FEA Summary Report_1
For APA Shipping Frame

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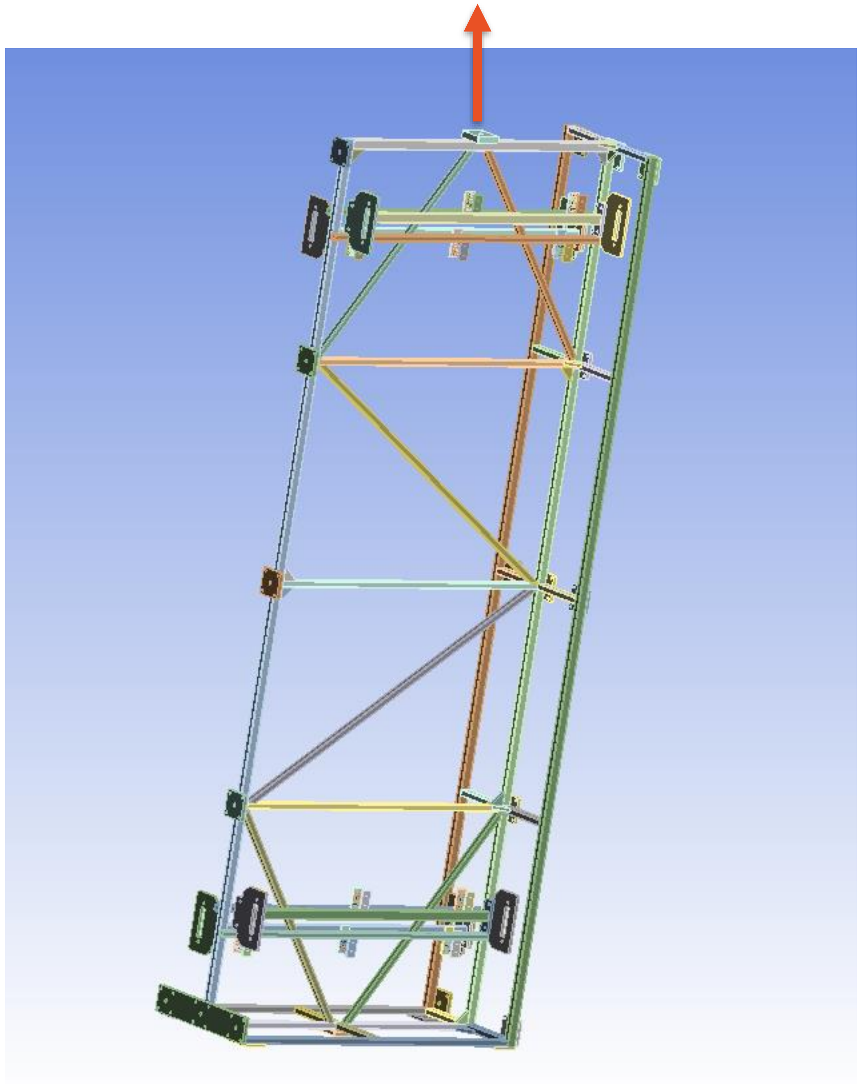
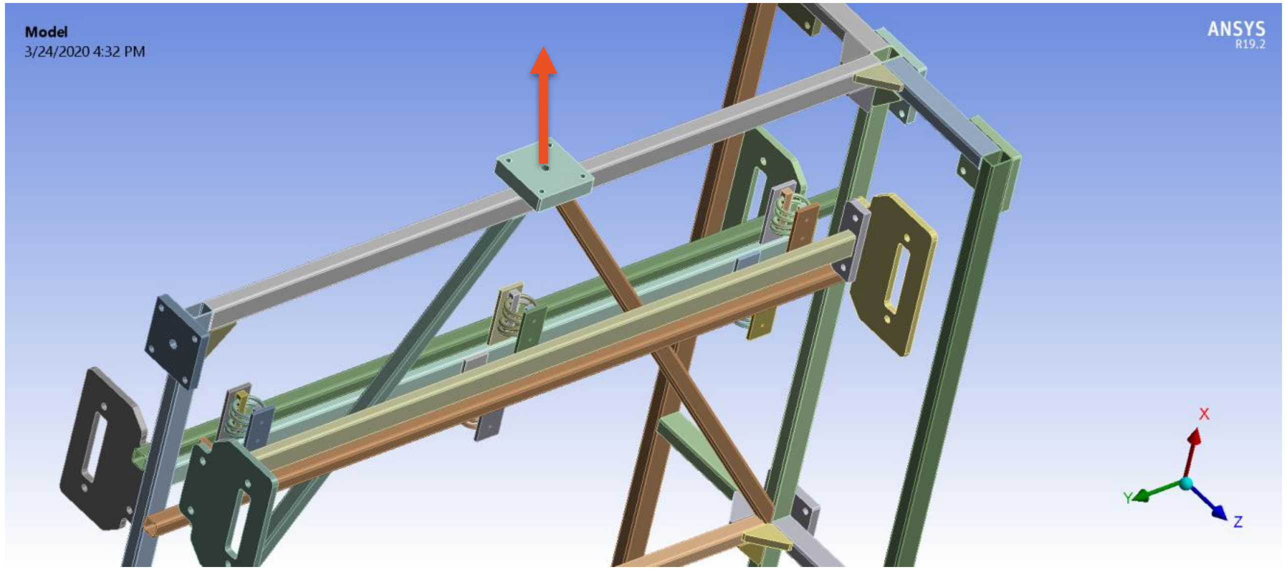
July 28, 2020

Summary of FEA Analysis for APA Shipping Frame

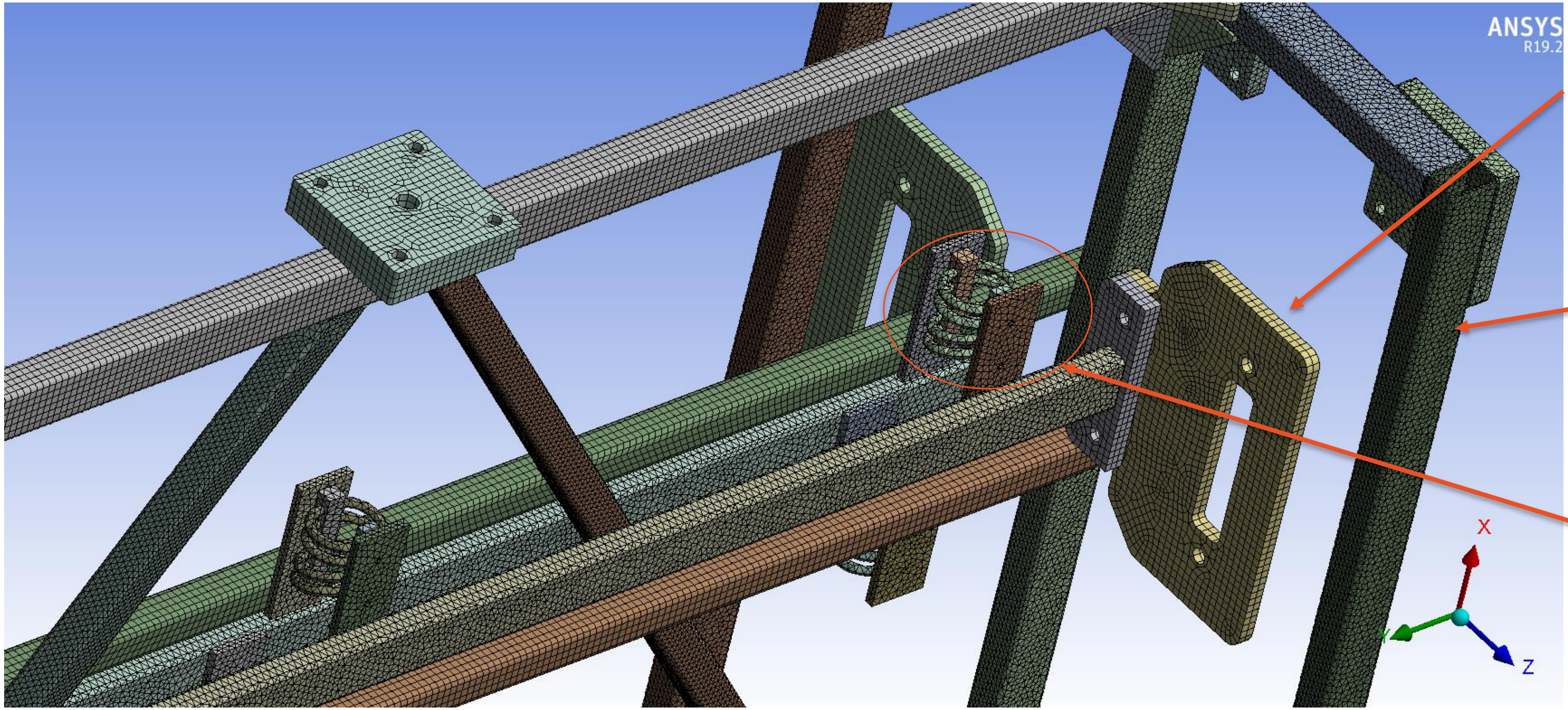




APA Shipping Frame mainly Consists of :

- S355 steel Tubing with S (yield)=355 MPa ; Su=470 MPa.
- Carbon steel plate.
- Shock Absorber _Wire Rope Isolator (WRI)

Summery of FEA Analysis for APA Shipping Frame



Steel Plate

Steel Tubing
3”x2”x1/8”
2”x2”x1/8”

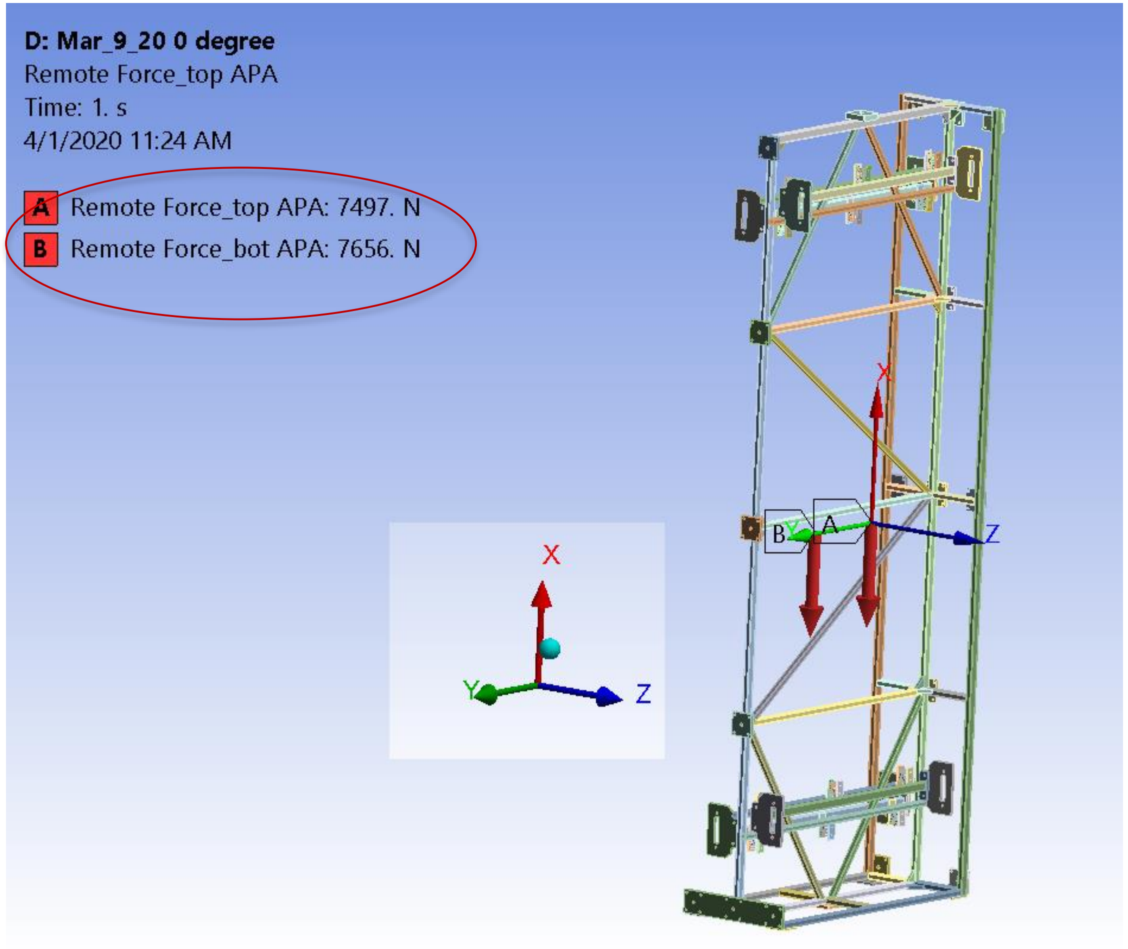
AVM Wire Shock Absorber

The solid Model is provided by George Stavrakis in STEP file format.
It is base on Version 1 of the drawing package https://edms.cern.ch/document/2368942/1

The ANSYS WB 19.2 is used for FEA analysis as shown above.

FEA Model: Loading and boundary condition

- STP file was imported into ANSYS WB 19.2. It is based on Version 1 of the drawing package https://edms.cern.ch/document/2368942/1. This EDMS folder includes the model, the technical drawings, and the center of mass calculations.
- The model is meshed with the solid element containing the middle node. The mesh size is ~10 mm which results a model of ~3.26 million nodes or ~10 million degree of freedom.
- The connection is treated as “bonded” with an exception of the “pin” connection area which is modeled as “slip joint”. The gigantic model requires some iterations to solve.
- The integrated APA mass is 562 kg (5.5 KN) for the upper one and 516 kg (5.1 KN) for the lower one respectively (EDMS #2281422). The FEA model uses 7497 (N) for the upper one and 7656 (N) for the lower one, as shown at right. It is modeled as the remote force scoped to the attachment plate where the APA is attached. It is a very conservative approach as it is analyzed without considering the stiffness of APA detector frame itself.
- The density of the steel frame has been modified to include the weight of frame itself and other components (for example, the protection panel and etc). The total weight of the structure is 31,840 (N), 3249 kg including both APAs and the shipping frame. This number has a ~25% or more contingency for further design iterations. It is an upper limit for the load.



Applicable Code used for FEA Analysis

- ASME BTH-1 Codes is used for the lifting device. It agrees with the *Compliance Office preliminary requirements_ Memorandum dated 2/11/2020 EDMS No.:2093094 for service class A.*

Table 2-3-1 Service Class

Service Class	Load Cycles
0	0–20,000
1	20,001–100,000
2	100,001–500,000
3	500,001–2,000,000
4	Over 2,000,000

2-2.1 Design Category A

(a) Design Category A should be designated when the magnitude and variation of loads applied to the lifter are predictable, where the loading and environmental conditions are accurately defined or not severe.

(b) Design Category A lifting devices shall be limited to Service Class 0.

(c) The nominal design factor for Design Category A shall be in accordance with para. 3-1.3.

3-1.3 Static Design Basis

3-1.3.1 Nominal Design Factors. The static strength design of a below-the-hook lifting device shall be based on the allowable stresses defined in sections 3-2 and 3-3. The minimum values of the nominal design factor, N_d, in the allowable stress equations shall be as follows:

N_d = 2.00 for Design Category A lifters
= 3.00 for Design Category B lifters
= 6.00 for Design Category C lifters

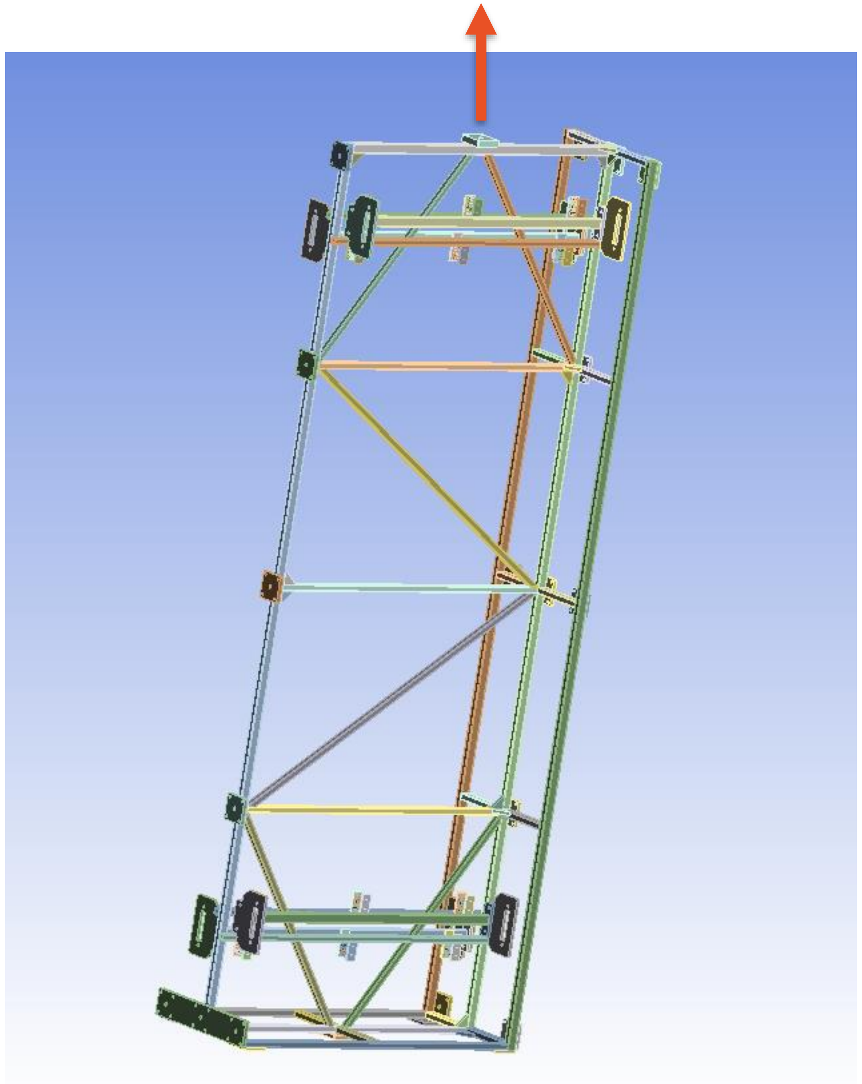
3-1.3.2 Other Design Conditions. Allowable stresses for design conditions not addressed herein shall be based on the following design factors:

(a) Design factors for Design Category A lifting devices shall be not less than 2.00 for limit states of yielding or buckling and 2.40 for limit states of fracture and for connection design.

Required (Safety factor) SF

ASME BTH-1 required

1) SF ≥ 2 for the structure member.
2) SF≥ 2.4 for the connections.
3) Above SF is respected to the yield stress of the material in use.
4) The shipping frame is made of S355 carbon steel, which has a yield stress of 355 MPa (~51.5 Ksi) and 470 MPa for its ultimate stress.
5) 7 (or more) possible configurations have been analysed.

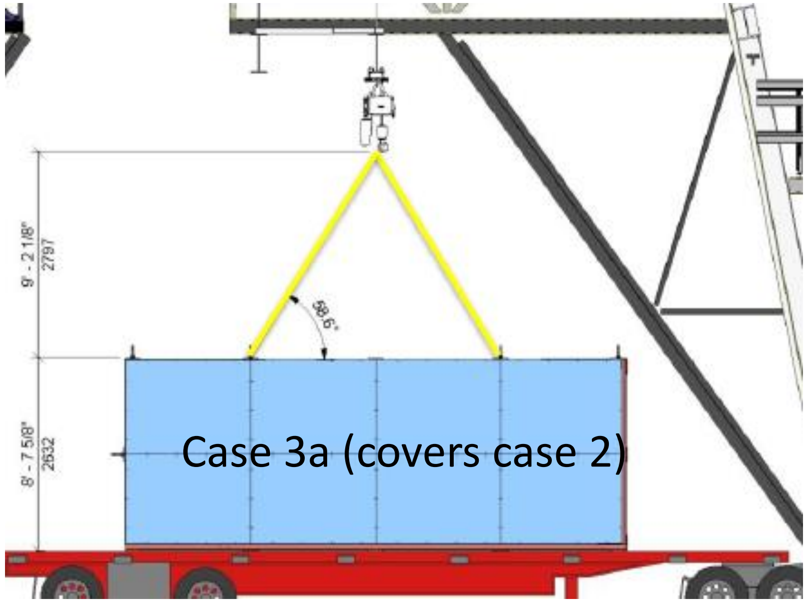


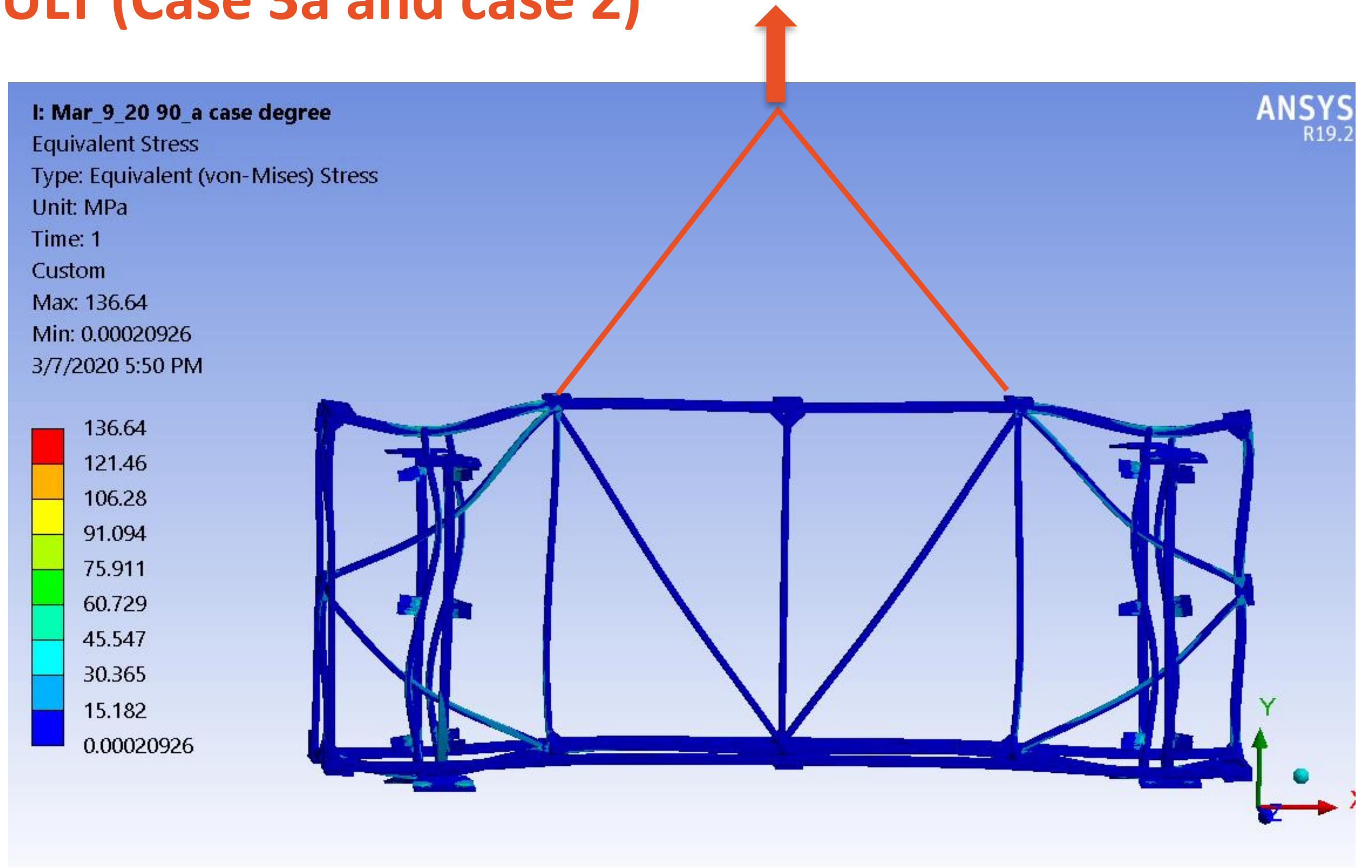
Load case study

- The load case 3,4 and 5 (total 7 configurations) are considered as the critical case to drive the design.
- We will go case by case in following pages

Transport frame Load Case	FEA Configuration	Status
1 _ Sitting on the factory floor	See case 3	Done
2 _ Lifting at the factory	See case 3	Done
3 _ Lifting in front of the Ross Shaft	Case 3a ,3b and 3c	Done
4 _ Lifting down the Ross Shaft	Case 4 (1 G and 2 G)	Done
5 _Lifting at the bottom of Ross shaft	Case 5a,5b,and 5c	Done
6_ On the underground trolley	The floor requirement from CF shows very smooth.	Done
7_ Lifting the frame vertical on a trolley	Similar to case 4 (Trolley weight is ~750 kg, it is still within 25% contingency).	Done
8_ Transport frame sitting in the vertical position	No worse than case 4	Done
9_ Additional case study for the attachment plate	Done	Done
10_ Additional case study for the attachment plate	Done	Done

FEA RESULT (Case 3a and case 2)



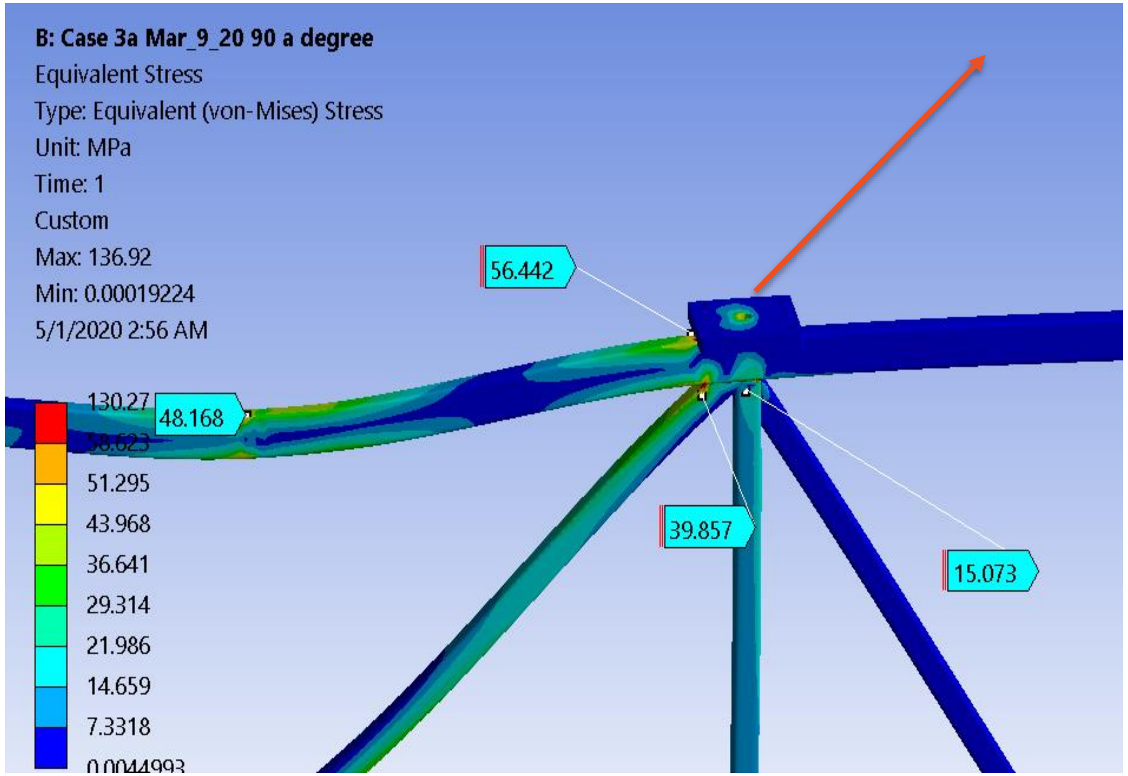


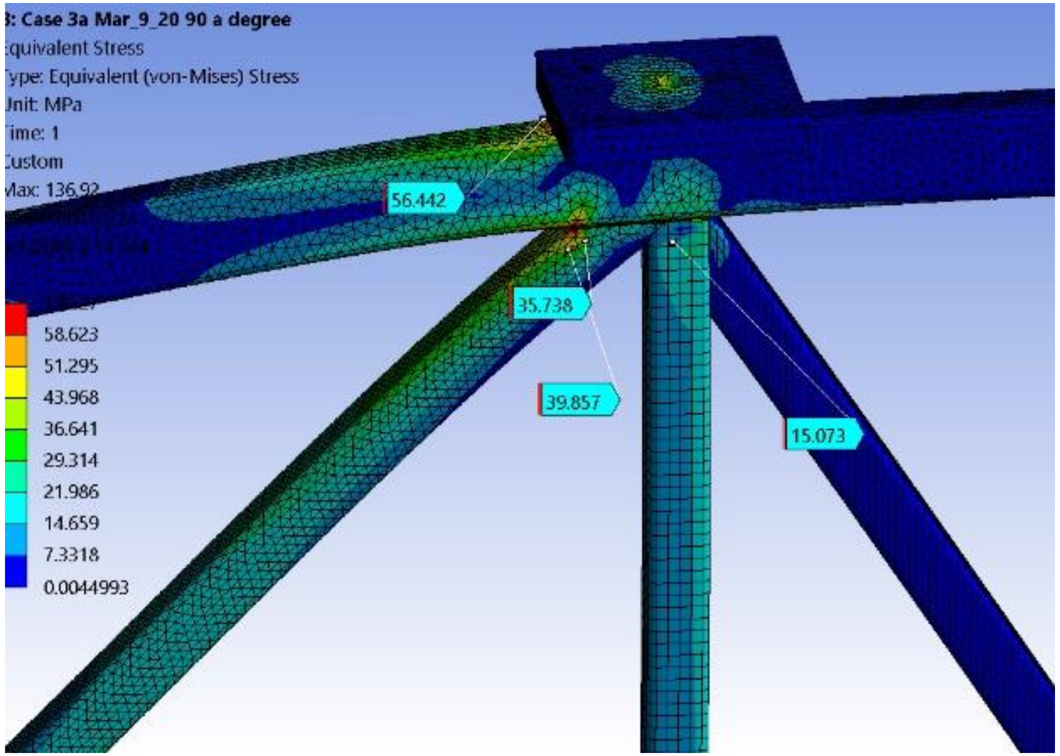
Above illustration is from Justin Freitag, January 24, 2020 report

Case 3a_ Stress (MPa)

SF=355/136.6=2.59>2

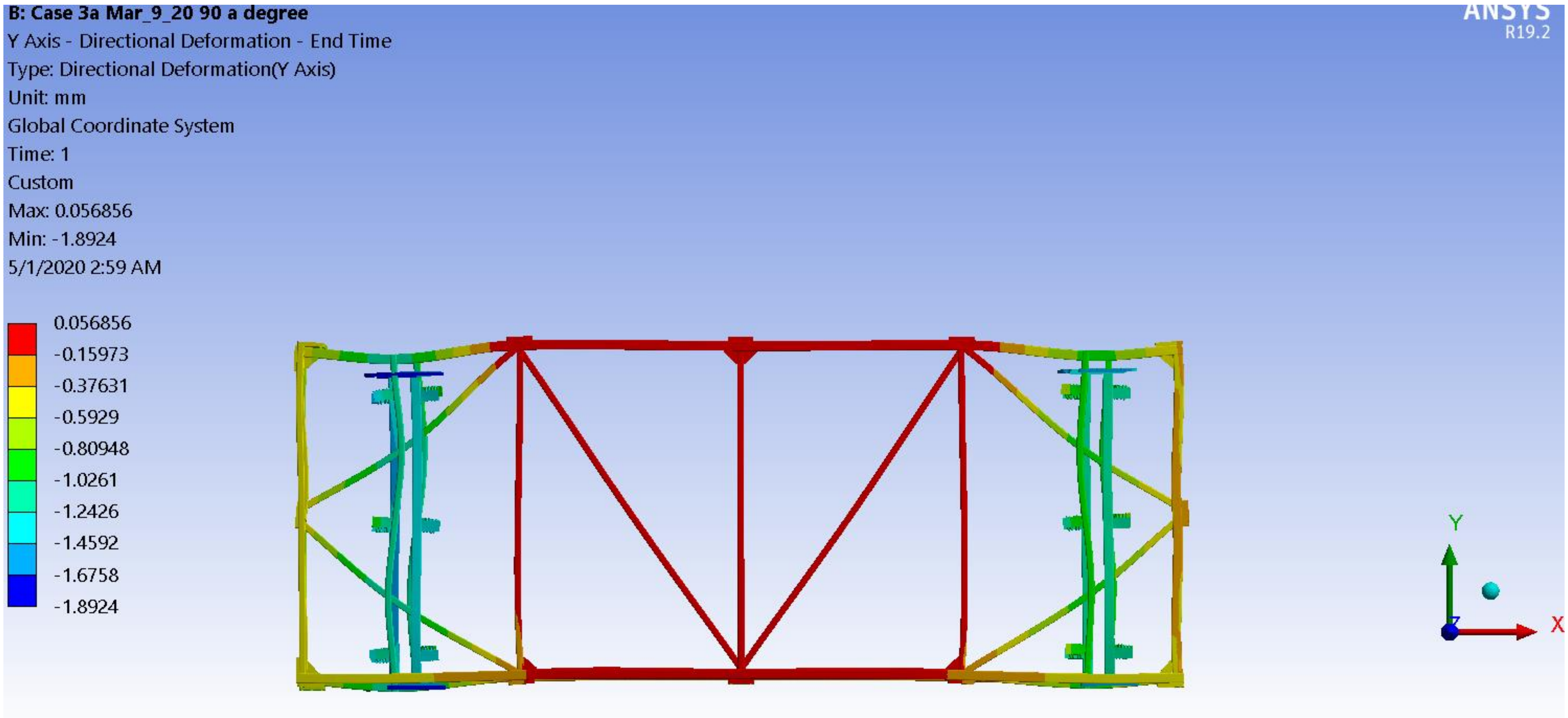
FEA RESULT (Case 3a and case 2)





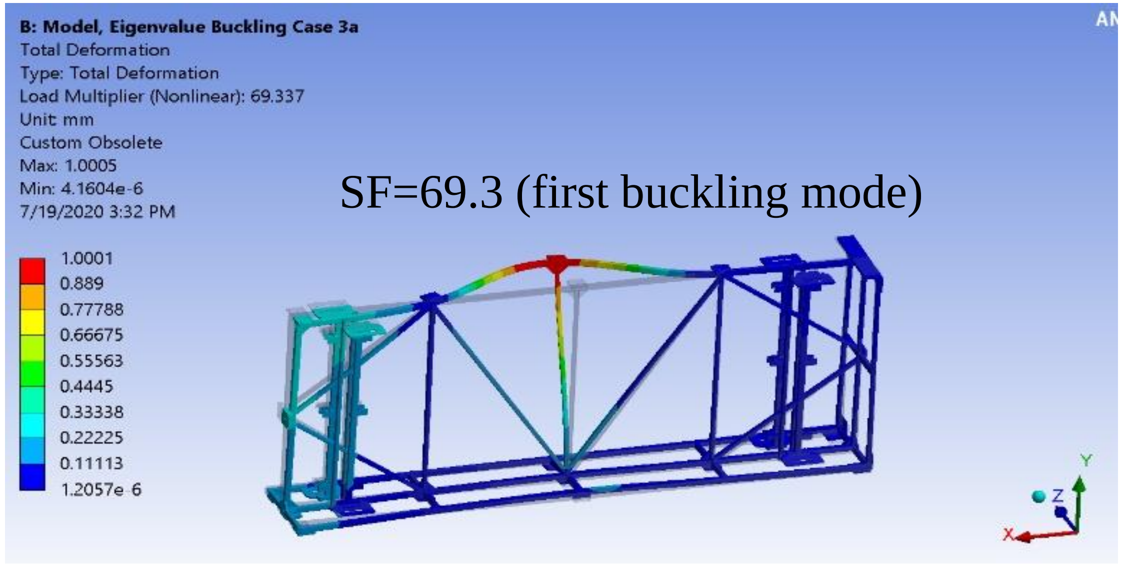
The stress around the lifting point is around 70 MPa
without considering stress concentration.

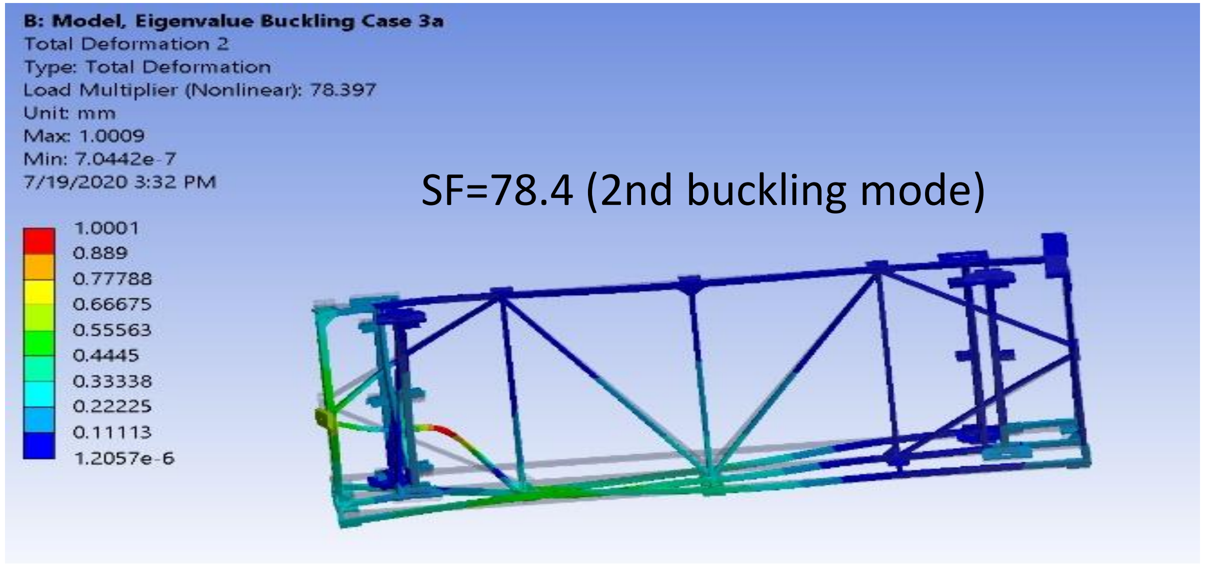
FEA RESULT (Case 3a and case 2)



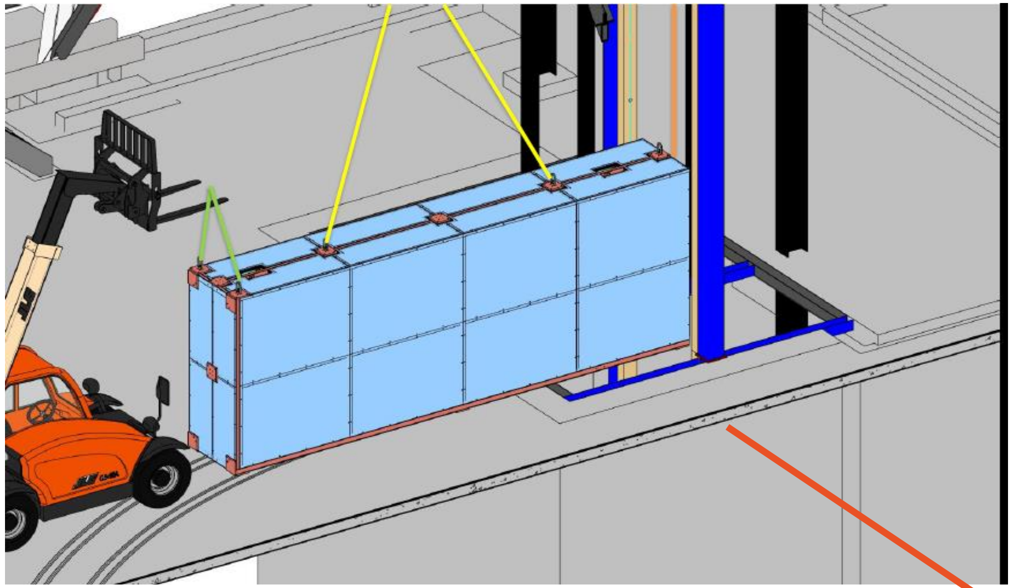
FEA RESULT (Case 3a)_ Buckling result SF min=69.

It is done without considering the stiffness contribution from the APA tubing



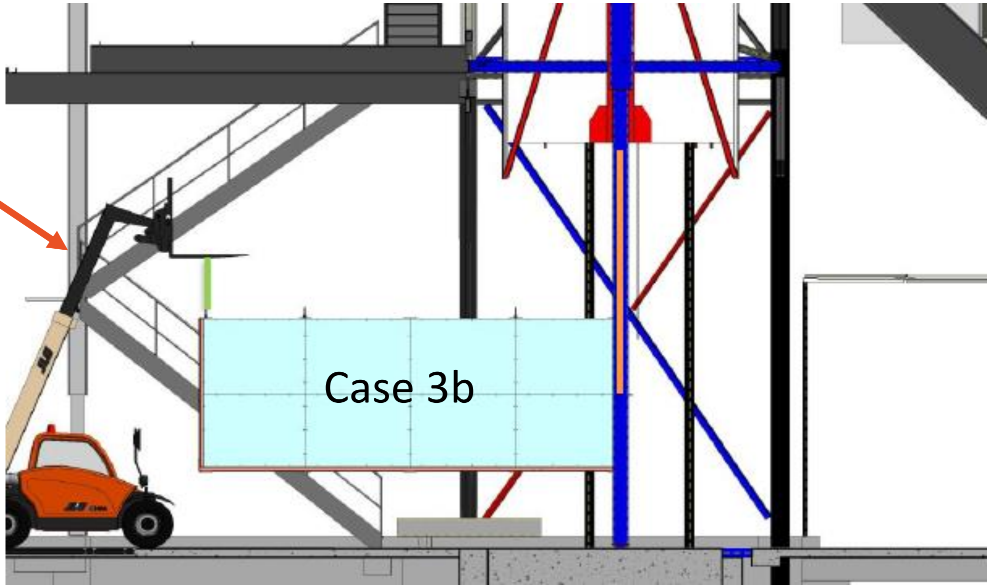


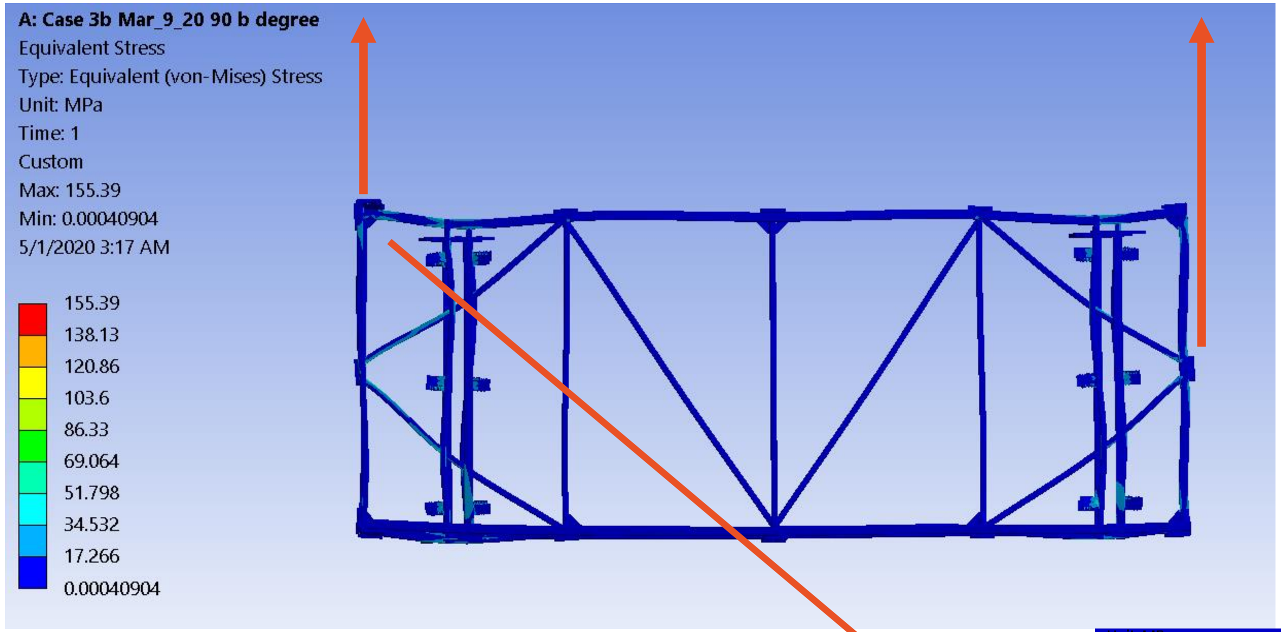
Fermilab DUNE



From Case 3a to Case 3b (just before the rotation start)

Case 3b



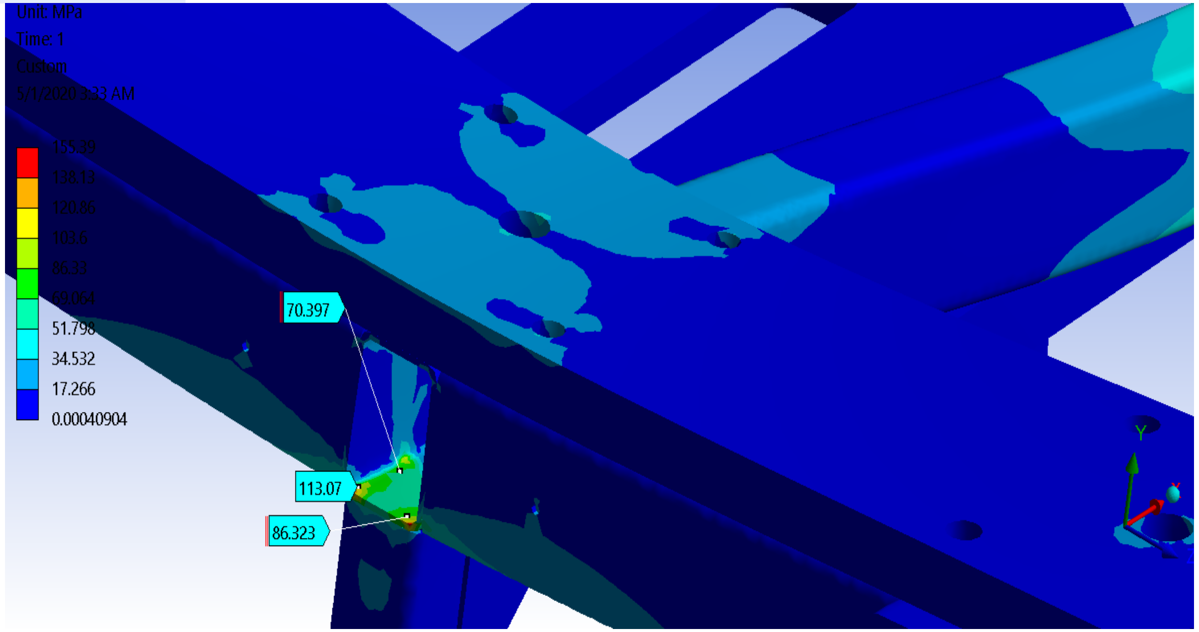


Case 3b

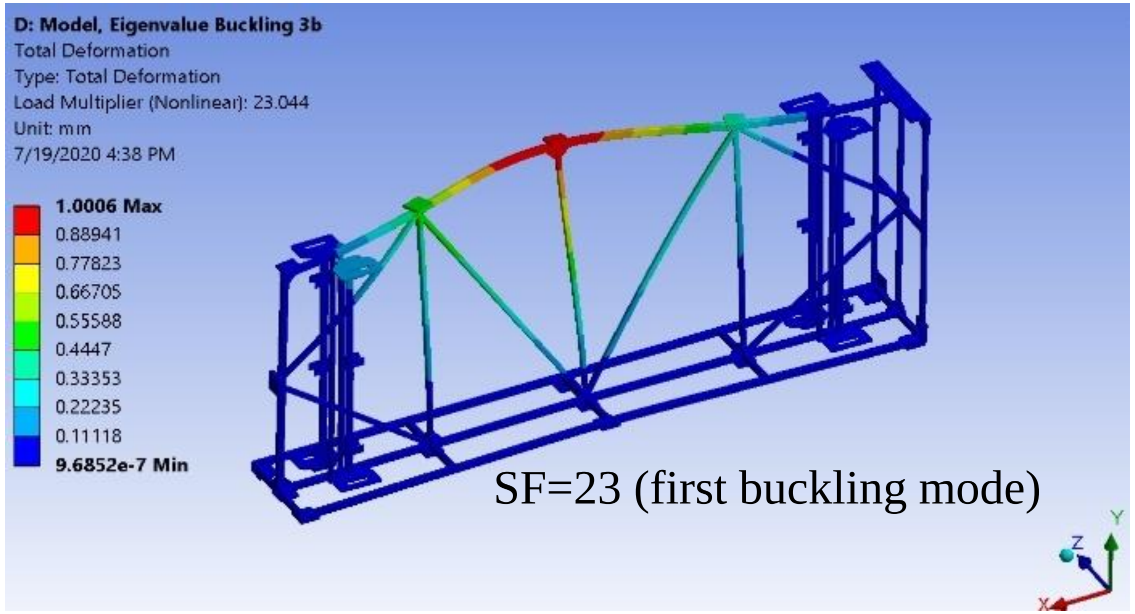
Just before to rotate

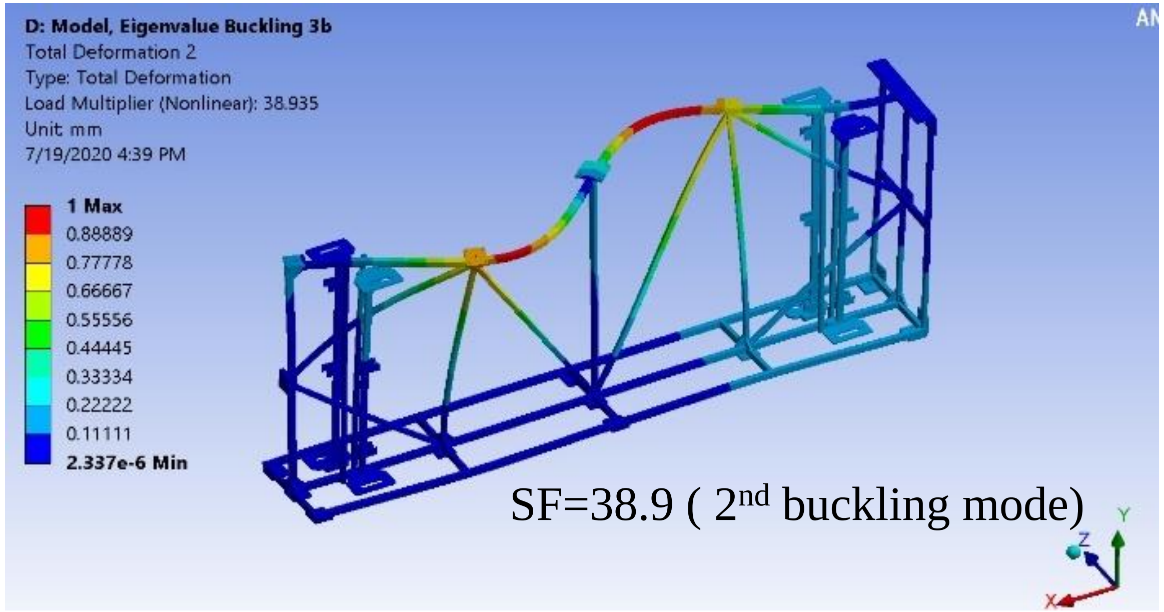
The stress (MPa) for case 3b.

Case 3b Stress MPa
SF=355/155.39=2.29

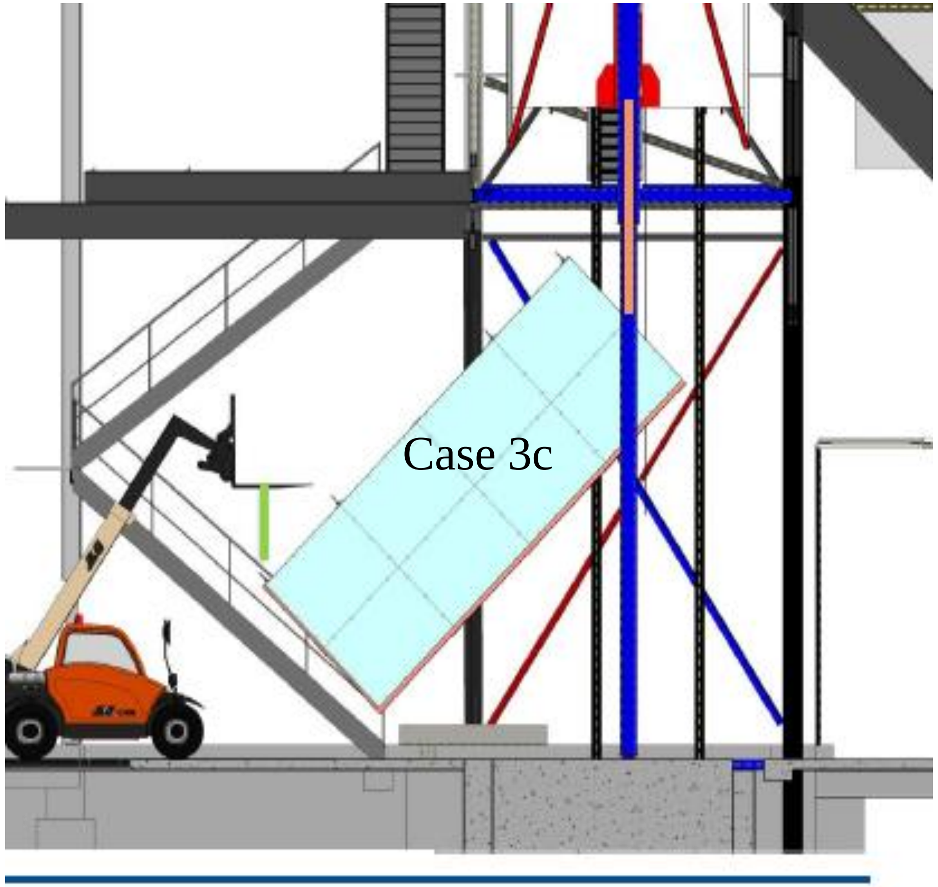


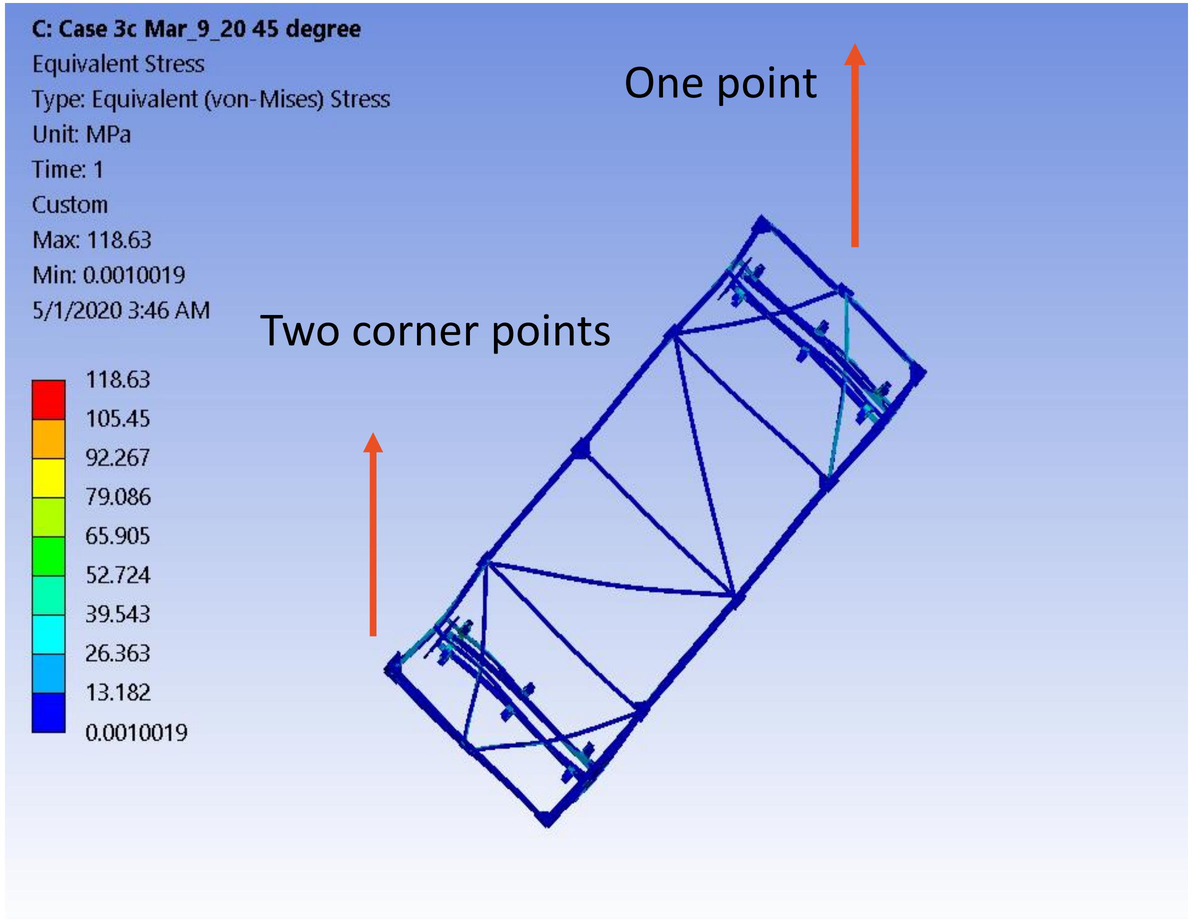
The buckling SF (min)=23 for case 3b



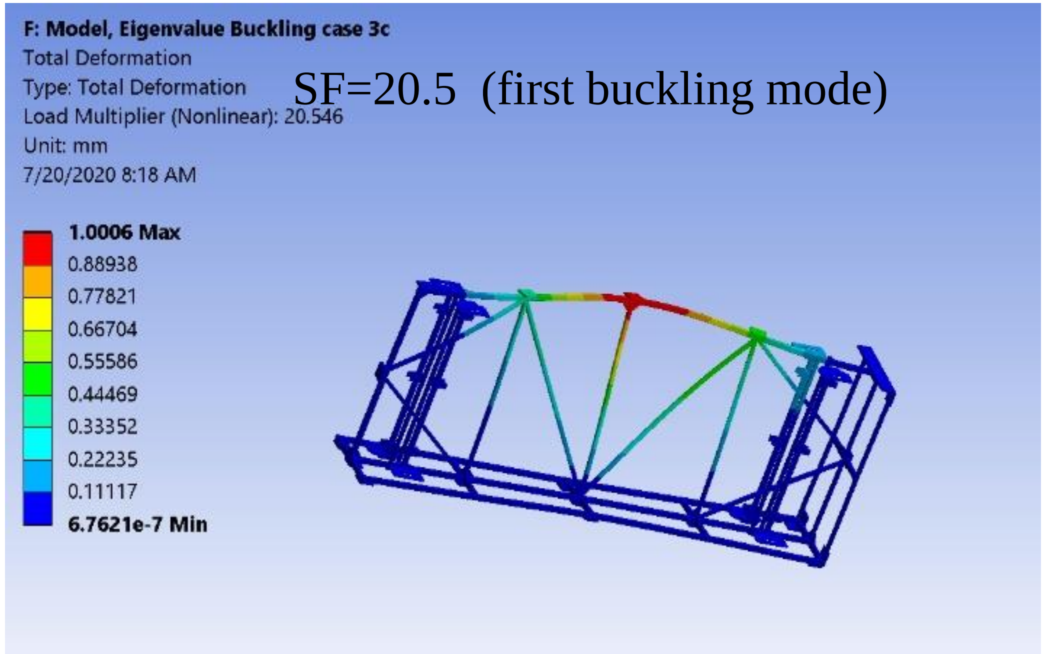


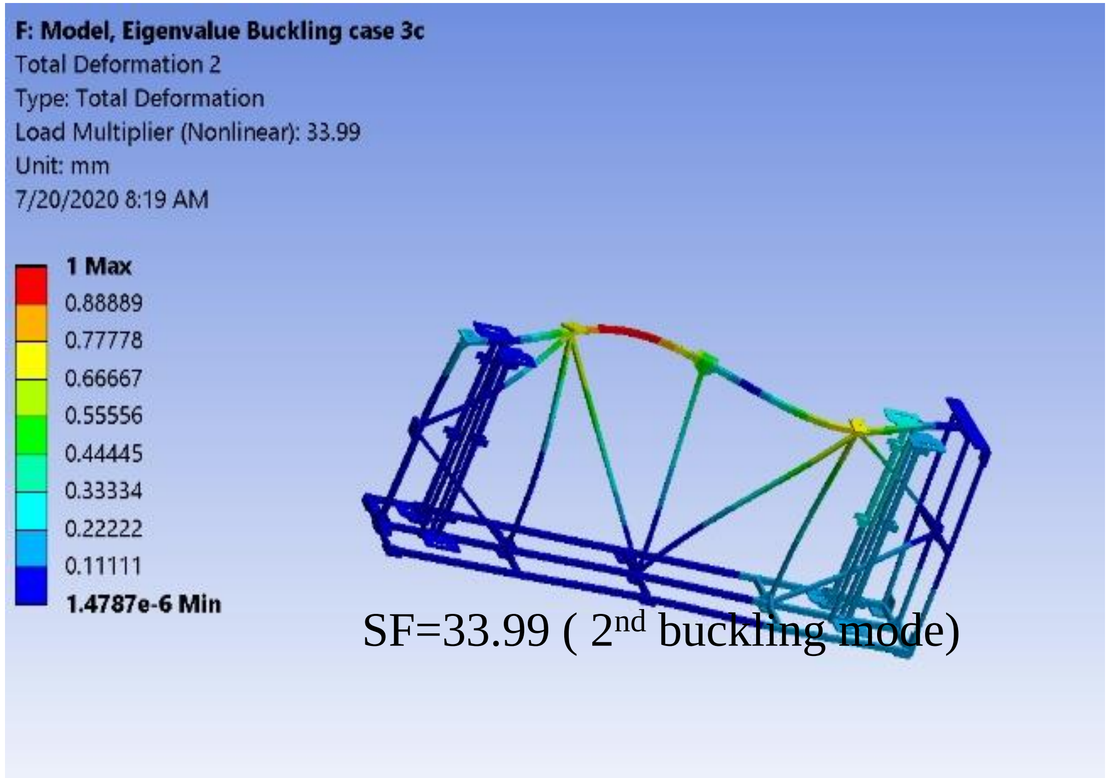
Case 3c Stress (MPa)
SF=355/118.63=2.99





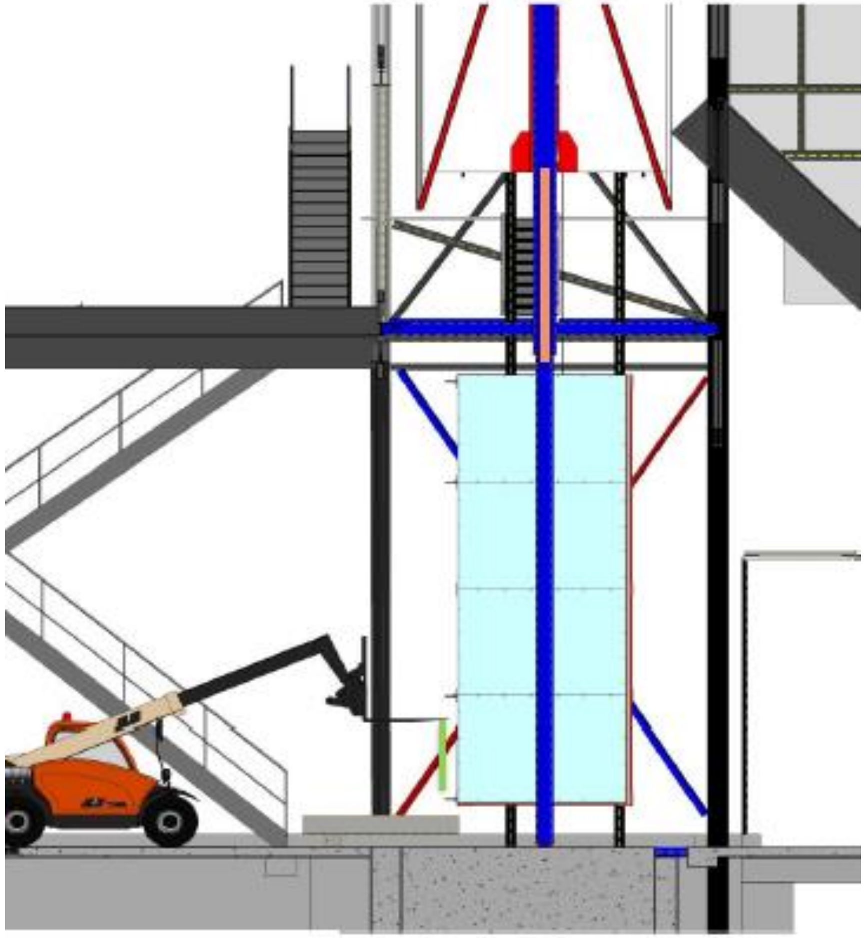
The buckling SF (min)=20.5 for case 3c

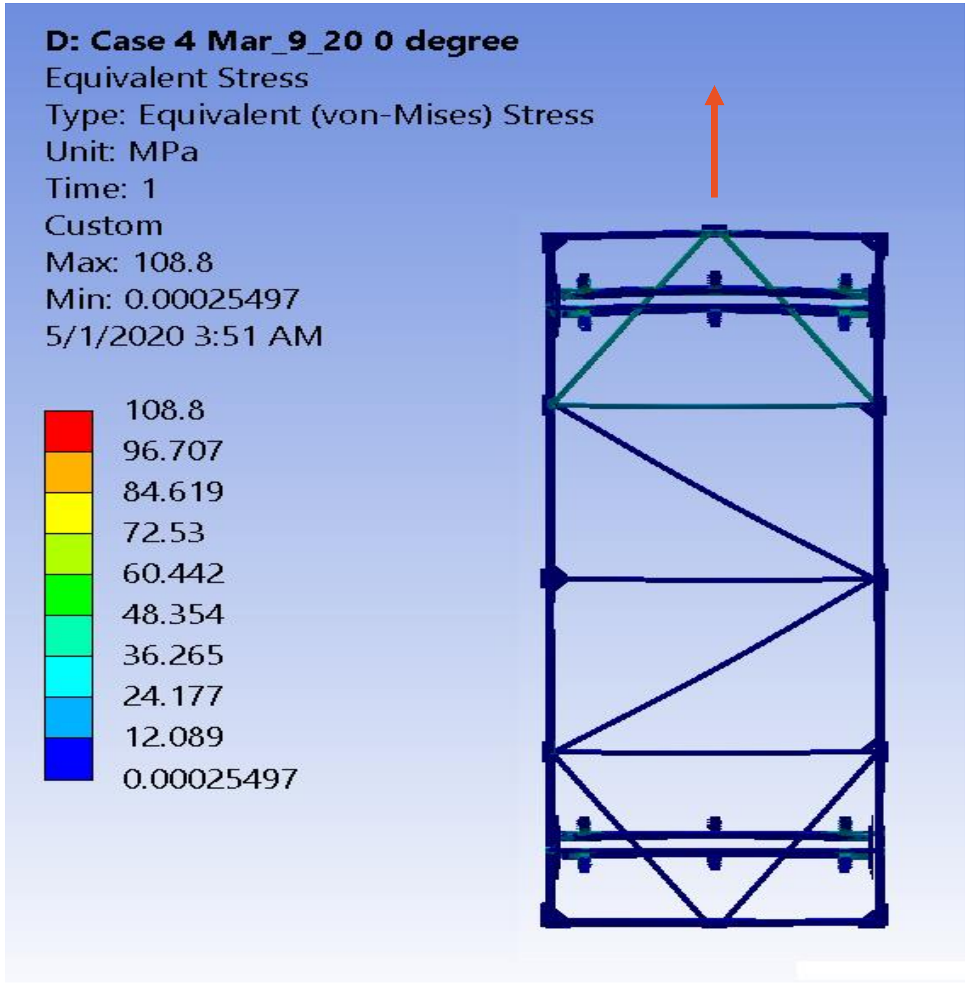




Case 4 Vertical position

F=31840 N=3249 Kg

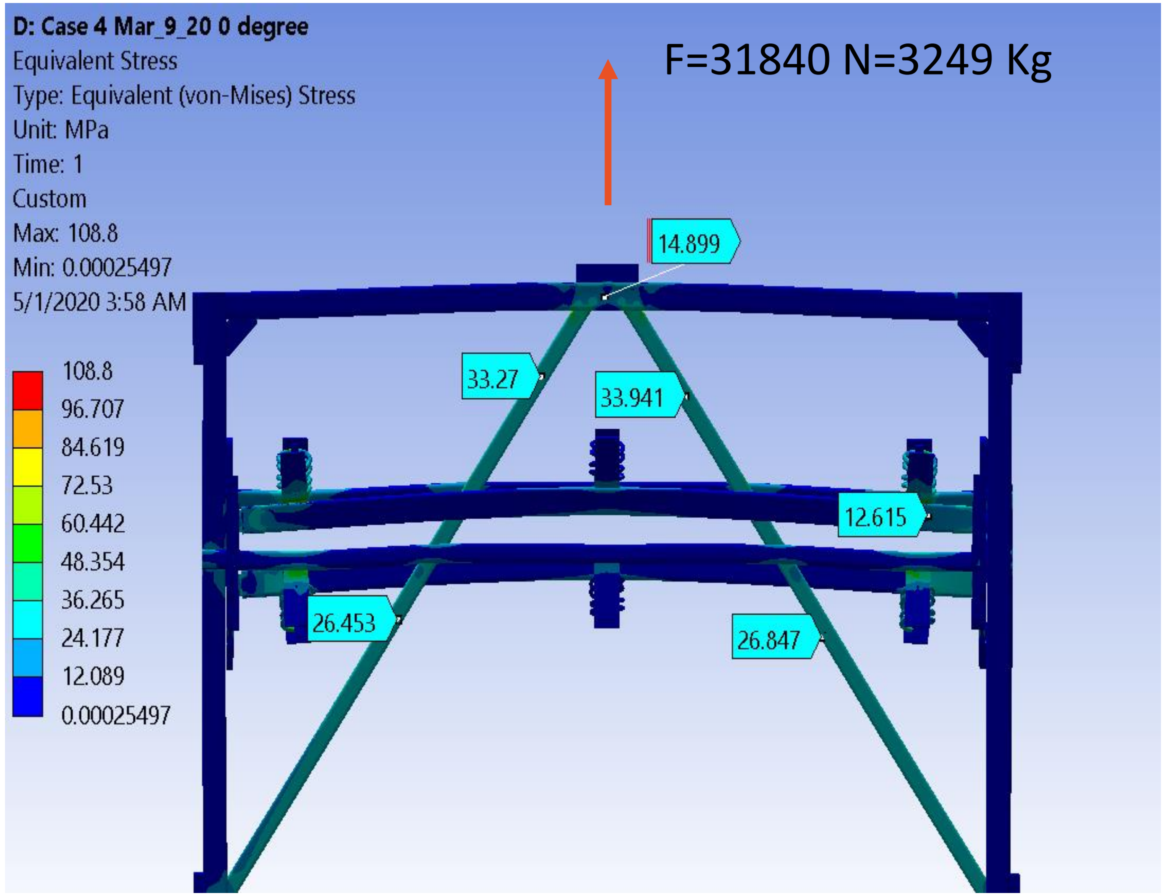




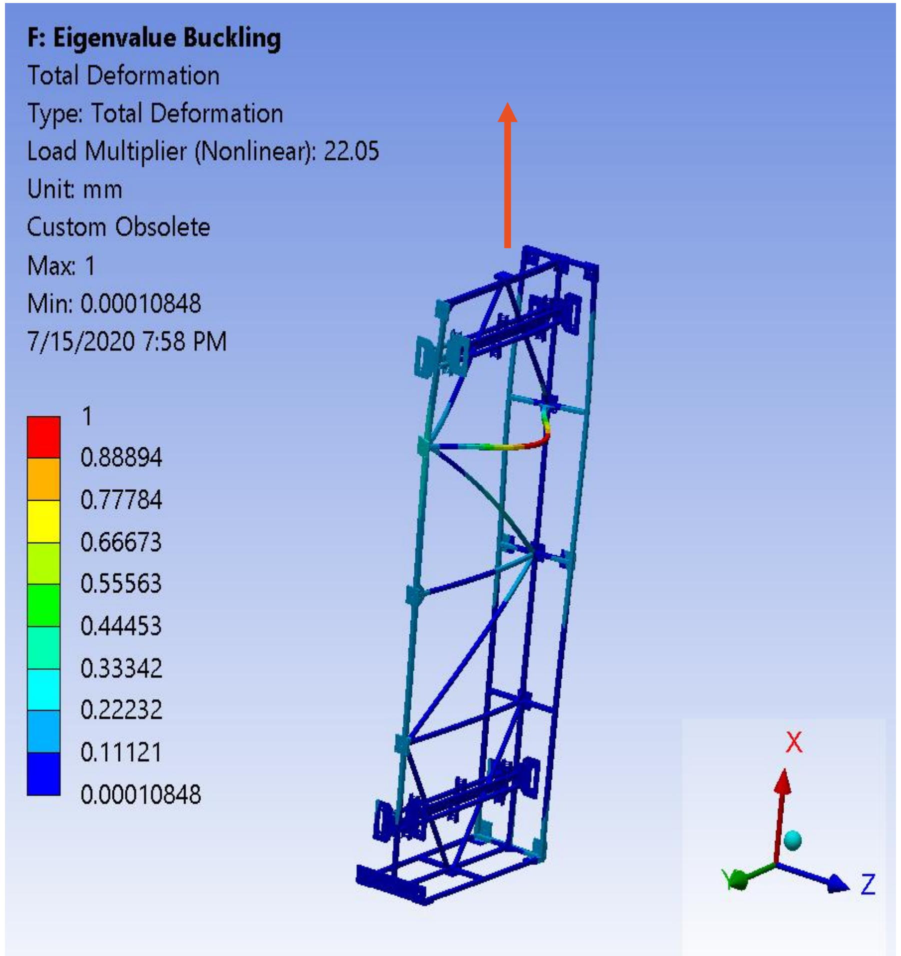
Case 4 Vertical stress (MPa); SF=355/108.90=3.26

Finished 1st rotation (from Horizontal to Vertical)

Buckling SF for Case 4

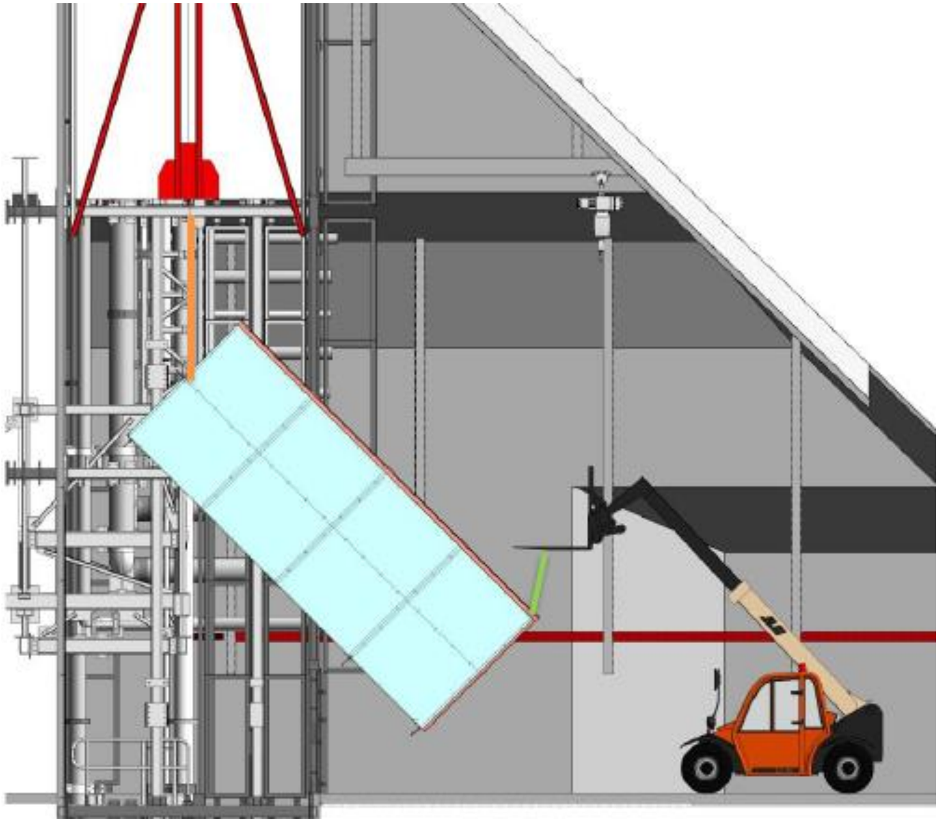


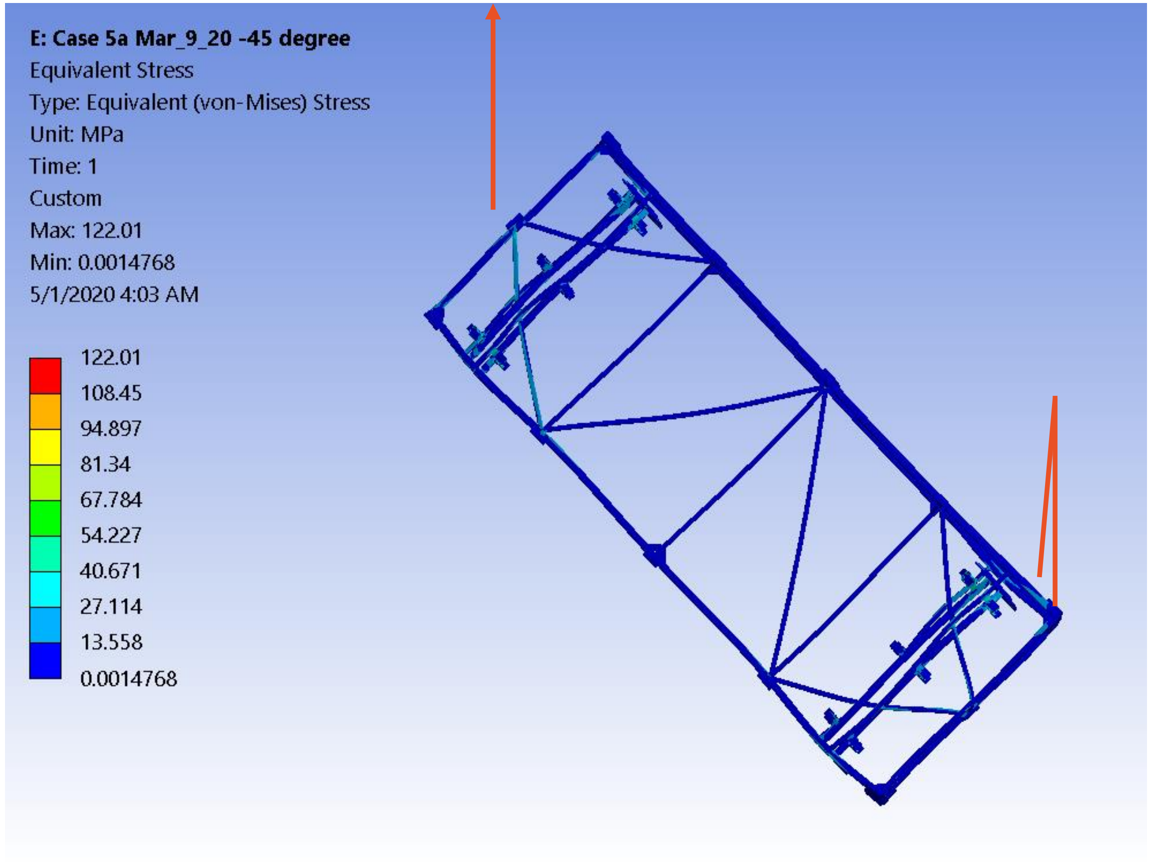
Stress (MPa) at the top section



The buckling SF (min)=22 for case 4

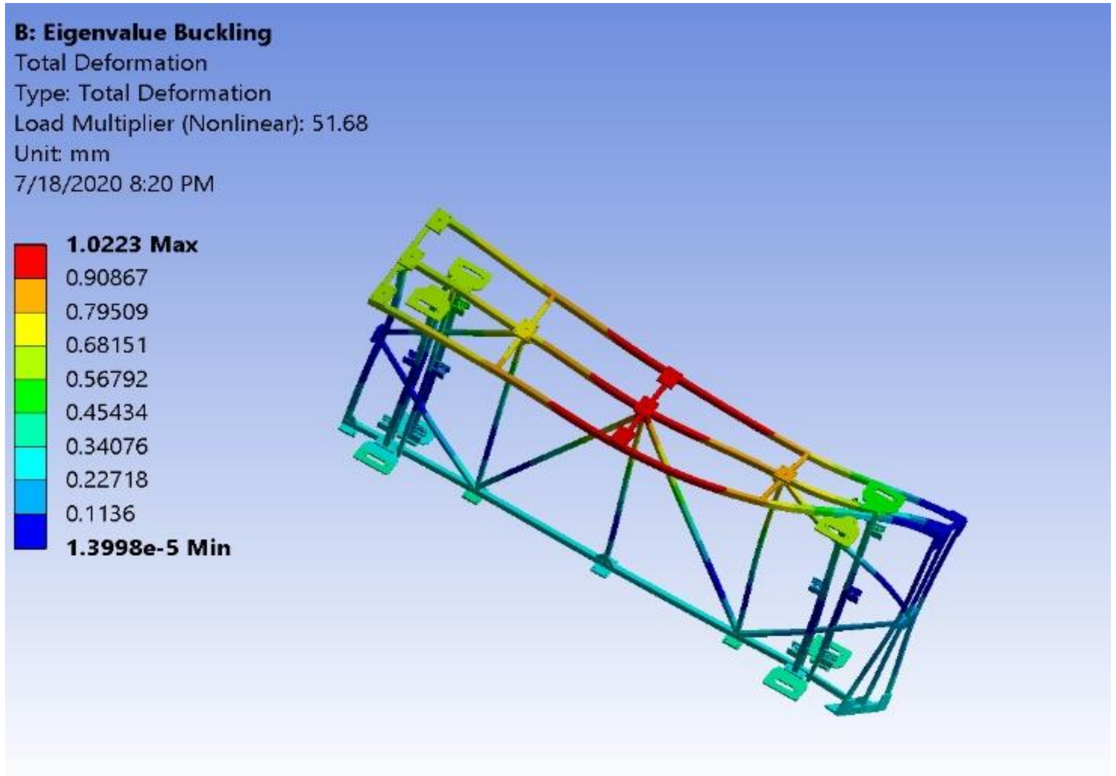
Case 5a _ Second rotation



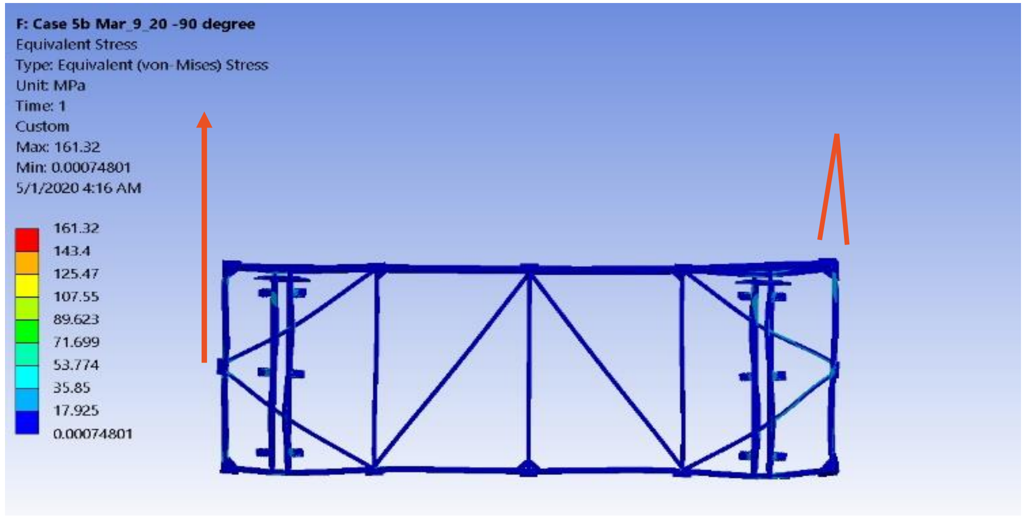


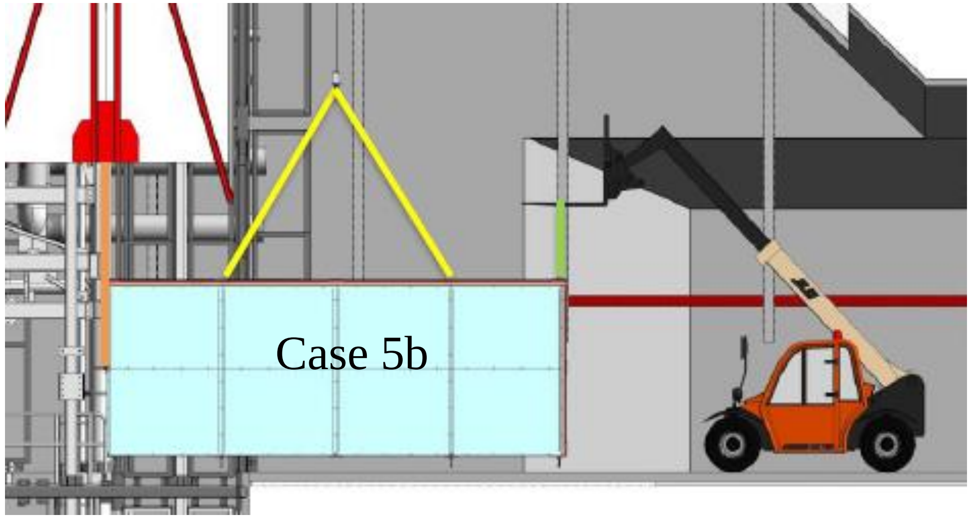
Case 5a The Second rotation (45 degree) Stress MPa;
SF=355/122.01=2.91 (Second rotation)

The buckling SF (min)=51.68 for case 5a

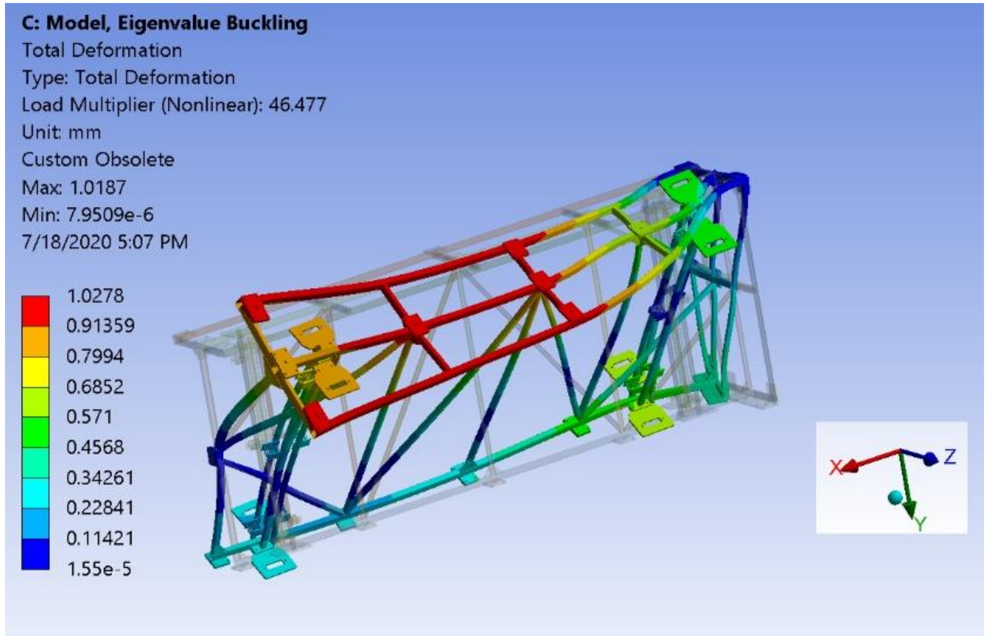


Case 5b Stress (MPa); SF (min) = 355/161.32 = 2.20.
(Just before the yellow sling to picked up the frame)

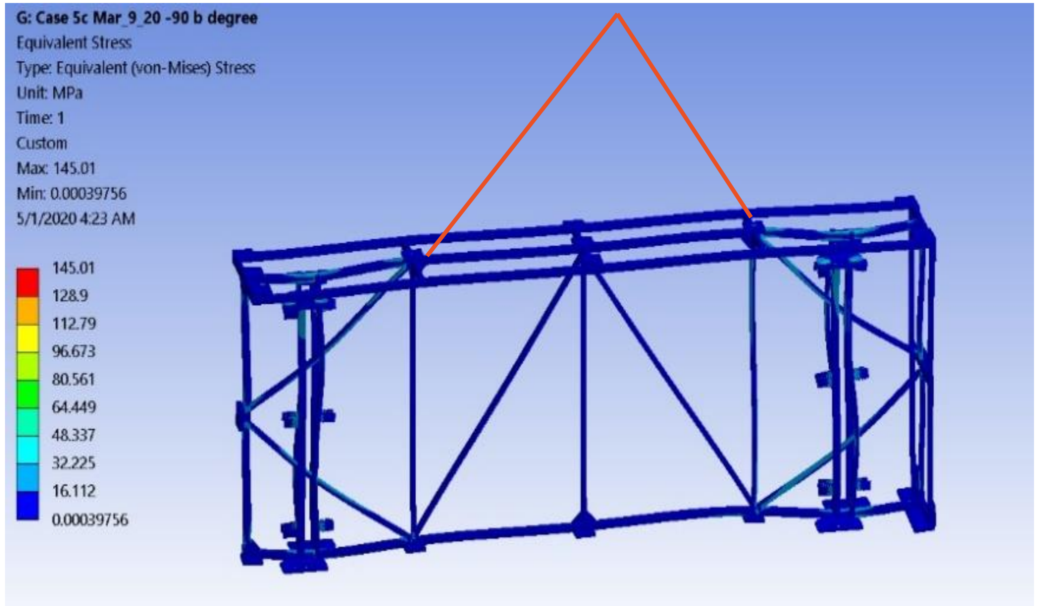


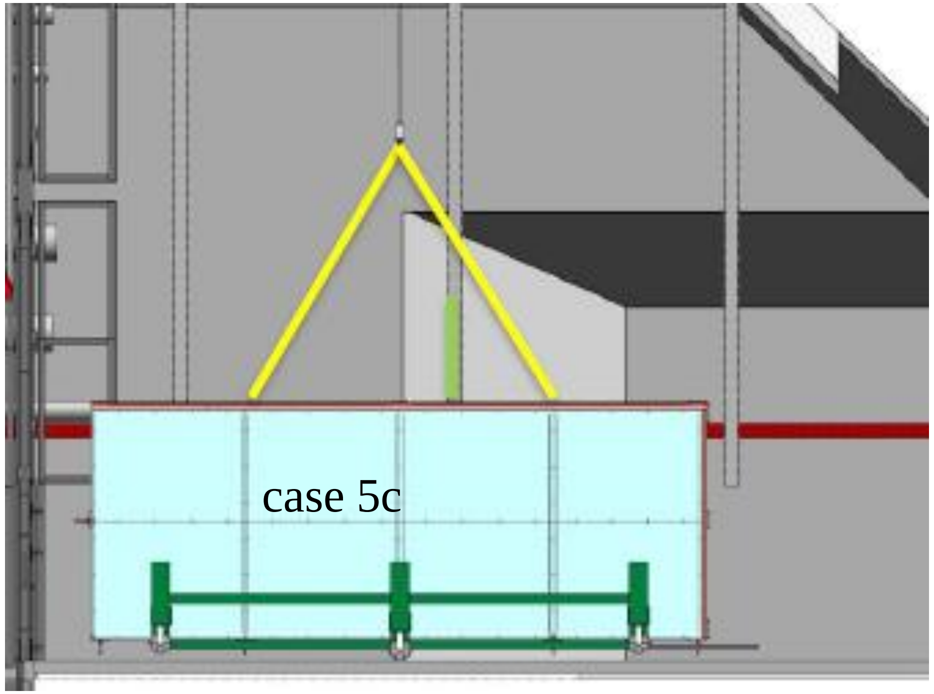


The buckling SF (min)=46.7 for case 5b



Case 5c Stress (MPa); SF=355/145.01=2.45





The buckling SF (min)=20.1 for case 5c

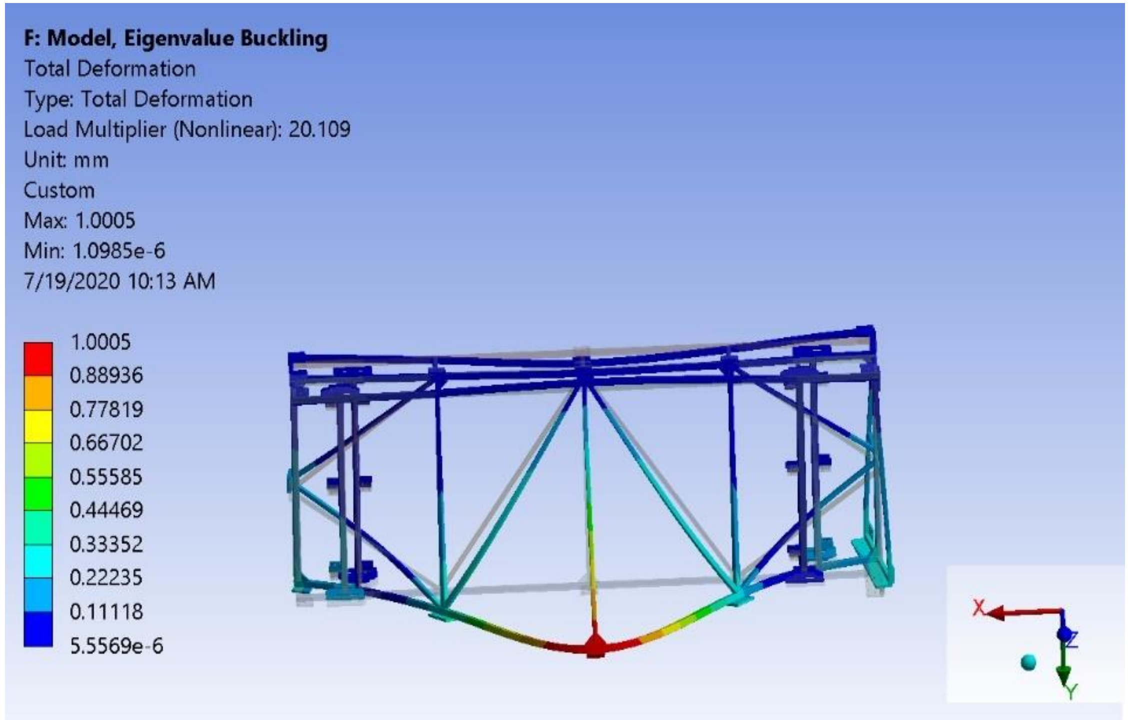


Table 2 - Summary of the results of the lift case analysis

Case	7 Configurations (Critical conditions)	Pick up points	Peak Stress (MPa)	SF (min) For the frame	BTH-1 req satisfaction	SF Buckling
3a = 2	Landscape Mode	2	136.92	2.59	Y	69.3
3b	Landscape Mode	3	155.39	2.28	Y	23
3c	45 degree _1st rotation	3	118.63	2.99	Y	20.5
4	Vertical position	3	108.80	3.26	Y	22.05
5a	45 degree _2nd rotation	3	122.01	2.90	Y	51.6
5b	Landscape Mode upside down	3	161.32	2.20	Y	46.5
5c	Landscape Mode upside down	2	145.01	2.45	Y	20.1

Case study conclusions

- Analysis of all 7 lifting configurations at SURF is summarized in Table 2.
- The shipping frame structure is more than adequate to satisfy the ASME BTH-1 requirement of SF (min) ≥ 2 based on the yield strength.
- For the case of the accident (2G load), the stress of the frame structure will remain below the yield stress of 355 MPa by (resultant stress x 2 < 355 MPa).
- SF of the buckling is more than adequate to resist the frame instability.
- The analysis is done without considering the stiffness of the APA frame (stainless steel tubing 4”x4”x1/8”). The actual stress will be lower than analyzed. The buckling SF will be much higher than calculated above as well.
- Weld stress needs to be checked. It is difficult task. So many welds and so many cases. The connection force and moment are extracted from FEA model. The weld stress is calculated according BTH code requirement for Nd=2.4 minimum.

Weld Stress Study

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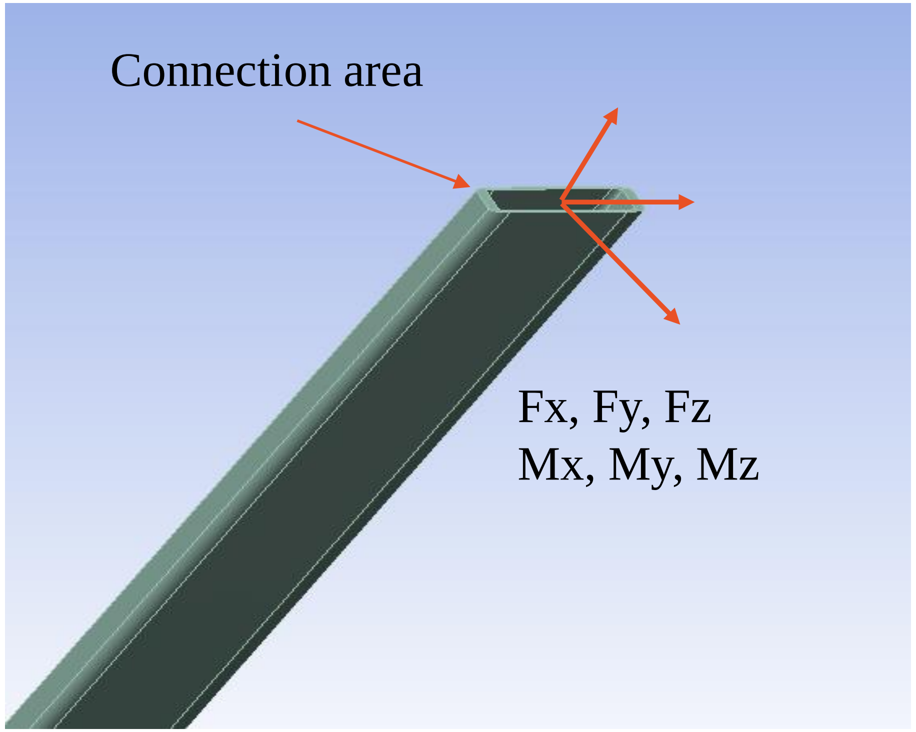


3-2.5 Combined Normal and Shear Stresses

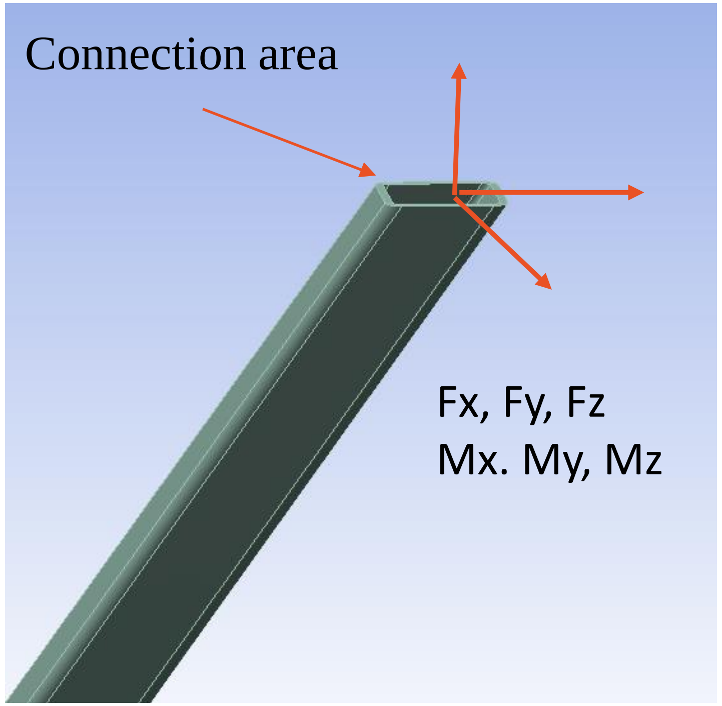
Regions of members subject to combined normal and shear stresses shall be proportioned such that the critical stress f_{cr} computed with eq. (3-37) does not exceed the allowable stress F_{cr} defined in the equation.

$$f_{cr} = \sqrt{f_x^2 - f_x f_y + f_y^2 + 3f_v^2} \le F_{cr} = \frac{F_y}{N_d} \qquad (3\text{-}37)$$

The resultant force is extracted at the connection, where Fy=355 MPa (parent material yield strength) and Nd=2.4 in above equation 3-37

Weld stress study

- Extracting the force (Fx, Fy and Fz) and moment (Mx, My and Mz) at each connection as illustrated. Both normal and shear stress are calculated based on the given weld size (3.2 mm).
- The combined stress is obtained based on BTH-1 code Eq (3-37). A complete detailed list for all 7 load cases is included in Appendix. All weld connections exceed the code requirement of SF(Nd)>2.4.
- It is noteworthy to mention that the connection between the 30 mm/50 mm plates and 3.2 mm wall thickness tubing requires a transition weld to satisfy BTH-1 section of 3-3.4.3 and table 3-3.4.3-1 requirement. A cheek plate design has been proposed. This solution is being validated by a BTH-qualified vender. However, the current analysis uses a minimum weld thickness of 3.2 mm. There is no further calculation is needed at this moment.



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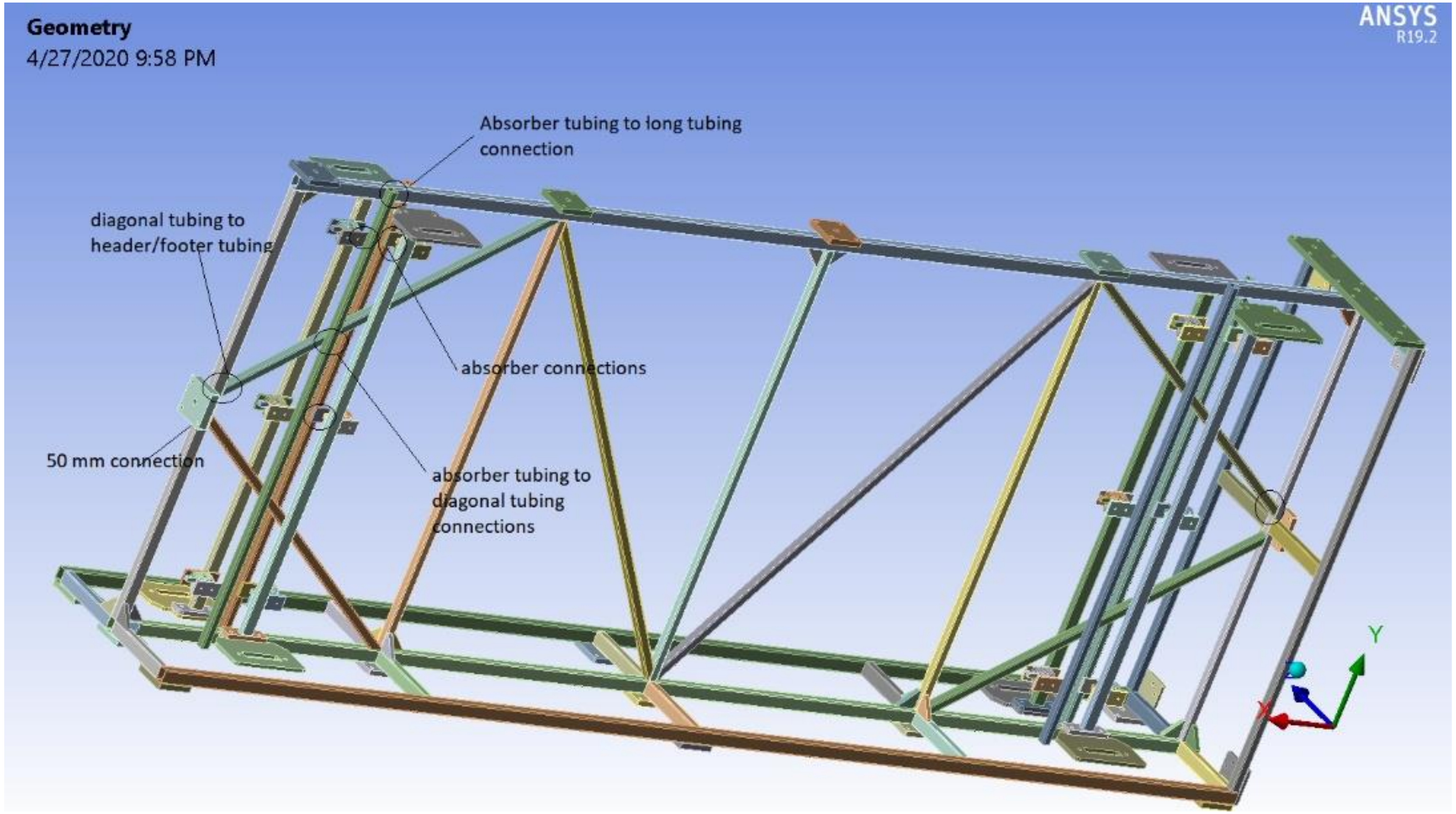
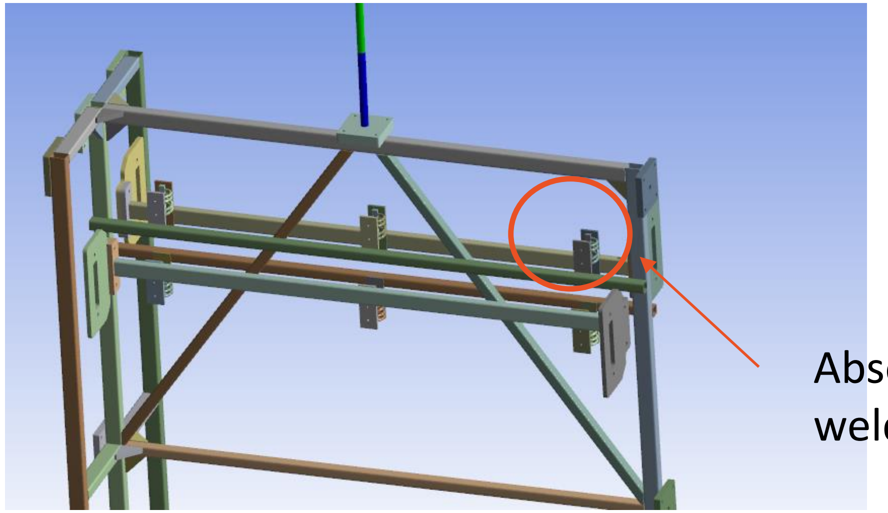
Examples of some critical weld along the load path





Absorber has 12 weld connections

BTH equation (3-37)

3-2.5 Combined Normal and Shear Stresses

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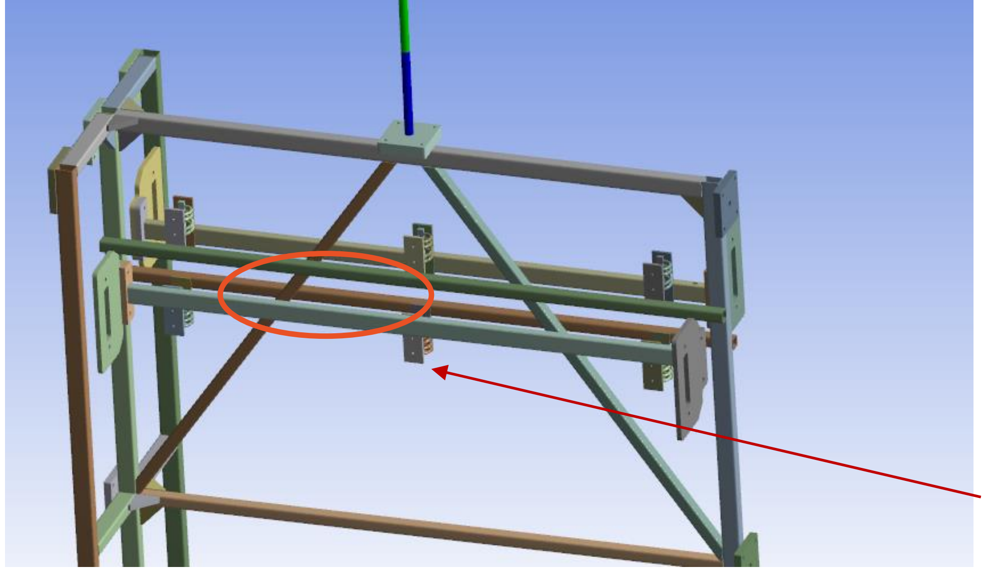
$$f_{cr} = \sqrt{f_x^2 - f_x f_y + f_y^2 + 3f_v^2} \le F_{cr} = \frac{F_y}{N_d} \qquad (3\text{-}37)$$

Weld SIZE		width		effective width	DY1	DX1	DY2	DX2	AREA	IXX	IYY	IZZ	Rmax		Combine force	
		3.20		2.26	80.00	31.80	86.40	38.20	756.48	696362.60	186966.49	883329.09	47.23			
absorber Plate	Fx	Fy	Fz	Mx	My	Mz	(MPa)	Sz_n	Sy+Sx_s	Smx_n	Smy_n	Smz_s	Sn_sub	S_shear	Scombined	**SF**
1.00	2363.3	-379.7	-185.86	32017.92	116499.44	-65662.68		0.25	3.16	1.99	11.90	3.51	14.13	6.68	18.26	**19.44**
2.00	926.31	33.85	-53.06	5093.2	50904.84	3775.08		0.07	1.23	0.32	5.20	0.20	5.59	1.43	6.11	**58.11**
3.00	2289.4	358.1	-215.87	4220.2	111375.47	57553.54		0.29	3.06	0.26	11.38	3.08	11.92	6.14	15.98	**22.22**
4.00	2625.45	176.52	181.42	32212.32	-124464.63	-47357.54		0.24	3.48	2.00	-12.71	2.53	-10.48	6.01	14.77	**24.04**
5.00	800.39	-24.82	-10.99	4432.57	-47243.13	3009.6		0.01	1.06	0.27	-4.83	0.16	-4.54	1.22	5.00	**70.94**
6.00	2535.7	-138.05	292.53	-340.93	-110788.37	34864.15		0.39	3.36	-0.02	-11.32	1.86	-10.95	5.22	14.20	**24.99**
7.00	1961.97	361.99	-184.12	29635.45	-99984.01	-58186.26		0.24	2.64	1.84	-10.21	3.11	-8.13	5.75	12.86	**27.61**
8.00	488.84	-14.72	132.05	2246.25	-11272.66	2067.59		0.17	0.65	0.14	-1.15	0.11	-0.84	0.76	1.56	**228.15**
9.00	1970.63	-358.78	-225.14	205.66	-98502.28	55613.52		0.30	2.65	0.01	-10.06	2.97	-9.75	5.62	13.78	**25.76**
10.00	2123.27	-158.9	190.08	26514.74	101074.73	-40796.33		0.25	2.81	1.64	10.33	2.18	12.22	5.00	14.98	**23.71**
11.00	446.06	8.71	401.75	2177.47	14178.69	1934.41		0.53	0.59	0.14	1.45	0.10	2.11	0.69	2.43	**145.99**
12.00	2123.39	130.72	289.21	-1373.42	94353.87	33392.83		0.38	2.81	-0.09	9.64	1.79	9.94	4.60	12.73	**27.88**
															SF (min)	**19.44**

> 2.4 (per ASME BTH -1 requirement)

Weld stress at the vertical position

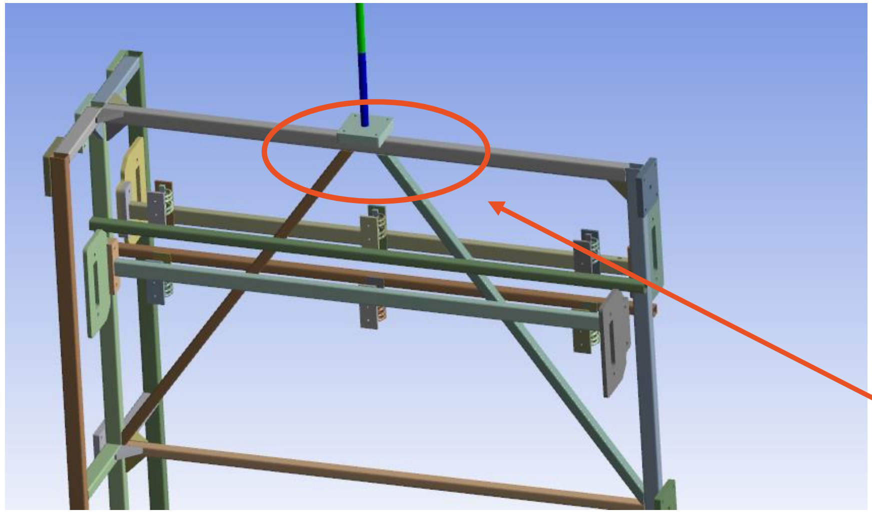


Diagnal beam connection

Weld SIZE		width		effective width	DY1	DX1	DY2	DX2	AREA	IXX	IYY	IZZ	Rmax			
diagnal		3.20		2.26	24.15	31.80	28.67	36.32	273.64	34046.45	49815.70	83862.14	23.14			
	Fx	Fy	Fz	Mx	My	Mz	(MPa)	Sz_n	Sy+Sx_s	Smx_n	Smy_n	Smz_s	Sn_sub	S_shear	Scombined	**SF**
1.00	1350.56	-662.96	-43.59	20764.97	62017.60	-38991.06		0.16	5.50	11.08	22.61	10.76	33.85	16.26	44.03	**8.06**
2.00	1192.64	704.06	105.10	-20509.72	56748.70	34131.59		0.38	5.06	10.94	20.69	9.42	32.02	14.48	40.67	**8.73**
3.00	1159.80	912.51	128.55	-18516.29	44280.42	-19752.49		0.47	5.39	9.88	16.14	5.45	26.49	10.84	32.47	**10.93**
4.00	1207.09	-898.73	145.27	16893.97	44617.25	20361.13		0.53	5.50	9.01	16.27	5.62	25.81	11.12	32.20	**11.02**
5.00	1571.30	-1460.81	-11.78	-25191.34	-59505.39	-41471.33		0.04	7.84	13.44	21.70	11.44	35.18	19.28	48.51	**7.32**
6.00	1598.74	1493.38	36.78	26847.63	-63074.30	40743.08		0.13	8.00	14.32	23.00	11.24	37.45	19.24	50.13	**7.08**
7.00	950.96	659.72	-158.01	17996.18	-45643.28	-15494.31		0.58	4.23	9.60	16.64	4.28	26.82	8.50	30.60	**11.60**
8.00	876.75	-725.91	14.58	-18501.06	-46826.69	19543.27		0.05	4.16	9.87	17.07	5.39	27.00	9.55	31.66	**11.21**

> 2.4 (per ASME BTH -1 requirement)

Weld stress at the vertical position



Connection at the top

SF>>2.4 required by ASME BTH-1

top section _diagnal beam																
Weld SIZE		width		effective width	DY1	DZ1	DY2	DZ2	AREA	IZZ	IYY	IXX	Rmax			
diagnal tubing		3.2		2.2624	62.285	50.8	66.8098	55.3248	532.1608	351962.7618	262352.1121	614314.8739	43.3716			
	Fx	Fy	Fz	Mx	My	Mz	(MPa)	Sx_n	Sy+Sz_s	Smz_n	Smy_n	Smx_s	Sn_sub	S_shear	Scombined	SF
1	-15153.3	10912.82	25.82	-1701.53	7836.49	2968.18		28.48	20.51	0.28	0.83	0.12	29.58	20.63	46.38	7.65
2	-15613.7	-11258.2	27.94	-4008.88	10840.6	-105.62		29.34	21.16	0.01	1.14	0.28	30.49	21.44	48.05	7.39
3	491.17	369.36	32.75	1676.09	-2153.1	6663.57		0.92	0.70	0.63	0.23	0.12	1.78	0.82	2.27	156.12
4	-18.82	31.96	23.11	-3299.53	-1140.07	10112.17		0.04	0.07	0.96	0.12	0.23	1.12	0.31	1.24	287.30
															SF (min)	7.39

50 mm plate																
Weld SIZE		width		effective width	DZ1	DY1	DZ2	DY2	AREA	IYY	IZZ	IXX	Rmax			
		3.20		2.26	38.10	190.00	42.62	194.52	1052.58	379712.42	4368722.19	4748434.61	99.57			
	Fx	Fy	Fz	Mx	My	Mz	(MPa)	Sx_n	Sz+Sy_s	Smy_n	Smz_n	Smx_s	Sn_sub	S_shear	Scombined	SF
1	30525.26	377.41	1.78	-532.44	42921.23	30335.6		29.00	0.36	2.41	0.68	0.01	32.08	0.37	32.09	11.06

Weld stress at the vertical position

Weld SIZE		width		effective width	DY1	DX1	DY2	DX2	AREA	IXX	IYY	IZZ	Rmax		Combine force	
		3.20		2.26	80.00	31.80	86.40	38.20	756.48	696362.60	186966.49	883329.09	47.23			
absorber Plate	Fx	Fy	Fz	Mx	My	Mz	(MPa)	Sz_n	Sy+Sx_s	Smx_n	Smy_n	Smz_s	Sn_sub	S_shear	Scombined	SF
1.00	2363.3	-379.7	-185.86	32017.92	116499.44	-65662.68		0.25	3.16	1.99	11.90	3.51	14.13	6.68	18.26	**19.44**
2.00	926.31	33.85	-53.06	5093.2	50904.84	3775.08		0.07	1.23	0.32	5.20	0.20	5.59	1.43	6.11	**58.11**
3.00	2289.4	358.1	-215.87	4220.2	111375.47	57553.54		0.29	3.06	0.26	11.38	3.08	11.92	6.14	15.98	**22.22**
4.00	2625.45	176.52	181.42	32212.32	-124464.63	-47357.54		0.24	3.48	2.00	-12.71	2.53	-10.48	6.01	14.77	**24.04**
5.00	800.39	-24.82	-10.99	4432.57	-47243.13	3009.6		0.01	1.06	0.27	-4.83	0.16	-4.54	1.22	5.00	**70.94**
6.00	2535.7	-138.05	292.53	-340.93	-110788.37	34864.15		0.39	3.36	-0.02	-11.32	1.86	-10.95	5.22	14.20	**24.99**
7.00	1961.97	361.99	-184.12	29635.45	-99984.01	-58186.26		0.24	2.64	1.84	-10.21	3.11	-8.13	5.75	12.86	**27.61**
8.00	488.84	-14.72	132.05	2246.25	-11272.66	2067.59		0.17	0.65	0.14	-1.15	0.11	-0.84	0.76	1.56	**228.15**
9.00	1970.63	-358.78	-225.14	205.66	-98502.28	55613.52		0.30	2.65	0.01	-10.06	2.97	-9.75	5.62	13.78	**25.76**
10.00	2123.27	-158.9	190.08	26514.74	101074.73	-40796.33		0.25	2.81	1.64	10.33	2.18	12.22	5.00	14.98	**23.71**
11.00	446.06	8.71	401.75	2177.47	14178.69	1934.41		0.53	0.59	0.14	1.45	0.10	2.11	0.69	2.43	**145.99**
12.00	2123.39	130.72	289.21	-1373.42	94353.87	33392.83		0.38	2.81	-0.09	9.64	1.79	9.94	4.60	12.73	**27.88**
															SF (min)	**19.44**
Weld SIZE		width		effective width	DY1	DX1	DY2	DX2	AREA	IXX	IYY	IZZ	Rmax			
Diagnal Tubing		3.20		2.26	24.15	31.80	28.67	36.32	273.64	34046.45	49815.70	83862.14	23.14			
flat side																
	Fx	Fy	Fz	Mx	My	Mz	(MPa)	Sz_n	Sy+Sx_s	Smx_n	Smy_n	Smz_s	Sn_sub	S_shear	Scombined	SF
1.00	1350.22	-665.32	-40.62	20708.16	62089.23	-38773.28		0.15	5.50	11.05	22.64	10.70	33.83	16.20	43.95	**8.08**
2.00	1195.1	706.84	108.53	-20453.77	56802.11	34125.15		0.40	5.07	10.91	20.71	9.42	32.02	14.49	40.68	**8.73**
3.00	1159.74	912.94	128.18	-18533.28	44299.89	-19785.73		0.47	5.39	9.89	16.15	5.46	26.51	10.85	32.50	**10.92**
4.00	1207.61	-898.26	145.75	16886.7	44616.86	20295.79		0.53	5.50	9.01	16.27	5.60	25.81	11.10	32.18	**11.03**
5.00	1574.11	-1460.55	-9.96	-24973.2	-59508.11	-41485.62		0.04	7.85	13.32	21.70	11.45	35.05	19.29	48.43	**7.33**
6.00	1599.21	1491.25	33.42	26423.57	-62948.08	40604.18		0.12	7.99	14.10	22.95	11.20	37.17	19.19	49.87	**7.12**
7.00	951.75	659.16	-157.94	18029.57	-45707.28	-15561.73		0.58	4.23	9.62	16.66	4.29	26.86	8.52	30.65	**11.58**
8.00	877.69	-726.92	14.52	-18492.11	-46798.31	19499.19		0.05	4.16	9.86	17.06	5.38	26.98	9.55	31.64	**11.22**
															SF (min)	**7.12**
top section _diagnal beam																
Weld SIZE		width		effective width	DY1	DZ1	DY2	DZ2	AREA	IZZ	IYY	IXX	Rmax			
diagnal tubing		3.2		2.2624	62.285	50.8	66.8098	55.3248	532.1608	351962.7618	262352.1121	614314.8739	43.3716			
	Fx	Fy	Fz	Mx	My	Mz	(MPa)	Sx_n	Sy+Sz_s	Smz_n	Smy_n	Smx_s	Sn_sub	S_shear	Scombined	SF
1	-15153.3	10912.82	25.82	-1701.53	7836.49	2968.18		28.48	20.51	0.28	0.83	0.12	29.58	20.63	46.38	**7.65**
2	-15613.7	-11258.2	27.94	-4008.88	10840.6	-105.62		29.34	21.16	0.01	1.14	0.28	30.49	21.44	48.05	**7.39**
3	491.17	369.36	32.75	1676.09	-2153.1	6663.57		0.92	0.70	0.63	0.23	0.12	1.78	0.82	2.27	**156.12**
4	-18.82	31.96	23.11	-3299.53	-1140.07	10112.17		0.04	0.07	0.96	0.12	0.23	1.12	0.31	1.24	**287.30**
															SF (min)	**7.39**
Weld SIZE		width		effective width	DY1	DX1	DY2	DX2	AREA	IXX	IYY	IZZ	Rmax			
Vertical flat		3.20		2.26	63.50	31.80	68.02	36.32	451.69	274321.53	101537.40	375858.92	38.56			
	Fx	Fy	Fz	Mx	My	Mz	(MPa)	Sz_n	Sy+Sx_s	Smx_n	Smy_n	Smz_s	Sn_sub	S_shear	Scombined	SF
1.00	1531.21	194.91	-1568.69	7070.63	-43235.56	77394.38		3.47	3.42	0.88	7.73	7.94	12.08	11.36	23.09	**15.38**
2.00	1483.07	-323.52	239.51	9876.92	-65405.63	-78127.85		0.53	3.36	1.22	11.70	8.01	13.45	11.38	23.86	**14.88**
3.00	1294.09	160.35	-1394.85	19752.47	-29523.35	116350.86		3.09	2.89	2.45	5.28	11.94	10.82	14.82	27.86	**12.74**
4.00	1366.94	-396.73	-184.03	-10809.84	-52830.91	-122879.48		0.41	3.15	1.34	9.45	12.61	11.20	15.76	29.50	**12.03**
5.00	1533.59	-516.97	-1817.24	21981.38	41457.7	90118.91		4.02	3.58	2.73	7.42	9.24	14.16	12.83	26.35	**13.47**
6.00	1543.95	727.55	-203.79	-11476.22	69020.87	-90857.67		0.45	3.78	1.42	12.35	9.32	14.22	13.10	26.78	**13.26**
7.00	1187.96	-162.81	-1216.57	7173.56	30991.36	95513.1		2.69	2.65	0.89	5.54	9.80	9.13	12.45	23.42	**15.16**
8.00	1224.31	421.5	212.41	9318.62	47892.8	-99411.15		0.47	2.87	1.16	8.57	10.20	10.19	13.06	24.82	**14.30**
															SF (min)	**12.03**

Sample of Weld stress at the vertical position

The full list is attached in Appendix B

Table 3 - Summary of SF for some of the critical connection

Case	Lifting configuration	Absorber plate connection (SF)	Diagonal tubing and absorber tubing connection (SF)	Diagonal tubing and header/footer tubing connection (SF)	Long tubing and absorber tubing connection (SF)	50 mm plate	Tubing connected to attachment
3a=2	1_landscape mode	13.42	10.71	14.89	9.42	N/A	9.97
3b	2_ landscape mode	13.62	5.43	7.68	6.77	11.84	9.25
3c	3_ 45 degree	18.25	5.99	8.34	7.28	10.44	4.45
4	4_ Vertical	19.44	7.12	7.39	12.03	11.06	5.12
5a	5_ 45 degree	15.17	5.86	8.83	6.56	10.88	5.12
5b	6_ landscape mode	13.45	5.28	7.02	7.95	11.78	9.04
5c	7_ landscape mode	13.10	11.50	15.16	9.62	N/A	7.76

where Fy=355 MPa (the yield strength of the parent material) and Nd=2.4 in equation 3-37

All the SF>>2.4 BTH-1 requirement

3-2.5 Combined Normal and Shear Stresses

Regions of members subject to combined normal and shear stresses shall be proportioned such that the critical stress f_{cr} computed with eq. (3-37) does not exceed the allowable stress F_{cr} defined in the equation.

$$f_{cr} = \sqrt{f_x^2 - f_x f_y + f_y^2 + 3f_v^2} \le F_{cr} = \frac{F_y}{N_d} \quad (3\text{-}37)$$

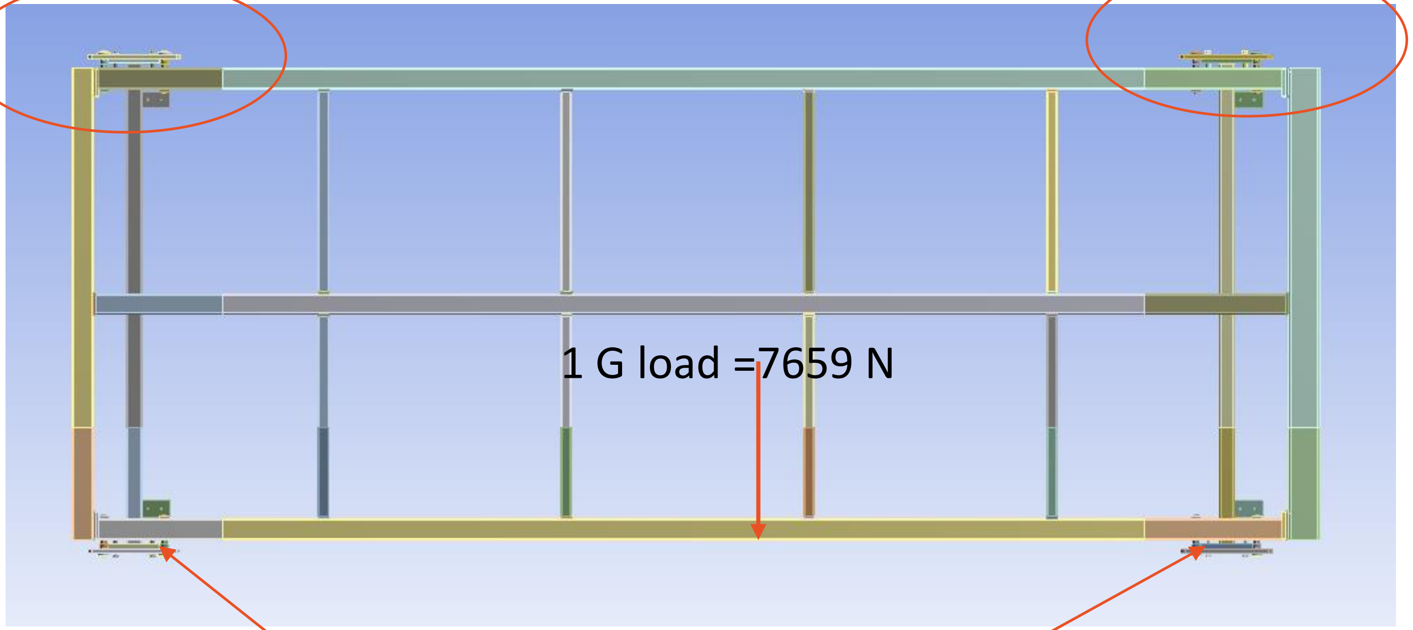
Additional case study

Case 9 and 10

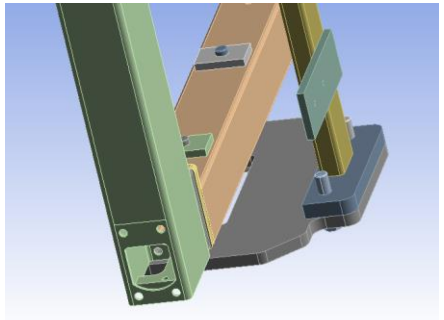
Attachment Plate and Connection Study (case 9 & case 10)

- In the previous case study, the APA detector weight was treated as force remotely applied to the attachment plate from its gravity center. it is a conservative approach without considering the stiffness of APA frame.
- However, it does not address how the actual APA detector is connected to the transport frame in great detail, which requires a separate FEA model.
- The APA frame is connected to shipping frame using 8 stainless steel M16 to M20 adaptors attached to a steel plate. During the installation, the APA detectors will be loaded into the shipping frame from the top.
- Total weight of the APA will be sitting on the lower attachment plate. Instead of 8 stainless steel adaptors, only 4 of them will participate in the load bearing, as it is considered as the worst case. To understand the resulting stress, a separate FEA model is created as case 9/10.

Top bracket is a “SLIP JOINT_SLIDING

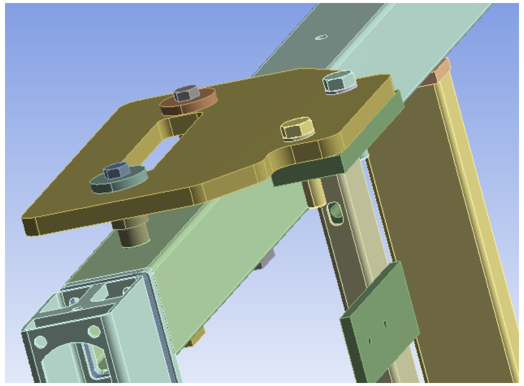


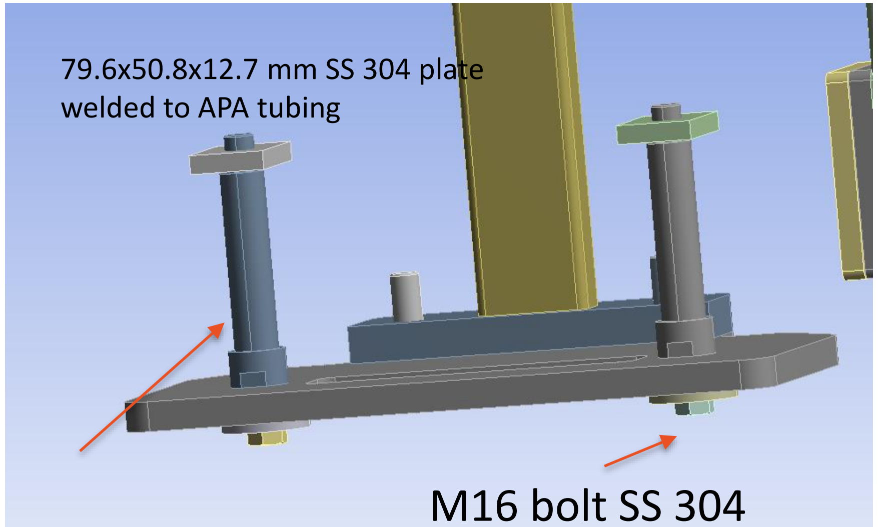
GRAVITY LOAD IS HOLD BY THESE TWO PLATE_ LOWER SECTION



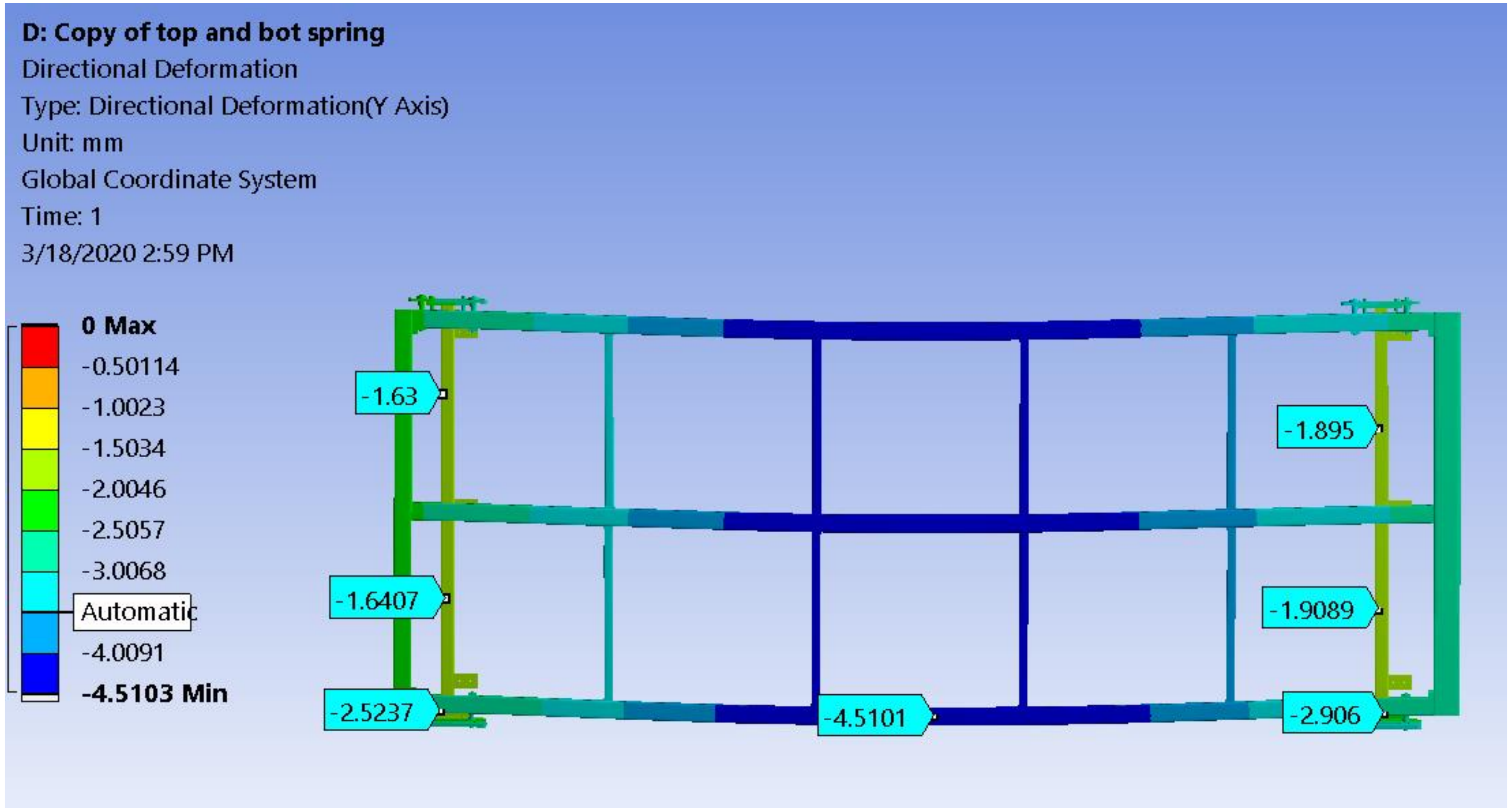
6 absorber plates:
Each of them is connected by THREEE springs with Kx, Ky and Kz , provided by Jake and Dan (PSL). THANK YOU!
The spring stiffness is as follows:

X = 726 kN/m
Y = 726 kN/m
Z = 2.742 MN/m

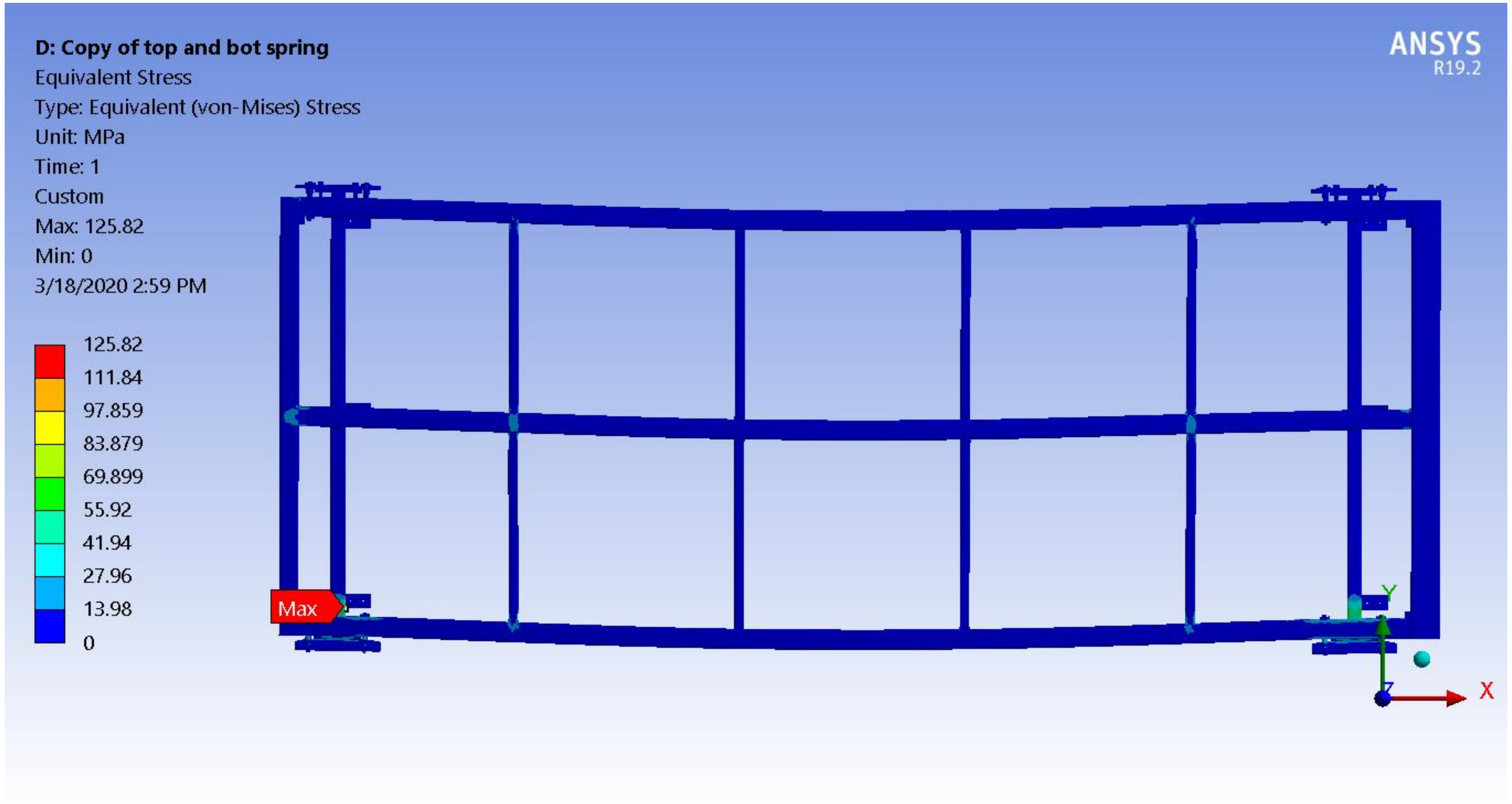




M16 to M20 adaptor SS 304



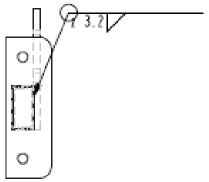
The deflection of APA frame is about 4.5-2.5=~2 mm
The vertical tubing has moved downward 1.66~1.9 mm (more like translation due to the spring attachment).
It is consistent with X=7659 N/(726e3*6)=~1.75 mm (Good agreement !)

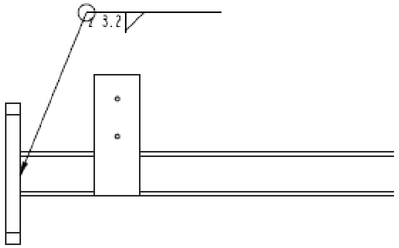


The FEA model indicates the stress is below ~125 Mpa << 355 MPa; SF=355/125=2.84

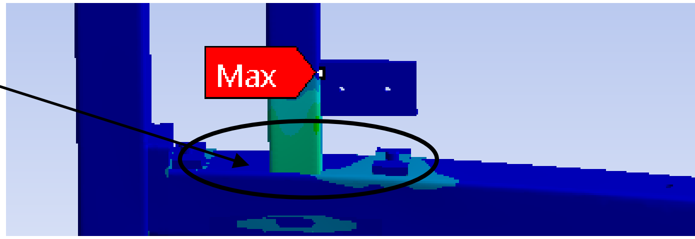
Weld stress check

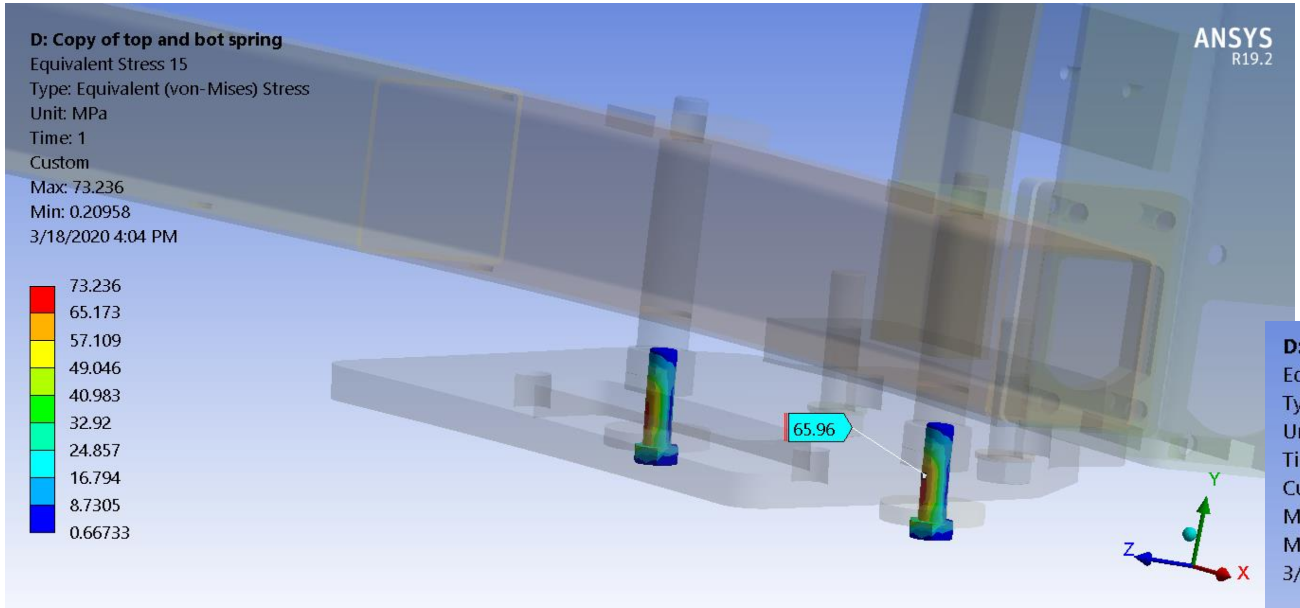
		width		effective width	DX1	DZ1	DX2	DZ2	AREA	IZZ	IXX	IYY	Rmax			
		3.20		2.26	62.29	38.10	66.81	42.62	474.70	292083.22	144104.52	436187.74	39.62			
	Fx	Fy	Fz	Mx	My	Mz	(MPa)	SY_n	Sx+Sz_s	Smz_n	Smy_S	Smx_N	Sn_sub	S_shear	Scombined	**SF**
1	-2.53	-4130.60	-77.65	532030.00	-1347.90	53473.00		8.70	0.16	6.12	0.12	78.68	93.50	0.29	93.50	**3.80**
2	-10.71	-3554.30	-68.19	468380.00	6140.90	-99012.00		7.49	0.15	11.32	0.56	69.27	88.08	0.70	88.09	**4.03**





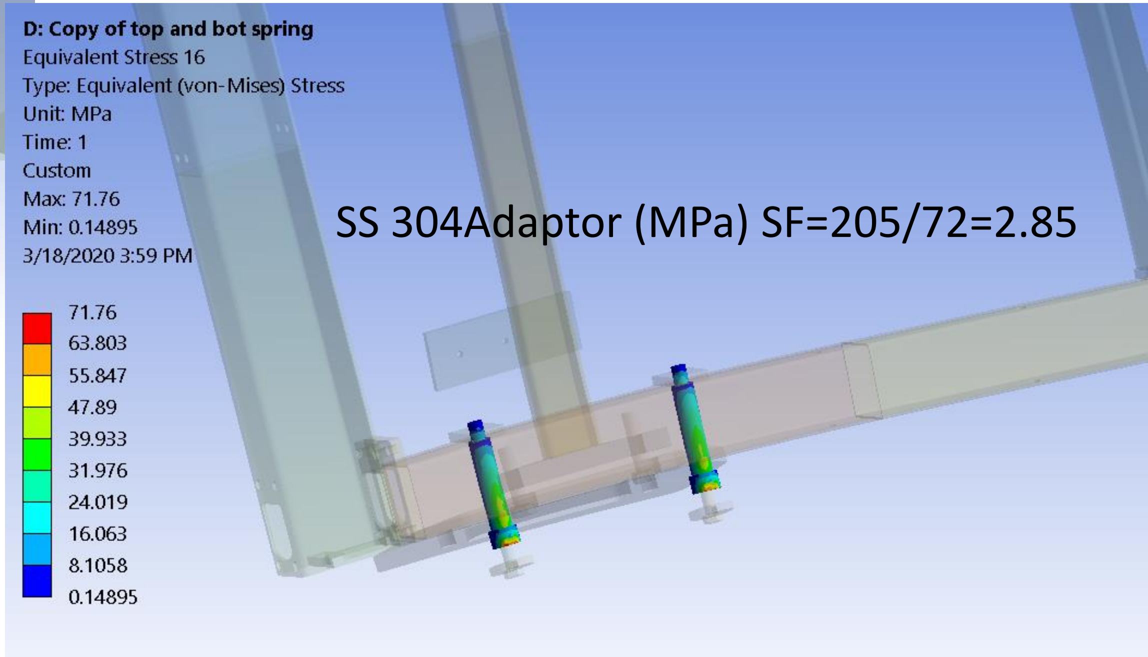
Check the weld stress



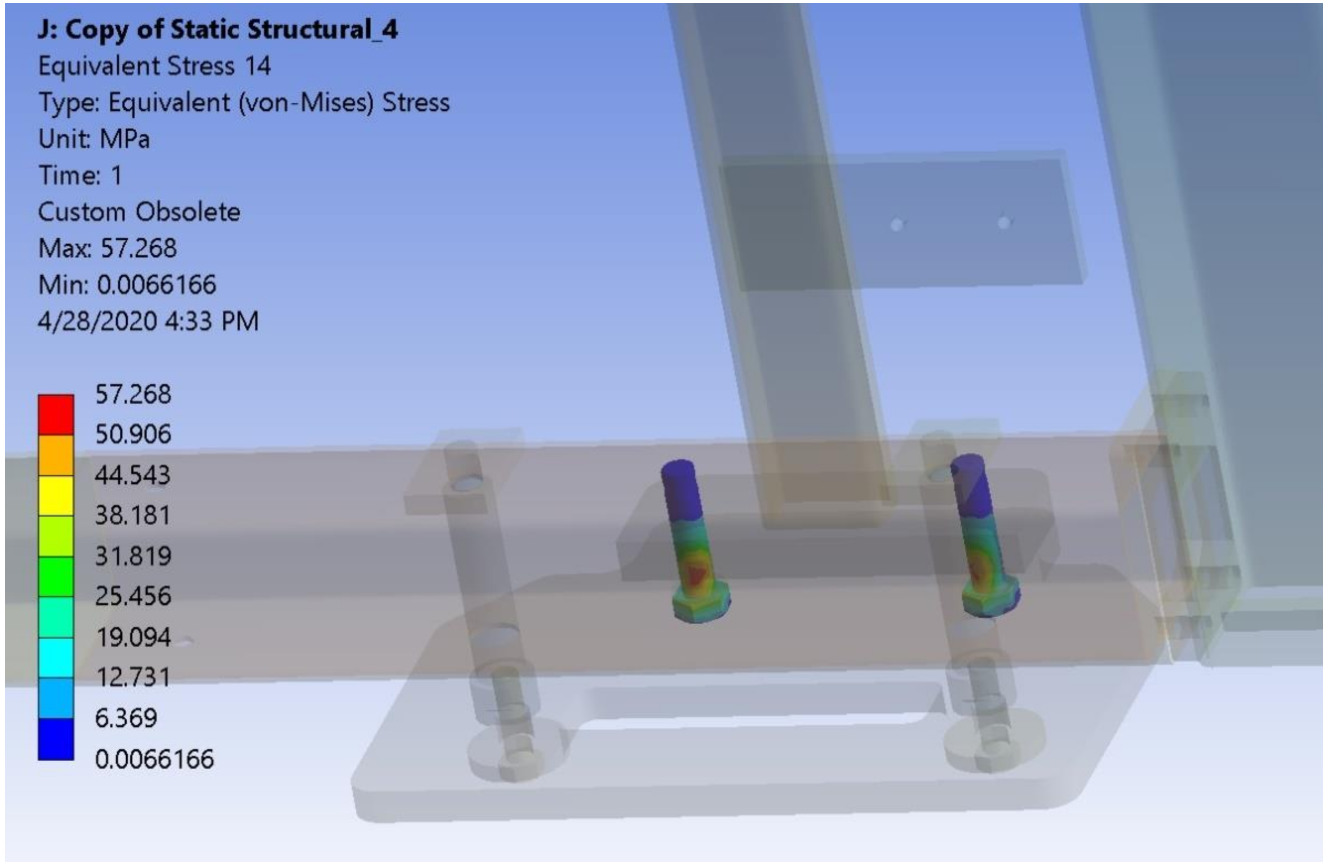


M16X2 SS bolt (grade 304); SF=205/73=2.82

SS 304
Syield=205 MPa min
Su=515 MPa min



SS 304Adaptor (MPa) SF=205/72=2.85

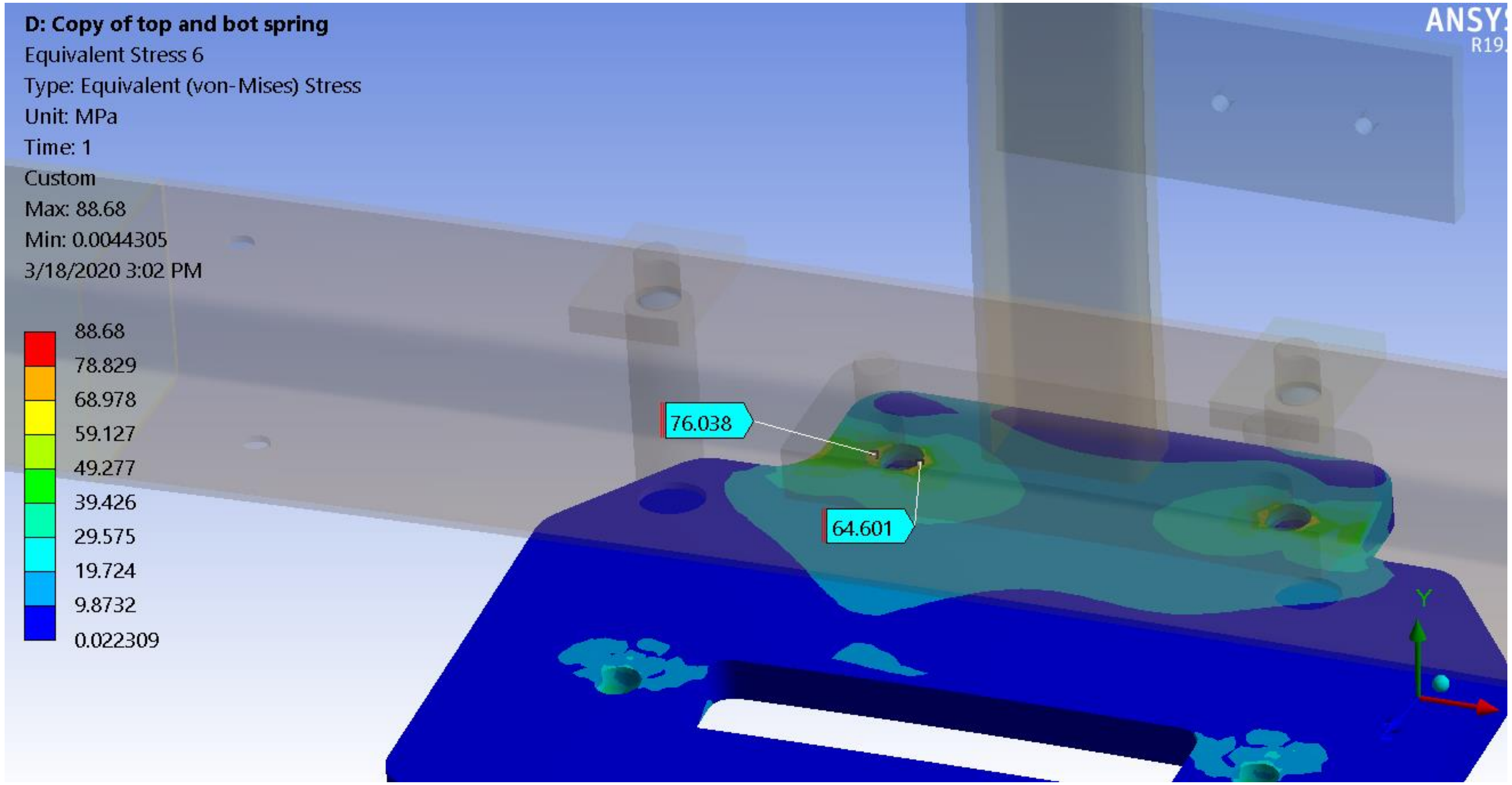


M20 steel bolt –stress (MPa)

M20 steel bolt is class 8.8
With minimum yield of
660 MPa and 830 MPa
ultimate strength.

SF=660/57.268=11.5

This bolt connection has been changed to the bolt/nut (instead of tap hole)



S355 carbon steel
Syield=355 MPa min

Attachment plate S355; SF=355/88.68=4

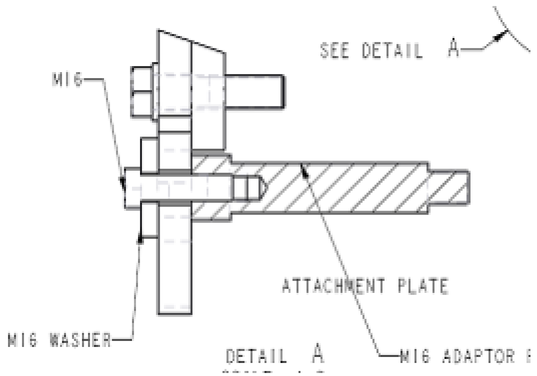
Thread Engagement Check

	D	p	Ds	At	Dp	Le min (mm)	L (design) (mm)
M16X2	16.00	2.00	14.12	156.67	14.70	13.57	24.00
M20X2.5	20.00	2.50	17.65	244.79	18.38	16.96	20.00

The engagement here is 20 mm
> Le=16.96 mm for M 20 bolt

$$L_e\,(min) = 2\,.\,A_t\,/\,[0.5\,.\pi\,.(D - 0.64952.p\,)]$$

The engagement here is 24 mm> Le=13.57 mm
for M16 bolt.



Summary of the attachment plate analysis (Case 9)

	Stress (MPa)	SF	Meet BTH-1 requirement?
Steel plate	87.2	355/87.2 = 4.1	Y
M20 Steel bolt (class 8.8)	57.3	660/57.3 = 11.5	Y
M16-M20 SS 304 adapter	76	205/76 = 2.7	Y
M16 SS 304 bolt	78	205/78 = 2.6	Y
Weld	92.41	355/92.41 = 3.84	Y

- The result shows that the attachment plate assembly satisfies ASME BTH-1 SF (min) ≥ 2.4 for the connections and SF (min) ≥ 2 for the rest of the structure.
- This case 10 should be applicable to case 9 since which is just a flip of the gravity vector. The case 10 is the worst case which places the M20 bolt in the tension. The other rotation positions will be analyzed for completeness in the future (we do not anticipate any problems since the other side of the joints will start to pick up the load when it is rotated from the landscape to the vertical position).

Conclusions

- Based on the preliminary static structural analysis result, the current design of the shipping frame is adequate to satisfy the requirements of ASME BTH-1 2017.
- The dynamic analysis will be continued to understand the dynamic response during the shipping environment with a proper shock absorber. We will present the result tomorrow.
- As the design progressed, the FEA analysis will be updated accordingly.
- Lastly, in a design improvement the two APAs within the shipping frame will be translated by 15 mm along their long direction to improve clearances (on the bottom ends) with no net change in the center of gravity. This is called Version 2 of the technical drawing package. Compared with the ~6,700 mm overall dimension, this shift has a negligible impact on these results. However, the analysis will be updated to reflect this and all updates to the final shipping frame design.

Reference

1) “Design of Below-the Hook Lifting Devices”, ASME BTH-1-2017, March 15, 2017.

2) “Compliance Office Preliminary Requirements Memorandum”, dated 2/11/2020 EDMS No.:2093094.

3) “Design recommendations for APA transport frame and detector” by M. Zimbru, J-L. Grenard, O. Beltramello (CERN).