Engineering Analysis

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DUNE PDR: APA Review

March 27, 2019

Contents

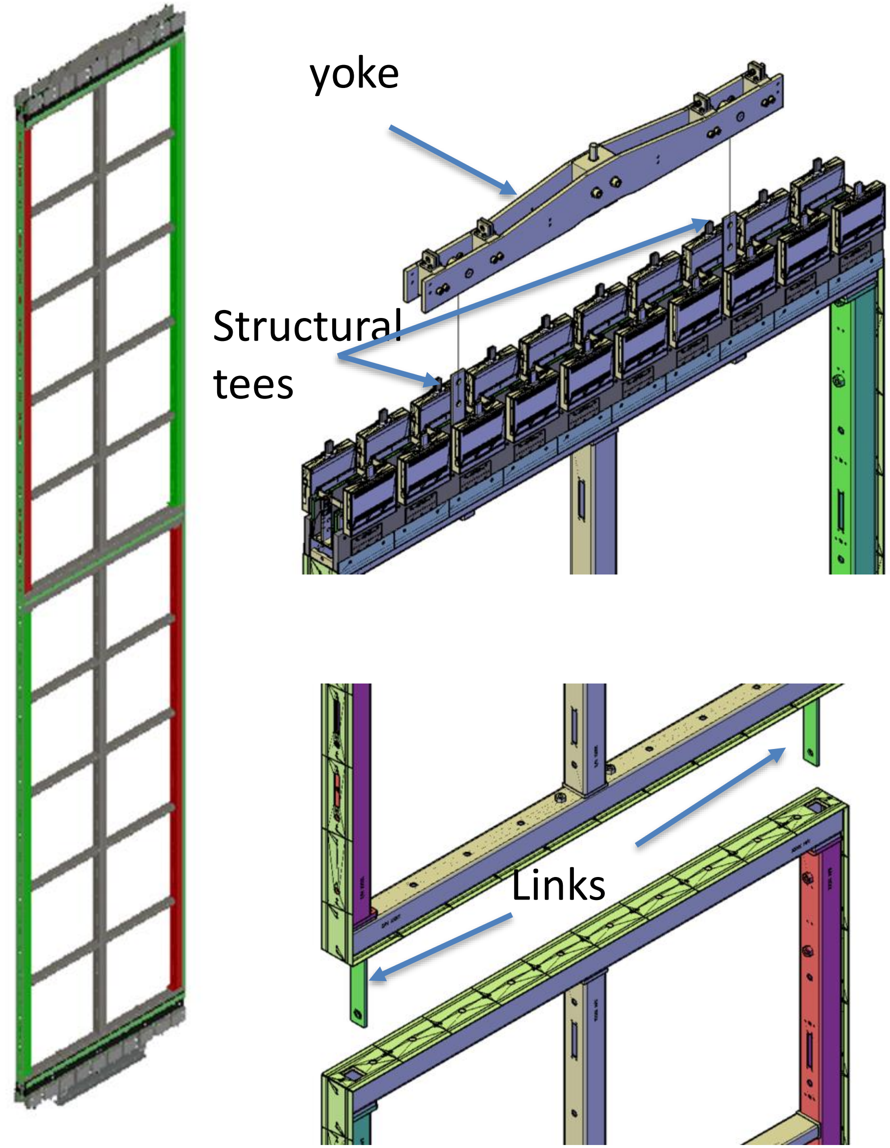
Charge question

- Are engineering analyses sufficient to ensure the design is safe during all phases, and have applicable design codes and standards been satisfied?

Note: The DUNE APA Structural Analysis can be found on EDMS at:
https://edms.cern.ch/document/2100877/1

Introduction

- The analysis of the APA Frame, Yoke, Structural Tee, and link for all significant load cases will be presented.
- The load factors and resistance factors used for Load Factor Resistance Design (LFRD) method will be identified.
- The APA structural members, welded connections and bolted connections will be checked.



Integrated APA with yoke structural tees and links

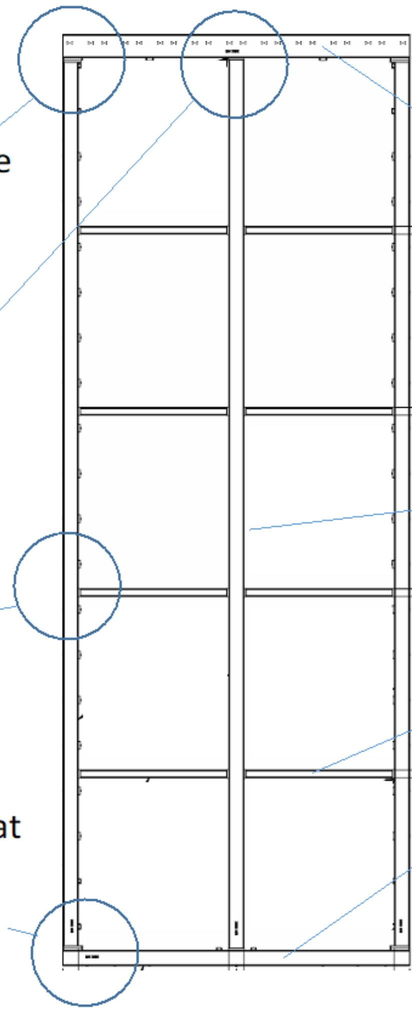
Nomenclature

Corner end plates: (two plates at this joint, one on end of side tube, one on end of head tube.)

Center tube end plate: (single plate at this joint, on end of center tube.)

Rib end plates: (single plate at this joint, on end of rib.)

Corner end plates: (two plates at this joint, one on end of side tube, one on end of foot tube.)



Head tube

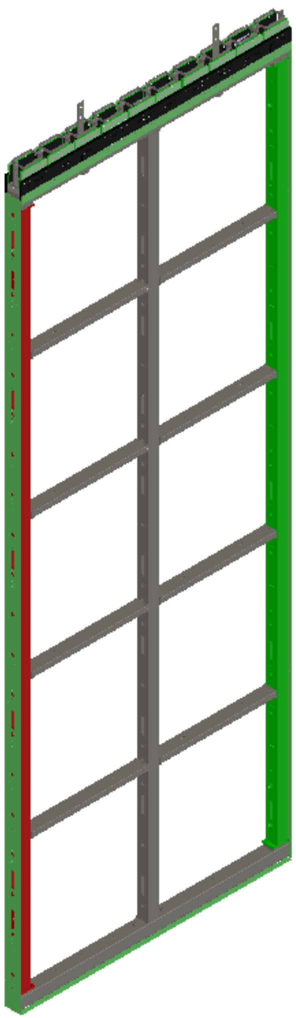
Side tube

Center tube

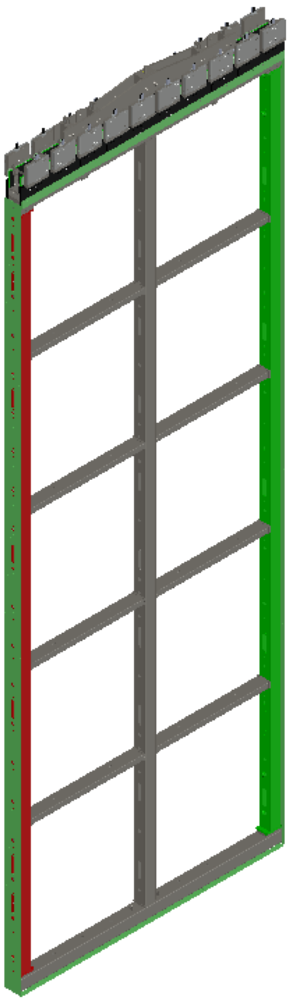
Rib tube

Foot tube

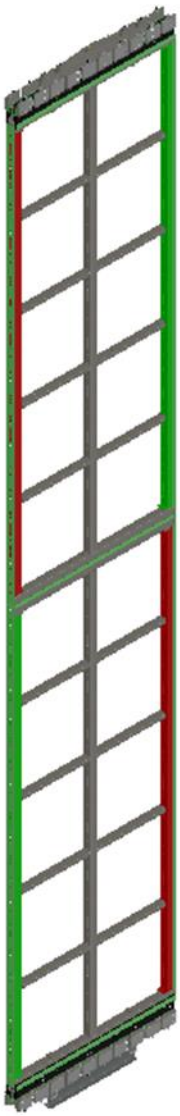
Nomenclature



Factory APA



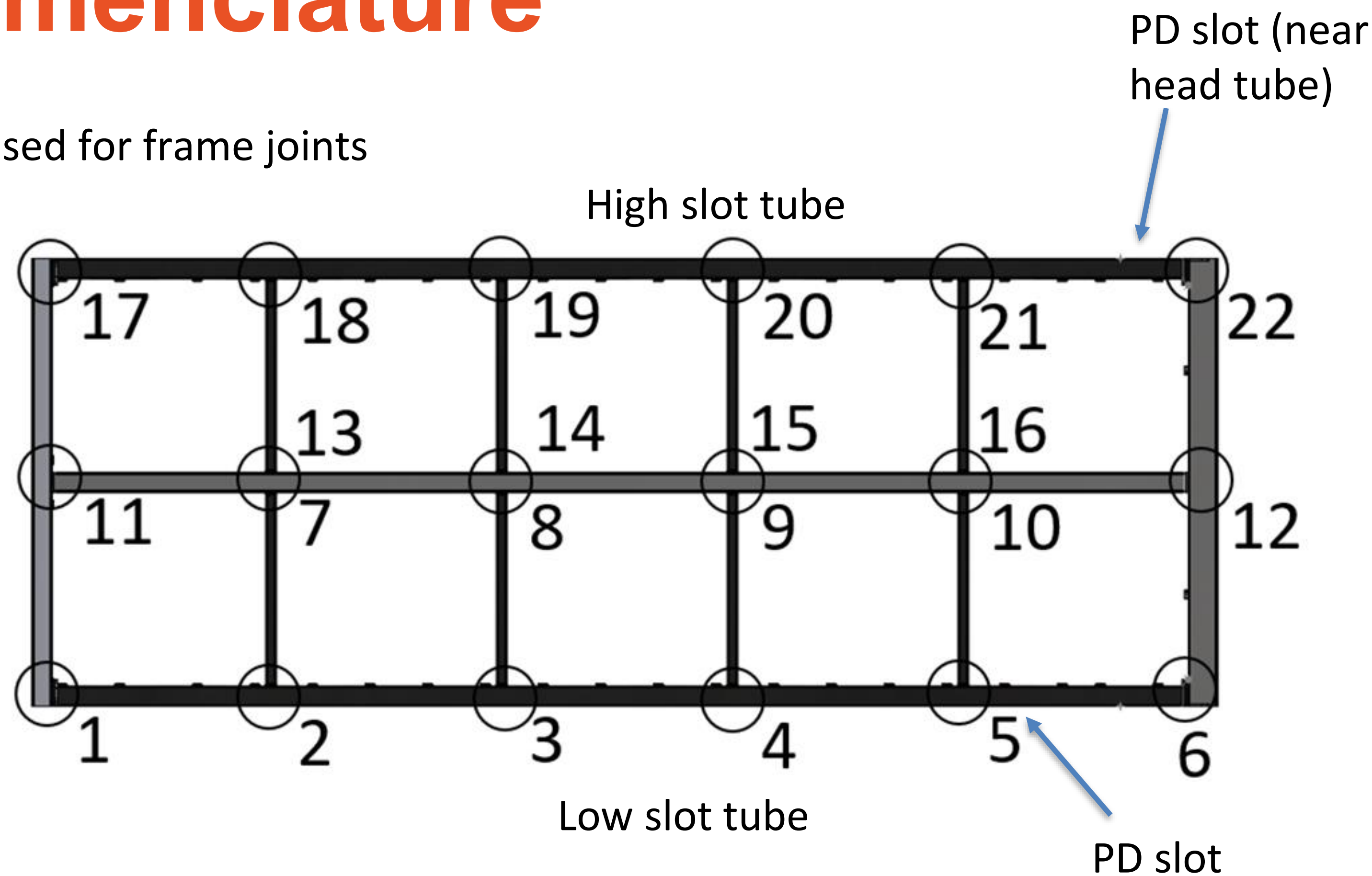
Integrated APA (PDs not shown)



APA Pair (PDs not shown)

Nomenclature

Labels used for frame joints



Design codes

- AISC's Specification for Structural Steel Buildings (AISC document 360-10)
- Design Guide 27: Structural Stainless Steel
- Load and Resistance Factor Design (LRFD) method for Stainless steel structures
  - Load Factor = 1.4
  - Member Resistance factor = 0.9
  - Weld nominal strength factor for shear = 0.6
  - Weld shear resistance factor = 0.55
  - Bolt resistance factor = .75
- JRC Science for Policy Report "Prospect for New Guidance in Design of FRP" as a guide for designing fiber reinforced plastics (FRP) structures
  - Safety factor of 3.75 for all effects of temperature, humidity, creep and material variation.

APA Frame Analysis - Loading

- The loading on the frame is defined in the order that the loads are applied to the frame as a frame makes its journey from the factory to final installation. Plans for the ITF are not so well understood, but worse case supporting and loading is anticipated. For example it is assumed that the APA will be handled with the edge lift kit and in the transport frame.
  - APA factory
  - ITF
  - Transport and rigging (dynamic)
  - Installation process
  - Installed state and cool down

APA Frame Analysis - Loading

- Masses and mass contingency

Appendix 2: Mass information

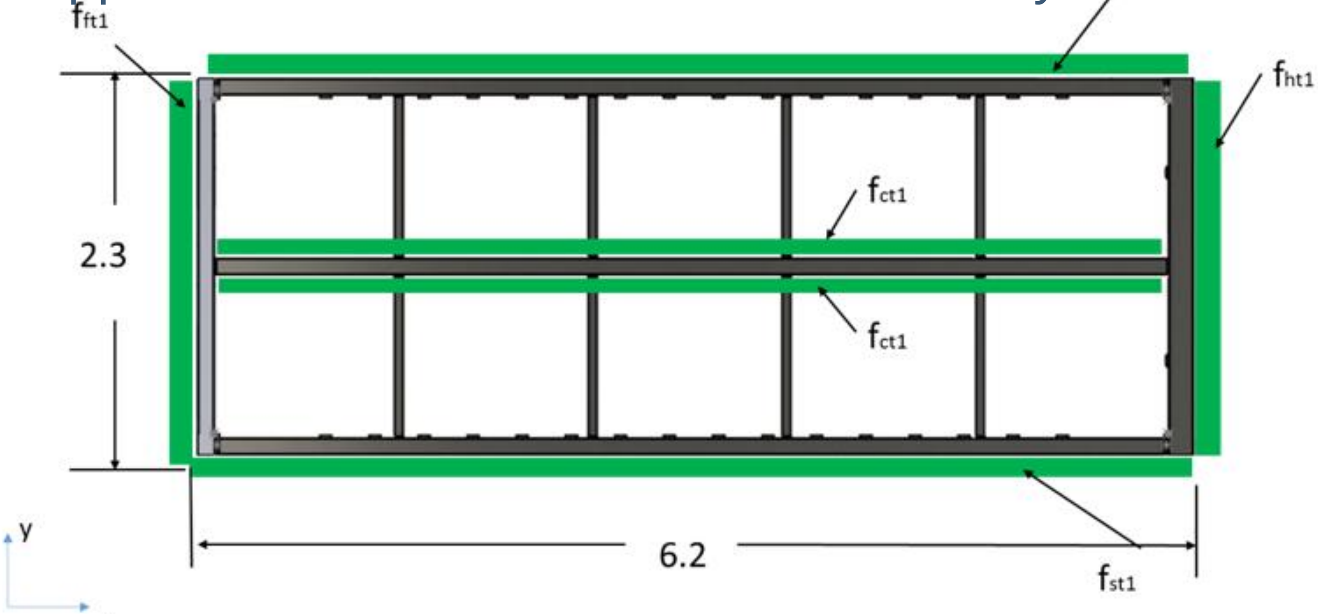
Mass detail

Mass Label	Mass Description	Support Location	Type of Load	Mass/ APA (kg)	Contin-gency %	Mass Total (kg)	Mass with Load Factor (kg)
Bare frame							
m1	Frame	n/a		315.8	2	322.1	451.0

APA with four wire layers							
m2	PD rails	side & center	dist	12.0	25	15.0	21.0
m3	PD cable hardware	side & center	dist	1.0	26	1.2	1.7
m4	PD cables	side & center	dist	10.0	10	11.0	15.4
m5	Mesh Windows	side & center	dist	52.9	5	55.6	77.8
m6	Combs	side & center	dist	6.9	10	7.6	10.7
m7	Foot boards	foot tube	dist	6.2	10	6.8	9.5
m8	hdw for FB & C	foot tube	dist	0.1	10	0.1	0.1
m9	Head boards	head tube	dist	25.4	10	28.0	39.2
m10	hdw for HB & C	head tube	dist	0.7	10	0.8	1.1
m11	Side boards	side tube	dist	16.4	10	18.1	25.3
m12	hdw for SB & C	side tube	dist	0.5	10	0.6	0.8
m13	Wire	side, foot, head	dist	3.6	10	4.0	5.5
m14	Solder	side, foot, head	dist	1.8	50	2.7	3.8
m15	Epoxy	side, foot, head	dist	0.2	50	0.3	0.4
Subtotal APA with four wire layers				453.6		473.8	663.4

APA Frame Analysis - Loading

- Application of distributed masses carried by the frame

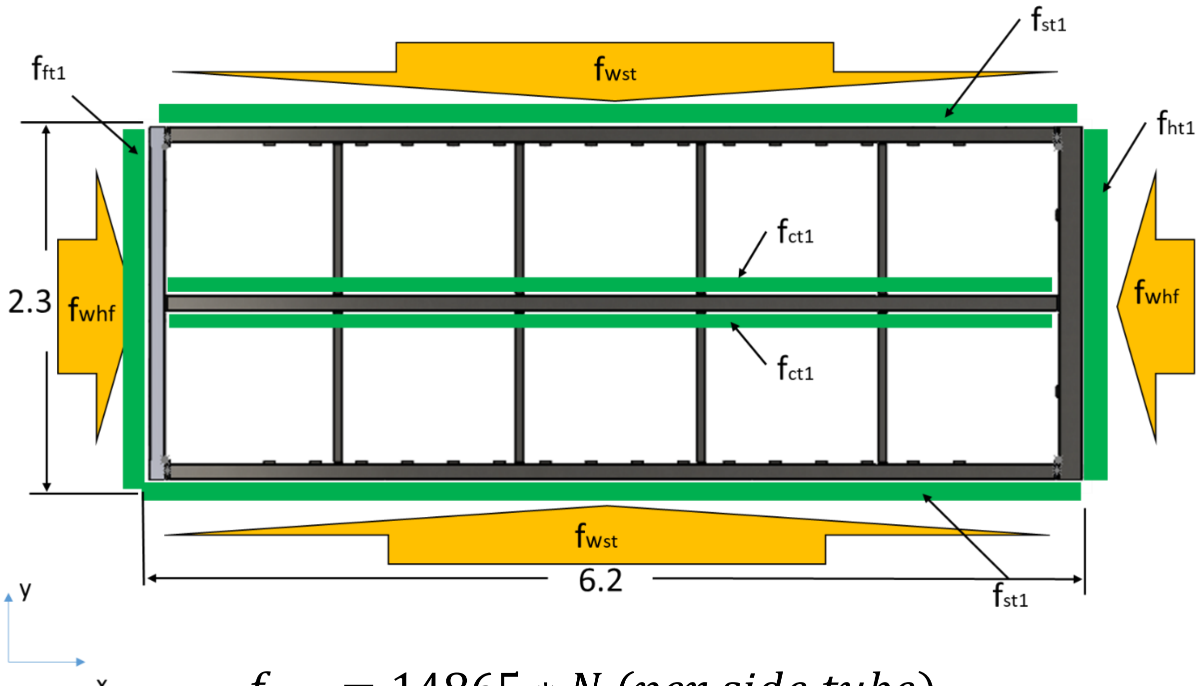


As the APA is manufactured components are mounted to the frame. The masses of these components are assigned to the frame members as a distributed mass. The FEA model applies gravity in the appropriate direction to convert the distributed load applied in the appropriate direction

1. APA with four wire loads
2. Integrated APA
3. The APA protection

APA Frame Analysis - Loading

- Wire load carried by the frame



$$f_{wst} = 14865 * N \; (per\ side\ tube)$$

$$f_{whf} = 27031 * N \; (per\ head\ or\ foot\ tube)$$

Load cases

- APA factory

  1 Bare frame

  2-4 APA in the winding machine

- ITF (Fully integrated APA with protection)

  5 & 6 In the process cart on edge and flat

  7 lifted by the edge lift kit

  8 Lying flat in the transport frame

- Transport and rigging

  9-11 Fully integrated top APA with protection and yoke in the transport frame at 0, 45 and 90 degrees)

  12-13 Fully integrated bottom APA with protection and FC support in the transport frame at 0 and 45 degrees)

Load cases

- Installation process

  13-14 Fully integrated bottom APA with protection supported by M20’s and by head end

  15 Fully integrated top APA with protection and bottom end supported by the structural tees

- Installed state and cool down

  17 Fully integrated bottom APA with head end down supporting the FC

  18 Fully integrated top APA with bottom APA, FC, CE and CE cables

  19 APA pair with maximum spatial temperature gradient

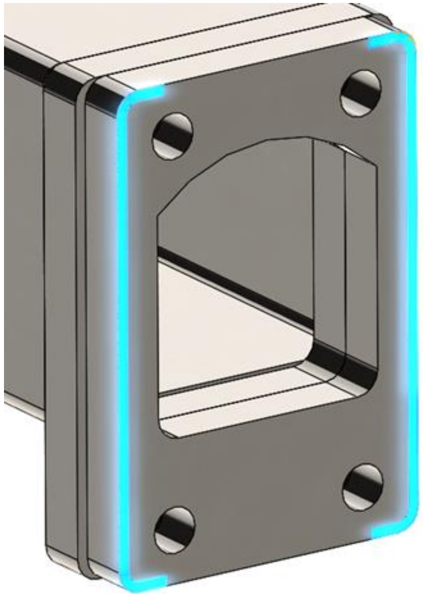
  20 Transient thermal case on fully integrated APA pair

FEA model

- A 3D representative model was built and Finite Element Analysis (FEA) was used to evaluate the frame.
- Primary software was SolidWorks Simulation. (Independent verification was done in ANSYS).
- Quadratic tetrahedral elements were used.
- Stresses in frame members were calculated by FEA
- Stresses in and near welds were calculated by FEA and used as reference
- Forces and moments on the joints were calculated for use in code calculations.

Analysis of welded connections

- The weld joints are identified and reported by their joint location.
- There are four different types of welds
  1. Pad to head or foot tube
  2. Endcap to side tube
  3. Endcap to center tube
  4. Endcap to ribs
- Forces and moments on each joint were pulled from the FEA
- The weld stresses were calculated for each weld joint per the AISC -306-10 code.
- The resistance factor of .55 from Design Guide 27: Structural Stainless Steel was used.



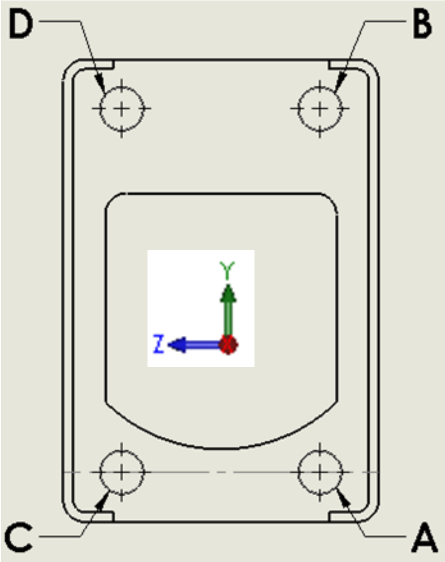
View of pad to head tube weld. Head tube not shown.

Analysis of welded connections

- The contribution of stresses from each of the 3 forces and 3 moments applied to the weld to determined the contribution to stress from each.
- The stresses from each force and moment are summed directly or vectorially (as appropriate) to arrive at the maximum value of force per unit length applied to the weld (N/m).
- The welds are also modeled in 3D FEA and the stresses evaluated. Linear FEA has difficulties capturing relavent stresses in areas of singularities and stress concentrations. Appendix 7 in the report explains the treatment of these very localized stresses

Analysis of bolted connections

- Individual bolts were labeled using the joint and bolt locations with respect to the Coordinate system
- Forces and moments on each joint were pulled from the FEA
- The tensile and shear forces were calculated for each bolt for each load case
- The Available strength of the M10 and M12 bolts was determined based on bolt size and materials (A2 Class 70 304 SS bolts and 0.75 resistance factor)
- Note: It was not necessary to evaluate combined stresses because both the shear and tensile strengths where never over 30% of the available strengths



Frame Member and weld Results –
Maximum stress for each case

Case	Maximum Beam Stress (MPa)	Ratio Available to Calculated (Beam Stress)	Maximum Weld Load (N/m)	Ratio Available to Calculated (Weld Load)
1	24.4	7.6	26.9E+3	8.1
2	81.4	2.3	86.4E+3	2.1
3	91.7	2.0	105.7E+3	1.7
4	85.5	2.2	87.7E+3	2.1
5	112.0	1.7	116.7E+3	1.6
6	103.0	1.8	70.9E+3	2.6
7	67.8	2.7	110.0E+3	1.7
8	117	1.6	78.4E+3	2.3
8 (High Gravity)	161	1.2	155.6E+3	1.4E+0
9	61.1	3.0	77.5E+3	8.1
9 (High Gravity)	167	1.1	172.5E+3	1.1E+0
10	87.4	2.1	82.0E+3	2.2
11	59.6	3.1	121.1E+3	1.8
12	76.3	2.4	74.3E+3	2.4
13	81.7	2.3	77.0E+3	2.4
13 (High Gravity)	63.7	2.9	169.6E+3	1.1E+0
14	82.1	2.3	83.5E+3	2.2
15	91.9	2.0	66.0E+3	2.8
16	81.2	2.3	93.9E+3	1.9
17	77.0	2.4	85.6E+3	2.1
18	80.3	2.3	26.9E+3	8.1
19	150	1.2	88.3E+3	2.1
20	129	1.4	113.6E+3	1.6

Maximum Axial Bolt Forces by Joint -1 g (N)

Table 4: Highest axial bolt forces by joint

Joint	Case	Bolt Type	Max Axial Force	Ratio of Available to Calculated	Axial Strength
1	19	M12	6.2E+3	5.1	OK
2	11	M10	2.1E+3	10.5	OK
3	1	M10	802.9E+0	27.4	OK
4	1	M10	522.7E+0	42.1	OK
5	7	M10	1.9E+3	11.3	OK
6	7	M12	3.1E+3	10.1	OK
7	11	M10	4.2E+3	5.3	OK
8	7	M10	1.4E+3	16.1	OK
9	1	M10	439.5E+0	50.1	OK
10	7	M10	1.9E+3	11.8	OK
11	1	M10	1.6E+3	13.5	OK
12	11	M10	4.0E+3	5.5	OK
13	8	M10	2.1E+3	10.4	OK
14	7	M10	1.4E+3	15.8	OK
15	1	M10	596.7E+0	36.9	OK
16	8	M10	2.3E+3	9.6	OK
17	19	M12	6.2E+3	5.1	OK
18	11	M10	2.1E+3	10.6	OK
19	7	M10	1.5E+3	14.8	OK
20	1	M10	717.8E+0	30.6	OK
21	7	M10	2.5E+3	8.6	OK
22	5	M12	2.5E+3	12.5	OK

Maximum Shear Bolt Forces by Joint -1g

Table 5: Highest shear bolt forces by joint

Joint	Case	Bolt Type	Max Shear Force	Ratio of Available to Calculated	Axial Strength
1	8	M12	1.2E+3	15.7	OK
2	11	M10	2.3E+3	5.7	OK
3	7	M10	154.7E+0	85.3	OK
4	12	M10	69.7E+0	189.4	OK
5	7	M10	192.6E+0	68.5	OK
6	9	M12	1.6E+3	12.2	OK
7	11	M10	2.1E+3	6.3	OK
8	7	M10	157.1E+0	84.0	OK
9	18	M10	62.6E+0	210.9	OK
10	7	M10	205.3E+0	64.3	OK
11	11	M10	587.1E+0	22.5	OK
12	7	M10	241.9E+0	54.6	OK
13	11	M10	3.8E+3	3.5	OK
14	7	M10	160.3E+0	82.3	OK
15	18	M10	62.9E+0	209.8	OK
16	7	M10	259.4E+0	50.9	OK
17	8	M12	1.2E+3	16.5	OK
18	11	M10	1.6E+3	8.1	OK
19	7	M10	146.8E+0	89.9	OK
20	8	M10	46.7E+0	282.7	OK
21	7	M10	200.8E+0	65.7	OK
22	10	M12	1.4E+3	13.4	OK

Maximum Weld Forces by Joint – 1g

Summary of Weld Forces by Joint

Weld forces are also summarized by joint. The table below lists the lowest ratio of available strength to calculated strength in each joint, and then lists the corresponding weld load and case to the ratio.

Joint	Case	Maximum Combined Weld Shear	Available Strength in Base	Available Strength in Weld	Ratio of Available Strength in Weld to Combined Shear
1 - Foot	16	118.4E+3	340.9E+3	343.2E+3	2.9
1 - Side	16	93.9E+3	340.9E+3	181.9E+3	1.9
2	11	68.1E+3	340.9E+3	217.9E+3	3.2
3	7	61.9E+3	340.9E+3	217.9E+3	3.5
4	10	26.4E+3	340.9E+3	217.9E+3	8.3
5	7	61.1E+3	340.9E+3	217.9E+3	3.6
6 - Head	7	129.8E+3	340.9E+3	343.2E+3	2.6
6 - Side	7	102.7E+3	340.9E+3	181.9E+3	1.8
7	11	121.1E+3	340.9E+3	217.9E+3	1.8
8	7	56.4E+3	340.9E+3	217.9E+3	3.9
9	16	26.3E+3	340.9E+3	217.9E+3	8.3
10	7	62.8E+3	340.9E+3	217.9E+3	3.5
11	5	97.9E+3	340.9E+3	181.9E+3	1.9
12	7	110.0E+3	340.9E+3	181.9E+3	1.7
13	7	64.2E+3	340.9E+3	217.9E+3	3.4
14	7	53.4E+3	340.9E+3	217.9E+3	4.1
15	2	26.9E+3	340.9E+3	217.9E+3	8.1
16	16	71.8E+3	340.9E+3	217.9E+3	3.0
17 - Foot	5	147.2E+3	340.9E+3	343.2E+3	2.3
17 - Side	5	116.7E+3	340.9E+3	181.9E+3	1.6
18	11	71.6E+3	340.9E+3	217.9E+3	3.0
19	7	52.7E+3	340.9E+3	217.9E+3	4.1
20	2	23.6E+3	340.9E+3	217.9E+3	9.2
21	9	69.0E+3	340.9E+3	217.9E+3	3.2
22 - Head	2	108.6E+3	340.9E+3	343.2E+3	3.2
22 - Side	2	86.2E+3	340.9E+3	181.9E+3	2.1

Maximum Axial Bolt Forces by Joint - 4g

Bolts are also compared in the following summary table by joint.

Joint	Case	Bolt Type	Max Axial Force	Ratio of Available to Calculated	Axial Strength
1	13	M12	6.3E+3	5.0	OK
2	9	M10	3.9E+3	5.6	OK
3	8	M10	136.3E+0	161.5	OK
4	9	M10	1.6E+3	13.9	OK
5	9	M10	4.8E+3	4.6	OK
6	13	M12	7.5E+3	4.2	OK
7	8	M10	7.8E+3	2.8	OK
8	9	M10	2.2E+3	9.9	OK
9	8	M10	1.4E+3	16.1	OK
10	8	M10	6.4E+3	3.4	OK
11	9	M10	4.5E+3	4.9	OK
12	9	M10	7.4E+3	3.0	OK
13	8	M10	8.9E+3	2.5	OK
14	9	M10	2.3E+3	9.7	OK
15	8	M10	1.3E+3	17.4	OK
16	8	M10	6.3E+3	3.5	OK
17	13	M12	6.1E+3	5.2	OK
18	9	M10	6.2E+3	3.5	OK
19	9	M10	3.0E+3	7.4	OK
20	13	M10	1.5E+3	14.6	OK
21	9	M10	4.9E+3	4.5	OK
22	13	M12	7.5E+3	4.2	OK

Maximum Shear Bolt Forces by Joint – 4g

Joint	Case	Bolt Type	Max Shear Force	Ratio of Available to Calculated	Axial Strength
1	8	M12	3.5E+3	5.5	OK
2	8	M10	837.1E+0	15.8	OK
3	8	M10	256.9E+0	51.4	OK
4	13	M10	207.1E+0	63.7	OK
5	9	M10	378.2E+0	34.9	OK
6	8	M12	4.8E+3	3.9	OK
7	8	M10	732.7E+0	18.0	OK
8	8	M10	316.6E+0	41.7	OK
9	9	M10	210.5E+0	62.7	OK
10	9	M10	438.3E+0	30.1	OK
11	9	M10	415.2E+0	31.8	OK
12	9	M10	650.6E+0	20.3	OK
13	8	M10	666.7E+0	19.8	OK
14	9	M10	285.4E+0	46.3	OK
15	8	M10	167.6E+0	78.7	OK
16	9	M10	469.4E+0	28.1	OK
17	8	M12	3.0E+3	6.3	OK
18	8	M10	800.3E+0	16.5	OK
19	8	M10	324.1E+0	40.7	OK
20	13	M10	199.8E+0	66.1	OK
21	9	M10	406.6E+0	32.5	OK
22	8	M12	3.7E+3	5.1	OK

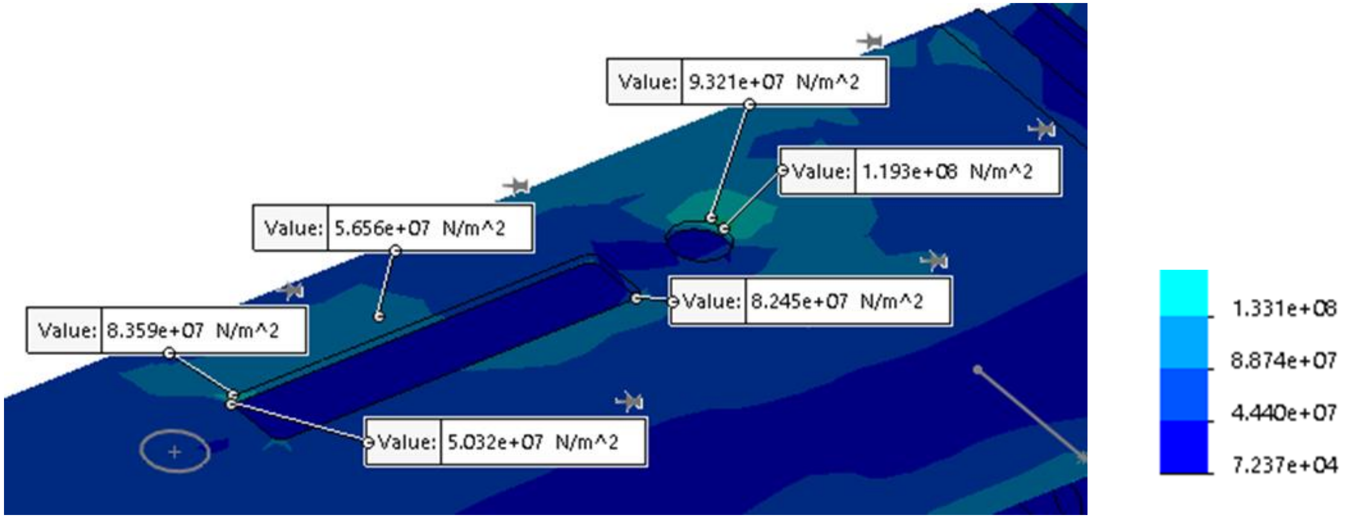
Weld Forces per Joint – 4a

Weld forces are also summarized by joint. The table below lists the lowest ratio of available strength to calculated strength in each joint, and then lists the corresponding weld load and case to the ratio

Joint	Case	Maximum Combined Weld Shear	Available Strength in Base	Available Strength in Weld	Ratio of Available Strength in Weld to Combined Shear
1 - Foot	13	214.4E+3	340.9E+3	343.2E+3	1.6
1 - Side	13	169.6E+3	340.9E+3	181.9E+3	1.1
2	9	153.4E+3	340.9E+3	217.9E+3	1.4
3	9	81.3E+3	340.9E+3	217.9E+3	2.7
4	13	58.6E+3	340.9E+3	217.9E+3	3.7
5	9	153.0E+3	340.9E+3	217.9E+3	1.4
6 - Head	13	138.1E+3	340.9E+3	343.2E+3	2.5
6 - Side	13	109.5E+3	340.9E+3	181.9E+3	1.7
7	9	137.7E+3	340.9E+3	217.9E+3	1.6
8	9	84.4E+3	340.9E+3	217.9E+3	2.6
9	13	47.2E+3	340.9E+3	217.9E+3	4.6
10	8	122.0E+3	340.9E+3	217.9E+3	1.8
11	9	140.0E+3	340.9E+3	181.9E+3	1.3
12	9	172.5E+3	340.9E+3	181.9E+3	1.1
13	8	155.6E+3	340.9E+3	217.9E+3	1.4
14	9	87.4E+3	340.9E+3	217.9E+3	2.5
15	9	55.9E+3	340.9E+3	217.9E+3	3.9
16	8	119.9E+3	340.9E+3	217.9E+3	1.8
17 - Foot	13	212.2E+3	340.9E+3	343.2E+3	1.6
17 - Side	13	167.5E+3	340.9E+3	181.9E+3	1.1
18	9	158.0E+3	340.9E+3	217.9E+3	1.4
19	9	100.8E+3	340.9E+3	217.9E+3	2.2
20	13	60.0E+3	340.9E+3	217.9E+3	3.6
21	9	135.1E+3	340.9E+3	217.9E+3	1.6
22 - Head	9	183.0E+3	340.9E+3	343.2E+3	1.9
22 - Side	9	146.2E+3	340.9E+3	181.9E+3	1.2

APA Slot investigation

- In order to keep analysis times reasonable, the PD slots were removed from the frame.
- Load case 9 with the 4g load was rerun with slots and stresses and forces checked.
- Maximum stress at the edge is 119MPa.
- Slots or no slots did not significantly affect Forces and Moments at the joints.



Cool down

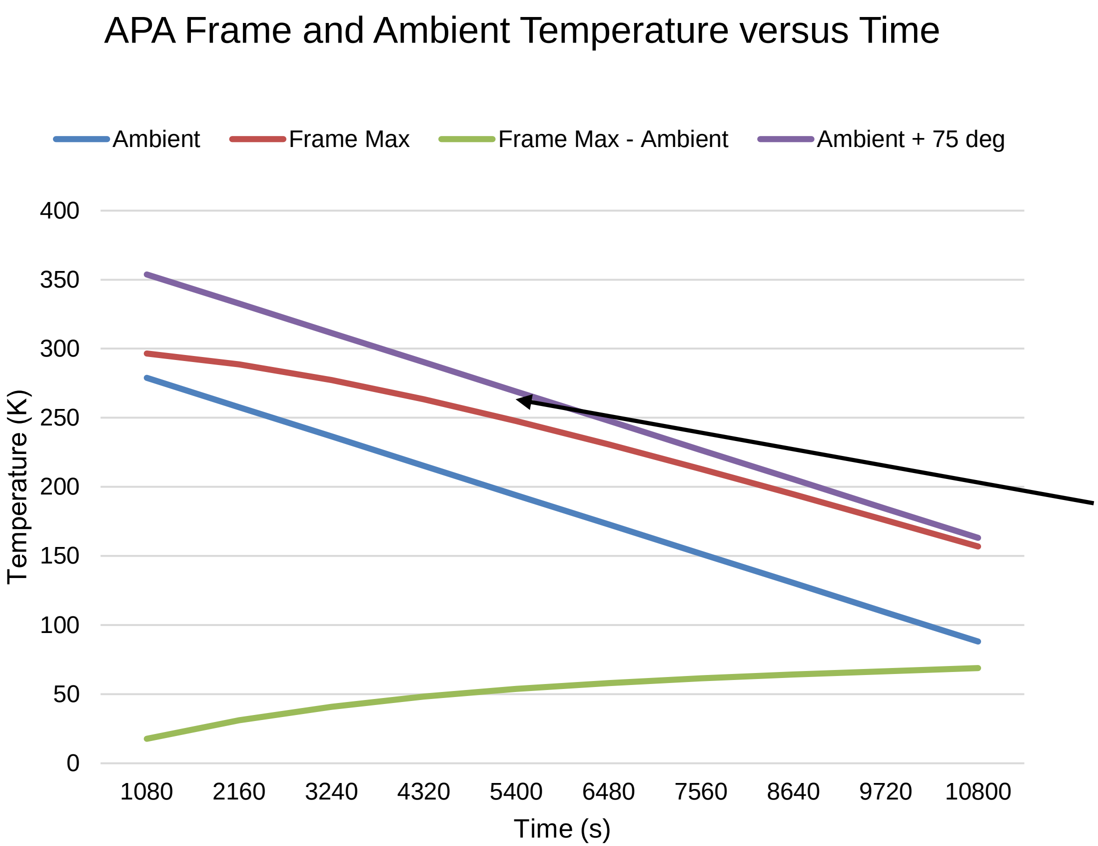
When an APA is quickly cooled, the wires will cool and contract faster than the frame. This will lead to an increase in tension in the wires and subsequent loading on the frame. In this case, 9N tension is applied to the frame. A limit of 9N tension equates to a delta T between the wires and the frame of 75 degrees C and ensures that the wire bonds are not overly stressed.

For this analysis it is assumed that the wire immediately follows the gaseous Argon temperature and the frame temperature. The rate that gaseous environment can cool down without exceeding the allowable temperature must be determined.

• Assumptions:

- Temperature-dependent thermal properties for GAr and SST 304.
- Cooling via free convection with film coefficients calculated using standard formulas.
    - Temperature dependent properties for GAr.
    - Frame temperature fixed at 300 K (conservative since film coefficients for a given delta-T increase with decreasing frame surface temperature).
- No cooling where boards mounted to head, foot, and side tubes. Cooling with 1/3 of calculated film coefficient on cross tube surfaces where comb bases are mounted.
- All surfaces designed to be in contact thermally bonded.

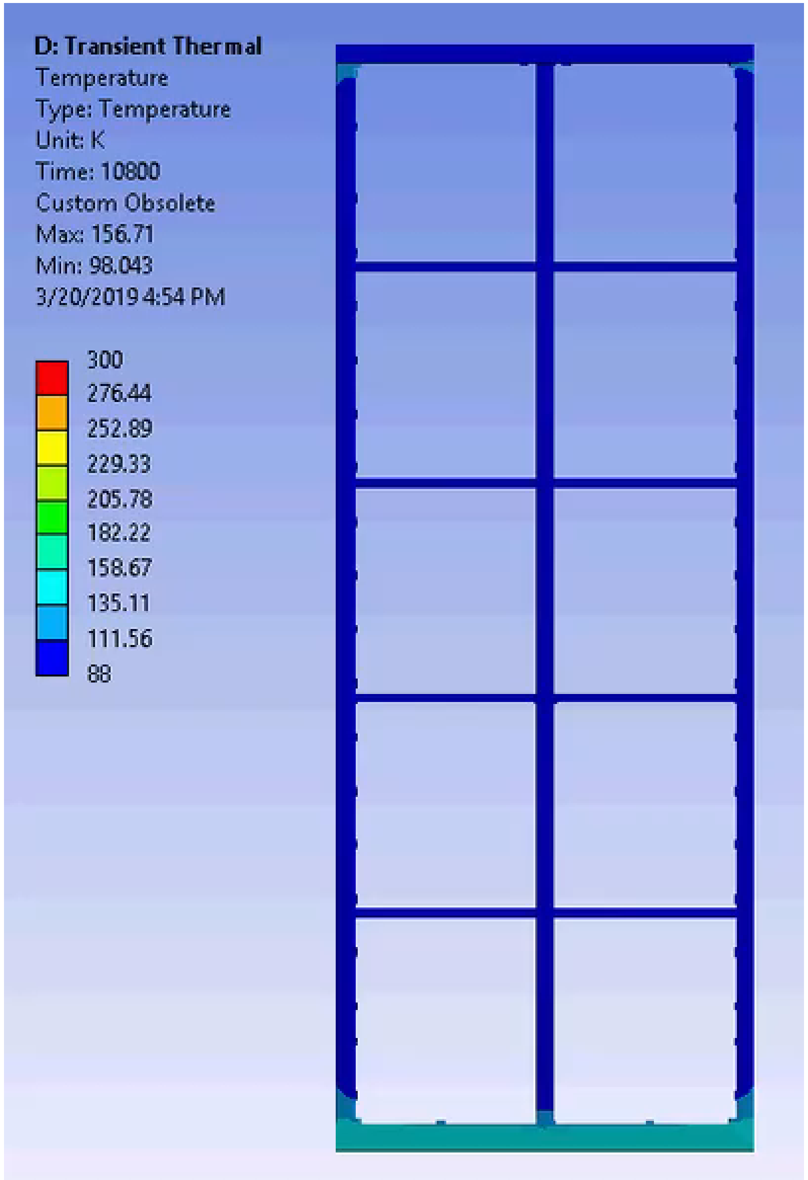
Results



Note: Because the film coefficients were calculated for a fixed temperature difference of 75 degrees, max frame temperature is generally understated so the temperature difference between wires and frame is expected to be larger than what is calculated. *However, given that the calculated maximum frame temperature does not at any time cross the uppermost curve, denoting a 75 degree temperature difference, it is assured that the actual temperature difference will not exceed 75 degrees since this would require film coefficients which are smaller than those calculated for that temperature difference.*

Therefore, this analysis shows that the temperature difference cannot exceed 75 degrees if cooldown is at or slower than 10800s (3 hours).

Results


D: Transient Thermal
Temperature
Type: Temperature
Unit: K
Time: 10800
Custom Obsolete
Max: 156.71
Min: 98.043
3/20/2019 4:54 PM
300
276.44
252.89
229.33
205.78
182.22
158.67
135.11
111.56
88

Weld Forces in Case 20 – High Tension

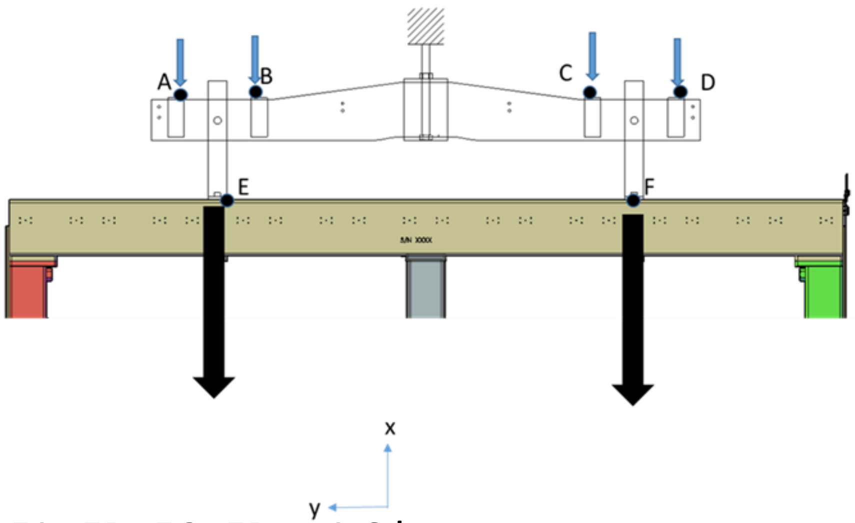
Load Case 20

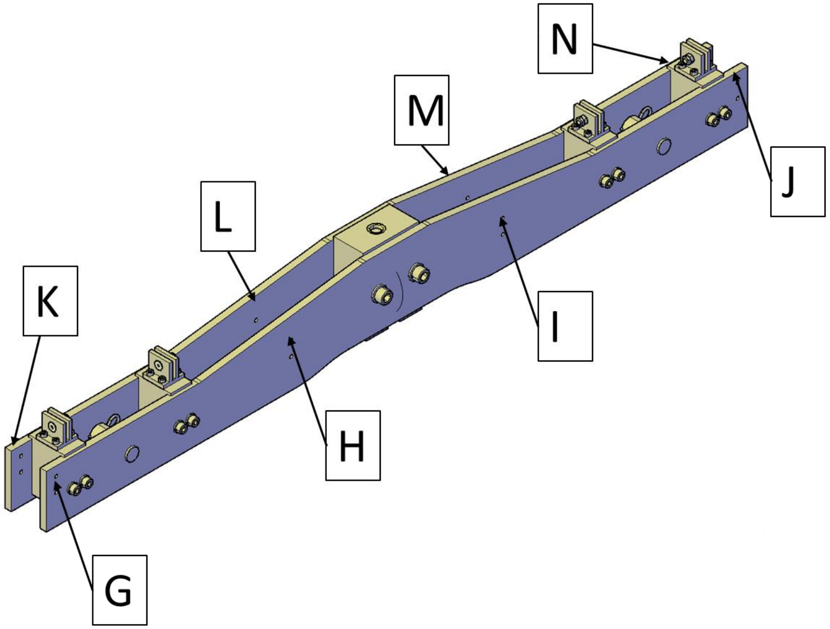
Weld	Combined weld shear (N)	Lowest available in base (N)	Lowest available in weld (N)
1 - Foot	143.3E+3	340.9E+3	343.2E+3
1 - Side	113.6E+3	340.9E+3	181.9E+3
2	30.0E+3	340.9E+3	217.9E+3
3	26.1E+3	340.9E+3	217.9E+3
4	24.2E+3	340.9E+3	217.9E+3
5	19.7E+3	340.9E+3	217.9E+3
6 - Head	49.2E+3	340.9E+3	343.2E+3
6 - Side	39.7E+3	340.9E+3	181.9E+3
7	24.6E+3	340.9E+3	217.9E+3
8	25.3E+3	340.9E+3	217.9E+3
9	22.5E+3	340.9E+3	217.9E+3
10	19.9E+3	340.9E+3	217.9E+3
11	53.0E+3	340.9E+3	181.9E+3
12	55.0E+3	340.9E+3	181.9E+3
13	25.1E+3	340.9E+3	217.9E+3
14	25.9E+3	340.9E+3	217.9E+3
15	23.5E+3	340.9E+3	217.9E+3
16	70.8E+3	340.9E+3	217.9E+3
17 - Foot	143.4E+3	340.9E+3	343.2E+3
17 - Side	113.6E+3	340.9E+3	181.9E+3
18	30.0E+3	340.9E+3	217.9E+3
19	25.7E+3	340.9E+3	217.9E+3
20	24.3E+3	340.9E+3	217.9E+3
21	59.4E+3	340.9E+3	217.9E+3
22 - Head	49.7E+3	340.9E+3	343.2E+3
22 - Side	40.2E+3	340.9E+3	181.9E+3

APA yoke – Installation case

Unbalance cable load on APA

Inputs:





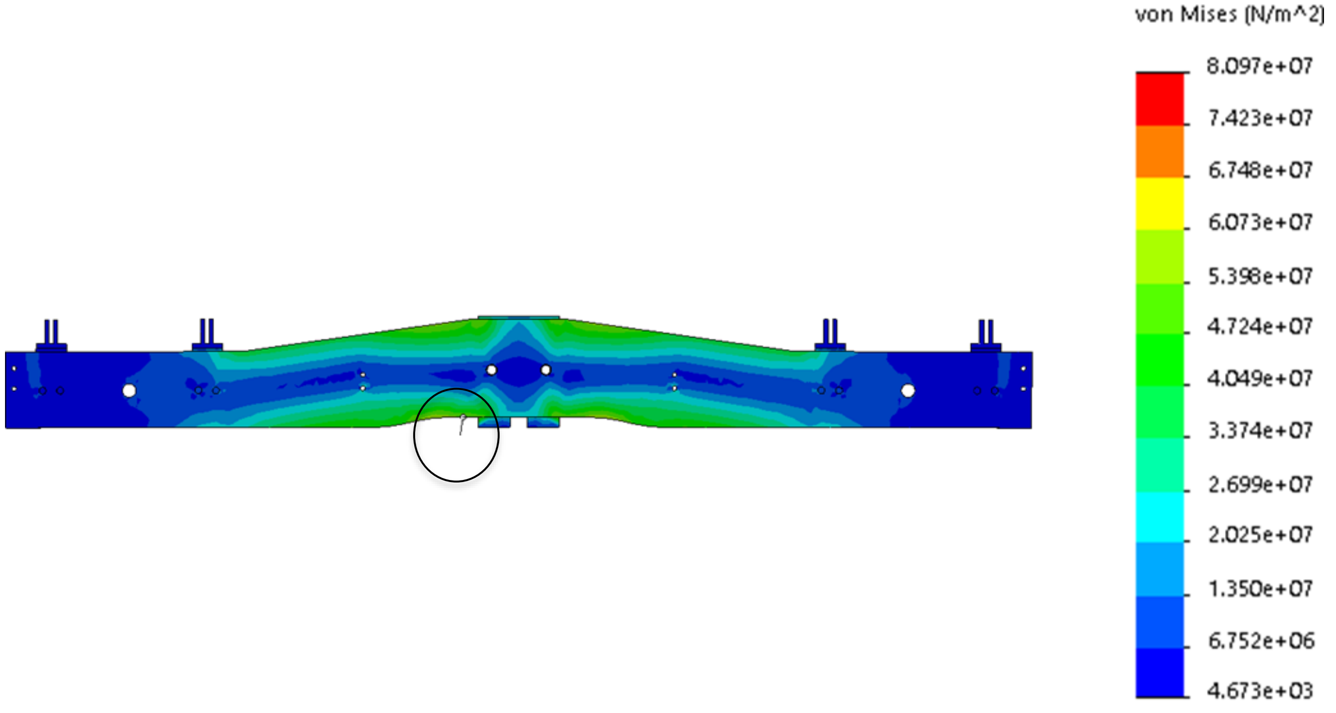
FA=FB=FC=FD==4.6 kg

FE=FF=960 kg

	G	H	I	J	K	L	M	N
Fx	611	369	370	607	-289	-131	-132	-226
Fy	-217	24.1	-19.4	219	40.8	-4.2	1	-44
Fz	859	534	536	851	-877	-517	-519	-899

APA yoke – Installation case

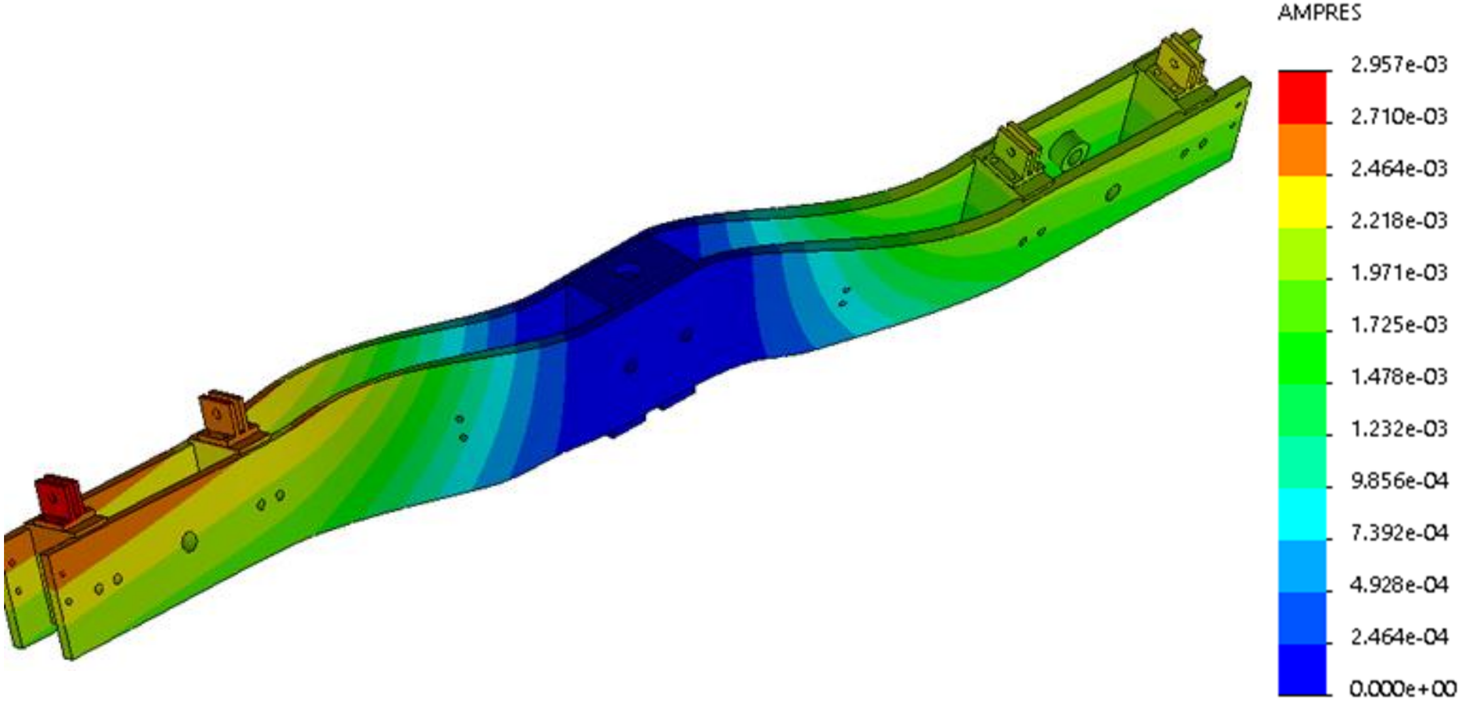
Unbalance cable load on APA
Results: Peak stress =81 MPa



APA yoke – Installation case

Unbalance cable load on APA

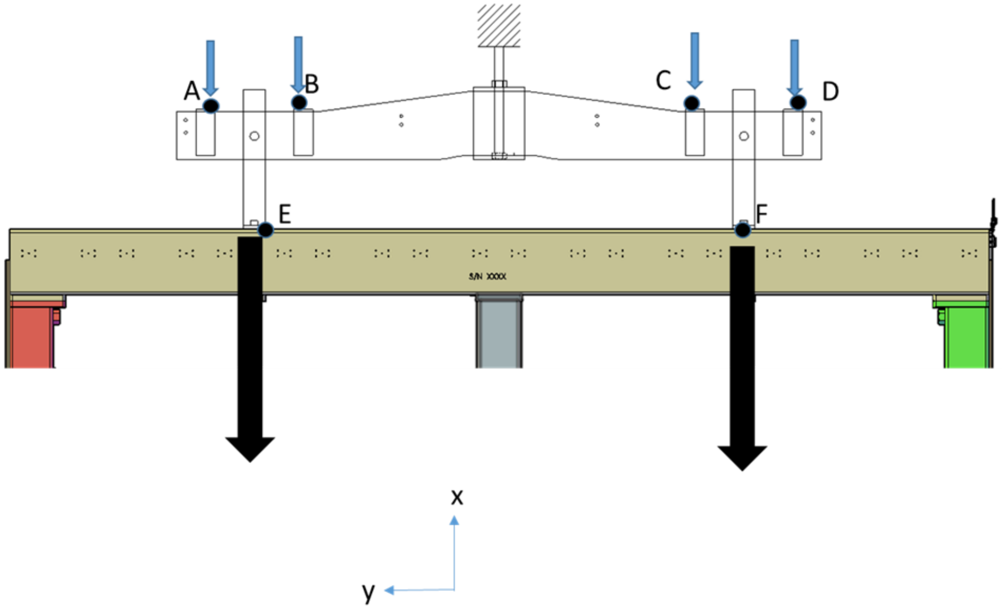
Results: 1st buckling load factor = 37.2



APA yoke – Installed APA

TOP CE cable tray transferred to DSS

Inputs:



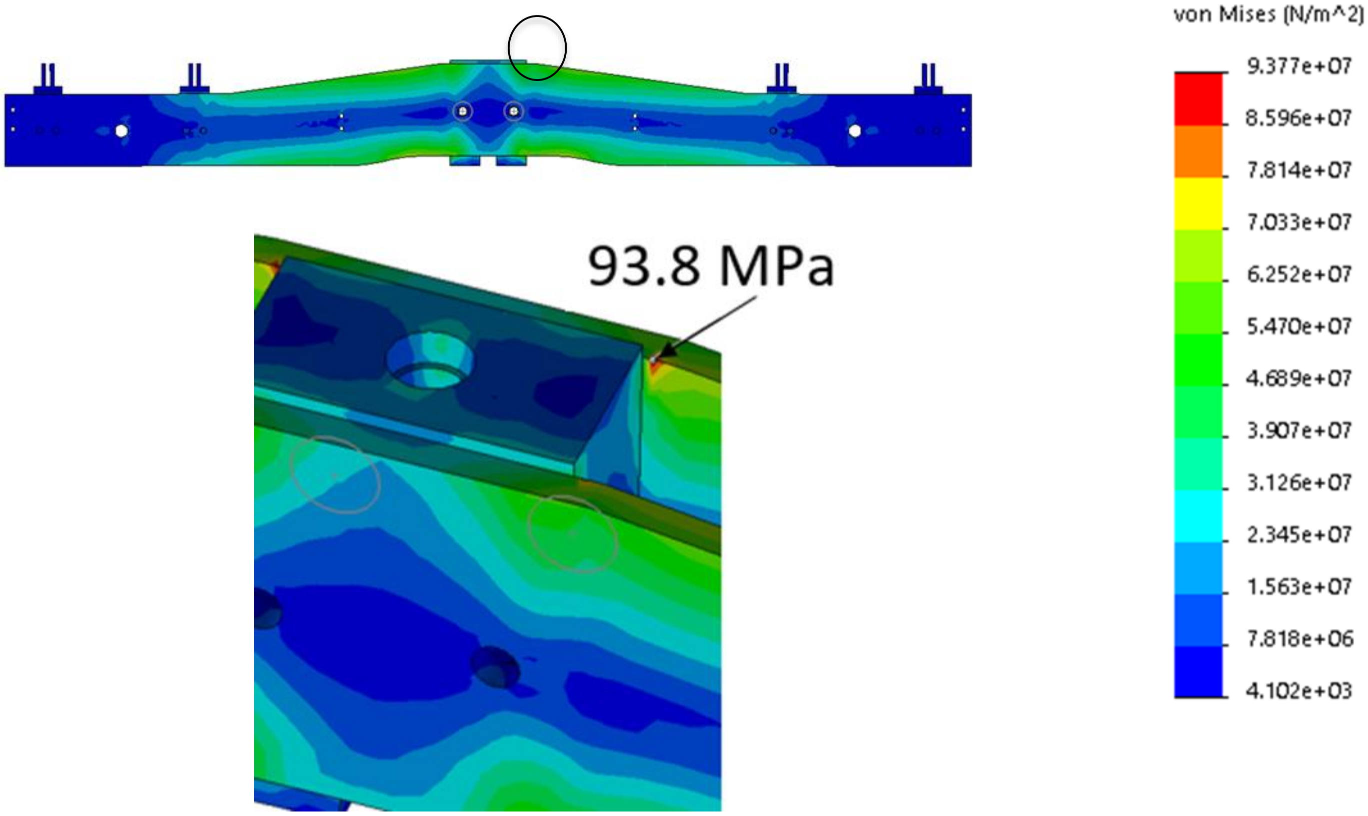
FA=FB=FC=FD==50.3 kg

FE=FF=1052 kg

APA yoke – Installed APA

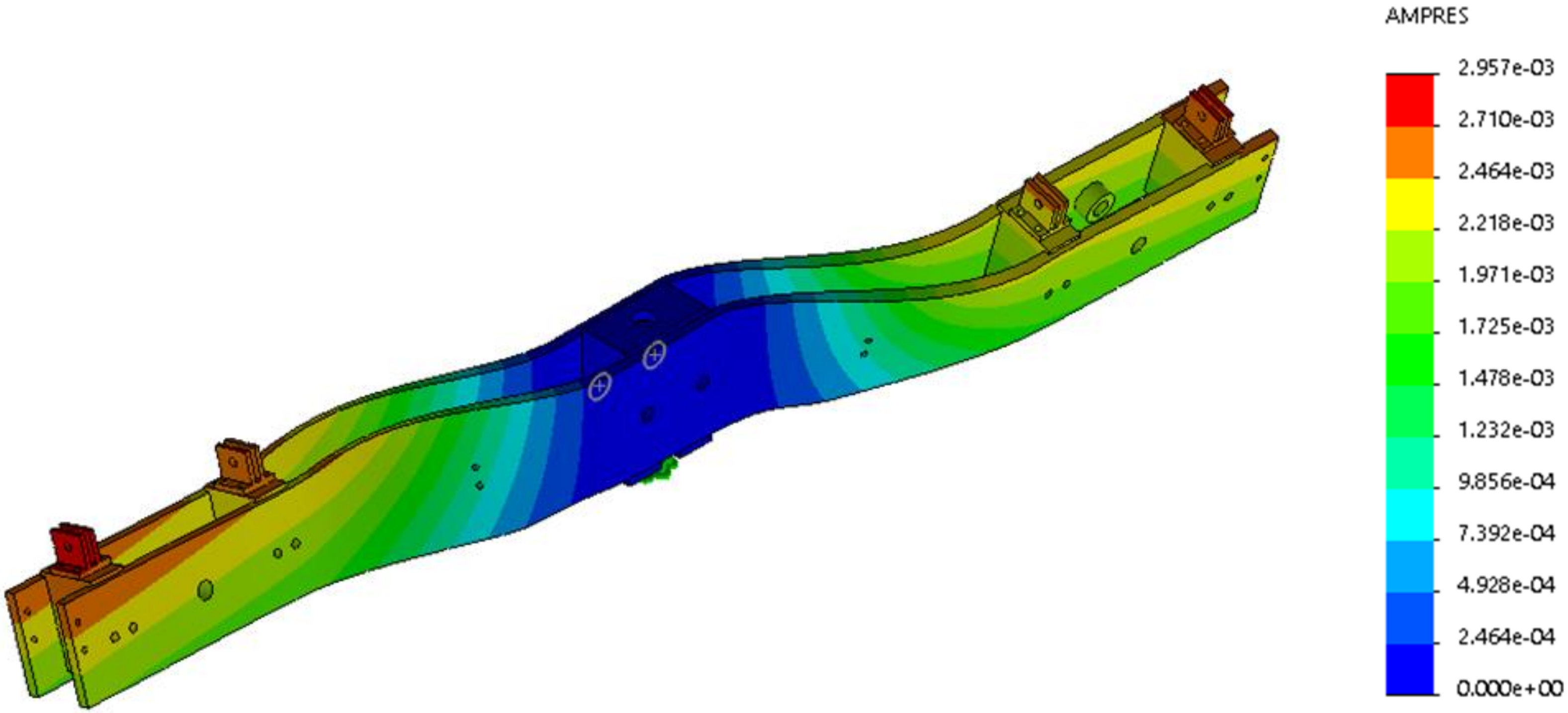
TOP CE cable tray transferred to DSS

Results: 93.8 MPa



APA yoke – Installed APA

TOP CE cable tray transferred to DSS
Results: 1st buckling load factor = 33.0

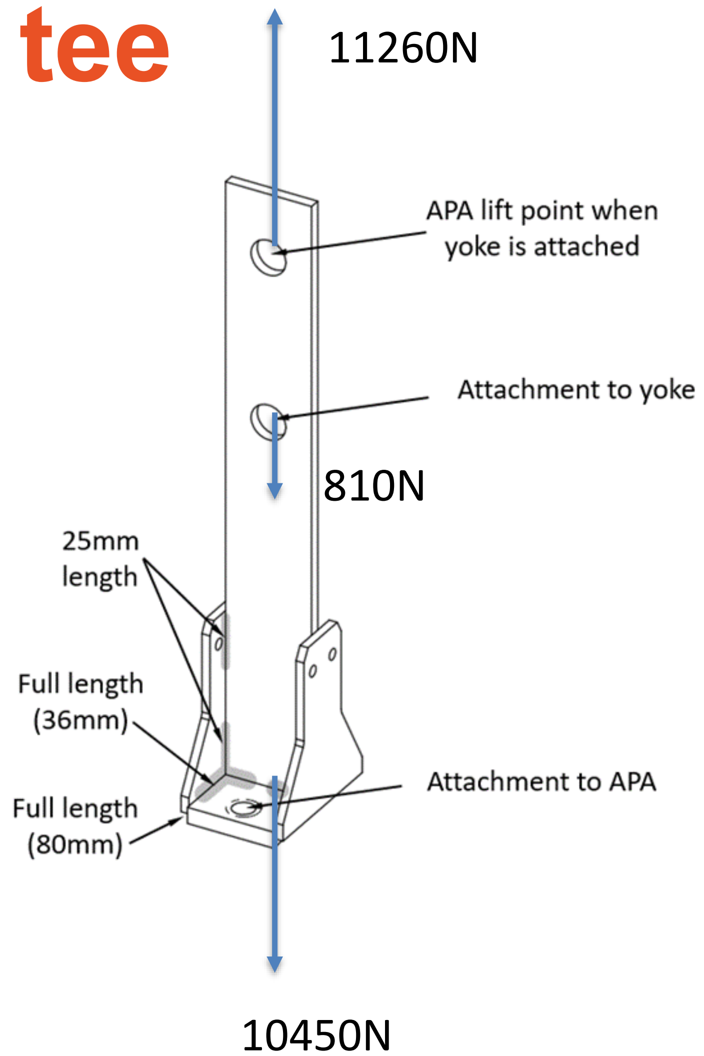


APA structural tee

Dimensions per drawing:

Loads: See figure.

Required Strength = 11260N



Loads on the structural tee

APA structural tee

Required Strength = 11260N

Vertical pinned link

Tensile rupture on net section

Available = 74600N

Tensile yielding on gross section

Available = 60100N

Tensile yielding on net section

Available = 38850N

Shear rupture on effective area

Available = 80820N

Bearing stress between pin and hole

Available = 35940N

APA structural tee

Welds

Available strength = 350N/mm

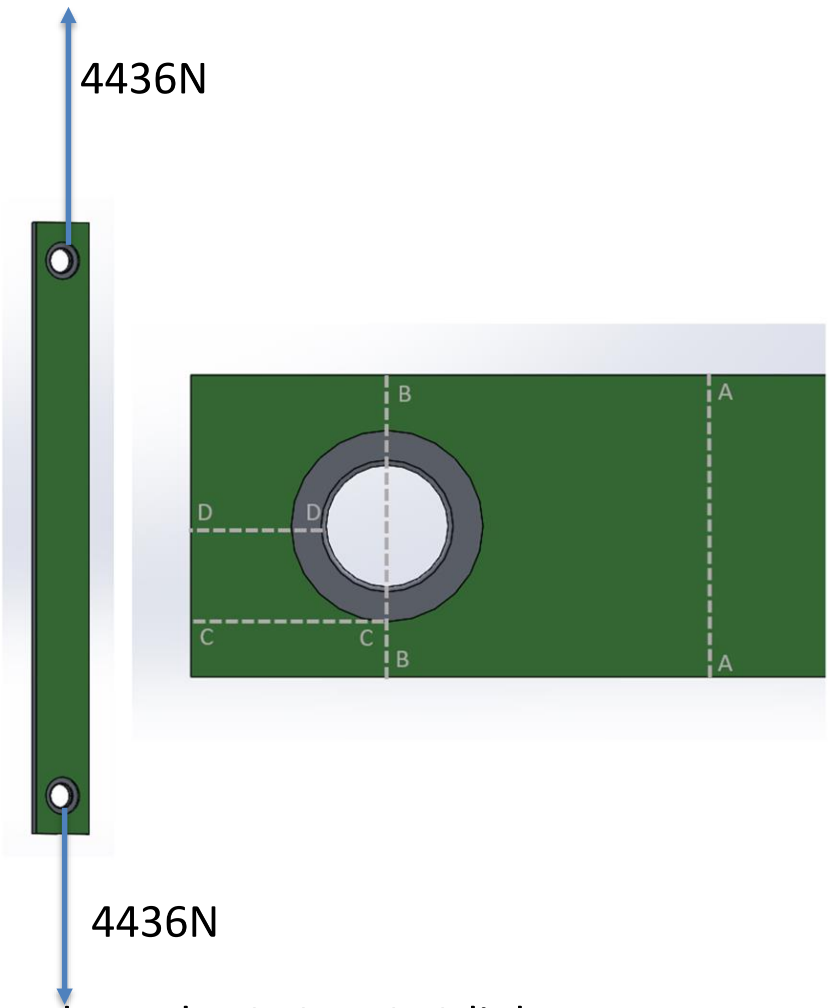
Unit load on vertical link to gusset welds = 52N/mm

Unit load on gussets to base plate welds = 34N/mm

APA to APA link

Dimensions per drawing:

Load: 4436N



Loads on the APA to APA link

APA to APA link

Results:

Required Safety factor for FRP 3.75

Tensile rupture on net area (line B-B)

SF = 10.7

Tensile rupture on gross area (line A-A)

SF = 17.9

Shear rupture on effective area

SF = 9.6

Bearing stress between pin and hole

SF = 7.2

APA to APA link

Assumptions:

Evaluation of stresses in the link due to the foot tube in the bottom APA cooling faster than the foot tube in the top.

Temperature assumptions:

Thermal special gradient at 17K/m

Head end of the bottom APA in LAr and foot tube at 88K

Top APA at temperature 9 m above the LAr = 241K

APA to APA link

The difference is shrinkage between the top and bottom = 4.6mm

The deflection at the midpoint of one link is 1.15mm.

The force to deflect the link 1.15 mm is 4N..

4N is insignificant compared to the 4436N supported by the link.

Conclusion

- FEA model and results have been verified in an independent analysis using ANSYS vs SolidWorks for the Case 17.
- The available strength of the APA structural members, weld joints, and bolted joints exceed the required strength:
  - For all cases under normal loading and room temperatures
  - For shipping and handling cases when a 4g acceleration is applied.
  - When subjected to a 17k/m spatial gradient or a linear cool down from room temperature to LAr temperature in 3 hours.
- The available strength of the yoke exceeds the required strength.
- The available strength of the structural tee base material and welds exceeds the required strength.
- The “ASD” safety factor of the link exceeds the minimum required.

Back ups

Weight of an APA

Mass Label	Mass Description	Support Location	Type of Load	Mass/ APA (kg)	Contin-gency %	Mass Total (kg)	Mass with Load Factor (kg)
Integrated APA (w/o yoke)							
m16	cover boards	side, foot, head	dist	13.9	5	14.6	20.4
m17	g-bias boards	head	dist	4.2	25	5.2	7.3
m18	CR boards	head	dist	7.7	2	7.8	11.0
m19	Adapter board	head	dist	3.3	2	3.4	4.7
m20	SHV connector bd	head	dist	0.4	25	0.5	0.7
m21	FC termination bd	head	dist	0.5	25	0.6	0.8
m22	CE brackets and tees	head	dist	6.0	2	6.2	8.6
m23	Structural Tee	head	dist	5.5	10	6.0	8.4
m24	Wire harness	head	dist	2.0	25	2.5	3.5
m25	PDs	side & center	dist	20.5	25	25.6	35.9
m26	CE boxes	head	dist	20.0	10	22.0	30.8
Subtotal integrated APA (w/o yoke)				537.5		568.2	795.5

Protection							
m27	Protection top	side, foot, head	dist	97.5	5	102.4	143.3
m28	Protection bottom	side, foot, head	dist	97.5	5	102.4	143.3
Subtotal APA with protection				635.0		670.6	938.8

Weight of an APA

Mass Label	Mass Description	Support Location	Type of Load	Mass/ APA (kg)	Contin- gency %	Mass Total (kg)	Mass with Load Factor (kg)
External loads							
m29	Cable conduit top		point	28.1	5.0	29.5	41.3
m30	Cable conduit bot		point	28.1	5.0	29.5	41.3
m31	Winder support bars		point	66.9	2.0	68.2	95.5
m32	Yoke bottom		point	10.5	25.0	13.2	18.4
m33	Yoke top		point	61.6	5.0	64.7	90.5
m34	APA bottom support beam		point	32.3	15.0	37.2	52.0
m35	Link		point	1.3	10.0	1.5	2.1
m36	Link hdw		point	0.2	10.0	0.2	0.3
m37	CE cables- in frame top		point	44.0	5.0	46.2	64.7
m38	CE cables- in frame bot		point	44.0	5.0	46.2	64.7
m39	Bot protection		point	14.0	2.0	14.3	20.0
m40	FC latches bot 4 total		point	24.4	25.0	30.5	42.7
m41	Diverter top		dist	10.0	10.0	11.0	15.4
m42	Diverter bottom		dist	10.0	10.0	11.0	15.4
m43	tie bars SS		point	1.8	10.0	2.0	2.8
m44	tie bars G10		point	0.2	10.0	0.3	0.4
m45	FC bottom		point	127.9	2.0	130.5	182.7
m46	CE cables and tray top		point	55.0	10	60.5	84.7
m47	FC latches top		point	12.0	10	13.2	18.5
m48	FC		point	127.9	2	130.5	182.7