



Mechanical Integration

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Design proposal for the LBNF APA trolley

Abstract:

This calculation note presents the structural assessment of the revised LBNF APA Trolley assembly in accordance with Eurocode 3

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1 Introduction

LBNF or Long Baseline Neutrino facility in USA will be home to the Deep Underground Neutrino Experiment (DUNE). DUNE, a collaborative experiment, begins at the Fermilab in Illinois where an intense neutrino beam is produced. Two detector facilities will attempt to observe the neutrinos' interactions with argon cooled to cryogenic temperatures. One of these detectors is placed near the source in Illinois, beyond this detector the beam travels 800 miles across Iowa to the Sanford underground research facility in South Dakota. The second, much larger facility will house 4 detector modules 1.5 km below ground, each 18x19x66 m in volume. The experiment aims to explain many unanswered questions about the neutrino particle such as the nature of neutrino oscillations, the mass of each flavour of neutrino and potentially discover new neutrino flavours that may be present in our universe. This knowledge could have a profound impact on the understanding of phenomena encapsulated by several physics fields including quantum physics and many cosmology disciplines.

Each Anode Plane Assembly (APA) takes the form of a panel and functions as a sensor for detecting charged electrons inside of the detector modules at DUNE. Each panel is 2.3m x 6m and to transport the panels into position inside each detector module a beam network and numerous hoist trolleys was selected as an appropriate method. The preliminary design of the trolley is pictured in *Fig 1*. The trolley traverses along an I-beam via eight 63 mm diameter flanged track rollers. The trolley side plate acts as a housing for a radial bearing and is connected to the bottom plate via three hex bolts. On the underside of each trolley there are four welded plates which form the connection between the trolley and saddles.

This report outlines an alternative design for the trolley element of the assembly which aims to improve the trolley's suitability to cryogenic testing and reduce it's number of parts.

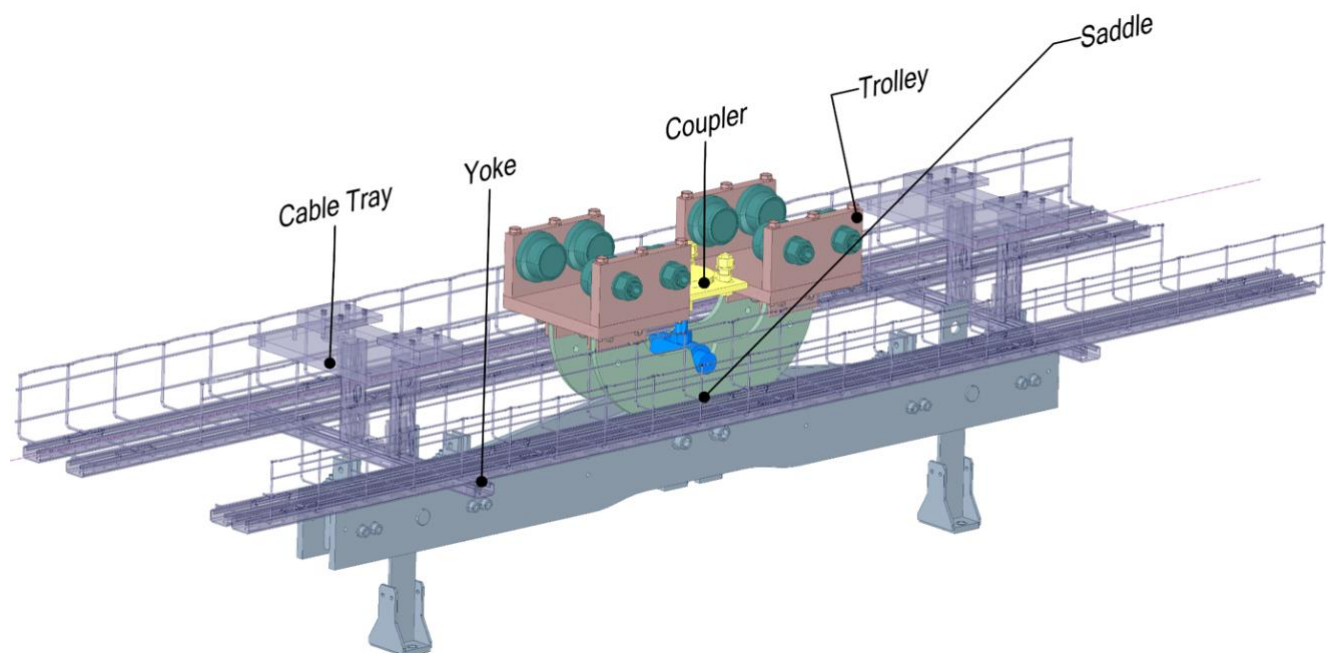


Figure 1: APA Hoist trolley preliminary design

2 Design Specification

Design core	Description
Performance	Trolley assembly should support the weight of the APA panel - 2000 <i>kg</i> Traverse at a speed less than 1 ms^{-1} along an I-beam Trolley suitably attaches to current APA attachment assembly Retain structural integrity despite thermal and mechanical stresses
Environment	Operational in liquid argon in the temperature range $-200^{\circ}\text{C} - 30^{\circ}\text{C}$ Operational in air between $-10^{\circ}\text{C} - 30^{\circ}\text{C}$ with slight exposure to moisture
Maintenance	No maintenance desired
Cost	Design and manufacturing costs desired to be low where functionality is not affected
Transportation	Dry transportation by air or sea
Quantity	At least 40 trolleys or 20 total assemblies
Manufacturing and processes	Low volume production so manual or semi-automated low economic batch size processes desired, with in house equipment
Size and weight	Trolley elements transportable by hand Design should be weight optimised for shipping Trolley width no more than 20% wider than DSS rail
Aesthetics and finish	Smooth finished
Materials	Sealed or self-lubricating bearings only Materials have similar CTE to avoid thermal induced stresses and poor alignment Ductile-brittle transition temperature $< -210^{\circ}\text{C}$
Standards and specifications	Eurocode 3 BS 8888 ISO
Ergonomics	Chamfer all over
Quality and reliability	Bought out parts inspected before integration Parts made in-house to be documented and manufactured according to GD&T practices to ensure accuracy and invariability.
Health and Safety	Design to be thermally and mechanically tested before approved
Installation	On site assembly via hand tools
Market	Customised necessity for experiment
End of life	Repurposable if possible, otherwise recyclable

3 Proposed redesign

A proposed redesign can be seen below in *Fig 1*. It uses the same centre block, saddle, DSS interface and APA hangers as the preliminary design and focuses on optimising the assembly above the saddle. Everything that is fastened to the Centre block will be referred to as the APA attachment assembly and the opposite will be called the trolley. The assembly as a whole will be termed the hoist trolley.

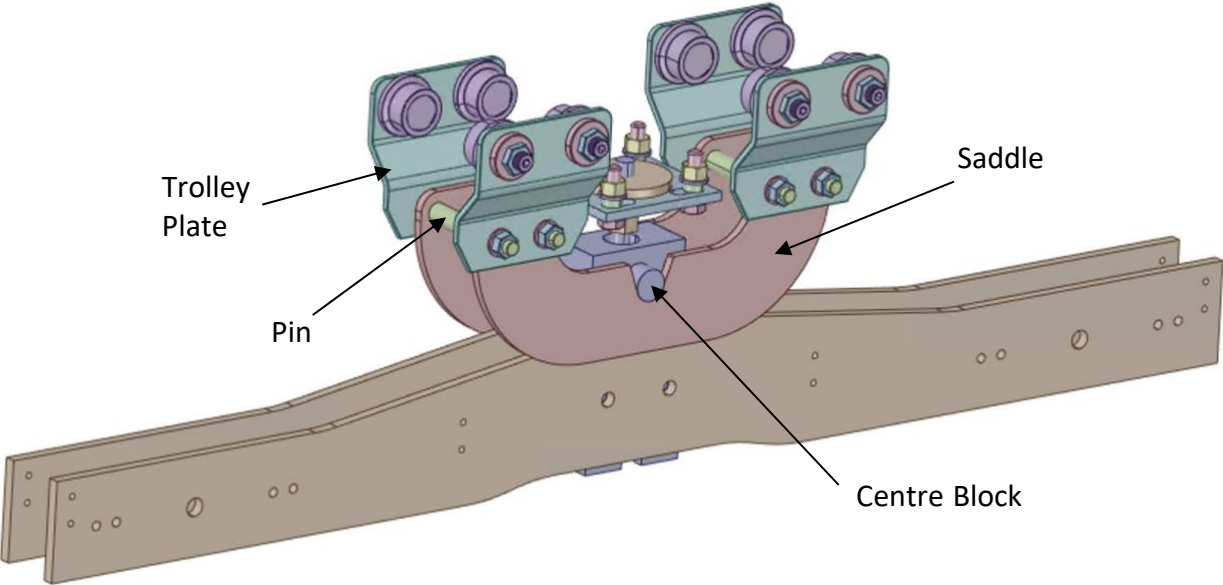


Figure 1: Proposed hoist trolley redesign

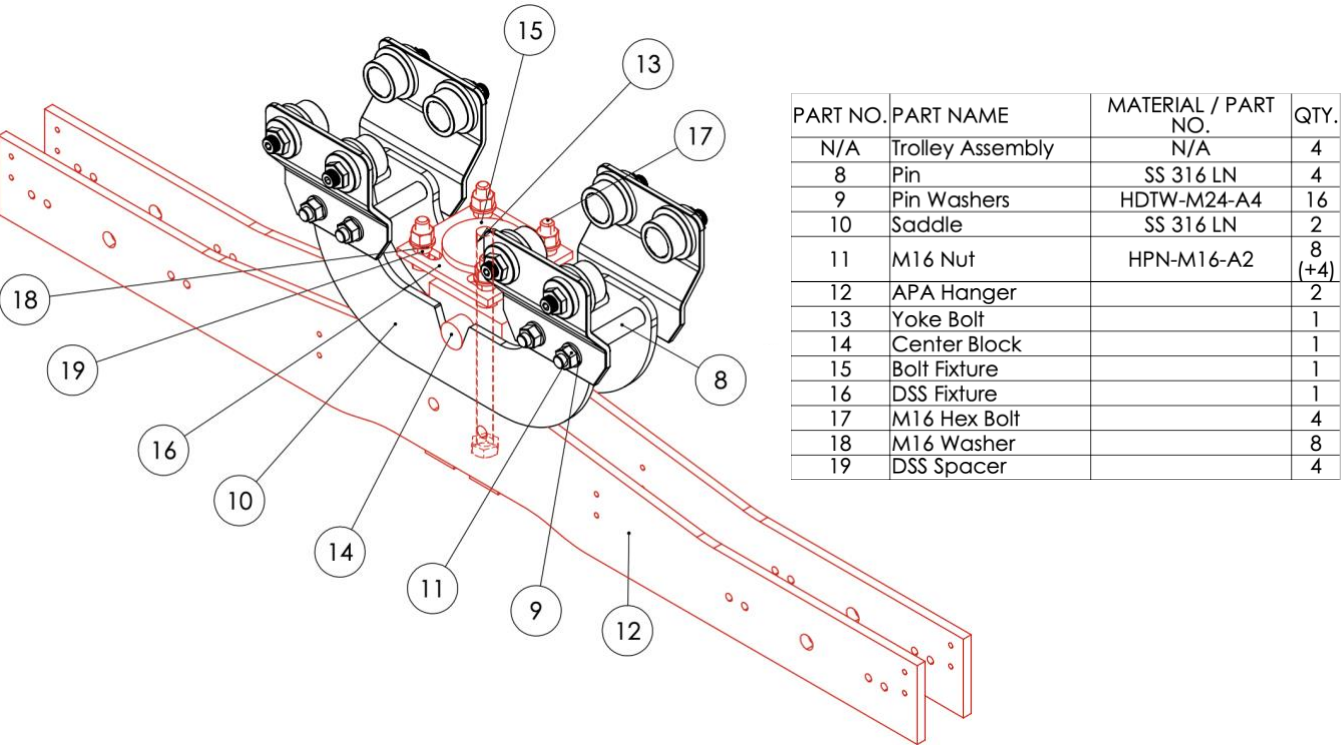


Figure 2: Bill of materials referencing the assembly of the hoist trolley, red outlines the APA attachment assembly.

4 Pin design

The proposed method of fastening and locating the saddles and trolley pairs is shown in *Fig 4*. The pin uses a step to separate the saddles and a washer to separate the trolley sides from the saddles. Since the pin has an M16x2 thread on either side, these components are then restrained against the outside of each trolley side by another washer and hex nut. Knowing the assembly and APA weight, the total force on each pin is 3770 N. The schematic in *Fig 3* shows half of the forces induced on each pin by the saddle and trolley side.

To ensure the pinned connection satisfies the Eurocode 3 standards it must have suitable shear, bearing, bending and combined shear bending resistances, *EN 1993-1-8 2005*. The following calculation note suggests that an M16 pin performs competently under the loading conditions.

Shear resistance	$F_{v,Rd} = \frac{0.6 \cdot A \cdot f_{up}}{\gamma_{M2}} \geq F_{v,Ed}$ $F_{v,Ed}$ is the largest shear force through the bolt which is an eighth the weight of the trolley = 1885 N	$F_{v,Rd} = r \frac{0.6 \cdot \pi \cdot 0.008^2 \cdot 5 \times 10^8}{1.25} = 48.25 \text{ KN}$ $48.25 \text{ KN} \geq 1885 \text{ N}$ $\therefore \text{OK}$
Bearing resistance	$F_{b,Rd} = \frac{1.5 \cdot t \cdot d \cdot f_y}{\gamma_{M0}} \geq F_{b,Ed}$ $F_{b,Ed} = 1885 \text{ N}$	$F_{b,Rd} = \frac{1.5 \cdot 0.008^2 \cdot 2 \times 10^8}{1} = 19.2 \text{ KN}$ $19.2 \text{ KN} \geq 1885 \text{ N}$ $\therefore \text{OK}$
Bending resistance	$M_{Rd} = \frac{1.5 \cdot W_{el} \cdot f_{yp}}{\gamma_{M0}} \geq M_{Ed}$ M_{Ed} from Figure 1 = $1885 \cdot 0.012 = 22.62 \text{ Nm}$	$M_{Rd} = \frac{1.5 \cdot 2 \times 10^{11} \cdot 2 \times 10^8}{1} = 6 \times 10^{19} \text{ Nm}$ $\therefore \text{OK}$
Combined shear and bending resistance	$\left[\frac{M_{Ed}}{M_{Rd}} \right]^2 + \left[\frac{F_{v,Ed}}{F_{v,Rd}} \right]^2 \leq 1$	$\left[\frac{22.62}{6 \times 10^{19}} \right]^2 + \left[\frac{1885}{48250} \right]^2 = 0.001526$ $\therefore \text{OK}$

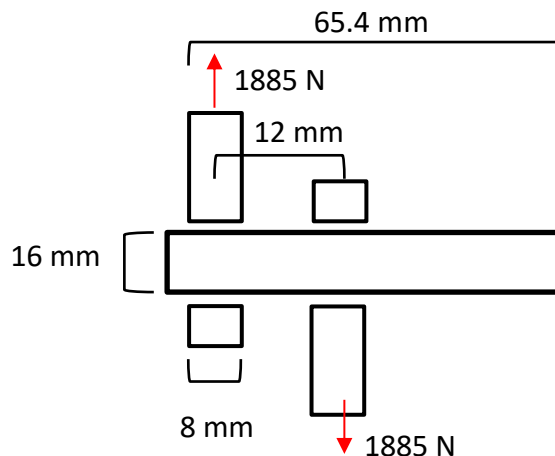


Figure 3: Pin connection between saddle and trolley side. Dotted line indicates a mirror.

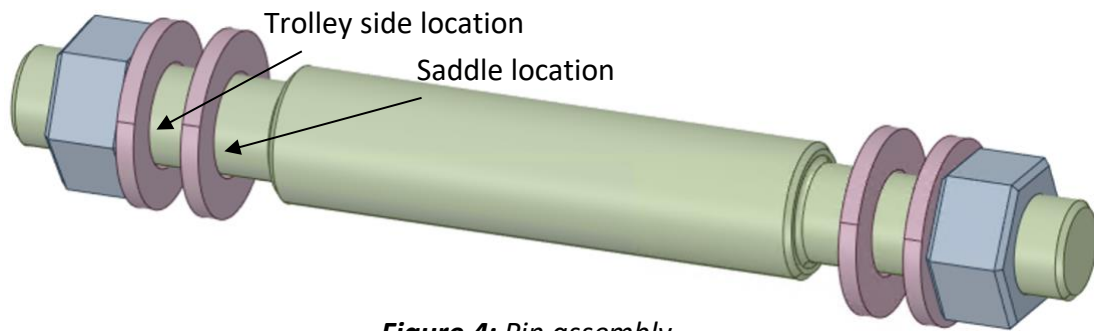


Figure 4: Pin assembly

The pin will be manufactured on a lathe and since all features are concentrically toleranced it is logical to set up an axis defined by two holes which will provide the references for an imaginary straight axis. These datum features will be selected by the manufacturer from ISO 1614.

5 Plate design

The trolley plate transfers the bearing loads from the lower pair of trolley bores to the upper trolley bores. These upper bores provide a means of securing the roller assemblies. A Z-bend can be seen in the plate featuring internal radii of 8 mm which is equal to the plate thickness and appropriate for many bending techniques, *MetalFormingMagazine 2008*. Table 1 details the geometry parameters and machine setup requirements in order to create the bends in Fig 5.

The upper bores are 23 mm in diameter of tolerance H7, this enables a PTFE lined stainless steel flanged bushing to be inserted from behind the view shown in Fig 5. From the front of the plate counterbores can be seen on the upper bores, these are 44.5 mm in diameter and 0.75 mm deep. These counterbores enable thrust washers to be located and feature dowel holes used to provide circumferential location, these design features are as advised by SKF.

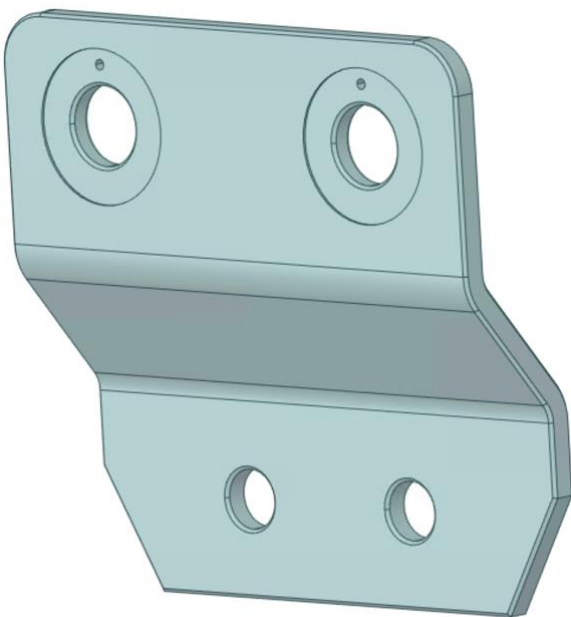


Figure 5: Hoist trolley plate

Table 1: Preliminary bending data according to Velling 2019.

Thickness <i>t</i> [mm]	Die Width <i>V</i> [mm]	Minimum Flange length <i>b</i> [mm]	Internal radii <i>r</i> [mm]	Tonnage per m
8	50	35	8	85

6 Roller design

Steel flanged track rollers were selected since they mate well with I-beams and are suitable for combined radial and thrust loads. They have a 20 mm stud diameter, 52 mm roller diameter, permanently lubricated and sealed. The total weight of the APA panel and trolley dictates a required radial load per roller of 1885 N. The selected rollers have a radial static load capacity of 1620 lbs which is around 7200 N. Therefore, for our application a factor of safety of 3.8.

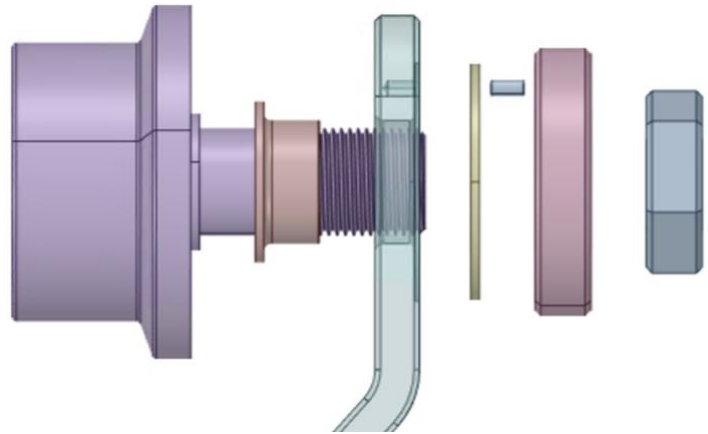


Figure 6: Roller-trolley side assembly

The rollers are not sufficient for use within cryogenic testing because the lubricant will solidify. For example, even SKF's best performing low temperature lubricants are only suitable to -50°C , SKF. To add this functionality a stainless-steel PTFE lined flanged bushing is housed in the trolley plate with a thrust washer embedded in the opposite side.

After cold testing the hoist trolley assembly 24 hours should be allowed for it to return to room temperature before moving. At this point it is predicted that the lubricant inside the rollers will return to a liquid state and operate as intended, if this is not the case the lubricant free elements are present in the mechanism and will enable any movement the trolley is required to perform between testing and dismantling.

6.1 Bearing ratings

The bearing components are not required to operate at high speeds or for many revolutions. The trolley will not need to travel at a speed higher than 1 ms^{-1} , since the rollers are 52 mm in diameter this demands a angular velocity of 38.5 rads^{-1} or more importantly a sliding velocity of 0.77 ms^{-1} . Furthermore each trolley will not need to travel further than 10 km in it's lifetime, considering the wheel radius this translates to a required L_{10} rating of 0.06.

Table 2: Bearing data

Parameter	Thrust Washer	Flanged Bushing
SKF product code	PCMW 264401.5 E	PCMF 202311.5 E
C Basic dynamic load rating	78 kN	14.3 kN
C_0 Basic static load rating	245 kN	45 kN radial 54 kN axial
K Specific dynamic load factor	80 N/mm^2	80 N/mm^2
K_0 Specific static load factor	250 N/mm^2	250 N/mm^2
Maximum Permissible sliding velocity	2 ms^{-1}	2 ms^{-1}
μ Coefficient of friction	0.25 - 0.03	0.25 - 0.03

7 Materials

Table 3: Summary of material properties. *Data from Granta Design Limited, 2009. Other data referenced from Hrivnak 2021.

Material	Physical Properties					Thermal Properties		Mechanical Properties		
	Density [kg/m ³]	Poisson ratio [–]	Young modulus [GPa]	Shear modulus [GPa]	Mean CTE [1/k · 10 ⁶]	Thermal conductivity [W/mK]	Specific Heat [J /kgK]	Yield strength Rp0.2 [MPa]	Tensile strength Rm [MPa]	Elongation A %
Invar 36	8100	0.28- 0.30	153.95	55.15	0.95	13.73	515	240	490	42
SS 304 L	7930	0.30	200	76.92	15.50	14.85	473	200	500	45
A4-80								600	800	30
SS 316 LN*	8000	0.27- 0.29	195-205	75-85	16.5-17.5	14.4-15.6	500	280	580-780	35-50

The Hoist trolley and DSS rail is constructed from the materials listed in *table 3*. In general, the DSS is made from Invar 36, the pins/some plate elements from SS 316 LN, the trolley plate from 304 L and the fixtures from A4-80. Materials have been considered to prevent: cold welding, failure by ductile-brittle transition phenomena and misalignment by significant CTE variation across fastened components.

8 Cost Bill of Materials

Table 4: Possible costing bill of materials for 40 total trolley assemblies, including spares. *meaning manufactured according to a drawing either onsite or by an external company.

Part	Source	Product code	No per assembly	Total	Cost
Wheels	McMaster- carr	6318K118	8	320	\$27,292.80
Flanged bushing	SKF	PCMF 202311.5 E	8	320	€ 1,107.60 Via https://fr.rubix.com/fr/
Thrust washer	SKF	PCMW 264401.5 E	8	320	Possible purchase via https://shop.eriks.be/en/
Heavy Washer	ACCU	HDTW-M20-A4	8	320	£480
Nut M20	ACCU	HFNF-M20-1.5-A4 (- BL)	8	320	£441.60
Dowel M3	ACCU	HDP-3-5-A1	8	320	£32
Washer M24	ACCU	HDTW-M24-A4	16	640	£1043.20
Nut M16	ACCU	HPN-M16-A2	8(+4)	320	£118.40
Trolley Plate	IN HOUSE*	-	4	160	-
Pin	IN HOUSE	-	4	160	-
Saddle	IN HOUSE	-	2	80	-

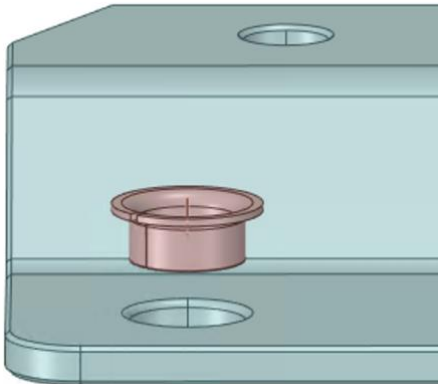
Table 4 details the trolley assembly, this is because the focus of this document was to redesign the trolley subassembly, validate the design choices and detail its cost as a subassembly. These details for the APA attachment subassembly are present in its supporting design documents. Finally, the fixtures detailed in

the table are sourced to dictate geometrical form and appropriate threads required. The source of these parts may be changed if other materials are preferred.

9 Assembly Protocol

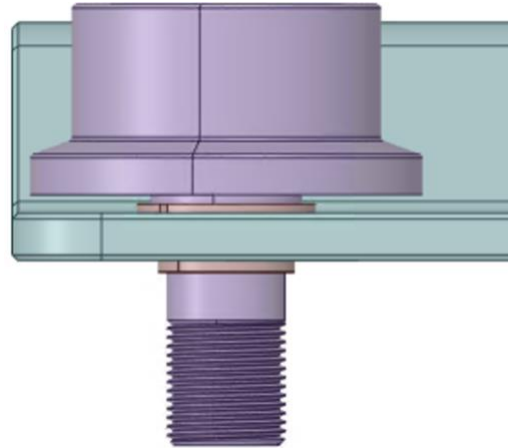
9.1 Trolley Assembly

1.



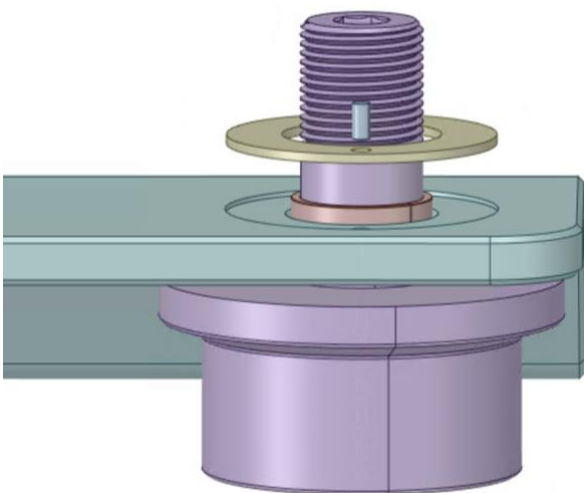
Ensuring that the trolley housing is clean, deburred, and clear of any damaging defects, proceed. Place plate counterbore side down and use a mounting dolly (specifically M20 f7) to drive the bushing all the way to the flange via hydraulic press or hammer. Do not cover the housing hole as the bushing will protrude from it. Light grease may be applied to the outside of the bushing to facilitate this.

2.



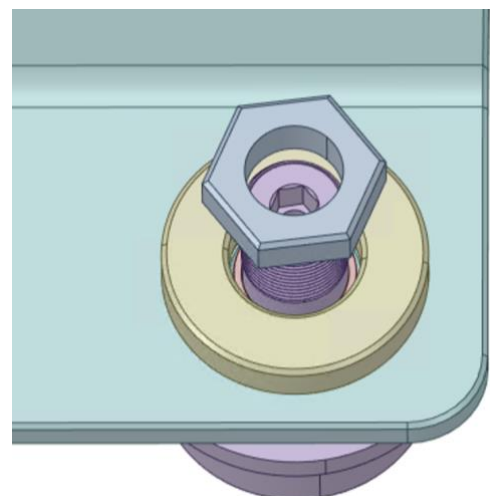
Place a flat object over the entirety of the roller and Press/lightly hammer the object to mate the roller shoulder up against the flange or the bushing.

3.



Slide thrust washer with PTFE side facing upwards into counterbore and tap dowel into hole until it is sunk inside the washer.

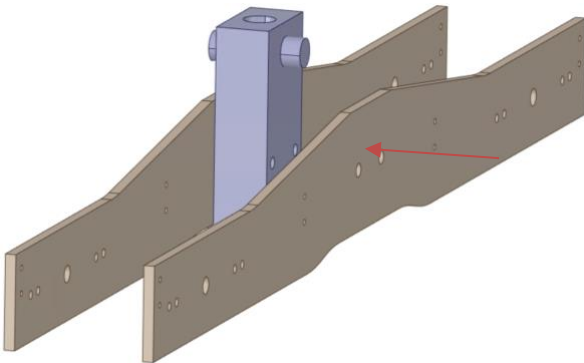
4.



Align M24 washer concentrically with roller thread and tighten M20 nut against washer ensuring radial clearance between flanged bushing and washer is maintained. Repeat 1-4 for all upper holes of Trolley Plates (x8 total).

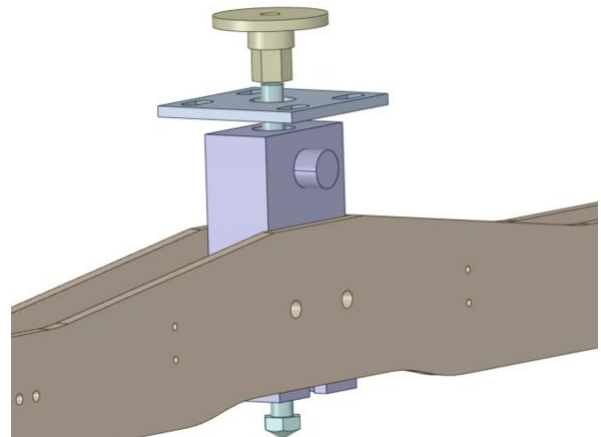
9.2 APA attachment Assembly

1.



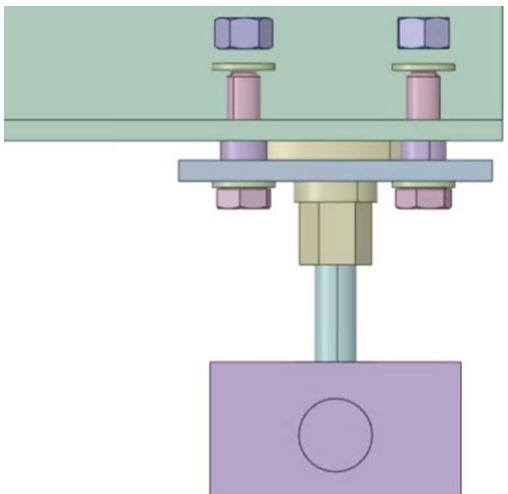
Locate the APA hangers against the centre block and secure with two hex bolts through the two central holes.

2.



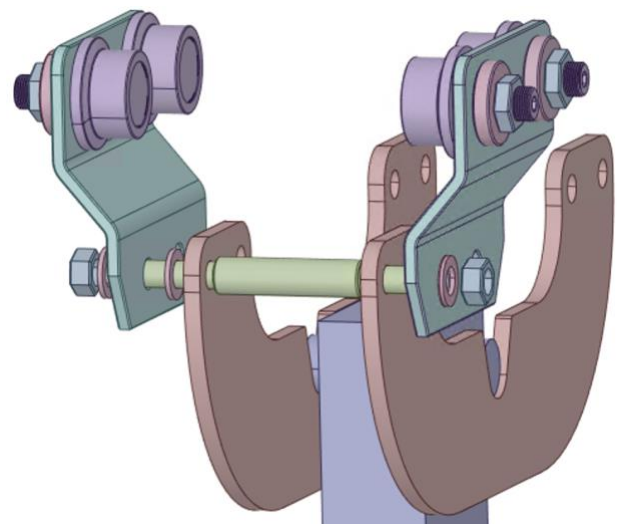
Insert Yoke bolt from the underside of the Centre block, slide DSS fixture over the bolt and screw the Bolt fixture onto the Yoke bolt.

3.



From below DSS fixture insert M16 washer and bolt, then place spacer between DSS fixture and rail. Push M16 Bolt through the DSS rail and fasten with washer and nut. This assembly will now be simplified to be the block for ease of illustration.

4.



Slide the top left-most hole of a saddle against the shoulder of the pin and the washer up against the saddle. Repeat this for both ends of the pin.

Simultaneously hang the trolley assemblies on the DSS rail and locate the pin in the lower holes as seen. Fasten another washer and nut on the pin against the outside of each trolley plate. Repeat 4. for all upper saddle holes.

Loosen M16 DSS attachment bolts gradually while using assistive equipment to lower the APA attachment assembly into the the trolley saddles so that the centre block cylinders can lie in the arced path of the saddles. Hoist trolley assembly is now ready to traverse along DSS rail.

10 Finite element model

The structural behaviour of the Hoist trolley was evaluated by finite element analysis using ANSYS 2020 R1, with the main objectives being to evaluate the stress and deformation of the assembly.

10.1 Models description

The models were constructed by making use of the two planes of symmetry, over which mirror the geometrical and loading features of the structure. Therefore, only a quarter of the model was modelled for computational efficiency. The model was discretized using the solid element SOLID185 only. Specifically, 255,880 nodes or 283,942 elements, *Grivnak 2021; Fig 7*.

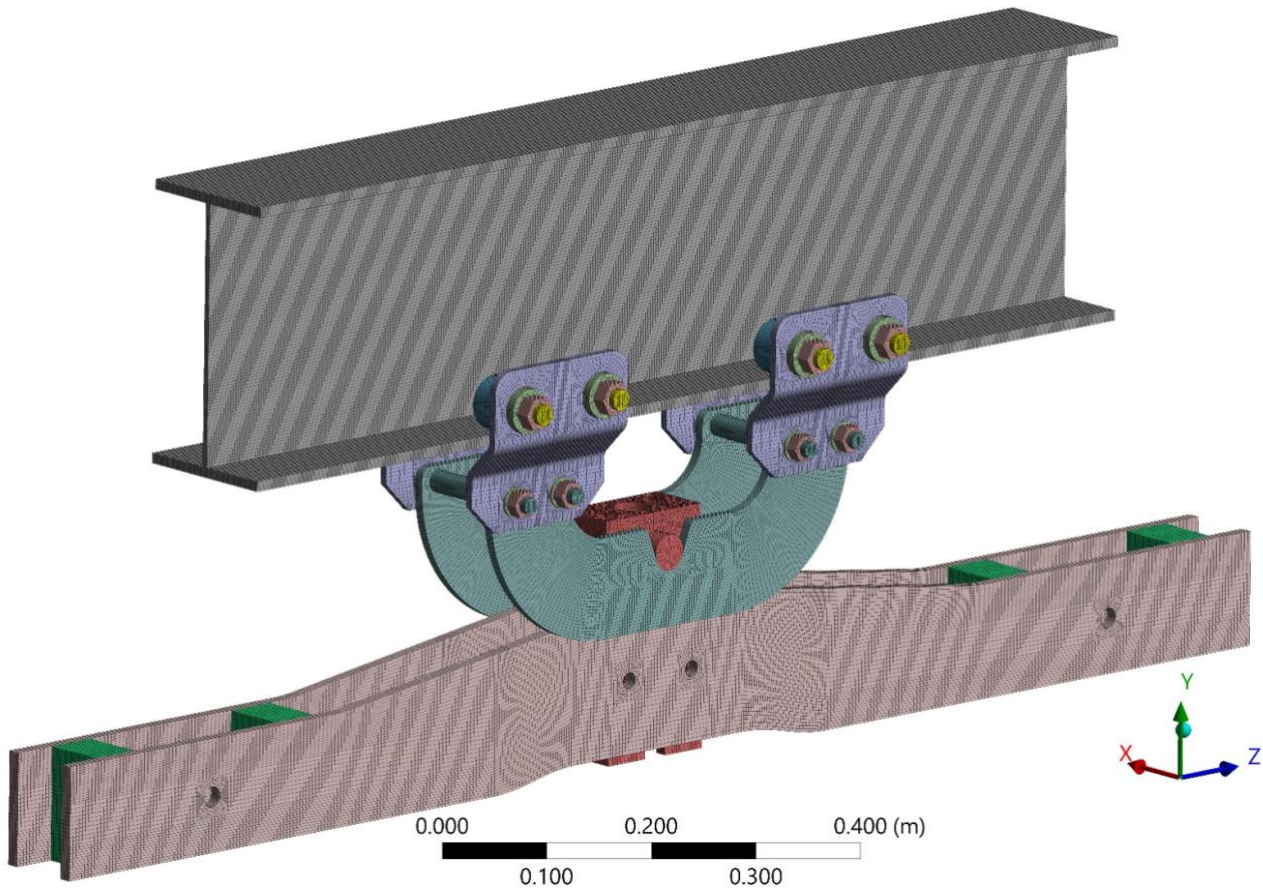


Figure 7: Mesh used for the Hoist trolley, mirrored across z and x axes to show effective full model.

10.2 Boundary conditions and loading

For the simulation of the Hoist trolley assembly, all DOF at the ends of the DSS rail have been restrained through a remote displacement boundary condition. Two load conditions have been considered in accordance with the EN structural regulations, *Fig 8*:

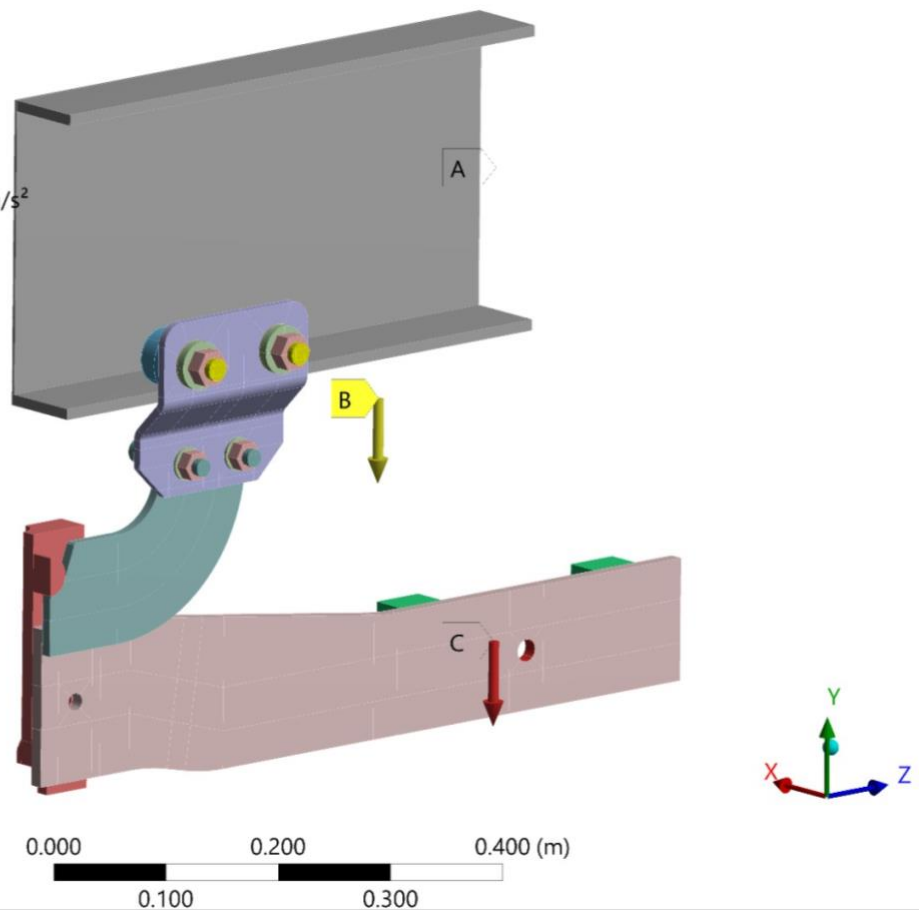
- **SLS**: one quarter of the dry APA panel weight, found in *EDMS 2281422*, is applied to the yoke. This load is used for the deformation calculations.
- **ULS**: forces from **SLS** amplified by a safety factor of 2, which overcompensates for the current standards for permanent loads which is 1.35. this load is used to investigate the stresses induced on the structure, as required by *Eurocode 3*.

C: Static Structural

Static Structural_SLS

Time: 1. s

- A** Remote Displacement
- B** Standard Earth Gravity: 9.807 m/s^2
- C** Remote Force: 3770 N



C: Static Structural

Static Structural_ULS

Time: 2. s

- A** Remote Displacement
- B** Standard Earth Gravity: 9.807 m/s^2
- C** Remote Force: 7540 N

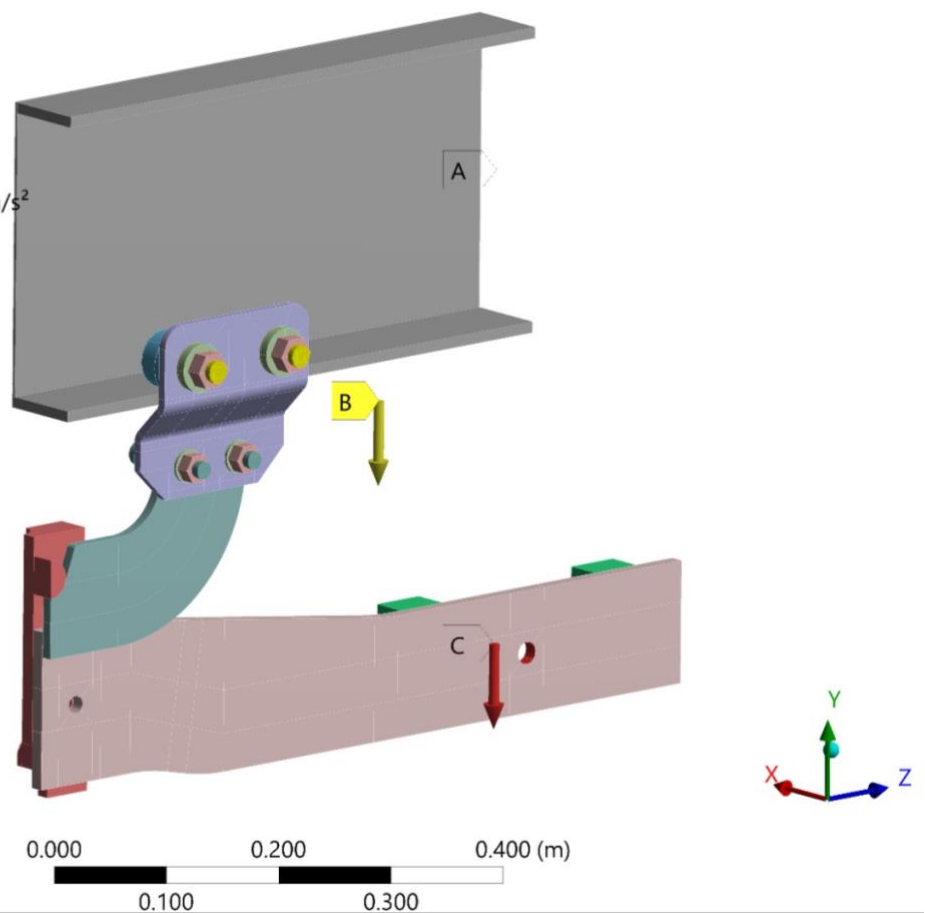


Figure 8: Quarter model loading and boundary conditions for SLS (top) and ULS (bottom)

11 Results from Finite Element Analysis

The total deformation for the **SLS** load conditions is shown in *Fig 9*. From the figure the maximum total displacement of the hoist trolley assembly is 1.13 mm. Note that the displacement is cumulative and therefore should not be compared to individual part deformation.

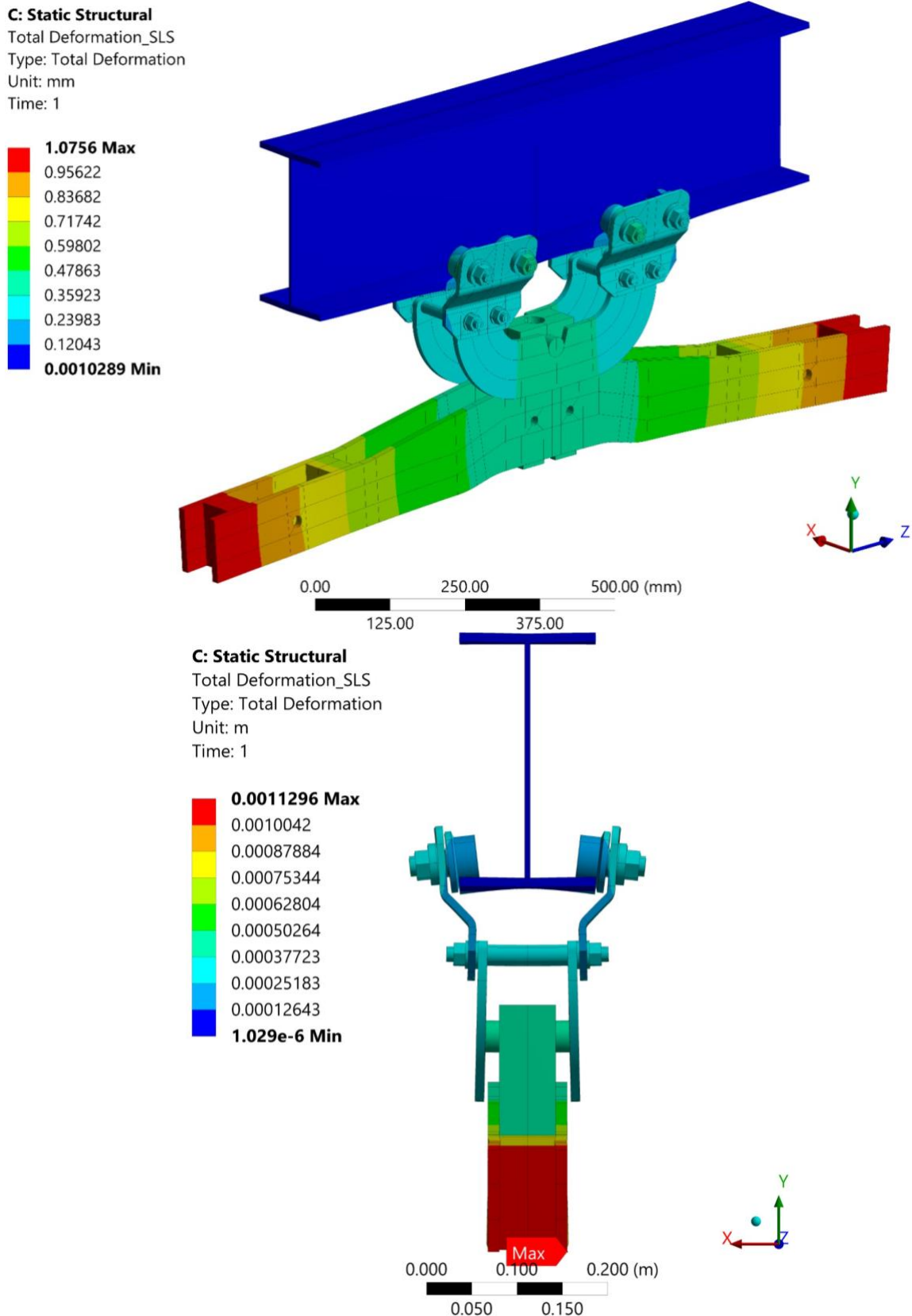


Figure 9: total deformation of the hoist trolley when subjected to **SLS**. ISO (top), Front (bottom)

Equivalent von-Mises stresses on the trolley assembly under **ULS** are shown in *Fig 10*. All of the real stresses obtained from this loading condition were lower than the yield strengths for the considered materials, therefore no plastic behaviour has been observed. Interestingly it shows the highest stressed elements to be the plate elements that form the trolley sides and the saddles. The Maximum stress according to the simulation is 200 MPa, however this occurs at a singularity which is a mathematical construct and is geometrically due to the sharp corner of the centre block on the saddle causing a discontinuity in the solver.

The true maximum stress occurs on the internal bend of the trolley side plate and is 159 MPa. This materialises for a number of reasons, some being: bending, normal stress and the concentration at the internal bend. To ensure this stress is acceptable, the yield stress of the material used (when reduced by a factor of 1.1) should be larger than the simulation stress:

$$\sigma_{sim,max} = 159 \text{ MPa} < \frac{200}{1.1} = 182 \text{ MPa} \checkmark$$

C: Static Structural

EQV_Stress_Trolley_ULS

Type: Equivalent (von-Mises) Stress

Unit: MPa

Time: 2

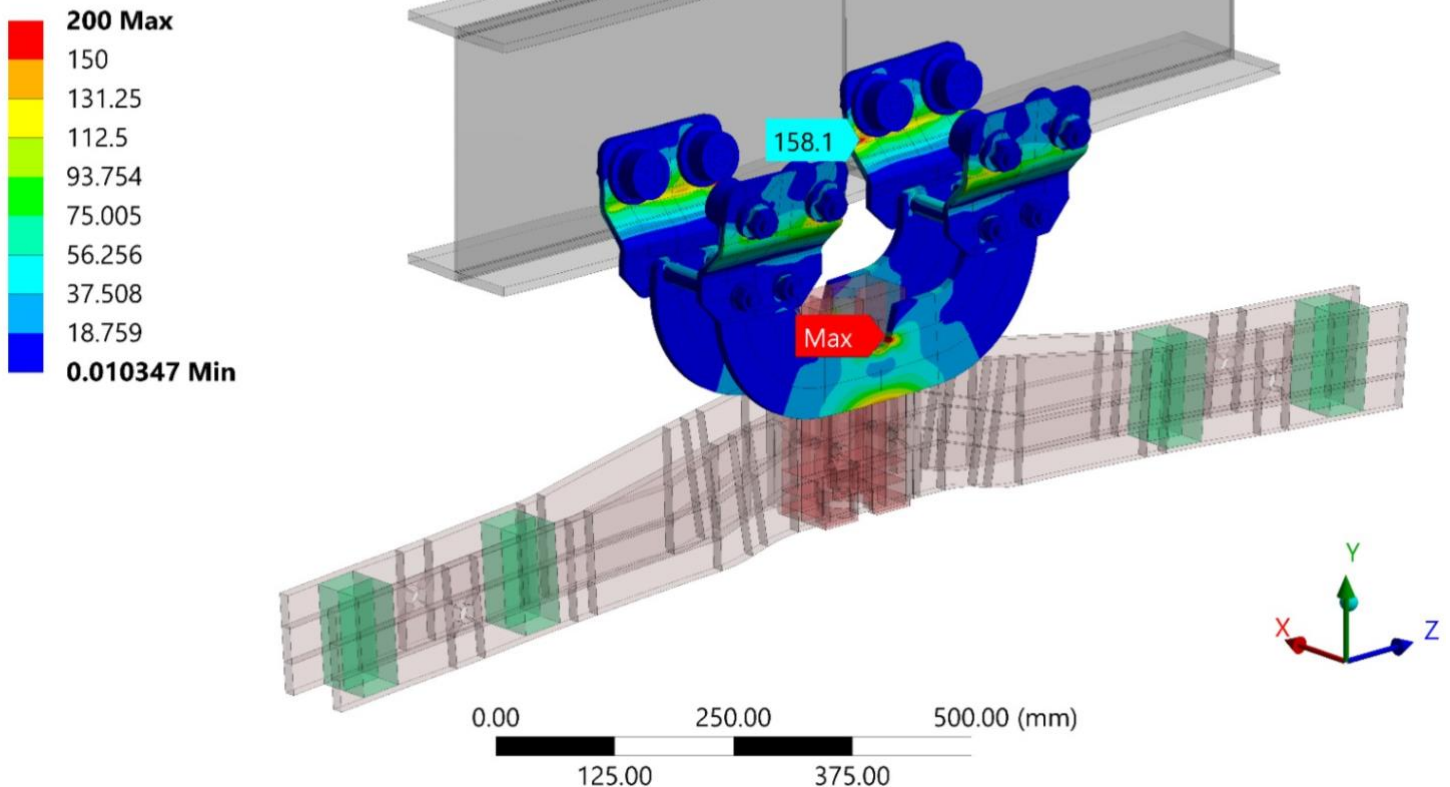


Figure 10: Maximum equivalent von-Mises stress of whole trolley at ULS

C: Static Structural

EQV_Stress_Plates_ULS

Type: Equivalent (von-Mises) Stress

Unit: MPa

Time: 2

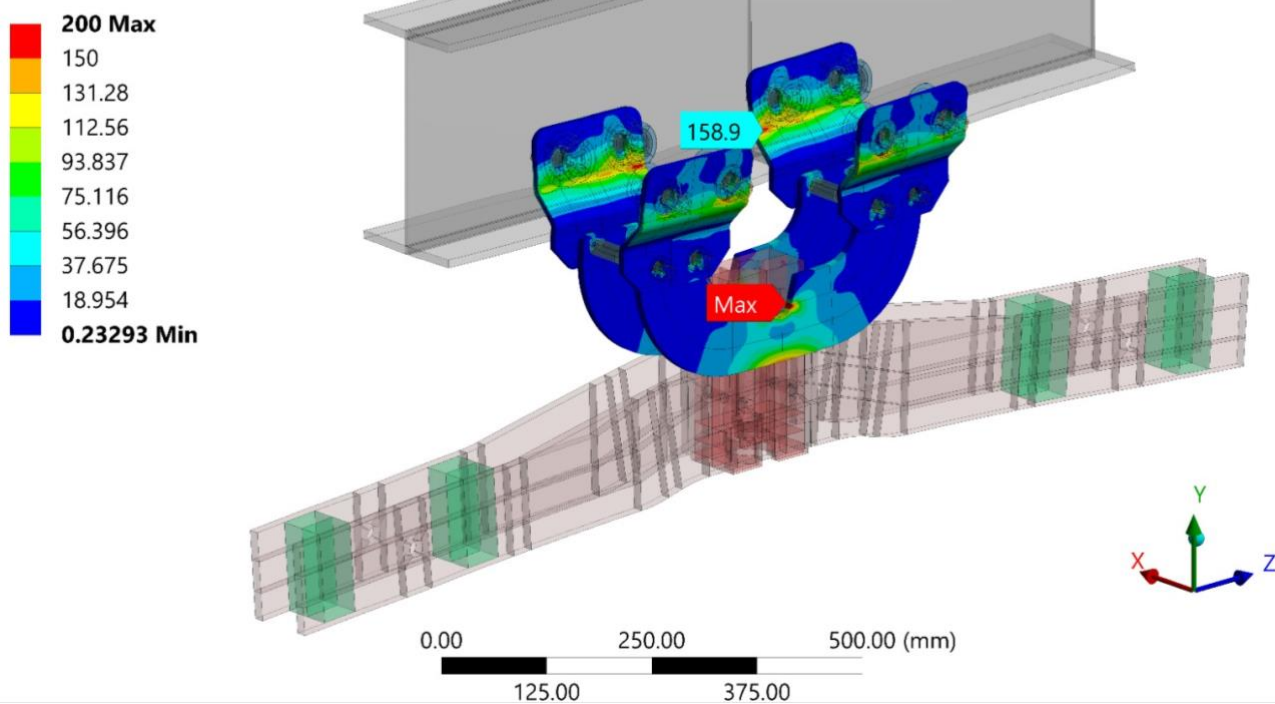


Figure 11: Maximum equivalent von-Mises stress of plate elements at ULS

C: Static Structural

EQV_Stress_Pins_ULS

Type: Equivalent (von-Mises) Stress

Unit: MPa

Time: 2

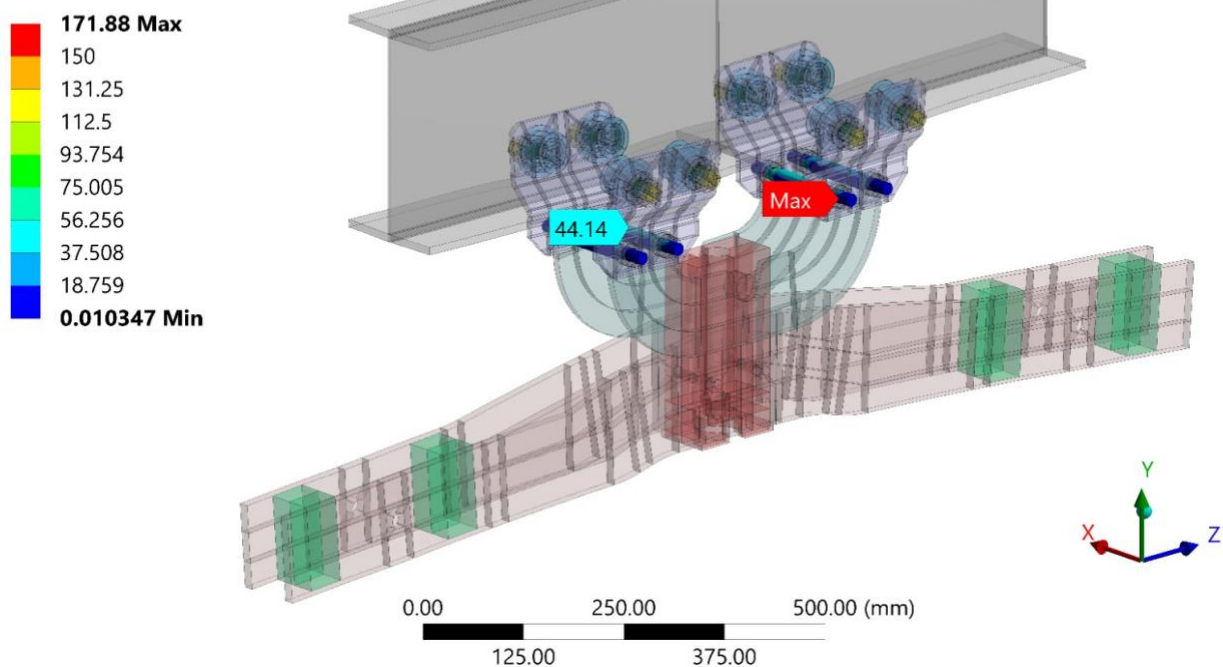


Figure 12: Equivalent von-Mises stress experienced by pinned connections at ULS

From *Fig 12* the maximum equivalent von-Mises stress on the pin is 171.88 MPa. However, this maximum is another singularity which has formed from edge features and therefore disregarded. The stress field on the pin largely describes bending and therefore a more accurate maximum stress may be the 44.14 MPa as highlighted. The pin will be made from SS 316 LN which has a yield stress of 280 MPa. Following EN 1993-1-8, the simulation stress was enlarged by a factor of 1.25 and the yield stress of the material was reduced by a factor of 1.1. These values were then compared, and the latter shown to be lower. As shown:

$$\sigma_{sim,max} = 44.14 \cdot 1.25 = 55 \text{ MPa} < \frac{280}{1.1} = 255 \text{ MPa} \checkmark$$

12 Conclusion

This design proposal detailed an alternative design for the LBNF APA trolley. This iteration has yielded a 'cryogenically testable' trolley and has reduced the number of parts from the last iteration while keeping the manufacturing /assembly processes low in cost. Finally, the finite element simulations have described the trolley to experience acceptable stress and deformation under the two loading conditions applied.

13 Symbols

A	– Cross sectional area
d	– Diameter
f_{up}	– Ultimate tensile strength
f_y	– Lower yield strength of pin or plate
f_{yp}	– Yield strength
$F_{b,Ed}$	– Design bearing force
$F_{b,Rd}$	– Design bearing resistance
$F_{v,Ed}$	– Design shear force of bolt at Ultimate Limit State
$F_{v,Rd}$	– Design shear resistance of bolt
M_{Ed}	– Design bending force
M_{Rd}	– Design bending resistance
W_{el}	– Young's modulus
t	– Thickness of plate
V	– Die width
b	– Minimum flange length
γ_{M0}	– Partial safety factor for resistance of members and cross sections – 1
γ_{M2}	– Partial safety factor for resistance of bolts – 1.25

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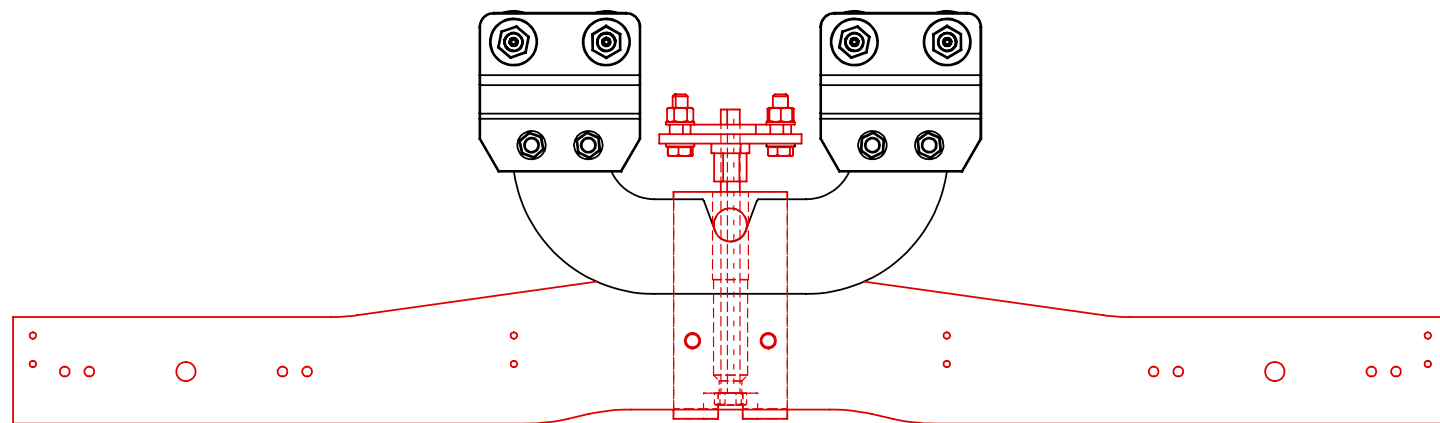
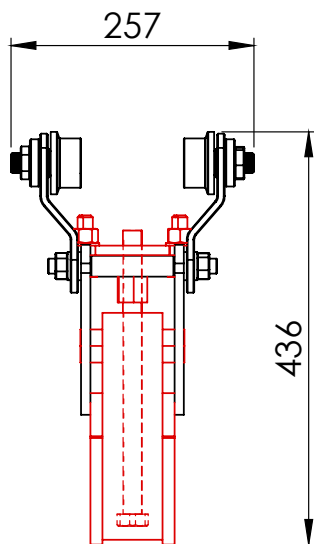
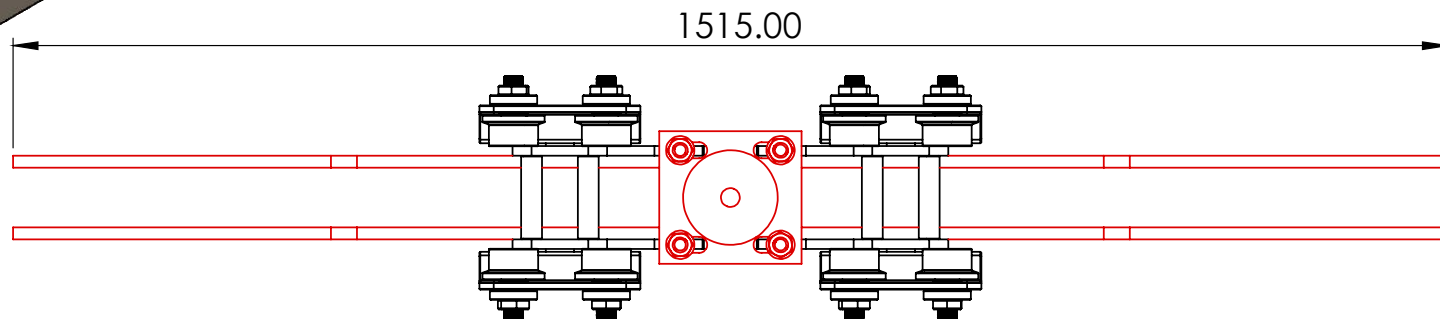
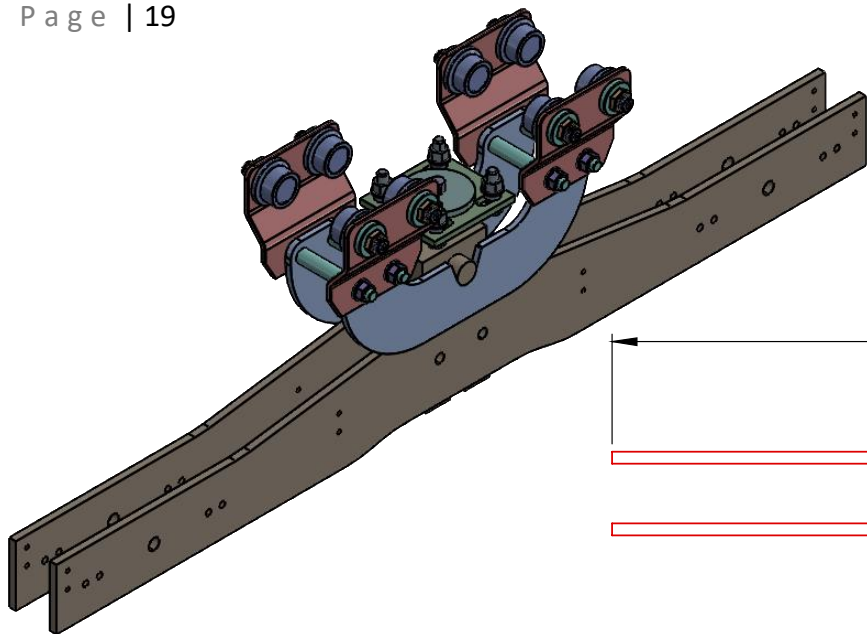
Hrivnak J, 2021, Structural Assessment of the LBNF trolley, EDMS 2470054

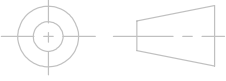
EDMS 2281422 – *SP Detector mass template*

15 Appendix

15.1 Assembly and Part drawings

See following pages:



MASS: 315 KG DRAWN TO BS 8888 ALL DIMENSIONS IN mm	SCALE 1:8	PROJECTION 	DRAWN BY: SAM MUNDAY	HOIST TROLLEY		
				14/07/2021	A4	SHEET 1 OF 3

74

98

168

NOTE:

Rollers from McMaster-Carr
Thrust bearing and washer from SKF
All other fixtures from ACCU

DRAWN TO BS 8888
ALL DIMENSIONS IN mm

SCALE
1:2

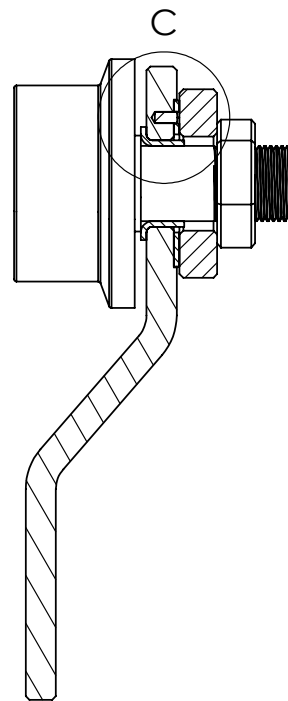


DRAWN BY:
SAM MUNDAY

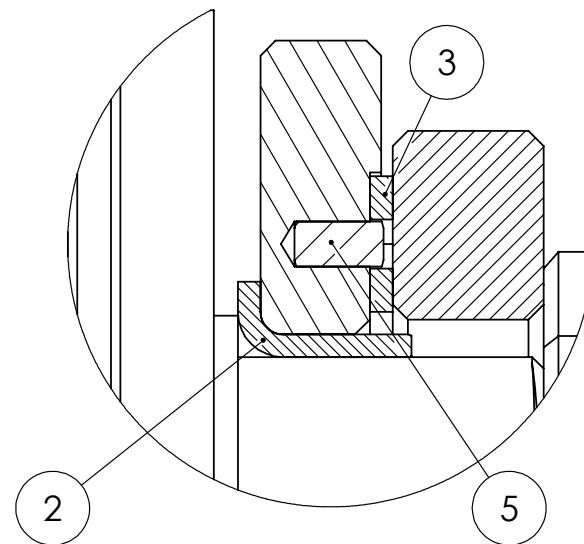
TROLLEY ASSEMBLY

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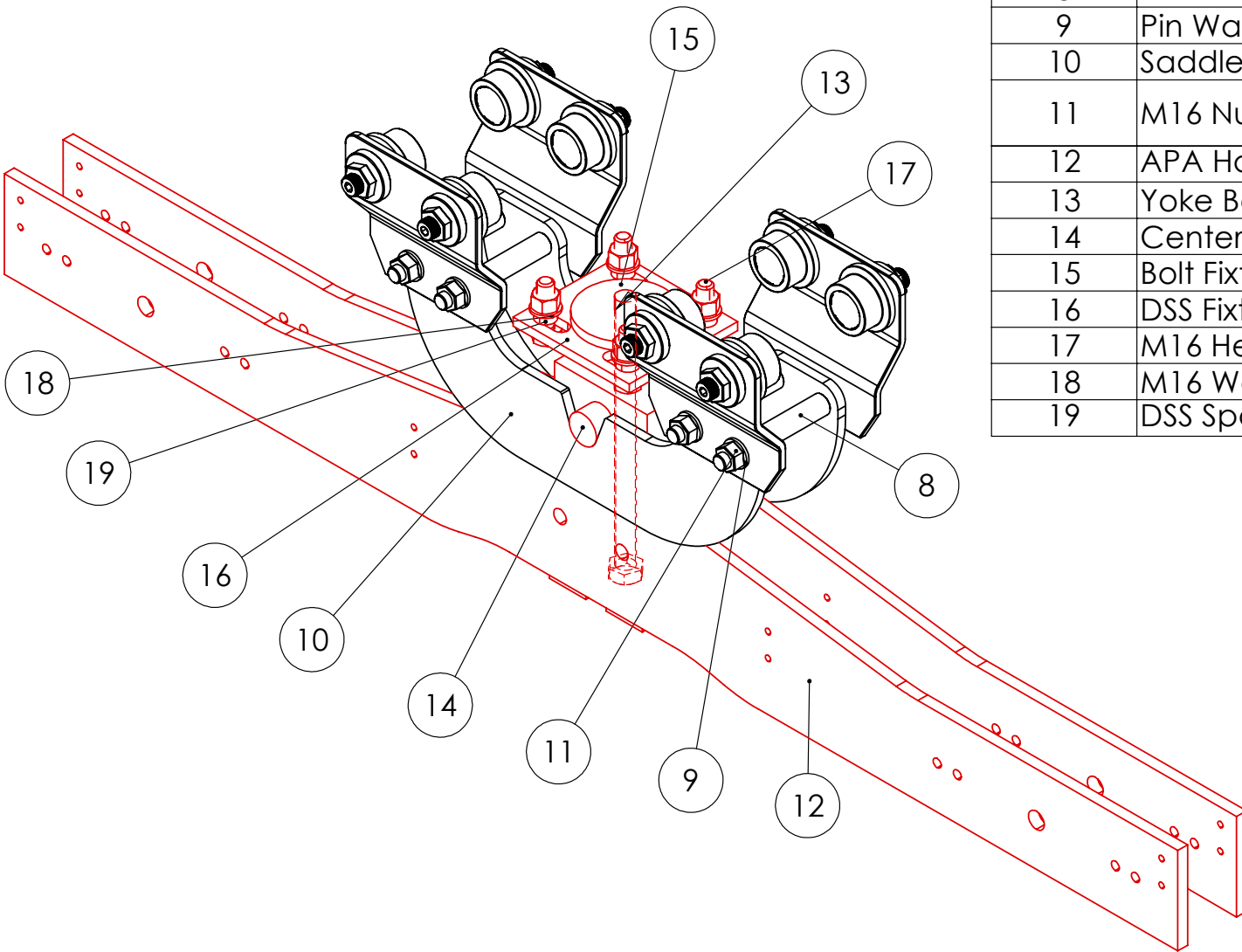
ITEM NO.	PART NAME	MATERIAL/ PART NO.	QTY.
1	Trolley Plate	SS304L	1
2	Flanged Bushing	PCMF 202311.5 E	2
3	Thrust Washer	PCMW 264401.5 E	2
4	Roller	6318K118	2
5	Dowel 3mm	HDP-3-5-A1	2
6	M24 Oversized Spacer	HDTW-M24-A4	2
7	M20 Nut	HFNF-M20-1.5-A4	2



SECTION B-B
SCALE 1 : 2



DETAIL C
SCALE 2 : 1



PART NO.	PART NAME	MATERIAL / PART NO.	QTY.
N/A	Trolley Assembly	N/A	4
8	Pin	SS 316 LN	4
9	Pin Washers	HDTW-M24-A4	16
10	Saddle	SS 316 LN	2
11	M16 Nut	HPN-M16-A2	8 (+4)
12	APA Hanger		2
13	Yoke Bolt		1
14	Center Block		1
15	Bolt Fixture		1
16	DSS Fixture		1
17	M16 Hex Bolt		4
18	M16 Washer		8
19	DSS Spacer		4

NOTE:

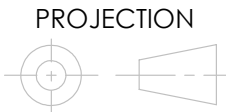
All fixtures sourced from ACCU

Previous labels omitted

Details of APA attachment assembly [RED] omitted as can be found from their own documents, however M16 Nuts used in the DSS attachment can be used on the trolley Pins, therefore (+4)

DRAWN TO BS 8888
ALL DIMENSIONS IN mm

SCALE
1:6



DRAWN BY:
SAM MUNDAY

BILL OF MATERIALS

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NOTE:

CHAMFER 1X45°
ALL OVER

2 x ϕ 3.2 ∇ 5.0
3.0 4.8

DETAIL B
SCALE 2 : 1

ϕ 0.1 A B

R1.75
1.50

2 x R14

// 0.1 A

2 x ϕ 23 H7 THRU
 ϕ 44.5 ∇ 0.75

ϕ 0.1 A B
 ϕ 0.1

$\perp$ 0.1 A

B

2 x ϕ 17 THRU

ϕ 0.1 A B

A

60°

2 x 20

60.05
59.95

55

— 0.1

28

— 0.1

8

B

17.6
17.4

R8 INTERNAL
BENDS

FLANGE LENGTHS
DIMENSIONED

72

46

62

40.1
40.0

// 0.1 C

SECTION A-A
SCALE 2 : 5

MATERIAL
SS 304L

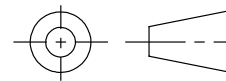
DRAWN TO BS 8888

FINISH TO BS 1134 ∇ 6.4 EXCEPT WHERE STATED

TOLERANCE
DIMENSIONAL $\pm$ 0.25 mm
ANGULAR $\pm$ 2°
UNLESS OTHERWISE STATED

SCALE
2:5

PROJECTION



DRAWN BY:
SAM MUNDAY

TROLLEY PLATE

14/07/2021

A4

SHEET 1 OF 1

6

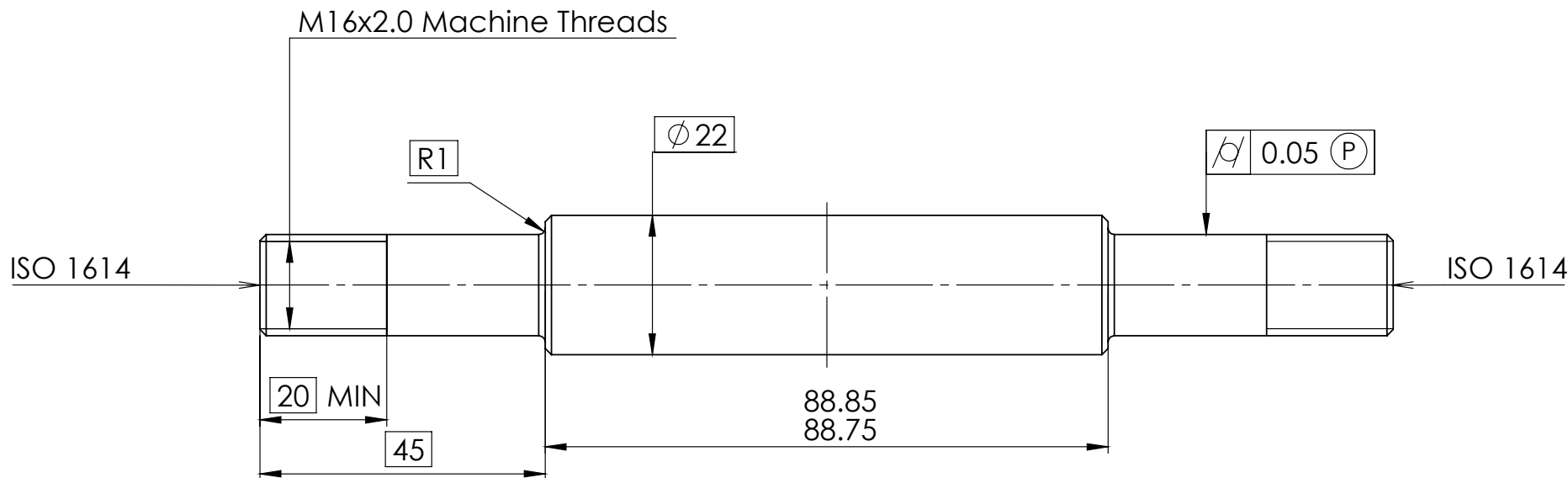
5

4

3

2

1

**NOTE:**ISO DATUMS INTENDED FOR
MANUFACTURING BY LATHE

CHAMFERS 1 x 45°

SYMMETRICAL FEATURES

MATERIAL
SS 316 LNDRAWN TO BS 8888 / ISO
FINISH TO BS 1134 $\nabla_{6.3}$ EXCEPT WHERE STATEDTOLERANCE
DIMENSIONAL ± 0.25 mm
ANGULAR $\pm 2^\circ$
UNLESS OTHERWISE STATEDSCALE
1:1DRAWN BY:
SAM MUNDAY**PIN**

14/07/2021

A4

SHEET 1 OF 1

6

5

4

3

2

1