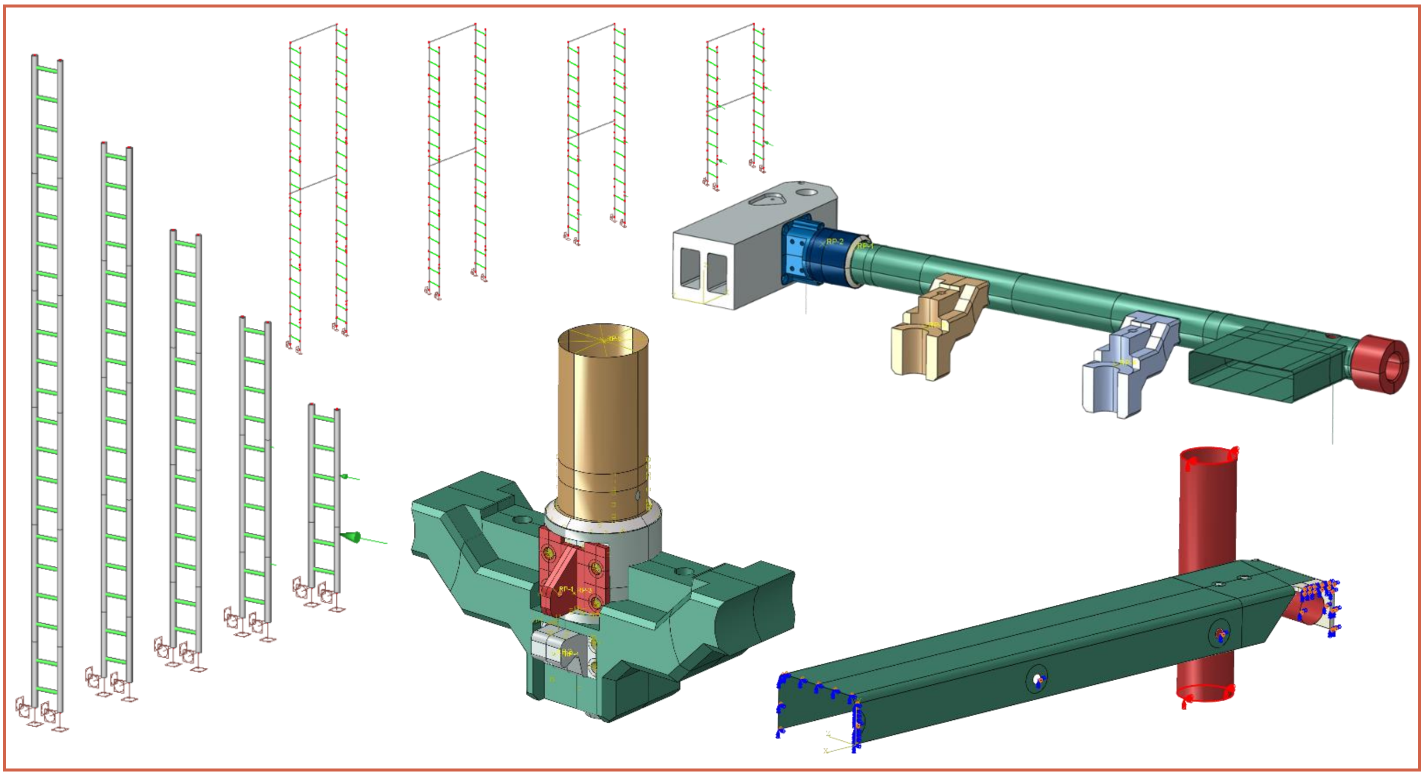
TECHNICAL REPORT

FINITE ELEMENT ANALYSES OF A STACKED VIDEO WALL 23-A0621-A_5M-H×0.5M-W-STACKING_ABSEN-PL ACCORDING TO THE STANDARD EN 13814



INDURIUM
ENGINEERING

Customer	Shenzen Twenty Three Electronics Co., Ltd

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3 DOCUMENT HISTORY

Revision 0	January 10th, 2019
	Base document

4 SUMMARY

This report contains the results of structural analyses on several stacking video wall configurations built with LED tiles from the brand Absen. The analyses presented in this document were carried out according to the standard EN 13814. Note that the base stand in the stacking configuration was only checked in combination with the dedicated outriggers. The following checks was checked:

- **Stability of video the walls** with heights varying from 0.5 up to 5 m, verified for indoor use. According to "Messe Essen Technical guidelines", structures for indoor use should be able to withstand a "draft" load. The guideline suggests a pressure of **125 Pa** for surfaces below 4 m. The pressure on all surfaces above 4 m is **63 Pa**.
- **Structural check of the ladders**: Sectional and stability (buckling) checks according to EN 13814 were carried out. Two ladder rigging variants were considered:
  - Variant-1: Each ladder is a standalone ladder and is only connected to the LED tiles and to the outrigger.
  - Variant-2: Each ladder is connected to its neighbouring ladder using a tube between the back main chords at the top and at ½ of the wall height.
- **Structural check of the base stand with outrigger:** Three possible counterweight positions (Case A, B and C) were considered (see Figure 1):
  - Case-A: Counterweights are placed on platforms which are attached to the ladders.
  - Case-B: Counterweights are put directly on the base stands, at the centreline of the ladders.
  - Case-C: Counterweights directly on the base stands, centres at a distance of 100 mm from the rear feet, towards the front of the wall.
- **Structural check of small details. These are:**
  - The platforms used for maintenance access and counterweight,
  - the feet of the base stand, and
  - the connection between the outrigger and the ladder. The load on this connection depends on the position of the counterweight.

The overall results of these checks are presented in the next sections. All parts of the stacking configuration were checked and verified for indoor use up to a wall height of 5.5 m.

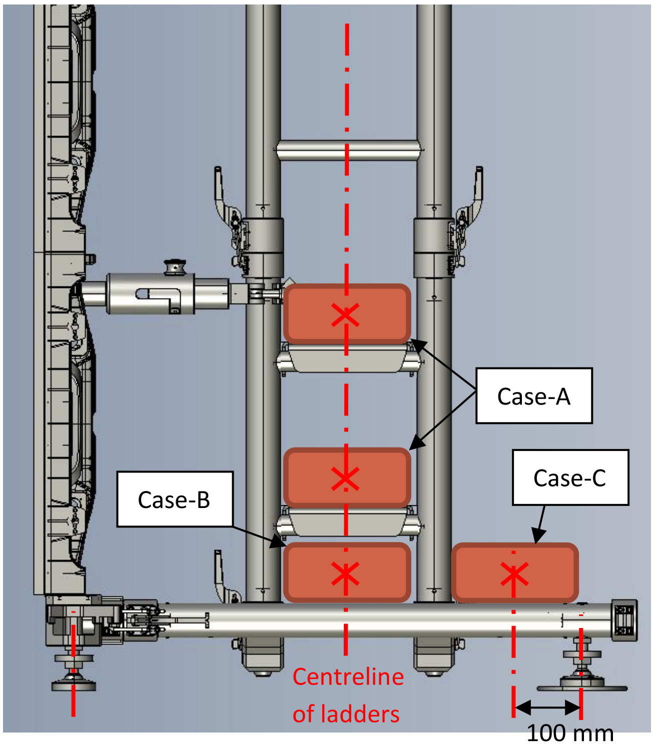

Figure 1 – Possible counterweight positions

4.1 CASE-A: COUNTERWEIGHTS PLACED ONTO LADDER PLATFORMS

The minimum required counterweight to ensure stability of the structure in Case-A, is presented in Table 1. Please take into account the following remarks:

- The minimum required counterweight is given in Table 1 for two load combinations:
  - Combination-1: Draft load combined with self-weight according to EN 13814.
  - Combination-2: Person pushing the wall with a load of 50 kg at a height of 1 m, combined with self-weight according to EN 13814.
- For Combination-1, the counterweight refers to the mass of a single orange block as drawn in Figure 2. **For Combination-2, the counterweight provided in Table 1 is the total counterweight distributed across the entire wall.**

- For configurations taller than 2.5 m, each ladder should be connected to its neighbouring ladder at the top of the wall and also halfway its length (variant-2). For walls of 2.5 m or shorter, these connections are not required.
- The stability calculation takes into account a Coulomb friction coefficient of 0.2. This friction coefficient is valid for steel to smooth concrete or steel to ground contact. This friction coefficient is sufficient as sliding stability is not critical. Note that the sliding stability is not checked for Combination-2.

Table 1 - Minimum required counterweight for indoor use, Case-A

Wall height [m]	Min. required counterweight		Required ladder rigging
	Combination-1 (draft load) [kg] Applied as in Figure 2	Combination-2 (50 kg at 1 m) [kg] Distributed across all base stands	
0.5	0	140	Variant-1
1	0	136	
1.5	7	136	
2	14	132	
2.5	25	132	
3	37	128	Variant-2
3.5	53	132	
4	70	128	
4.5	80	128	
5	91	124	
5.5	104	128	

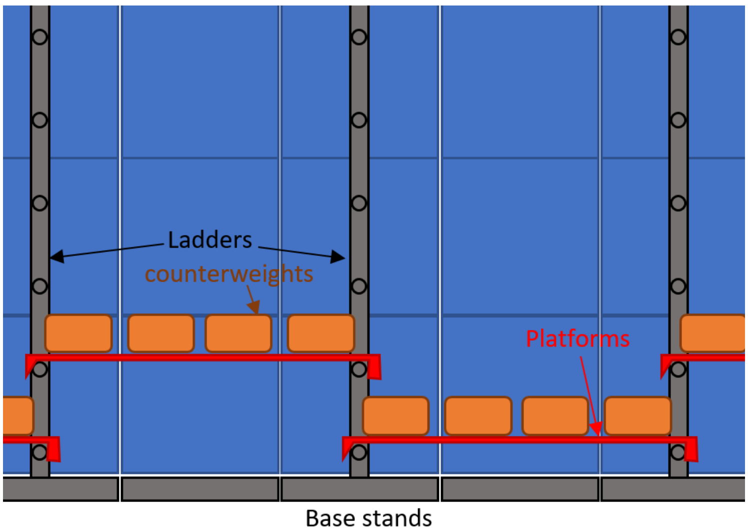

Figure 2 – Schematic drawing of Case-A (rear view)

4.2 CASE-B: COUNTERWEIGHTS PLACED DIRECTLY ONTO OUTRIGGERS, AT CENTRELINES OF LADDERS

The minimum required counterweight to ensure stability of the structure in Case-B, is presented in Table 2. Please take into account the following remarks:

- The minimum required counterweight is given in Table 2 for two load combinations:
    - Combination-1: Draft load combined with self-weight according to EN 13814.
    - Combination-2: Person pushing the wall with a load of 50 kg at a height of 1 m, combined with self-weight according to EN 13814.
- For Combination-1, the counterweight refers to the mass of a single green block as drawn in Figure 3. **For Combination-2, the counterweight provided in Table 2 is the total counterweight distributed across the entire wall.**

- For configurations taller than 2.5 m, each ladder should be connected to its neighbouring ladder at the top of the wall and also halfway its length (variant-2).
- The stability calculation takes into account a Coulomb friction coefficient of 0.2. This friction coefficient is valid for steel to smooth concrete or steel to ground contact. This friction coefficient is sufficient as sliding stability is not critical. Note that the sliding stability is not checked for Combination-2.

Table 2 - Minimum required counterweight for indoor use, Case-B

Wall height [m]	Min. required counterweight		Required ladder rigging
	Combination-1 (draft load) [kg] Applied as in Figure 3	Combination-2 (50 kg at 1 m) [kg] Distributed across all base stands	
0.5	0	140	Variant-1
1	0	136	
1.5	28	136	
2	56	132	
2.5	100	132	
3	148	128	Variant-2
3.5	212	132	
4	280	128	
4.5	320	128	
5	364	124	
5.5	416	128	

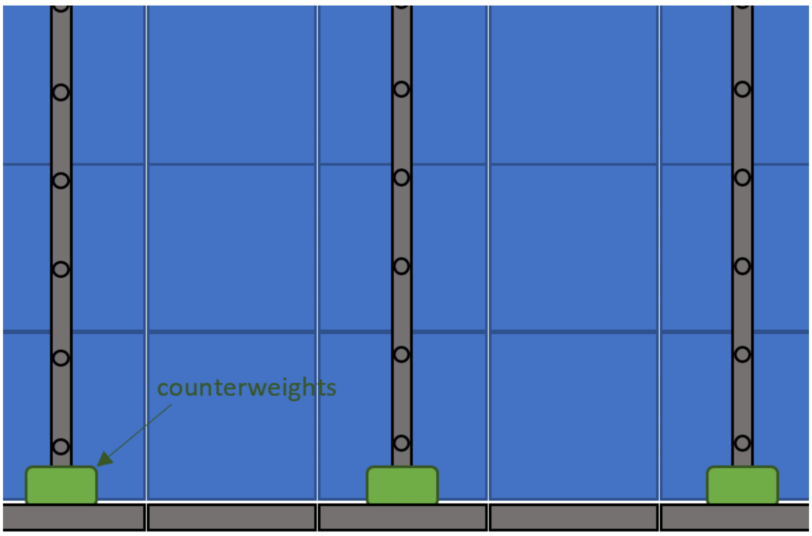

Figure 3 – Schematic drawing of Case-B (rear view)

4.3 CASE-C: COUNTERWEIGHTS ONTO OUTRIGGERS, AT 100 MM FROM THE REAR FEET

The minimum required counterweight to ensure stability of the structure in Case-C, is presented in Table 3. Please take into account the following remarks:

- The minimum required counterweight is given in Table 3 for two load combinations:
  - Combination-1: Draft load combined with self-weight according to EN 13814.
  - Combination-2: Person pushing the wall with a load of 50 kg at a height of 1 m, combined with self-weight according to EN 13814.
- For Combination-1, the counterweight refers to the mass of a single green block as drawn in Figure 4. **For Combination-2, the counterweight provided in Table 3 is the total counterweight distributed across the entire wall.**
- For configurations taller than 2.5 m, each ladder should be connected to its neighbouring ladder at the top of the wall and also halfway its length (variant-2). For walls of 2.5 m or shorter, these connections are not required.
- The stability calculation takes into account a Coulomb friction coefficient of 0.2. This friction coefficient is valid for steel to smooth concrete or steel to ground contact. This friction coefficient is sufficient as sliding stability is not critical. Note that the sliding stability is not checked for Combination-2.

Table 3 - Minimum required counterweight for indoor use, Case-C

Wall height [m]	Min. required counterweight		Required ladder rigging
	Combination-1 (draft load) [kg] Applied as in Figure 4	Combination-2 (50 kg at 1 m) [kg] Distributed across all base stands	
0.5	0	304	Variant-1
1	0	128	
1.5	20	84	
2	36	84	
2.5	64	84	
3	92	80	Variant-2
3.5	132	84	
4	176	80	
4.5	200	80	
5	228	76	
5.5	260	80	

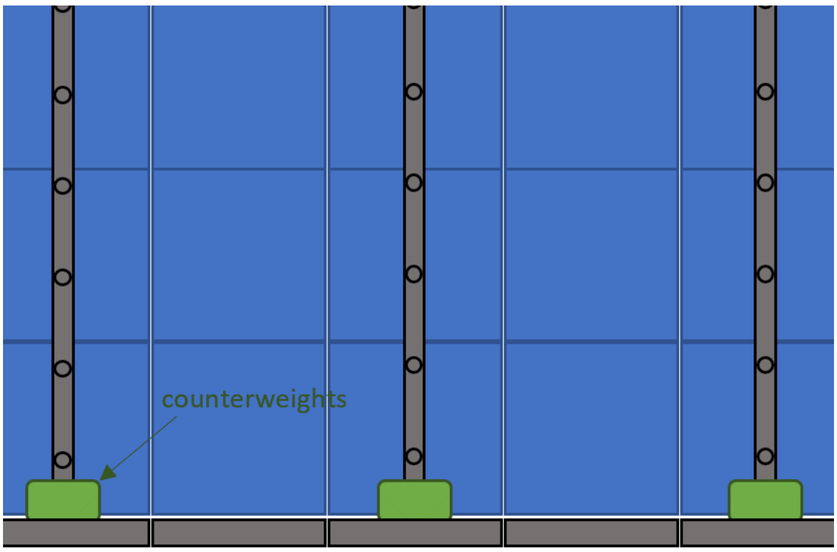

Figure 4 – Schematic drawing of Case-C (rear view)

5 REFERENCED DOCUMENTS AND FILES

5.1 INPUT DOCUMENTS AND FILES

Type	Description or reference
Spreadsheets	23-L0086-A_Tile-500x500_Absen-PL - 180820.xlsx 23-L0086-A_Tile-500x500_Absen-PL.xlsx BOM Production 23-A0226-C_OUTRIGGER-0.8m_STACKING_Absen.xlsx BOM 23-A0227-B_PLATFORM-1m_STACKING_Absen-170918.xlsx
STEP files (3D)	23-A0227-B_PLATFORM-1m_STACKING_Absen.stp 23-a0621-b_5m-h0_50001_asm.stp 23-a0626-a_5m-h1m-0001_asm.stp 23-A0226-C_OUTRIGGER-0.8m_STACKING_Absen.stp
Datasheet	323_331_341.pdf

5.2 REFERENCED STANDARDS, GUIDELINES OR OTHER LITERATURE

Type	Description or reference
Standard	EN 13814 - Fairground and amusement park machinery and structures - Safety (2004)
Standard	EN 1990 – Eurocode – Basis of structural design (2002)
Document	Technische_Richtlinien_-_Technical_guidelines_2017_01
Standard	EN 1993-1-1 - Eurocode 3 - Design of steel structures - Part 1-1 - General rules and rules for buildings (2005)
Standard	EN 1993-1-4 - Eurocode 3 - Design of steel structures - Part 1-4 - General rules - Supplementary rules for stainless steels (2006)
Standard	EN 1999-1-1 - Eurocode 9 - Design of aluminium structures - Part 1-1 - General structural rules (2007)
Standard	EN 482-2 – Aluminium and aluminium alloys – Sheet, strip and plate – Part 2 – Mechanical properties (2013)
Standard	EN 10088-3 - Stainless steels – Part 3 – Technical delivery conditions for semi-finished products, bars, rods, wire, sections and bright products of corrosion resisting steels for general purposes (2014)
Standard	EN 1993-1-5 - Eurocode 3 - Design of steel structures - Part 1-5 - Plated structural elements (2006)
Standard	EN 1993-1-8 - Eurocode 3 - Design of steel structures - Part 1-8 - Design of joints (2005)
Book	Roloff/Matek – Theory manual, 4th edition

6 SOFTWARE

Type	Name	Version
Finite element software	Abaqus	6.14
Finite element software	Scia Engineer	2018
Office software	Microsoft Office	2016

7 FINITE ELEMENT MODEL

7.1 GEOMETRY

A total of 4 finite element models were created:

- Model of the ladders
- Model of the base stand with outrigger
- Model of the platform
- Model of the ladder connection

Note that the stability was checked by analytical calculations, and not simulations. The models are described in the next sections.

7.1.1 MODEL OF THE LADDERS

A single model including 5 different sizes was created in SCIA Engineer. The members of the ladders were modelled using deformable beams. For the ladders with a height of 3.5, 4.5 and 5.5 m, the adjacent ladders were connected to each other using beams with a section identical to the main chords of the ladders. Hinged connections were considered at the ends of the connecting tubes.

The model is illustrated in Figure 5.

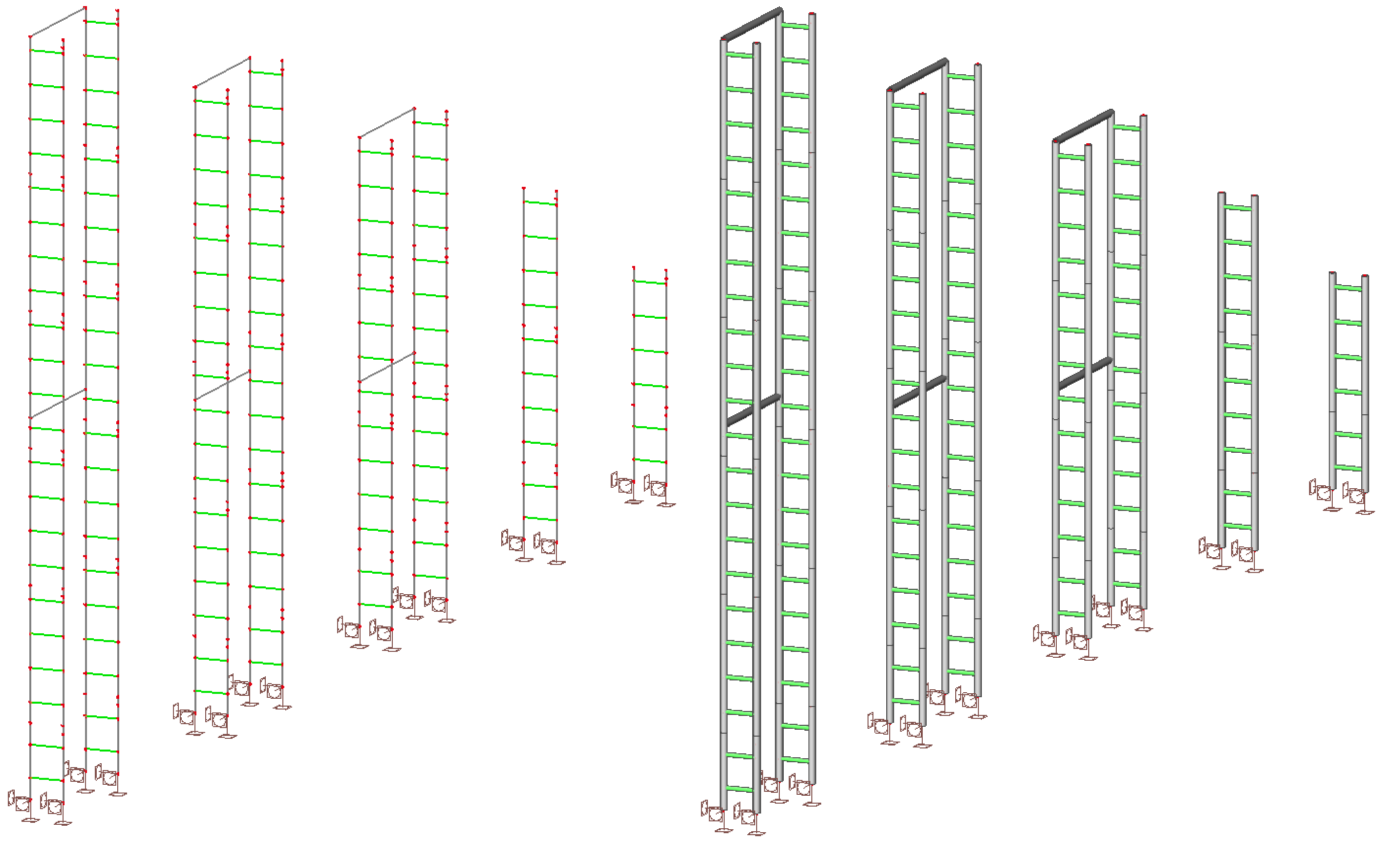

Figure 5 - Finite element model of the ladders (left: wireframe; right: sections visualized)

7.1.2 MODEL OF THE BASE STAND WITH OUTRIGGER

The model of the base stand and the outrigger is based on the 3D-step drawing provided by the customer. The main features are:

- Because of symmetry, only half of the base stand with the outrigger was modelled.
- Small chamfers and rounds were omitted.
- The outrigger tube and the hinge plate of the latch connection were modelled using shells (no thickness modelled).
- The dowel pins between the tube and its end parts were not modelled because they are only used for positioning. The weld seams between the tube and its end parts were modelled using solid parts.
- The bolts and feet were modelled using deformable beams of which the ends were coupled to the appropriate faces. Here distributed couplings were used; these do not add additional stiffness to the model. Note that for the bolts, an equivalent section was used that was determined according to the method described in Roloff/Matek.
- All other parts were modelled as solid.
- Perfect "tie" connections were considered between the parts "23-D0475-B_SHIP_OUTRIGGER_1" and "23-D0489-B_TUBE-_50xS4-OUT_1", and between the welds and the welded parts.
- The ladder was not modelled. Instead, two reference points were placed at each hole in the parts "23-D0475-B_SHIP_OUTRIGGER_1". These reference points were each coupled to their respective faces using distributed couplings.
- The latch itself was replaced by a link connector which can only transfer axial forces. The ends of this connector were coupled to the appropriate faces using distributed couplings.
- Hard contact with a Coulomb friction coefficient of 0.1 was defined between all interacting parts.

The model is illustrated in Figure 6 to Figure 9.

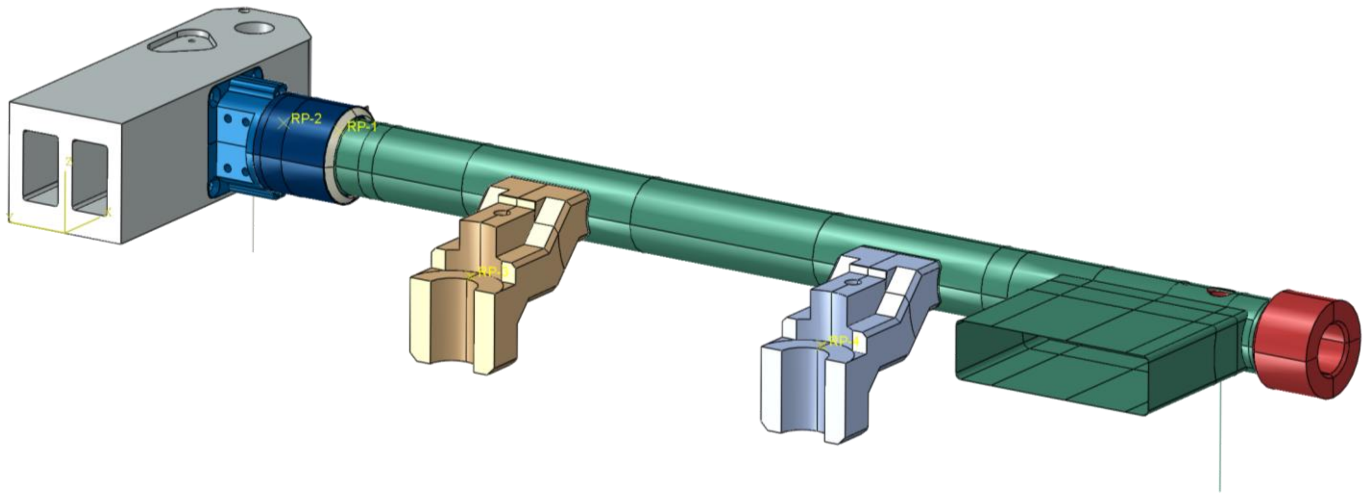

Figure 6 - Finite element model of the base stand and outrigger - overview

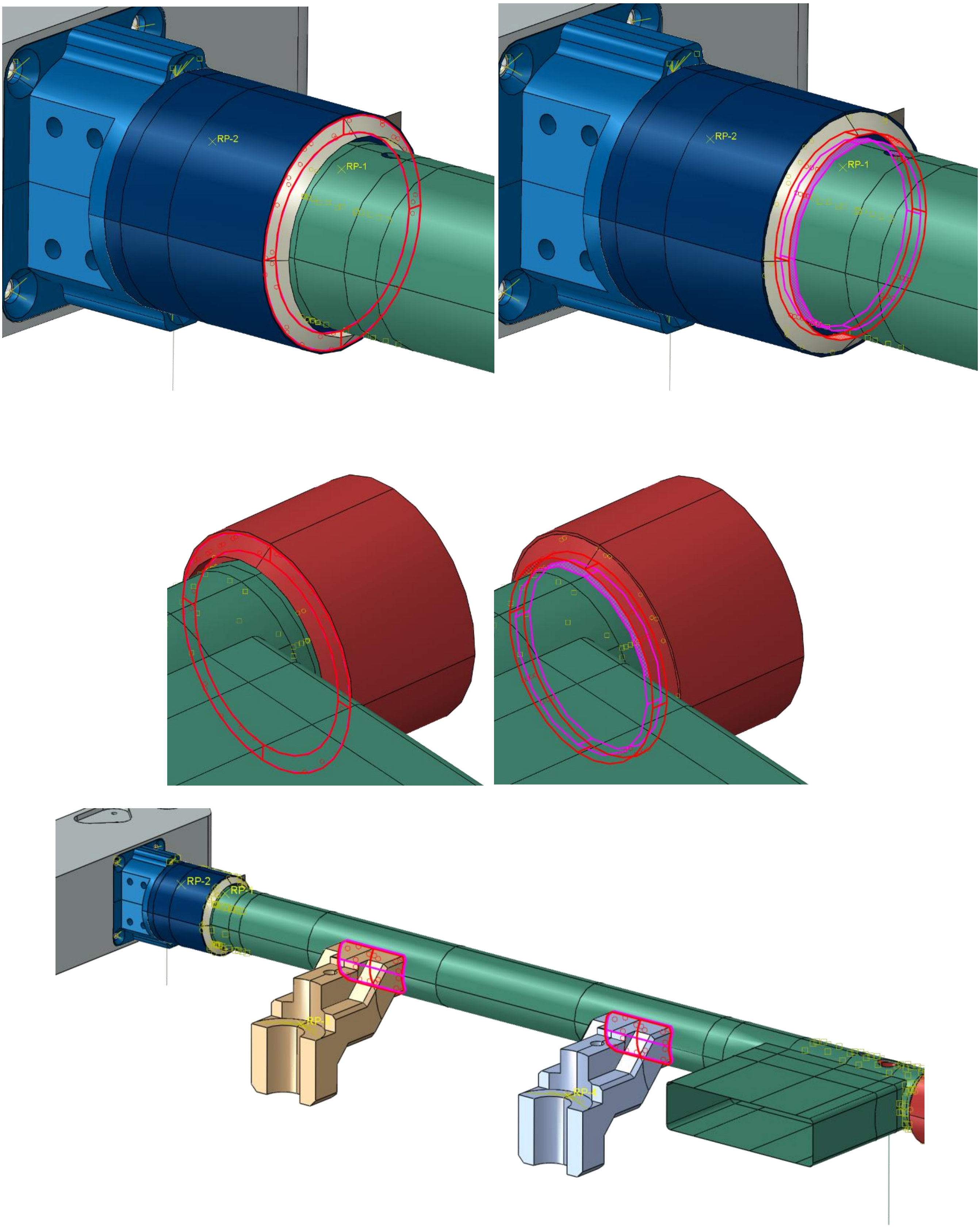

Figure 7 – Finite element model - perfect connections (ties)

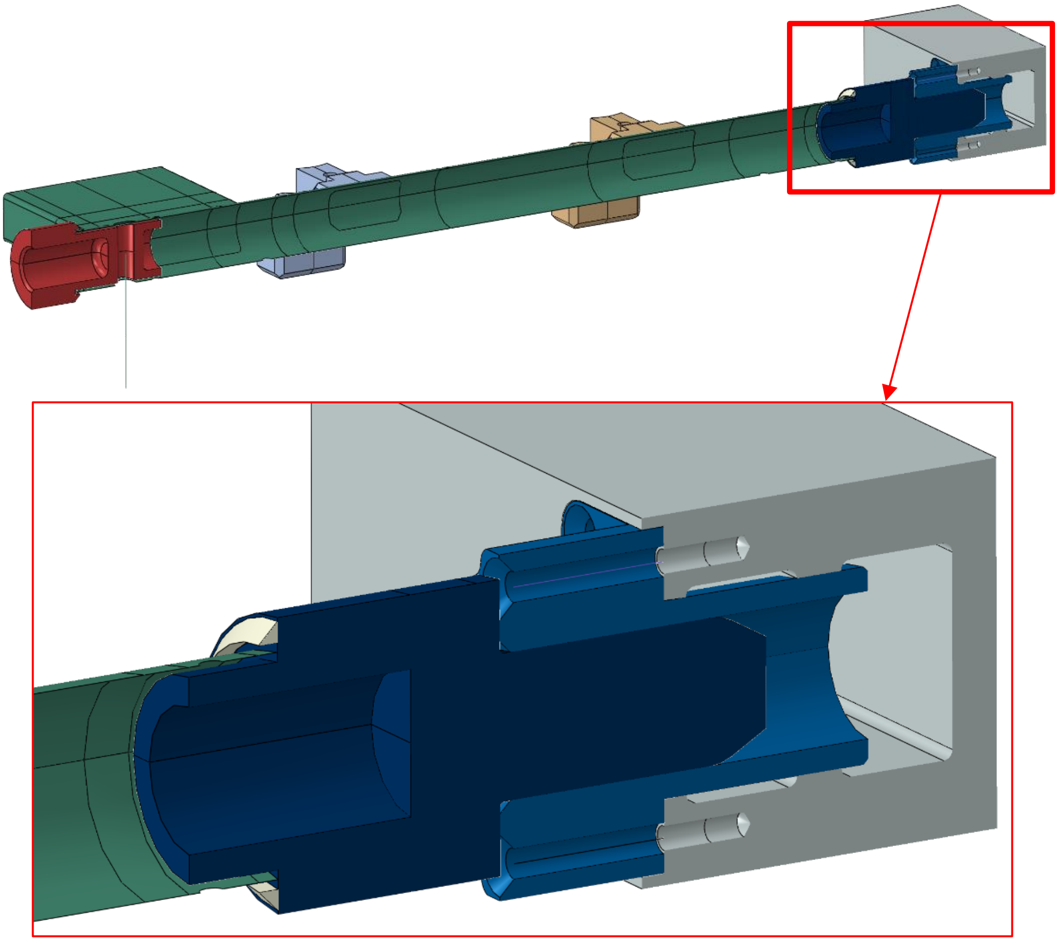

Figure 8 – Finite element model - connection between the base stand and the outrigger - cut view

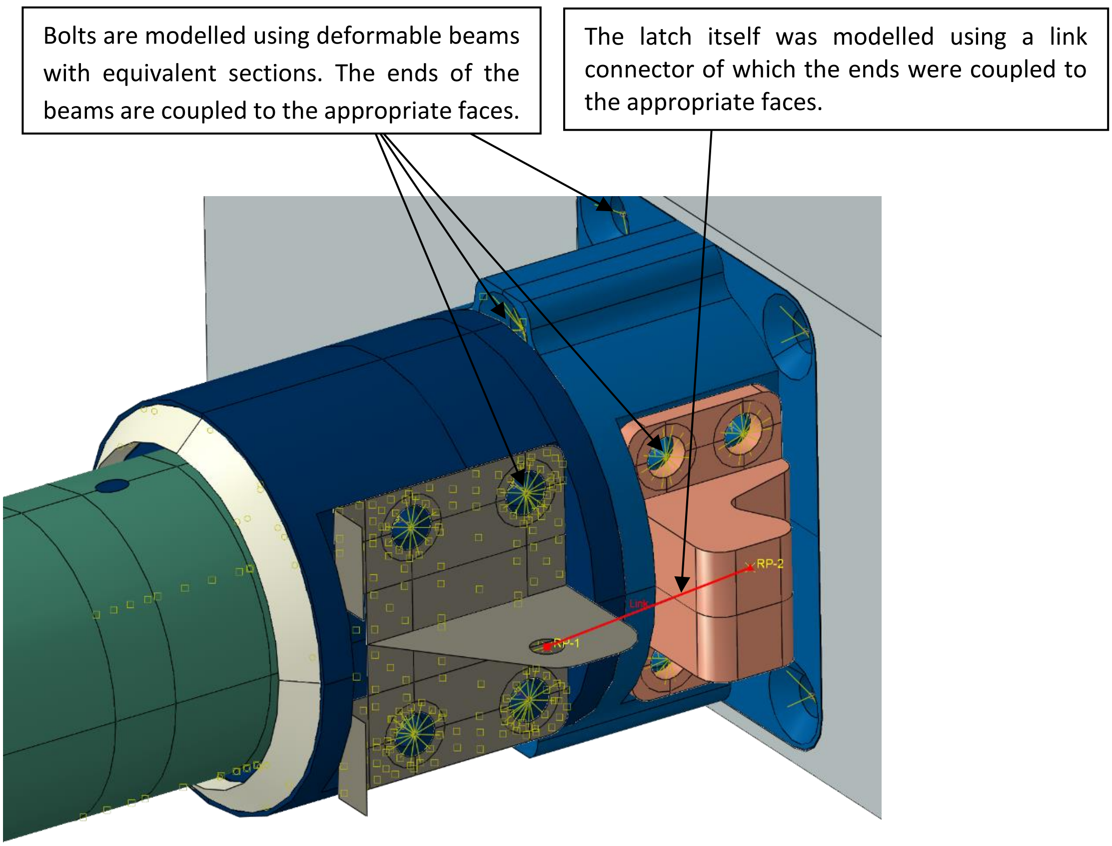

Figure 9 – Finite element model – detailed view of the latch connection

7.1.3 MODEL OF THE PLATFORM

For the platform a separate model was created. This model was based on the 3D-STEP drawing provided by the customer. The main features are:

- Only ¼ of the platform and a small piece of the ladder were modelled.
- All other parts were modelled using shells, except for the part "23-D0551-A_SIDE-PLATE_STACKING" and the bolts.
- The bolts were modelled as deformable beams of which the ends were coupled to the appropriate faces around the bolt holes. Note that the section of the bolts is an equivalent section determined using Roloff/Matek.
- Hard contact with a Coulomb friction coefficient of 0.1 was defined between the platform and the side plate, and between the side plate and the ladder.

The model is illustrated in Figure 10.

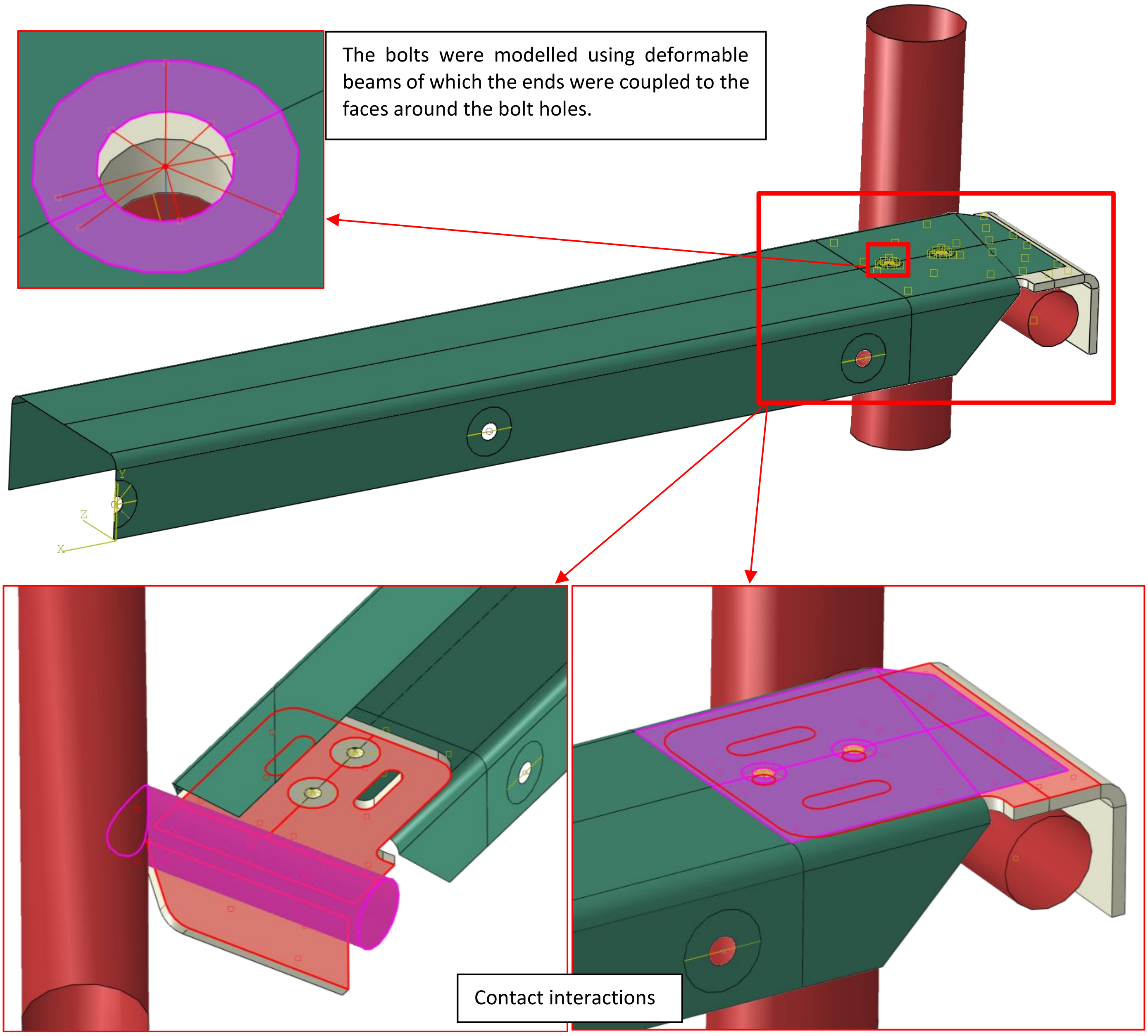

Figure 10 - Finite element model of the platform

7.1.4 MODEL OF THE LADDER CONNECTION

This model includes the connection between the ladder and the outrigger. The main features are:

- All parts, except the ladder tube, were modelled as solids. The ladder was only partially modelled as a shell tube.
- Small chamfers and rounds were omitted.
- The dowel pins between the tube and its end parts were not modelled because they are only used for positioning. The weld seams between the tube and the male kingpin were explicitly modelled using solids.
- The bolts were modelled using deformable beams of which the ends were coupled to the appropriate faces. Distributed couplings were used, which do not add additional stiffness to the model. Note that for the bolts, an equivalent section was used that was determined according to the method described in Roloff/Matek.
- Perfect connections (ties) were defined between the welds and the welded parts.
- The latch itself was replaced by a link connector which can only transfer axial forces. The ends of this connector were coupled to the appropriate faces using distributed couplings.
- Hard contact with a Coulomb friction coefficient of 0.1 was defined between all interacting faces.
- At the top the ladder, modelled as a shell tube, a reference point was coupled. This reference point is used only to apply the loading.

The model is illustrated in Figure 11 and Figure 12.

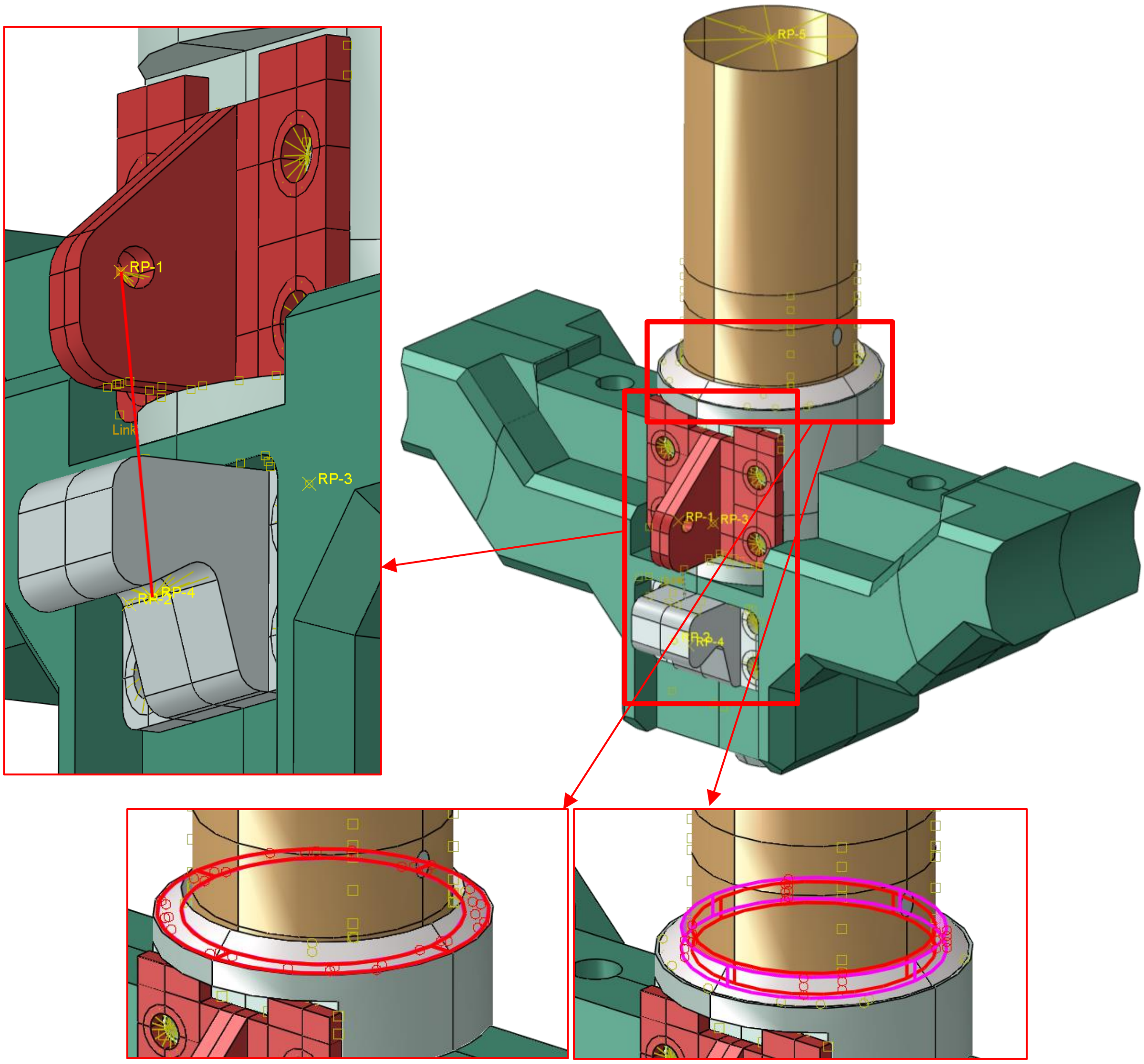

Figure 11 - Finite element model – overview and perfect connections (ties)

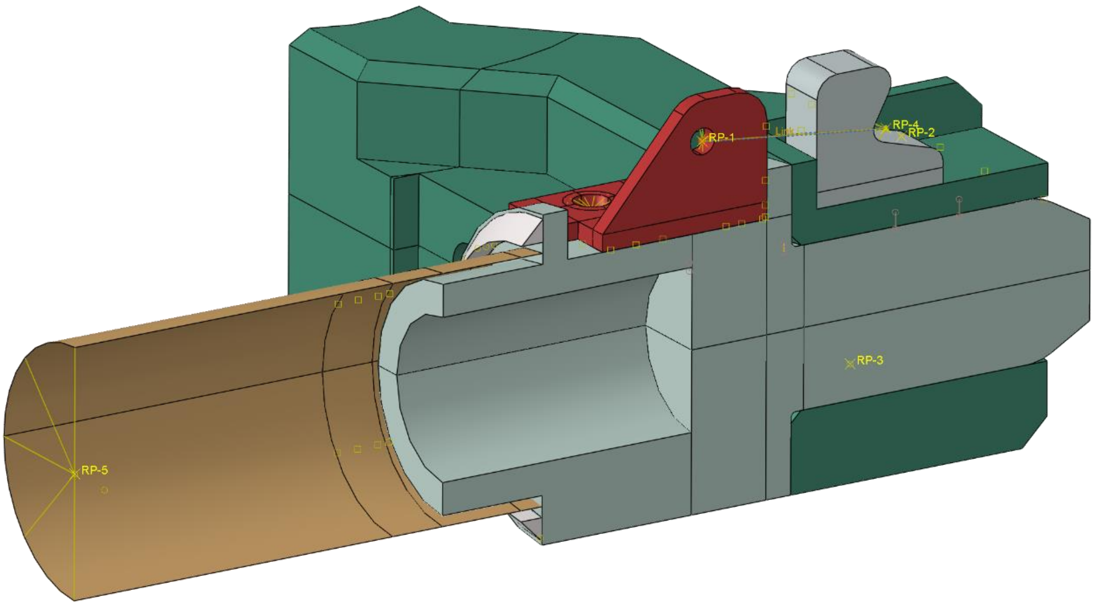

Figure 12 - Finite element model - cut view

7.2 MATERIAL PROPERTIES

7.2.1 EN-AW 6061 T6

Name	EN AW-6061 T6
Applies to	Model of the ladders: ▪ 23-D0473-A_TUBE-1m-Ø50xS4-LADDER_STACKING_Absen ▪ 23-D0018-A_STEP-LADDER_TUBE-Ø30xS3_STACKING_Absen Model of the base stand and outrigger: ▪ 23-D0467-B_ROUND-CLAMP-SUPPORT_STACKING_Absen ▪ 23-D0468-B_SLOT-CLAMP-SUPPORT_STACKING_Absen ▪ 23-D1020-B_EXTRUSION-MAIN-BODY_BASESTAND-0.5m_Absen-PL ▪ 23-D0475-B_SHIP_OUTRIGGER_STACKING_Absen ▪ 23-D0443-B_STRENGTHEN_OUTRIGGER-0.8M_STACKING_Absen Model of the platform: ▪ 23-D0550-A_PLATFORM-1m_STACKING_Absen ▪ 23-D0551-A_SIDE-PLATE_STACKING_Absen ▪ 23-D0018-A_STEP-LADDER_TUBE-Ø30xS3_STACKING_Absen ▪ 23-D0473-A_TUBE-1m-Ø50xS4-LADDER_STACKING_Absen Model of the ladder connection: ▪ 23-D0475-B_SHIP_OUTRIGGER_STACKING_Absen ▪ 23-D0471-A_MALE-KINGPIN_STACKING_Absen ▪ 23-D0473-A_TUBE-1m-Ø50xS4-LADDER_STACKING_Absen
Material model	Linear elastic, ideal plastic
Reference	EN 1999-1-1 and EN 485-2
Modulus of elasticity [GPa]	70
Coefficient of Poisson	0.3
Density [kg/m^3]	2700
Yield strength [MPa]	240
Yield strength (HAZ) [MPa]	115
Design resistance (plastic limit)	5% principal strain according to EN 1993-1-5, annex C*
Additional remarks	*Valid for small peak strains only. Large plastic zones are always rejected.

7.2.2 1.4301 (STAINLESS STEEL 304)

Name	1.4301
Applies to	Model of the base stand and outrigger: ▪ 23-D0469-A_CLAMP-HOOK_Absen-M2.9 Model of the ladder connection: ▪ 23-D0469-A_CLAMP-HOOK_Absen-M2.9
Material model	Linear elastic, ideal plastic
Reference	EN 1993-1-4, EN 10088-3
Modulus of elasticity [GPa]	200
Coefficient of Poisson	0.3
Density [kg/m³]	7850
Yield strength [MPa]	190
Design resistance (plastic limit)	5% principal strain according to EN 1993-1-5, annex C*
Additional remarks	*Valid for small peak strains only. Large plastic zones are always rejected.

7.2.3 STAINLESS STEEL

Name	Stainless steel
Applies to	Bolts
Material model	Linear elastic
Reference	
Modulus of elasticity [GPa]	200
Coefficient of Poisson	0.3
Density [kg/m³]	7850
Yield strength [MPa]	/
Design resistance (plastic limit)	/
Additional remarks	The stresses in the bolts were not checked. Instead, the sectional forces were extracted from the models and checked according to EN 1993-1-8.

7.2.4 STEEL

Name	Steel
Applies to	23-B0027-A_CLAMP-HS-431-NORMAL-STEEL
Material model	Linear elastic
Reference	
Modulus of elasticity [GPa]	210
Coefficient of Poisson	0.3
Density [kg/m^3]	7,850
Yield strength [MPa]	/
Design resistance (plastic limit)	/*
Additional remarks	*The stresses in this part were not checked. The maximum force in the latch was extracted from the model to verify the resistance of the latches.

7.3 LOADS AND BOUNDARY CONDITIONS

7.3.1 LOADS

The loads considered in the analyses are self-weight, counterweight and wind (draft) loading. The maximum allowable counterweight on the outrigger was determined first. Secondly, the required counterweight was determined per configuration with the analytical stability calculations. Also the strength and stability of the ladders was checked. Finally, the configuration with a height of 5.5 m was used in the verification of the base stand, the outrigger and the draw latch system.

7.3.1.1 SELF-WEIGHT ($G_{K,1}$)

The self-weight of the modelled structure was defined by applying a downward acceleration of 9.81 m/s². For the model including the base stand with outrigger, the weight of the LED-tiles was defined by applying a pressure load on the face illustrated in Figure 13. The mass of a single tile was provided by the customer and is 9.6 kg. The weight of the ladders was defined using concentrated forces at the reference points near the centre of the parts “23-D0475-B_SHIP_OUTRIGGER_STACKING_Absen”.

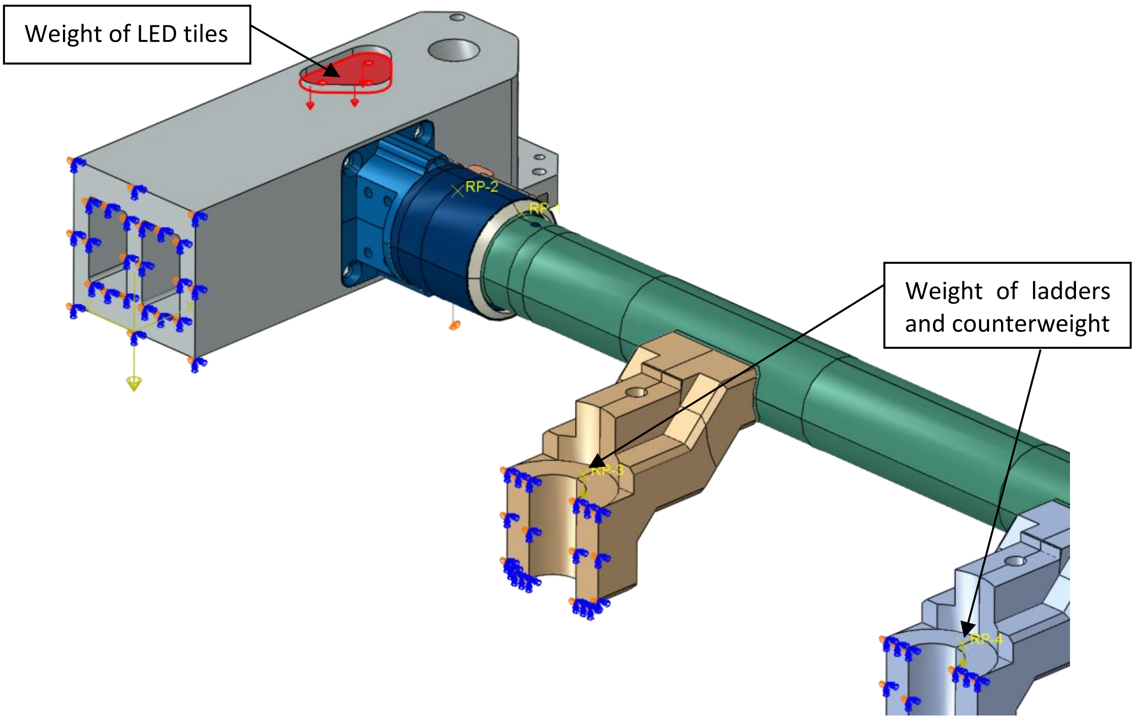

Figure 13 - Weight of the LED tiles

7.3.1.2 COUNTERWEIGHT ($G_{K,CW}$)

The way the counterweight was applied depends on the considered configuration:

- Configuration-A and B: Two identical concentrated forces were applied at the reference points near the centre of the parts “23-D0475-B_SHIP_OUTRIGGER_STACKING_Absen”.
- Configuration-C: A single concentrated force was applied in the reference point positioned at 100 mm from the rear feet. This reference point was coupled to the top face of the part “23-D0443-B_STRENGTHEN_OUTRIGGER-0.8M_STACKING_Absen” using distributed couplings.

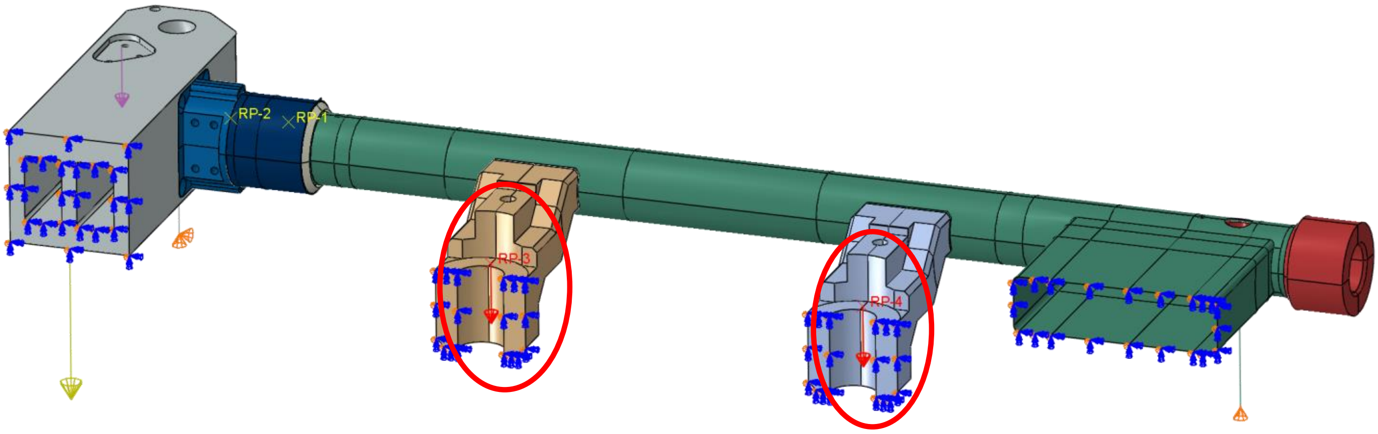

Figure 14 – Configuration-A and B: counterweight applied as two concentrated forces

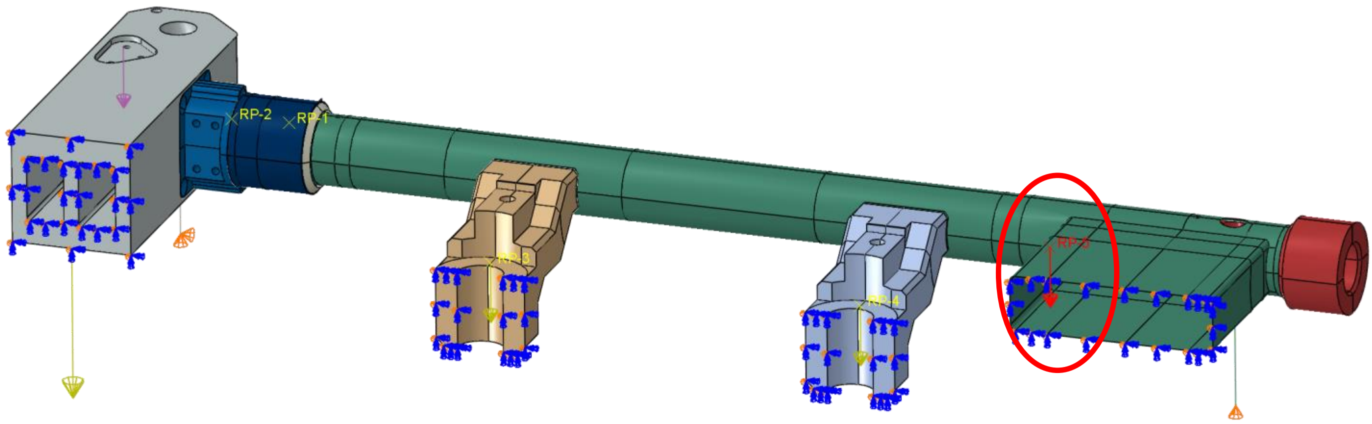

Figure 15 - Configuration-C: counterweight applied as a single concentrated force at 100 mm from the rear feet

Two different counterweight loads were considered:

- In the models used to determine the maximum allowable counterweight: 300 kg/block (= 1200 kg per meter wall width); applied in steps of 25 kg.
- In the models with a wall height of 5.5 m and draft load:
  - Counterweight positioned at the centreline of the ladder: 106 kg/block* (= 424 kg per meter wall width)
  - Counterweight positioned at 100 mm from the rear feet: 265 kg per outrigger*.

*The counterweights used in the ULS (ultimate limit state) combinations are slightly different from the ones calculated in the stability calculations, because the combination factors are different. In the ULS the combination factors are 1.1 for the self-weight and 1.35 for the draft load; while in the stability limit state the factors are 1.0 for the favourable portion of the self-weight, 1.1 for the unfavourable portion of the self-weight and 1.2 for the draft load. To prevent instability of the finite element model, the counterweights were increased by applying the combination factors of the ULS instead.

7.3.1.3 DRAFT LOAD ($Q_{K,D}$)

A “draft” load (i.e. wind load used for indoor applications) was considered, according to “Messe Essen Technical guidelines”. The guideline suggests a pressure of 125 Pa for all surfaces below 4 m. The pressure load on all surfaces above 4 m is 63 Pa.

7.3.2 BOUNDARY CONDITIONS

7.3.2.1 MODEL OF THE LADDERS

All DOF's of the nodes at the bottom of the ladders were constrained. The same boundary conditions were applied for all variants.

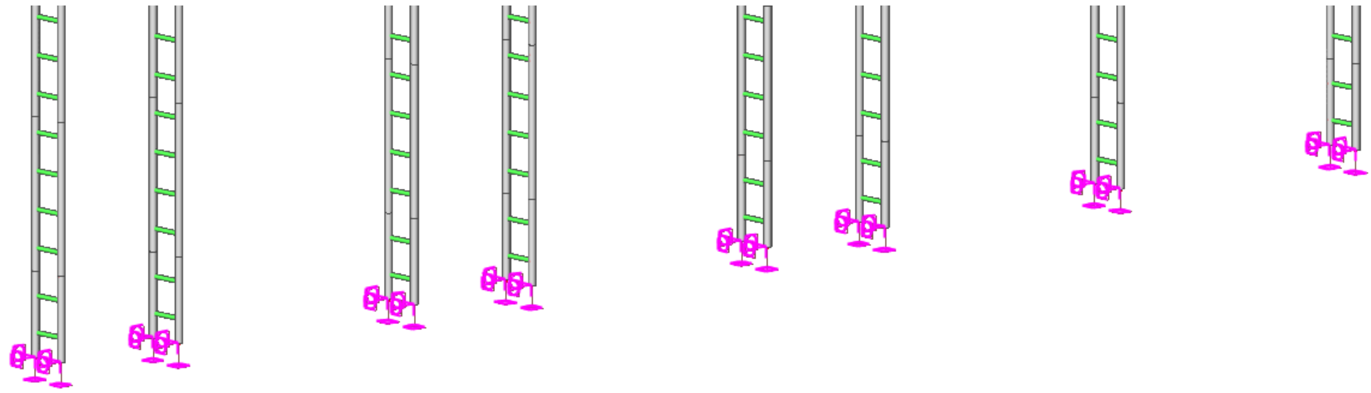

Figure 16 - Boundary conditions

7.3.2.2 MODEL OF THE BASE STAND AND OUTRIGGER

Symmetry boundary conditions were applied to the cut faces. For both feet, the translations in the Z-direction were constrained. The boundary conditions at the feet of the structure depend on the direction of the wind:

- For wind on the back of the wall, the translations in the Y-direction of the base stand foot were constrained (the rear foot has smaller pressure force in case of wind loading on the back), see Figure 17.
- For wind on the front of the wall, the translations in the Y-direction of the rear foot were constrained (the rear foot has greater pressure force in case of wind loading on the front), see Figure 18.

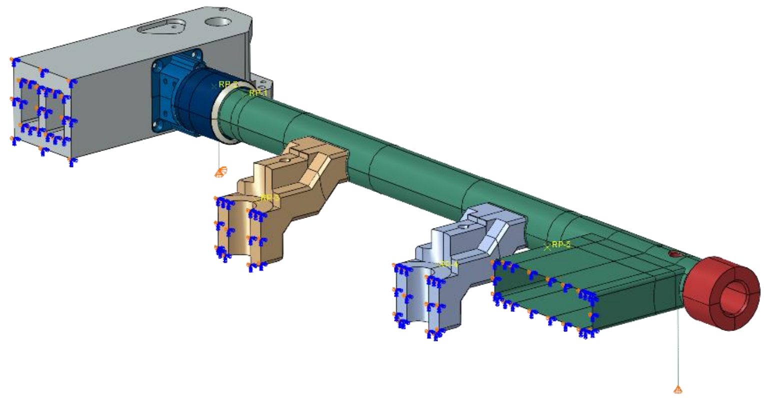

Figure 17 - Boundary conditions, wind on back

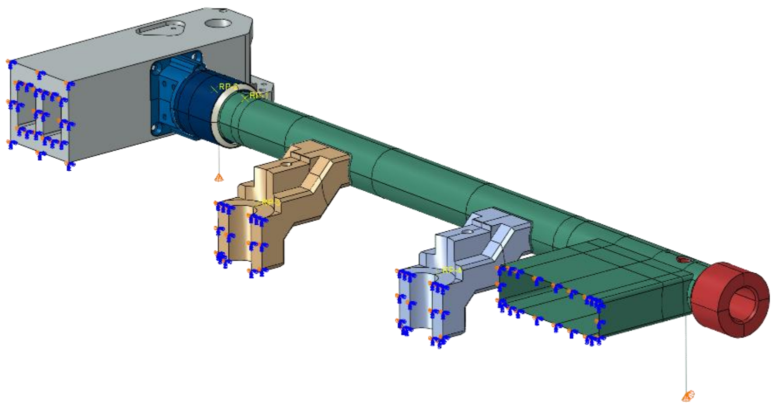

Figure 18 - Boundary conditions, wind on front

7.3.2.3 MODEL OF THE PLATFORM

All DOF's of the cut faces of the main chord of the ladder were constrained. Symmetry boundary conditions were applied on all nodes in the planes of symmetry. The boundary conditions are illustrated in Figure 19.

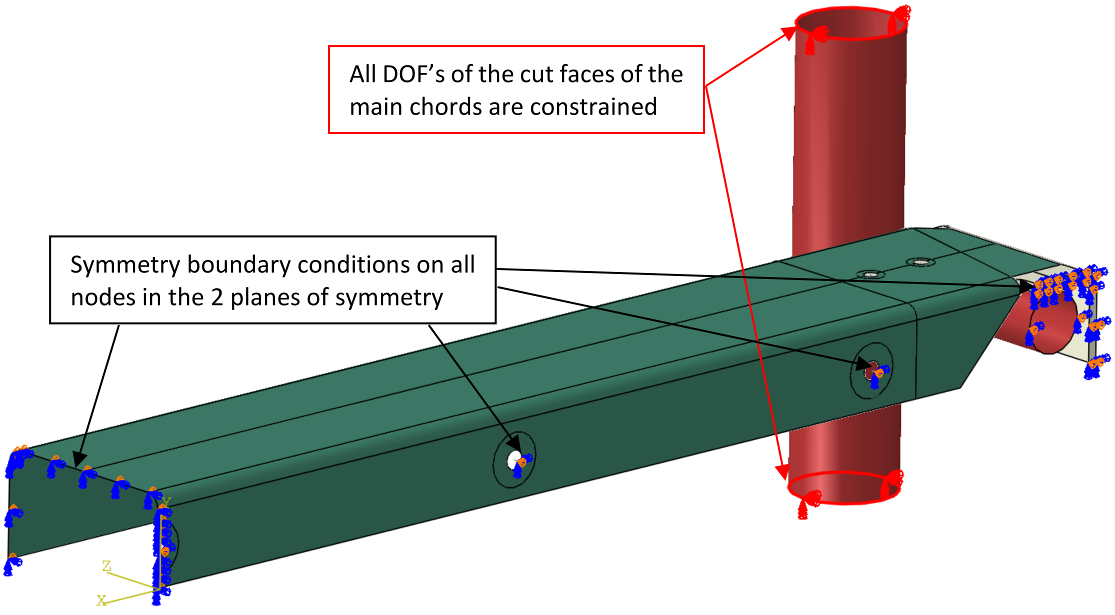

Figure 19 - Boundary conditions

7.3.2.4 MODEL OF THE LADDER CONNECTION

All DOF's of the 2 faces at the sides of the part "23-D0475-B_SHIP_OUTRIGGER_STACKING_Absen" were constrained. The boundary conditions are indicated in red in Figure 20.

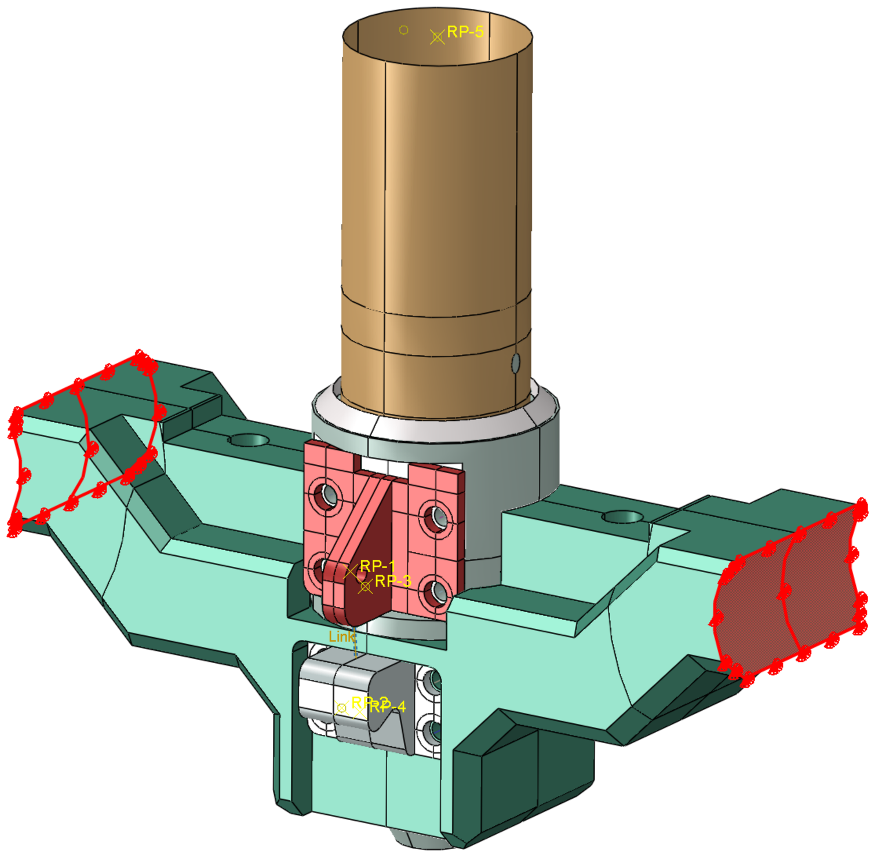

Figure 20 - Boundary conditions

7.4 LOAD COMBINATIONS AND METHOD OF ANALYSIS

7.4.1 ULTIMATE LIMIT STATES (EN 13814)

Ultimate limit state	Stability limit state (loss of equilibrium)
Design situation	Persistent
Method of analysis	Analytical
Load combinations	
ULS-1	(1.0 or 1.1)* x $G_{k,1}$ + 1.0 $G_{k,cw}$ + 1.2 $Q_{k,d}$
Additional remarks	*the combination factor of the dead load depends on the position of the mass in the overall structure. A factor of 1.0 was taken where the dead load is favourable. Where the dead load is unfavourable, a factor of 1.1 was considered.

Ultimate limit state	Plastic limit
Design situation	Persistent
Method of analysis	Linear elastic analysis (static)
Load combinations	
ULS-2	1.1 $G_{k,1}$ + 1.35 x $G_{k,cw}$
Additional remarks	

Ultimate limit state	Plastic limit
Design situation	Persistent
Method of analysis	Linear elastic analysis (static)
Load combinations	
ULS-3	1.1 ($G_{k,1}$ + $G_{k,cw}$) + 1.35 $Q_{k,w}$
Additional remarks	This combination was used for the static verification of the structural components.

7.5 ELEMENT CHOICE AND MESH

Element type(s)	▪ 2-node linear beams (B31), ▪ 4-node doubly curved shells with reduced integration, hourglass control and finite membrane strains (S4R), ▪ 3-node triangular general-purpose shells with finite membrane strains (S3), ▪ 8-node linear bricks with reduced integration and hourglass control (C3D8R), ▪ 4-node linear tetrahedrons (C3D4), ▪ 10-node general purpose tetrahedrons with improved surface stress formulation (C3D10I), and ▪ 8-node quadrilateral in-plane general-purpose continuum shells with reduced integration, hourglass control and finite membrane strains (SC8R).
Average element size	
Model of the base stand and outrigger:	3.0 to 1.5 mm
Model of the platform:	3.0 to 1.0 mm
Model of the ladder connection:	3.0 to 1.5 mm
Number of elements	
Model of the base stand and outrigger:	294,922
Model of the platform:	26,653
Model of the ladder connection:	203,486
Number of nodes	
Model of the base stand and outrigger:	408,593
Model of the platform:	36,403
Model of the ladder connection:	342,283
Degrees-of-freedom	
Model of the base stand and outrigger:	1,064,346
Model of the platform:	128,991
Model of the ladder connection:	896,572
Additional remarks	(1) Only the models for which the number of elements and DOF's are the highest, are summarized in this table. (2) As the model of the ladders is modelled in SCIA Engineer, the standard element size was applied for the ladders.

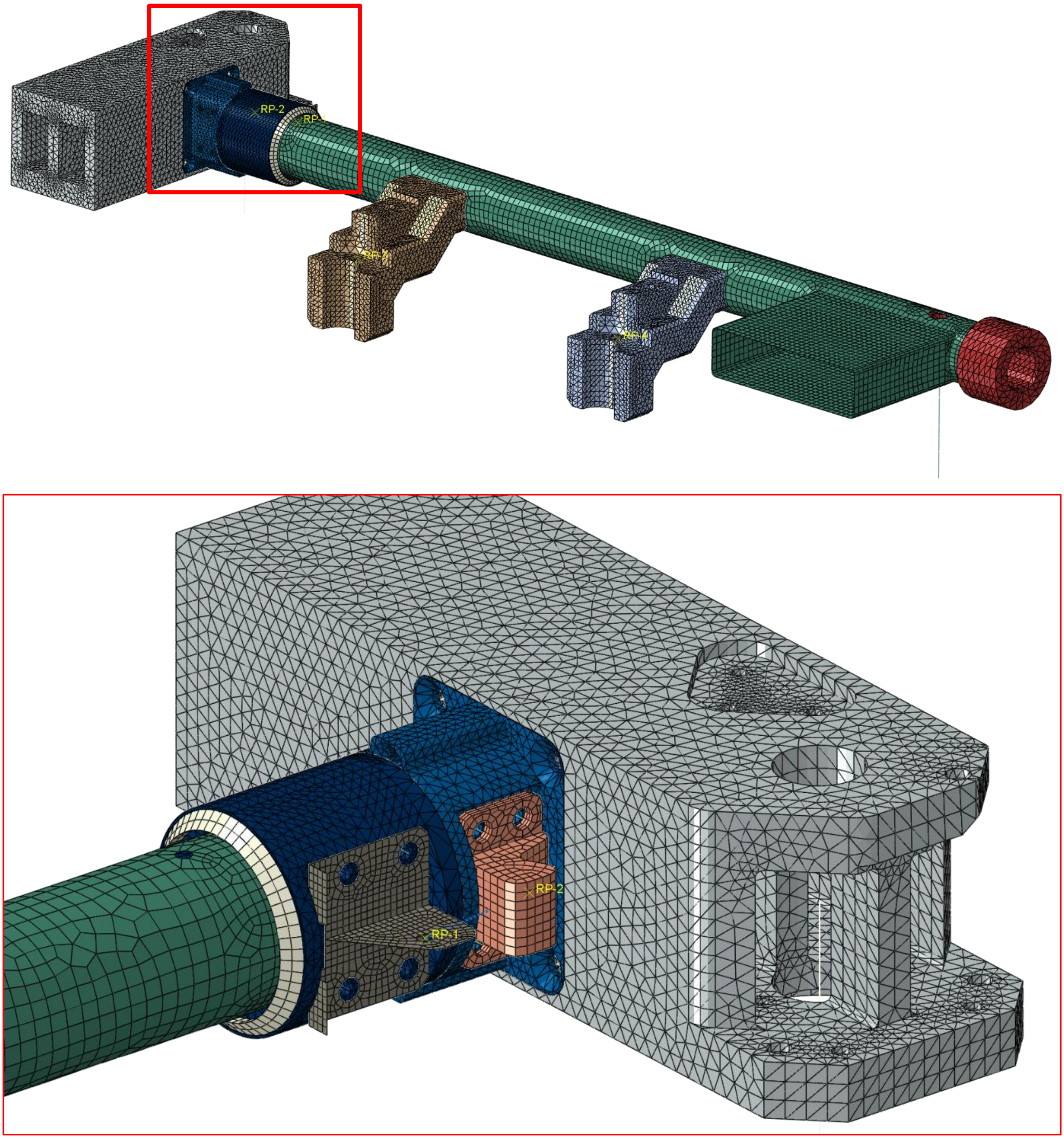

Figure 21 - Model of the base stand with outrigger - mesh

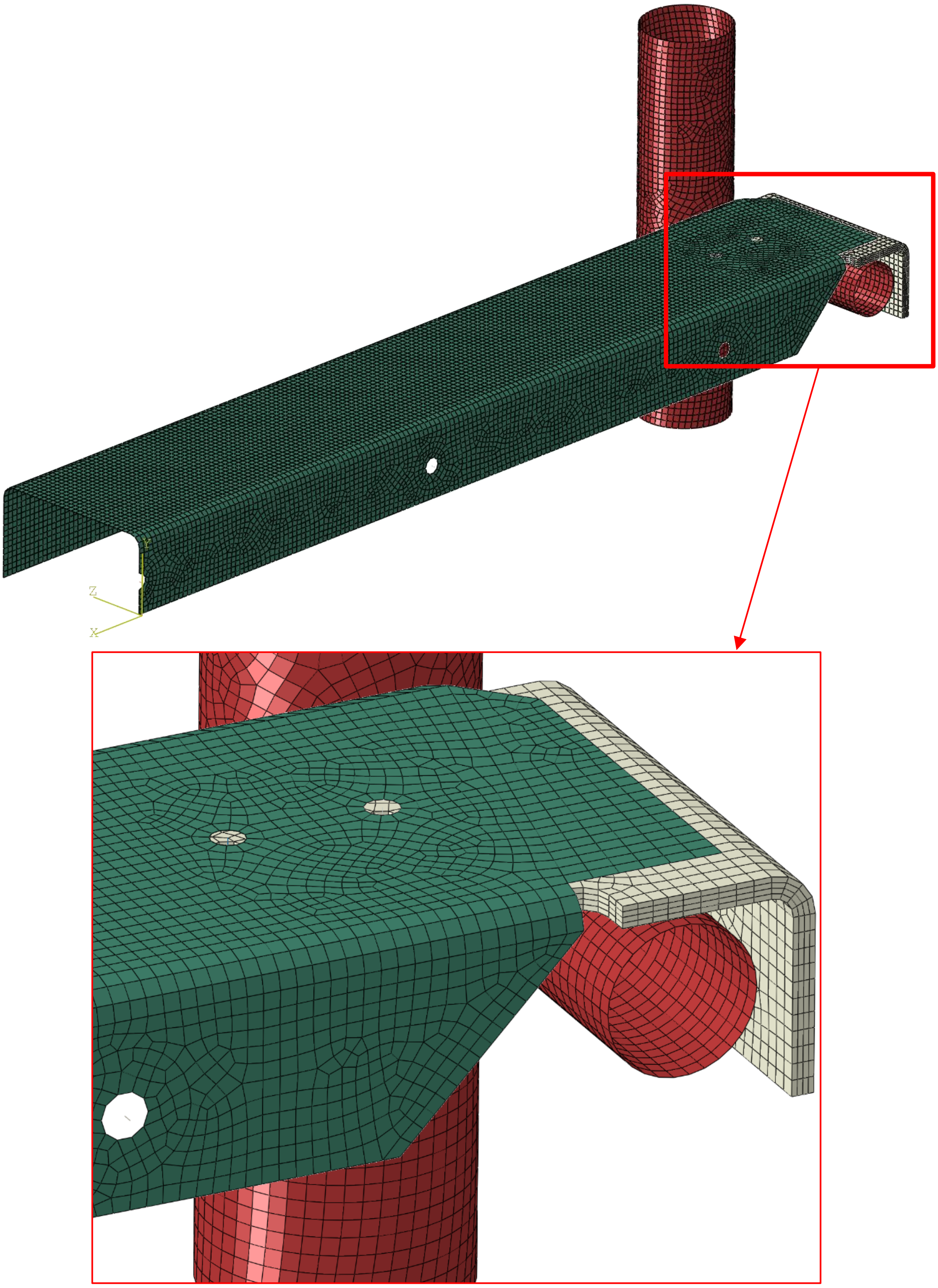

Figure 22 - Model of the platform - mesh

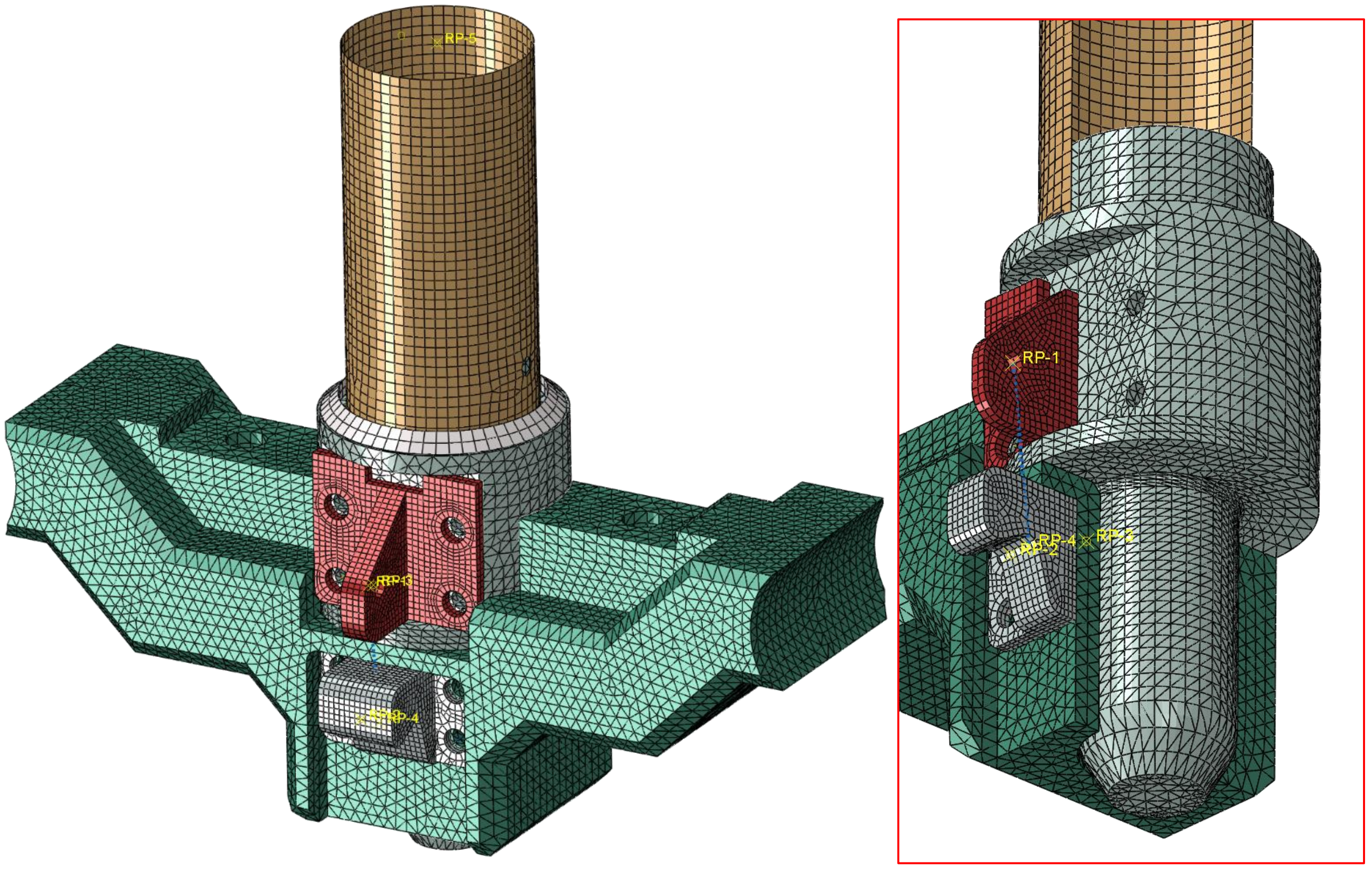

Figure 23 - Model of the ladder connection - mesh (left side: entire model; right side: partial cut view)

8 RESULTS

8.1 INTRODUCTION

The results of the finite element analyses are presented in this section.

Note: unless explicitly mentioned otherwise the legends of the figures in this section show stress values in Pa, displacements in m and reaction forces in N.

8.2 STABILITY CALCULATION (ULS-1)

Stability calculations are done for multiple video wall configurations and multiple counter weight values. The calculations are done analytically. An example of a stability check for one specific configuration (5.5 m high, 1m wide, 260 kg counter weight per outrigger located at 100 mm away from the rear feet) is presented in the next sections.

A summary table showing all considered configurations is presented in section 8.2.6.

8.2.1 LIST OF MASSES

The masses of the distinct parts and their corresponding moments are presented in Table 4. The moments are given without safety factors. The distances of the centres of gravity (COG) are given from the front feet as indicated in Figure 24.

Table 4 - List of parts with their weight and their corresponding moments from the front and rear feet

Item	Quantity	Mass [kg]	COG [mm]	Mass x Qty [kg]	Moment from front [Nmm]	Moment from back [Nmm]	Reference / remarks
LED tile	22	9.6	-33.8	211.2	-70,029	1,607,358	9.6 kg and 5 mm to 10 mm from the centreline of the kingpins, towards the front of the tile (whichever is more critical). Source: email Water Fu on September 5th, 2018
Ladder 1.0 m	5	5.652	401	28.26	111,169	94,536	5.652 kg. Source: BOM 23-J00027_STACKING_Absen-PL-Strength Calculation.xlsx
Ladder 0.56 m	1	3.89	401	3.89	15,303	13,013	3.89 kg. Source: BOM 23-J00027_STACKING_Absen-PL-Strength Calculation.xlsx
Outrigger 0.8m	1	9.584	459.3	9.584	43,186	26,576	9.584 kg based on "BOM Production 23-A0226-C_OUTRIGGER-0.8m_STACKING_Absen.xlsx". Position COG estimated from the centre of volume
Base stand	2	7.56	0	15.12	0	110,059	Source: BOM 23-J00027_STACKING_Absen-PL-Strength Calculation.xlsx. Position COG is taken as 0 mm.
Clamps	6	1.461	149.9	8.766	12,887	50,921	1.461 kg based on "BOM 23-J00027_STACKING_Absen-PL-Strength Calculation.xlsx". Position COG estimated from the centre of volume
Counter weight	1	260	642	260	1,637,485	255,060	Variable value, to be calculated

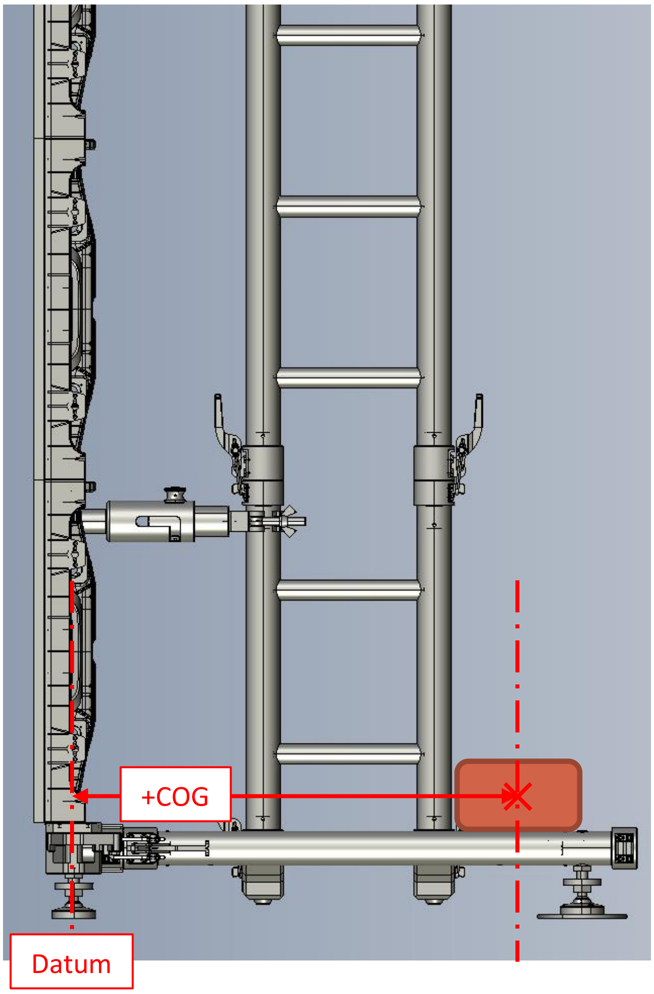

Figure 24 - Definition of the distance COG

8.2.2 BACK TO FRONT OVERTURNING STABILITY

The net stabilizing moment is calculated from the values in Table 4. If the moment is stabilizing, the value is multiplied by a combination factor of 1.0. If the moment is destabilizing, a factor of 1.1 is used. The resulting values are presented in Table 5.

Table 5 - Stabilizing and destabilizing moments due to the dead loads

Item	Moment from front [Nmm]	Stabilizing moment [Nmm]	Destabilizing moment [Nmm]
LED tile	-70029.2736	/	77,032
Ladder 1.0 m	111169.4706	111,169	/
Ladder 0.56 m	15302.5209	15,303	/
Outrigger 0.8m	43185.76564	43,186	/
Base stand	0	/	0
Clamps	12887.12978	12,887	/
Counter weight	1637485.2	1,637,485	/
	Totals:	1,820,030	77,032

For back to front overturning stability, the allowable destabilizing moment is 1,742,998 Nmm.

The destabilizing moment caused by draft load is:

$$M_{draft} = 1.2 \cdot [(1\,m \cdot 4\,m \cdot 125\,Pa) \cdot 2\,m + (1\,m \cdot 1.5\,m \cdot 63\,Pa) \cdot 4.75\,m] = 1{,}738.65\,Nm$$

The unity check for back to front overturning stability is:

$$\frac{1{,}738.65\,Nm}{1{,}743.00\,Nm} = 0.998\ (\leq 1.0 \rightarrow OK!)$$

8.2.3 FRONT TO BACK OVERTURNING STABILITY

The resulting moments for front to back overturning stability are presented in Table 6.

Table 6 - Stabilizing and destabilizing moments due to the dead loads

Item	Moment from back [Nmm]	Stabilizing moment [Nmm]	Destabilizing moment [Nmm]
LED tile	1607358.298	1,607,358	/
Ladder 1.0 m	94535.6346	94,536	/
Ladder 0.56 m	13012.8669	13,013	/
Outrigger 0.8m	26576.36204	26,576	/
Base stand	110058.7824	110,059	/
Clamps	50920.75954	50,921	/
Counter weight	255060	255,060	/
	Totals:	2,157,523	0

For front to back overturning stability, the allowable destabilizing moment is 2,157,523 Nmm.

The destabilizing moment caused by draft load is identical as for back to front overturning stability and is 1,738.65 Nm. The unity check for back to front overturning stability is:

$$\frac{1{,}738.65\ Nm}{2{,}157.52\ Nm} = 0.806\ (< 1.0 \rightarrow OK!)$$

8.2.4 SLIDING STABILITY

The total vertical component of the dead weight is:

$$F_{vert} = 536.82\ \mathrm{kg} \cdot 9.81\ \mathrm{m/s^2} \cdot 1.0 = 5{,}266.20\ N$$

With a Coulomb friction coefficient of 0.2 (value for steel-concrete contact, according to EN 13814), the stabilizing load is:

$$F_{stab} = 5{,}266.20\ N \cdot 0.2 = 1053.24\ N$$

The destabilizing load caused by the draft is:

$$F_{draft} = 1.2 \cdot [(1\ m \cdot 4\ m \cdot 125\ Pa) + (1\ m \cdot 1.5\ m \cdot 63\ Pa)] = 713.4\ N$$

The stabilizing action is greater than the destabilizing load caused by the draft load. The unity check is 68%.

8.2.5 CONCLUSION

The structure is stable. The most critical check is the back to front overturning stability for which the unity check is 99.8%.

8.2.6 RESULT TABLES

The calculations presented in sections 8.2.1 to 8.2.5 are done for several wall configurations.Table 7 shows the minimum required
counterweight as a function of the wall height.

Table 7 - Minimum required counterweight (indoor use only)

Wall height [m]	Min. required counterweight [kg]			
	Combination-1 (draft load) Applied per meter wall width		Combination-2 (50 kg at 1 m height) Distributed across all base stands	
	Applied at centreline of ladder	Applied at 100 mm from rear feet	Applied at centreline of ladder	Applied at 100 mm from rear feet
0.5	0	0	140	304
1	0	0	136	128
1.5	28	20	136	84
2	56	36	132	84
2.5	100	64	132	84
3	148	92	128	80
3.5	212	132	132	84
4	280	176	128	80
4.5	320	200	128	80
5	364	228	124	76
5.5	416	260 (see example in §8.2)	128	80

8.3 LADDERS (ULS-3)

The draft load, as suggested by the Messe Essen Technical Guidelines, is applied on all ladders using concentrated loads at the clamps. For configurations with a height of 3.5 m to 5.5 m, horizontal bracings are required to prevent the main chords of the ladders from buckling. The unity checks of all configurations are summarized in Table 8 and are illustrated in Figure 25. Note that, regardless of the wall height, the most critical check is the buckling check of the vertical members.

Table 8 – Maximum unity checks

Wall height [m]	Horizontal bracing?	Unity check
1.5	No	0.14
2.5		0.63
3.5	Yes	0.31
4.5		0.55
5.5		0.86

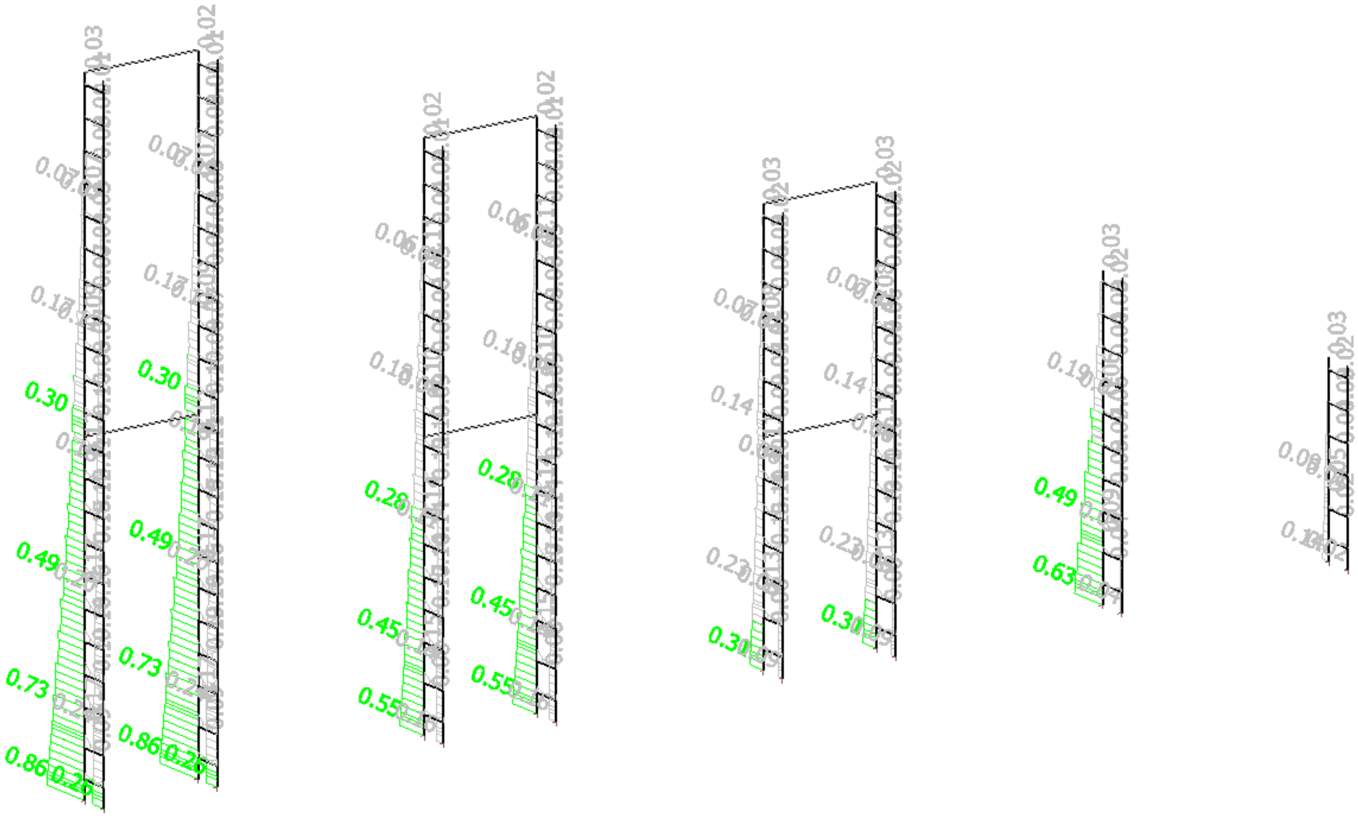

Figure 25 - Unity checks

8.4 BASE STAND WITH OUTRIGGER

In total, 6 variants were created:

- Models with the counterweight positioned at the centreline of the ladder:
  - Model-1: Model in which the maximum allowable counterweight is determined (ULS-2).
  - Model-3a: Model with the draft load on the back (ULS-3).
  - Model-3b: Model with the draft load on the front (ULS-3).
- Models with the counterweight positioned at 100 mm from the rear feet:
  - Model-2: Model in which the maximum allowable counterweight is determined (ULS-2).
  - Model-4a: Model with the draft load on the back (ULS-3).
  - Model-4b: Model with the draft load on the front (ULS-3).

8.4.1 COUNTERWEIGHT POSITIONED AT THE CENTRELINE OF THE LADDER

8.4.1.1 MAXIMUM ALLOWABLE COUNTERWEIGHT

The maximum allowable counterweight applied in the centreline of the ladder, is 250 kg per block (= 1,000 kg per meter wall width). The most critical parts are the male kingpin and the welded outrigger tube. The yield strength of the material is reached in both parts. However, because the maximum logarithmic principal strain is only 0.26% and because the zones of plastic yielding remain local, this result is accepted. The stresses and strains in the assembly are illustrated in Figure 26 to Figure 29.

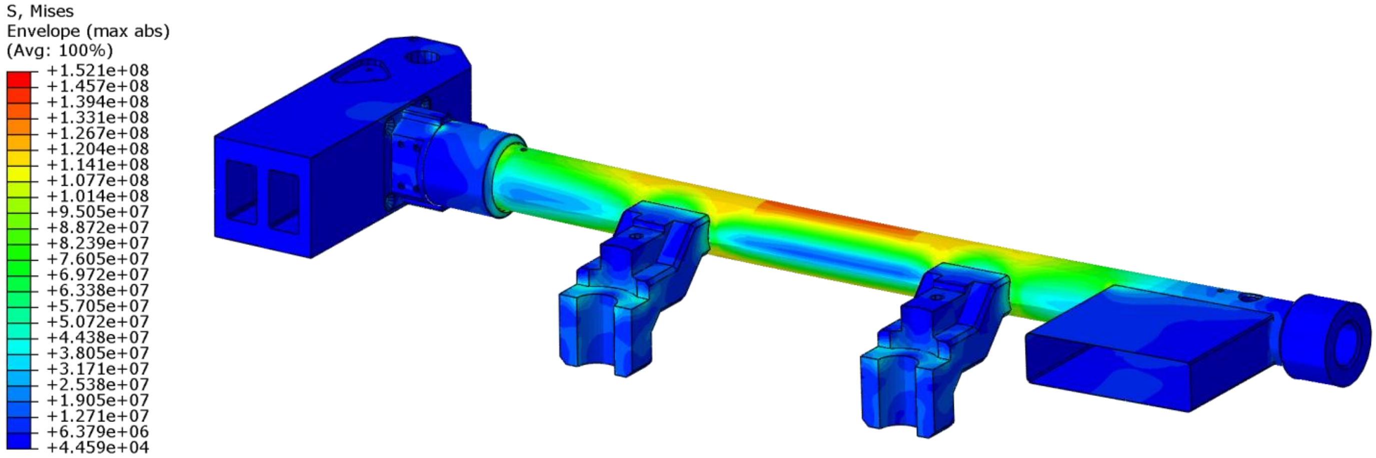

Figure 26 - Von Mises stresses at 250 kg counterweight

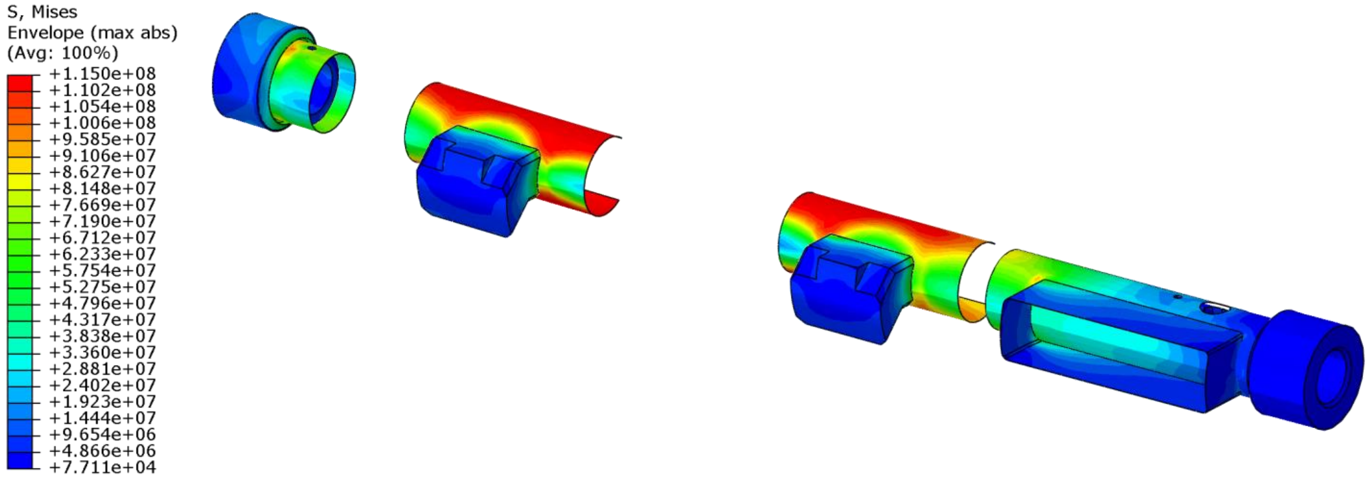

Figure 27 - Von Mises stresses in the heat affected zones due to the welding (HAZ)

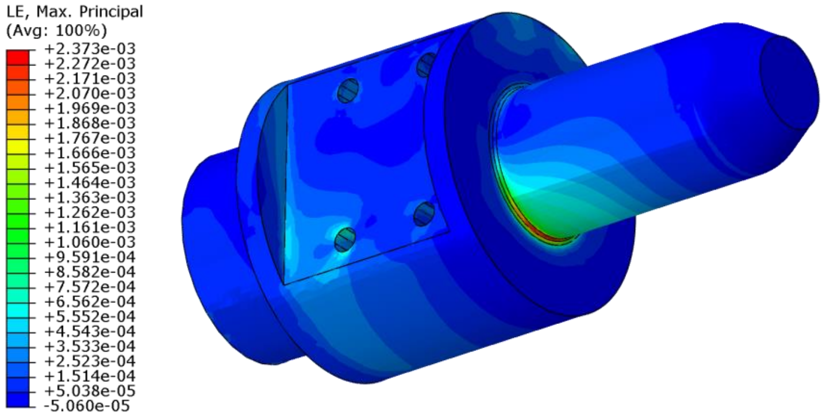

Figure 28 - Maximum logarithmic principal strain in the male kingpin

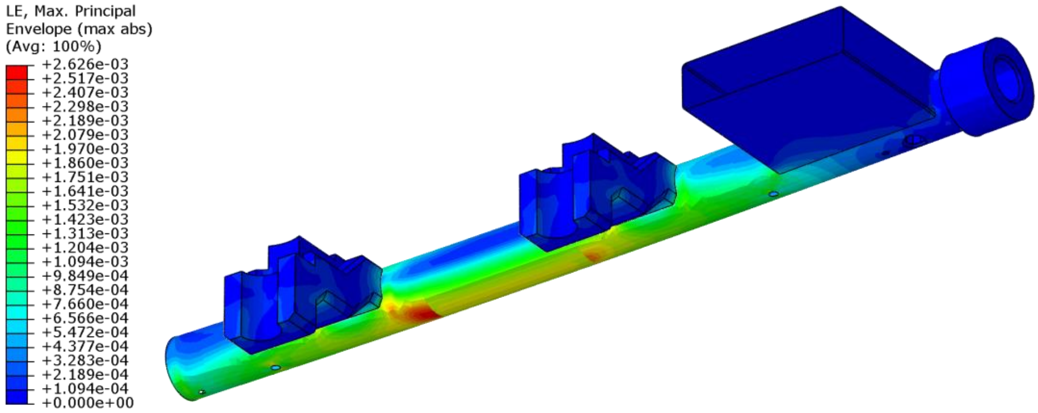

Figure 29 - Maximum logarithmic principal strains in the outrigger tube

8.4.1.2 DRAFT LOAD

The base stand and the outrigger are checked for a video wall height of 5.5 m, loaded by draft. To ensure the stability of the structure, a counterweight of 424 kg per meter wall width is considered.

The maximum stress in the outrigger is 106 MPa, occurs near one of the holes in the outrigger tube, and is found for draft on the back of the video wall. This value is smaller than the yield strength of the material EN-AW 6061 T6 of 240 MPa. Also in the heat affected zones the maximum stress of 94 MPa is smaller than the yield strength of 115 MPa. Therefore, it is concluded that the base stand and outrigger can withstand the indoor draft load if the counterweight is positioned at the centreline of the ladders. The stresses and strains in the structure are illustrated in Figure 30 to Figure 32.

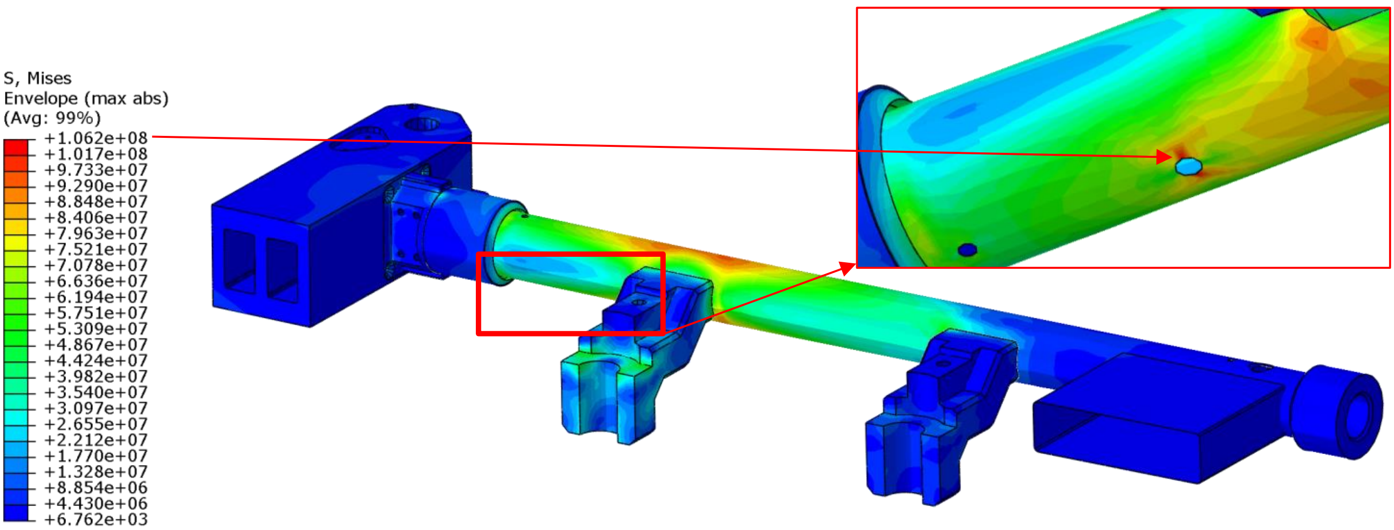

Figure 30 - Von Mises stresses in the base stand and outrigger

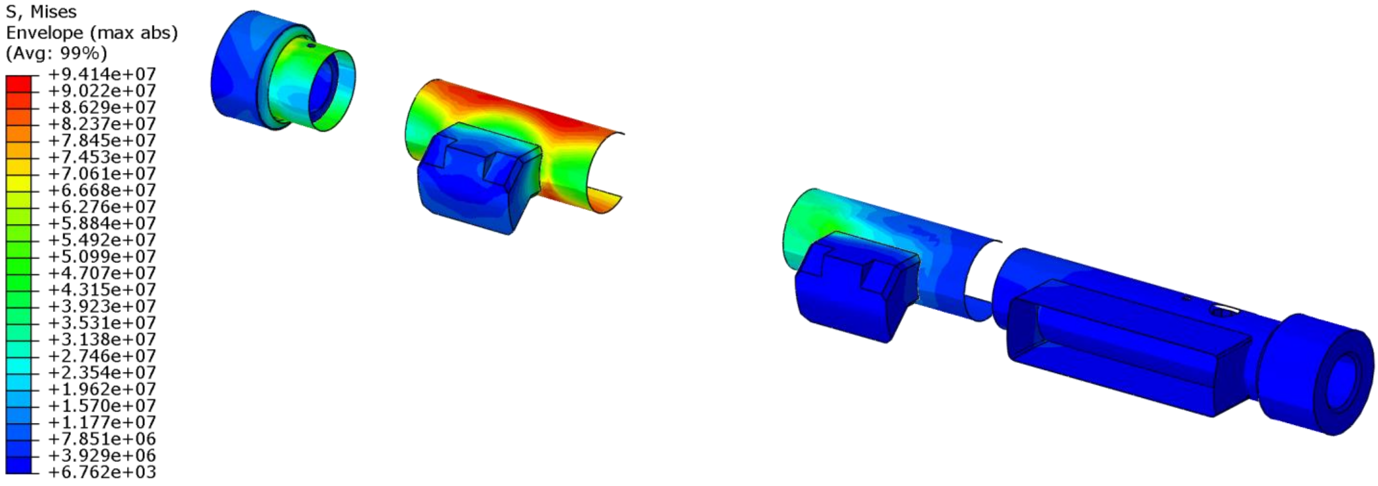

Figure 31 - Von Mises stresses in the heat affected zones (HAZ)

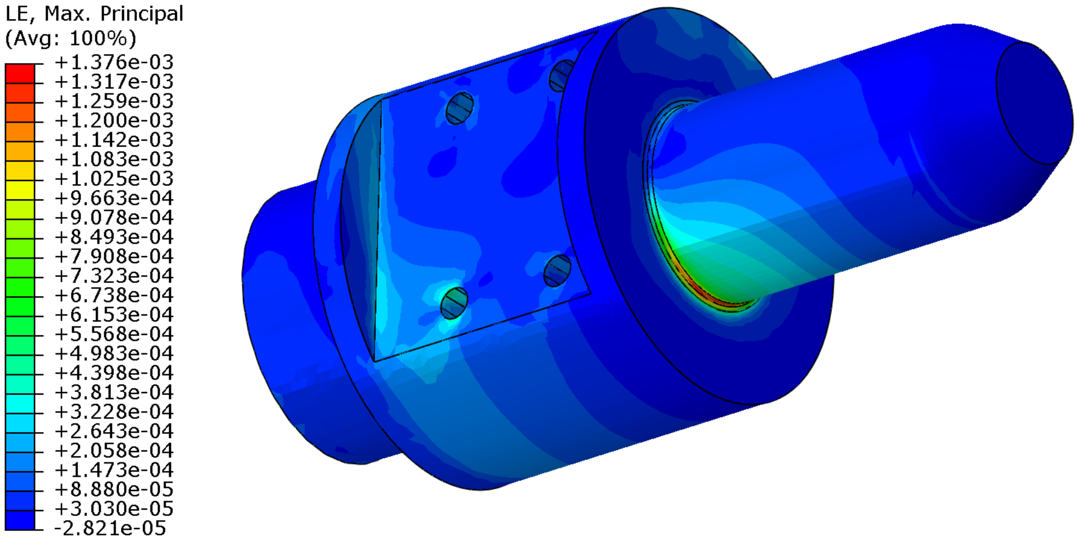

Figure 32 - Maximum logarithmic principal strains in the male kingpin

8.4.2 COUNTERWEIGHT POSITIONED AT 100 MM FROM THE BACK FEET

8.4.2.1 MAXIMUM ALLOWABLE COUNTERWEIGHT

The maximum allowable counterweight applied at 100 mm from the back feet is 600 kg per outrigger and is limited by the rectangular hollow section “23-D0443-B_STRENGTHEN_OUTRIGGER-0.8M_STACKING_Absen”. The von Mises stresses in this part reach the yield strength of 240 MPa. The maximum logarithmic principal strain is 0.46%, which is well below the limit of 5% according to EN 1993-1-5, annex C. The von Mises stresses are illustrated in Figure 33 and Figure 34. The logarithmic principal strains are illustrated in Figure 35.

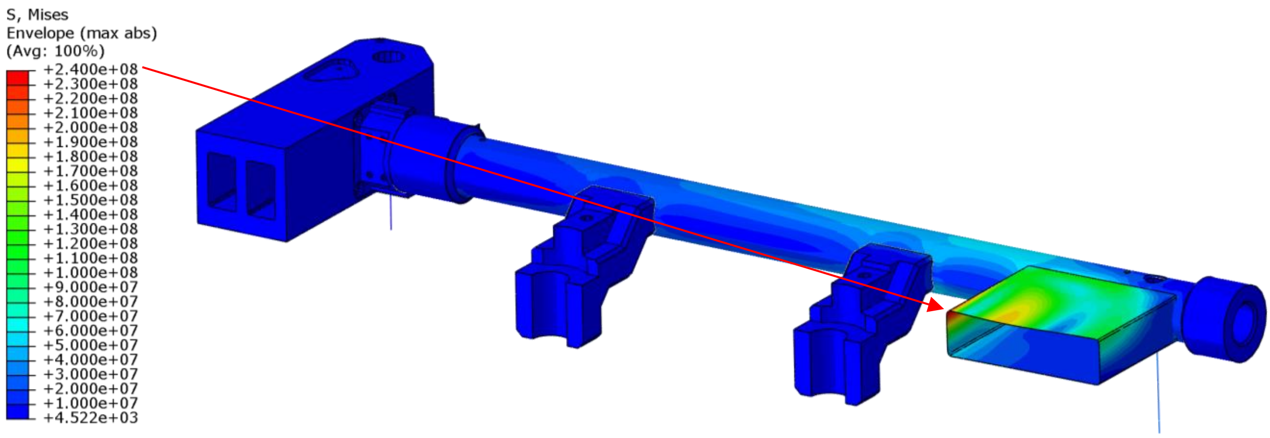

Figure 33 - Von Mises stresses in the base stand and outrigger

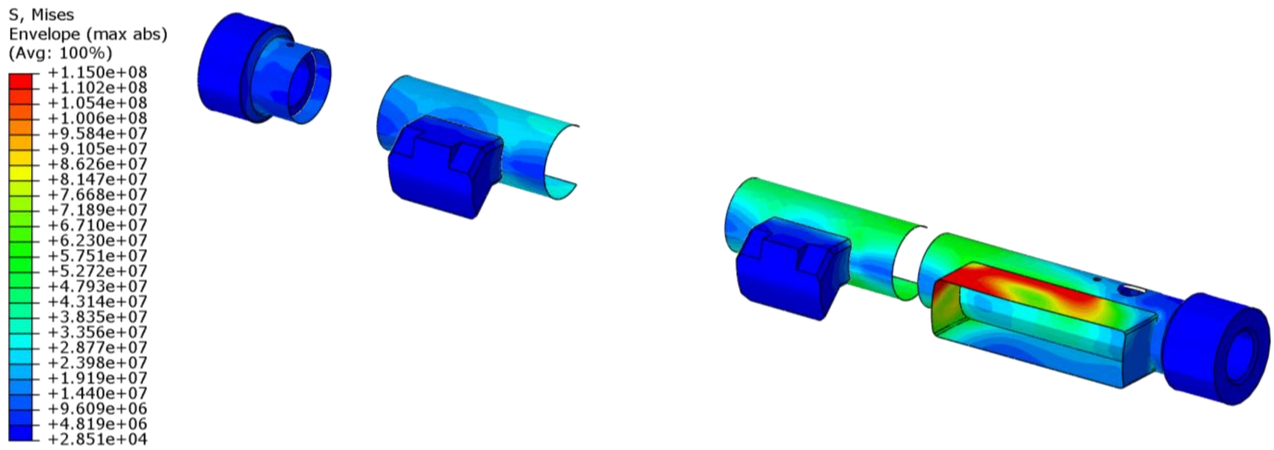

Figure 34 - Stresses in the HAZ of the material EN AW 6061 T6

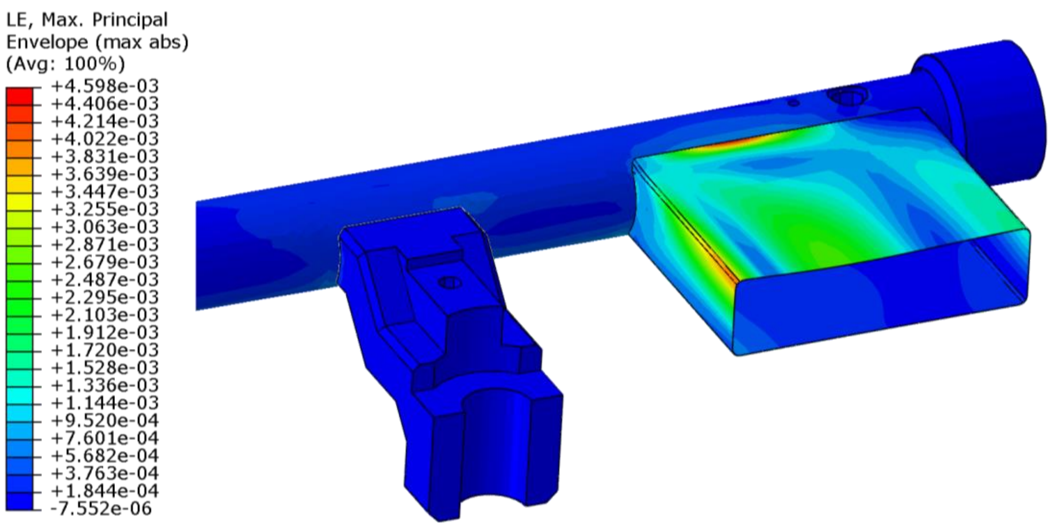

Figure 35 - Maximum logarithmic principal strains

The value of 600 kg per outrigger is limited by the extent of the plastic zones rather than the maximum value of the logarithmic principal strain. The plastic zones are illustrated in Figure 36 (grey areas) by applying an upper value of the scale of the plastic equivalent strains to 0.2%.

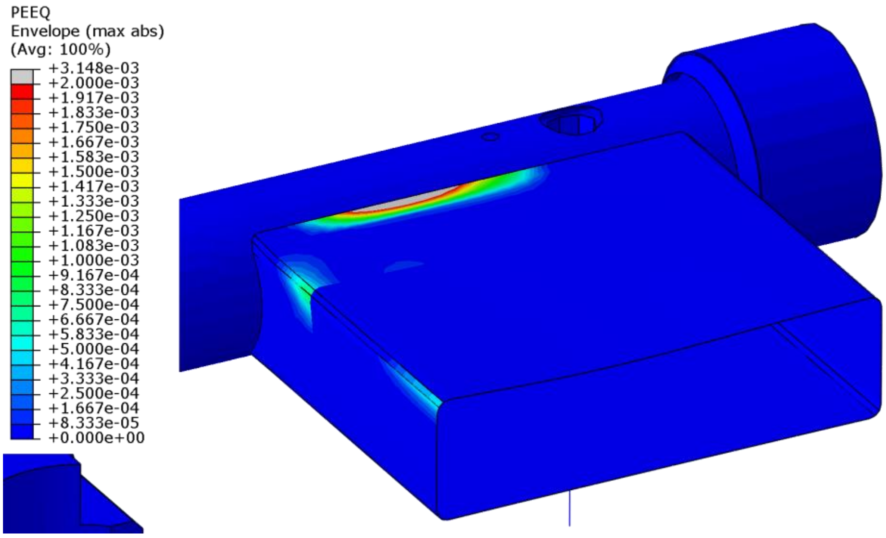

Figure 36 - Plastic equivalent strains in the rectangular hollow section

8.4.2.2 DRAFT LOAD

The base stand and the outrigger are checked for a video wall height of 5.5 m. To ensure the stability of the structure, a counterweight of 265 kg per meter wall width is considered.

The maximum stress in the outrigger is 94 MPa, occurs in the rectangular hollow section at the back of the outrigger, and is found for the draft load on the front of the video wall. This value is smaller than the yield strength of the material EN-AW 6061 T6 of 240 MPa. Also in the heat affected zones the maximum stress of 75 MPa is smaller than the yield strength of 115 MPa. Therefore, it is concluded that the base stand and outrigger can withstand the indoor draft load if the counterweight is positioned at 100 mm from the rear feet of the base stand. The stresses and strains in the structure are illustrated in Figure 37 to Figure 40.

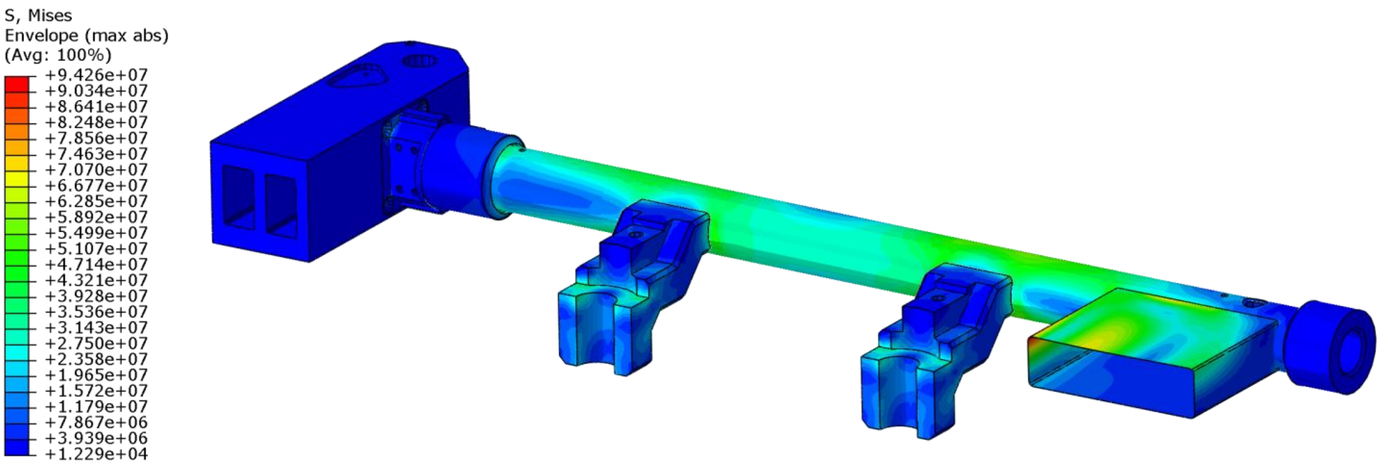

Figure 37 - Von Mises stresses in the base stand and outrigger

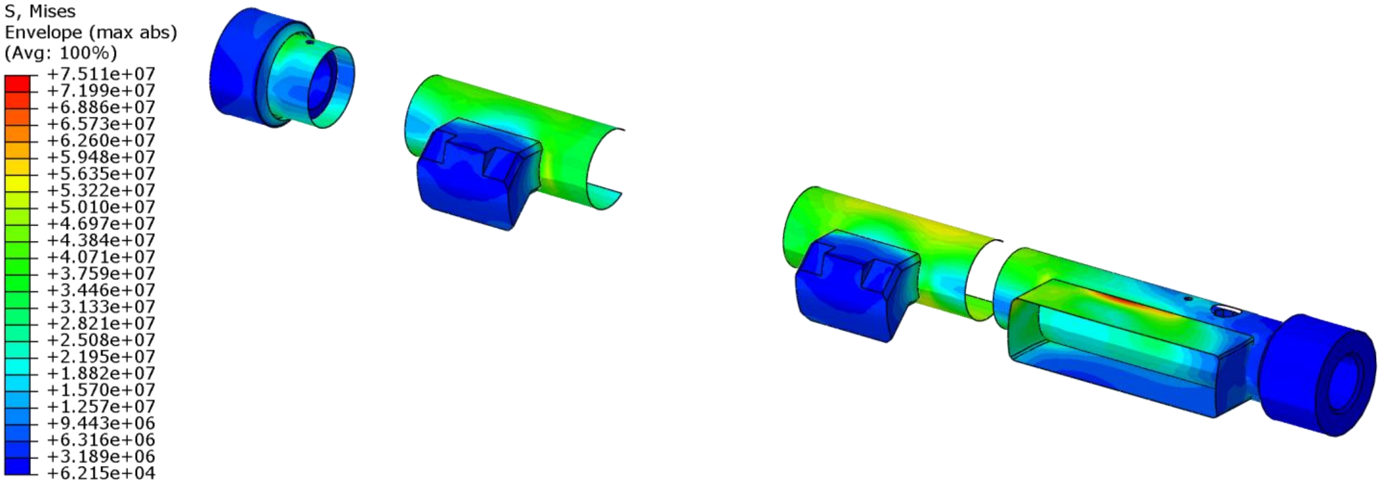

Figure 38 - Von Mises stresses in the heat affected zones (HAZ)

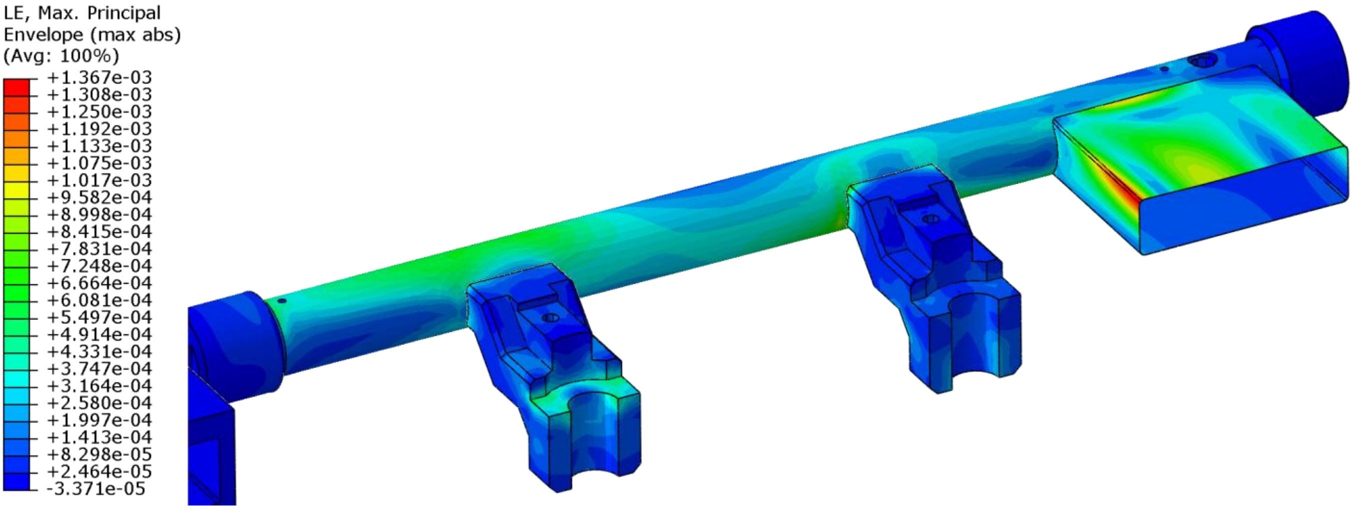

Figure 39 - Maximum logarithmic principal strains in the base stand and outrigger

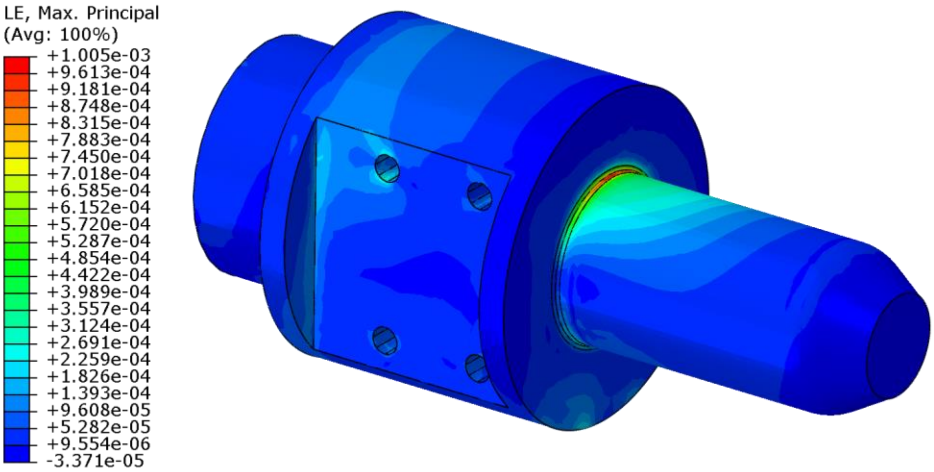

Figure 40 - Maximum logarithmic principal strains in the male kingpin

8.5 PLATFORM

The maximum allowable counterweight on the platform is 280 kg (the total allowable mass on the platform is 4 x 280 = 1120 kg). For a counterweight of 280 kg, the stresses reach the yield strength of the material EN-AW 6061 T6 of 240 MPa at the connection with the ladder and at the centre of the platform. Because the zones of plastic yielding remain local and the maximum logarithmic principal strain is 1.0% (which is less than the maximum allowable principal strain of 5% according to EN 1993-1-5, Annex C), the result is accepted. The stresses and strains in the assembly are illustrated in Figure 41 and Figure 42.

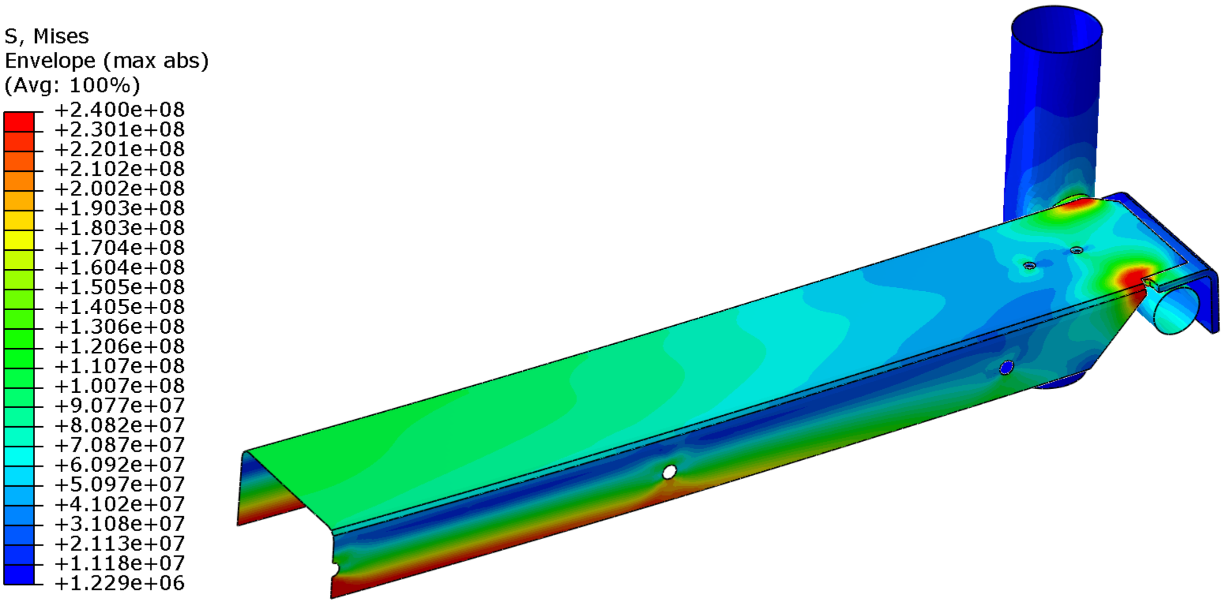

Figure 41 - von Mises stresses in the platform

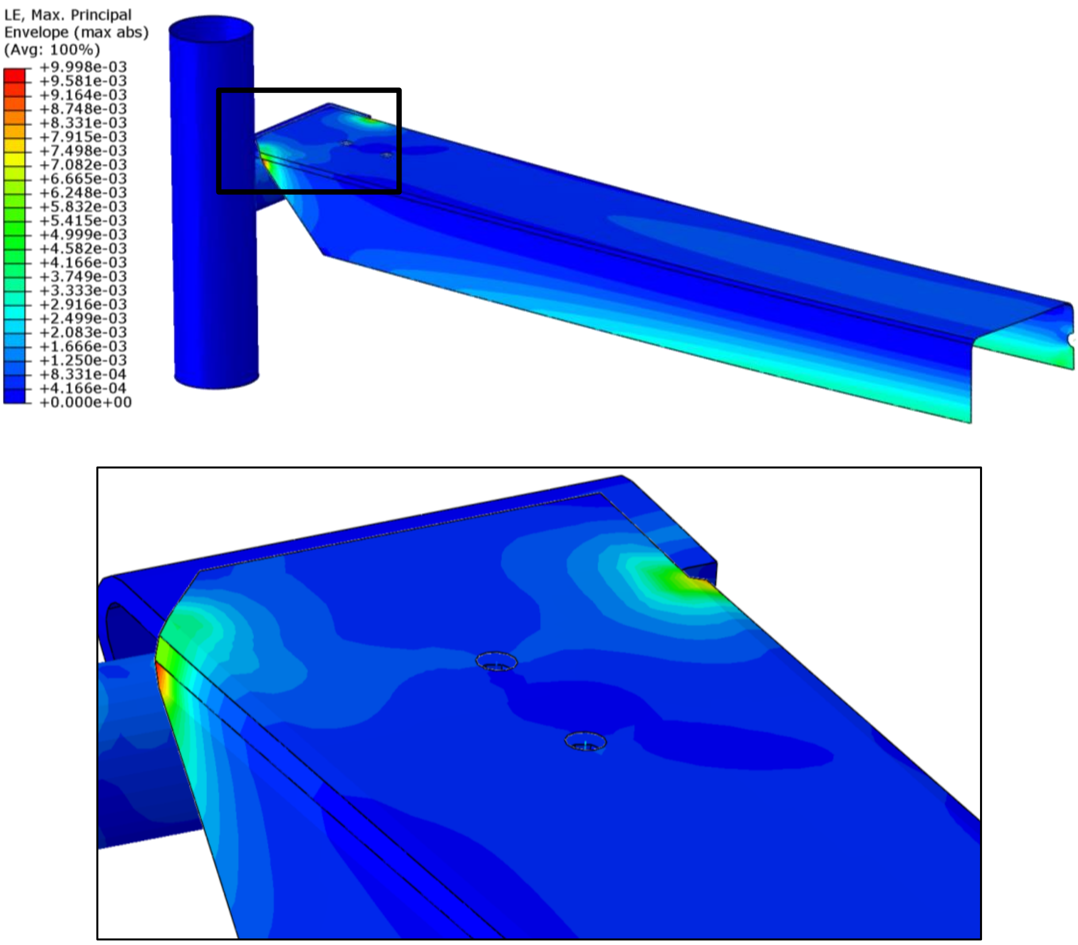

Figure 42 - Maximum principal logarithmic strains

8.6 FEET OF THE BASE STAND

The feet of the base stand are checked analytically. The feet are threaded stainless steel (1.4301) rods with a nominal diameter M16. For a stress diameter of 14.14 mm, the plastic section modulus of the cross section is:

$$W_{pl} = \frac{1.698 \cdot (14.14\ mm)^3 \cdot \pi}{32} = 471.29\ mm^3$$

The maximum horizontal force for indoor use is:

$$F_{foot,indoor} = \frac{(125\ Pa \cdot 4\ m \cdot 1\ m + 63\ Pa \cdot 1.5\ m \cdot 1\ m) \cdot 1.35}{2} = 401.29\ N$$

With a distance between the bottom face of the base stand and the floor of 77.5 mm, the bending moment in the foot is:

$$M_b = 422.25\ N \cdot 77.5\ mm = 31{,}100\ Nmm$$

The resulting normal stress is:

$$\sigma = \frac{M_b}{W_{pl}} = 65.99\ MPa\ (< 190/1.1\ = 173\ MPa \rightarrow OK!)$$

The stress in the feet is smaller than the design resistance of 173 MPa. The feet can withstand the load.

8.7 LADDER CONNECTION

8.7.1 STRESS CHECK

The connection between the ladder and the outrigger is checked in this section. For an axial tensile loading of 4,274 N on the main chord of the ladder, the force in the connector of the model equals 3,200 N. The maximum stress in the aluminium parts for a force of 4,274 N is 146 MPa and is found outside de HAZ of the male kingpin part. This value is smaller than the yield strength of the material (240 MPa). The maximum stress in the HAZ equals 78 MPa; which is also smaller than the yield strength of the heat affected zone (115 MPa). In the steel support parts of the DESTACO coupling the maximum von Mises stress is 204 MPa. The von Mises stresses are illustrated in Figure 43 to Figure 45.

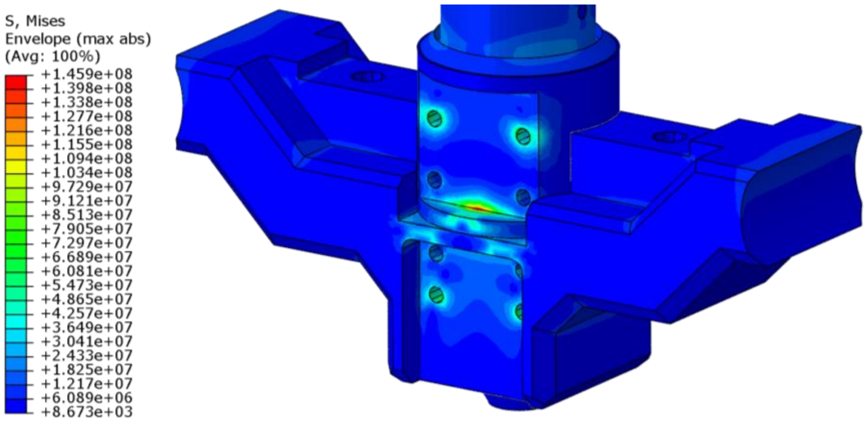

Figure 43 - Stresses in the ladder connection assembly

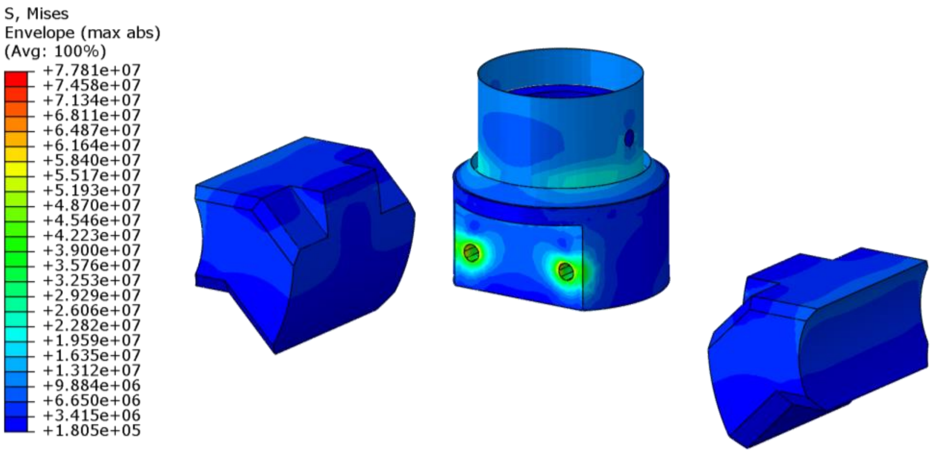

Figure 44 - Stresses in the HAZ of EN-AW 6061 T6

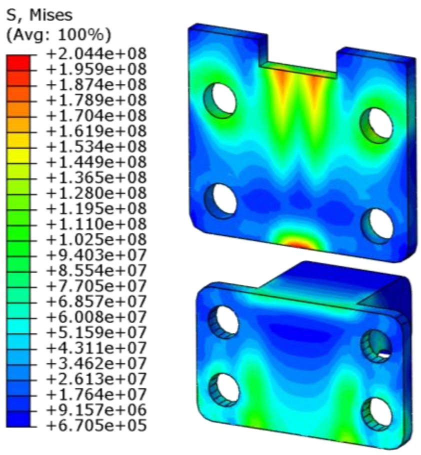

Figure 45 – Stresses in the steel support parts of the DESTACO coupling

8.7.2 TENSILE FORCE ON THE LADDER CONNECTIONS

The tensile force on the bottom ladder connection depends on the position of the counterweights. The client suggests 3 cases:

- Case-A: Counterweights are placed onto platforms which are attached to the ladders.
- Case-B and C: Counterweights are put directly onto the base stands.

The maximum tensile force on the ladder connections assembly per wall height is summarized in Table 9. Note that the tensile forces acting on the DESTACO couplings are smaller than the tensile forces acting on the ladder connection assembly due to the friction between the male kingpin and the part "23-D0475-B_SHIP_OUTRIGGER_STACKING_Absen" (see section 8.7.1).

Table 9 - Tensile force on the ladder connections per case for various wall heights (serviceability loads)

wall height [m]	Tensile force [N]		
	Bottom ladder connection		Second ladder connection
	Case-A	Case-B and C	Any case
0.5	63	63	N/A
1	250	250	31
1.5	425	563	181
2	725	1,000	456
2.5	1,072	1,563	856
3	1,524	2,250	1,381
3.5	2,023	3,063	2,031
4	2,627	4,000	2,806
4.5	2,966	4,536	3,423
5	3,349	5,134	3,951
5.5	3,755	5,796	4,542

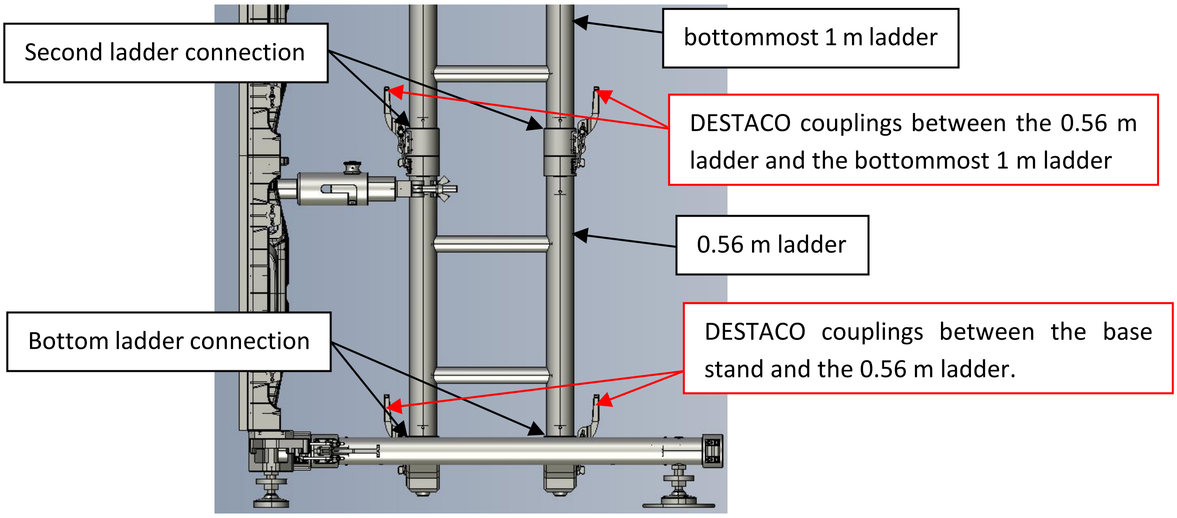

Figure 46 - Identification of critical DESTACO couplings

8.8 BOLTED CONNECTIONS

All bolted connections are checked in this chapter according to EN 1993-1-8. The forces in the bolts are obtained from the finite element models. Note that for most connections no checks were carried out because the bolt loads are very small.

8.8.1 BOLTED CONNECTIONS IN THE BASE STAND AND OUTRIGGER

The bolts are identified in Figure 47.

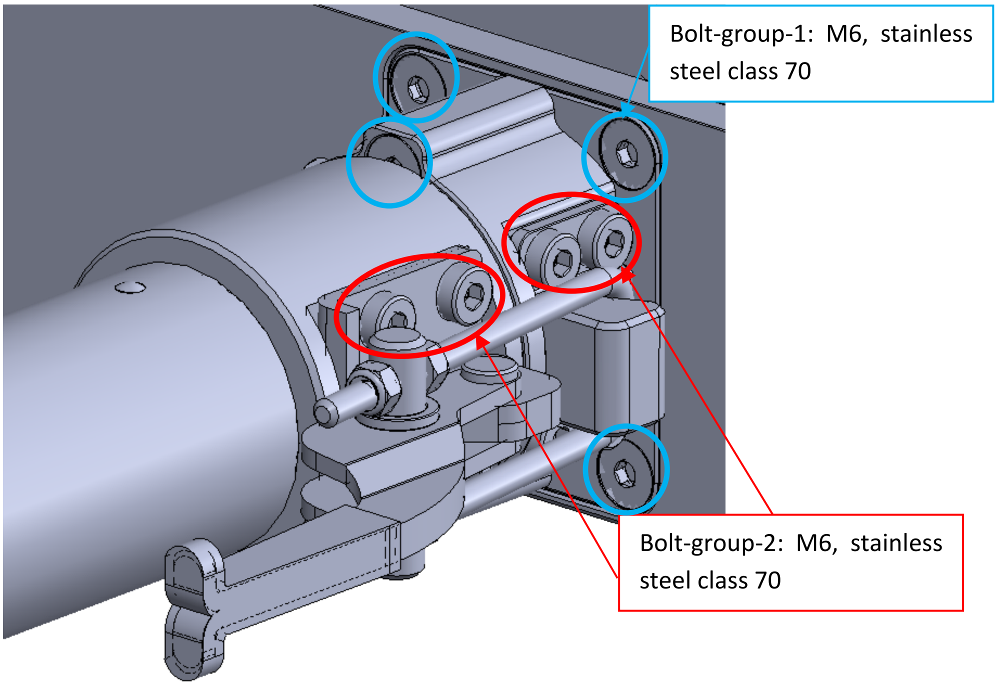

Figure 47 - Bolted connections in the base stand and outrigger

The maximum bolt forces are:

- Bolt-group-1:
  - In tension: 688 N
  - In shear: 549 N
- Bolt-group-2:
  - In tension: 790 N
  - In shear: 512 N

Because the forces are small it can be concluded that the bolts can withstand the loading.

8.8.2 BOLTED CONNECTIONS IN THE PLATFORMS

The bolts are identified in Figure 48.

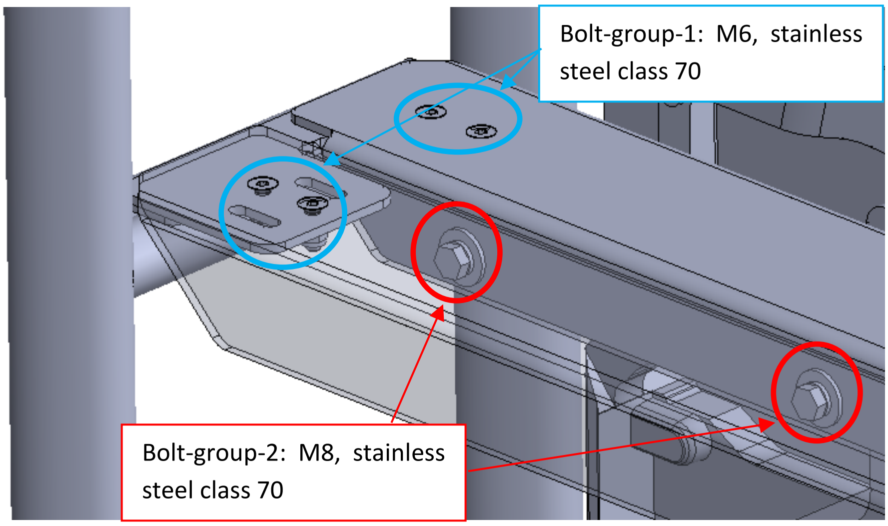

Figure 48 - Bolted connections in the platforms

The maximum bolt forces are:

- Bolt-group-1:
  - In tension: 608 N
  - In shear: 528 N
- Bolt-group-2:
  - In tension: 241 N
  - In shear: 0 N

Because the forces are small it can be concluded that the bolts can withstand the loading.

8.8.3 BOLTED CONNECTIONS IN THE LADDER CONNECTION ASSEMBLY

The bolts are identified in Figure 49.

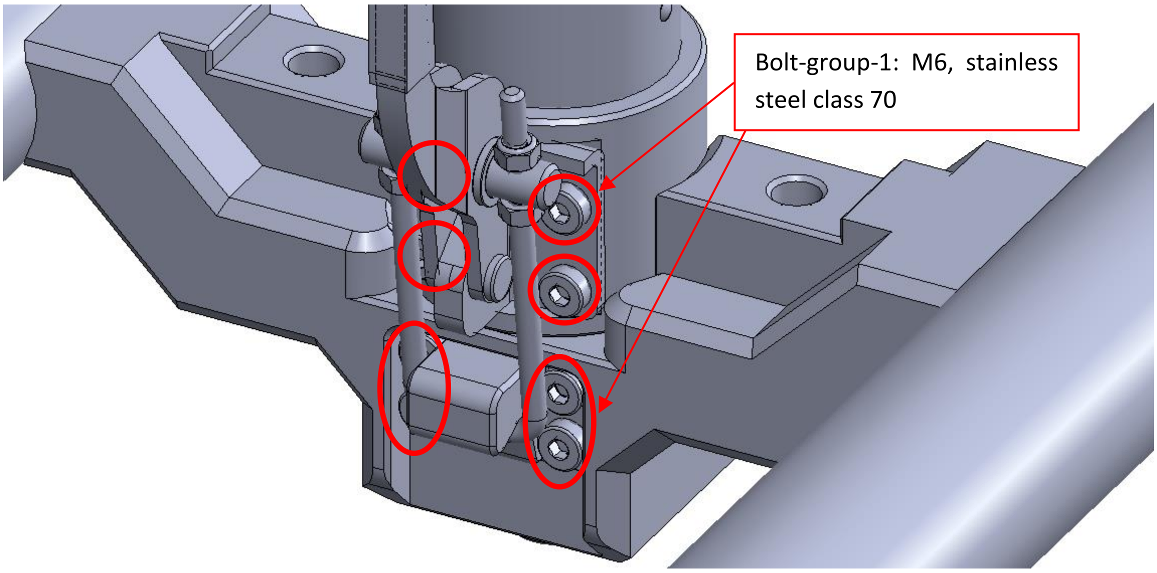

Figure 49 - Bolted connections in the ladder connection assembly

The maximum bolt forces are:

- In tension: $F_{t,Ed}$ = 2,153 N
- In shear: $F_{v,Ed}$ = 400 N

The bolt design resistances are:

- In tension: $F_{t,Rd} = \frac{k_2 \cdot f_{u,b} \cdot A_S}{\gamma_{M2}} = \frac{0.9 \cdot 700 \cdot 20.1}{1.25} = 10{,}130\ N\ (> F_{t,Ed} \rightarrow OK!)$
- In shear: $F_{v,Rd} = \frac{\alpha_v \cdot f_{u,b} \cdot A_S}{\gamma_{M2}} = \frac{0.5 \cdot 700 \cdot 20.1}{1.25} = 5{,}628\ N\ (> F_{v,Ed} \rightarrow OK!)$

The unity check of the bolts is:

- $\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1.4 \cdot F_{t,Rd}} = \frac{400}{5{,}628} + \frac{2{,}153}{1.4 \cdot 10{,}130} = 0.22\ (< 1.0 \rightarrow OK!)$

The bolts are acceptable.

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