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HAM ISI Installation Fixture

Dimensioning and Specifications

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Distribution of this document:
Advanced LIGO Project

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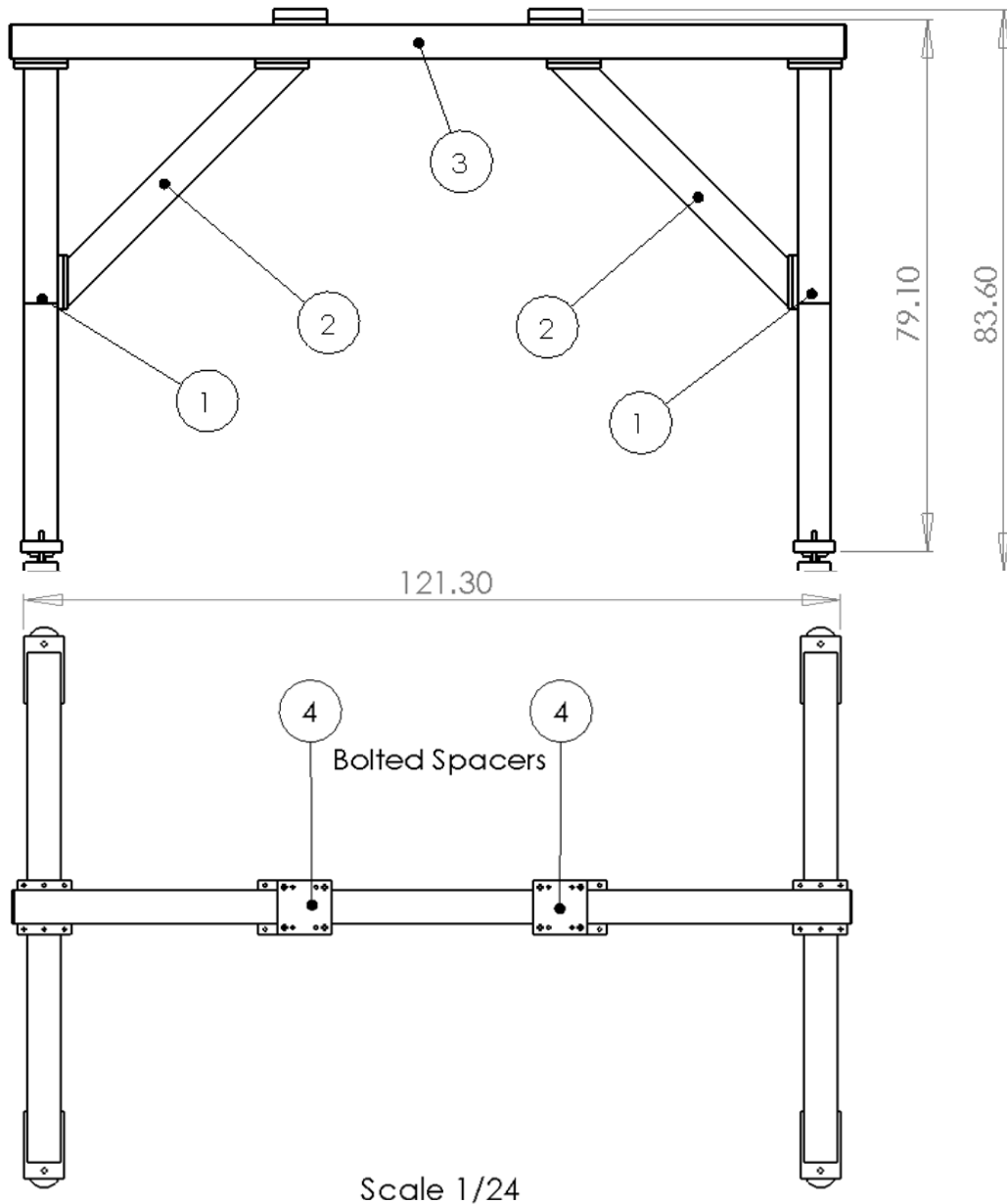**Livingston, LA 70754**
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Contents

1. Front Stand Dimensioning

1.1 Structure characteristics

The front and the back stand are identical. All tubes are 5"x5" – Thickness 3/16, Structural Steel ASTM A 500 GrB.

Scale 1/24

1	External Stand - Vertical Support D070587-00-D Sheet 2/4
2	External Stand - Horizontal Support D070587-00-D Sheet 3/4
3	External Stand - Angle Support D070587-00-D Sheet 4/4
4	External Stand - Spacer D070591-00-D (Bolted NO Weldment)

- Section 5"*5":

Principal Moment of inertia:	$I_x = 3.07 * 10^{-6} \, m^4$	(1)
Section modulus:	$Z_x = 4.84 * 10^{-5} \, m^3$	(2)
Section area:	$A = 1.19 * 10^{-3} \, m^2$	(3)

- Structural Steel ASTM A 500 GrB:

Tensile Yield Strength:	$\sigma_{Yield} = 315 \, Mpa$	(4)
Ultimate Tensile Strength:	$\sigma_{Ultimate} = 400 \, Mpa$	(5)
Modulus of elasticity:	$E = 199 \, Gpa$	(6)

- Load :

We assume that all the mass of the ISI can be temporarily held by one stand. The mass of the ISI is:

M = 5630 pds   (7)
P = 25100 N   (8)

Values based on Solidworks Model: *p06109-400-A Asm, HAM Isolation Table*.

1.2 Static Dimensioning

Several analyses have been done:

- Finite Element Static analysis using beam elements. This analysis permits to evaluate with accuracy the maximum stress far from the joints (far from the connections between the beams). It also permits to compare results using different boundary conditions.
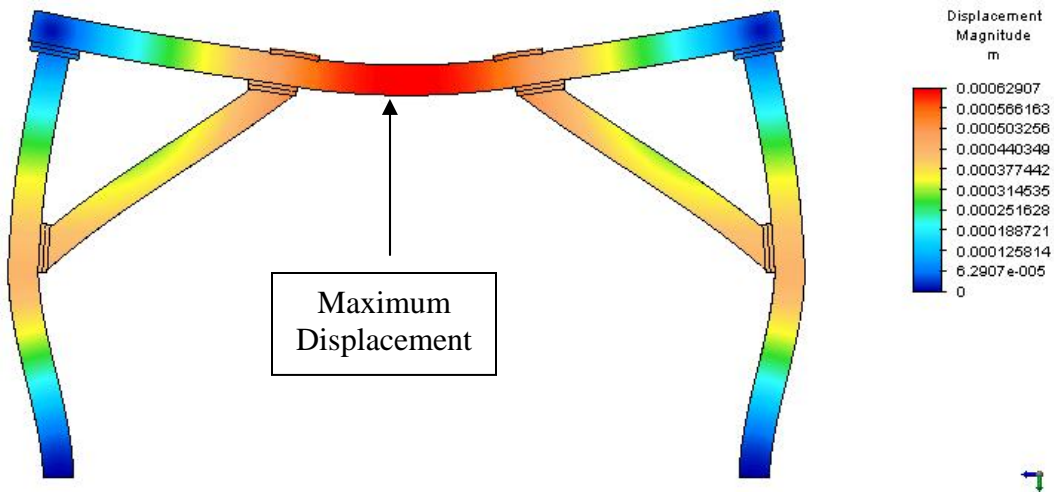
- Finite Element Static analysis using 3D elements. This analysis permits evaluate accuracy the maximum stress close to the joints. The meshing used fro this FEA is presented below:
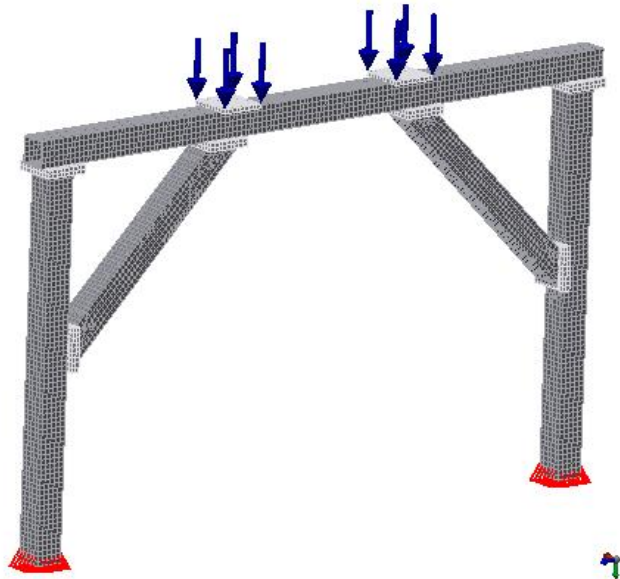
The Maximum Stress are in the area shown below:
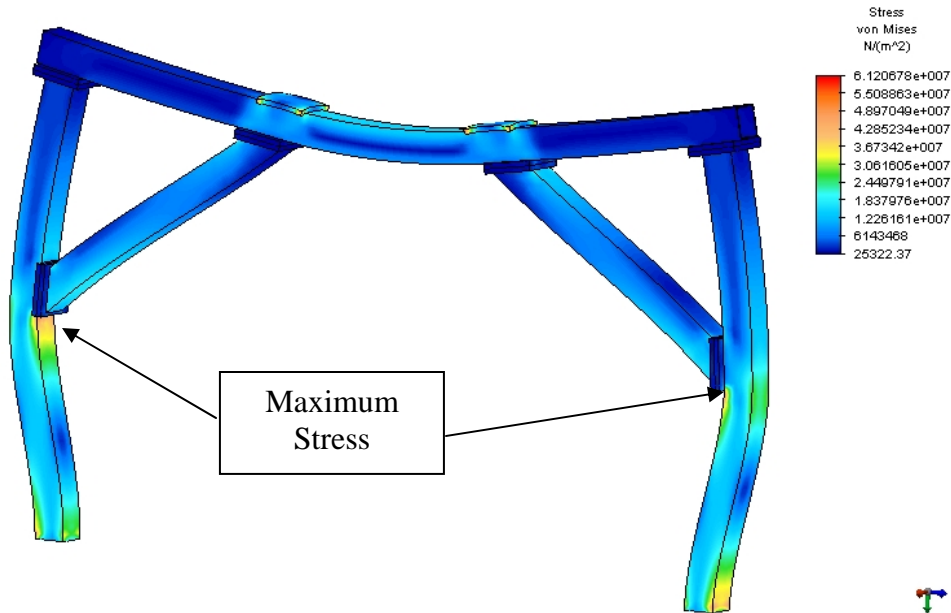
Maximum deflexion is in the area shown below   :

Results Summary:

Element Type	Boundary Conditions	Nodes	Max Disp (mm)	Max Stress (Mpa)	Safety Ratio
Brick	Clamped	18568	0.6	61	5.1
Brick	Clamped	89,200	1.0	87	3.6
Beam	Clamped	89	1.8	92	3.4
Beam	Pinned	89	3.0	113	2.8

The table above summarizes the results obtained with each analysis. The last one (Beam elements, basis pinned) is based on the most pessimistic assumptions (pinned basis can rotate), but keep a sufficiently high safety ratio.

1.3 Front Stand Components

- **Caster Wheels**

Stands Wheels McMASTER 9936T62
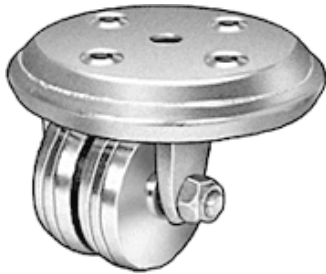
Number of casters in parallel: $\qquad$ $N = 4$ (9)

Load: $\qquad$ $M = M_{stand} + M_{beams} = 910 + 2*302 = 1514 \text{ pds}$ (10)

Work limit $\qquad$ $M_{lim} = 600 \text{ pds}$ (11)

Safety ratio: $\qquad$ $\lambda = \dfrac{N\,M_{lim}}{M_{ISI}} = 1.58$ (12)

- **Leveling pads**

Stands Leveling Pads.   Ref : McMASTER 63965K69
Number of pads in parallel: $\qquad$ $N = 6$ (13)
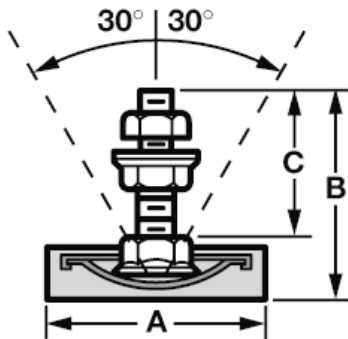
Threads: ¾"-10
$A = 2.375"$ (14)
$B = 1.016"$ (15)
$C = 0.75"$ (16)
Work limit: $\qquad$ $M_{lim} = 8000 \text{pds}$ (17)

Load: $\qquad$ $M = M_{stand} + M_{beams} + M_{ISI} = 1514 + 5600 = 7114 \text{ pds}$ (18)

Number of pads effectively carrying the load: $\qquad$ $N_{eff} = 2$ (19)

Safety ratio: $\qquad$ $\lambda = \dfrac{N_{eff}\,M_{lim}}{M} = 2.25$ (20)

2. Middle Stand Dimensioning

2.1 Structure characteristics and FEA analysis

All tubes are 5"x5" – Thickness 3/16, Structural Steel ASTM A 500 GrB
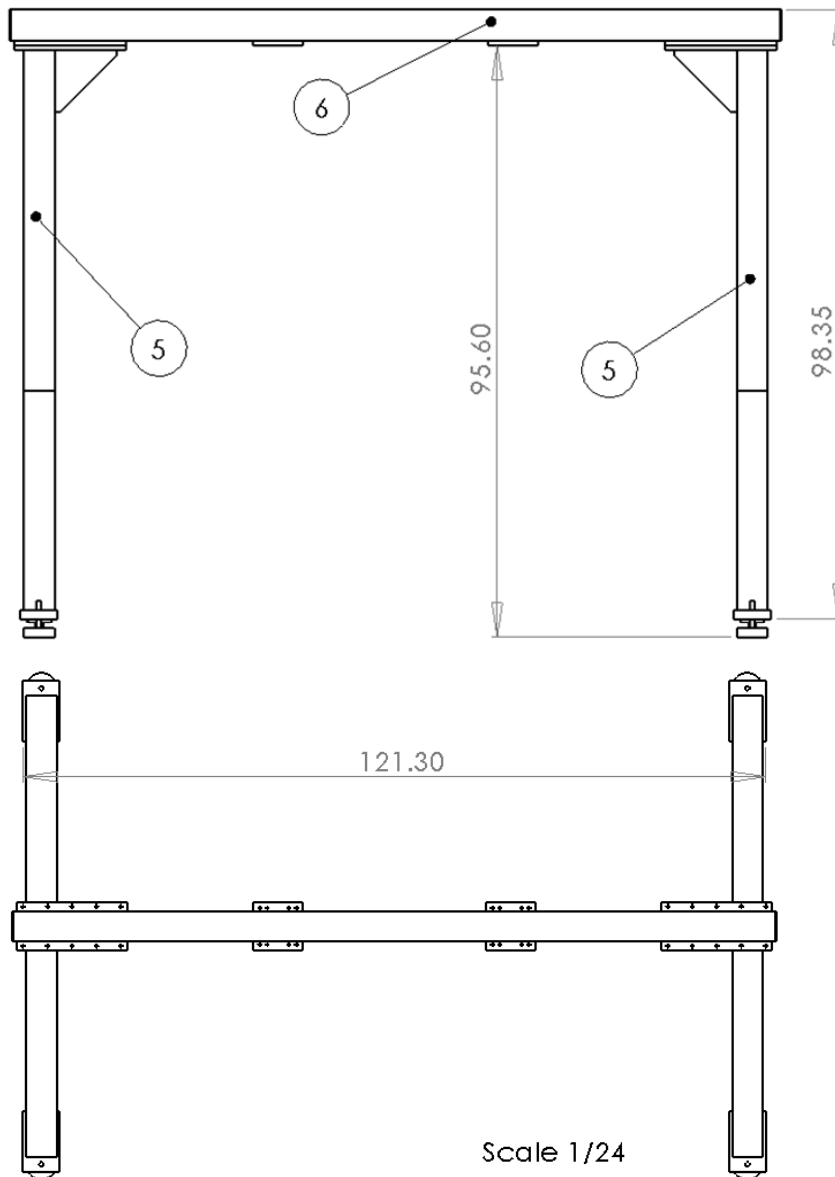
5	Middle Stand - Vertical Support -D070588-00-D Sheet 2/3
6	Middle Stand - Horizontal Support- D070588-00-D Sheet3/3

Cross sections, materials, and load assumptions are the same as in section 1.2. The Maximum Stress are in the area shown below:
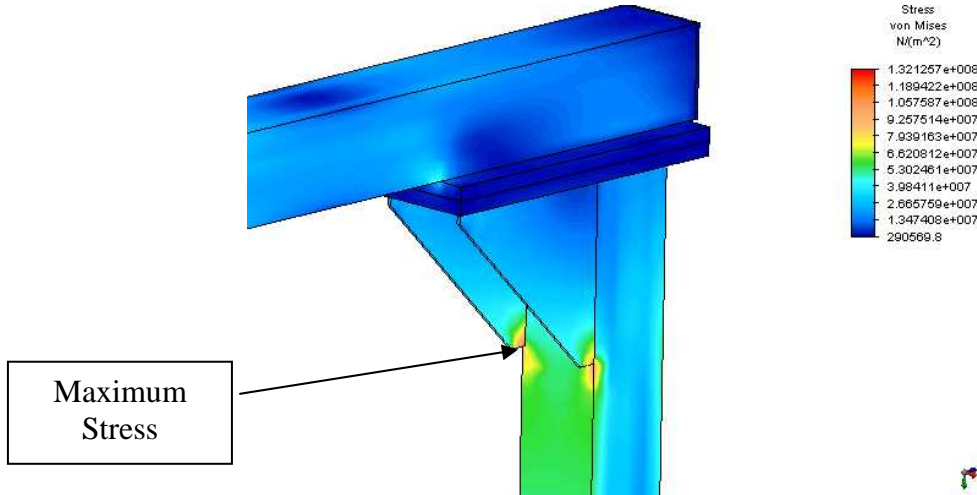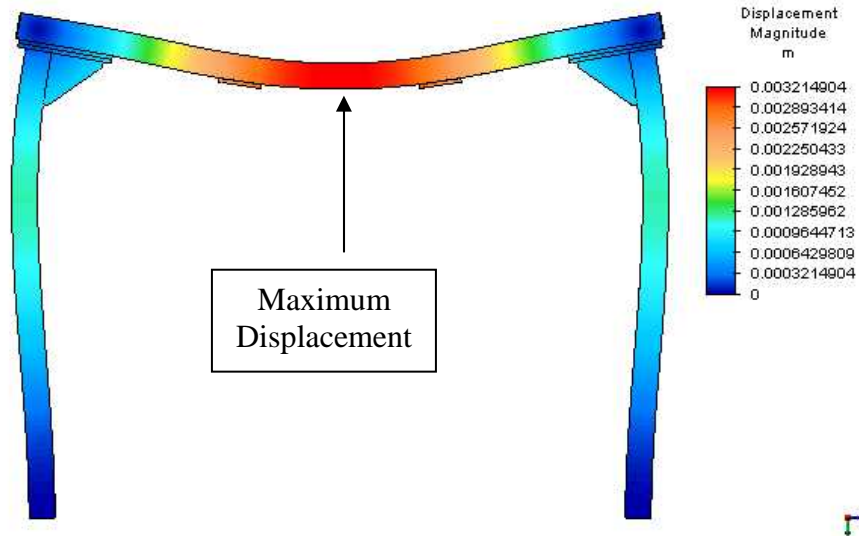

Maximum deflexion is in the area shown below   :

Results Summary:

The table above summarizes the results obtained with different analysis. The last one (Beam elements, basis modeled pinned) is based on the most pessimistic assumptions. Like for the front stand, it provides a sufficiently high safety ratio.

Method	Boundary Conditions	Nodes	Max Disp (mm)	Max Stress (Mpa)	Safety Ratio
FEA Brick	Clamped	38,853	3.2	132	2.4
FEA Beam	Clamped	126	7.9	123	2.6
FEA Beam	Pinned	126	8.7	132	2.4

2.2 Middle Stand Components

- **Caster Wheels**

Same reference as in section 1.3.

Load:
$$M = M_{stand} + M_{beams} = 781 + 2*302 = 1385 \text{ pds} \tag{21}$$

Safety ratio:
$$\lambda = \frac{N\,M_{lim}}{M_{ISI}} = 1.7 \tag{22}$$

- **Leveling pads**

Same ref as in section 1.3.

Load:
$$M = M_{stand} + M_{beams} + M_{ISI} = 1385 + 5600 = 6985 \text{ pds} \tag{23}$$

We assume that only the two pads directly below the stand carry the load. : Number of effective pads holding the load:
$$N_{eff} = 2 \tag{24}$$

Safety ratio:
$$\lambda = \frac{N_{eff}\,M_{lim}}{M} = 2.3 \tag{25}$$

- Tensile stress in the screws

Each rail beam is tightened to the middle stands by 4 screws. So each screw carries 1/8 of the load. The bolts are:

Bumax 88 Stainless Steel, 1/2"-13, Minimum Tensile Strength: 116,000 psi

The nominal load carried by each screw is:
$$M_{nom} = \frac{M_{ISI}}{N_{screw}} = 704 \text{ pds} \tag{26}$$

with M_{ISI} the mass of the ISI and N_{screws} the number of screws:
$$M_{ISI} = 5630 \text{ pds} \qquad\qquad N_{screws} = 8 \tag{27}$$

Using standard torque values for stainless steel screws of this diameter:

Tightening torque:
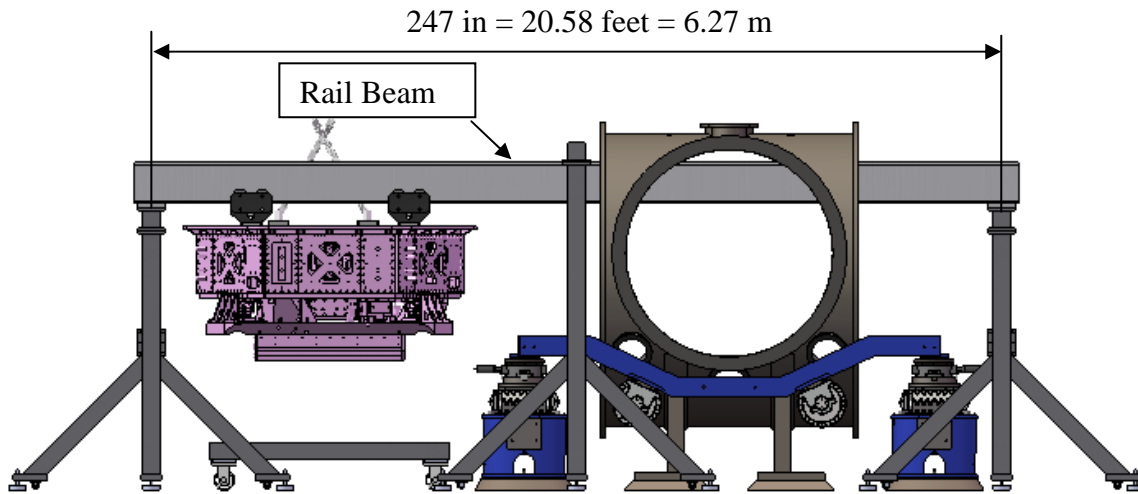$$\tau = 542 \text{ pds.in}$$

The corresponding preload can be obtained by:
$$F_i = \frac{\tau}{K\,D} = 5420 \text{ pds}$$

Where K is a constant that depends on the bolt material and size (0.2 here) and D is the bolt diameter.

Conclusion: The load M_{nom} is much lower than the preload F_i in each screw. The preload is high enough using the standard torque values. No risk to yield.

3 Rail beam analysis

The beams are clamped on each of the stands. The boundary conditions can however allow a certain amount of rotations. So two cases have been studied:

- the beams assumed to be clamped on each stand
- the beams assumed to be pinned on each stand

In section 3.1 the beam characteristics are presented. In section 3.2 the static deformations are studied for the two types of boundary conditions. In section 3.3 the flange local deformations of the beam are studied.

3.1 Beam Section characteristic

I-Beam Aluminum Association Standard:
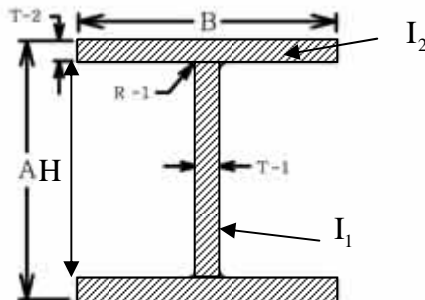
Beam properties summary:

Beam length: $\qquad$ $L_b = 258\,\text{in} = 21.50\,\text{feet} = 6.55\,\text{m}$

Distance between stands: $\qquad$ $L = 247\,\text{in} = 20.58\,\text{feet} \approx 6.30\,\text{m}$

Beam height: $\qquad$ $A = 12\,\text{in} = 0.3048\,\text{m}$

Beam width: $\qquad$ $B = 7\,\text{in} = 0.1778\,\text{m}$

Internal section height: $\qquad$ $T_1 = 0.31\,\text{in} = 7.88*10^{-3}\,\text{m}$

Internal section height:
$$H = A - 2\,T_2 = 0.2733\,\text{m}$$

Flange width:
$$T_2 = 0.62\,\text{in} = 15.75*10^{-3}\,\text{m}$$

Section Area:
$$S = H\,T_1 + 2\,B\,T_2 = 7.75*10^{-3}\,\text{m}^2$$

Aluminum 6061 density:
$$\rho = 2700\,\text{kg}/\text{m}^3$$

Beam Mass:
$$M = \rho\,S\,L = 131\,\text{kg}$$

Momentum of inertia:
$$I = 0.130*10^{-3}$$

Material:
6061-T6

Modulus of elasticity:
$$E = 68.9\,\text{GPa}$$

Tensile Yield Strength:
$$\sigma_E = 276\,\text{Mpa}$$

3.2 Static bending analysis

Deflexion and stress have been evaluated using FEM analysis. Beam elements are used. Each trolley carries a quarter of the total load. These loads are applied on the beam at the most critical position: half way between the front stand and the middle stand.
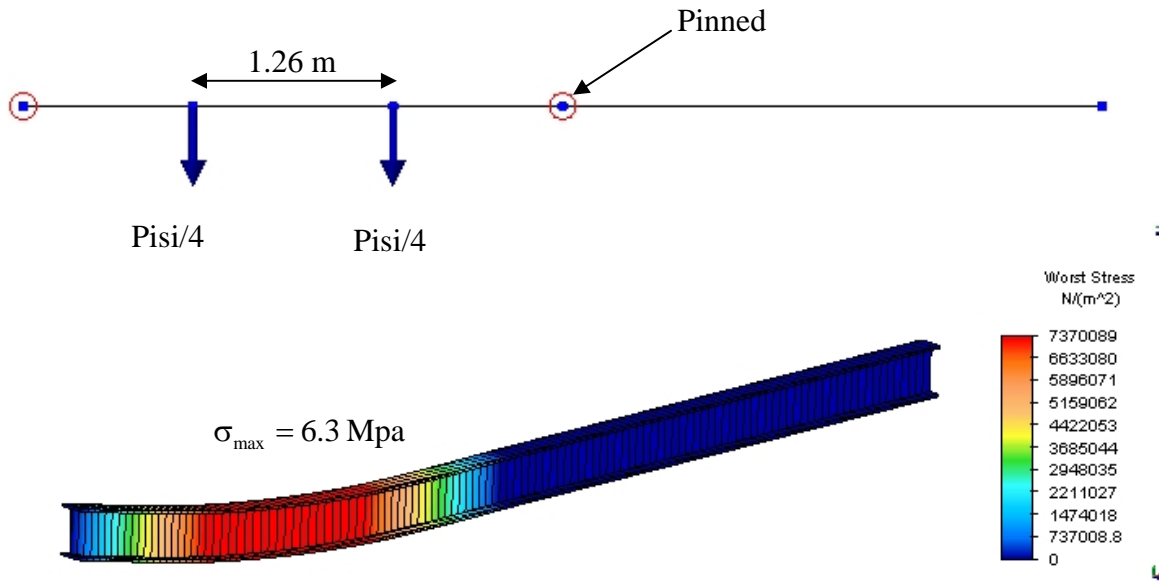
- Study 1:

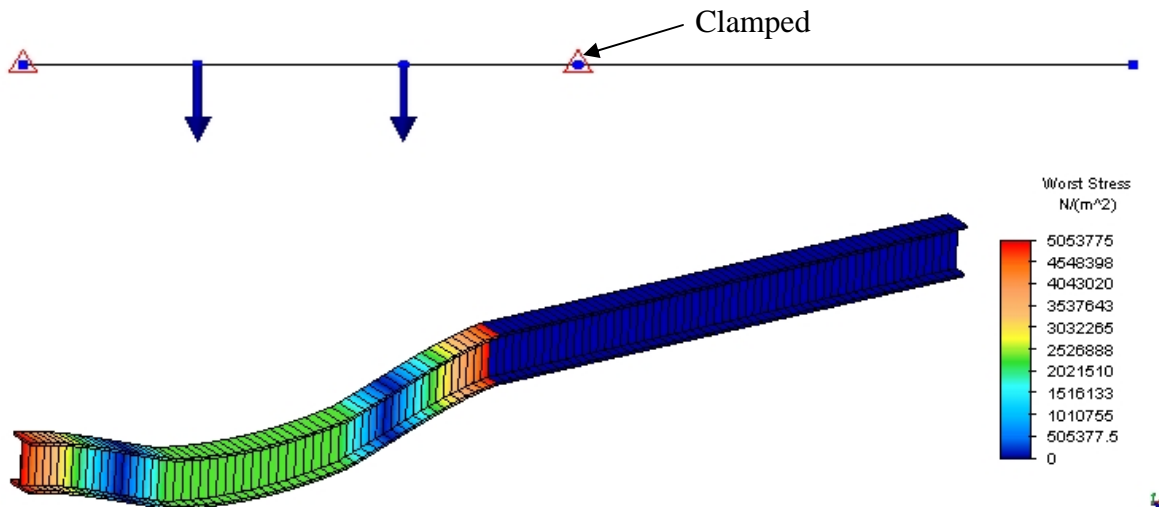Connections between the stands and the beam are assumed simply supported:

$$\delta_{max} = 0.65\,\text{mm}$$

$$\sigma_{max} = 6.3\,\text{Mpa}$$
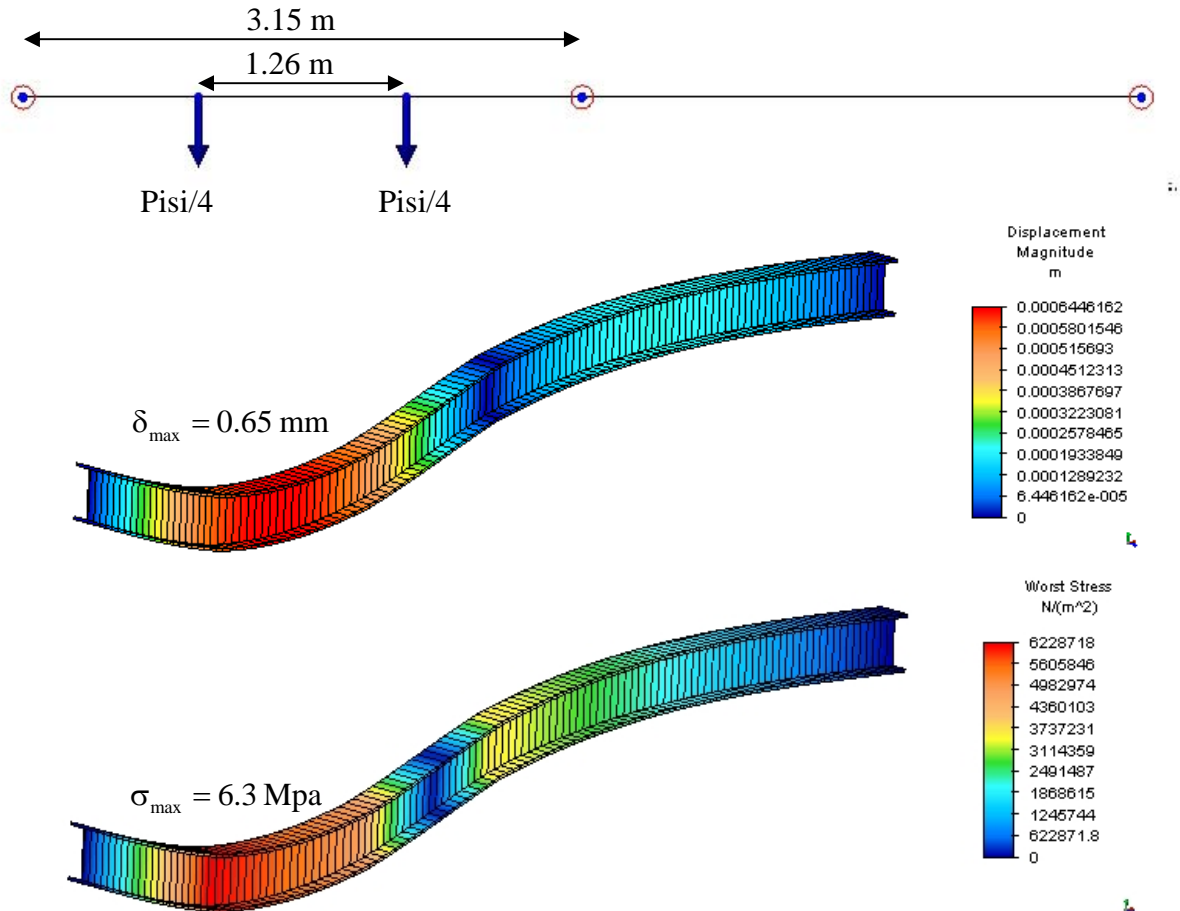
- Study 2:

Connections between two stands and the beam are assumed simply supported. The influence of the third stand is ignored:

Pinned

1.26 m

Pisi/4   Pisi/4

$\sigma_{max} = 6.3$ Mpa

Worst Stress
N/(m^2)

7370089
6633080
5896071
5159062
4422053
3685044
2948035
2211027
1474018
737008.8
0

- Study 3:

Connections between two stands and the beam are assumed to be clamped.

Clamped

Worst Stress
N/(m^2)

5053775
4548398
4043020
3537643
3032265
2526888
2021510
1516133
1010755
505377.5
0

|	Max Deflexion (mm)	Max Stress (Mpa)	Safety Ratio
• Case 1 (Pinned on three Stands)	0.65	6.3	44
• Case 2 (Pinned on two Stands)	2.4	7.37	37
• Case 3 (Clamped on two Stands)	0.26	5.5	50

Conclusion: no risk regarding the global bending of the beams. Local deformation are studied in next section.

3.3 Flange local deformation

In this section, the local deformation of the flange is studied. We use two trolleys per beam. Each trolley carry half the load P (P is half the ISI weight). Each trolley applies a quarter of the load on each flange.

Although each trolley has several wheels, we prefer assuming that the force on each flange is punctual. This avoids making delicate assumptions on the load carried by each wheels, and the local pressure in the wheels/rail contact.

The forces are modeled by single punctual forces:
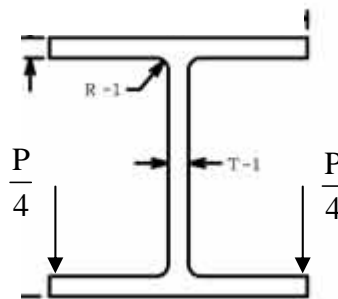
This configuration permits to obtain the upper estimation of the local deformations and stresses (in reality the forces is shared on several wheels and the force is applied other a full surface of contact).

The four forces are applied on the edge of the flange of a FE model. The beam is pinned on the edges.
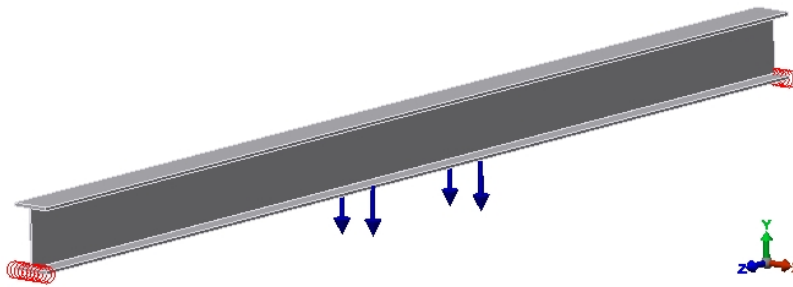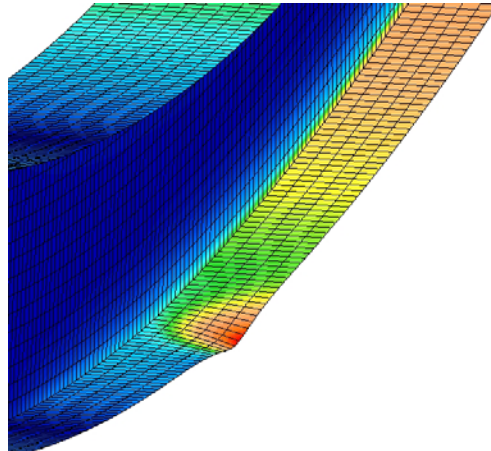

Two FE models have been made. One is made of plate elements, which is appropriated to this study. Second one is made of 3D brick, which is less accurate but permits to check the results of the first analysis using a different model.

- Plate and brick meshing:
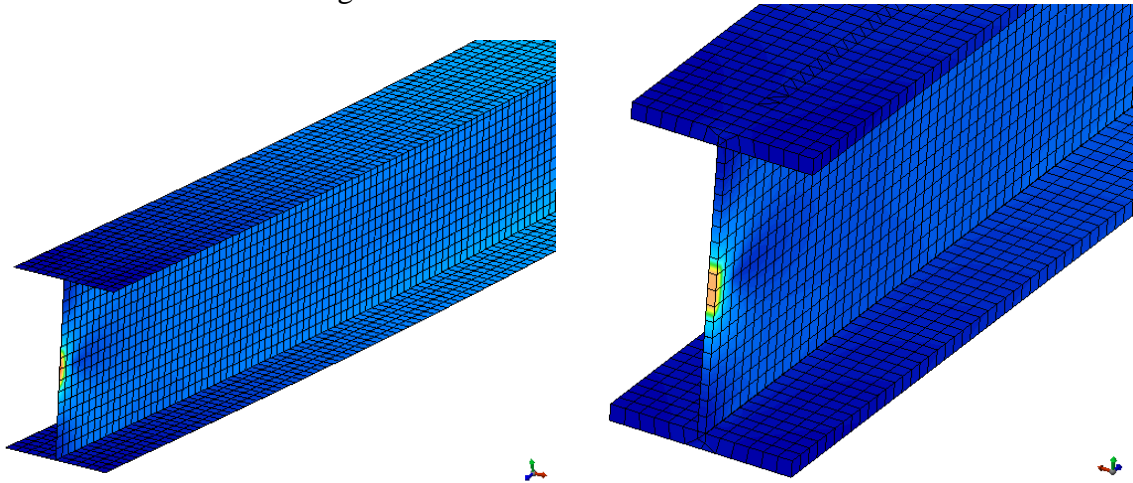
The following figure shows the local deformation of the flange.

The following table summarizes the results obtained with both models.
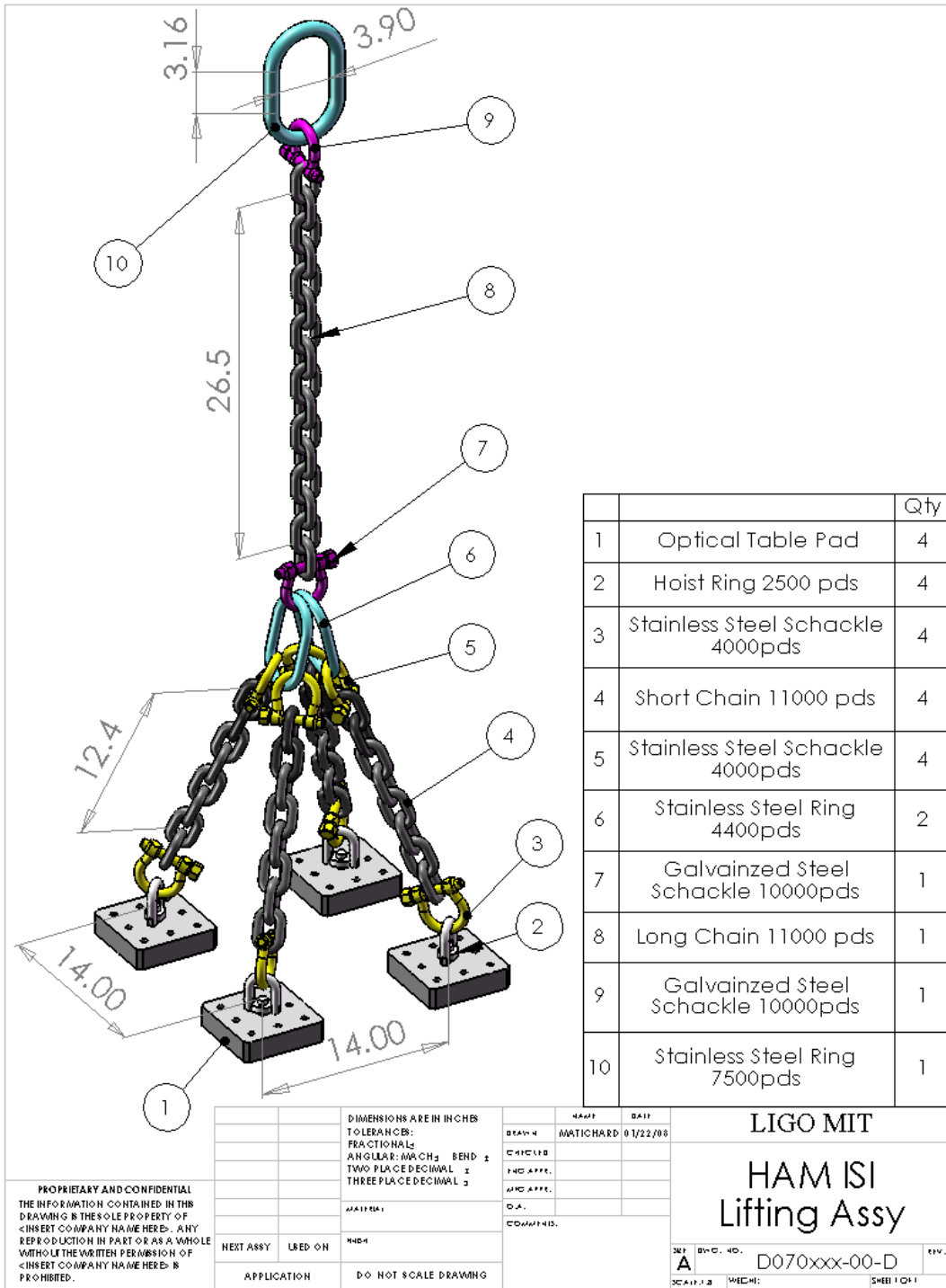
	Max Deflexion (mm)	Max Stress (Mpa)	Safety Ratio
• Plate	0.70	51.6	5.25
• Brick	0.72	52.1	5.25

Conclusion:

The flanges are strong enough to carry the load of the ISI.

4 Lifting elements

The 5Tons crane lifts the ISI through a Stainless Steel ring, item #10 on the picture below. The resistance of each item (#1 to #10) between the optical table and the hook is described in this section.


		Qty
1	Optical Table Pad	4
2	Hoist Ring 2500 pds	4
3	Stainless Steel Schackle 4000pds	4
4	Short Chain 11000 pds	4
5	Stainless Steel Schackle 4000pds	4
6	Stainless Steel Ring 4400pds	2
7	Galvainzed Steel Schackle 10000pds	1
8	Long Chain 11000 pds	1
9	Galvainzed Steel Schackle 10000pds	1
10	Stainless Steel Ring 7500pds	1

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HAM ISI
Lifting Assy

DWG. NO. D070xxx-00-D

- **Load in components**

The load applied on the Item #1 to # 6 is not normal direction of those items:
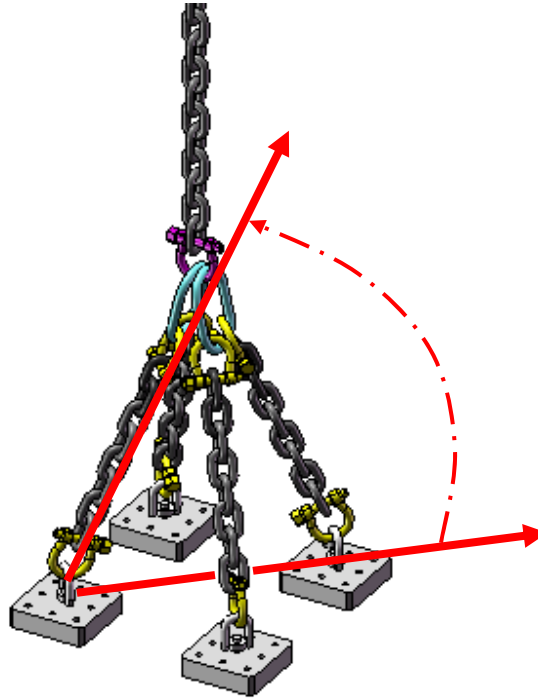
The force F applied on these items is function of the normal load N and the angle **α:**
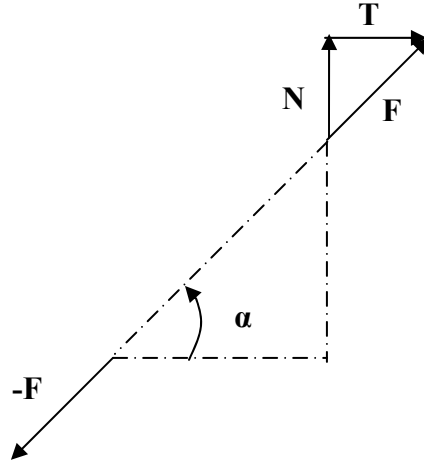
$$F = \frac{N}{\sin(\alpha)} \tag{28}$$

With
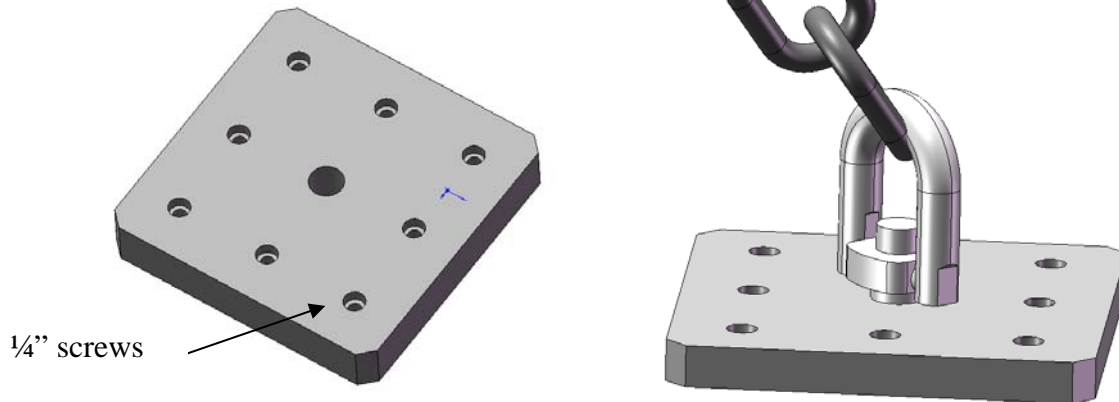
$$\alpha = 69° \tag{29}$$

$$\frac{1}{\sin(\alpha)} = 1.07 \tag{30}$$

- **Item #1: Optical table Pad**

¼" screws

- **Tensile stress in the screws**

The bolts are:

Bumax 88 Stainless Steel, 1/4"-20, Minimum Tensile Strength: 116,000 psi

The nominal load in each screw is:

$$M_{nom} = \frac{M_{ISI}}{N_{plates} N_{screw}} = 176 \, pds \tag{31}$$

with P_{ISI} the load of the ISI, N_{plates} the number of plate and N_{screws} the number of screws per plate:

$$M_{ISI} = 5630 \, pds, \quad N_{plates} = 4, \quad N_{screws} = 8 \tag{32}$$

Using standard values for stainless steel screws of this diameter:

Tightening torque: $\tau = 78.8 \, pds.in$

The corresponding preload can be obtained by:

$$F_i = \frac{\tau}{K D} = 1560 \, pds$$

Where K is a constant that depends on the bolt material and size (0.2 here) and D is the bolt diameter
The ratio Preload/Load is:

$$\lambda = \frac{F_i}{M_{nom}} = 8.9 \tag{33}$$

Conclusion: The load M_{nom} is much lower than the preload F_i in each screw. The preload is high enough using the standard torque values. No risk to yield

- **Shear stress in the optical table thread**

The shear area of one thread is:

$$A_s = \pi \, d \, w_0 \, p \tag{34}$$

With d the outside, w_0 the major area factor for UNS threads, and p is the thread pitch.

$$w_0 = 0.88 \tag{35}$$

$$d = 0.25 \, in \tag{36}$$

$$p = 1/20 \tag{37}$$

The shear stress in one thread is:

$$\tau_s = \frac{F_i}{A_s \, n} = 9028 \, psi \tag{38}$$

With n the number of threads assumed to be engaged: $n = 5$
The safety ratio is:

$$\lambda = \frac{S_{ys}}{\tau_s} = 2.5 \tag{39}$$

with λ the safety ratio, S_{ys} the shear yield strength of aluminum 6061, τ_t the shear stress in the thread:
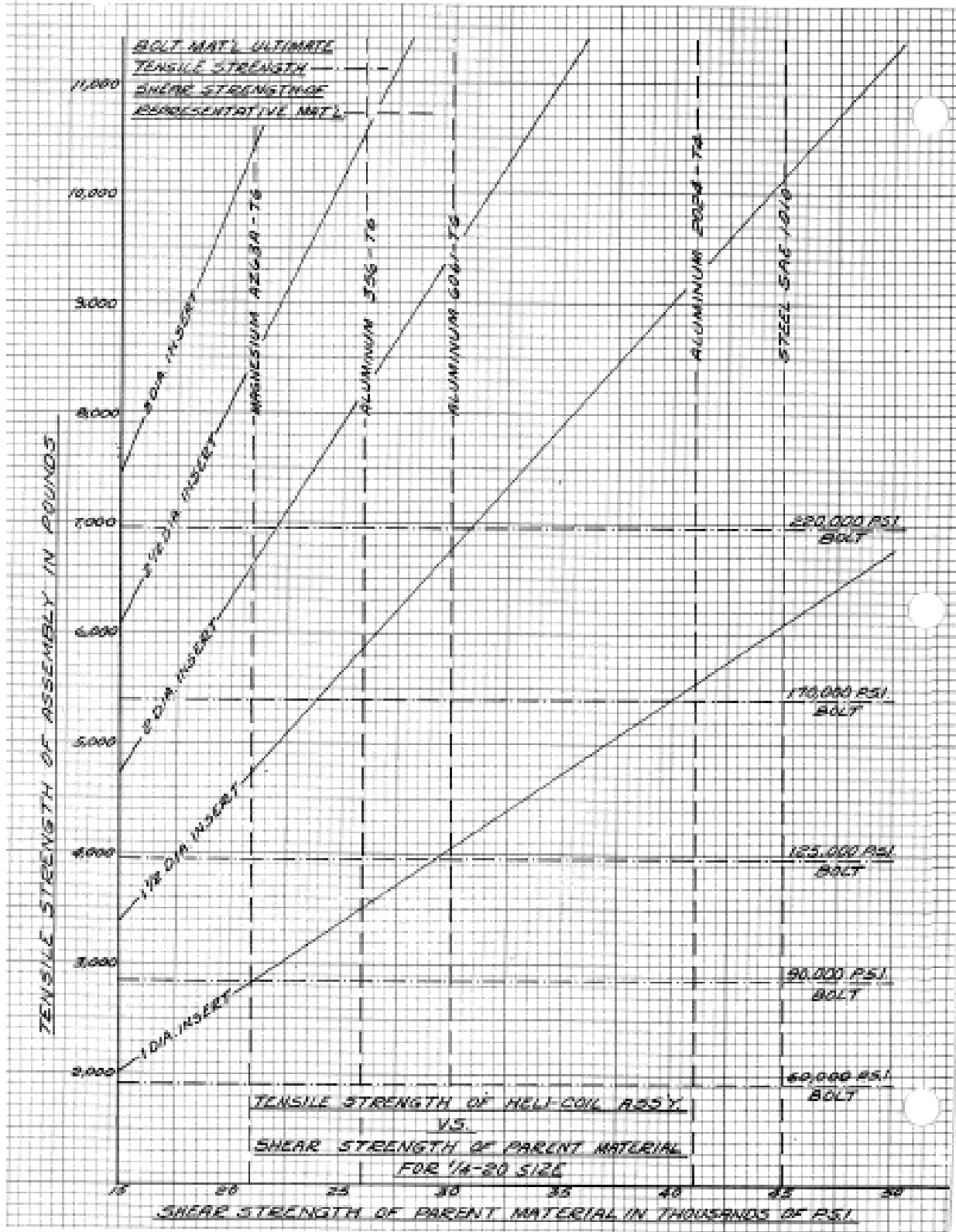
$$S_{ys} \approx 0.58 * Sy = 23142 \, psi \tag{40}$$

The plot on next page shows that with a preload of 1560 pds, and 1 diameter of engagement, the shear stress in the parent material will be inferior to 15000psi (Safety ratio superior to 2).
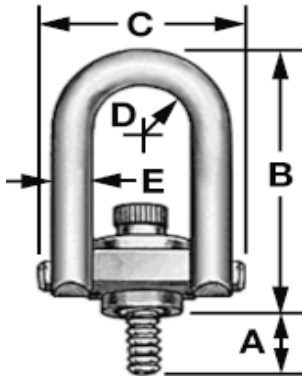
Shear strength of parent material for screws ¼-20
Provided by Helicoil Products, Division of mite corporation representative.

- **Item #2: Hoist Ring**

Hoist Ring thread 3/4"-10 Stainless Steel. Ref: McMASTER 2949T41
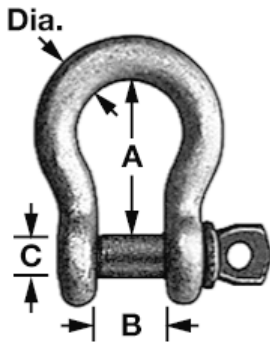

Number of rings in parallel: $\quad\quad\quad$ N = 4 $\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad$ (41)

Work limit

$$M_{lim} = 2500 pds \quad\quad\quad\quad\quad\quad (42)$$

Safety ratio:

$$\lambda = \frac{N\,M_{lim}\,\sin(\alpha)}{M_{ISI}} = 1.66 \quad\quad\quad\quad (43)$$

- **Item #3: Anchor Shackles (Stainless Steel)**

Stainless Steel Anchor Shackles. Ref: McMASTER3583T85
Number of shackles in parallel: $\quad\quad$ N = 4 $\quad\quad\quad\quad\quad\quad\quad\quad\quad$ (44)

A = 2.375" $\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad$ (45)
B = 1.016" $\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad$ (46)
C = 0.75" $\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\;$ (47)
Work limit: $\quad\quad\quad\quad\quad$ $M_{lim} = 4000 pds$ $\quad\quad\quad\quad\quad\quad\quad$ (48)

Safety ratio:

$$\lambda = \frac{N\,M_{lim}\,\sin(\alpha)}{M_{ISI}} = 2.6 \quad\quad\quad\quad (49)$$

- **Item #4: The Chain**

Stainless Steel Chain. Ref: McMASTER 33645T55

Work Load Limit: $M_{lim} = 11000 pds$ (50)

Inside link width: $w_i = 0.85"$ (51)

Safety ratio:

$$\lambda = \frac{N\, M_{lim}\, \sin(\alpha)}{M_{ISI}} = 7.3 \tag{52}$$

Conclusion: This item is over dimensioned, but this inside link width is necessary in order to fit with the Stainless steel shackles pin diameter.

- **Item #5: Anchor Shackles (Stainless Steel, 2nd set)**
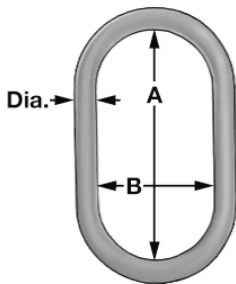
Same reference and as item #3.

Number of shackles in parallel: $N = 4$ (53)

Safety ratio: $\lambda = \dfrac{N\, M_{lim}\, \sin(\alpha)}{M_{ISI}} = 2.6$ (54)

- **Item #6: Stainless Steel Ring (Short ones)**

Sling Ring. Ref: McMASTER 30567T91

Number of links in parallel: $N = 2$ (55)
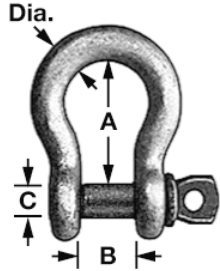

$Diam = 0.688"$ (56)

$A = 5.31"$ (57)

$B = 2.95"$ (58)

Work limit: $M_{lim} = 4400 pds$ (59)

Safety ratio: $\lambda = \dfrac{N\, M_{lim}\, \sin(\alpha)}{M_{ISI}} = 1.46$ (60)

- ### **Item #7 and #9: Anchor Shackles**

Galvanized Alloy Steel Shackles. Ref: McMASTER 3663T43

Number of shackles in parallel: $\qquad$ N = 1 $\qquad$ (61)

$Dia = 0.625", \ A = 2.375", \ B = 1.065", \ C = 0.75"$ $\qquad$ (62)

Work limit: $\qquad$ $M_{lim} = 10000 \text{pds}$ $\qquad$ (63)

Safety ratio: $\qquad$ $\lambda = \dfrac{M_{lim}}{M_{ISI}} = 1.7$ $\qquad$ (64)

- ### **Item #8: The Chain**

Stainless Steel Chain. Ref: McMASTER 33645T55

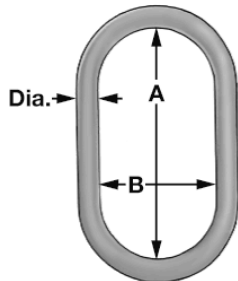Work Load Limit: $\qquad$ $M_{lim} = 11000 \text{pds}$ $\qquad$ (65)

Safety ratio: $\qquad$ $\lambda = \dfrac{N_{lim}}{M_{ISI}} = 1.9$ $\qquad$ (66)

Conclusion: This item is over dimensioned, but this inside link width is necessary in order to fit with the Stainless steel shackles pin diameter.

- ### **Item #10: Stainless Steel Ring (Long ones)**

Sling Ring. Ref: McMASTER 30567T91
Number of links in parallel: $\quad$ N = 2 $\qquad$ (67)

$Diam = 0.88", \ A = 6.30", \ B = 3.55"$ $\qquad$ (68)
Work limit: $\qquad$ $M_{lim} = 7500 \text{pds}$ $\qquad$ (69)

Safety ratio: $\qquad$ $\lambda = \dfrac{M_{lim}}{M_{ISI}} = 1.33$ $\qquad$ (70)

5 Trolleys Connection

- **Extra Stable Manual Trolley**

Ref. McMASTER 3267T64

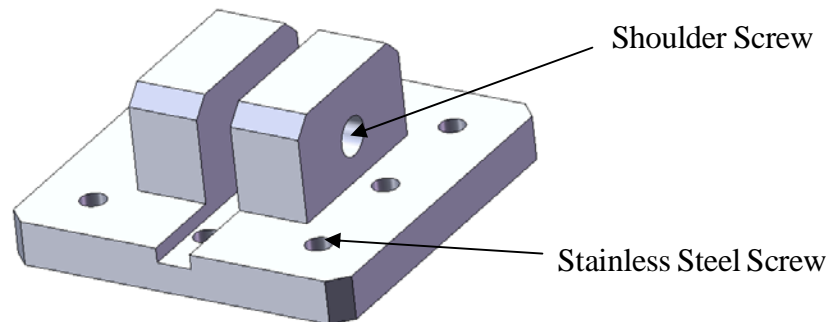Number of links in parallel: $N = 4$ (71)

Work limit: $M_{lim} = 4400\,\text{pds}$ (72)

Safety ratio: $\lambda = \dfrac{N\,M_{lim}}{M_{ISI}} = 3.1$ (73)

- **Trolley connector**

Shoulder Screw

Stainless Steel Screw

- **Shear stress in shoulder screw screws**

Diameter: $D = 1\,\text{in}$, 4 shoulder screws.   (74)

Shear Stress: $\tau = \dfrac{M_{isi}}{4\,A_s} = 1782\,\text{psi}$ (75)

With A_s the shear area.

The safety ratio is: $\lambda = \dfrac{S_{ys}}{\tau_s} = 22$ (76)

with λ the safety ratio, S_{ys} the shear yield strength of aluminum 6061, τ_t the shear stress in the thread ($S_{ys} \approx 0.58 * Sy = 40600\ \text{psi}$)

Ccl: the shoulder screw is over dimensioned but this diameter permit to fit properly with the trolley's hole.

- **Tensile stress in the screws**

The bolts are: Bumax 88 Stainless Steel, 1/4"-20, Minimum Tensile Strength: 116,000 psi.

The nominal load in each screw is:

$$M_{nom} = \frac{M_{ISI}}{N_{plates} N_{screw}} = 156 \, pds \qquad (77)$$

with P_{ISI} the load of the ISI, N_{plates} the number of plate and N_{screws} the number of screws per plate ($M_{ISI} = 5630 \, pds$, $N_{plates} = 4$, $N_{screws} = 9$).

Using standard values for stainless steel screws of this diameter:

Tightening torque: $\tau = 78.8 \, pds.in$

The corresponding preload can be obtained by:

$$F_i = \frac{\tau}{K \, D} = 1560 \, pds$$

Where K is a constant that depends on the bolt material and size (0.2 here) and D is the bolt diameter
The ratio preload/load is:

$$\lambda = \frac{F_i}{M_{nom}} = 10 \qquad (78)$$

Conclusion: The load M_{nom} is much lower than the preload F_i in each screw. The preload is high enough using the standard torque values. No risk to yield

- **Shear stress in the optical table thread**

The shear area of one thread is:

$$A_s = \pi \, d \, w_0 \, p \qquad (79)$$

With d the outside, w_0 the major area factor for UNS threads, and p is the thread pitch.

$$w_0 = 0.88, \; d = 0.25 \, in, \; p = 1/20 \qquad (80)$$

The shear stress in one thread is:

$$\tau_s = \frac{F_i}{A_s \, n} = 9028 \, psi \qquad (81)$$
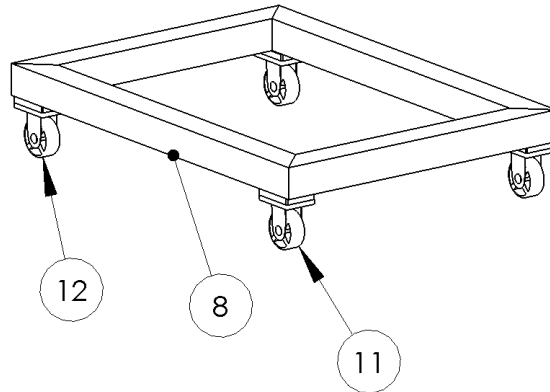
With n the number of threads engaged: $n = 5$

The safety ratio is: $\qquad \lambda = \frac{S_{ys}}{\tau_s} = 2.5 \qquad (82)$

with λ the safety ratio, S_{ys} the shear yield strength of aluminum 6061, τ_t the shear stress in the thread ($S_{ys} \approx 0.58 * Sy = 23142 \, psi$) $\qquad (83)$
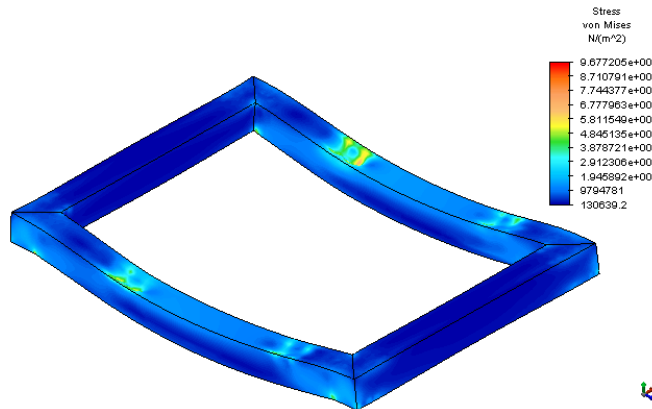
LIGO

6 The Cart

Cart Structure	D070589-00-D
-Cart Wheels Adaptors	D070591-00-D
-Cart Wheels	2487T65
-Cart Wheels with brake	2487T98

- Cart Structure

Tensile Yield Strength: $\sigma_{Yield} = 315\,\text{Mpa}$ (84)

FEA analysis provide a maximum stress of 97 Mpa.

Safety ratio: $\lambda = \dfrac{S_y}{\sigma_{max}} = 3.2$ (85)

- Wheels:

Number of wheels in parallel: $N = 4$ (86)

Work limit: $M_{lim} = 2500\,\text{pds}$ (87)

Safety ratio:

$$\lambda = \dfrac{N\,M_{lim}}{M_{ISI}} = 1.77$$ (88)