Curtain wall structural calculation report

[Document Number]

Rev. 00

Site:

18.08.2023

Contents

1. Introduction

1.1 Object location

Object .

1.2 Calculation method

Structural calculations and design were performed based on following standards:

1. Loads:

– self-weight, imposed loads –group of BS EN 1991-1-1+NA;
– wind - group of BS EN 1991-1-4+NA;
– snow - group of BS EN 1991-1-3+NA;
– load combinations – BS EN 1990 + NA.

2. Steel design:

– BS EN 1993+NA;
– BS EN 1993-1-5;
– BS EN 1993-1-8.

3. Aluminium design:

– BS EN 1999+NA.

4. Curtain walls:

– BS EN 13830+NA.

Structural calculations were performed in the FEM program RFEM 6.02.

1.3 Material and profiles

1.3.1 Curtain wall 23-08 Elevation A is a stick system of glass structural façade, consisting of aluminium vertical profiles (mullions), horizontal profiles (transoms) and glass units.

Following elements are utilized according to the catalogue of aluminium profiles “CW50 Reynaers Aluminium” :

– vertical profiles (mullions) – art. 034.2503;
– horizontal profiles (transoms) – art. 034.3525;
– reinforcment – art. 034.5593.00.

Dimensions of profile cross-sections see chapter 2.1.

1.3.2 Curtain wall are supported by steel frame (horizontal beams and posts) and concrete walls by means of designed steel brackets.

Steel frame (horizontal beams and posts) and concrete walls are costumer’s responsibility.

1.3.3 Material of profiles – aluminium, alloy EN 6060 (ET,EP,ER/B) T6.

Table 1.3.1 Material properties of aluminium (extract from RFEM 6.02)

Description	Symbol	Value	Unit
Basic Properties			
Modulus of elasticity	E	70000.0	N/mm^2
Shear modulus	G	27000.0	N/mm^2
Poisson's ratio	ν	0.300	--
Mass density	ρ	2700.00	kg/m^3
Specific weight	γ	27.00	kN/m^3
Coefficient of thermal expansion	α	0.000023	1/°C
Characteristic value of 0.2% proof strength	f_o	140.000	N/mm^2
Characteristic value of ultimate strength	f_u	170.000	N/mm^2
0.2% proof strength in heat affected zone, HAZ	$f_{o,haz}$	60.000	N/mm^2
Ultimate strength in heat affected zone, HAZ	$f_{u,haz}$	100.000	N/mm^2
Ratio between 0.2% proof strength in HAZ and in parent material	ρo,haz	0.430	--
Ratio between ultimate strength in HAZ and in parent material	ρu,haz	0.590	--
Additional Information			
Temper		T6	

1.3.4 Material for support brackets - carbon steel S355.

Table 1.3.2 Material properties of steel (extract from RFEM 6.02)

Description	Symbol	Value	Unit
Basic Properties			
Modulus of elasticity	E	210000.0	N/mm^2
Shear modulus	G	80769.2	N/mm^2
Poisson's ratio	ν	0.300	--
Mass density	ρ	7850.00	kg/m^3
Specific weight	γ	78.50	kN/m^3
Coefficient of thermal expansion	α	0.000012	1/°C
Thickness range No. 1			
Maximum thickness	t_{max}	40.0	mm
Yield strength	f_y	355.000	N/mm^2
Ultimate strength	f_u	490.000	N/mm^2
Weld Properties			
Correlation factor	βw	0.900	--

1.4 Construction

In the case when the entire construction is not completed according to further calculation, it can cause the entire construction or connection instability or collapse. All fasteners (bolts, anchors etc.) need to be installed according to manufacturer instructions.

2. Curtain wall A structural calculation

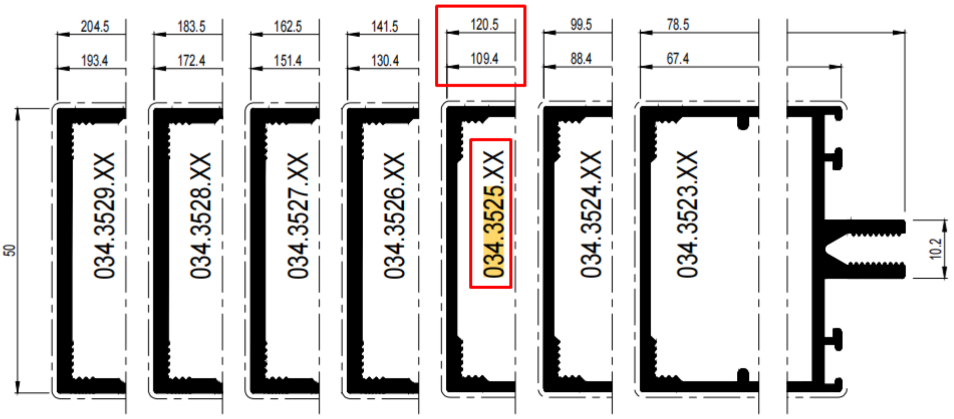
2.1 Profiles cross-sections

Cross-sections of aluminium profiles are created in the program Dlubal RSECTION 1. Cross-sections were calculated and values of their geometric characteristics were determined.

Verification of modelled sections were performed comparing with essential values (moment of inertia I, section modulus W) from the catalogue of aluminium profiles “CW50 Reynaers Aluminium”.

Following sections have been modelled and calculated:

1. Transom (art. 034.3525).



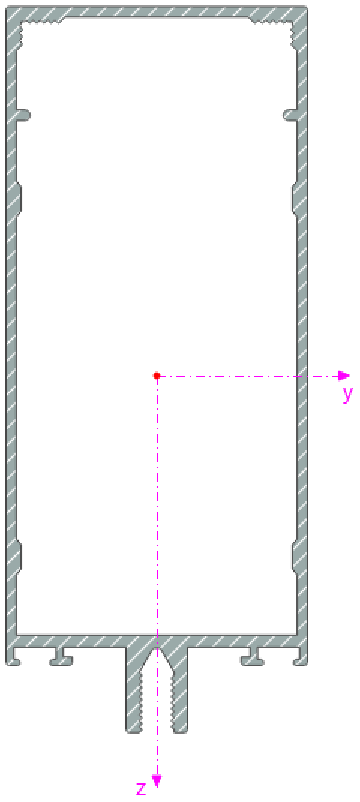
CW 50-MT

DWARSPROFIEL
TRAVERSE
TRANSOM
RIEGELPROFIEL

Reynaers Aluminium

	A dm²/m	P dm²/m	Lm	Ix cm^4	Wx cm^3	ax mm	Iy cm^4	Wy cm^3	ay mm
034.3520.XX	20.58	1.1	7.00	0.384	0.322	11.93	3.070	1.228	25.00
034.3521.XX	24.35	9.8	7.00	3.608	1.824	19.78	8.243	3.297	25.00
034.3522.XX	28.85	14.3	7.00	14.897	5.134	29.02	12.707	5.082	25.00
034.3523.XX	32.51	18.5	7.00	38.079	9.595	39.69	18.515	7.405	25.00
034.3524.XX	36.71	22.7	7.00	71.612	14.272	49.32	23.098	9.239	25.00
034.3525.XX	40.91	26.9	7.00	118.387	19.337	59.28	27.268	10.906	25.00
034.3526.XX	45.11	31.1	7.00	205.583	28.900	71.14	39.544	15.817	25.00
034.3527.XX	49.31	35.3	7.00	297.468	36.554	81.38	45.472	18.181	24.99
034.3528.XX	53.51	39.5	7.00	412.021	44.867	91.67	51.400	20.551	24.99
034.3529.XX	57.71	43.7	7.00	551.562	53.808	101.99	57.328	22.920	24.99

Fig. 2.1.1 Transom art. 034.3525 (extract from catalogue “CW50 Reynaers Aluminium”)



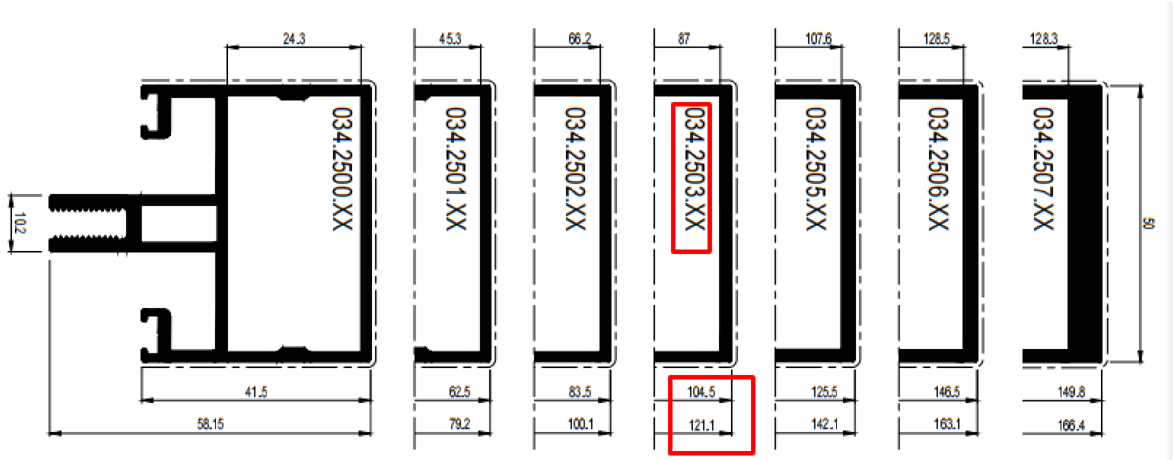
Section Properties | 0343525 (transom)

Section Values | Stress Points

Sectional Area			
Sectional area	A	6.76	cm^2
Geometric sectional area	Ageom	6.76	cm^2
Bending			
Location of centroidal axis in y-direction	e_y	25.0	mm
Location of centroidal axis in z-direction	e_z	61.2	mm
Area moment of inertia about y-axis	I_y	118.31	cm^4
Area moment of inertia about z-axis	I_z	27.25	cm^4
Product of inertia about y,z-axes	I_{yz}	-0.01	cm^4
Area moment of inertia about u-axis	I_u	118.31	cm^4
Area moment of inertia about v-axis	I_v	27.25	cm^4
Polar area moment of inertia	I_p	145.56	cm^4
Polar area moment of inertia with respect to shear center	$I_{p,SC}$	148.63	cm^4
Inclination of principal axes	α	0.00	deg
Radius of gyration about y-axis	i_y	41.8	mm
Radius of gyration about z-axis	i_z	20.1	mm
Radius of gyration about y,z-axes	i_{yz}	0.4	mm
Radius of gyration about u-axis	i_u	41.8	mm
Radius of gyration about v-axis	i_v	20.1	mm
Polar radius of gyration	i_p	46.4	mm
Polar radius of gyration with respect to shear center	$i_{p,SC}$	46.9	mm
Elastic section modulus about y-axis	$W_{y,min}$	-19.32	cm^3
Elastic section modulus about y-axis	$W_{y,max}$	19.96	cm^3
Elastic section modulus about z-axis	$W_{z,min}$	-10.90	cm^3
Elastic section modulus about z-axis	$W_{z,max}$	10.90	cm^3
Elastic section modulus about u-axis	$W_{u,min}$	-19.33	cm^3
Elastic section modulus about u-axis	$W_{u,max}$	19.95	cm^3
Elastic section modulus about v-axis	$W_{v,min}$	-10.90	cm^3
Elastic section modulus about v-axis	$W_{v,max}$	10.90	cm^3
Elastic section modulus about y-axis	W_y	19.32	cm^3
Elastic section modulus about z-axis	W_z	10.90	cm^3
Elastic section modulus about u-axis	W_u	19.33	cm^3
Elastic section modulus about v-axis	W_v	10.90	cm^3

Fig. 2.1.2 Transom cross-section and its properties (extract from RFEM 6.02)

2. Mullion (art. 034.2503)

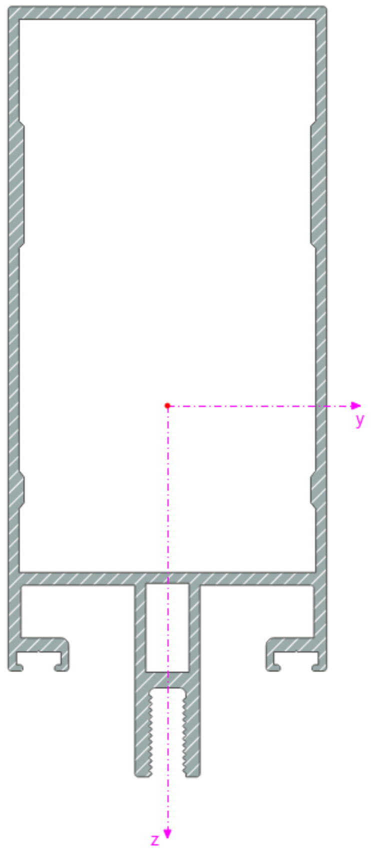


CW 50-MT

DRAAGPROFIEL
MENEAU
SUSPENSION PROFILE
PFOSTENPROFIL

	A dm^2/m	P dm^2/m	Lm	Ix cm^4	Wx cm^3	ax mm	Iy cm^4	Wy cm^3	ay mm
034.2500.XX	35.46	13.3	7.00	13.720	4.359	31.48	13.741	5.496	25.00
034.2501.XX	39.66	17.5	7.00/5.00	33.247	8.346	39.31	18.327	7.331	25.00
034.2502.XX	43.86	21.7	7.00/5.00	66.660	12.927	48.58	23.767	9.507	25.00
034.2503.XX	48.06	25.9	7.00/5.00	117.658	18.745	58.38	28.103	11.241	25.00
034.2504.XX	48.06	25.9	7.00	150.770	23.320	64.65	32.893	13.157	25.00
034.2505.XX	52.26	30.1	7.00	201.687	28.112	70.41	37.032	14.812	25.00
034.2506.XX	56.46	34.3	7.00/5.00	297.277	36.009	80.59	42.392	16.956	25.00
034.2507.XX	57.12	35.0	7.00	403.011	43.458	92.74	46.040	18.416	25.00
034.2508.XX	60.66	38.5	7.00	503.535	51.251	98.25	53.283	21.313	25.00
034.2509.XX	64.86	42.7	7.00	695.156	63.478	109.51	62.735	25.093	25.00

Fig. 2.1.3 Mullion art. 034.2503 (extract from catalogue "CW50 Reynaers Aluminium")



Section Properties | 0342503 (mullion)

Section Values | Stress Points

Sectional Area			
Sectional area	A	7.65	cm^2
Geometric sectional area	Ageom	7.65	cm^2
Bending			
Location of centroidal axis in y-direction	ey	25.0	mm
Location of centroidal axis in z-direction	ez	62.8	mm
Area moment of inertia about y-axis	Iy	117.60	cm^4
Area moment of inertia about z-axis	Iz	28.09	cm^4
Product of inertia about y,z-axes	Iyz	0.00	cm^4
Area moment of inertia about u-axis	Iu	117.60	cm^4
Area moment of inertia about v-axis	Iv	28.09	cm^4
Polar area moment of inertia	Ip	145.69	cm^4
Polar area moment of inertia with respect to shear center	Ip,SC	166.05	cm^4
Inclination of principal axes	α	0.00	deg
Radius of gyration about y-axis	iy	39.2	mm
Radius of gyration about z-axis	iz	19.2	mm
Radius of gyration about y,z-axes	iyz	0.2	mm
Radius of gyration about u-axis	iu	39.2	mm
Radius of gyration about v-axis	iv	19.2	mm
Polar radius of gyration	ip	43.7	mm
Polar radius of gyration with respect to shear center	ip,SC	46.6	mm
Elastic section modulus about y-axis	Wy,min	-18.73	cm^3
Elastic section modulus about y-axis	Wy,max	20.14	cm^3
Elastic section modulus about z-axis	Wz,min	-11.24	cm^3
Elastic section modulus about z-axis	Wz,max	11.24	cm^3
Elastic section modulus about u-axis	Wu,min	-18.74	cm^3
Elastic section modulus about u-axis	Wu,max	20.14	cm^3
Elastic section modulus about v-axis	Wv,min	-11.24	cm^3
Elastic section modulus about v-axis	Wv,max	11.24	cm^3
Elastic section modulus about y-axis	Wy	18.73	cm^3
Elastic section modulus about z-axis	Wz	11.24	cm^3
Elastic section modulus about u-axis	Wu	18.74	cm^3
Elastic section modulus about v-axis	Wv	11.24	cm^3

Fig. 2.1.4 Mullion cross-section and its properties (extract from RFEM 6.02)

3. Reinforcement (art. 034.5593.00).

CW 50-MT

VERBINDINGS- EN DILATATIEPROFIEL
PROFILE DE RACCORDEMENT ET DILATATION
CONNECTION AND EXPANSION PROFILE
VERBUND- UND AUSDEHNUNGSPROFIL

Reynaers Aluminium

	A dm²/m	P dm²/m	Lm	Ix cm⁴	Wx cm³	ax mm	Iy cm⁴	Wy cm³	ay mm
034.5591.00	28.65	-	7.00	15.070	6.912	21.80	9.641	4.382	22.00
034.5592.00	33.00	-	7.00	41.766	12.944	32.27	12.189	5.540	22.00
034.5593.00	37.11	-	7.00	82.314	19.529	42.15	14.532	6.605	22.00
034.5594.00	41.03	-	7.00	145.690	27.500	52.92	16.749	7.790	21.50
034.5595.00	45.21	-	7.00	230.512	36.347	63.38	19.082	8.875	21.50
034.5596.00	48.85	-	7.00	326.437	44.863	72.74	21.304	10.049	21.20
034.5597.00	55.52	-	7.00	513.320	61.734	83.15	23.360	10.240	19.19
034.5598.00	61.12	-	7.00	809.712	77.751	104.14	26.691	12.894	20.70

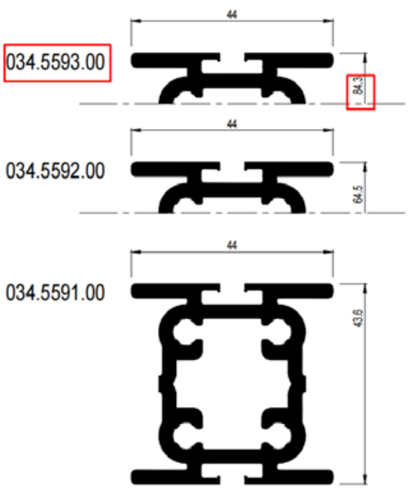
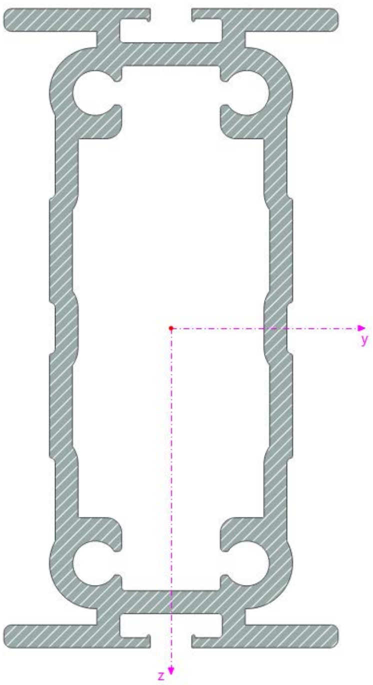


Fig. 2.1.5 Reinforcement art. 034.5593.00 (extract from catalogue "CW50 Reynaers Aluminium")



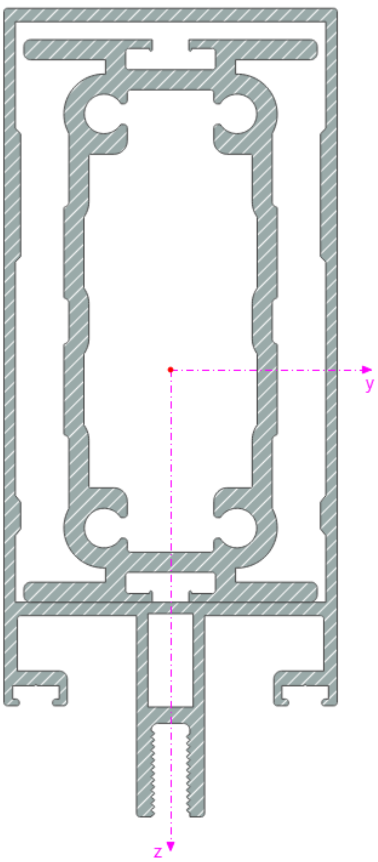
Section Properties | 0345593 (reinforcment)

Section Values | Stress Points

Sectional Area			
Sectional area	A	9.04	cm²
Geometric sectional area	Ageom	9.04	cm²
Bending			
Location of centroidal axis in y-direction	ey	22.0	mm
Location of centroidal axis in z-direction	ez	42.1	mm
Area moment of inertia about y-axis	Iy	81.91	cm⁴
Area moment of inertia about z-axis	Iz	14.50	cm⁴
Product of inertia about y,z-axes	Iyz	0.00	cm⁴
Area moment of inertia about u-axis	Iu	81.91	cm⁴
Area moment of inertia about v-axis	Iv	14.50	cm⁴
Polar area moment of inertia	Ip	96.41	cm⁴
Polar area moment of inertia with respect to shear center	Ip,SC	96.41	cm⁴
Inclination of principal axes	α	0.00	deg
Radius of gyration about y-axis	iy	30.1	mm
Radius of gyration about z-axis	iz	12.7	mm
Radius of gyration about y,z-axes	iyz	0.1	mm
Radius of gyration about u-axis	iu	30.1	mm
Radius of gyration about v-axis	iv	12.7	mm
Polar radius of gyration	ip	32.7	mm
Polar radius of gyration with respect to shear center	ip,SC	32.7	mm
Elastic section modulus about y-axis	Wy,min	-19.43	cm³
Elastic section modulus about y-axis	Wy,max	19.43	cm³
Elastic section modulus about z-axis	Wz,min	-6.59	cm³
Elastic section modulus about z-axis	Wz,max	6.59	cm³
Elastic section modulus about u-axis	Wu,min	-19.43	cm³
Elastic section modulus about u-axis	Wu,max	19.43	cm³
Elastic section modulus about v-axis	Wv,min	-6.59	cm³
Elastic section modulus about v-axis	Wv,max	6.59	cm³
Elastic section modulus about y-axis	Wy	19.43	cm³
Elastic section modulus about z-axis	Wz	6.59	cm³
Elastic section modulus about u-axis	Wu	19.43	cm³
Elastic section modulus about v-axis	Wv	6.59	cm³

Fig. 2.1.6 Reinforcement cross-section and its properties (extract from RFEM 6.02)

4. Mullion (art. 034.2503) with inner reinforcement (art. 034.5593.00).



Section Properties | 0342503+0345593 (mullion+reinforcment)

Section Values | Stress Points

Sectional Area			
Sectional area	A	16.68	cm²
Geometric sectional area	Ageom	16.68	cm²
Bending			
Location of centroidal axis in y-direction	ey	25.0	mm
Location of centroidal axis in z-direction	ez	54.1	mm
Area moment of inertia about y-axis	Iy	209.99	cm⁴
Area moment of inertia about z-axis	Iz	42.59	cm⁴
Product of inertia about y,z-axes	Iyz	0.00	cm⁴
Area moment of inertia about u-axis	Iu	209.99	cm⁴
Area moment of inertia about v-axis	Iv	42.59	cm⁴
Polar area moment of inertia	Ip	252.58	cm⁴
Polar area moment of inertia with respect to shear center	Ip,SC	255.78	cm⁴
Inclination of principal axes	α	0.00	deg
Radius of gyration about y-axis	iy	35.5	mm
Radius of gyration about z-axis	iz	16.0	mm
Radius of gyration about y,z-axes	iyz	0.2	mm
Radius of gyration about u-axis	iu	35.5	mm
Radius of gyration about v-axis	iv	16.0	mm
Polar radius of gyration	ip	38.9	mm
Polar radius of gyration with respect to shear center	ip,SC	39.2	mm
Elastic section modulus about y-axis	Wy,min	-38.78	cm³
Elastic section modulus about y-axis	Wy,max	31.34	cm³
Elastic section modulus about z-axis	Wz,min	-17.04	cm³
Elastic section modulus about z-axis	Wz,max	17.03	cm³
Elastic section modulus about u-axis	Wu,min	-38.78	cm³
Elastic section modulus about u-axis	Wu,max	31.34	cm³
Elastic section modulus about v-axis	Wv,min	-17.04	cm³
Elastic section modulus about v-axis	Wv,max	17.04	cm³
Elastic section modulus about y-axis	Wy	31.34	cm³
Elastic section modulus about z-axis	Wz	17.03	cm³
Elastic section modulus about u-axis	Wu	31.34	cm³
Elastic section modulus about v-axis	Wv	17.04	cm³

Fig. 2.1.7 Mullion art. 034.2503 with inner reinforcement art. 034.5593.00 section and its properties (extract from RFEM 6.02)

5. Double mullion (2 x art. 034.2503) and fixing aluminium angle 80x80x6 mm.

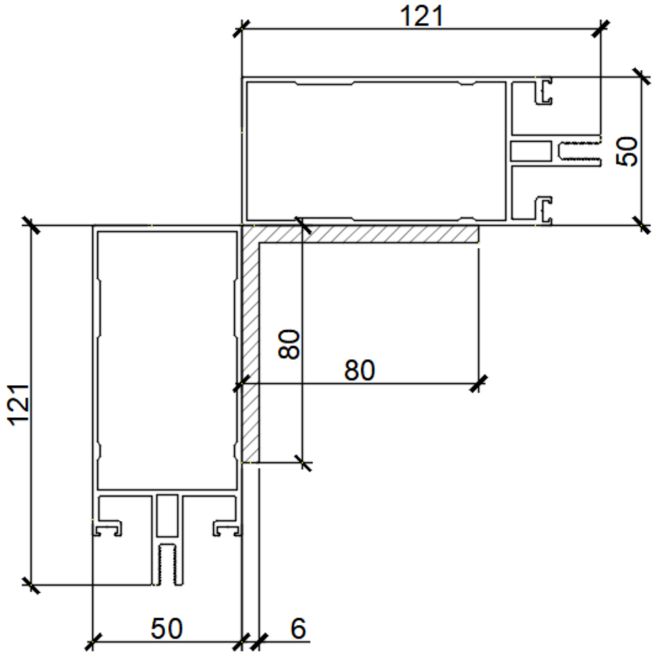
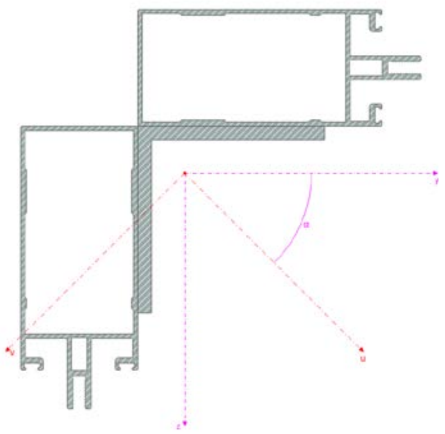


Fig. 2.1.8 Double mullion (2 x art. 034.2503) and fixing aluminium angle 80x80x6 mm cross-section



Section Properties | 0342503 (2 mullions+angle)

Section Values | Stress Points

Sectional Area			
Sectional area	A	24.53	cm^2
Geometric sectional area	Ageom	24.53	cm^2
Bending			
Location of centroidal axis in y-direction	ey	70.1	mm
Location of centroidal axis in z-direction	ez	70.1	mm
Area moment of inertia about y-axis	Iy	498.03	cm^4
Area moment of inertia about z-axis	Iz	498.04	cm^4
Product of inertia about y,z-axes	Iyz	-327.89	cm^4
Area moment of inertia about u-axis	Iu	170.15	cm^4
Area moment of inertia about v-axis	Iv	825.93	cm^4
Polar area moment of inertia	Ip	996.07	cm^4
Polar area moment of inertia with respect to shear center	Ip,SC	1136.75	cm^4
Inclination of principal axes	α	45.00	deg
Radius of gyration about y-axis	iy	45.1	mm
Radius of gyration about z-axis	iz	45.1	mm
Radius of gyration about y,z-axes	iyz	36.6	mm
Radius of gyration about u-axis	iu	26.3	mm
Radius of gyration about v-axis	iv	58.0	mm
Polar radius of gyration	ip	63.7	mm
Polar radius of gyration with respect to shear center	ip,SC	68.1	mm
Elastic section modulus about y-axis	Wy,min	-33.93	cm^3
Elastic section modulus about y-axis	Wy,max	37.92	cm^3
Elastic section modulus about z-axis	Wz,min	-33.93	cm^3
Elastic section modulus about z-axis	Wz,max	37.92	cm^3
Elastic section modulus about u-axis	Wu,min	-26.74	cm^3
Elastic section modulus about u-axis	Wu,max	37.64	cm^3
Elastic section modulus about v-axis	Wv,min	-75.75	cm^3
Elastic section modulus about v-axis	Wv,max	75.75	cm^3
Elastic section modulus about y-axis	Wy	33.93	cm^3
Elastic section modulus about z-axis	Wz	33.93	cm^3
Elastic section modulus about u-axis	Wu	26.74	cm^3
Elastic section modulus about v-axis	Wv	75.75	cm^3

Fig. 2.1.9 Mullion art. 034.2503 with inner reinforcement art. 034.5593.00 section and its properties (extract from RFEM 6.02)

6. Double mullion (2 x art. 034.2503) with inner reinforcement (2 x art. 034.5593.00) and fixing aluminium angle 80x80x6 mm.

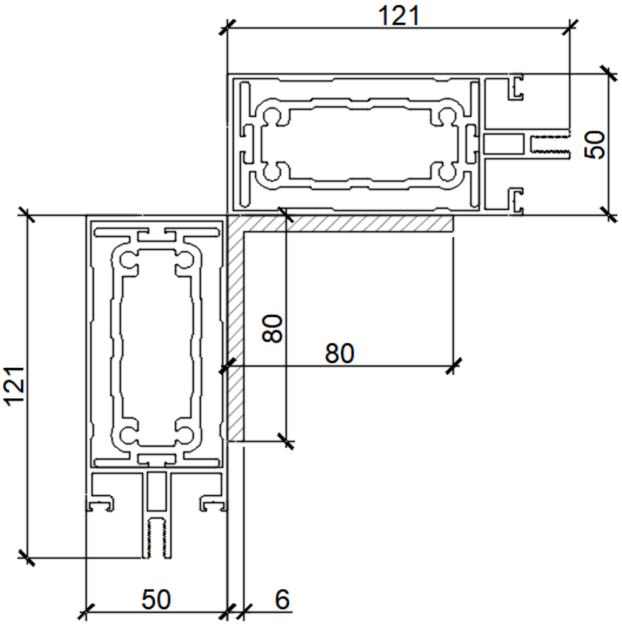
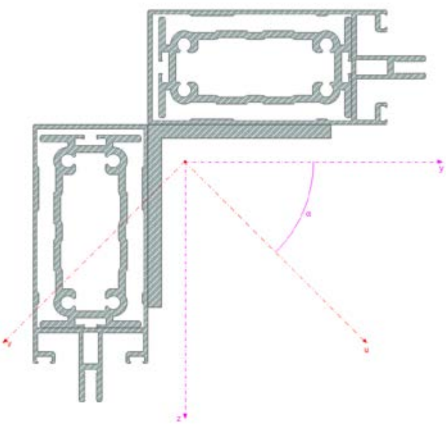


Fig. 2.1.10 Double mullion (2 x art. 034.2503) with inner reinforcement (2 x art. 034.5593.00) and fixing aluminium angle 80x80x6 mm cross-section



Section Properties | 0342503+0345593 (2 mullions+reinf+angle)

Section Values | Stress Points

Sectional Area			
Sectional area	A	42.60	cm²
Geometric sectional area	Ageom	42.60	cm²
Bending			
Location of centroidal axis in y-direction	ey	66.2	mm
Location of centroidal axis in z-direction	ez	66.2	mm
Area moment of inertia about y-axis	Iy	836.53	cm⁴
Area moment of inertia about z-axis	Iz	836.53	cm⁴
Product of inertia about y,z-axes	Iyz	-552.31	cm⁴
Area moment of inertia about u-axis	Iu	284.23	cm⁴
Area moment of inertia about v-axis	Iv	1388.84	cm⁴
Polar area moment of inertia	Ip	1673.07	cm⁴
Polar area moment of inertia with respect to shear center	Ip,SC	1715.70	cm⁴
Inclination of principal axes	α	45.00	deg
Radius of gyration about y-axis	iy	44.3	mm
Radius of gyration about z-axis	iz	44.3	mm
Radius of gyration about y,z-axes	iyz	36.0	mm
Radius of gyration about u-axis	iu	25.8	mm
Radius of gyration about v-axis	iv	57.1	mm
Polar radius of gyration	ip	62.7	mm
Polar radius of gyration with respect to shear center	ip,SC	63.5	mm
Elastic section modulus about y-axis	Wy,min	-61.52	cm³
Elastic section modulus about y-axis	Wy,max	58.39	cm³
Elastic section modulus about z-axis	Wz,min	-61.52	cm³
Elastic section modulus about z-axis	Wz,max	58.39	cm³
Elastic section modulus about u-axis	Wu,min	-48.92	cm³
Elastic section modulus about u-axis	Wu,max	56.03	cm³
Elastic section modulus about v-axis	Wv,min	-127.37	cm³
Elastic section modulus about v-axis	Wv,max	127.37	cm³
Elastic section modulus about y-axis	Wy	58.39	cm³
Elastic section modulus about z-axis	Wz	58.39	cm³
Elastic section modulus about u-axis	Wu	48.92	cm³
Elastic section modulus about v-axis	Wv	127.37	cm³

Fig. 2.1.11 Mullion art. 034.2503 with inner reinforcement art. 034.5593.00 section and its properties (extract from RFEM 6.02)

2.2 Calculation scheme and supports conditions

2.2.1 FEA model of curtain wall A is created in order to perform static analysis and calculations.
Horizontal and vertical profiles have been modelled as beams (members) in RFEM 6.02.

2.2.2 Cross-sections for members are created in the program Dlubal RSECTION 1 (see chapter 2.1).

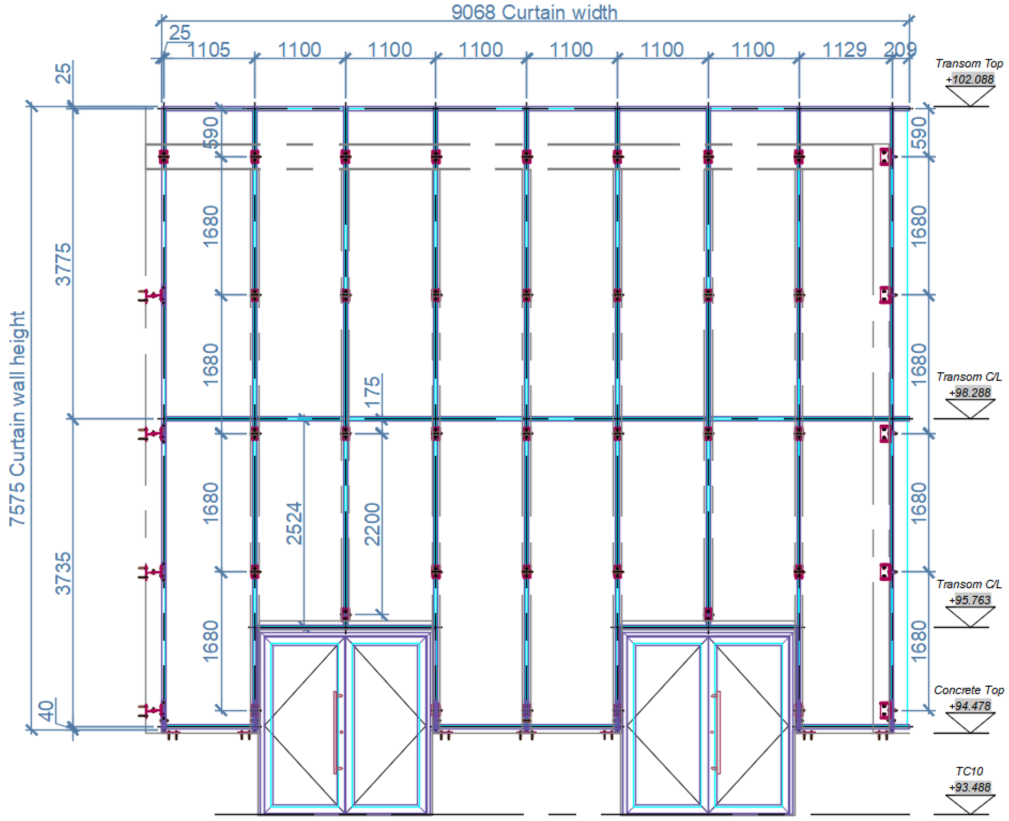


Fig. 2.2.1 Curtain wall 23-08 Elevation A drawing

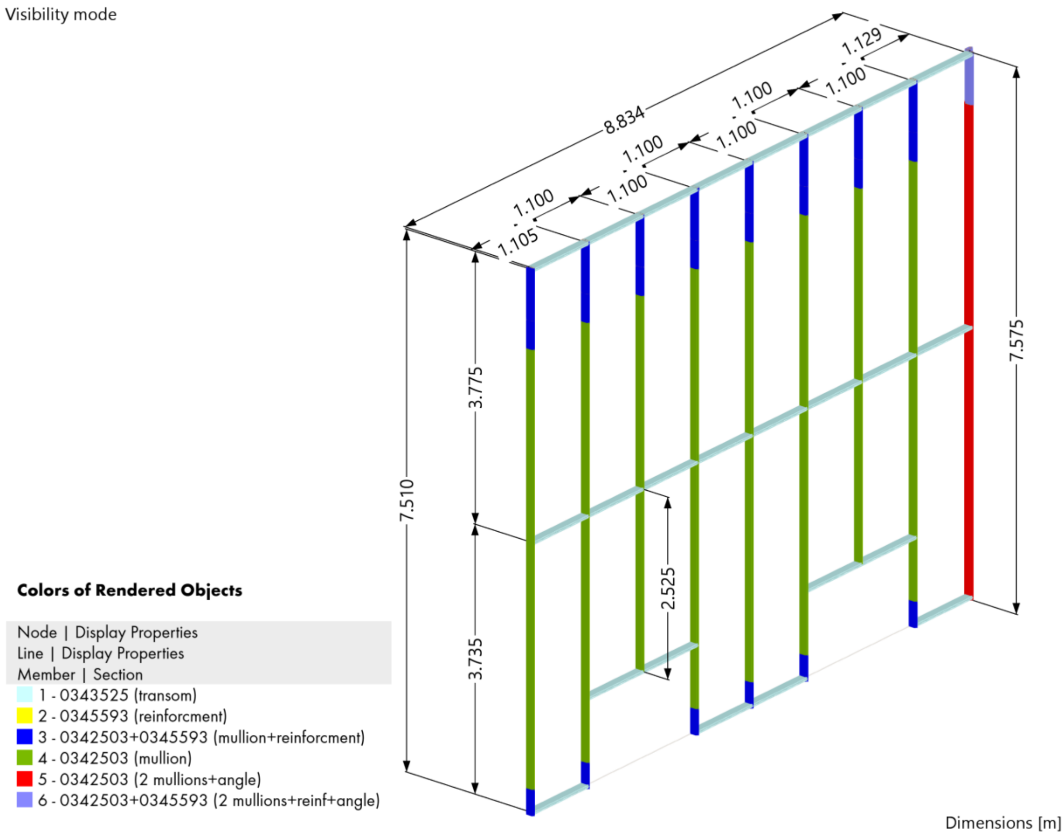


Fig. 2.2.2 Curtain wall 23-08 Elevation A FEA model (extract from RFEM 6.02)

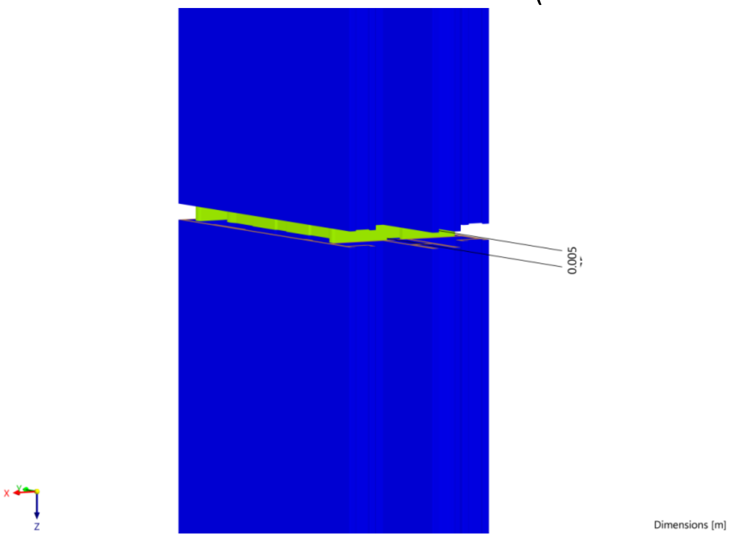


Fig. 2.2.3 Profiles sections in thermal extension gap (extract from RFEM 6.02)

2.2.3 According to the static scheme of the curtain wall, self weight has to cause compression forces in the vertical elements (mullions).

In order to meet this requirement, bearing supports (carrying wind and dead load) are placed on the bottom parts of mullions. Assigned supports are shown in the fig. 2.2.4.

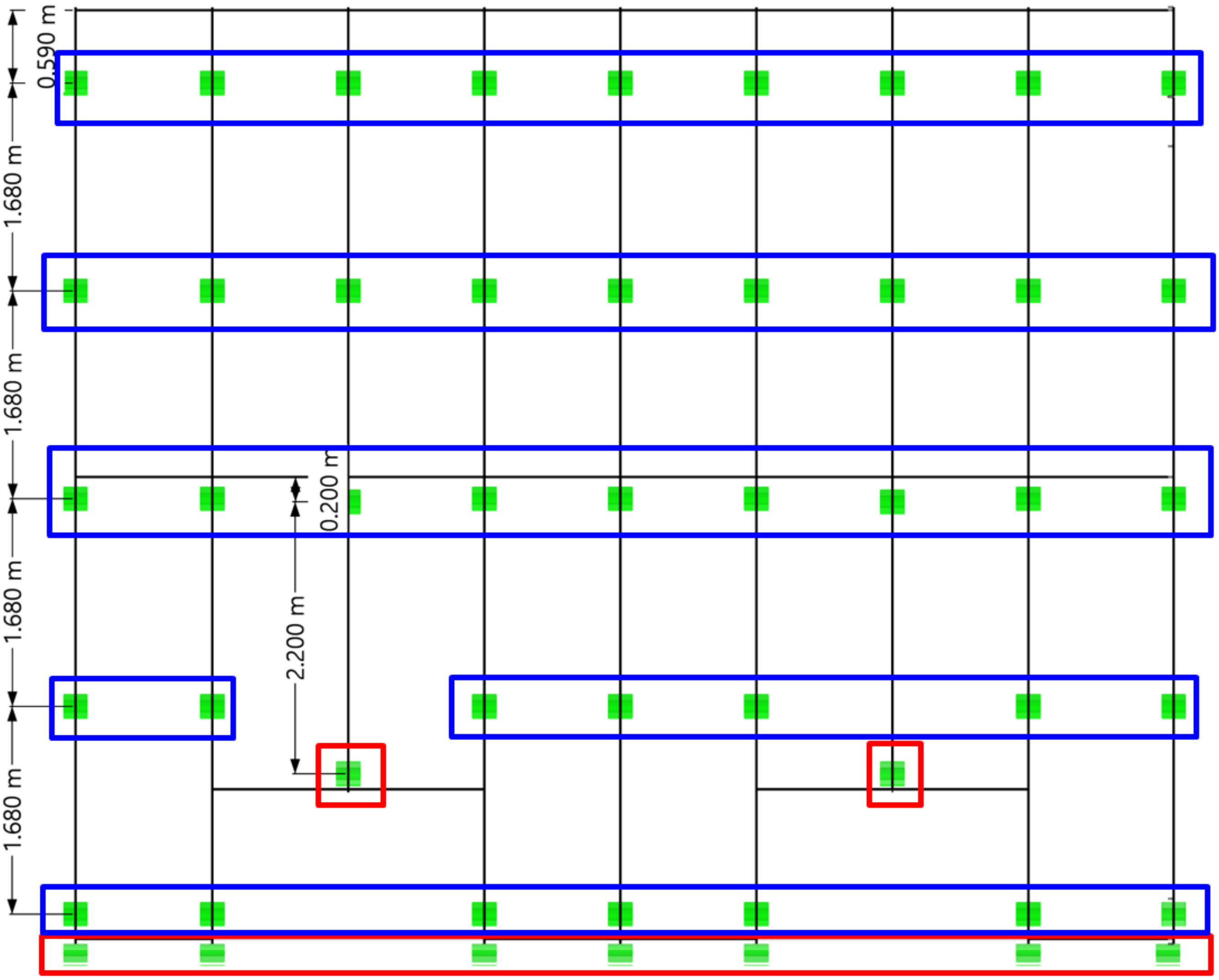


Fig. 2.2.4 FEA model with assigned supports (extract from RFEM 6.02). Red frame - wind+dead load supports, blue frame - wind load supports.

2.3 Loads

Following loads are applied to the calculation scheme:

- self weight of aluminium profiles;
- self weight of glass units;
- wind pressure;
- wind suction;
- snow weight;
- imposed horizontal barrier load.

Loads and their magnitudes are shown in the table 2.3.1.

Table 2.3.1 Loads and their magnitudes

Load	**Load Case**	**Action Category**	**Load type**	**Load magnitude**	**Notice**
Case	**Description**	**EN 1990-1-1**		**(characteristic value)**	
LC1	Dead load (self-weight) :				

	aluminium profiles	Permanent	Uniform force	According to profile weight	1. Automatically accounted by RFEM 6.02.
	glass units	Permanent	Concentrated force	Vary according to the glass units weight	1. Eccentricity 109 mm relatively to shear centre. 2. Distributed between to points (150 mm from the profile start and profile end).
LC2	Wind pressure load	Wind	Surface load	2.92 kN/m^2	1. Distributed between transoms and mullions.
LC3	Wind suction load	Wind	Surface load	1.85 kN/m^2	1. Distributed between transoms and mullions.
LC4	Snow load	Snow	Uniform force	0.5 kN/m	
LC5	Imposed load "+" outside pressure	Imposed load (category C.3)	Uniform force	1 kN/m	1. Distributed between mullions (1.2 m height from the floor level). According table 6.12 EN 1990-1-1 .
LC6	Imposed load "-" inside pressure	Imposed load (category C.3)	Uniform force	1 kN/m	2. Distributed between mullions (1.2 m height from the floor level). 3. According table 6.12 EN 1990-1-1 .

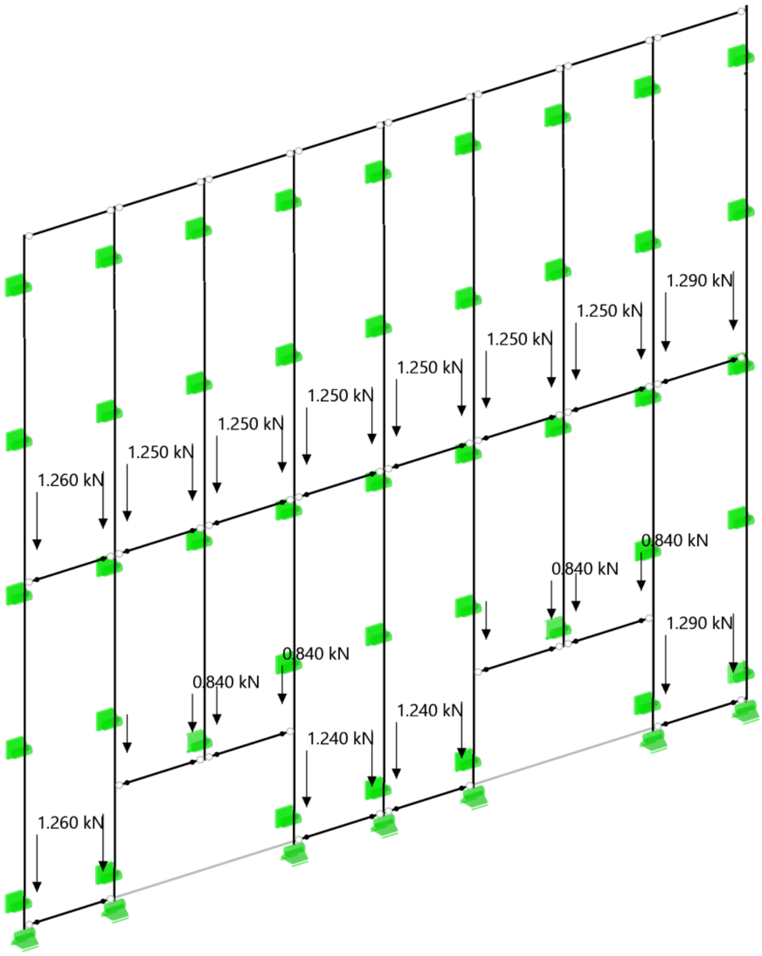


Fig. 2.3.1 FEA model with applied dead load (extract from RFEM 6.02)

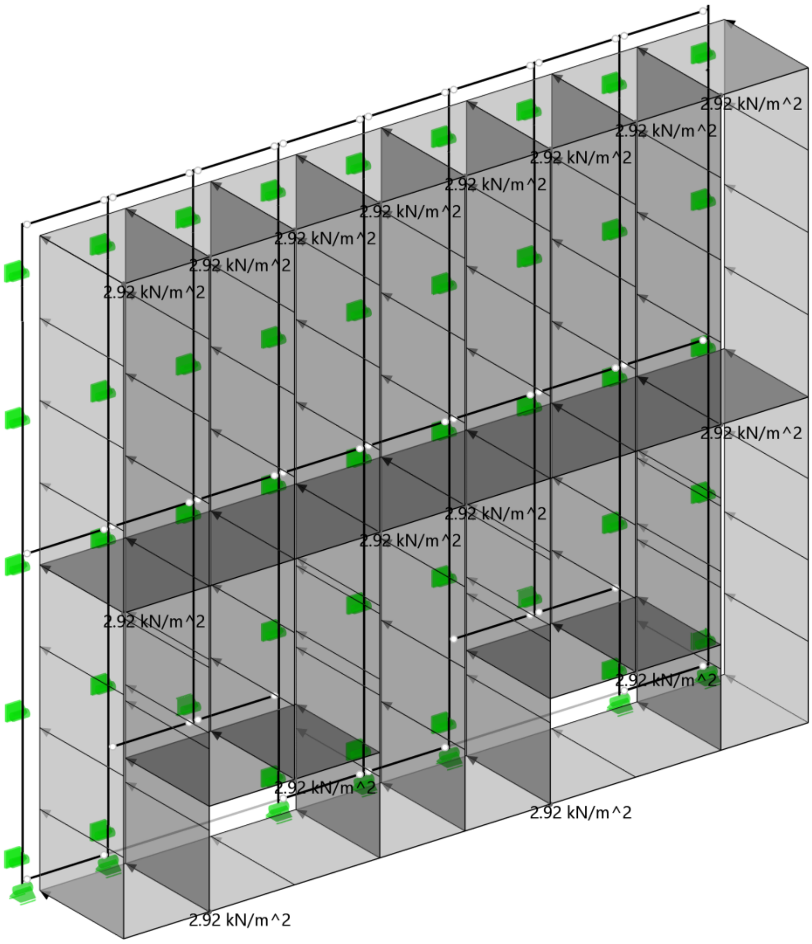


Fig. 2.3.2 FEA model with applied wind pressure (extract from RFEM 6.02)

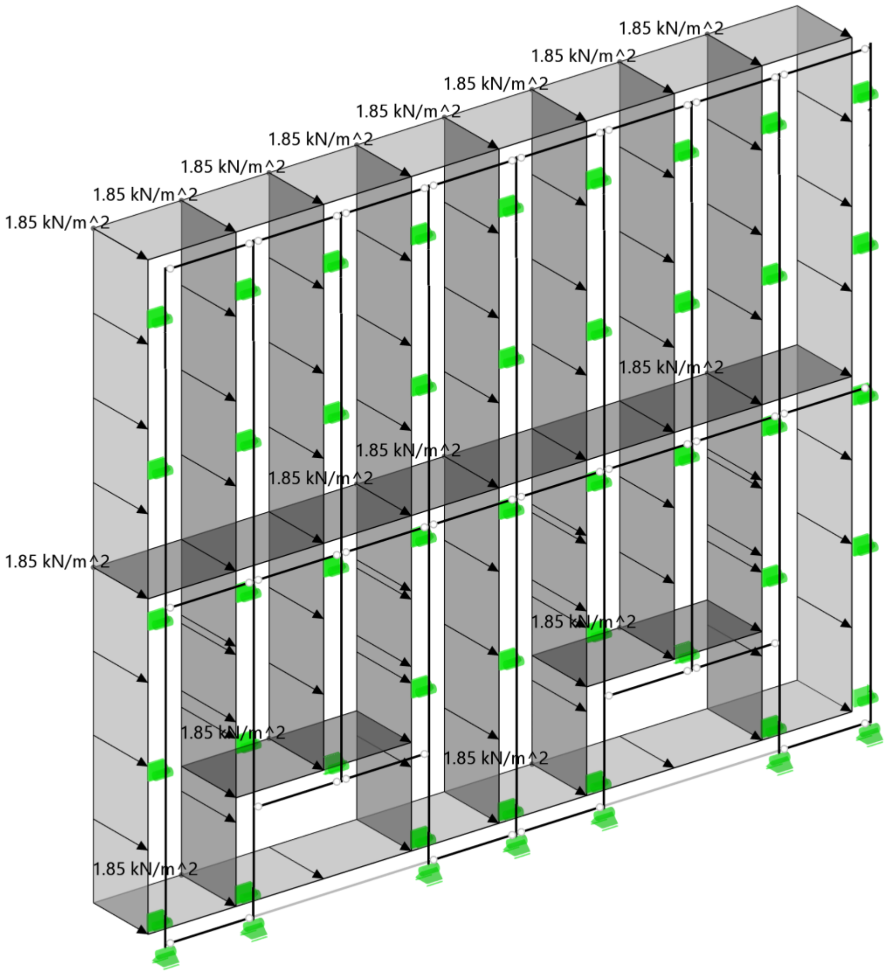


Fig. 2.3.3 FEA model with applied wind suction (extract from RFEM 6.02)

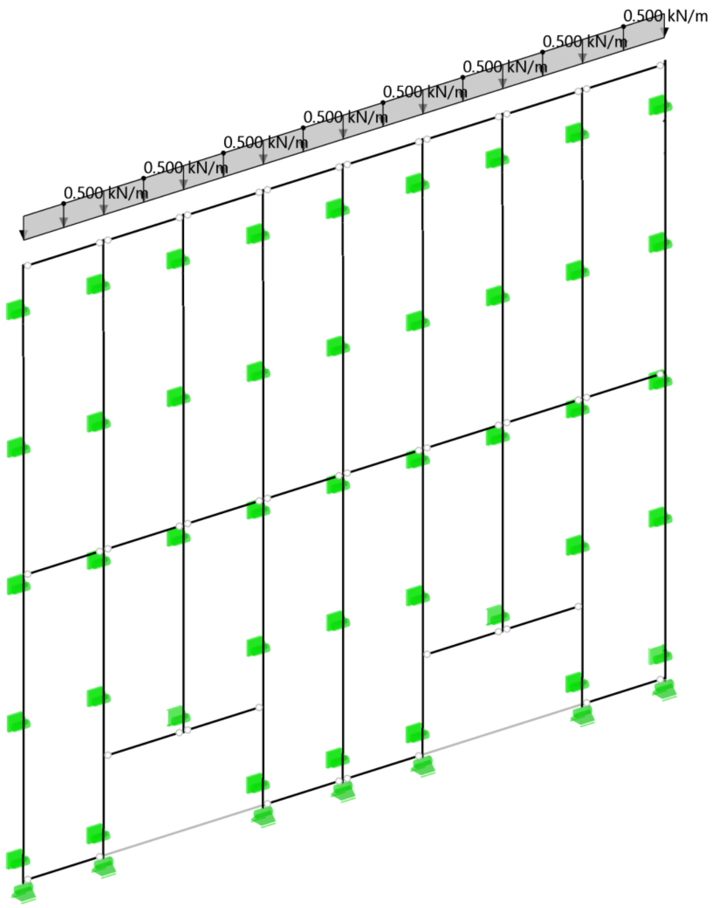


Fig. 2.3.4 FEA model with applied snow load (extract from RFEM 6.02)

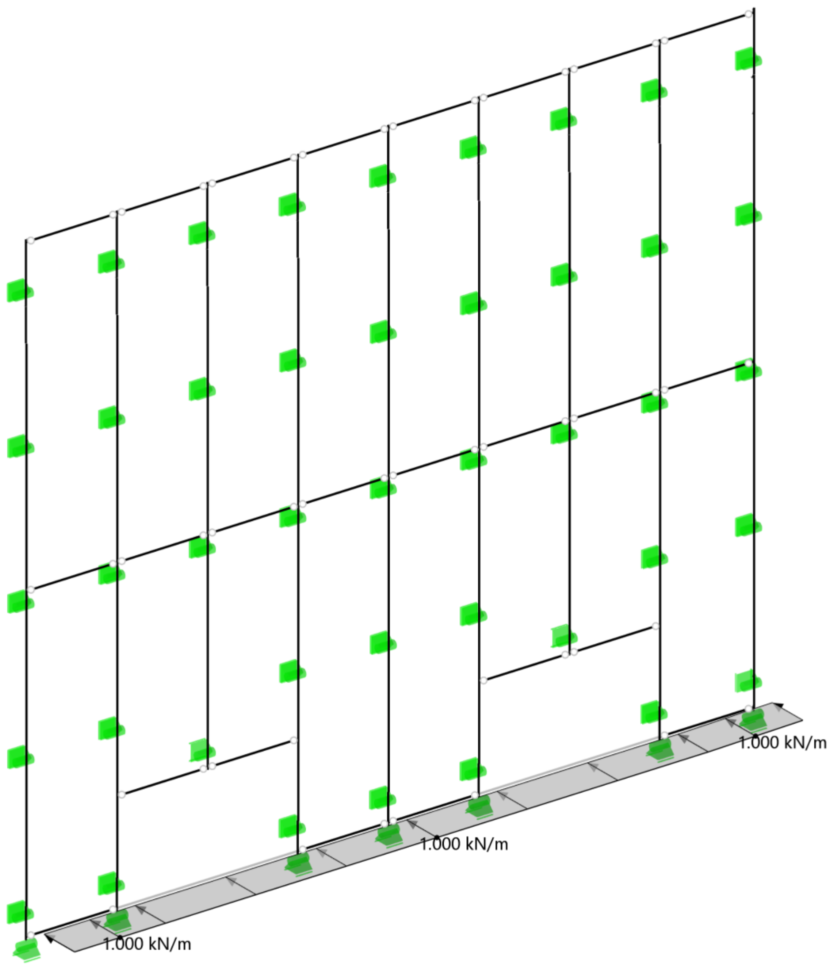


Fig. 2.3.5 FEA model with applied imposed load “+” outside pressure (extract from RFEM 6.02)

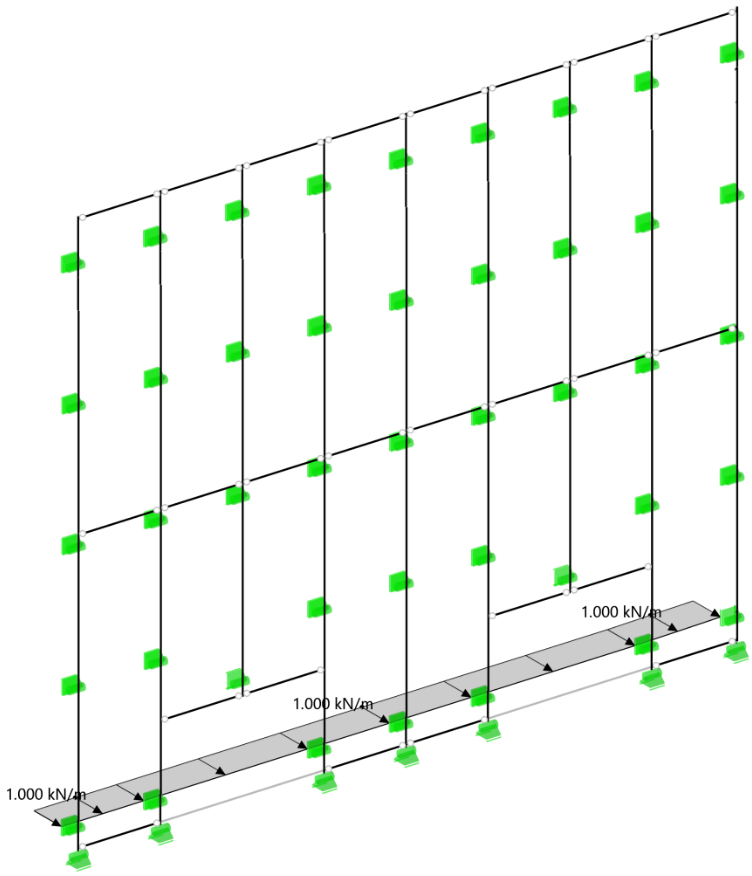


Fig. 2.3.6 FEA model with applied imposed load “-” inside pressure (extract from RFEM 6.02)

2.4 Load combinations

Load combinations are generated according to EN 1990-1-1 (equation 6.10).
Load combinations are shown in the table 2.4.1.

Table 2.4.1 Loads combinations

	Load Combin.	Name	LC.1		LC.2		LC.3		LC.4	
			Factor	No.	Factor	No.	Factor	No.	Factor	No.
ULS	CO1	1.35 * LC1	1.35	LC1						
	CO2	1.35 * LC1 + 1.50 * LC2	1.35	LC1	1.50	LC2				
	CO3	1.35 * LC1 + 1.50 * LC3	1.35	LC1	1.50	LC3				
	CO4	1.35 * LC1 + 1.50 * LC2 + 0.75 * LC4	1.35	LC1	1.50	LC2	0.75	LC4		
	CO5	1.35 * LC1 + 1.50 * LC3 + 0.75 * LC4	1.35	LC1	1.50	LC3	0.75	LC4		
	CO6	1.35 * LC1 + 1.50 * LC2 + 0.75 * LC4 + 1.05 * LC5	1.35	LC1	1.50	LC2	0.75	LC4	1.05	LC5
	CO7	1.35 * LC1 + 1.50 * LC2 + 0.75 * LC4 + 1.05 * LC6	1.35	LC1	1.50	LC2	0.75	LC4	1.05	LC6
	CO8	1.35 * LC1 + 1.50 * LC3 + 0.75 * LC4 + 1.05 * LC5	1.35	LC1	1.50	LC3	0.75	LC4	1.05	LC5
	CO9	1.35 * LC1 + 1.50 * LC3 + 0.75 * LC4 + 1.05 * LC6	1.35	LC1	1.50	LC3	0.75	LC4	1.05	LC6
	CO10	1.35 * LC1 + 1.50 * LC2 + 1.05 * LC5	1.35	LC1	1.50	LC2	1.05	LC5		
	CO11	1.35 * LC1 + 1.50 * LC2 + 1.05 * LC6	1.35	LC1	1.50	LC2	1.05	LC6		
	CO12	1.35 * LC1 + 1.50 * LC3 + 1.05 * LC5	1.35	LC1	1.50	LC3	1.05	LC5		
	CO13	1.35 * LC1 + 1.50 * LC3 + 1.05 * LC6	1.35	LC1	1.50	LC3	1.05	LC6		
	CO14	1.35 * LC1 + 1.50 * LC4	1.35	LC1	1.50	LC4				

	CO15	1.35 * LC1 + 0.90 * LC2 + 1.50 * LC4	1.35	LC1	0.90	LC2	1.50	LC4		
	CO16	1.35 * LC1 + 0.90 * LC3 + 1.50 * LC4	1.35	LC1	0.90	LC3	1.50	LC4		
	CO17	1.35 * LC1 + 0.90 * LC2 + 1.50 * LC4 + 1.05 * LC5	1.35	LC1	0.90	LC2	1.50	LC4	1.05	LC5
	CO18	1.35 * LC1 + 0.90 * LC2 + 1.50 * LC4 + 1.05 * LC6	1.35	LC1	0.90	LC2	1.50	LC4	1.05	LC6
	CO19	1.35 * LC1 + 0.90 * LC3 + 1.50 * LC4 + 1.05 * LC5	1.35	LC1	0.90	LC3	1.50	LC4	1.05	LC5
	CO20	1.35 * LC1 + 0.90 * LC3 + 1.50 * LC4 + 1.05 * LC6	1.35	LC1	0.90	LC3	1.50	LC4	1.05	LC6
	CO21	1.35 * LC1 + 1.50 * LC4 + 1.05 * LC5	1.35	LC1	1.50	LC4	1.05	LC5		
	CO22	1.35 * LC1 + 1.50 * LC4 + 1.05 * LC6	1.35	LC1	1.50	LC4	1.05	LC6		
	CO23	1.35 * LC1 + 1.50 * LC5	1.35	LC1	1.50	LC5				
	CO24	1.35 * LC1 + 1.50 * LC6	1.35	LC1	1.50	LC6				
	CO25	1.35 * LC1 + 0.90 * LC2 + 1.50 * LC5	1.35	LC1	0.90	LC2	1.50	LC5		
	CO26	1.35 * LC1 + 0.90 * LC2 + 1.50 * LC6	1.35	LC1	0.90	LC2	1.50	LC6		
	CO27	1.35 * LC1 + 0.90 * LC3 + 1.50 * LC5	1.35	LC1	0.90	LC3	1.50	LC5		
	CO28	1.35 * LC1 + 0.90 * LC3 + 1.50 * LC6	1.35	LC1	0.90	LC3	1.50	LC6		
ULS	CO29	1.35 * LC1 + 0.90 * LC2 + 0.75 * LC4 + 1.50 * LC5	1.35	LC1	0.90	LC2	0.75	LC4	1.50	LC5
	CO30	1.35 * LC1 + 0.90 * LC2 + 0.75 * LC4 + 1.50 * LC6	1.35	LC1	0.90	LC2	0.75	LC4	1.50	LC6
	CO31	1.35 * LC1 + 0.90 * LC3 + 0.75 * LC4 + 1.50 * LC5	1.35	LC1	0.90	LC3	0.75	LC4	1.50	LC5
	CO32	1.35 * LC1 + 0.90 * LC3 + 0.75 * LC4 + 1.50 * LC6	1.35	LC1	0.90	LC3	0.75	LC4	1.50	LC6
	CO33	1.35 * LC1 + 0.75 * LC4 + 1.50 * LC5	1.35	LC1	0.75	LC4	1.50	LC5		
	CO34	1.35 * LC1 + 0.75 * LC4 + 1.50 * LC6	1.35	LC1	0.75	LC4	1.50	LC6		
	CO35	LC1	1.00	LC1						
	CO36	LC1 + LC2	1.00	LC1	1.00	LC2				
	CO37	LC1 + LC3	1.00	LC1	1.00	LC3				
	CO38	LC1 + LC2 + 0.50 * LC4	1.00	LC1	1.00	LC2	0.50	LC4		
	CO39	LC1 + LC3 + 0.50 * LC4	1.00	LC1	1.00	LC3	0.50	LC4		
	CO40	LC1 + LC2 + 0.50 * LC4 + 0.70 * LC5	1.00	LC1	1.00	LC2	0.50	LC4	0.70	LC5
	CO41	LC1 + LC2 + 0.50 * LC4 + 0.70 * LC6	1.00	LC1	1.00	LC2	0.50	LC4	0.70	LC6
	CO42	LC1 + LC3 + 0.50 * LC4 + 0.70 * LC5	1.00	LC1	1.00	LC3	0.50	LC4	0.70	LC5
	CO43	LC1 + LC3 + 0.50 * LC4 + 0.70 * LC6	1.00	LC1	1.00	LC3	0.50	LC4	0.70	LC6
	CO44	LC1 + LC2 + 0.70 * LC5	1.00	LC1	1.00	LC2	0.70	LC5		
	CO45	LC1 + LC2 + 0.70 * LC6	1.00	LC1	1.00	LC2	0.70	LC6		
SLS	CO46	LC1 + LC3 + 0.70 * LC5	1.00	LC1	1.00	LC3	0.70	LC5		
	CO47	LC1 + LC3 + 0.70 * LC6	1.00	LC1	1.00	LC3	0.70	LC6		
	CO48	LC1 + LC4	1.00	LC1	1.00	LC4				
	CO49	LC1 + 0.60 * LC2 + LC4	1.00	LC1	0.60	LC2	1.00	LC4		
	CO50	LC1 + 0.60 * LC3 + LC4	1.00	LC1	0.60	LC3	1.00	LC4		
	CO51	LC1 + 0.60 * LC2 + LC4 + 0.70 * LC5	1.00	LC1	0.60	LC2	1.00	LC4	0.70	LC5
	CO52	LC1 + 0.60 * LC2 + LC4 + 0.70 * LC6	1.00	LC1	0.60	LC2	1.00	LC4	0.70	LC6
	CO53	LC1 + 0.60 * LC3 + LC4 + 0.70 * LC5	1.00	LC1	0.60	LC3	1.00	LC4	0.70	LC5
	CO54	LC1 + 0.60 * LC3 + LC4 + 0.70 * LC6	1.00	LC1	0.60	LC3	1.00	LC4	0.70	LC6
	CO55	LC1 + LC4 + 0.70 * LC5	1.00	LC1	1.00	LC4	0.70	LC5		
	CO56	LC1 + LC4 + 0.70 * LC6	1.00	LC1	1.00	LC4	0.70	LC6		
	CO57	LC1 + LC5	1.00	LC1	1.00	LC5				

	CO58	LC1 + LC6	1.00	LC1	1.00	LC6				
	CO59	LC1 + 0.60 * LC2 + LC5	1.00	LC1	0.60	LC2	1.00	LC5		
	CO60	LC1 + 0.60 * LC2 + LC6	1.00	LC1	0.60	LC2	1.00	LC6		
	CO61	LC1 + 0.60 * LC3 + LC5	1.00	LC1	0.60	LC3	1.00	LC5		
	CO62	LC1 + 0.60 * LC3 + LC6	1.00	LC1	0.60	LC3	1.00	LC6		
	CO63	LC1 + 0.60 * LC2 + 0.50 * LC4 + LC5	1.00	LC1	0.60	LC2	0.50	LC4	1.00	LC5
	CO64	LC1 + 0.60 * LC2 + 0.50 * LC4 + LC6	1.00	LC1	0.60	LC2	0.50	LC4	1.00	LC6
	CO65	LC1 + 0.60 * LC3 + 0.50 * LC4 + LC5	1.00	LC1	0.60	LC3	0.50	LC4	1.00	LC5
	CO66	LC1 + 0.60 * LC3 + 0.50 * LC4 + LC6	1.00	LC1	0.60	LC3	0.50	LC4	1.00	LC6
	CO67	LC1 + 0.50 * LC4 + LC5	1.00	LC1	0.50	LC4	1.00	LC5		
	CO68	LC1 + 0.50 * LC4 + LC6	1.00	LC1	0.50	LC4	1.00	LC6		

3. Results of structural calculation

3.1 Deformation of FEA model

3.1.1 Deflection in mullions from SLS combinations. Maximum deformation u=4.7 mm.

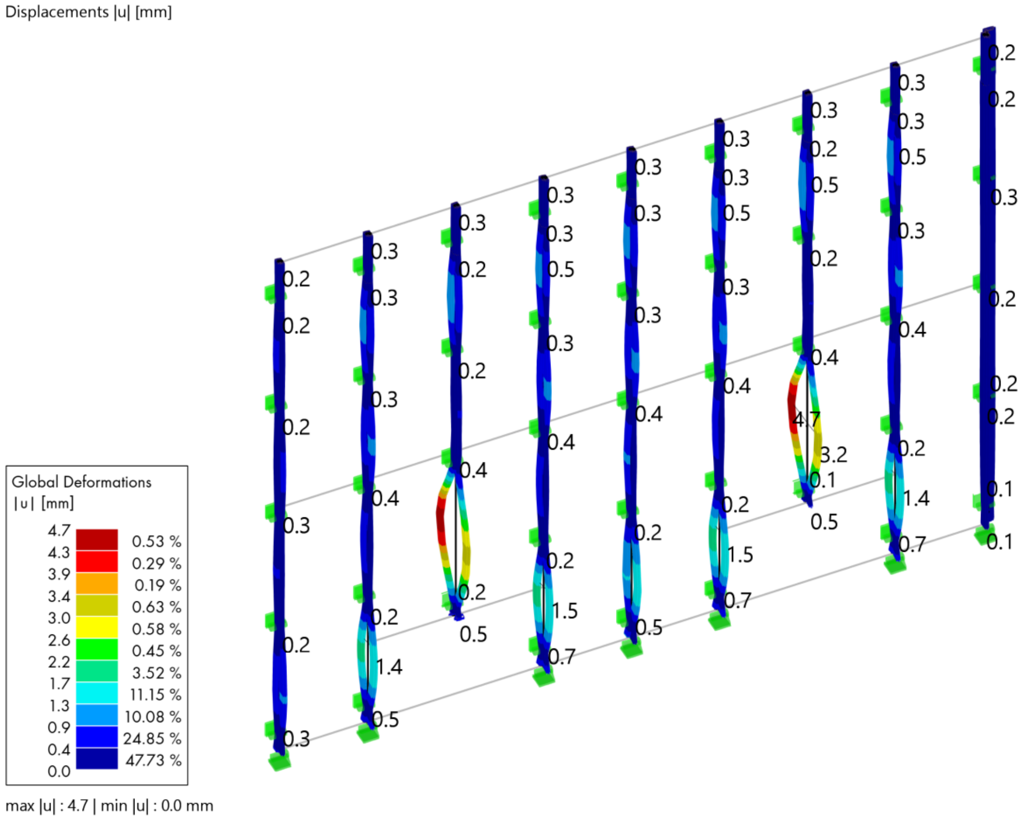


Fig. 3.1.1 Deflection in mullions from SLS combinations (extract from RFEM 6.02)

3.1.2 Deflection in transoms from SLS combinations. Maximum deformation u=1.9 mm.

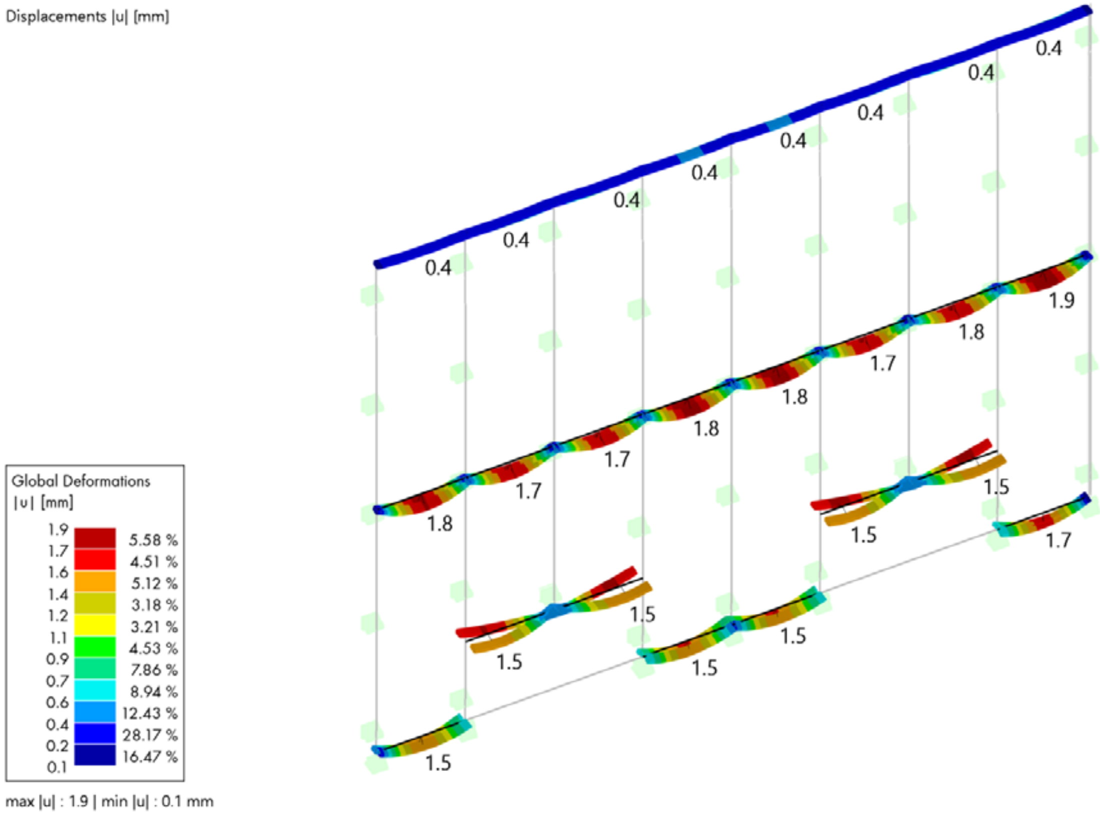


Fig. 3.1.2 Deflection in transoms from SLS combinations (extract from RFEM 6.02)

3.1.3 Deflection in transoms from self weight (load case LC1, load combination CO35). Maximum deformation u=1.8 mm.

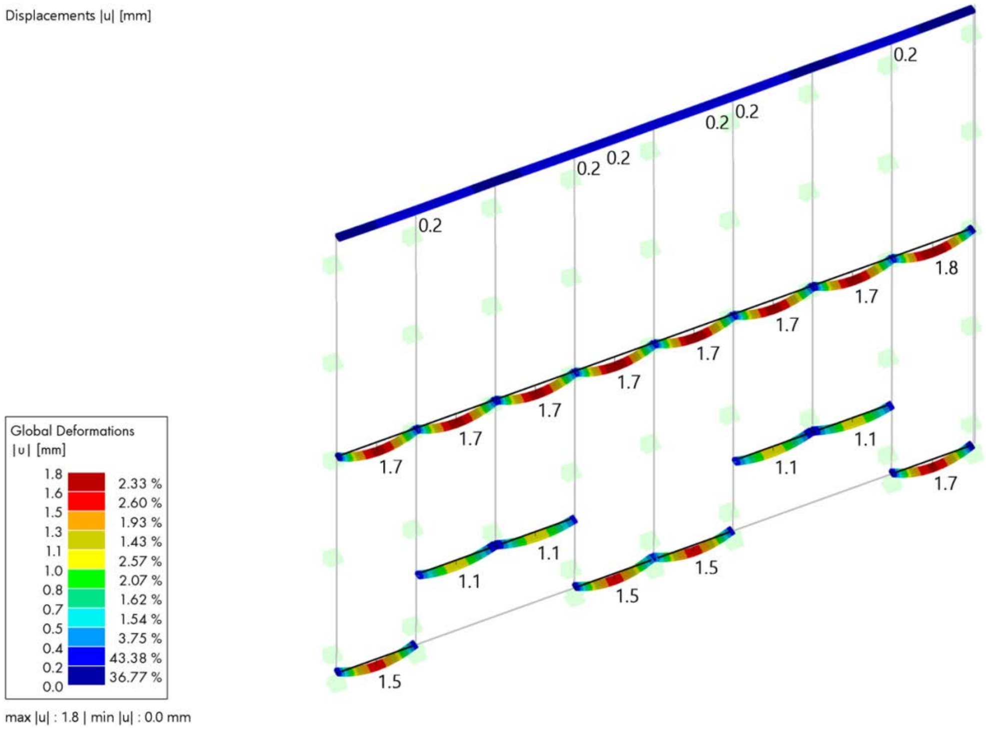


Fig. 3.1.3 Deflection in transoms from self weight (load case LC1, load combination CO35) (extract from RFEM 6.02)

3.2 Internal forces

Internal forces for profiles are calculated in RFEM 6.02.

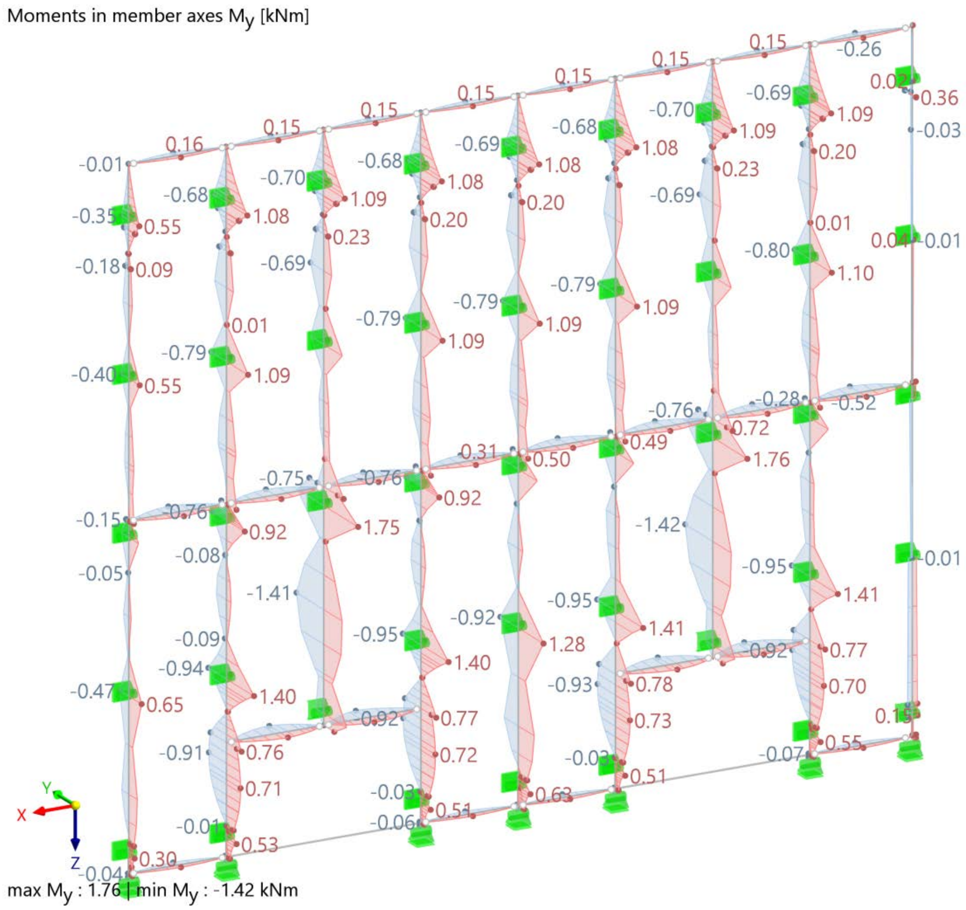


Fig. 3.2.1 Internal forces (M_y, ULS combinations) (extract from RFEM 6.02)

3.3 Support reactions

3.3.1 Support reactions P_z . Maximum value P_z=7.89 kN (load combinations CO14 - CO22).

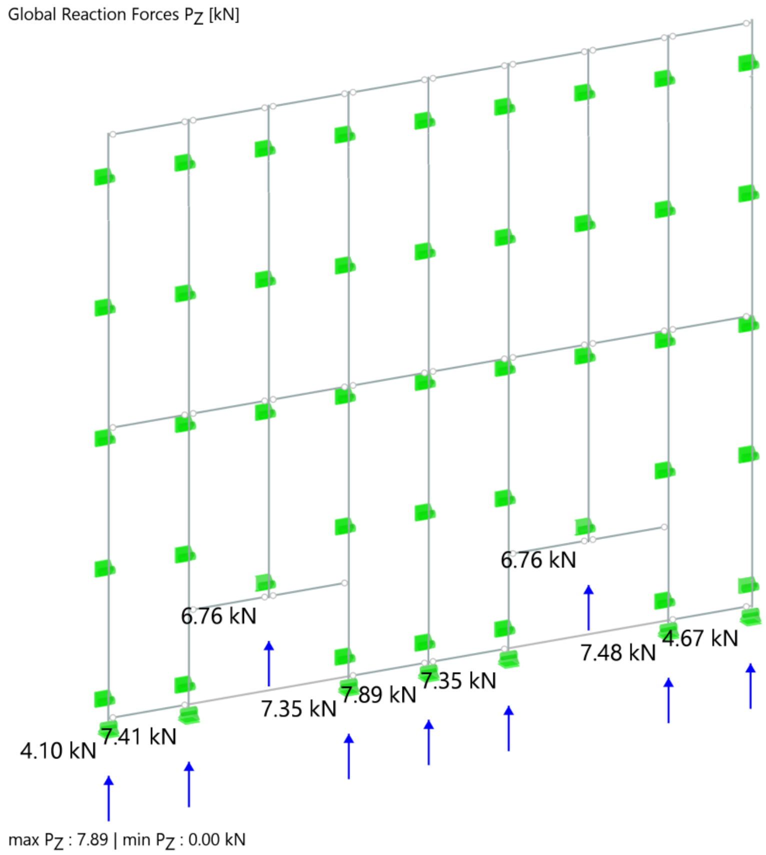


Fig. 3.3.1 Support reactions P_z (load combinations CO14) (extract from RFEM 6.02)

3.3.2 Support reactions "+" P_y. Maximum value P_y= 10,64 kN (load combinations CO6).

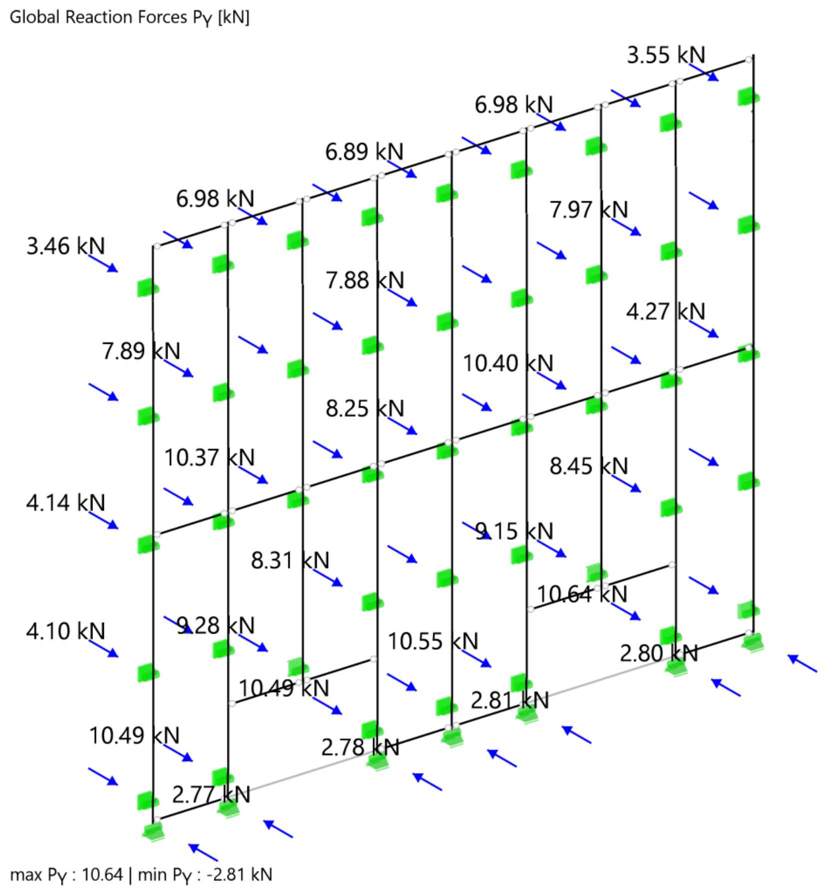


Fig. 3.3.2 Support reactions "+" P_y (load combination CO6) (extract from RFEM 6.02)

3.3.3 Support reactions ”-” P_y. Maximum value P_y= - 8.16 kN (load combination CO9).

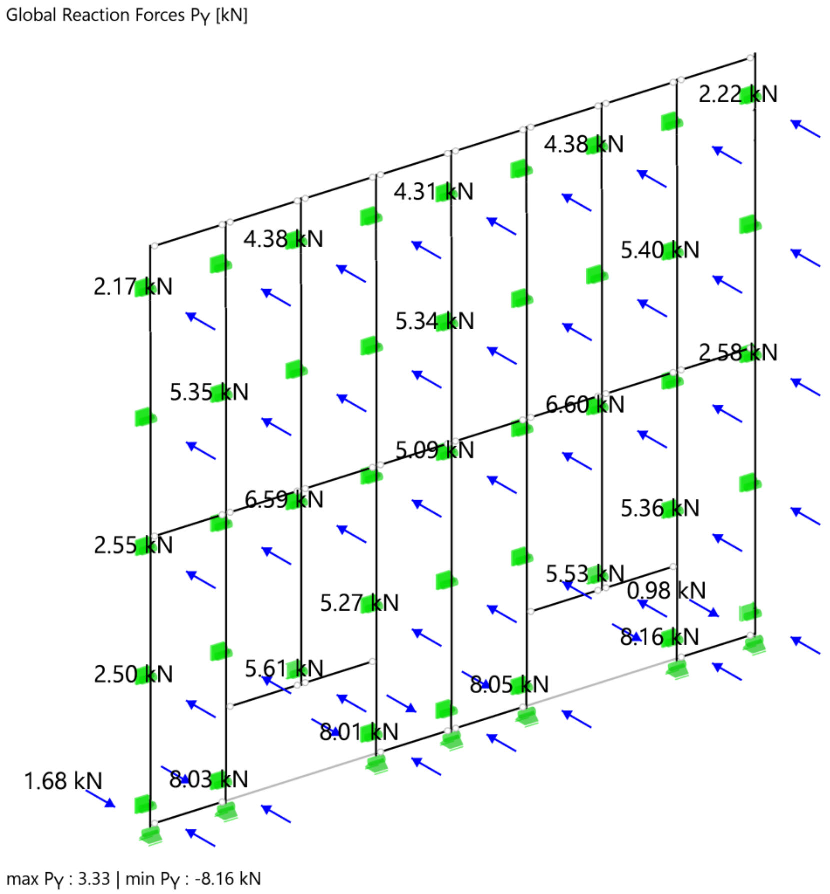


Fig. 3.3.3 Support reactions ”-” P_y (load combination CO9) (extract from RFEM 6.02)

3.4 Serviceability limit state (SLS) design

3.5.1 Deformation limit for mullion is L/200=2200/200=11 mm or 15 mm according to EN 13830.

Maximum deflection of mullion from applied loads (SLS combinations) is 4.7 mm (fig. 3.1.1), that less than limit value 11 mm.

3.5.2 Frontal deformation limit for transom from wind load is L/200=1129/200=5,6 mm or 12 mm according to EN 13830.

Maximum deflection of transom from applied loads (SLS combinations) is 1.9 mm (fig. 3.1.2), that less than limit value 6.5 mm.

3.5.3 Maximum deformation limit for transom from dead load (self weight) is L/500=1304/500=2.6 mm or 3 mm according to EN 13830.

Maximum deflection of transom from applied loads (SLS combinations) is 1.8 mm (fig. 3.1.3), that less than limit value 2.6 or 3 mm.

In order to compensate surplus transom deflection special glass support elements should be applied (see fig. 3.5.1).

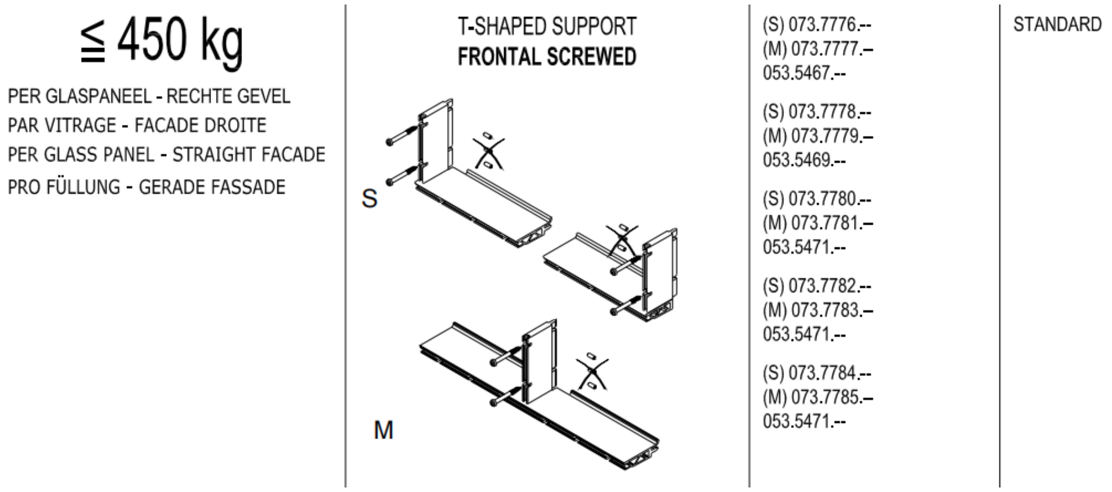


Fig. 3.5.1 Glass support element

3.5.4 All calculated SLS design ratios are less then 1.
Deflections from existing loads is less then maximum deflections according to EN 13830.
The entire structure has been designed properly and safety.

4. Bracket calculations

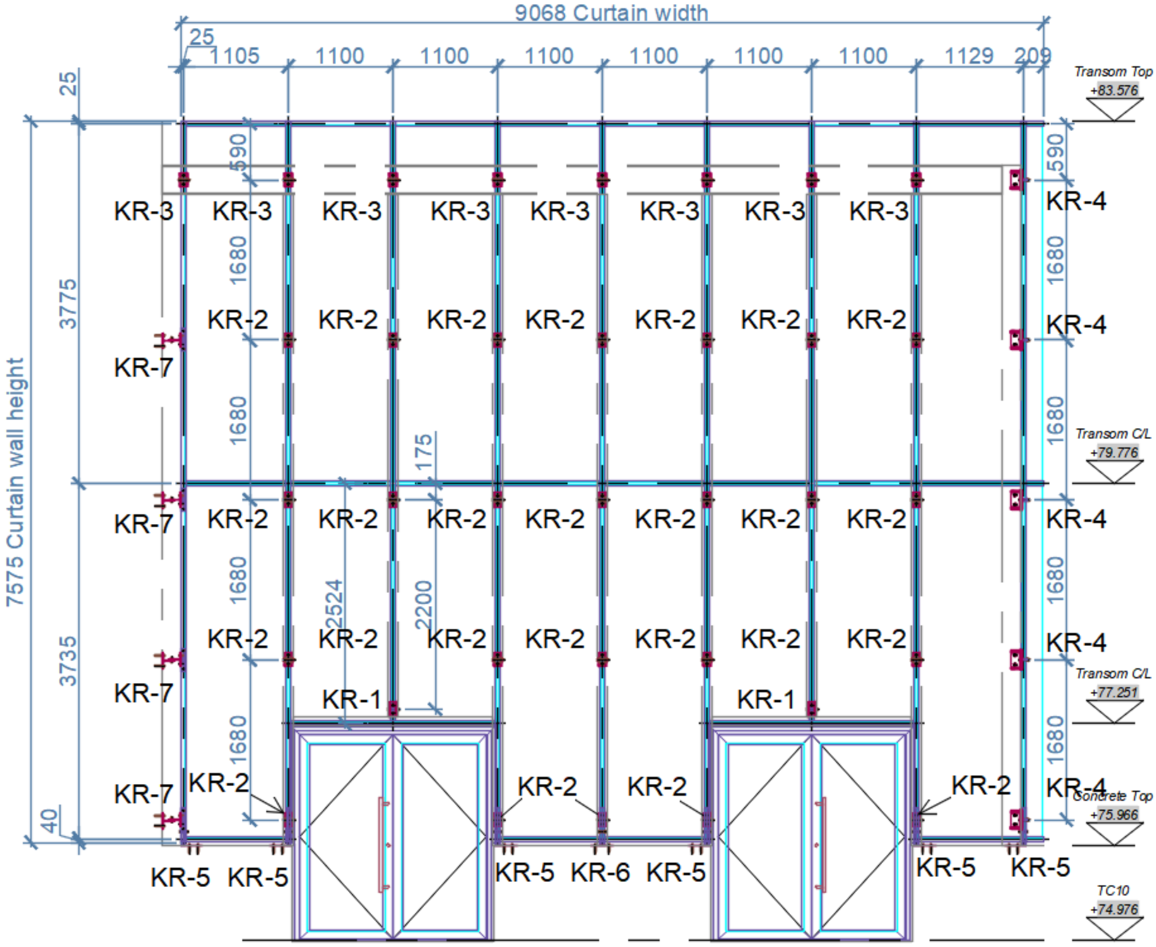


Fig. 4.1 Brackets location

4.1 Bracket type KR-1

4.1.1 Steel calculation

Bracket KR-1 location (the most loaded bracket) is shown in the fig. 4.1.1.

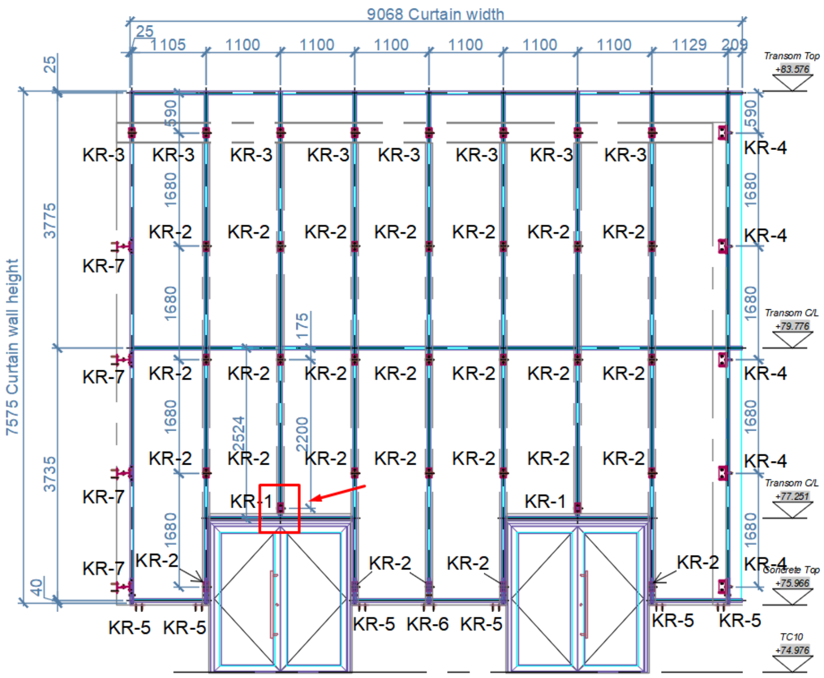


Fig. 4.1.1 Bracket KR-1 location

Bracket KR-1 scheme is shown in the fig. 4.1.2.

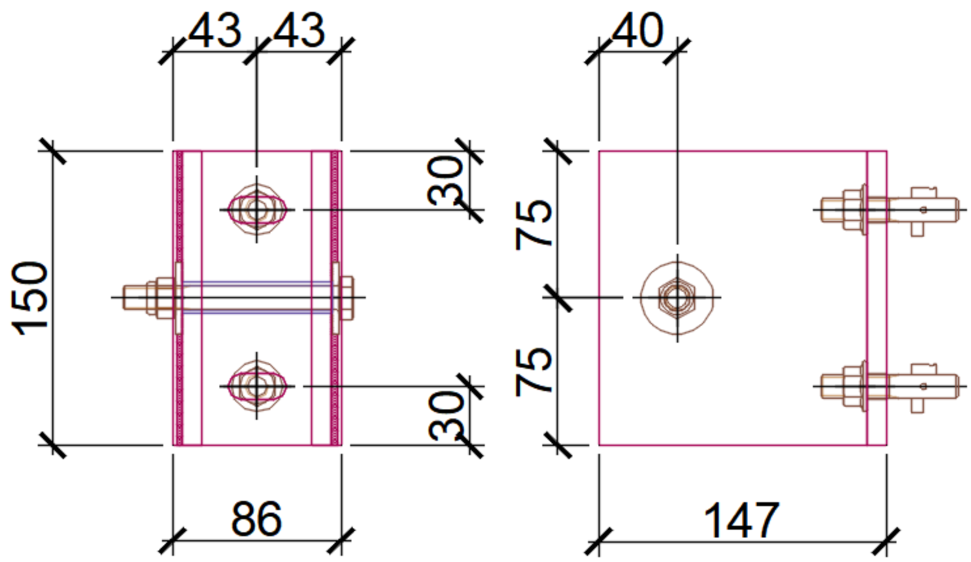


Fig. 4.1.2 Bracket KR-1 scheme

Bracket KR-1 FEA model is shown in the fig. 4.1.3.

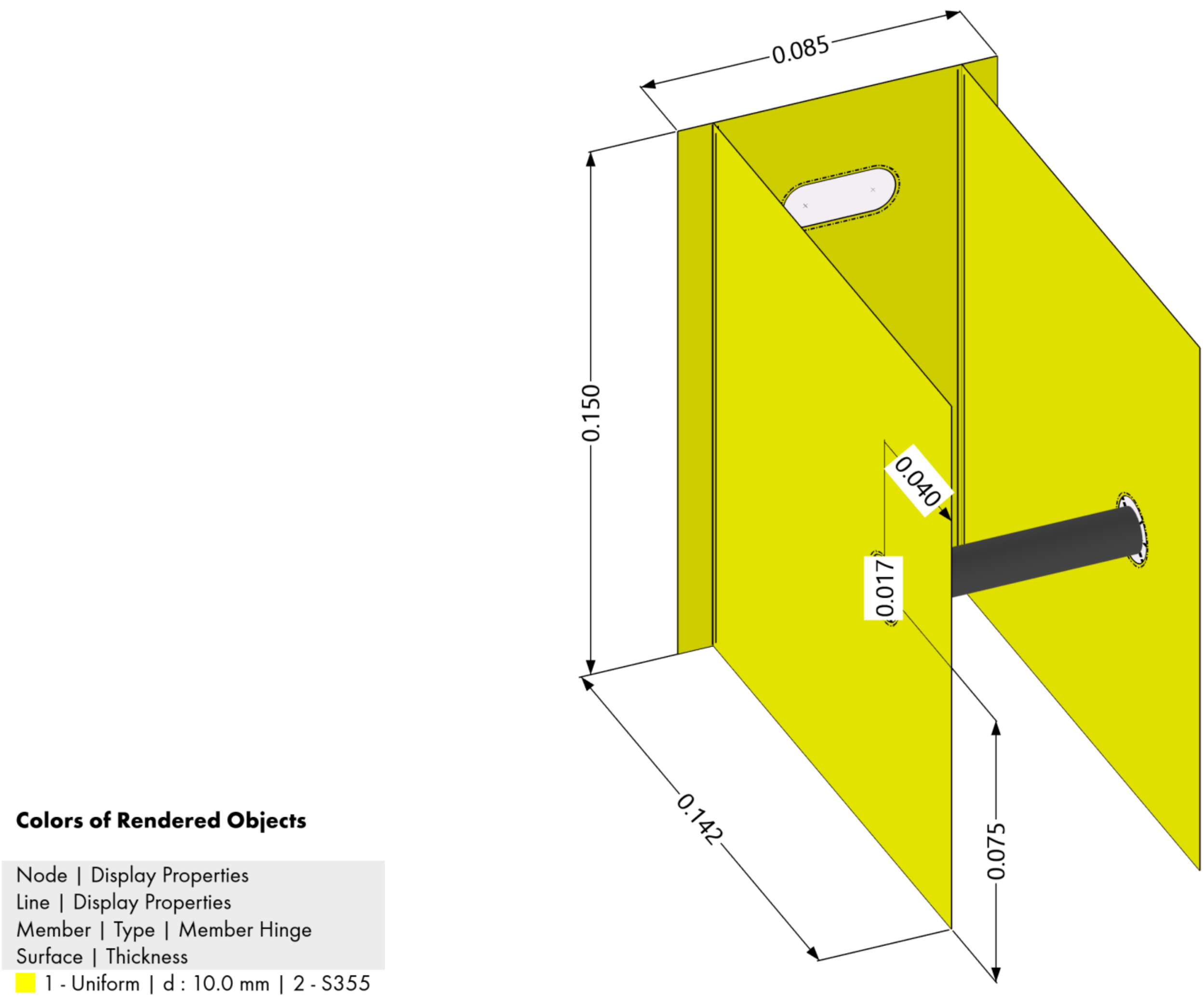


Fig. 4.1.3 Bracket KR-1 FEA model (extract from RFEM 6.02)

FEA model of bracket KR-1 with applied loads is shown in the fig. 4.1.4.

The most unfavourable load combinations for bracket KR-1:
- CO6 with support reactions P_z=6,35 kN, P_y=9,3 kN;
- CO9 with support reactions P_z=6,35 kN, P_y= - 5,63 kN;
- CO14 with support reactions P_z=6,76 kN, P_y=0,16 kN.

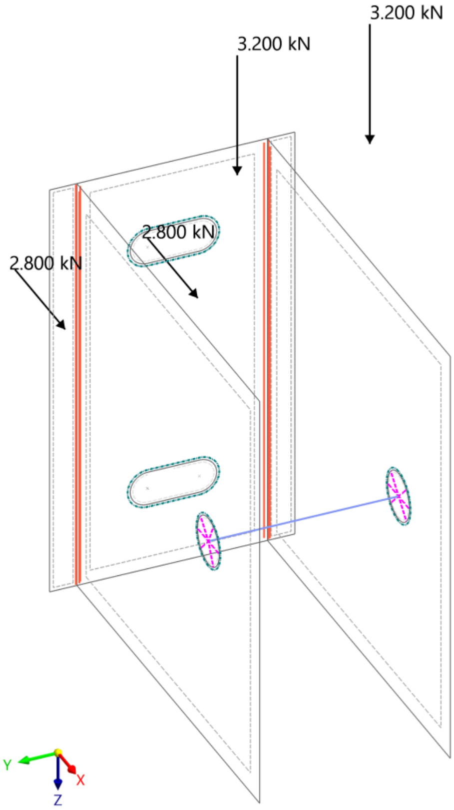


Fig. 4.1.4 Loads to bracket KR-1 - CO9 load combination (extract from RFEM 6.02)

Result of stress-strain analysis of bracket KR-1 (existing stresses) is shown in the fig. 4.1.5.

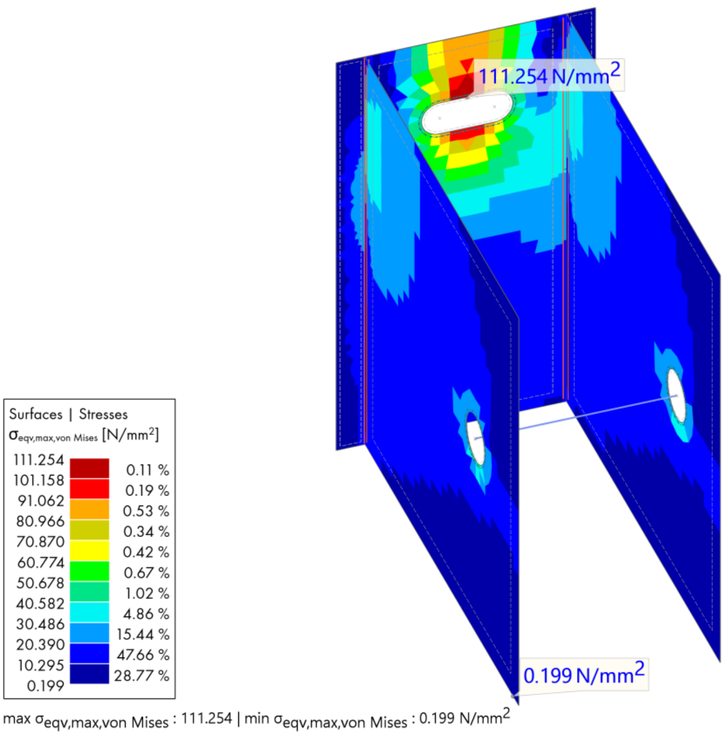


Fig. 4.1.5 Stresses in bracket KR-1 (extract from RFEM 6.02)

ULS design of bracket KR-1 is performed it the table 4.1.1.

Table 4.1.1 Bracket KR-1 calculation (extract from RFEM 6.02)

Thick. No.	Design Situation	Loading No.	Stress Type	Stress [N/mm^2] Existing	Limit	Stress Ratio η [--]
1	DS1	CO9	$\sigma_{1,+}$	124.266	355.000	**0.350**
1	DS1	CO9	$\sigma_{2,+}$	54.007	355.000	**0.152**
1	DS1	CO9	$\sigma_{1,-}$	-72.056	355.000	**0.203**
1	DS1	CO9	$\sigma_{2,-}$	-121.135	355.000	**0.341**
1	DS1	CO9	$\sigma_{1,m}$	22.267	355.000	**0.063**
1	DS1	CO9	$\sigma_{2,m}$	-25.235	355.000	**0.071**
1	DS1	CO9	τ_{max}	26.980	204.959	**0.132**
1	DS1	CO9	$\sigma_{eqv,max,von\ Mises}$	111.254	355.000	**0.313**

All calculated ULS design ratios are less then 1.
The bracket KR-1 has been designed properly and safety.

4.1.2 Weld seam calculation

Weld seam calculation is performed according to simplified method (par. 4.5.3.3 EN 1993-1-8).

Weld seam parameters are shown in the fig. 4.1.6. Weld size a_1=8 mm.

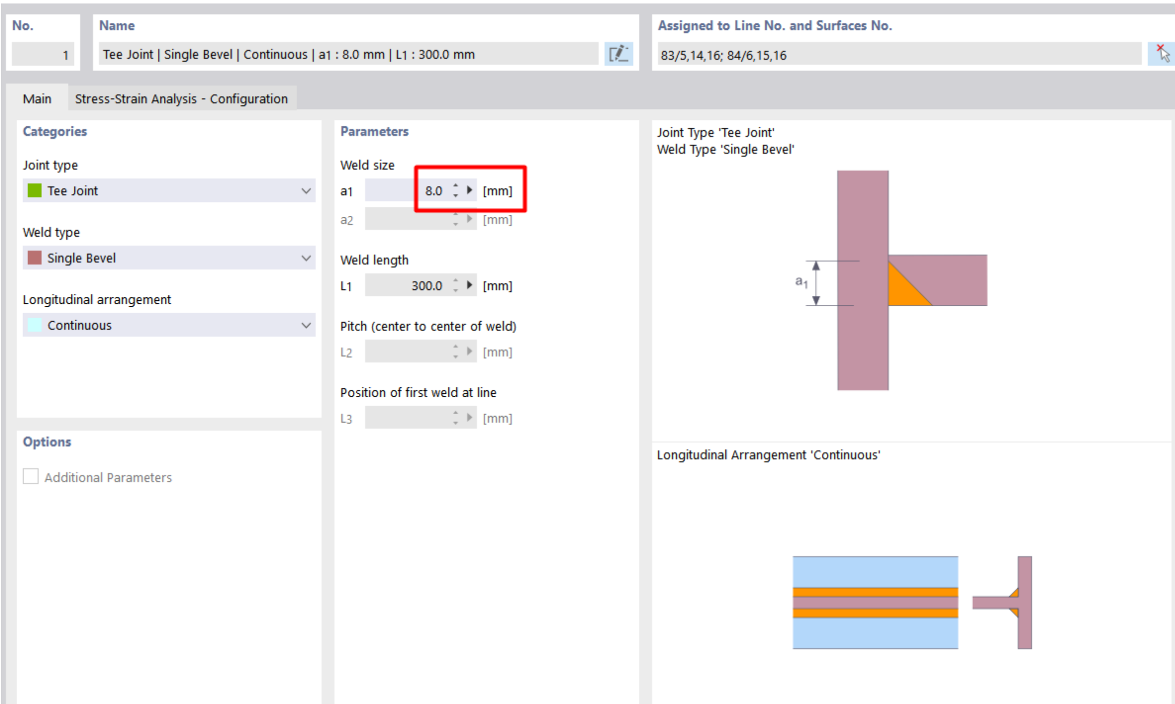


Fig. 4.1.6 Weld seam parameters (extract from RFEM 6.02)

Existing stresses in the weld seam are shown in the fig. 4.1.7.

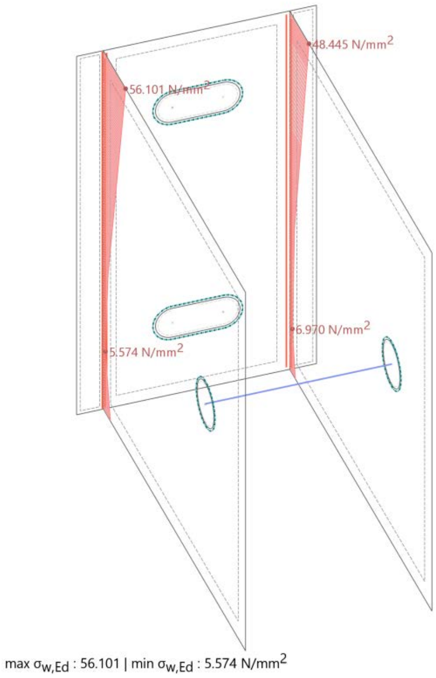


Fig. 4.1.7 Existing stresses in the weld seam (extract from RFEM 6.02)

Calculation of weld seam is performed it the table 4.1.2.

Table 4.1.2 Weld seam calculation (extract from RFEM 6.02)

Design Situation	Loading No.	Stress Type	Stress [N/mm²]		**Stress Ratio η [--]**	Note
			Existing	Limit		
DS1	CO9	f_{normal}	13.045			
DS1	CO9	$f_{bending}$	42.992			
DS1	CO9	$f_{s,shear}$	-1.123			
DS1	CO9	$f_{w,shear}$	-2.678			
DS1	CO9	$\sigma_{w,Ed}$	56.101	251.500	**0.223**	β_w=0.9 for S355 steel

4.1.3 Bolt calculation (mullion to bracket)

Bolt fixing mullion to bracket has to be calculated (see fig. 4.1.8).
Designed bolt is M16 DIN 931. Bolt class is 8.8.

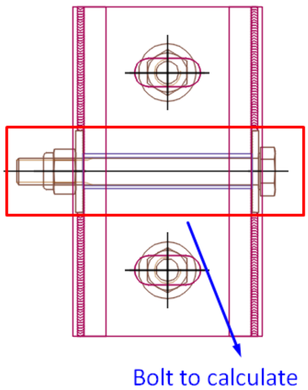


Fig. 4.1.8 Bolt to calculate for bracket KR-1

Bolt calculation according to BS EN 1993-1-8 (table 3.4) from support reaction forces (P_z=6,35 kN, P_y=9,3 kN, load combination CO6) is performed it the table 4.1.3.

Tension forces in bolt due to their negligible values are neglected.

Table 4.1.3 Bolt M12 for bracket KR-1 calculation (vertical component of support reaction)

Bolt M12 calculation bracket KR-1			
Bolt size	M12		
Bolt class	8.8		
f_{yb}	640	MPa	Yield strength
f_{ub}	800	MPa	Ultimate tensile strength
Shear resistance per shear plane calculation			
$\mathbf{F_{v,Ed}}$	**5.63**	**kN**	The design shear force per bolt for the ultimate limit state
$\mathbf{F_{v,Rd}}$	**31.87**	**kN**	The shear resistance per bolt
$\mathbf{F_{v,Ed}/F_{v,Rd}}$	**0.18**		**Criteria $F_{v,Ed} \leq F_{v,Rd}$ is performed**
α_V	0.6		Factor for bolt class 8.8
A_s	83.0	mm^2	Stress area (threaded part)
γ_{M2}	1.25		Safety factor - EN 1993-1-18
Bearing resistance calculation			
$\mathbf{F_{v,Ed}}$	**11.26**	**kN**	The design shear force per bolt for the ultimate limit state
$\mathbf{F_{b,Rd}}$	**22.53**	**kN**	The design bearing resistance per bolt
$\mathbf{F_{v,Ed}/F_{b,Rd}}$	**0.50**	**kN**	**Criteria $F_{v,Ed} \leq F_{b,Rd}$ is performed**
Material			Aluminium EN 6060 (ET,EP,ER/B) T6
f_u	170	MPa	
d	16	mm	Diametr of aluminium pipe
t	4.40	mm	Total thickness of crumpled webs (mullion)
k_1	2.50		
α_b	0.94		

4.1.4 Blind bolt calculation (bracket to steel frame)

Bolt fixing bracket to steel beam has to be calculated (see fig. 4.1.9). Designed bolt is M12 blind bolt (certificated product).

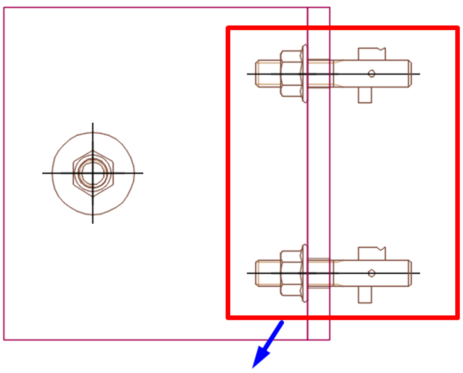


Fig. 4.1.9 Bolt to calculate

Support reactions from existing loads are shown in the fig. 4.1.10.

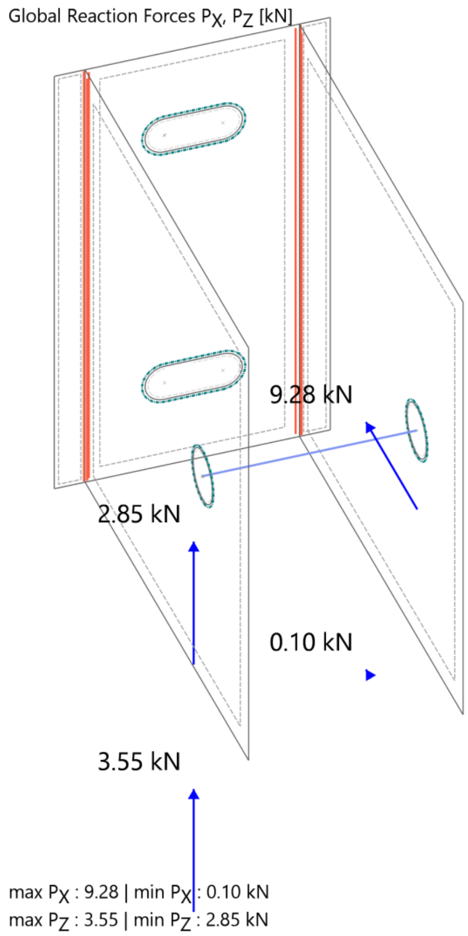


Fig. 4.1.10 Support reactions from bracket KR-1 (extract from RFEM 6.02)

Designed forces in bolt are less then bolt resistance guaranteed by manufacturer (see fig. 4.1.11).

Blind bolt M12 can be applied.

High Tensile Hot Dip Galvanised Blind Bolt - Design to BS EN 1993-1-8

Diameter	Tension Resistance $F_{t,Rd}$ (kN)	Shear Resistance Over Thread $F_{v,Rd}$ thread (kN)	Shear Resistance Over Slot $F_{v,Rd}$ slot (kN)	Bearing Resistance in 10mm Plate S275 $F_{b,Rd}$ (kN)	Bearing Resistance in 10mm Plate S355 $F_{b,Rd}$ (kN)	Recommended Tightening Torque (Nm)
M8	9.8	14.6	9.1	65.6	75.2	15
M10	14.1	23.2	19.0	82.0	94.0	24
M12	22.4	33.7	26.4	98.4	112.8	30
M14	34.8	46.7	29.0	114.8	131.6	34
M16	38.8	62.7	49.1	131.2	150.4	50
M20	71.4	97.9	76.1	164.0	188.0	65
M24	116.7	141.0	105.4	196.8	225.6	75
M30	174.5	224.0	164.6	246.0	282.0	85

Fig. 4.1.11 Bolt resistance (extract from blind bolt catalogue)

4.2 Bracket type KR-2

4.2.1 Steel calculation

Bracket KR-2 location (the most loaded bracket) is shown in the fig. 4.2.1 (see "Curtain wall structural calculation report. 23-08 Elevation B").

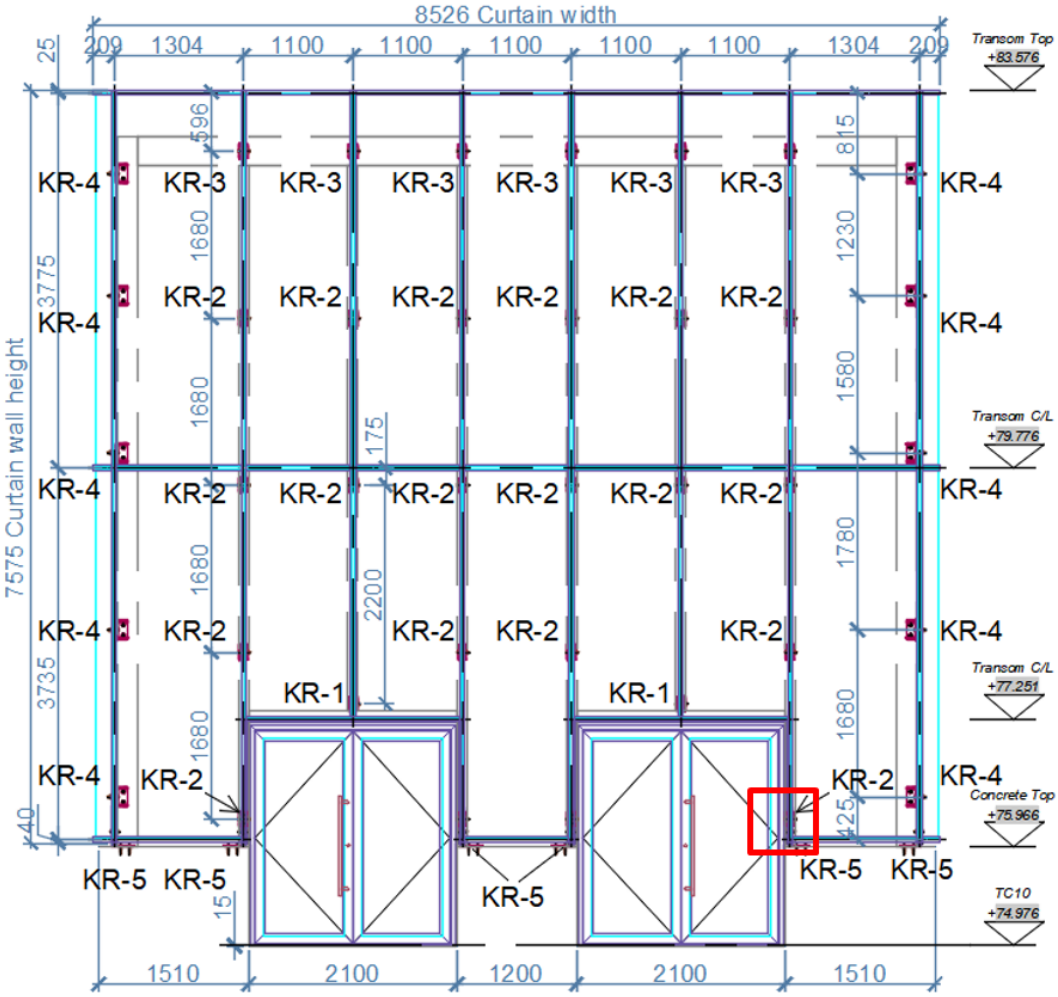


Fig. 4.2.1 Bracket KR-2 location

Bracket KR-2 scheme is shown in the fig. 4.2.2.

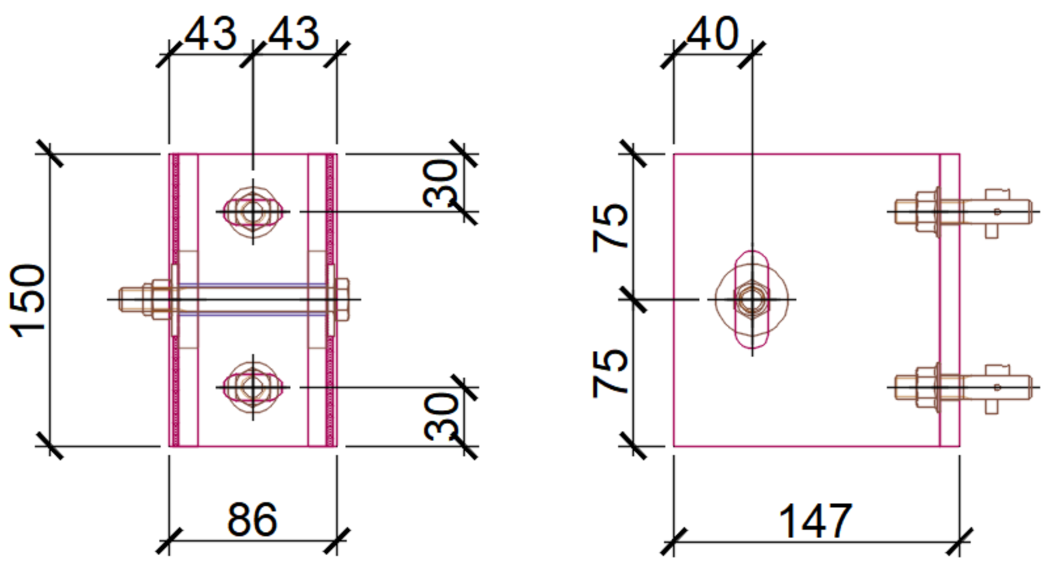


Fig. 4.2.2 Bracket KR-2 scheme

Bracket KR-2 FEA model is shown in the fig. 4.2.3.

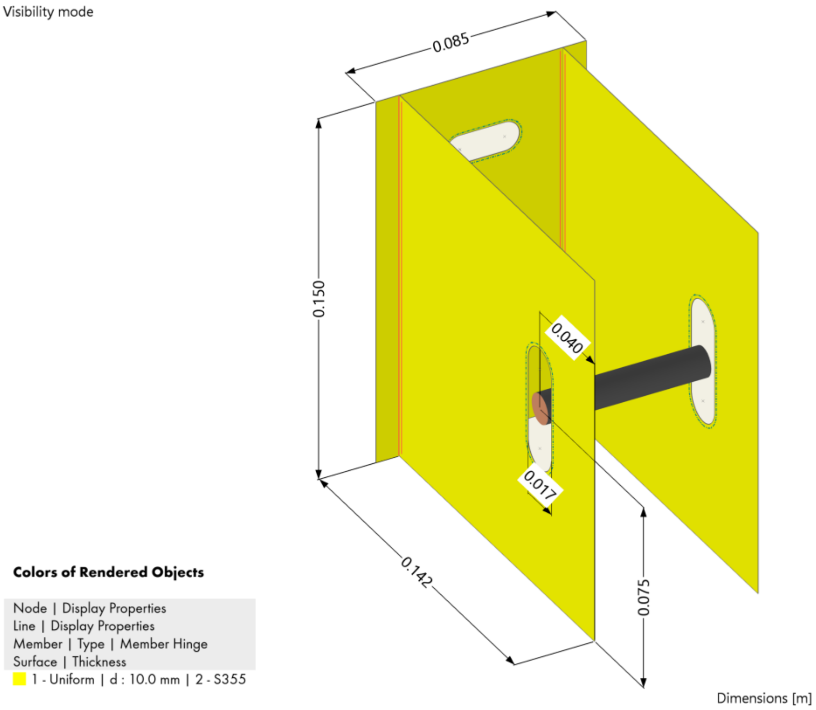


Fig. 4.2.3 Bracket KR-2 FEA model (extract from RFEM 6.02)

FEA model of bracket KR-2 with applied loads is shown in the fig. 4.2.4.

The most unfavourable load combination for bracket KR-2 is CO6 with support reaction P_y=10,75 kN and CO9 with support reaction P_y= - 8.95 kN (see fig. 3.3.2, 3.3.3 “Curtain wall structural calculation report. 23-08 Elevation B“).

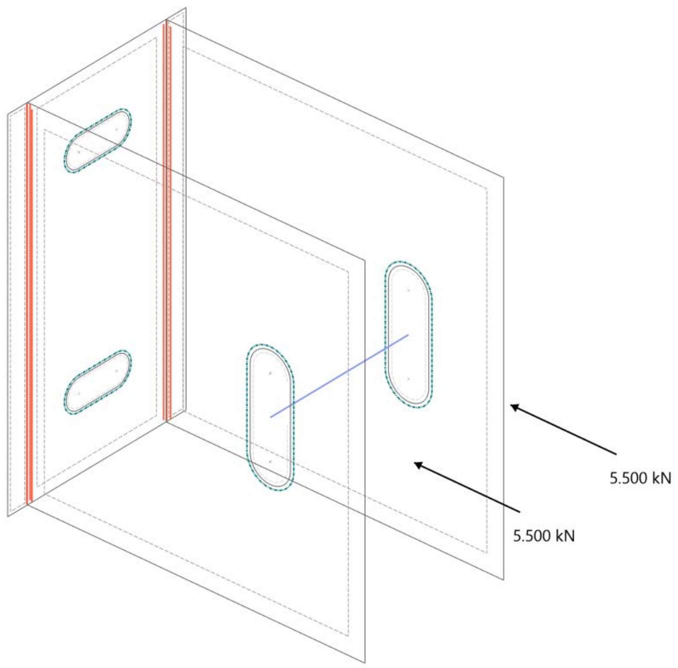


Fig. 4.2.4 Loads to bracket KR-2 - CO6 load combination (extract from RFEM 6.02)

Result of stress-strain analysis of bracket KR-2 (existing stresses) is shown in the fig. 4.2.5.

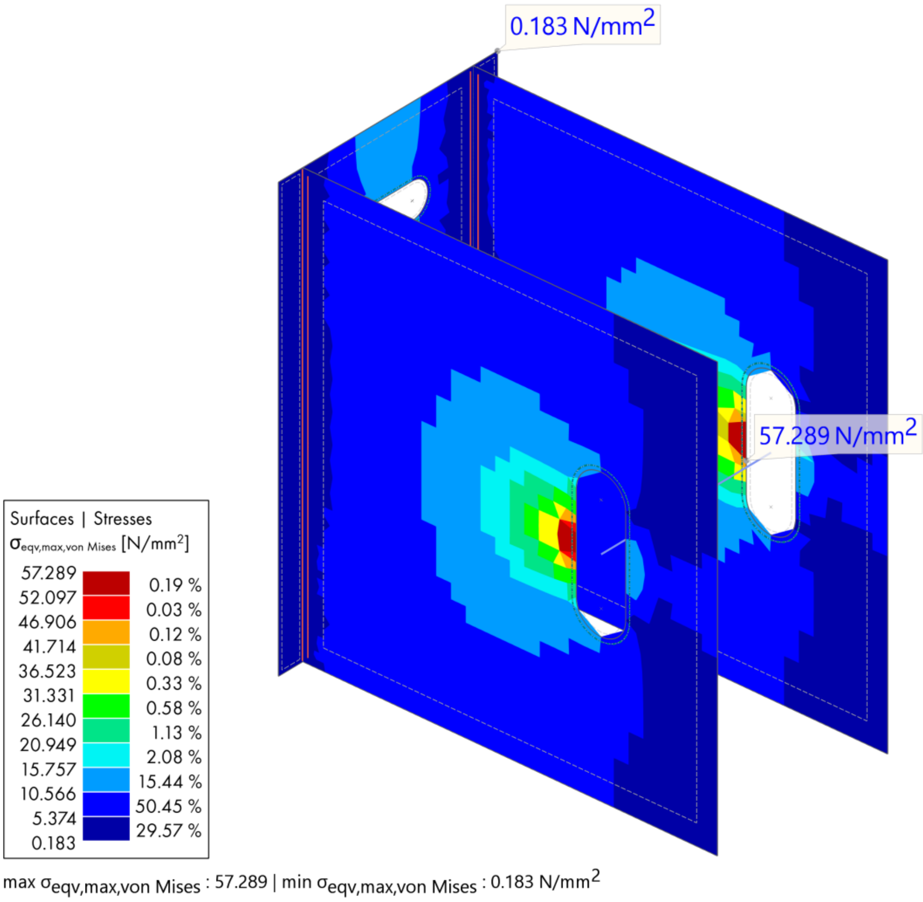


Fig. 4.2.5 Stresses in bracket KR-2 (extract from RFEM 6.02)

ULS design of bracket KR-2 is performed it the table 4.2.1.

Table 4.2.1 Bracket KR-2 calculation (extract from RFEM 6.02)

Thick. No.	Design Situation	Loading No.	Stress Type	Stress [N/mm²] Existing	Limit	Stress Ratio η [--]
1	DS1	CO6	$\sigma_{1,+}$	18.226	355.000	0.051
1	DS1	CO6	$\sigma_{2,+}$	-18.219	355.000	0.051
1	DS1	CO6	$\sigma_{1,-}$	18.343	355.000	0.052
1	DS1	CO6	$\sigma_{2,-}$	-60.873	355.000	0.171
1	DS1	CO6	$\sigma_{1,m}$	6.351	355.000	0.018
1	DS1	CO6	$\sigma_{2,m}$	-29.068	355.000	0.082
1	DS1	CO6	τ_{max}	6.459	204.959	0.032
1	DS1	CO6	$\sigma_{eqv,max,von\ Mises}$	57.289	355.000	**0.161**

All calculated ULS design ratios are less then 1.
The bracket KR-2 has been designed properly and safety.

4.2.2 Weld seam calculation

Weld seam calculation is performed according to simplified method (par. 4.5.3.3 EN 1993-1-8).

Weld seam parameters are shown in the fig. 4.1.6. Weld size a_1=8 mm.

Existing stresses in the weld seam are shown in the fig. 4.2.6.

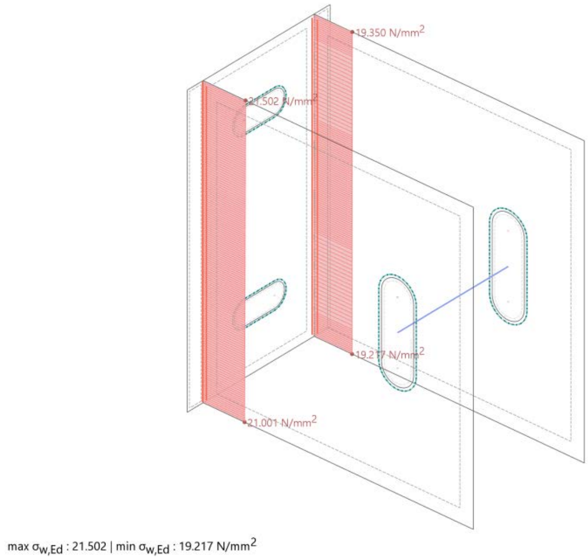


Fig. 4.2.6 Existing stresses in the weld seam (extract from RFEM 6.02)

Calculation of weld seam is performed it the table 4.2.2.

Table 4.2.2 Weld seam calculation (extract from RFEM 6.02)

Design Situation	Loading No.	Stress Type	Stress [N/mm²]		**Stress Ratio η [--]**	Note
			Existing	Limit		
DS1	CO6	f_{normal}	3.737			
DS1	CO6	$f_{bending}$	17.765			
DS1	CO6	$f_{s,shear}$	-0.159			
DS1	CO6	$f_{w,shear}$	-0.015			
DS1	CO6	$\sigma_{w,Ed}$	21.502	251.500	**0.085**	β_w=0.9 for S355 steel

4.2.3 Bolt calculation (mullion to bracket)

Bolt fixing mullion to bracket has to be calculated (see fig. 4.2.7).
Designed bolt is M12 DIN 931. Bolt class is 8.8.

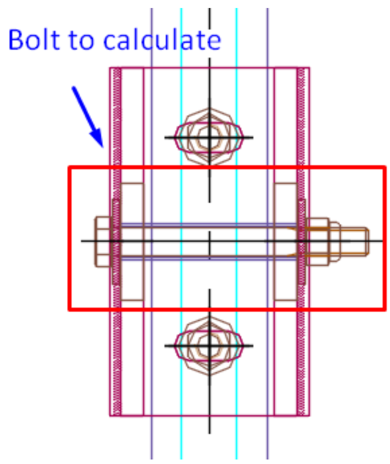


Fig. 4.2.7 Bolt to calculate for bracket KR-2

Bolt calculation according to BS EN 1993-1-8 (table 3.4) from support reaction forces (P_y=10,37 kN, load combination CO2) is performed it the table 4.2.3.

Tension forces in bolt due to their negligible values are neglected.

Table 4.2.3 Bolt M12 for bracket KR-2 calculation

Bolt M12 calculation bracket KR-2			
Bolt size	M12		
Bolt class	8.8		
f_{yb}	640	MPa	Yield strength
f_{ub}	800	MPa	Ultimate tensile strength
Shear resistance per shear plane calculation			
$F_{v,Ed}$	**5.50**	**kN**	The design shear force per bolt for the ultimate limit state
$F_{v,Rd}$	**31.87**	**kN**	The shear resistance per bolt
$F_{v,Ed}/F_{v,Rd}$	**0.17**		**Criteria $F_{v,Ed} \leq F_{v,Rd}$ is performed**
α_V	0.6		Factor for bolt class 8.8
A_s	83.0	mm^2	Stress area (threaded part)
γ_{M2}	1.25		Safety factor - BS EN 1993-1-18
Bearing resistance calculation			
$F_{v,Ed}$	**11.00**	**kN**	The design shear force per bolt for the ultimate limit state
$F_{b,Rd}$	**22.53**	**kN**	The design bearing resistance per bolt
$F_{v,Ed}/F_{b,Rd}$	**0.49**		**Criteria $F_{v,Ed} \leq F_{b,Rd}$ is performed**
Material			Aluminium EN 6060 (ET,EP,ER/B) T6
f_u	170	MPa	
d	16	mm	Diametr of aluminium pipe
t	4.40	mm	Total thickness of crumpled webs (mullion)
k_1	2.50		
α_b	0.94		

4.2.4 Blind bolt calculation (bracket to steel frame)

Bolt fixing bracket to steel beam has to be calculated (see fig. 4.2.8). Designed bolt is M12 blind bolt (certificated product).

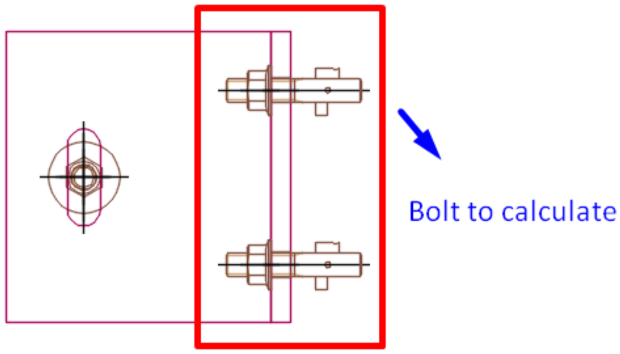


Fig. 4.2.8 Bolt to calculate

Support reactions from existing loads are shown in the fig. 4.2.9.

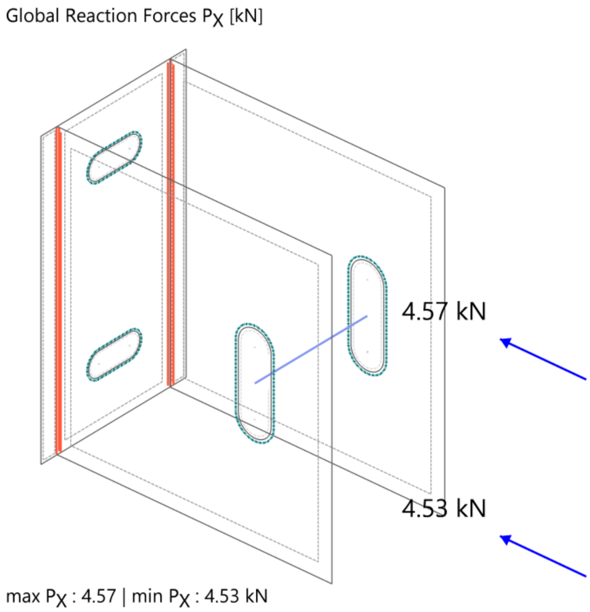


Fig. 4.2.9 Support reactions from bracket KR-2 (extract from RFEM 6.02)

Designed forces in bolt are less then bolt resistance (see fig. 4.1.11).

Blind bolt M12 can be applied.

4.3 Bracket type KR-3

4.3.1 Steel calculation

Bracket KR-3 location (the most loaded bracket) is shown in the fig. 4.3.1 (see "Curtain wall structural calculation report. 23-08 Elevation B").

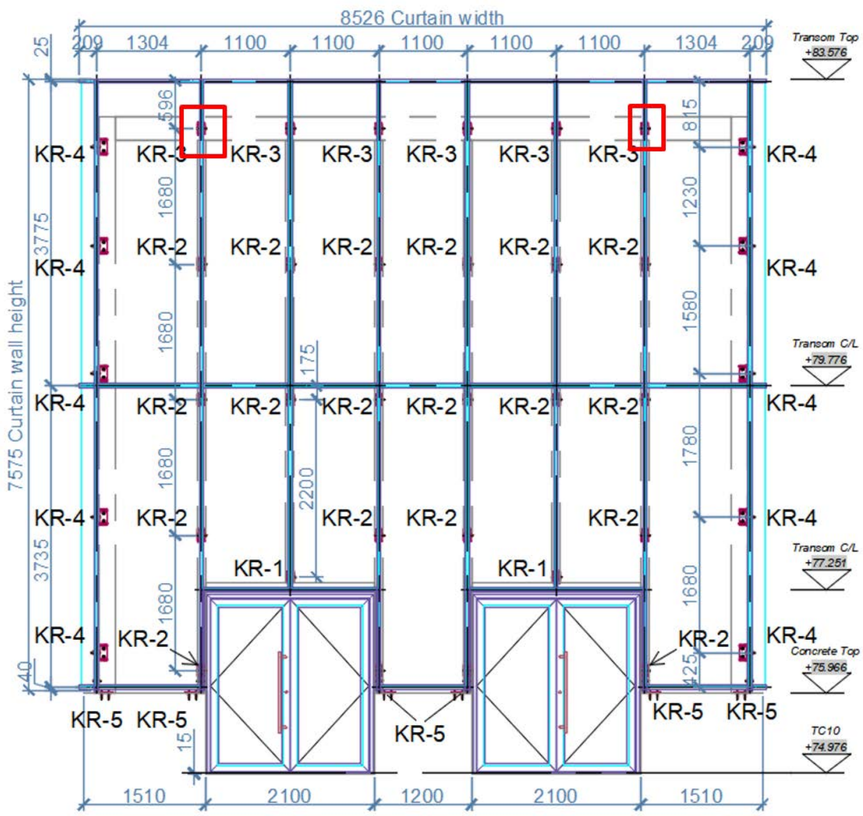


Fig. 4.3.1 Bracket KR-3 location

Bracket KR-3 scheme is shown in the fig. 4.3.2.

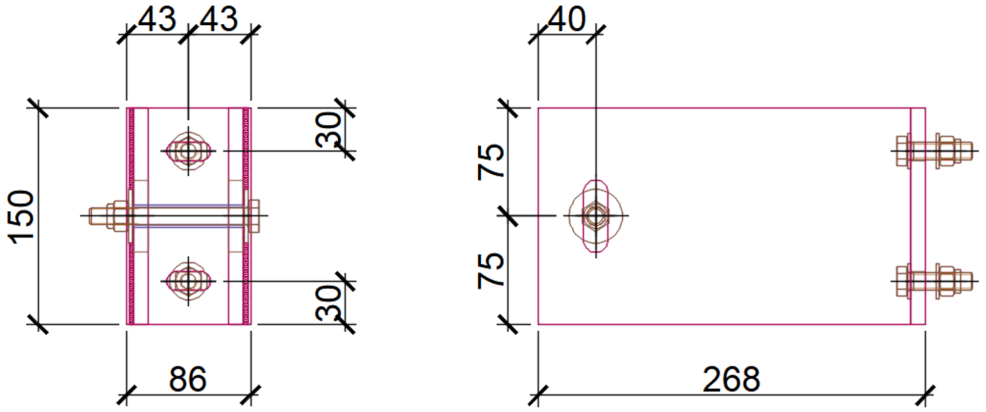


Fig. 4.3.2 Bracket KR-3 scheme

Bracket KR-3 FEA model is shown in the fig. 4.3.3.

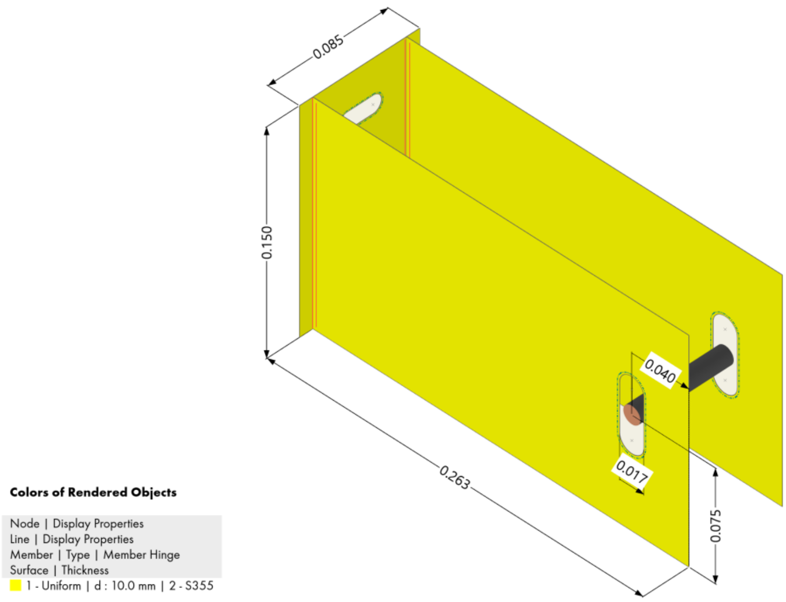


Fig. 4.3.3 Bracket KR-3 FEA model (extract from RFEM 6.02)

FEA model of bracket KR-3 with applied loads is shown in the fig. 4.3.4.

The most unfavourable load combination for bracket KR-3 is CO6 with support reaction P_y=7,55 kN and CO9 with support reaction P_y= - 4.77 kN (see fig. 3.3.2, 3.3.3 "Curtain wall structural calculation report. 23-08 Elevation B").

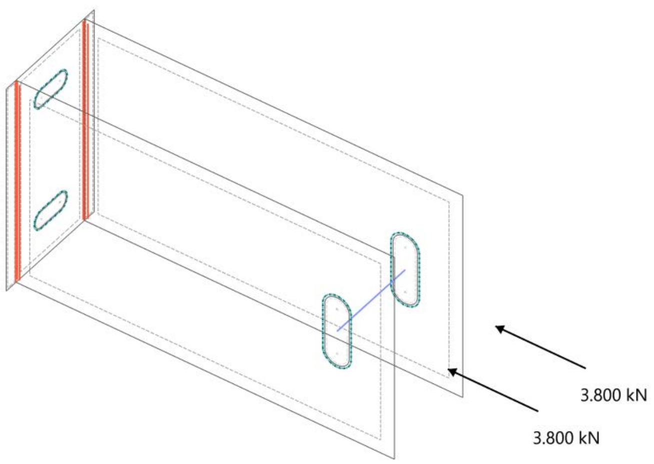


Fig. 4.3.4 Loads to bracket KR-3 - CO6 load combination (extract from RFEM 6.02)

Result of stress-strain analysis of bracket KR-3 (existing stresses) is shown in the fig. 4.3.5.

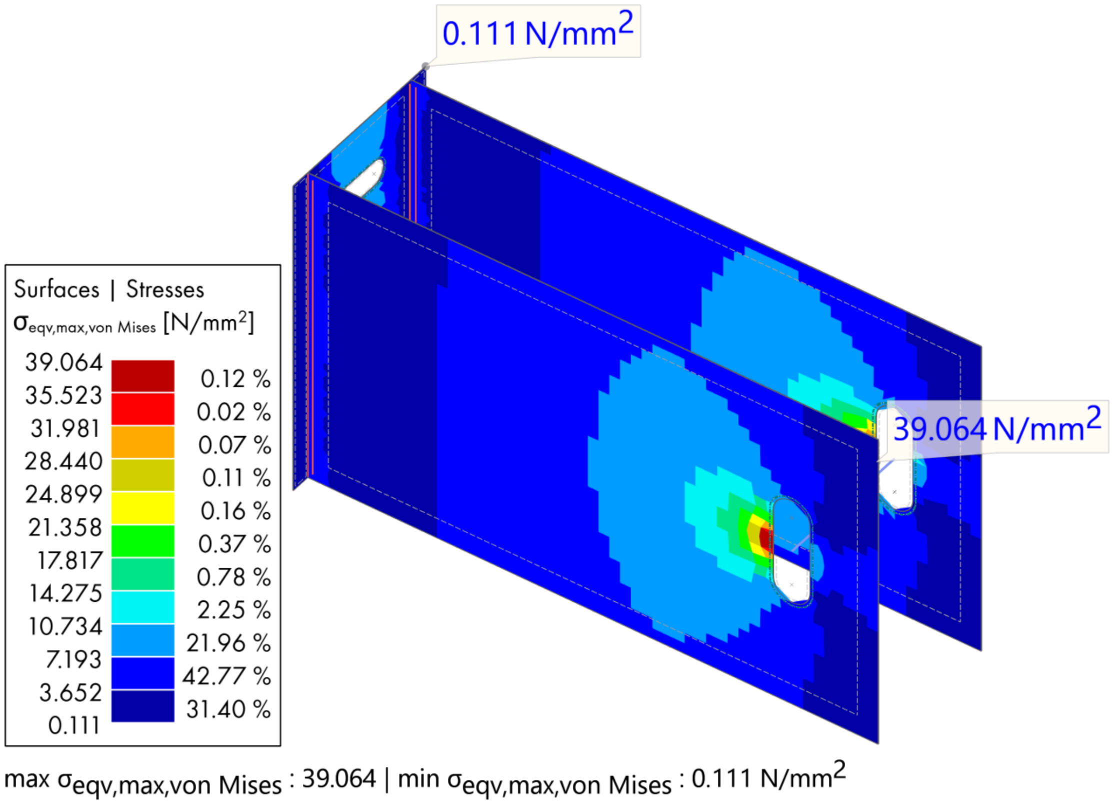


Fig. 4.3.5 Stresses in bracket KR-3 (extract from RFEM 6.02)

ULS design of bracket KR-3 is performed it the table 4.3.1.

Table 4.3.1 Bracket KR-3 calculation (extract from RFEM 6.02)

Thick. No.	Design Situation	Loading No.	Stress Type	Stress [N/mm²] Existing	Stress [N/mm²] Limit	Stress Ratio η [--]
1	DS1	CO6	$\sigma_{1,+}$	10.976	355.000	0.031
1	DS1	CO6	$\sigma_{2,+}$	-12.290	355.000	0.035
1	DS1	CO6	$\sigma_{1,-}$	12.374	355.000	0.035
1	DS1	CO6	$\sigma_{2,-}$	-40.880	355.000	0.115
1	DS1	CO6	$\sigma_{1,m}$	4.326	355.000	0.012
1	DS1	CO6	$\sigma_{2,m}$	-20.069	355.000	0.057
1	DS1	CO6	τ_{max}	4.000	204.959	0.020
1	DS1	CO6	$\sigma_{eqv,max,von\ Mises}$	39.064	355.000	**0.110**

All calculated ULS design ratios are less then 1.
The bracket KR-3 has been designed properly and safety.

4.3.2 Weld seam calculation

Weld seam calculation is performed according to simplified method (par. 4.5.3.3 EN 1993-1-8).

Weld seam parameters are shown in the fig. 4.1.6. Weld size a_1=8 mm.
Existing stresses in the weld seam are shown in the fig. 4.3.6.

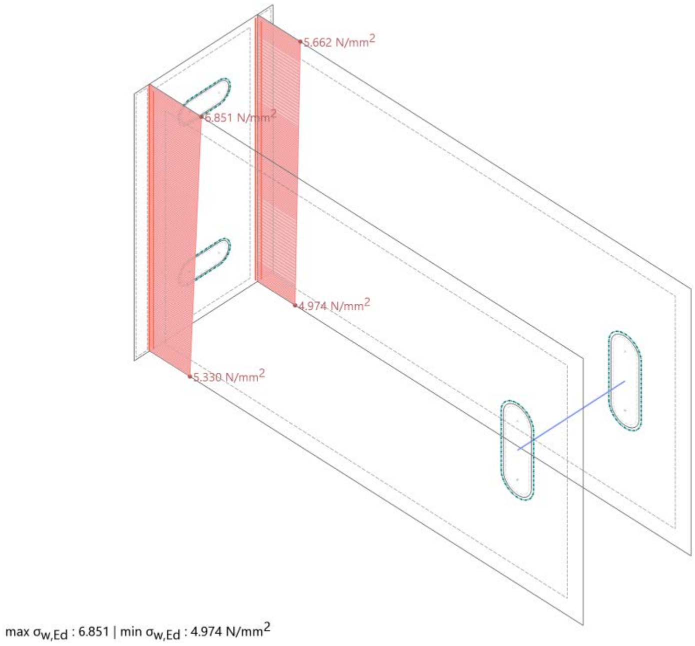


Fig. 4.3.6 Existing stresses in the weld seam (extract from RFEM 6.02)

Calculation of weld seam is performed it the table 4.3.2.

Table 4.3.2 Weld seam calculation (extract from RFEM 6.02)

Design Situation	Loading No.	Stress Type	Stress [N/mm²]		**Stress Ratio η [--]**	Note
			Existing	Limit		
DS1	CO6	f_{normal}	1.926			
DS1	CO6	$f_{bending}$	4.926			
DS1	CO6	$f_{s,shear}$	-0.096			
DS1	CO6	$f_{w,shear}$	-0.028			
DS1	CO6	$\sigma_{w,Ed}$	6.851	251.500	**0.027**	β_w=0.9 for S355 steel

4.3.4 Bolt calculation (mullion to bracket)

Bolt fixing mullion to bracket has to be calculated (see fig. 4.3.7).
Designed bolt is M12 DIN 931. Bolt class is 8.8.

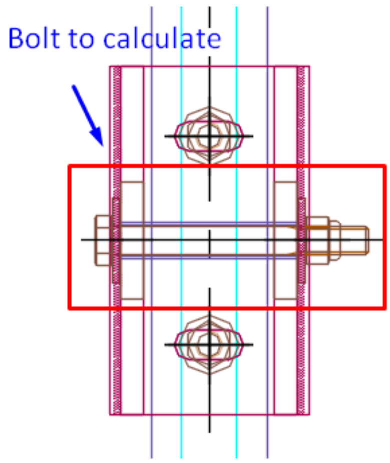


Fig. 4.3.7 Bolt to calculate for bracket KR-3

Bolt calculation according to BS EN 1993-1-8 (table 3.4) from support reaction forces (P_y=7 kN, load combination CO2) is performed it the table 4.233.

Tension forces in bolt due to their negligible values are neglected.

Table 4.3.3 Bolt M12 for bracket KR-3 calculation

Bolt M12 calculation bracket KR-3			
Bolt size	M12		
Bolt class	8.8		
f_{yb}	640	MPa	Yield strength
f_{ub}	800	MPa	Ultimate tensile strength
Shear resistance per shear plane calculation			
$F_{v,Ed}$	**3.78**	**kN**	The design shear force per bolt for the ultimate limit state
$F_{v,Rd}$	**31.87**	**kN**	The shear resistance per bolt
$F_{v,Ed}/F_{v,Rd}$	**0.12**		**Criteria $F_{v,Ed} \leq F_{v,Rd}$ is performed**
α_V	0.6		Factor for bolt class 8.8
A_s	83.0	mm^2	Stress area (threaded part)
γ_{M2}	1.25		Safety factor - BS EN 1993-1-18
Bearing resistance calculation			
$F_{v,Ed}$	**7.55**	**kN**	The design shear force per bolt for the ultimate limit state
$F_{b,Rd}$	**53.25**	**kN**	The design bearing resistance per bolt
$F_{v,Ed}/F_{b,Rd}$	**0.14**		**Criteria $F_{v,Ed} \leq F_{b,Rd}$ is performed**
Material			Aluminium EN 6060 (ET,EP,ER/B) T6
f_u	170	MPa	
d	16	mm	Diametr of aluminium pipe
t	10.40	mm	Total thickness of crumpled webs (mullion and reinforcment)
k_1	2.50		
α_b	0.94		

4.3.5 Blind bolt calculation (bracket to steel frame)

Bolt fixing bracket to steel beam has to be calculated (see fig. 4.3.8).
Designed bolt is M12 blind bolt (certificated product).

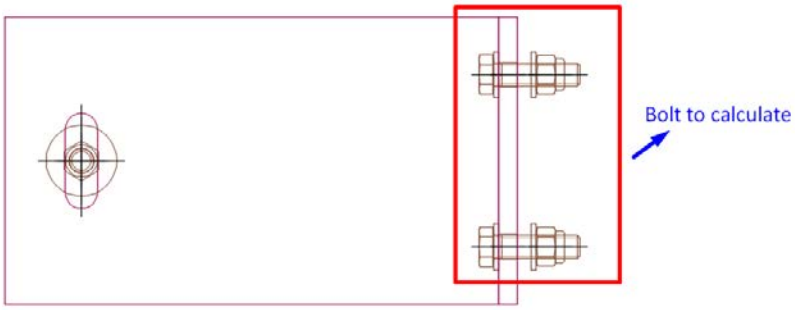


Fig. 4.3.8 Bolt to calculate

Support reactions from existing loads are shown in the fig. 4.3.9.

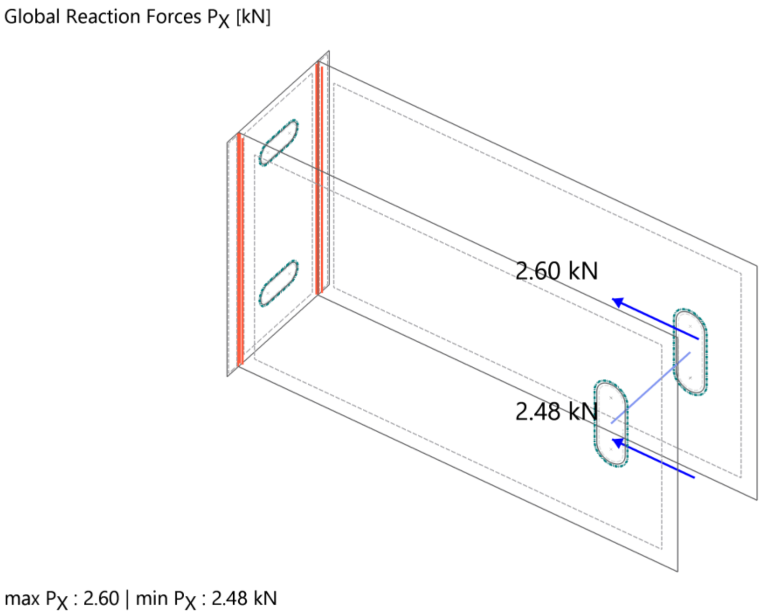


Fig. 4.3.9 Support reactions from bracket KR-3 (extract from RFEM 6.02)

Designed forces in bolt are less then bolt resistance (see fig. 4.1.11).
Blind bolt M12 can be applied.

4.4 Bracket type KR-4

4.4.1 Steel calculation

Bracket KR-4 location is shown in the fig. 4.4.1 (see "Curtain wall structural calculation report. 23-08 Elevation B").

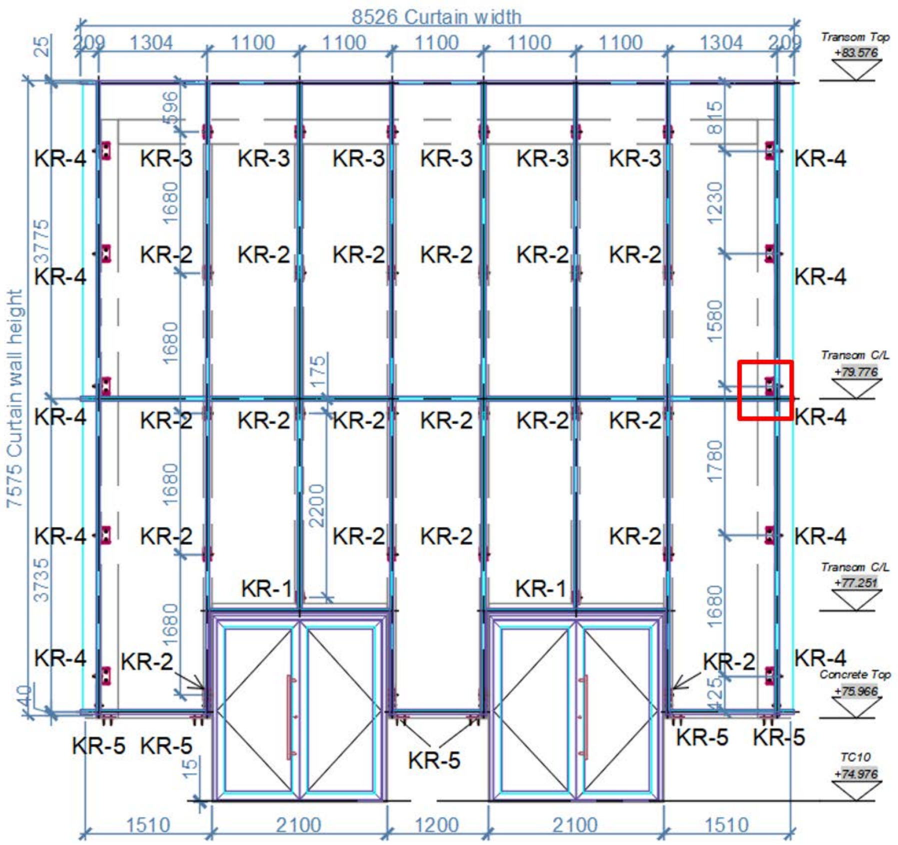


Fig. 4.4.1 Bracket KR-4 location

Bracket KR-4 scheme is shown in the fig. 4.4.2.

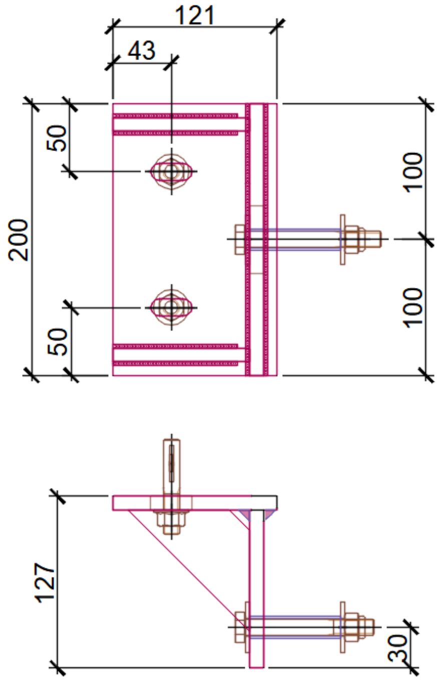


Fig. 4.4.2 Bracket KR-4 scheme

Bracket KR-4 FEA model is shown in the fig. 4.4.3.

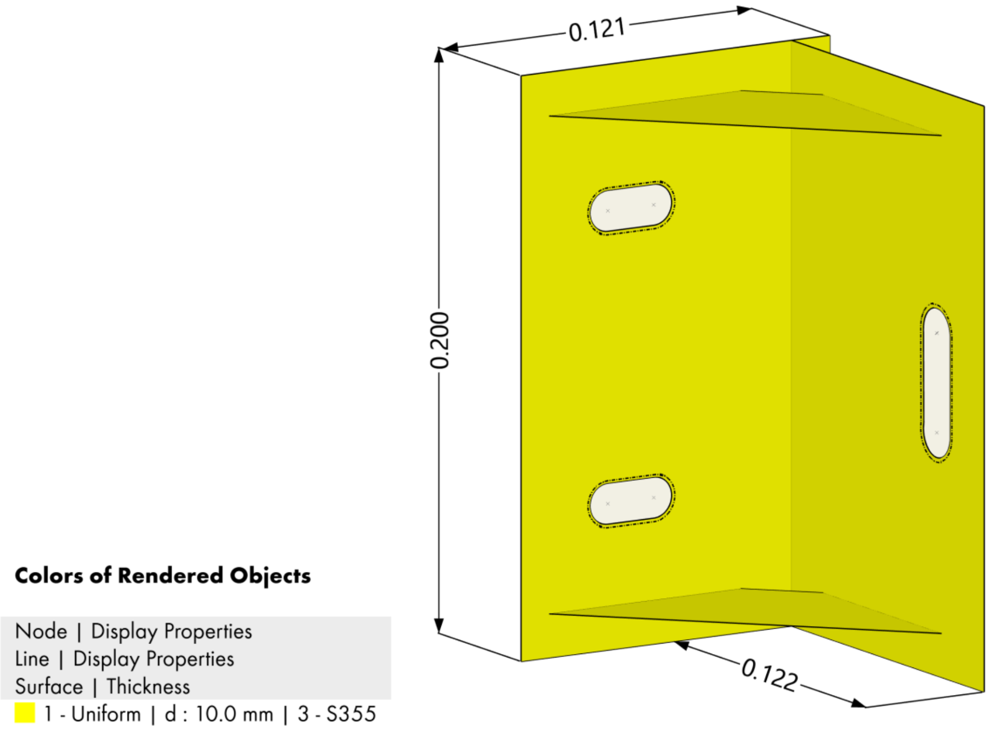


Fig. 4.4.3 Bracket KR-4 FEA model (extract from RFEM 6.02)

FEA model of bracket KR-4 with applied loads is shown in the fig. 4.4.4.

The most unfavourable load combinations for bracket KR-4 is CO6 with support reaction P_y=5,05 kN and CO9 with support reaction P_y= - 3,31 kN (see fig. 3.3.2, 3.3.3 “Curtain wall structural calculation report. 23-08 Elevation B“).

.

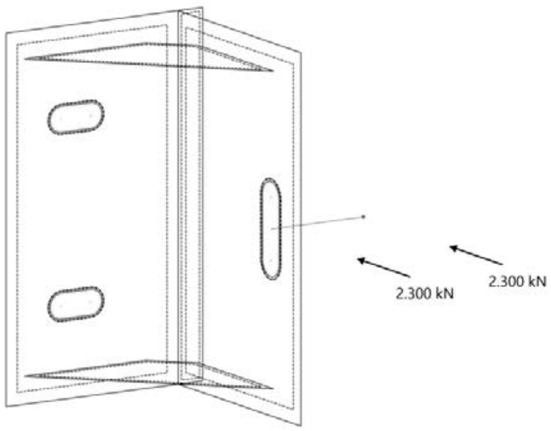


Fig. 4.4.4 Loads to bracket KR-4 - CO6 load combination (extract from RFEM 6.02)

Result of stress-strain analysis of bracket KR-4 (existing stresses) is shown in the fig. 4.4.5.

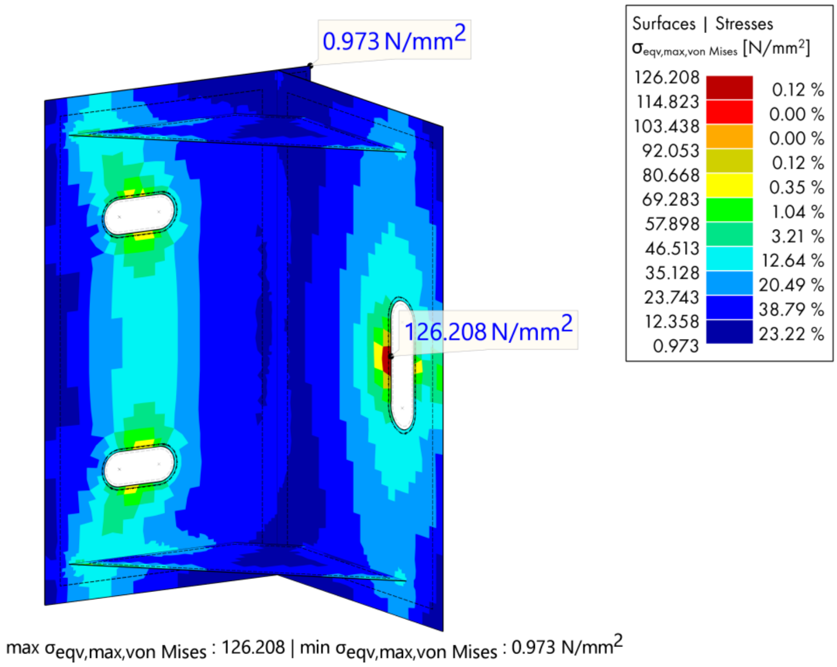


Fig. 4.4.5 Stresses in bracket KR-4 (extract from RFEM 6.02)

ULS design of bracket KR-4 is performed it the table 4.4.1.

Table 4.4.1 Bracket KR-4 calculation (extract from RFEM 6.02)

Thick. No.	Design Situation	Loading No.	Stress Type	Stress [N/mm²] Existing	Stress [N/mm²] Limit	Stress Ratio η [--]
1	DS1	CO6	$\sigma_{1,+}$	97.744	355.000	0.275
1	DS1	CO6	$\sigma_{2,+}$	-85.783	355.000	0.242
1	DS1	CO6	$\sigma_{1,-}$	85.968	355.000	0.242
1	DS1	CO6	$\sigma_{2,-}$	-149.893	355.000	0.422
1	DS1	CO6	$\sigma_{1,m}$	38.934	355.000	0.110
1	DS1	CO6	$\sigma_{2,m}$	-66.325	355.000	0.187
1	DS1	CO6	τ_{max}	24.660	204.959	0.120
1	DS1	CO6	$\sigma_{eqv,max,von\ Mises}$	137.736	355.000	**0.388**

All calculated ULS design ratios are less then 1.
The bracket KR-4 has been designed properly and safety.

4.4.2 Weld seam calculation

Weld seam calculation is performed according to simplified method (par. 4.5.3.3 EN 1993-1-8).

Weld seam parameters are shown in the fig. 4.4.6. Weld size a_1=6 mm.
Existing stresses in the weld seam are shown in the fig. 4.4.7.

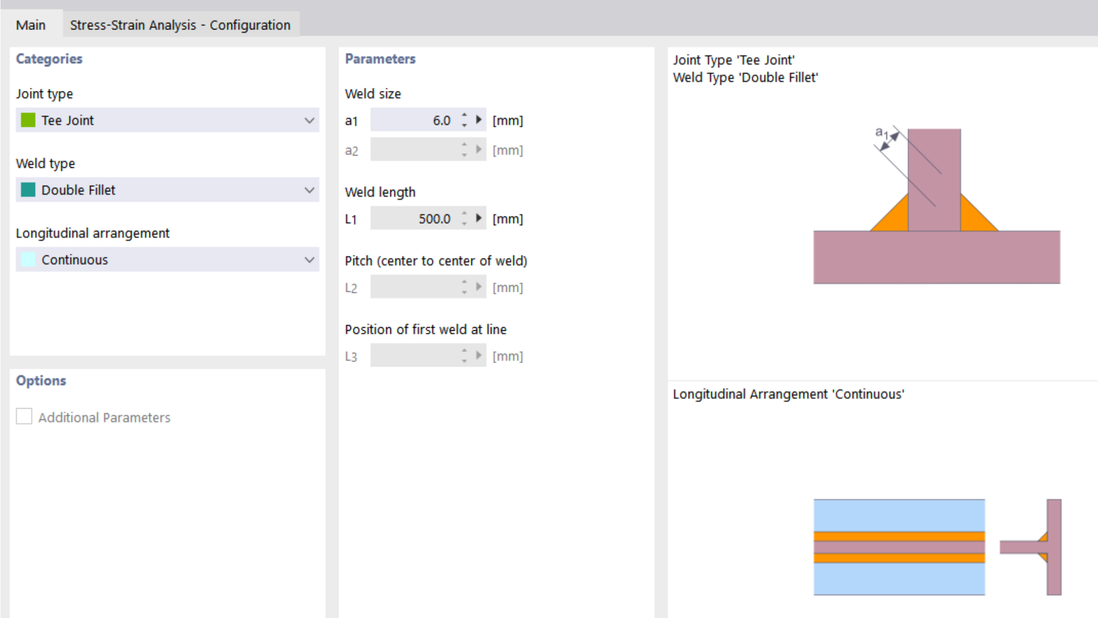


Fig. 4.4.6 Weld seam parameters (extract from RFEM 6.02)

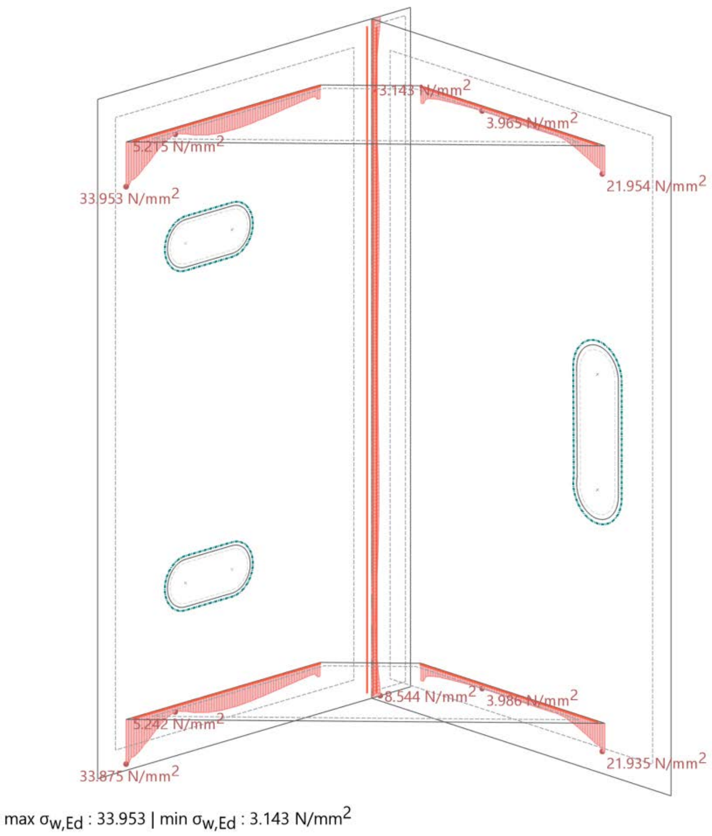


Fig. 4.4.7 Existing stresses in the weld seam (extract from RFEM 6.02)

Calculation of weld seam is performed it the table 4.4.2.

Table 4.4.2 Weld seam calculation (extract from RFEM 6.02)

Design Situation	Loading No.	Stress Type	Stress [N/mm²] Existing	Limit	**Stress Ratio η [--]**	Note
DS1	CO6	f_{normal}	-23.320			
DS1	CO9	$f_{bending}$	7.191			
DS1	CO9	$f_{s,shear}$	3.182			
DS1	CO9	$f_{w,shear}$	24.139			
DS1	CO9	$\sigma_{w,Ed}$	33.953	251.500	**0.135**	β_w=0.9 for S355 steel

4.4.3 Bolt calculation (mullion to bracket)

Bolt fixing mullion to bracket has to be calculated (see fig. 4.4.8).
Designed bolt is M12 DIN 931. Bolt class is 8.8.

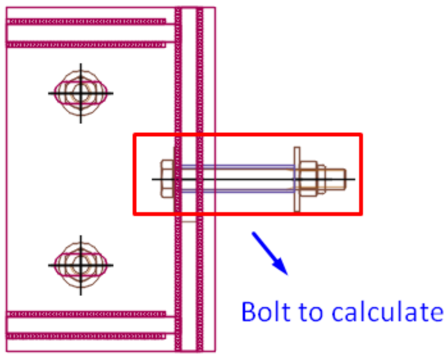


Fig. 4.4.8 Bolt to calculate

Calculation of the bolt according to the EN 1993-1-8 (table 3.4) is performed it the table 4.4.3.

Table 4.4.3 Bolt M12 for bracket KR-4 calculation

Bolt M12 calculation bracket KR-4			
Bolt size	M12		
Bolt class	8.8		
f_{yb}	640	MPa	Yield strength
f_{ub}	800	MPa	Ultimate tensile strength
Shear resistance per shear plane calculation			
$F_{v,Ed}$	**5.05**	**kN**	The design shear force per bolt for the ultimate limit state
$F_{v,Rd}$	**31.87**	**kN**	The shear resistance per bolt
$F_{v,Ed}/F_{v,Rd}$	**0.16**		**Criteria $F_{v,Ed} \leq F_{v,Rd}$ is performed**
α_V	0.6		Factor for bolt class 8.8
A_s	83.0	mm²	Stress area (threaded part)
γ_{M2}	1.25		Safety factor - EN 1993-1-18

Bearing resistance calculation			
$F_{v,Ed}$	**5.05**	**kN**	The design shear force per bolt for the ultimate limit state
$F_{b,Rd}$	**22.53**	**kN**	The design bearing resistance per bolt
$F_{v,Ed}/F_{b,Rd}$	**0.22**		**Criteria $F_{v,Ed} \leq F_{b,Rd}$ is performed**
Material			Aluminium EN 6060 (ET,EP,ER/B) T6
f_u	170	MPa	
d	16	mm	Diametr of aluminium pipe
t	4.40	mm	Total thickness of crumpled webs (mullion)
k_1	2.50		
α_b	0.94		

4.4.4 Blind bolt calculation (bracket to steel frame)

Bolt fixing bracket to steel beam has to be calculated (see fig. 4.4.9). Designed bolt is M12 blind bolt (certificated product).

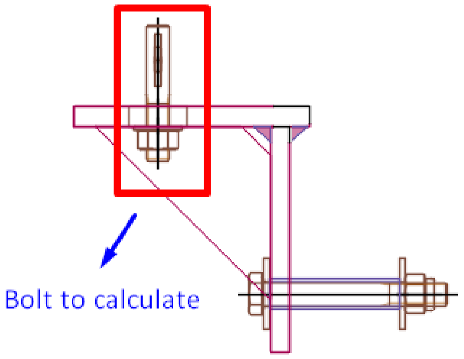


Fig. 4.4.9 Bolt to calculate

Support reactions from existing loads are shown in the fig. 4.4.10.

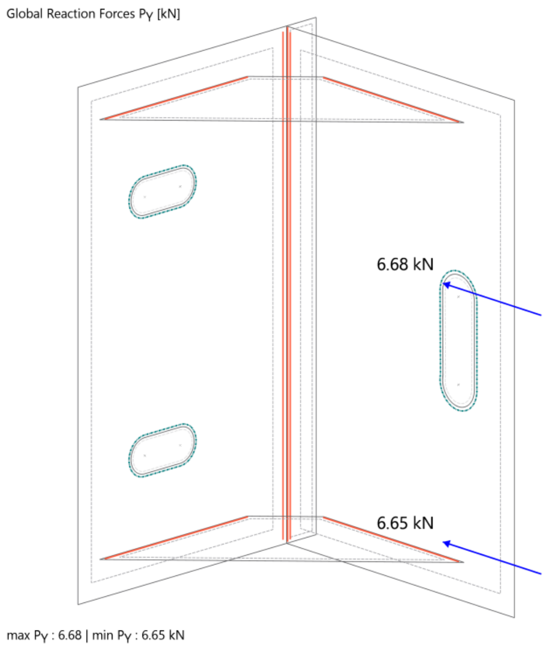


Fig. 4.4.10 Support reactions from bracket KR-4 (extract from RFEM 6.02)

Designed forces in bolt are less then bolt resistance (see fig. 4.1.11).

Blind bolt M12 can be applied.

4.5 Bracket type KR-5

Bracket KR-5 location (the most loaded bracket) is shown in the fig. 4.5.1 (see “Curtain wall structural calculation report. 23-08 Elevation B“).

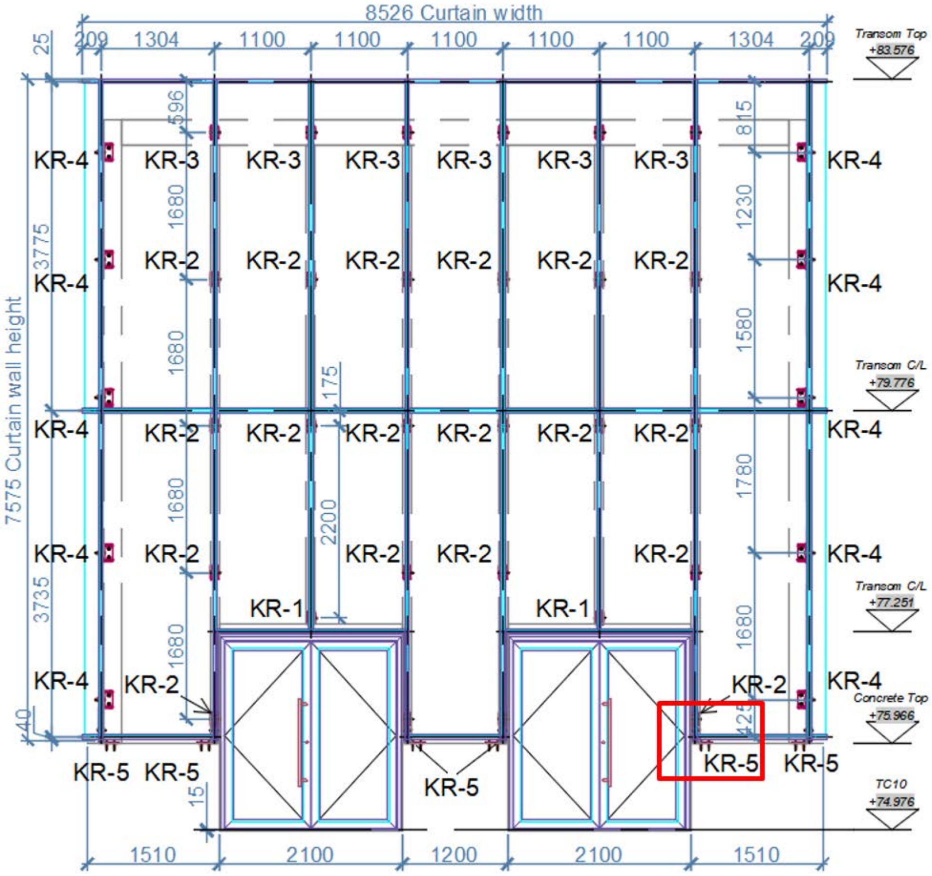


Fig. 4.5.1 Bracket KR-5 location

Bracket KR-5 scheme is shown in the fig. 4.5.2.

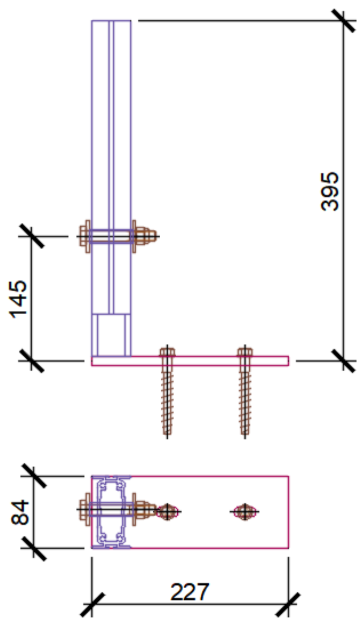


Fig. 4.5.2 Bracket KR-5 scheme

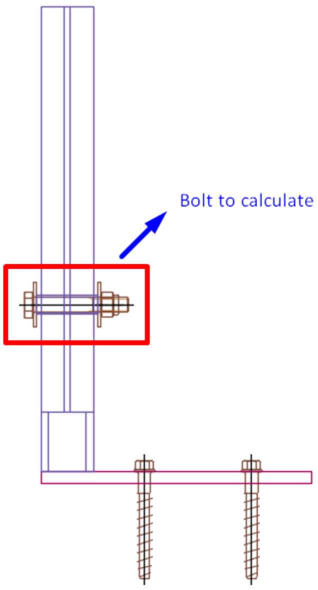


Fig. 4.5.3 Bolt to calculate

Bracket KR-5 FEA model with applied loads is shown in the fig. 4.5.4.

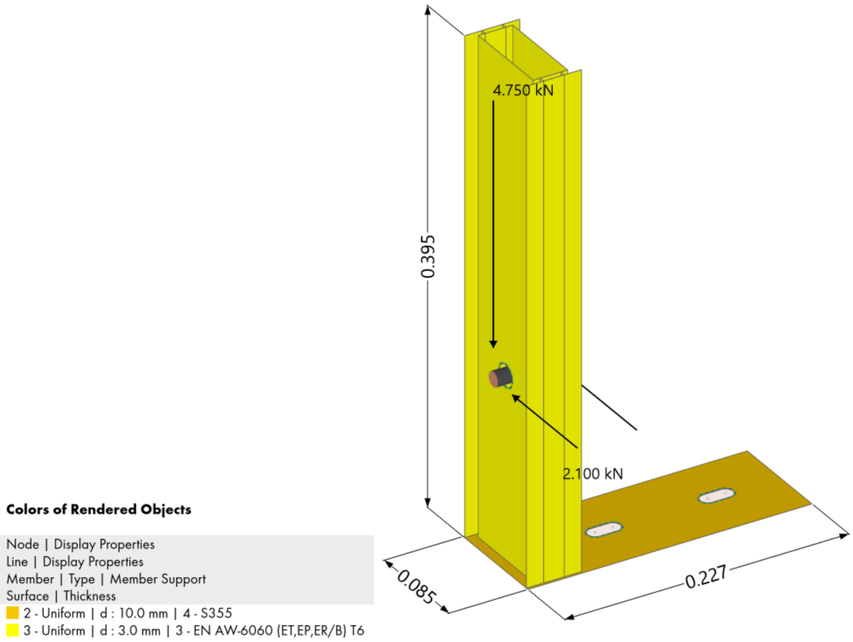


Fig. 4.5.4 Bracket KR-5 FEA model (extract from RFEM 6.02)

Result of stress-strain analysis of bracket KR-5 (existing stresses) is shown in the fig. 4.5.5.

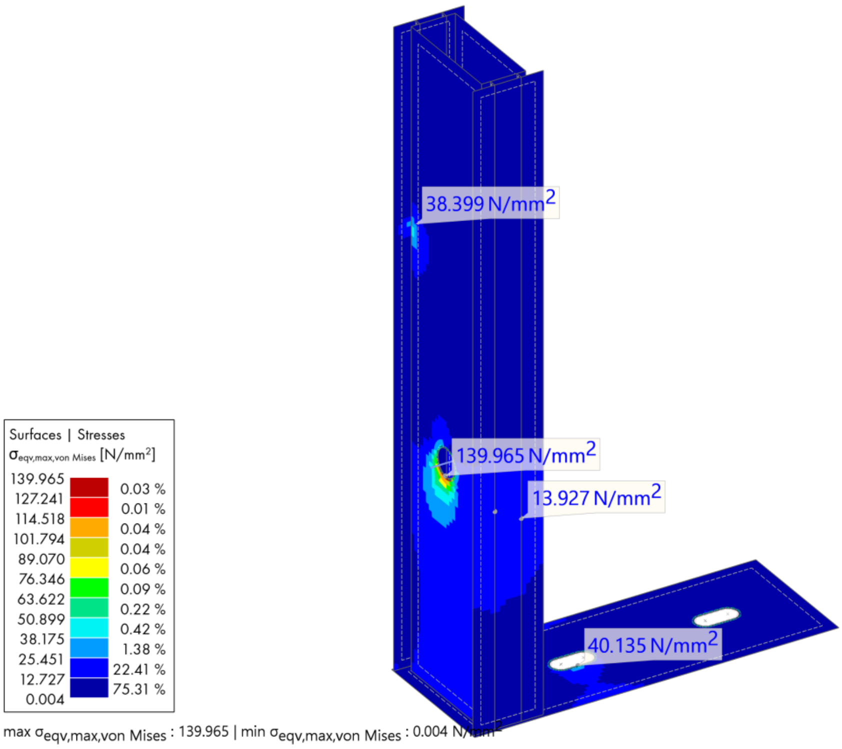


Fig. 4.5.5 Stresses in bracket KR-5 (extract from RFEM 6.02)

Bolt fixing mullion to bracket has to be calculated (see fig. 4.5.3).

Designed bolt is M12 DIN 931. Bolt class is 8.8.

Bolt calculation according to BS EN 1993-1-8 (table 3.4) from support reaction forces (P_z=9,37 kN, P_y=4,08 kN load combination CO8, see fig. 3.3.2, 3.3.3 “Curtain wall structural calculation report. 23-08 Elevation B“) is performed it the table 4.5.1.

Tension forces in bolt due to their negligible values are neglected.

Table 4.5.1 Bolt M12 for bracket KR-5 calculation

	Bolt M12 calculation bracket KR-5		
Bolt size	M12		
Bolt class	8.8		
f_{yb}	640	MPa	Yield strength
f_{ub}	800	MPa	Ultimate tensile strength
	Shear resistance per shear plane calculation		
$F_{v,Ed}$	**10.22**	**kN**	The design shear force per bolt for the ultimate limit state
$F_{v,Rd}$	**31.87**	**kN**	The shear resistance per bolt
$F_{v,Ed}/F_{v,Rd}$	**0.32**		**Criteria $F_{v,Ed} \leq F_{v,Rd}$ is performed**
α_V	0.6		Factor for bolt class 8.8
A_s	83.0	mm^2	Stress area (threaded part)
γ_{M2}	1.25		Safety factor - EN 1993-1-18
	Bearing resistance calculation		
$F_{v,Ed}$	**8.73**	**kN**	The design shear force per bolt for the ultimate limit state
$F_{b,Rd}$	**20.48**	**kN**	The design bearing resistance per bolt
$F_{v,Ed}/F_{b,Rd}$	**0.43**		**Criteria $F_{v,Ed} \leq F_{b,Rd}$ is performed**
Material			Aluminium EN 6060 (ET,EP,ER/B) T6
f_u	170	MPa	
d	16	mm	Diameter of aluminium pipe
t	4.00	mm	Total thickness of crumpled webs
k_1	2.50		
α_b	0.94		

4.6 Bracket type KR-6

Bracket KR-6 location (the most loaded bracket) see the fig. 4.1.
Bracket KR-6 scheme is shown in the fig. 4.6.1.

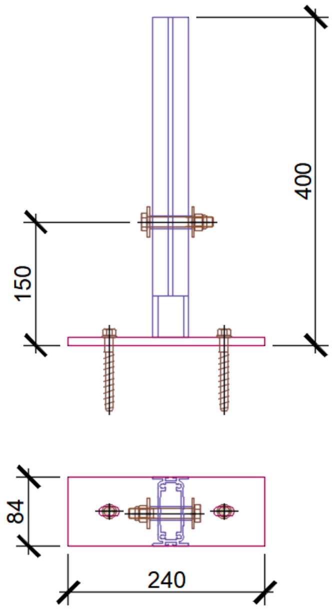


Fig. 4.6.1 Bracket KR-5 scheme

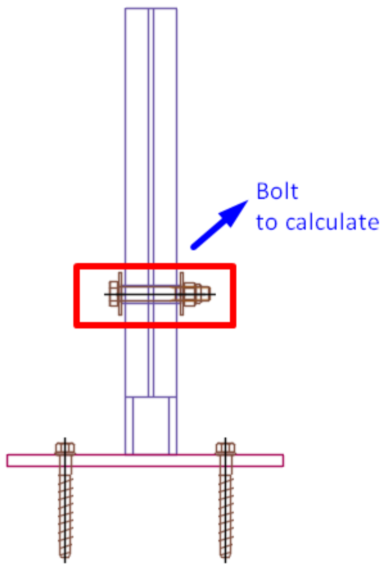


Fig. 4.6.2 Bolt to calculate

Bracket KR-6 FEA model with applied loads is shown in the fig. 4.6.3.

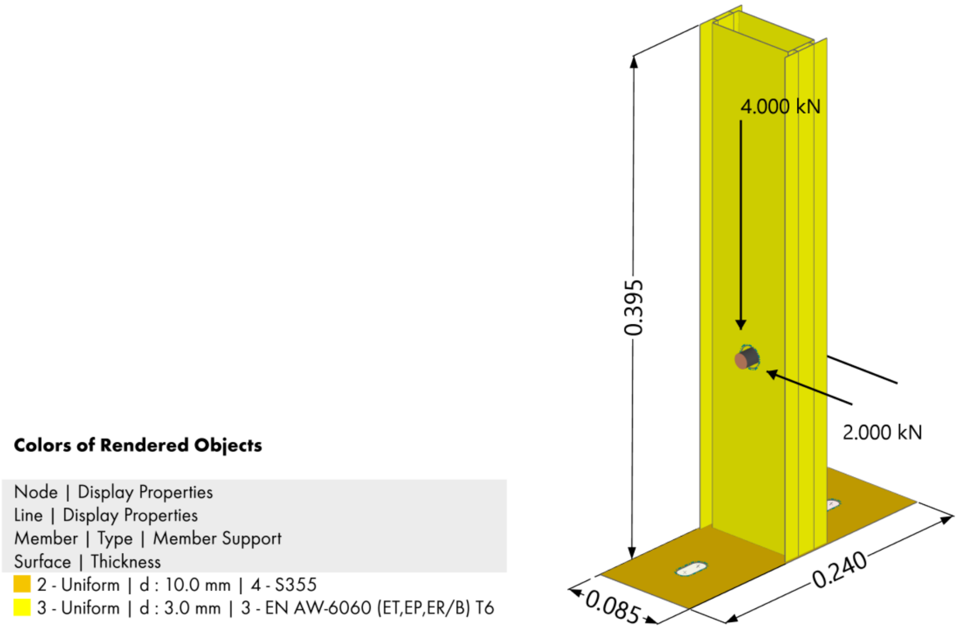


Fig. 4.6.3 Bracket KR-6 FEA model (extract from RFEM 6.02)

Result of stress-strain analysis of bracket KR-5 (existing stresses) is shown in the fig. 4.5.5.

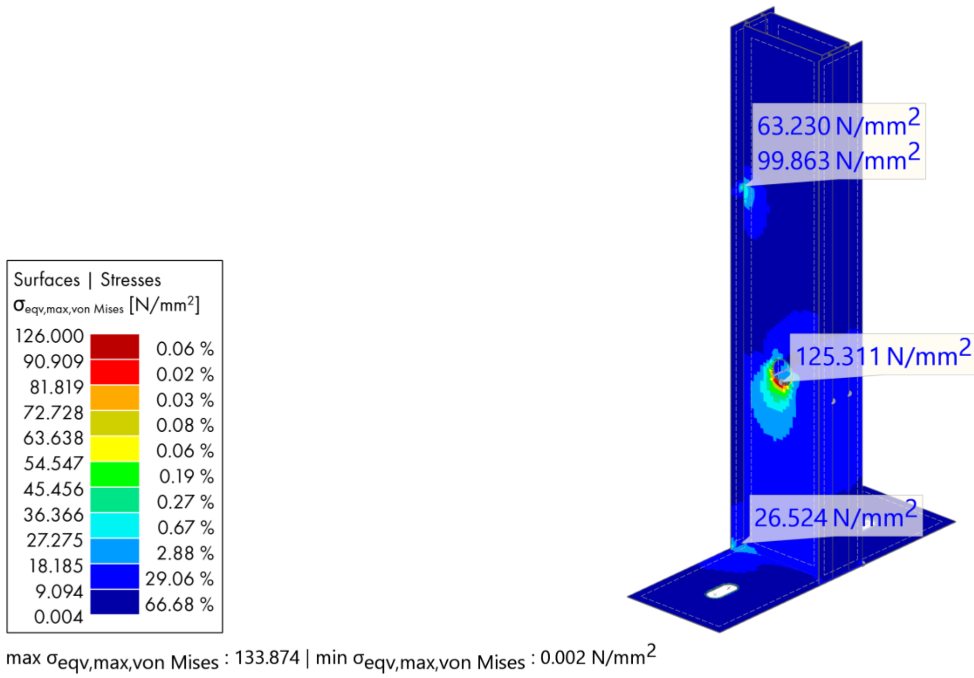


Fig. 4.5.5 Stresses in bracket KR-5 (extract from RFEM 6.02)

Bolt fixing mullion to bracket has to be calculated (see fig. 4.6.2).

Designed bolt is M12 DIN 931. Bolt class is 8.8.

Bolt calculation according to BS EN 1993-1-8 (table 3.4) from support reaction forces (P_z=7,89 kN, P_y=3,92 kN load combination CO8) is performed it the table 4.6.1.

Tension forces in bolt due to their negligible values are neglected.

Table 4.6.1 Bolt M12 for bracket KR-6 calculation

Bolt M12 calculation bracket KR-6			
Bolt size	M12		
Bolt class	8.8		
f_{yb}	640	MPa	Yield strength
f_{ub}	800	MPa	Ultimate tensile strength
Shear resistance per shear plane calculation			
$F_{v,Ed}$	**8.82**	**kN**	The design shear force per bolt for the ultimate limit state
$F_{v,Rd}$	**31.87**	**kN**	The shear resistance per bolt
$F_{v,Ed}/F_{v,Rd}$	**0.28**		**Criteria $F_{v,Ed} \leq F_{v,Rd}$ is performed**
α_V	0.6		Factor for bolt class 8.8
A_s	83.0	mm^2	Stress area (threaded part)
γ_{M2}	1.25		Safety factor - EN 1993-1-18
Bearing resistance calculation			
$F_{v,Ed}$	**8.82**	**kN**	The design shear force per bolt for the ultimate limit state
$F_{b,Rd}$	**20.48**	**kN**	The design bearing resistance per bolt
$F_{v,Ed}/F_{b,Rd}$	**0.43**		**Criteria $F_{v,Ed} \leq F_{b,Rd}$ is performed**
Material			Aluminium EN 6060 (ET,EP,ER/B) T6
f_u	170	MPa	
d	16	mm	Diameter of bolt
t	4.00	mm	Total thickness of crumpled plates
k_1	2.50		
α_b	0.94		

4.7 Bracket type KR-7

4.7.1 Steel calculation

Bracket KR-7 location (the most loaded bracket) is shown in the fig. 4.7.1.

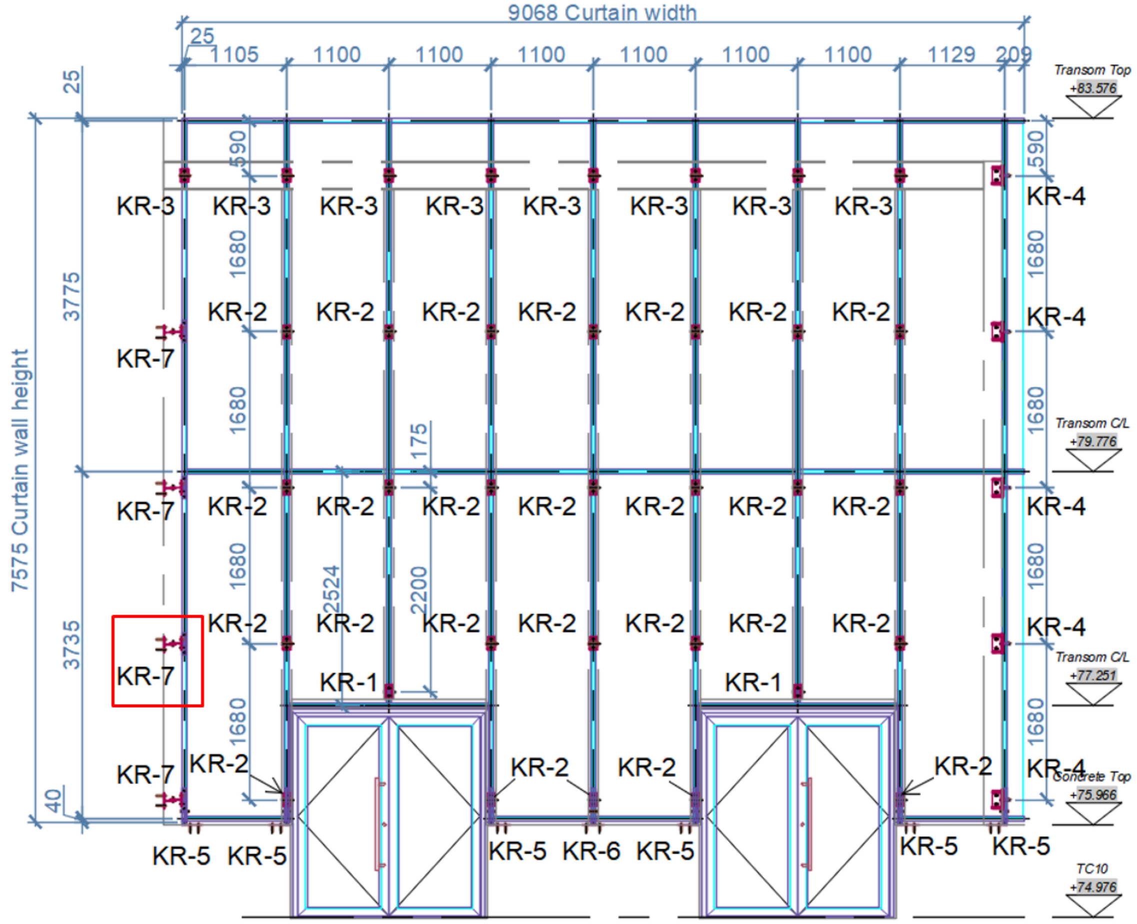


Fig. 4.7.1 Bracket KR-7 location

Bracket KR-7 scheme is shown in the fig. 4.7.2.

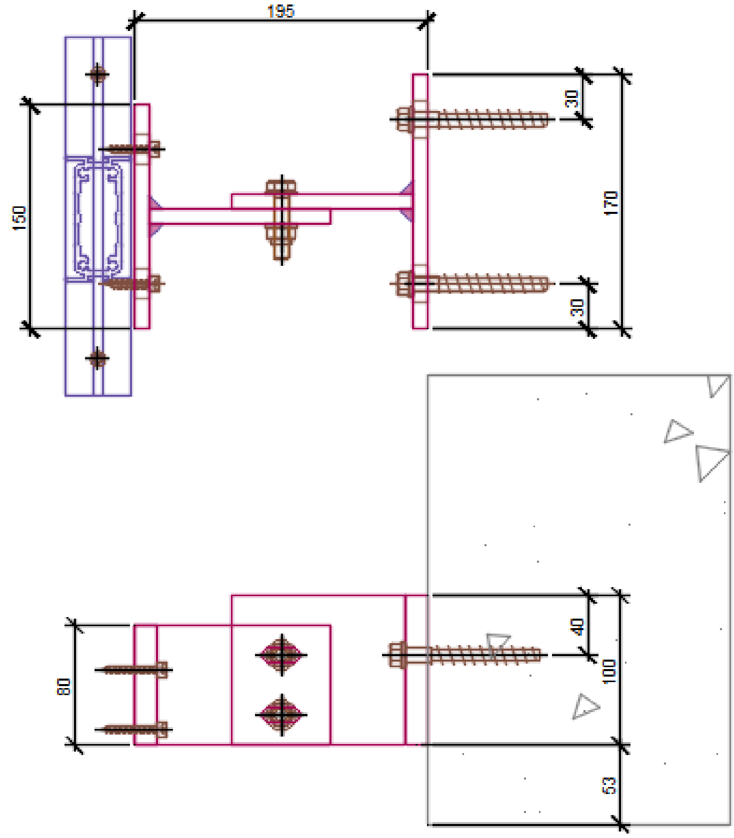


Fig. 4.7.2 Bracket KR-7 scheme

Bracket KR-6 FEA model is shown in the fig. 4.7.3.

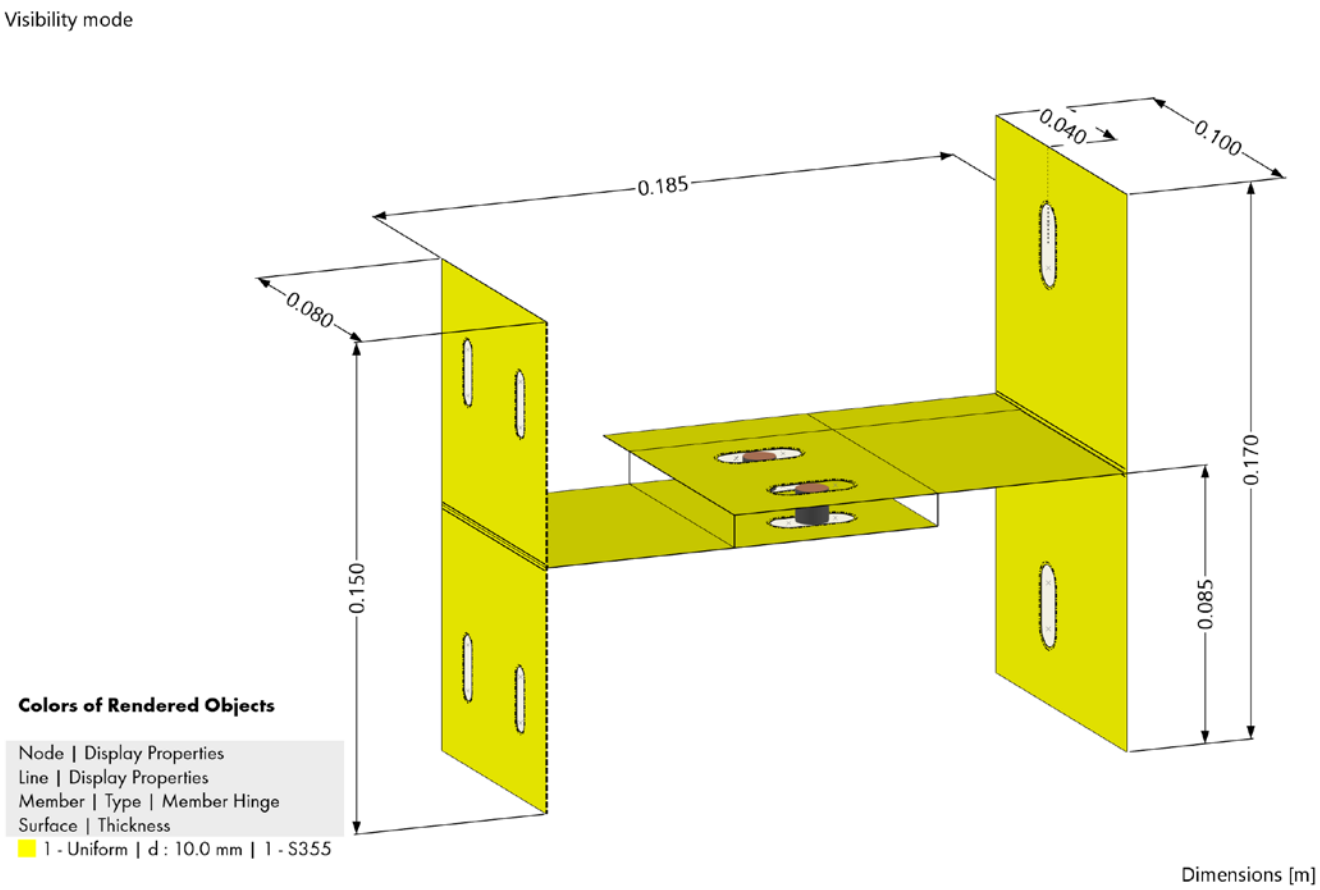


Fig. 4.7.3 Bracket KR-7 FEA model (extract from RFEM 6.02)

FEA model of bracket KR-7 with applied loads is shown in the fig. 4.7.4.

The most unfavourable load combinations for bracket KR-7 are CO2 with support reactions P_y=4,34 kN.

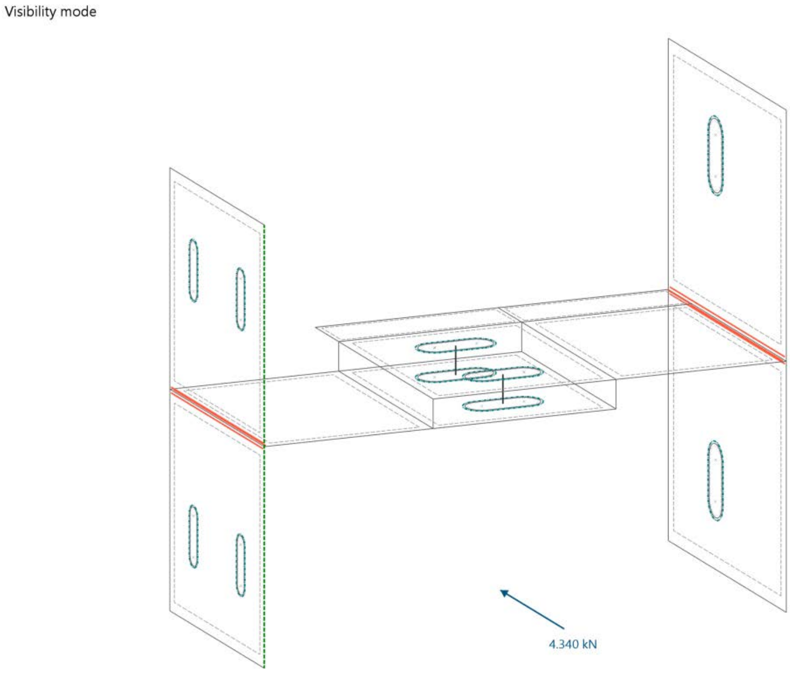


Fig. 4.7.4 Loads to bracket KR-7 - CO6 load combination (extract from RFEM 6.02)

Result of stress-strain analysis of bracket KR-7 (existing stresses) is shown in the fig. 4.7.5.

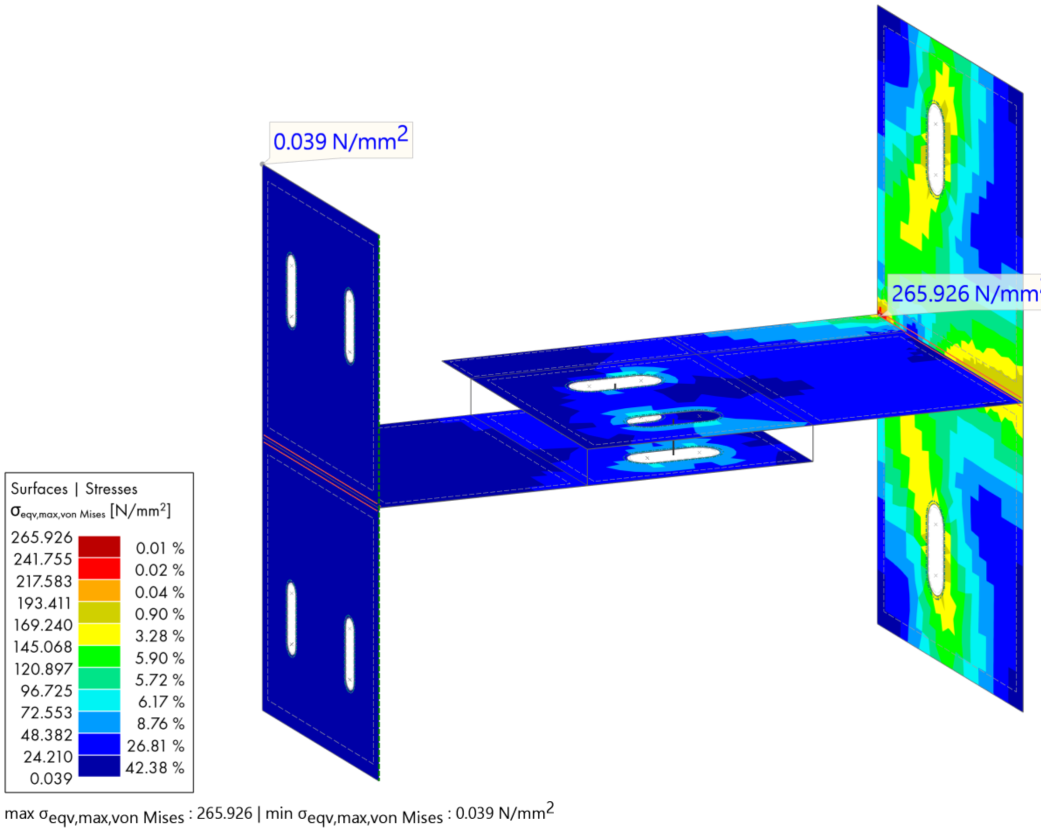


Fig. 4.7.5 Stresses in bracket KR-7 (extract from RFEM 6.02)

ULS design of bracket KR-7 is performed it the table 4.7.1.

Table 4.7.1 Bracket KR-7 calculation (extract from RFEM 6.02)

Thick. No.	Design Situation	Loading No.	Stress Type	Stress [N/mm²] Existing	Limit	Stress Ratio η [--]
	Thikness 10 mm					
1	DS1	CO2	$\sigma_{1,+}$	276.393	355.000	**0.779**
1	DS1	CO2	$\sigma_{2,+}$	-214.850	355.000	**0.605**
1	DS1	CO2	$\sigma_{1,-}$	209.621	355.000	**0.590**
1	DS1	CO2	$\sigma_{2,-}$	-248.206	355.000	**0.699**
1	DS1	CO2	$\sigma_{1,m}$	50.717	355.000	**0.143**
1	DS1	CO2	$\sigma_{2,m}$	-155.160	355.000	**0.437**
1	DS1	CO2	τ_{max}	113.570	204.959	**0.554**
1	DS1	CO2	$\sigma_{eqv,max,von\ Mises}$	265.926	355.000	**0.749**

All calculated ULS design ratios are less then 1.
The bracket KR-7 has been designed properly and safety.

4.7.2 Weld seam calculation

Weld seam calculation is performed according to directional method (par. 4.5.3.2 EN 1993-1-8).

Weld seam parameters are shown in the fig. 4.7.6. Weld size a_1=6 mm.

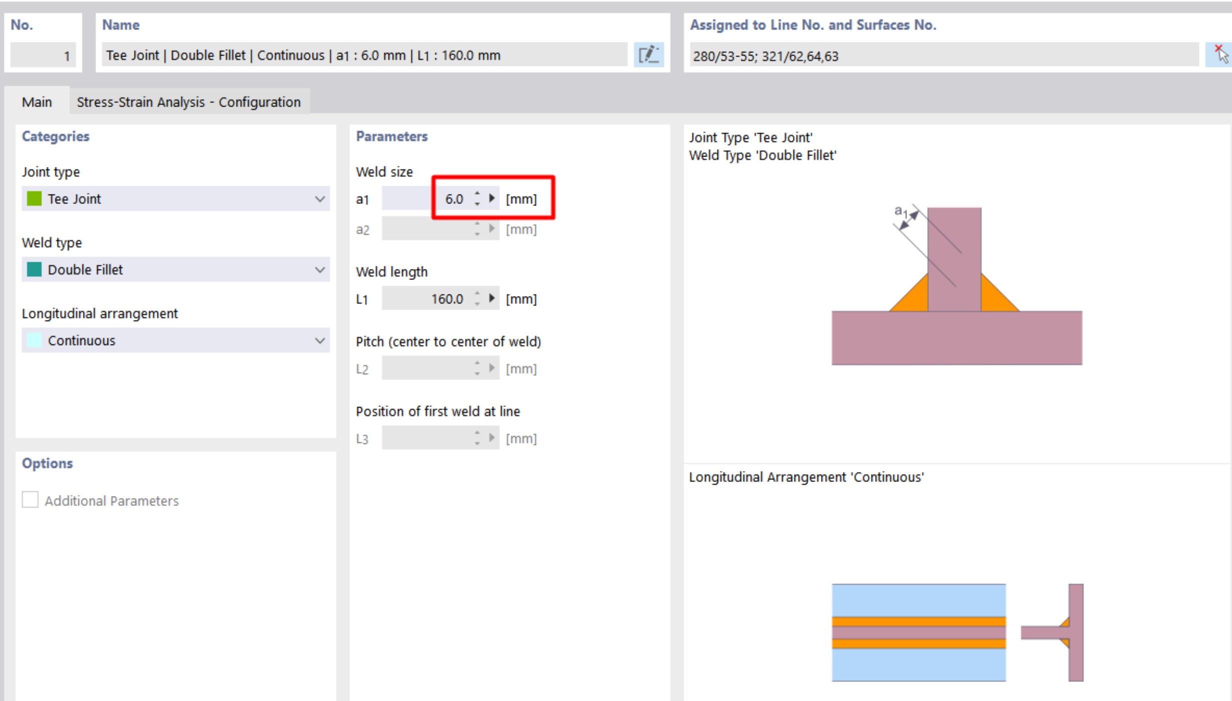


Fig. 4.7.6 Weld seam parameters (extract from RFEM 6.02)

Existing stresses in the weld seam are shown in the fig. 4.7.7.

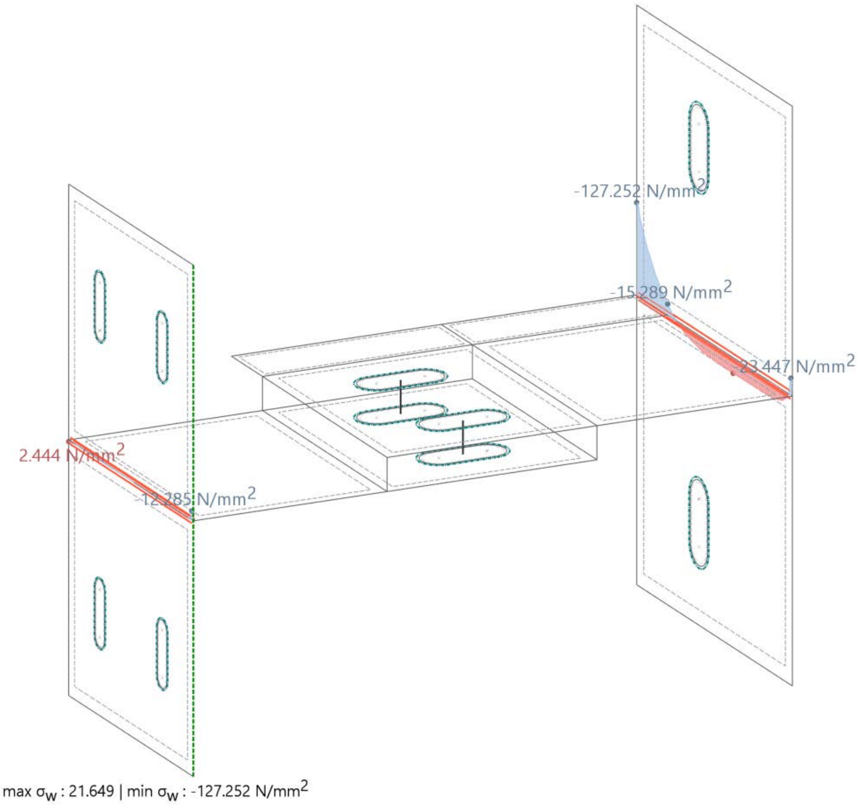


Fig. 4.7.7 Existing stresses in the weld seam (extract from RFEM 6.02)

Calculation of weld seam is performed it the table 4.7.2.

Table 4.7.2 Weld seam calculation (extract from RFEM 6.02)

Design Situation	Loading No.	Stress Type	Stress [N/mm²]		**Stress Ratio η [--]**	Note
			Existing	Limit		
DS1	CO2	σ_w	-127.252	251.500	**0.506**	β_w=0.9 for S355 steel
DS1	CO2	τ_w	3.391			
DS1	CO2	$\sigma_{\perp,+45°}$	92.162			
DS1	CO2	$\tau_{\perp,+45°}$	96.267			
DS1	CO2	$\sigma_{\perp,-45°}$	96.267			
DS1	CO2	$\tau_{\perp,-45°}$	92.162			
DS1	CO2	$\tau_{\parallel}$	17.390			
DS1	CO2	$\sigma_{V,w,+45°,Ed}$	192.294			
DS1	CO2	$\sigma_{V,w,-45°,Ed}$	188.228			
DS1	CO2	σ_{max}	-127.252	251.500	**0.506**	

4.7.3 Bolt calculation (bracket plates)

Bolts fixing bracket plates have to be calculated (see fig. 4.7.8).
Designed bolt is M10 DIN 931. Bolt class is 8.8.

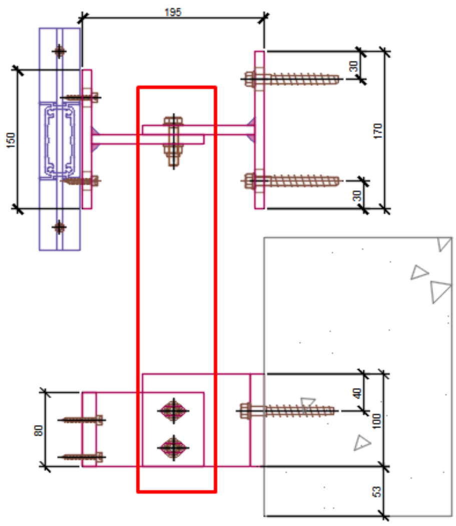


Fig. 4.7.8 Bolt to calculate

Calculation of the bolt according to the EN 1993-1-8 (table 3.4) is performed it the table 4.7.4.

Table 4.7.4 Bolt M10 for bracket KR-7 calculation

Bolt M10 calculation bracket KR-7			
Bolt size	M10		
Bolt class	8.8		
f_{yb}	640	MPa	Yield strength
f_{ub}	800	MPa	Ultimate tensile strength
Shear resistance per shear plane calculation			
$F_{v,Ed}$	**10.39**	**kN**	The design shear force per bolt for the ultimate limit state
$F_{v,Rd}$	**22.27**	**kN**	The shear resistance per bolt
$F_{v,Ed}/F_{v,Rd}$	**0.47**		**Criteria $F_{v,Ed} \leq F_{v,Rd}$ is performed**
α_V	0.6		Factor for bolt class 8.8
A_s	58.0	mm^2	Stress area (threaded part)
γ_{M2}	1.25		Safety factor - EN 1993-1-18
Bearing resistance calculation			
$F_{b,Ed}$	**10.39**	**kN**	The design shear force per bolt for the ultimate limit state
$F_{b,Rd}$	**35.64**	**kN**	The design bearing resistance per bolt
$F_{b,Ed}/F_{b,Rd}$	**0.29**		**Criteria $F_{v,Ed} \leq F_{b,Rd}$ is performed**
Material			Steel S355
f_u	490	MPa	
d	10	mm	Diametr of bolt
t	10.00	mm	Total thickness of crumpled plates
k_1	2.50		
α_b	0.61		
	0.60		Factor for slotted holes

Tension resistance calculation			
F $_{t,Ed}$	**0.60**	**kN**	The design shear force per bolt for the ultimate limit state
F $_{t,Rd}$	**33.41**	**kN**	The design bearing resistance per bolt
F $_{t,Ed}$**/F** $_{t,Rd}$	**0.02**		**Criteria F** $_{v,Ed} \leq$ **F** $_{b,Rd}$ **is performed**
K_2	0.9		

4.7.4 Anchor calculation (bracket to concrete wall)

Anchorage calculation below is based on several assumptions on reinforced concrete parameters.

Anchor calculation was performed in the program Hilti PROFIS Engineering 3.0.8.

The total capacity of anchorage and reinforced concrete connection is indicative and must be checked by concrete designer.

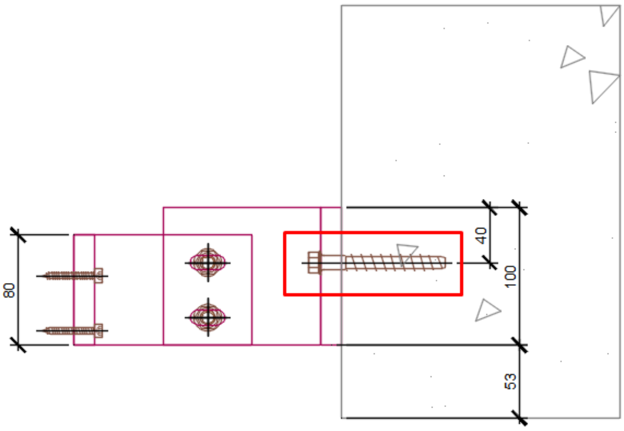


Fig. 4.7.9 Bolt to calculate

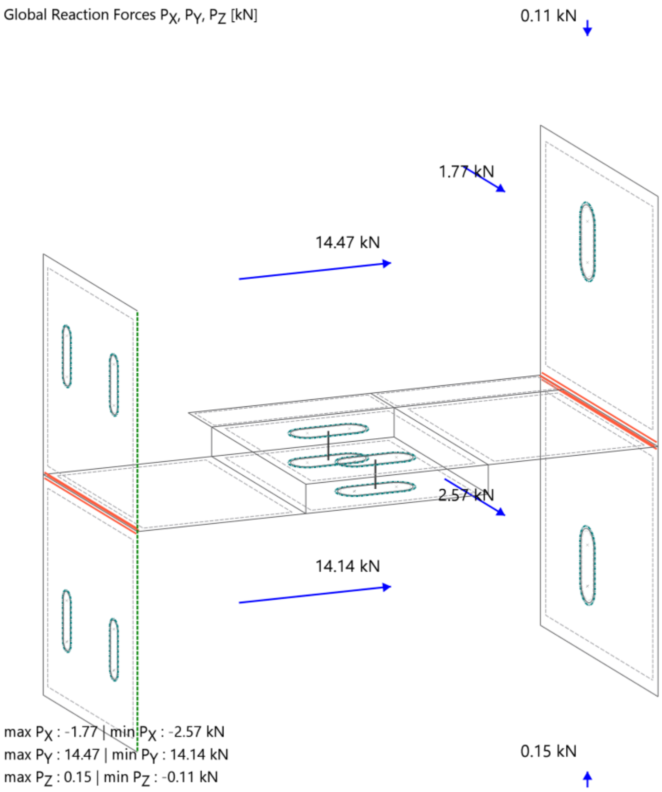


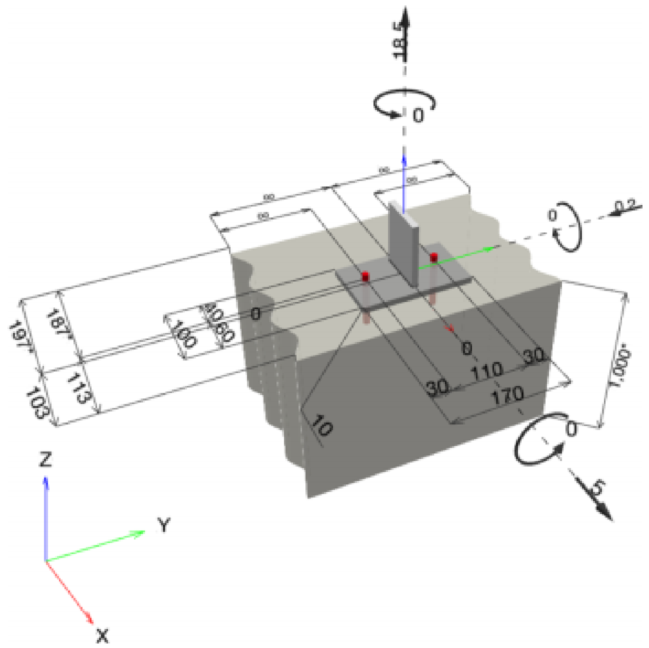
Fig. 4.7.10 Support reactions from bracket KR-7 (extract from RFEM 6.02)

1 Input data

Anchor type and size:	**HUS4-H 10 h_nom3**
Return period (service life in years):	50
Item number:	2293556 HUS4-H 10x100 45/25/15
Effective embedment depth:	h_{ef} = 68.0 mm ($h_{ef,ETA}$ = 68.0 mm), h_{nom} = 90.0 mm
Material:	Carbon Steel
Approval No.:	ETA-20/0867
Issued I Valid:	14/07/2022 | -
Proof:	Design Method EN 1992-4, Mechanical
Stand-off installation:	e_b = 0.0 mm (no stand-off); t = 10.0 mm
Baseplate[CBFEM] :	l_x x l_y x t = 100.0 mm x 170.0 mm x 10.0 mm;
Profile:	Flat bar, 75 x 10; (L x W x T) = 75.0 mm x 10.0 mm
Base material:	uncracked concrete, C25/30, $f_{c,cyl}$ = 25.00 N/mm^2; h = 1,000.0 mm, User-defined partial material safety factor γ_c = 1.500
Installation:	**hammer drilled hole, Installation condition: Dry**
Reinforcement:	No reinforcement or Reinforcement spacing >= 150 mm (any Ø) or >= 100 mm (Ø <= 10 mm)
	no longitudinal edge reinforcement

[CBFEM] - The anchor calculation is based on a component-based Finite Element Method (CBFEM)

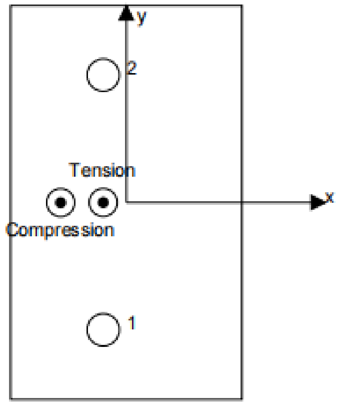
Geometry [mm] & Loading [kN, kNm]



1.1 Load combination

Case	Description	Forces [kN] / Moments [kNm]	Seismic	Fire	Max. Util. Anchor [%]
1	Kombinacja 1	N = 18.500; V_x = 5.000; V_y = -0.200; M_x = 0.000; M_y = 0.000; M_z = 0.000;	no	no	98

2 Load case/Resulting anchor forces



Anchor reactions [kN]
Tension force: (+Tension, -Compression)

Anchor	Tension force	Shear force	Shear force x	Shear force y
1	14.578	2.482	2.482	-0.044
2	14.572	2.523	2.518	-0.156

resulting tension force in (x/y)=(-10.0/-0.0): 29.150 [kN]
resulting compression force in (x/y)=(-28.4/-0.1): 11.315 [kN]

Anchor forces are calculated based on a component-based Finite Element Method (CBFEM)

3 Tension load (EN 1992-4, Section 7.2.1)

	Load [kN]	Capacity [kN]	Utilization β_N [%]	Status
Steel failure*	14.578	36.667	40	OK
Pull-out failure*	14.578	20.561	71	OK
Concrete Breakout failure**	29.150	31.643	93	OK
Splitting failure**	29.150	45.784	64	OK

* highest loaded anchor **anchor group (anchors in tension)

3.1 Steel failure

$N_{Ed} \leq N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{M,s}}$ EN 1992-4, Table 7.1

$N_{Rk,s}$ [kN]	$\gamma_{M,s}$	$N_{Rd,s}$ [kN]	N_{Ed} [kN]
55.000	1.500	36.667	14.578

3.2 Pull-out failure

$N_{Ed} \leq N_{Rd,p} = \frac{\psi_c \cdot N_{Rk,p}}{\gamma_{M,p}}$ EN 1992-4, Table 7.1

$N_{Rk,p}$ [kN]	ψ_c	$\gamma_{M,p}$	$N_{Rd,p}$ [kN]	N_{Ed} [kN]
27.585	1.118	1.500	20.561	14.578

3.3 Concrete Breakout failure

$N_{Ed} \leq N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{M,c}}$ EN 1992-4, Table 7.1

$N_{Rk,c} = N^0_{Rk,c} \cdot \frac{A_{c,N}}{A^0_{c,N}} \cdot \psi_{s,N} \cdot \psi_{re,N} \cdot \psi_{ec1,N} \cdot \psi_{ec2,N} \cdot \psi_{M,N}$ EN 1992-4, Eq. (7.1)

$N^0_{Rk,c} = k_1 \cdot \sqrt{f_{ck}} \cdot h_{ef}^{1,5}$ EN 1992-4, Eq. (7.2)

$A^0_{c,N} = s_{cr,N} \cdot s_{cr,N}$ EN 1992-4, Eq. (7.3)

$\psi_{s,N} = 0.7 + 0.3 \cdot \frac{c}{c_{cr,N}} \leq 1.00$ EN 1992-4, Eq. (7.4)

$\psi_{ec1,N} = \frac{1}{1 + \left(\frac{2 \cdot e_{N,1}}{s_{cr,N}}\right)} \leq 1.00$ EN 1992-4, Eq. (7.6)

$\psi_{ec2,N} = \frac{1}{1 + \left(\frac{2 \cdot e_{N,2}}{s_{cr,N}}\right)} \leq 1.00$ EN 1992-4, Eq. (7.6)

$\psi_{M,N} = 1$ EN 1992-4, Eq. (7.7)

$A_{c,N}$ [mm²]	$A^0_{c,N}$ [mm²]	$c_{cr,N}$ [mm]	$s_{cr,N}$ [mm]	$f_{c,cyl}$ [N/mm²]
64,056	41,616	102.0	204.0	25.00

$e_{c1,N}$ [mm]	$\psi_{ec1,N}$	$e_{c2,N}$ [mm]	$\psi_{ec2,N}$	$\psi_{s,N}$	$\psi_{re,N}$
0.0	1.000	0.0	1.000	1.000	1.000

z [mm]	$\psi_{M,N}$	k_1	$N^0_{Rk,c}$ [kN]	$\gamma_{M,c}$	$N_{Rd,c}$ [kN]	N_{Ed} [kN]
18.4	1.000	11.000	30.841	1.500	31.643	29.150

Group anchor ID
1, 2

3.4 Splitting failure

$N_{Ed} \leq N_{Rd,sp} = \frac{N_{Rk,sp}}{\gamma_{Msp}}$ EN 1992-4, Table 7.1

$N_{Rk,sp} = N^0_{Rk,sp} \cdot \frac{A_{c,N}}{A^0_{c,N}} \cdot \psi_{s,N} \cdot \psi_{re,N} \cdot \psi_{ec1,N} \cdot \psi_{ec2,N} \cdot \psi_{h,sp}$ EN 1992-4, Eq. (7.23)

$N^0_{Rk,sp} = N^0_{Rk,sp,ETA}$

$A^0_{c,N} = s_{cr,sp} \cdot s_{cr,sp}$ EN 1992-4, Eq. (7.3)

$\psi_{s,N} = 0.7 + 0.3 \cdot \frac{c}{c_{cr,sp}} \leq 1.00$ EN 1992-4, Eq. (7.4)

$\psi_{ec1,N} = \frac{1}{1 + \left(\frac{2 \cdot e_{N,1}}{s_{cr,sp}}\right)} \leq 1.00$ EN 1992-4, Eq. (7.6)

$\psi_{ec2,N} = \frac{1}{1 + \left(\frac{2 \cdot e_{N,2}}{s_{cr,sp}}\right)} \leq 1.00$ EN 1992-4, Eq. (7.6)

$\psi_{h,sp} = \left(\frac{h}{h_{min}}\right)^{2/3} \leq \max\left\{1; \left(\frac{h_{ef} + 1.5 \cdot c_1}{h_{min}}\right)^{2/3}\right\} \leq 2.00$ EN 1992-4, Eq. (7.24)

$A_{c,N}$ [mm²]	$A^0_{c,N}$ [mm²]	$c_{cr,sp}$ [mm]	$s_{cr,sp}$ [mm]	$\psi_{h,sp}$	$f_{c,cyl}$ [N/mm²]
75,039	50,355	112.2	224.4	1.494	25.00

$e_{c1,N}$ [mm]	$\psi_{ec1,N}$	$e_{c2,N}$ [mm]	$\psi_{ec2,N}$	$\psi_{s,N}$	$\psi_{re,N}$	k_1
0.0	1.000	0.0	1.000	1.000	1.000	11.000

$N^0_{Rk,sp}$ [kN]	$\gamma_{M,sp}$	$N_{Rd,sp}$ [kN]	N_{Ed} [kN]
30.841	1.500	45.784	29.150

Group anchor ID
1, 2

4 Shear load (EN 1992-4, Section 7.2.2)

	Load [kN]	Capacity [kN]	Utilization β_V [%]	Status
Steel failure (without lever arm)*	2.523	20.480	13	OK
Steel failure (with lever arm)*	N/A	N/A	N/A	N/A
Pryout failure*	2.523	31.647	8	OK
Concrete edge failure in direction x+**	5.004	19.697	26	OK

* highest loaded anchor **anchor group (relevant anchors)

4.1 Steel failure (without lever arm)

$V_{Ed} \leq V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{M,s}}$ EN 1992-4, Table 7.2

$V_{Rk,s} = k_7 \cdot V^0_{Rk,s}$ EN 1992-4, Eq. (7.35)

$V^0_{Rk,s}$ [kN]	k_7	$V_{Rk,s}$ [kN]	$\gamma_{M,s}$	$V_{Rd,s}$ [kN]	V_{Ed} [kN]
32.000	0.800	25.600	1.250	20.480	2.523

4.2 Pryout failure

$V_{Ed} \leq V_{Rd,cp} = \frac{V_{Rk,cp}}{\gamma_{M,cp}}$ EN 1992-4, Table 7.2

$V_{Rk,cp} = k_8 \cdot N_{Rk,c}$ EN 1992-4, Eq. (7.39a)

$N_{Rk,c} = N^0_{Rk,c} \cdot \frac{A_{c,N}}{A^0_{c,N}} \cdot \psi_{s,N} \cdot \psi_{re,N} \cdot \psi_{ec1,N} \cdot \psi_{ec2,N} \cdot \psi_{M,N}$ EN 1992-4, Eq. (7.1)

$N^0_{Rk,c} = k_1 \cdot \sqrt{f_{ck}} \cdot h_{ef}^{1,5}$ EN 1992-4, Eq. (7.2)

$A^0_{c,N} = s_{cr,N} \cdot s_{cr,N}$ EN 1992-4, Eq. (7.3)

$\psi_{s,N} = 0.7 + 0.3 \cdot \frac{c}{c_{cr,N}} \leq 1.00$ EN 1992-4, Eq. (7.4)

$\psi_{ec1,N} = \frac{1}{1 + \left(\frac{2 \cdot e_{V,1}}{s_{cr,N}}\right)} \leq 1.00$ EN 1992-4, Eq. (7.6)

$\psi_{ec2,N} = \frac{1}{1 + \left(\frac{2 \cdot e_{V,2}}{s_{cr,N}}\right)} \leq 1.00$ EN 1992-4, Eq. (7.6)

$\psi_{M,N} = 1$ EN 1992-4, Eq. (7.7)

$A_{c,N}$ [mm²]	$A^0_{c,N}$ [mm²]	$c_{cr,N}$ [mm]	$s_{cr,N}$ [mm]	k_8	$f_{c,cyl}$ [N/mm²]
32,028	41,616	102.0	204.0	2.000	25.00

$e_{c1,V}$ [mm]	$\psi_{ec1,N}$	$e_{c2,V}$ [mm]	$\psi_{ec2,N}$	$\psi_{s,N}$	$\psi_{re,N}$	$\psi_{M,N}$
0.0	1.000	0.0	1.000	1.000	1.000	1.000

k_1	$N^0_{Rk,c}$ [kN]	$\gamma_{M,c,p}$	$V_{Rd,cp}$ [kN]	V_{Ed} [kN]
11.000	30.841	1.500	31.647	2.523

Group anchor ID
2

4.3 Concrete edge failure in direction x+

$V_{Ed} \leq V_{Rd,c} = \frac{V_{Rk,c}}{\gamma_{M,c}}$ EN 1992-4, Table 7.2

$V_{Rk,c} = k_T \cdot V^0_{Rk,c} \cdot \frac{A_{c,V}}{A^0_{c,V}} \cdot \psi_{s,V} \cdot \psi_{h,V} \cdot \psi_{\alpha,V} \cdot \psi_{ec,V} \cdot \psi_{re,V}$ EN 1992-4, Eq. (7.40)

$V^0_{Rk,c} = k_9 \cdot d^{\alpha}_{nom} \cdot l^{\beta}_f \cdot \sqrt{f_{ck}} \cdot c_1^{1,5}$ EN 1992-4, Eq. (7.41)

$\alpha = 0.1 \cdot \left(\frac{l_f}{c_1}\right)^{0,5}$ EN 1992-4, Eq. (7.42)

$\beta = 0.1 \cdot \left(\frac{d_{nom}}{c_1}\right)^{0,2}$ EN 1992-4, Eq. (7.43)

$A^0_{c,V} = 4.5 \cdot c_1^2$ EN 1992-4, Eq. (7.44)

$\psi_{s,V} = 0.7 + 0.3 \cdot \frac{c_2}{1.5 \cdot c_1} \leq 1.00$ EN 1992-4, Eq. (7.45)

$\psi_{h,V} = \left(\frac{1.5 \cdot c_1}{h}\right)^{0,5} \geq 1.00$ EN 1992-4, Eq. (7.46)

$\psi_{ec,V} = \frac{1}{1 + \left(\frac{2 \cdot e_V}{3 \cdot c_1}\right)} \leq 1.00$ EN 1992-4, Eq. (7.47)

$\psi_{\alpha,V} = \sqrt{\frac{1}{(\cos \alpha_V)^2 + (0.5 \cdot \sin \alpha_V)^2}} \geq 1.00$ EN 1992-4, Eq. (7.48)

l_f [mm]	d_{nom} [mm]	k_9	α	β	$f_{c,cyl}$ [N/mm^2]
68.0	10.00	2.400	0.078	0.062	25.00

c_1 [mm]	$A_{c,V}$ [mm^2]	$A^0_{c,V}$ [mm^2]
113.0	76,106	57,460

$\psi_{s,V}$	$\psi_{h,V}$	α_V [°]	$\psi_{\alpha,V}$	$e_{c,V}$ [mm]	$\psi_{ec,V}$	$\psi_{re,V}$
1.000	1.000	2.29	1.001	0.4	0.998	1.000

$V^0_{Rk,c}$ [kN]	k_T	$\gamma_{M,c}$	$V_{Rd,c}$ [kN]	V_{Ed} [kN]
22.346	1.0	1.500	19.697	5.004

5 Combined tension and shear loads (EN 1992-4, Section 7.2.3)

Steel failure

β_N	β_V	α	Utilization $\beta_{N,V}$ [%]	Status
0.397	0.123	2.000	18	OK

$\beta_N^{\alpha} + \beta_V^{\alpha} \leq 1.0$

Concrete failure

β_N	β_V	α	Utilization $\beta_{N,V}$ [%]	Status
0.921	0.254	1.000	98	OK

$(\beta_N + \beta_V) / 1.2 \leq 1.0$

6 Warnings

- The anchor design methods in PROFIS Engineering require rigid baseplates as per current regulations (ETAG 001/Annex C, EOTA TR029, etc.). This means load re-distribution on the anchors due to elastic deformations of the baseplate are not considered - the baseplate is assumed to be sufficiently stiff, in order not to be deformed when subjected to the design loading. PROFIS Engineering calculates the minimum required baseplate thickness with CBFEM to limit the stress of the baseplate based on the assumptions explained above. The proof if the rigid base plate assumption is valid is not carried out by PROFIS Engineering. Input data and results must be checked for agreement with the existing conditions and for plausibility!
- In general, the conditions given in ETAG 001, Annex C, section 4.2.2.1 and 4.2.2.3 b) are not fulfilled because the diameter of the clearance hole in the fixture acc. to Annex 3, Table 3 is greater than the values given in Annex C, Table 4.1 and AS5126 for the corresponding diameter of the anchor. Therefore the design resistance for anchor groups is limited to twice the steel resistance (of a single anchor) in accordance with the approval.
- Checking the transfer of loads into the base material is required in accordance with EN 1992-4, Annex A!
- The design is only valid if the clearance hole in the fixture is not larger than the value given in Table 6.1 of EN 1992-4! For larger diameters of the clearance hole see section 6.2.2 of EN 1992-4!
- The accessory list in this report is for the information of the user only. In any case, the instructions for use provided with the product have to be followed to ensure a proper installation.
- For the determination of the $\psi_{re,V}$ (concrete edge failure) the minimum concrete cover defined in the design settings is used as the concrete cover of the edge reinforcement.
- Please ensure that the fastening system is statically indeterminded
- The anchor design methods in PROFIS Engineering require rigid baseplates, as per current regulations (AS 5216:2021, ETAG 001/Annex C, EOTA TR029 etc.). This means that the baseplate should be sufficiently rigid to prevent load re-distribution to the anchors due to elastic/plastic displacements. The user accepts that the baseplate is considered close to rigid by engineering judgment."
- The characteristic bond resistances depend on the return period (service life in years): 50

Fastening meets the design criteria!