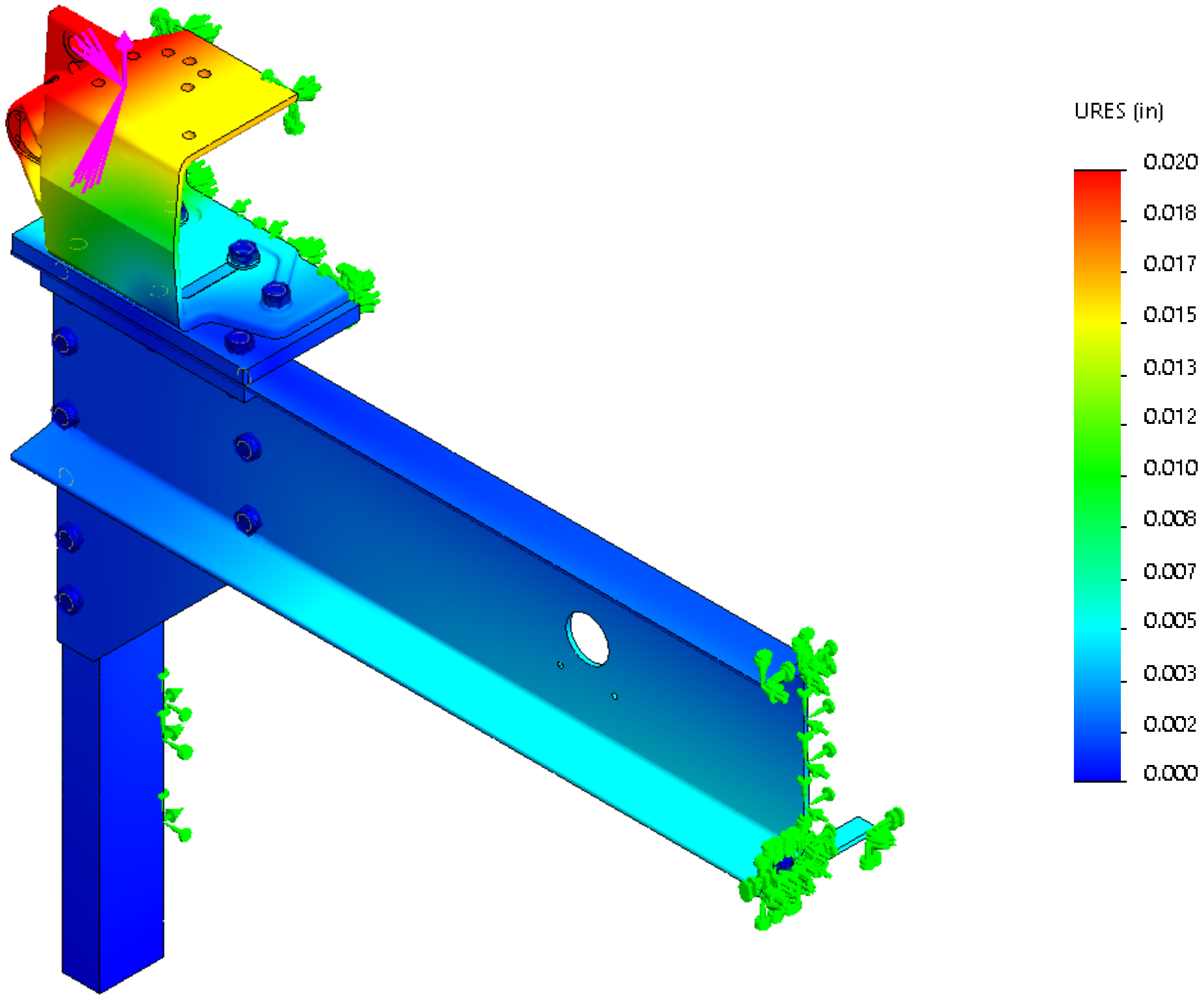
Stress Results – Crosshead Upward Load

Crosshead stress is ~10,000 psi.



Displacement Results – Crosshead Upward Load

Crosshead displacement is ~0.002”



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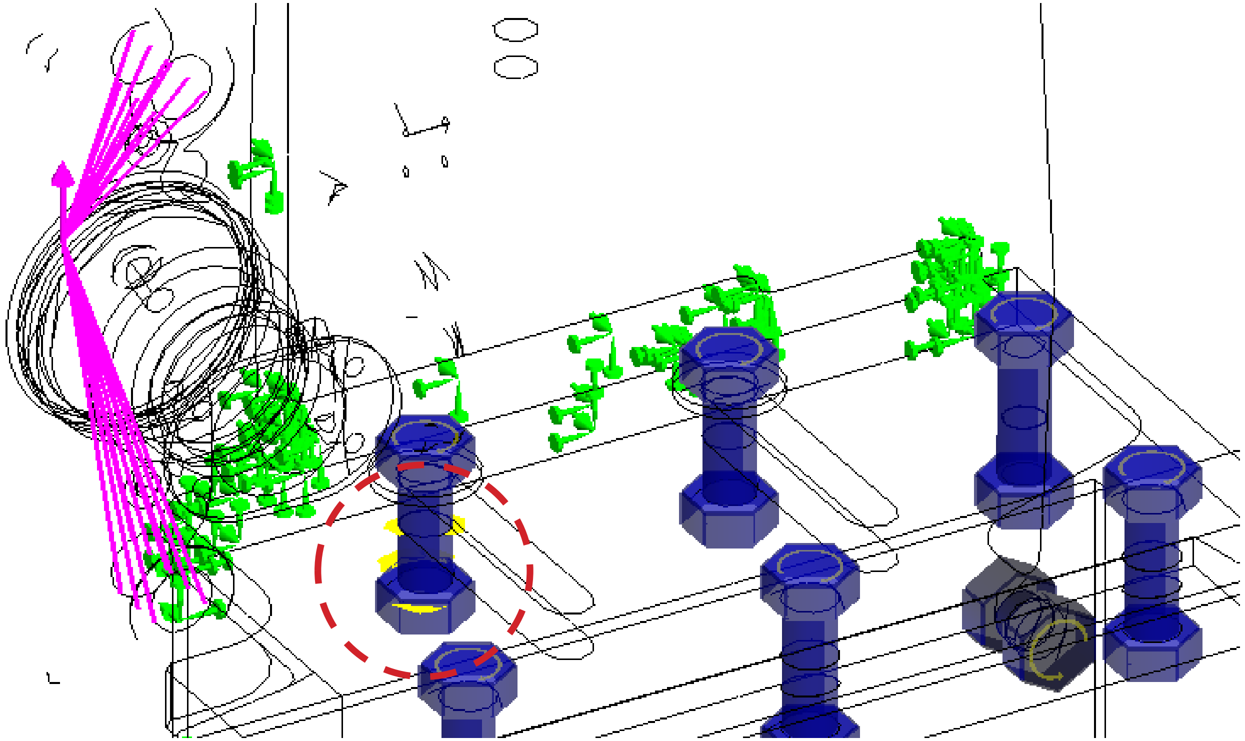
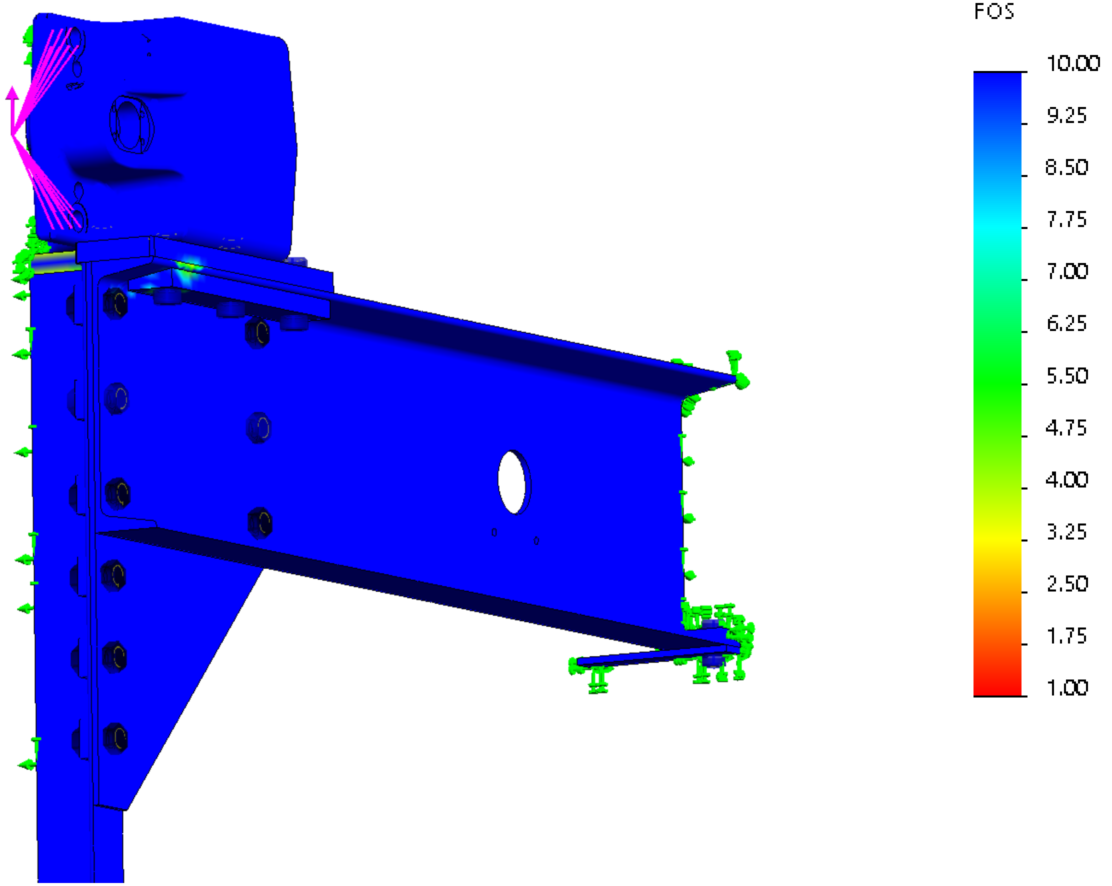
Factor of Safety Results – Crosshead Upward Load

Crosshead FOS is over 3.5X.





Iso clip at a value of ~3.5X FOS shows no failure and highlighted area (yellow) is isolated and of no concern.

Factor of Safety Results – Bolts Upward Load

Applied appropriate preload to all bolts (e.g. 212 ft-lbs torque for 5/8”)
Increase load to 3.5x (5341 lbs upward) since we need a 3.5x FOS

- We’re increasing load because factor-of-safety plots would incorrectly show an unloaded bolt failing due to installation torque alone

No bolts yield with 3.5x applied load

Highest load thru any bolt is 22,167 lbs (83,335 psi) which is well below the yield strength of 130,000 psi for a grade 8 bolt

Type	X-Component	Y-Component	Z-Component	Resultant	Connector
Axial Force (lbf)	0	22,167	0	22,167	Counterbore with Nut-14
Axial Force (lbf)	0	21,788	0	21,788	Counterbore with Nut-11
Axial Force (lbf)	0	0	20,639	20,639	Counterbore with Nut-7
Axial Force (lbf)	0	0	20,557	20,557	Counterbore with Nut-8
Axial Force (lbf)	0	0	20,497	20,497	Counterbore with Nut-1
Axial Force (lbf)	0	0	20,495	20,495	Counterbore with Nut-9
Axial Force (lbf)	0	20,494	0	20,494	Counterbore with Nut-15
Axial Force (lbf)	0	0	20,476	20,476	Counterbore with Nut-2
Axial Force (lbf)	0	20,461	0	20,461	Counterbore with Nut-13
Axial Force (lbf)	0	20,454	0	20,454	Counterbore with Nut-12
Axial Force (lbf)	0	0	20,450	20,450	Counterbore with Nut-6
Axial Force (lbf)	0	0	20,435	20,435	Counterbore with Nut-5
Axial Force (lbf)	0	0	20,433	20,433	Counterbore with Nut-3
Axial Force (lbf)	0	0	20,424	20,424	Counterbore with Nut-4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]