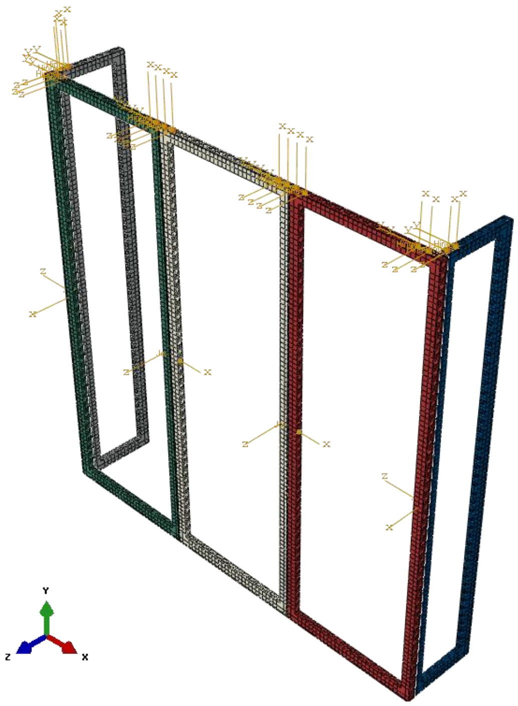
TECHNICAL REPORT

FINITE ELEMENT ANALYSIS OF ALUMINIUM FRAMES USED IN STAND CONSTRUCTIONS



Customer	beMatrix

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3 DOCUMENT HISTORY

Revision 0	August 10, 2016
	Base document
Revision 1	
Revision 2	
Revision 3	

4 DESCRIPTION

beMatrix produces modular aluminium frames which can be combined into larger structures, used mainly for stand construction. The frames are available in two dimensions: 2976x992 and 2480x992 m. Here, only the 2976x992 m frame is considered, built up in 1 row. If the same recommendations are used for the smaller 2480x992 m frame, then these will automatically satisfy the strength requirements too.

One of the main purposes of the frames is the construction of walls for booths at conventions, motor shows, … The goal of the calculations is to check the resistance of the walls against draft, which is air movement inside a large building due to the opening of windows or garage doors. The value considered for the wind load is 0.125 kN/m^2 as prescribed in the technical guidelines of the Messe Essen). On request of beMatrix also the values of 0.240 kN/m^2 (approx. 5 psf) and 0.480 kN/m^2 (approx. 10 psf) were considered.

For this report, three different lengths were considered: 3, 6 and 9 m.

Note: all calculations presented in this report consider the same type of profile, namely DMK. This profile has moments of inertia of ca. 172.000, resp. 142.000 mm^4. beMatrix also produces the so-called super DMK profile with the same height, but increased width. This profile has moments of inertia of ca. 236.000, resp. 208.000 mm^4. As this super DMK is significantly stiffer than the DMK profile used in this report, all configurations that are deemed safe with DMK profiles can be equally constructed with super DMK profiles. Additional calculations are not necessary to demonstrate the strength.

5 SUMMARY

Based on the finite element calculations it can be concluded that the combinations discussed below should be used. They are discussed separately for each of the configurations. Note that all configurations should be fixed to the ground at all times to prevent instability or movement due to the wind load. Also note that for an exterior use, a strengthening of the connection plate is necessary to avoid any failure of this part in case of a high wind load.

5.1 I-CONFIGURATION

The build-up of the I-walls is always the same, independent of the direction of wind loading. These are shown below for the 3, 6 and 9 m configuration.

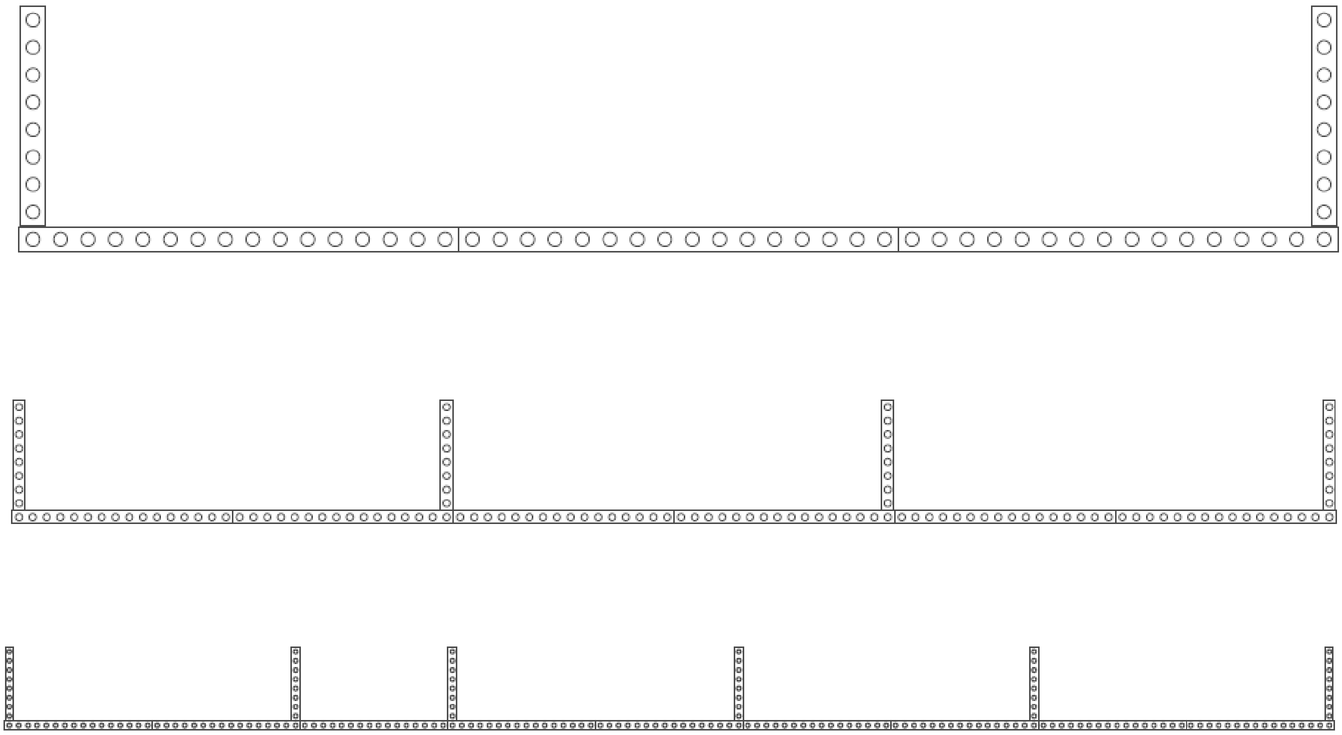


Figure 1 - 3, 6 and 9m configurations

6 REFERENCED DOCUMENTS AND FILES

6.1 INPUT DOCUMENTS AND FILES

Type	Description or reference
Digital file	Type muur I-Wall - oplossing te zwak.dwg,
Document	Type verbinding standaard muur.pdf, Standaard Frame.pdf

6.2 REFERENCED STANDARDS, GUIDELINES OR OTHER LITERATURE

Type	Description or reference
Standard	EN 1990 – Eurocode – Basis of structural design (2002)
Standard	EN 1991-1-4 – Eurocode 1 – Actions on structures – Part 1-4 – General actions – Wind actions (2005)
Standard	EN 1999-1-1 – Eurocode 9 – Design of aluminium structures – Part 1-1 – General structural rules (2007)
Document	Messe Essen - Technische Richtlinien

7 SOFTWARE

Type	Name	Version
Finite element software	Abaqus	6.14

8 FINITE ELEMENT MODEL

8.1 GEOMETRY

The geometry was drawn in Abaqus/CAE based on the delivered dwg files. The main features are the same for all configurations. They are illustrated below with the 3 m configuration:

- All parts were modeled as shell (thickness not modeled).
- The connections were simplified into join or hinge connectors as described in Figure 3. Join connectors prevent the translational degrees of freedom only, while the hinge connector only releases the rotation around its axis. A join connector was used for the modeling of the connectors which allow the local rotation around the axis of the connector. The hinge connectors were used to avoid any singularity in the top connection.
- Connections at the top were modeled as plates as illustrated in Figure 4.
- Between all interacting parts a hard contact definition was defined with a coulomb friction coefficient of 0.1.

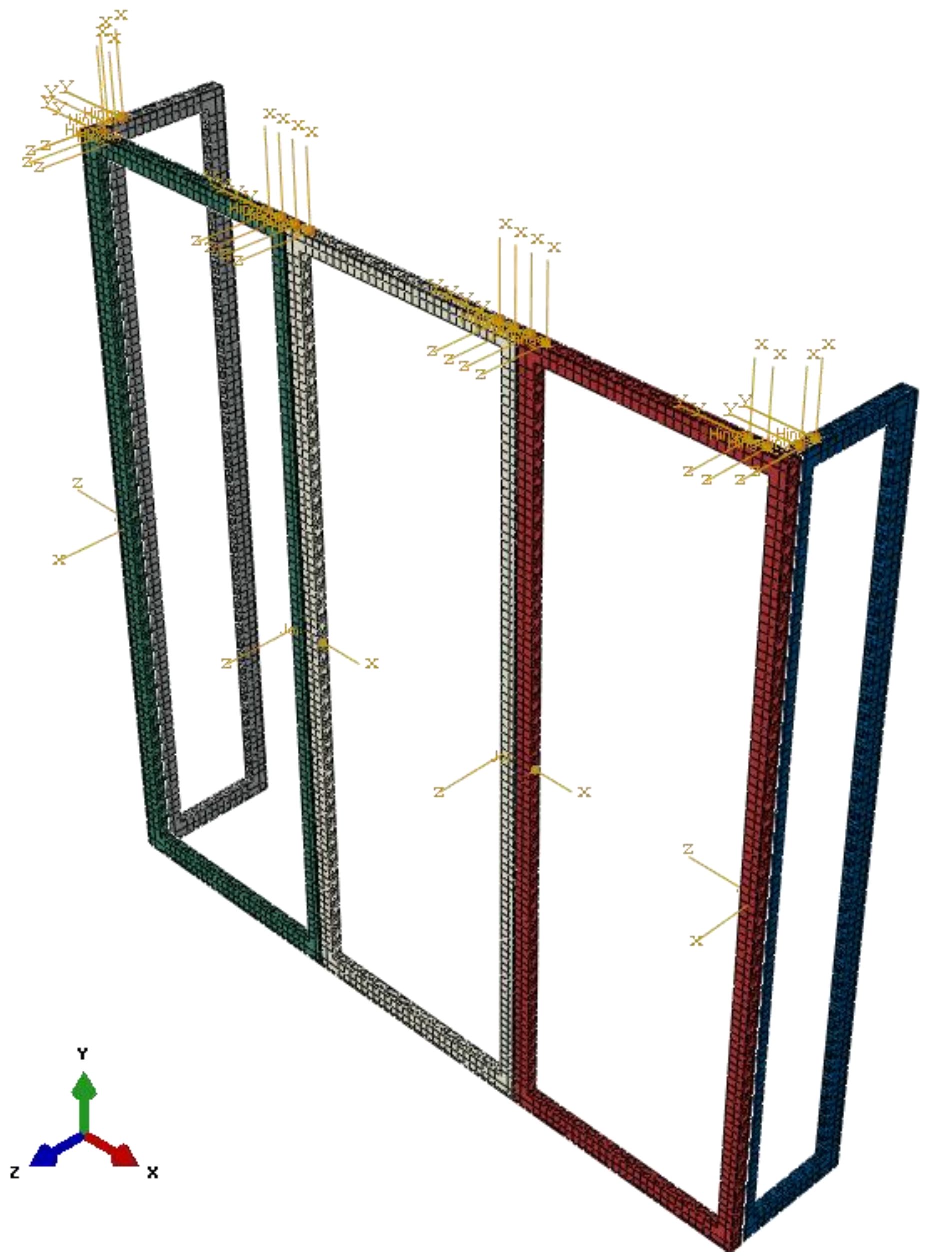


Figure 2 - Geometry I-configuration, 3 m

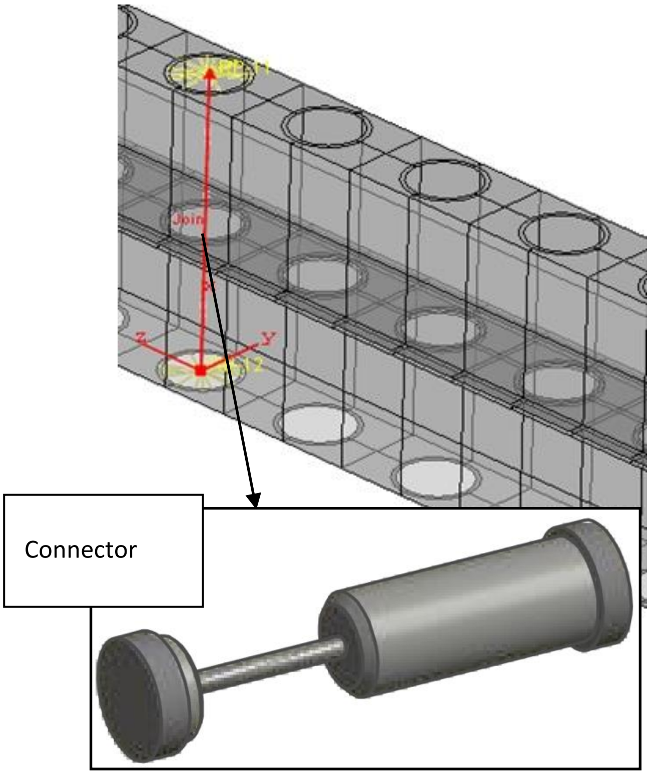


Figure 3 - Internal connections

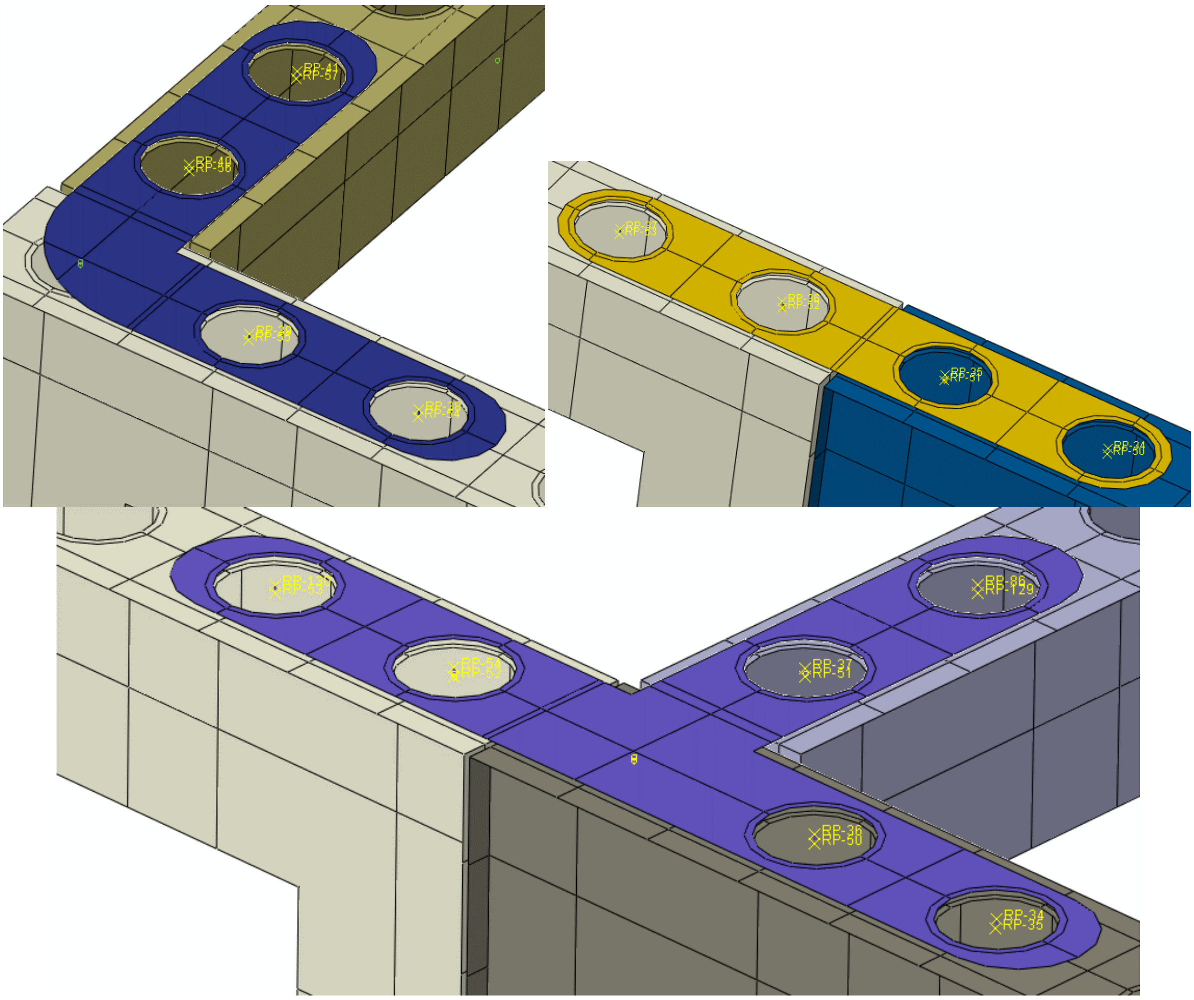


Figure 4 - Top connections

The following configurations were considered:

Table 1 - Configurations

Model	Configuration	Length
1	I	3 m
2	I	6 m
3	I	9 m

A top view of all the models is given in Figure 5.

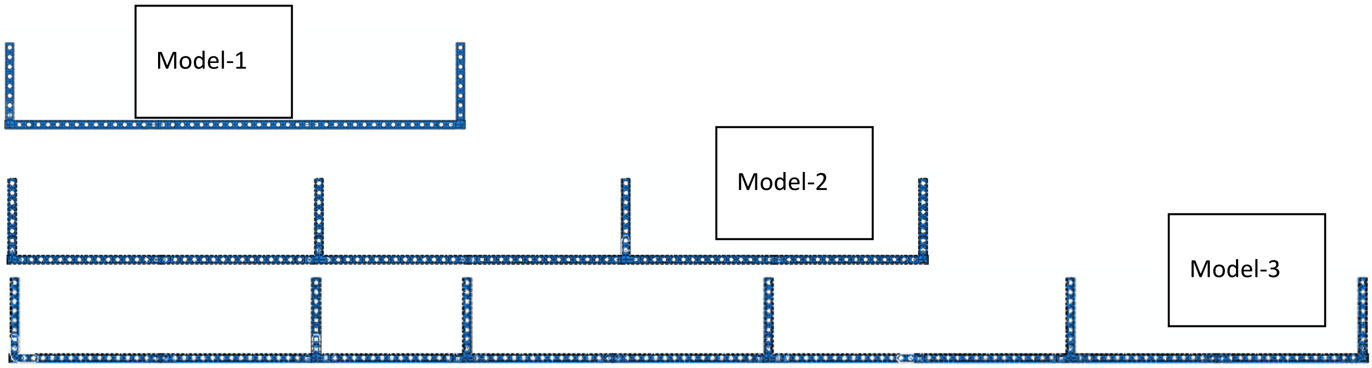


Figure 5 - Configurations 3, 6 and 9m

8.2 MATERIAL PROPERTIES

8.2.1 EN AW 6060 T6

Name	EN AW 6060 T6
Applies to	Whole model
Material model	Ideal Plastic
Reference	EN 1999-1-1:2007
Modulus of elasticity [GPa]	70
Coefficient of Poisson	0.3
Density [kg/m^3]	2700
Yield strength [MPa]	140
Design resistance (plastic limit)	140/1.1 = 127 MPa
Limit principal strain	5%*
Additional remarks	*EN 1993-1-5 Annex C, only applicable to small peaks

8.3 LOADS AND BOUNDARY CONDITIONS

8.3.1 LOADS

Only the wind and self-weight were assumed.

8.3.1.1 SELF WEIGHT $G_{K,1}$

The self-weight of the aluminium frames was introduced in the models by activating the gravity (acceleration: 9.81 m/s^2). Additional mass due to filler plates was added to the models by increasing the density of the frames (large frames only). The additional mass per frame depends on the number of plates and the type of plate used:

1. Light plate: 6.3 kg/plate, one or two per frame
2. Heavy plate: 11.4 kg/plate, one or two per frame

For the stresses it is expected that the heaviest frame will lead to the highest stresses, this is 2x11.4 kg extra per frame.

8.3.1.2 WIND $Q_{K,WIND}$

The frames are placed inside a building. For buildings which have large closable openings it is advised to check the resistance of the structure against draft. The following is stated in paragraph 7.2.9 of EN 1991-1-4: *"(3) Where an external opening, such as a door or a window, would be dominant when open but is considered to be closed in the ultimate limit state, during severe windstorms, the condition with the door or window open should be considered as an accidental design situation in accordance with EN 1990."* For the magnitude of the wind pressure we refer to Messe Essen - Technische Richtlinien in which a wind pressure of 125 Pa is defined.

To comply with the customer requirements, two additional wind loads are considered in this analysis:

- A wind pressure of 240 Pa (5 psf) for interior use,
- A wind pressure of 480 Pa (10 psf) for exterior use.

Every model is check for the 2 wind directions (models 1a, 2a, 3a from the front side, 1b, 2b, 3b from the back side).

8.3.2 BOUNDARY CONDITIONS

The boundary conditions are identical for all models. They are illustrated for Model-1 in Figure 6 where the bottom surface was fixed.

Figure 6 - Boundary conditions

8.4 LOAD COMBINATIONS AND METHOD OF ANALYSIS

8.4.1 ULTIMATE LIMIT STATES

Ultimate limit state	Plastic limit
Design situation	Accidental
Method of analysis	Linear elastic + ideal plastic analysis (static)
Load combinations	
ULS	1.00 $G_{k,1}$ + 1.00 $Q_{k,wind}$
Additional remarks	/

8.5 ELEMENT CHOICE AND MESH

Element type(s)	4 node linear shell elements with reduced integration (S4R)
Average element size (if applicable)	10 mm
Number of elements*	109,631 345,279
Number of nodes*	140,506 453,996
Degrees-of-freedom*	622,398 1,917,264
Additional remarks	*Varies between min. and max. value with Model-1 on the left and Model-3 on the right. The mesh of Model-1 is illustrated.

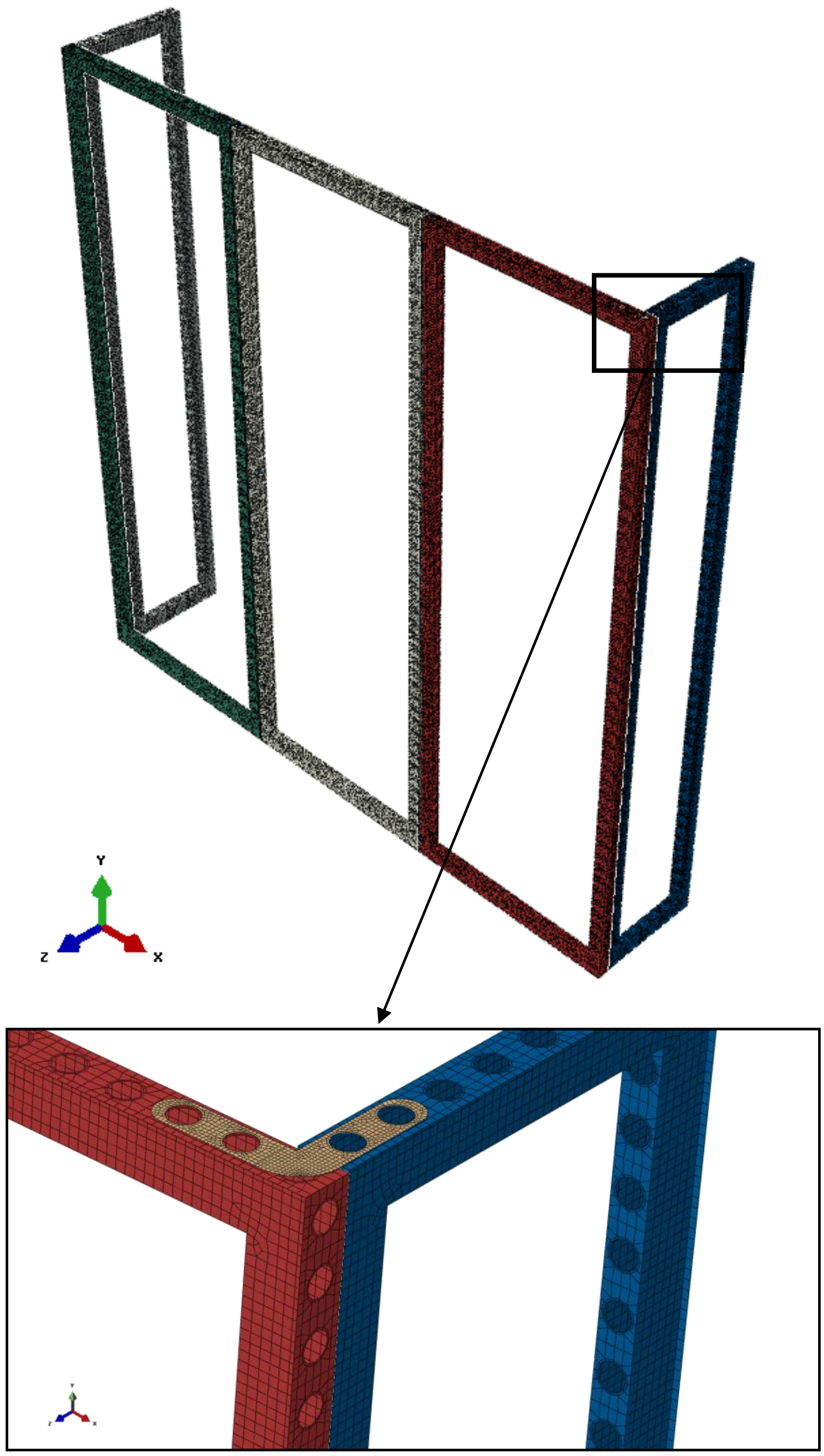


Figure 7 - Mesh

9 RESULTS

9.1 INTRODUCTION

The evaluation of the calculated stresses and strains is done in two ways:

- General criterion: Von Mises stresses compared to design resistance (yield strength divided by material factor of 1.1 for aluminum).
- Local criterion: Logarithmic principal strains for local peaks with a limit value of 5% (based on EN 1993-1-5 Annex C).

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. The stresses were limited to 127 MPa (design resistance), areas with stresses greater than this value are displayed in grey.

9.2 GLOBAL RESULTS

For each model, the maximal logarithmic principal stress is checked at a wind load of 125, 240 and 480 Pa, this for the frames and for the connection plates separately. These results are illustrated in Table 2.

Table 2 - Results of the analysis

Model	Wind Load (Pa)	Frames: Principal Strain (%)	Frames: Comment	Connection plates: Principal Strain (%)	Connection plates: Comment
1a	125	0.06	< 1%	0.12	< 1%
	240	0.13	< 1%	0.33	< 1%
	480	0.59	< 1%	**3.78**	NOK*
1b	125	0.06	< 1%	0.12	< 1%
	240	0.13	< 1%	0.32	< 1%
	480	0.57	< 1%	**3.51**	NOK*
2a	125	0.16	< 1%	0.08	< 1%
	240	0.32	< 1%	0.14	< 1%
	480	0.69	< 1%	0.91	< 1%
2b	125	0.16	< 1%	0.07	< 1%
	240	0.32	< 1%	0.14	< 1%
	480	0.72	< 1%	0.93	< 1%
3a	125	0.16	< 1%	0.08	< 1%
	240	0.31	< 1%	0.14	< 1%
	480	0.68	< 1%	0.78	< 1%
3b	125	0.15	< 1%	0.1	< 1%
	240	0.29	< 1%	0.2	< 1%
	480	0.65	< 1%	0.79	< 1%

The logarithmic principal strain in the frames never exceeds 1%.

The logarithmic principal strain in the connection plate exceeds 3% in Model 1. The distribution of the strain across the whole section (see Figure 9) indicates it is not acceptable (it is not a small peak). It is advised to increase the strength of this plate; e.g. by increasing the thickness or by using a stronger material.

9.3 DETAILED RESULTS

The following sections shows the detailed results for the models 1a, 2a and 3a and this for a wind pressure of 480 Pa.

9.3.1 MODEL-1A

The stresses in Figure 8 show that the most stressed location is the connection plate at the top of the structure. The principal logarithmic strain is checked in Figure 9.

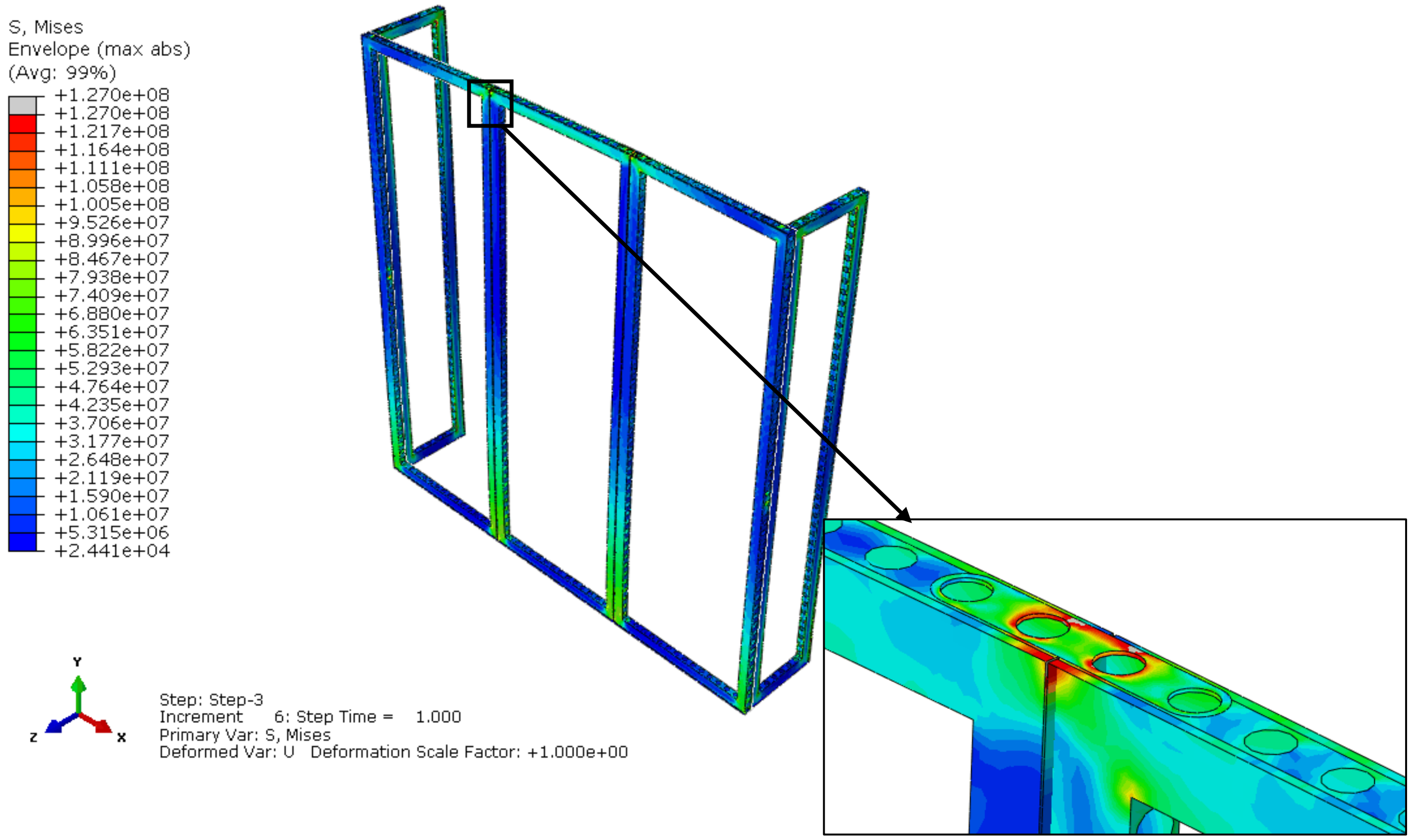
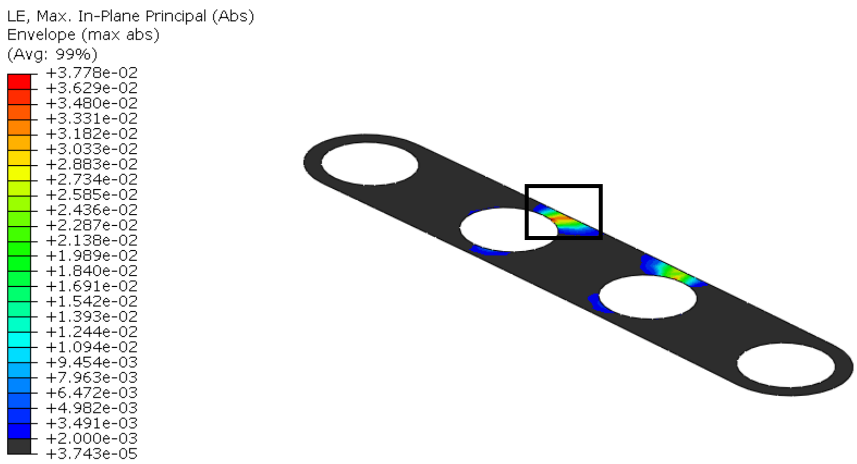


Figure 8 - Von Mises stresses Model-1a



The maximal logarithmic principal strain is more than 3% and is found through the entire section next to the hole. Increasing the strength of this part is advised.

Figure 9 - Logarithmic principal strain Model-1a, detail of top connection

9.3.2 MODEL-2A

The stress in the connection plate is smaller than in model 1a, which allows the strain to drop under 1% as shown in Figure 11.

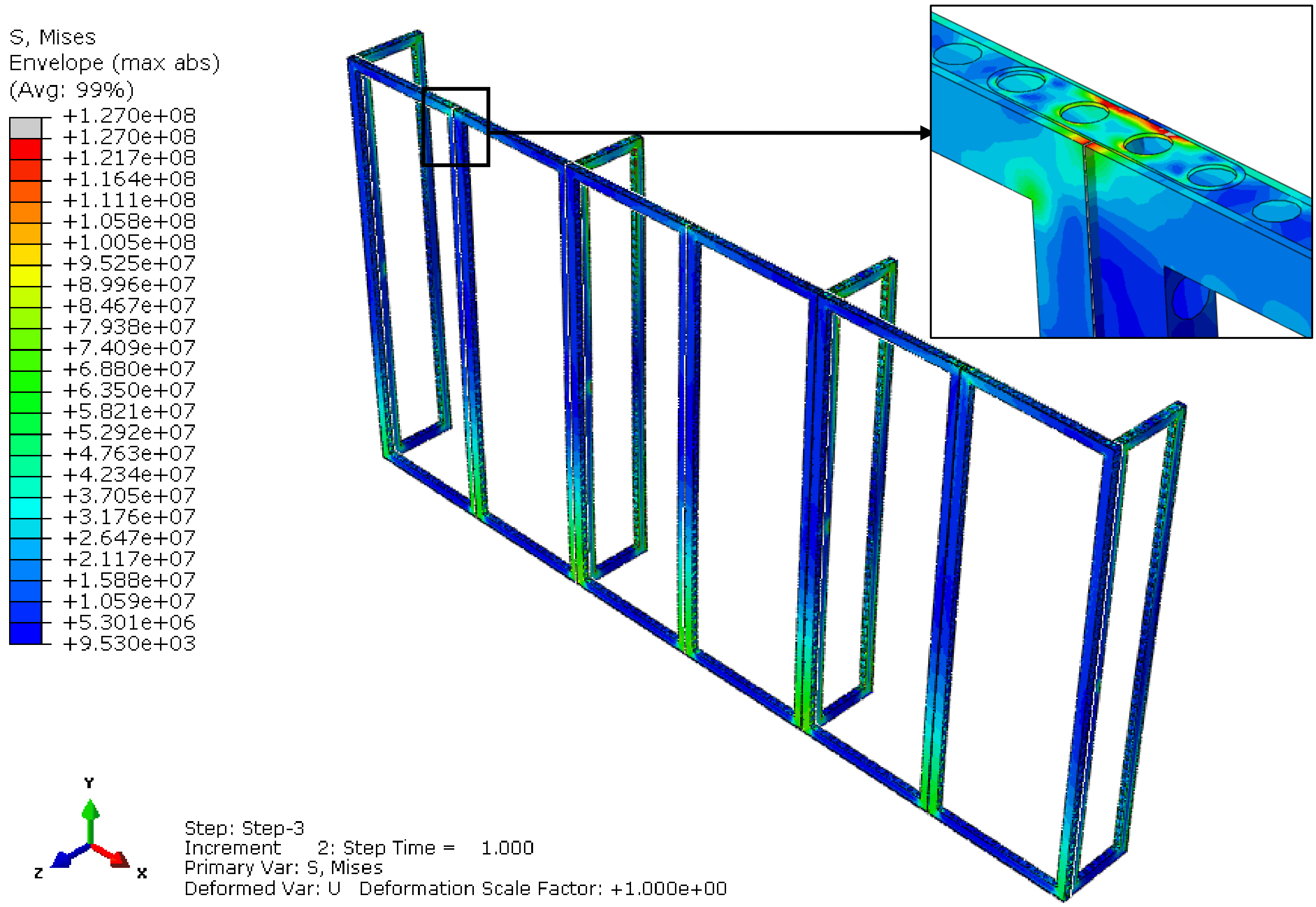


Figure 10 - Von Mises stresses Model-2a

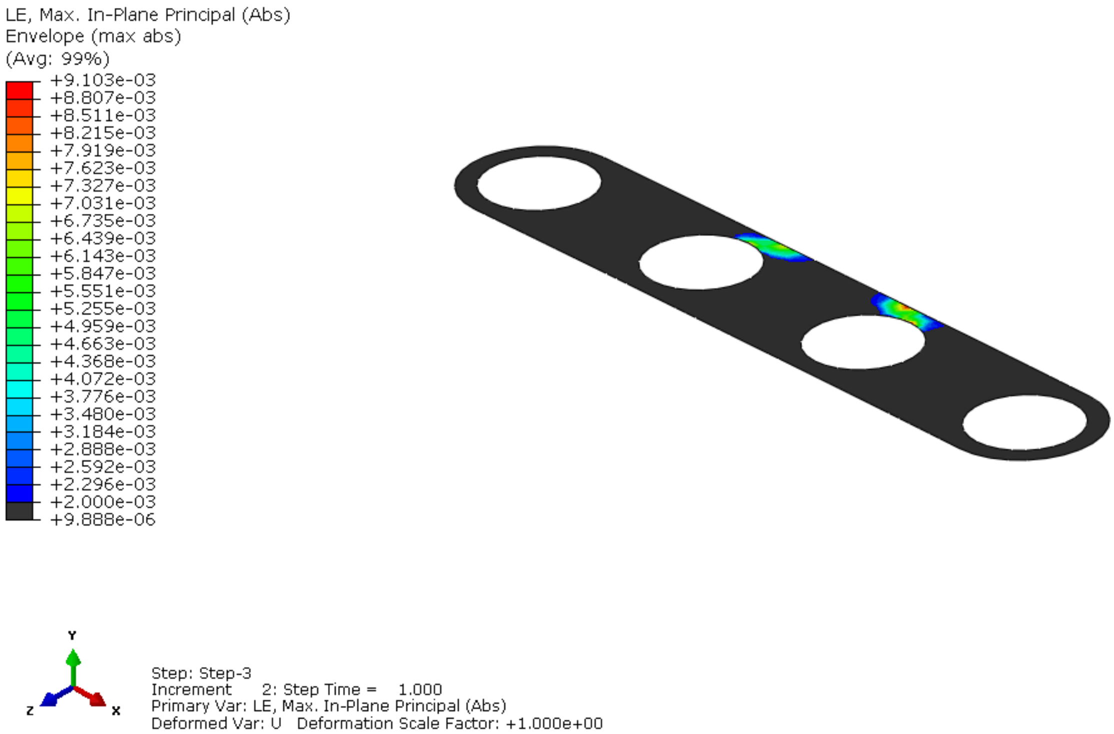


Figure 11 - Logarithmic principal strain Model-2a, detail of top connection

9.3.3 MODEL-3A

The stress in the connection plate is smaller than in model 1a, which allows the strain to drop under 1% as shown in Figure 13.

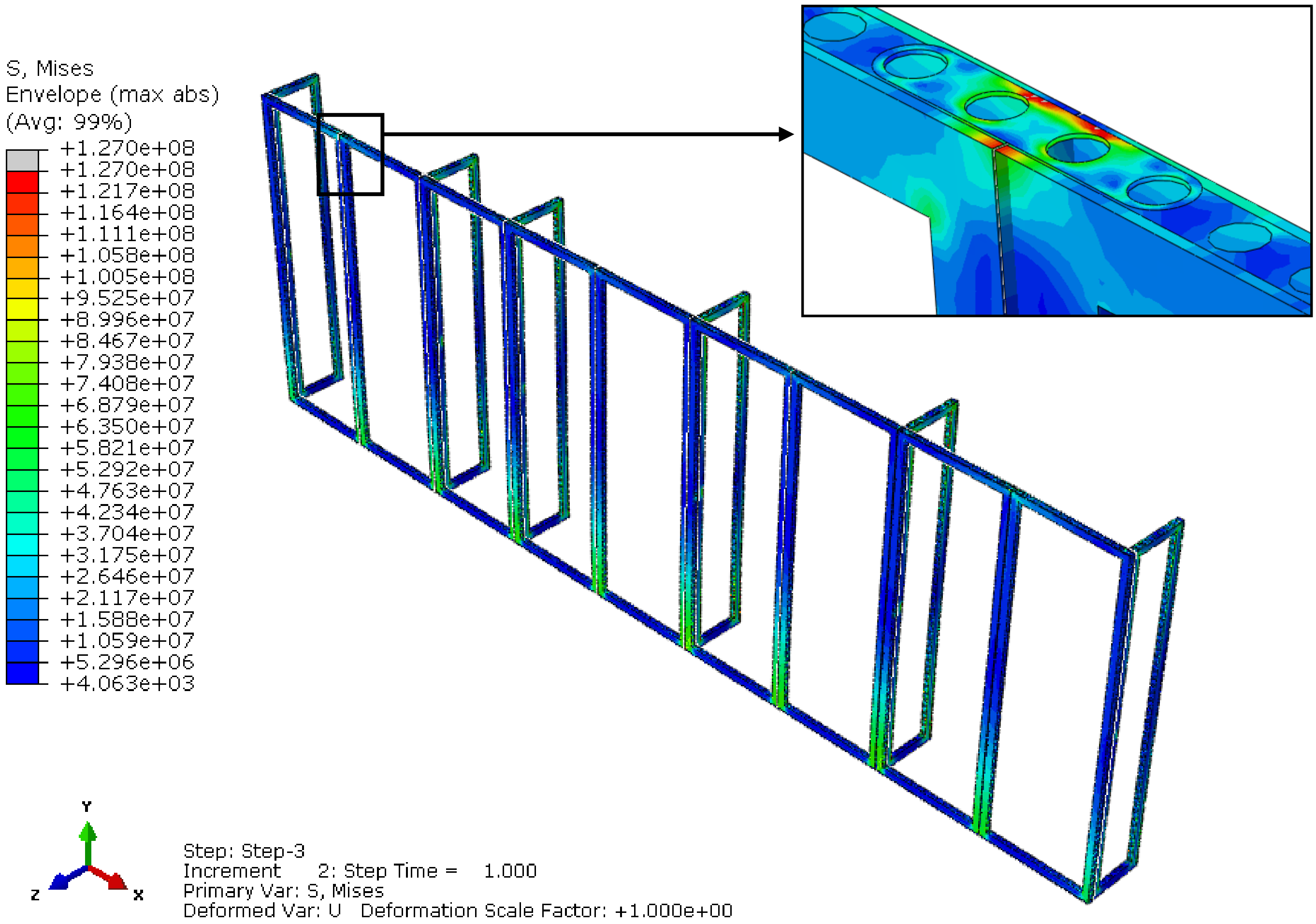


Figure 12 - Von Mises stresses Model-3a

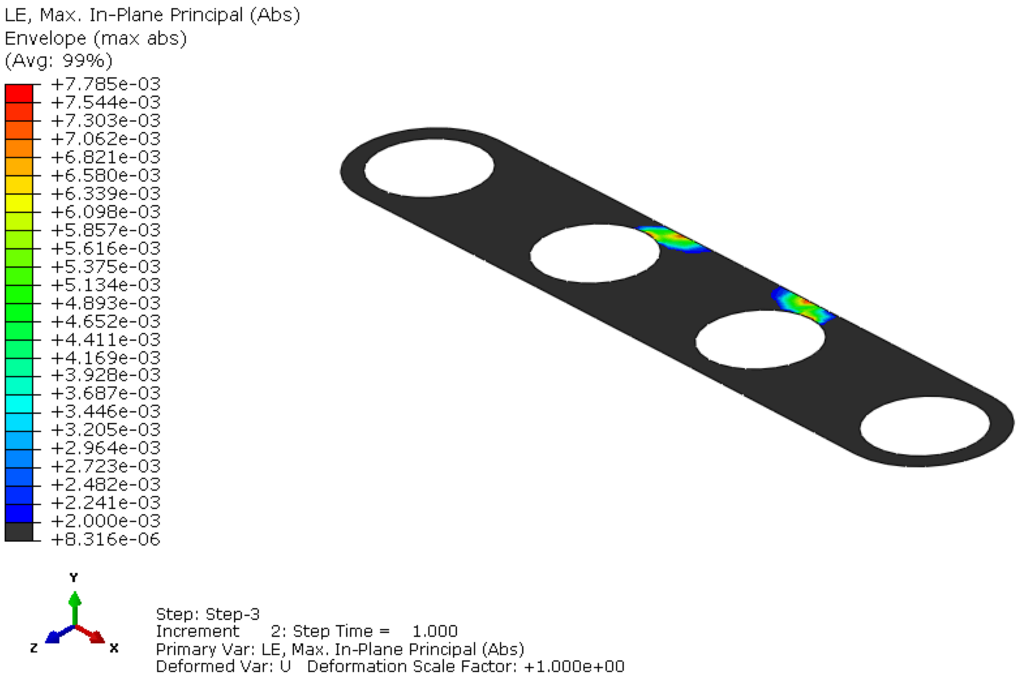


Figure 13 - Logarithmic principal strain Model-3a, detail of top connection

9.4 STABILITY AND FLOOR FRICTION

9.4.1 STABILITY

For the stability check it is assumed that the large frames are filled with one light filler plate: 6.3 kg/frame and are loaded with a pressure of 480 Pa. The total mass per frame is 14.21 kg for the large frames and 6.83 kg for the small frames. The mass of the entire configuration and the total wind load are:

Table 3 - Mass, wind load, moment arms and resulting moments

	Total mass [kg]	Moment arm mass [m]	**Moment mass [Nm]**	Wind load [N]	Moment arm wind [m]	**Moment wind [Nm]**
1	56	0.478	**263**	4320	1.488	**6428**
2	113	0.478	**530**	8640	1.488	**12856**
3	169	0.478	**792**	12960	1.488	**19284**

Based on the moments in **Fout! Verwijzingsbron niet gevonden.** can be concluded that the structure is not stable if it is not connected to the floor.

9.4.2 FRICTION

Comparing the total mass in Table 3 with the wind loads in the same table shows that the structure will move unless connected to the ground.

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