

# Curved curtain wall for the extension of aspire academy qatar

## Abstract

The here presented paper deals with a case study of façade structural design for the extension of Aspire Academy in Doha Qatar. Different curtain walls using stick system for various spans and heights were designed. All the external curtain walls are subjected to a wind load of 2.3kPa as per the project specification. Double glazed units are considered for the curtain walls. The building has a curved elevation on the East and West side where stick curtain wall system is considered and the analysis and design is presented in this paper. The mullions of the curtain walls are curved member along the strong axis having high inertia which conventionally was not possible to achieve such section with a normal extruded profile; hence Aluminium sheets were cut in curved shapes to form the desired shape. The transoms are conventional extruded profile of the same depth as those of the mullions. The paper addresses some technical issues together with the design of the curtain wall that are believed to be useful for the façade structural design.

**Keywords:** curtain walls, built up sections, mullions, transoms, glazed units, aluminium profiles

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## Introduction

Transparent building façades are really the ongoing trend these days. Complex structural geometry, extreme temperatures, large openings and bad weather conditions make it quite challenging for the façade structural engineers to envelop the building fulfilling the efficient energy consumptions and optimum resistant to the external forces. Middle east countries has huge sunshine throughout the year and having high temperatures, still the use of glass as glazing units in the façade is the general trend specially for skyscrapers. Use of Aluminum with glass as glazing unit is very common and therefore in extreme weather, expansion of Aluminium is another challenging task to be cover by the façade engineers. Weather condition in Doha is extreme; it has high winds and high temperature in summer that makes it difficult to fulfill the design requirements together with the Architectural constraints of the building façade which goes side by side.<sup>1</sup> In this paper a double curvature curtain wall (highlighted in black in Figure 1) has been designed and examined. The considered curtain wall for the building has Maximum Mullion spacing (Maximum Transom Length) of around 3m; therefore it is the worst scenario for the design calculations. All the transoms are assumed pinned connected, transferring only shear forces. Stresses and deflection checks obtained from the numerical model<sup>2</sup> have been carried out for glass and Aluminum mullions. The brackets are realized and checked for the corresponding induced forces and they are modeled separately in Robot software.<sup>3</sup> Instead the anchor bolts are designed using Hilti profis software.<sup>4</sup> All the structural system has been found SAFE according to different acceptance criterion.<sup>5-7</sup>

Regarding Glass, Aluminum and other elements, the deal load is calculated by the software (SAP 2000).<sup>2</sup> The wind load is specified as 2.3kPa as per the project specification. With regards to the temperature Loading, the Initial temperature is assumed to be  $\pm 10^{\circ}\text{C}$ , whereas the final temperature to be  $\pm 50^{\circ}\text{C}$ , as the coefficient of thermal expansion for Aluminium ( $\alpha$ ) equals  $23 \times 10^{-6}$ , therefore the change in length, i.e.,  $\Delta_L$  equals  $\alpha \cdot \Delta_T \cdot L = (23 \times 10^{-6}) \cdot (40) \cdot (6500)$  equals

5.98mm. The expansion of Aluminium material is more critical than that of steel material, therefore in this case vertical slots are provided to accommodate thermal expansion and contraction, and hence temperature load is not accounted in the analysis model. In some cases where slots may not be favorable and not provided, stresses due to temperature need to be verified prior to the installation.<sup>8-10</sup>



**Figure 1** Extension of aspire academy (Double curvature curtain wall highlighted in black).

## Numerical modeling

### General and profiles

A built up section is fabricated by cutting Aluminium sheets with Mullion nose fixed to it. The width of Mullion is 52mm whereas the depth equals 223mm. In ALUTEC facility it was not possible to create a Mullion being bend in the strong axis from an Aluminum tube that simultaneously satisfy the deflection and strength requirements. Moreover smaller tube with steel insert is also not a practical solution and in this case the curtain wall has double curves (concave and convex) creating a radius of curvature of about 11m as shown in Figure 2. Therefore 4mm thick sheets are cut in precise

shape to achieve the desire curve and then screwed to the sides of 10mm thick Aluminium sheets as shown in Figure 2. These screws are spaced at around 200mm center to center, thus gives rise to very strong Aluminum tube. The local strength check of this built up tube is considered beyond the scope of the current paper and can be address in a separate article. Mullion nose, obtained from Technal FM 257 system, is mechanically fixed through screws at the front of the built up Mullion. Transoms, that are pinned connected to the Mullions at the two sides, are supporting the gravity (dead) load of glass and composite panels as per Technal FM 257 system, see Catalogue page of Technal in Figure 3.<sup>11,12</sup>

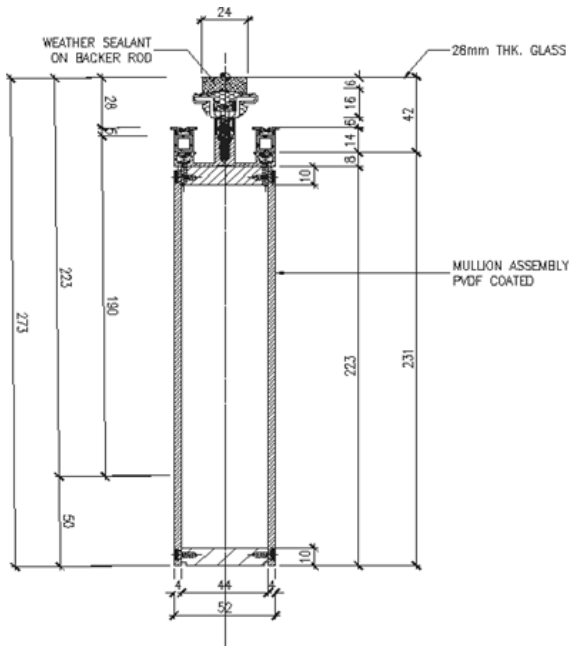


Figure 2 Built up mullion profile.

**Grid transom profiles**

Inertia value for calculating the dead load on transom along the axis 'Y'

Charts only must be used to determine sizing of grid and glazing load bearing

Reference	FM165	FM166	FM252	FM155	FM156	FM253	FM169	FM254
Inertia without reinforcement	8.52 cm <sup>4</sup>	14.24 cm <sup>4</sup>	16.87 cm <sup>4</sup>	19.09 cm <sup>4</sup>	24.17 cm <sup>4</sup>	27.20 cm <sup>4</sup>	32.82 cm <sup>4</sup>	35.73 cm <sup>4</sup>
Inertia with reinforcement	27.5 cm <sup>4</sup>	30.1 cm <sup>4</sup>	52.3 cm <sup>4</sup>	73 cm <sup>4</sup>	76 cm <sup>4</sup>	96.3 cm <sup>4</sup>	100.2 cm <sup>4</sup>	118.4 cm <sup>4</sup>
Steel tube	20x32	20x32	40x32	50x32	50x32	50x32	80x32	80x32

Reference	FM157	FM158	FM255	FM256	FM159	FM257
Inertia without reinforcement	38.37 cm <sup>4</sup>	48.80 cm <sup>4</sup>	52.98 cm <sup>4</sup>	56.18 cm <sup>4</sup>	63.74 cm <sup>4</sup>	66.80 cm <sup>4</sup>
Inertia with reinforcement	147.76 cm <sup>4</sup>	142.5 cm <sup>4</sup>	147.7 cm <sup>4</sup>	151.9 cm <sup>4</sup>	201.1 cm <sup>4</sup>	204.2 cm <sup>4</sup>
Steel tube	120x32	120x32	120x32	120x32	120x32 et 40x32	120x32 et 40x32

27 MX - Géode

Figure 3 Transoms profile inertia with and without steel insert (Technal system).

**Geometry**

The complete geometry of the typical curtain wall is shown in Figure 4 & 5, which represents the east elevation continuing from ground floor to top floor. The curtain wall is connected at four locations, top (roof level) is supported by the space frame, bottom (ground level) is supported by reinforce concrete beam, whereas two reinforced concrete floor slabs provide supports at the intermediate levels. In order to allow the Mullions to breath in vertical direction (thermal expansion and contraction), slots are provided; therefore temperature load does not induce any stresses in the Mullions.

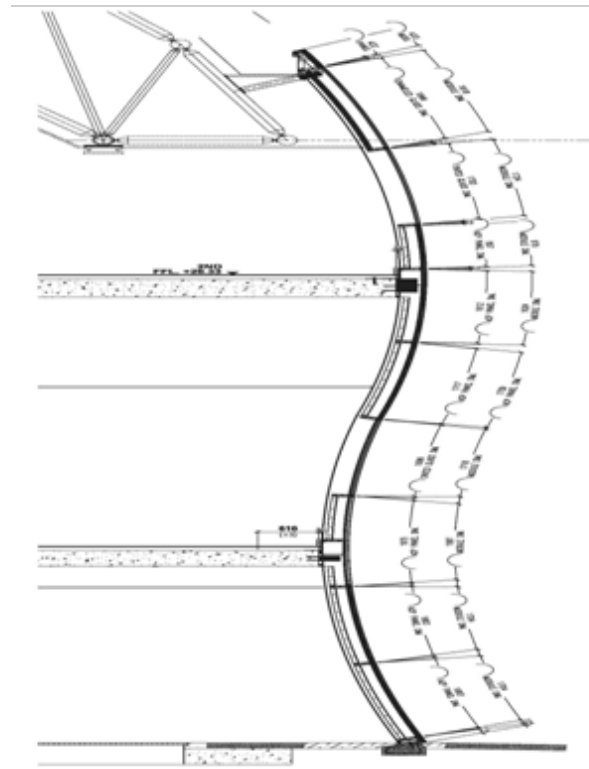


Figure 4 Curtain wall section view.

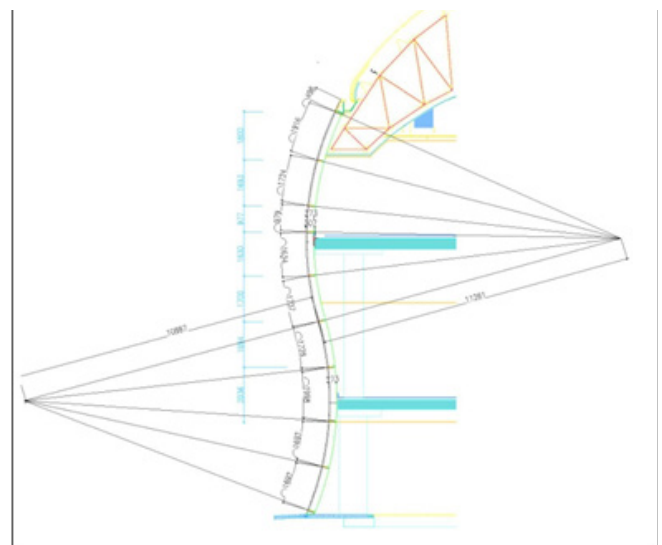


Figure 5 Curtain wall section view showing radius of curvature.

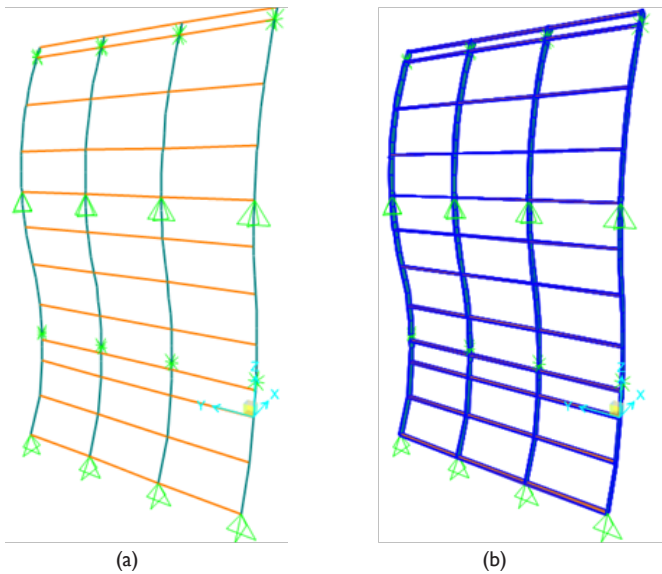


Figure 6 Curtain wall, (a) Model and (b) Numerical model 3D.

**Numerical model**

SAP 2000 numerical software is used to model the curtain wall. The transoms are pin connected (transferring only shear) as shown in Figure 6. Hinge supports are used, two restraining the translations in

x, y as well as z, whereas the rest two are restraining only translation in x and y and therefore allows the slight movement of the curtain wall in z (vertical) direction in case if any (Figure 7). The coordinates of the Joints are shown in Table 1.

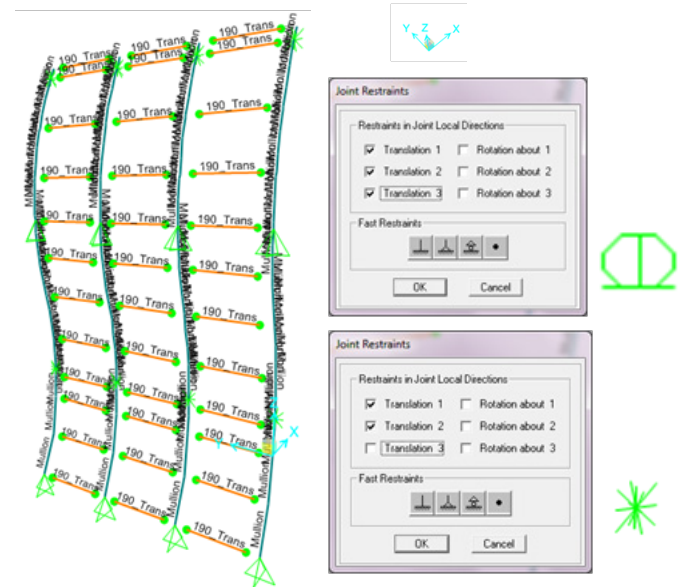


Figure 7 Curtain wall, (a) Frame releases and restraints and (b) Restraints condition.

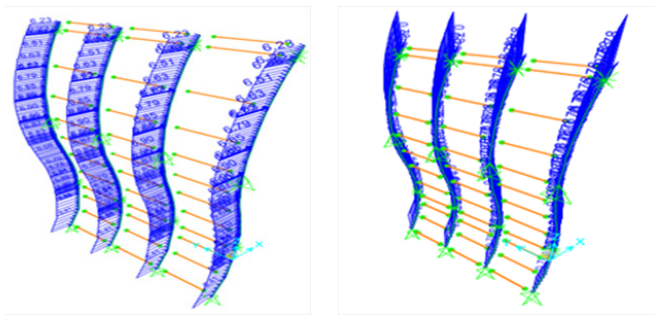
Table 1 Joint coordinates

Joint	Coord sys	Coord type	XorR	Y	Z	Special Jt	Global X	Global Y	Global Z
Text	Text	Text	m	m	m	Yes/No	m	m	m
1	Global	Cartesian	3	11	0	Yes	3	11	0
3	Global	Cartesian	3.1	11	1.2	No	3.1	11	1.2
8	Global	Cartesian	2.7	11	4.1	No	2.7	11	4.1
9	Global	Cartesian	3.4	11	12.3	No	3.4	11	12.3
32	Global	Cartesian	3.1	11	0.9	No	3.1	11	0.9
33	Global	Cartesian	3	11	2.4	No	3	11	2.4
34	Global	Cartesian	2.4	11	5.6	No	2.4	11	5.6
35	Global	Cartesian	2.2	11	6.9	No	2.2	11	6.9
36	Global	Cartesian	2.3	11	8.4	No	2.3	11	8.4
37	Global	Cartesian	2.6	11	10.1	No	2.6	11	10.1
38	Global	Cartesian	3.3	11	11.9	No	3.3	11	11.9
39	Global	Cartesian	3	14	0	Yes	3	14	0
41	Global	Cartesian	3.1	14	1.2	No	3.1	14	1.2
46	Global	Cartesian	2.7	14	4.1	No	2.7	14	4.1
47	Global	Cartesian	3.4	14	12.3	No	3.4	14	12.3
61	Global	Cartesian	3.1	14	0.9	No	3.1	14	0.9
62	Global	Cartesian	3	14	2.4	No	3	14	2.4
63	Global	Cartesian	2.4	14	5.6	No	2.4	14	5.6

Table continued...

Joint	Coord sys	Coord type	XorR	Y	Z	Special Jt	Global X	Global Y	Global Z
Text	Text	Text	m	m	m	Yes/No	m	m	m
64	Global	Cartesian	2.2	14	6.9	No	2.2	14	6.9
65	Global	Cartesian	2.3	14	8.4	No	2.3	14	8.4
66	Global	Cartesian	2.6	14	10.1	No	2.6	14	10.1
67	Global	Cartesian	3.3	14	11.9	No	3.3	14	11.9
68	Global	Cartesian	3	17	0	Yes	3	17	0
70	Global	Cartesian	3.1	17	1.2	No	3.1	17	1.2
75	Global	Cartesian	2.7	17	4.1	No	2.7	17	4.1
76	Global	Cartesian	3.4	17	12.3	No	3.4	17	12.3
90	Global	Cartesian	3.1	17	0.9	No	3.1	17	0.9
91	Global	Cartesian	3	17	2.4	No	3	17	2.4
92	Global	Cartesian	2.4	17	5.6	No	2.4	17	5.6
93	Global	Cartesian	2.2	17	6.9	No	2.2	17	6.9
94	Global	Cartesian	2.3	17	8.4	No	2.3	17	8.4
95	Global	Cartesian	2.6	17	10.1	No	2.6	17	10.1
96	Global	Cartesian	3.3	17	11.9	No	3.3	17	11.9
97	Global	Cartesian	3	20	0	Yes	3	20	0
99	Global	Cartesian	3.1	20	1.2	No	3.1	20	1.2
104	Global	Cartesian	2.7	20	4.1	No	2.7	20	4.1
105	Global	Cartesian	3.4	20	12.3	No	3.4	20	12.3
119	Global	Cartesian	3.1	20	0.9	No	3.1	20	0.9
120	Global	Cartesian	3	20	2.4	No	3	20	2.4
121	Global	Cartesian	2.4	20	5.6	No	2.4	20	5.6
122	Global	Cartesian	2.2	20	6.9	No	2.2	20	6.9
123	Global	Cartesian	2.3	20	8.4	No	2.3	20	8.4
124	Global	Cartesian	2.6	20	10.1	No	2.6	20	10.1
125	Global	Cartesian	3.3	20	11.9	No	3.3	20	11.9
126	Global	Cartesian	2.2	11	-2.9	Yes	2.2	11	-2.9
127	Global	Cartesian	2.2	14	-2.9	Yes	2.2	14	-2.9
128	Global	Cartesian	2.2	17	-2.9	Yes	2.2	17	-2.9
129	Global	Cartesian	2.2	20	-2.9	Yes	2.2	20	-2.9
130	Global	Cartesian	2.8	20	-1.5	Yes	2.8	20	-1.5
131	Global	Cartesian	2.8	17	-1.5	Yes	2.8	17	-1.5
132	Global	Cartesian	2.8	14	-1.5	Yes	2.8	14	-1.5
133	Global	Cartesian	2.8	11	-1.5	Yes	2.8	11	-1.5

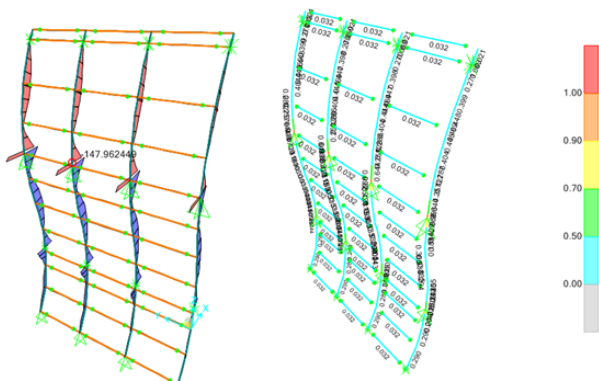
The structural calculations for the typical panel are presented here being the dimension of which will govern the design for the rest of the curtain wall. Wind load is applied linear along the height that equals  $2.3 \times 3 = 6.9 \text{ kN/m}$ . The additional dead load from the transoms and glass is applied on the Mullions and equals  $0.78 \text{ kN/m}$  (Figure 8).



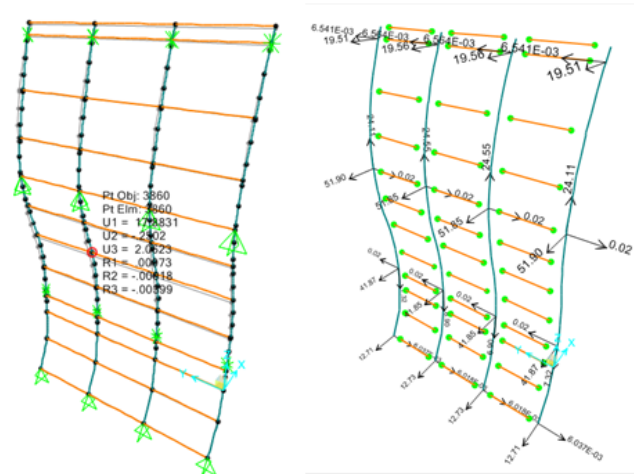
**Figure 8** Curtain wall, (a) Wind loading (2.3kPa) and (b) Dead loading of glass and panels.

**Numerical results**

In this section, some results obtained from the numerical model are presented. Maximum Induced Stress in Mullions under ULS is 147.9MPa < The allowable bending stress=160MPa (Figure 9). Maximum Deflection in Mullions is 17.88mm. Limiting value=Span/175 = 6000/175= 34.82mm or 19mm whichever is lesser (Figure 10).



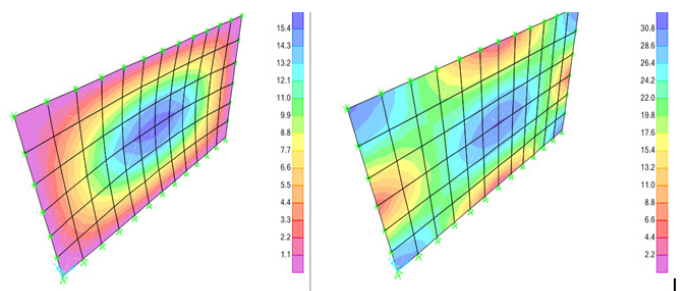
**Figure 9** Stresses in the mullions and transoms (left) and demand to capacity ratios of the framing under uls<1.0 (right).



**Figure 10** Deflection of mullions (left) and support reactions on the brackets (right).

**Glass, composite panels and Transoms**

The numerical model for double glaze glass unit is realized in SAP 2000 through the use of shell elements. In general, the glass panel DGU is resting on mullions and transoms grid, and is checked for strength and deflection. Conservatively, it is assumed to be without the air gap and all the glass thicknesses are safe. The boundaries are considered pinned and the shell elements are meshed in such a way to obtain approximate stress results. The maximum glass size is 3000x1980 for which 8mm-thick glass external panel+(14 Air gap)+6mm-thick glass internal panel. In SAP 2000, the outer and external panels are assumed to behave equally therefore these are considered as a single panel having a combine thickness of 14mm. Under the applied wind pressure, a maximum stress of 30.8MPa is under ultimate limit state (Figure 11). The deflection under serviceability limit state equals 15.4mm<span/60=1980/60=33mm.



**Figure 11** Glass contours (left) obtained deflected shape and (right) stresses in the glass panel.

With regarding to the Aluminium composite panels, these are 4mm-thick. The maximum span for the panels is 3m and the maximum width considered for the calculations purpose is 2m. Stiffeners at the back are provided; these are Aluminium tube 40x40x3 at each 600mm C/C.

Moment of Inertia=I=1682967mm<sup>4</sup>

Perpendicular Distance to the N.A=Y=39mm<sup>4</sup>

Wind Load=2.3kN/m<sup>2</sup>

Wind Load /m’= 6.9kN/m’

Bending Moment =BM=6.9x2X2X1.2/8 = 4.14kN.m

Flexural (Bending) Stress = f= M.Y/I =95.94MPa<125MPa  
OK

Deflection =12.20mm<2000/90 OK

The composite panels are safe in carrying the applied loads due to the use of stiffeners at the back of the panels. Considering that transom carries dead load of glass, therefore, Linear load from glass on 3m transom, carrying 3m glass of 1.9m height), being its self-weight equals 0.06KN/m whereas, Self weight of glass=0.665KN/m, hence total Load on transom for SLS=0.06KN/m+0.665KN/m=0.72KN/m (See Figure 11). Maximum Induced Deflection in Transom is 2.62mm (Figure 12 &13). Maximum Stress in Transom is 29.45MPa<The allowable bending stress=160MPa (Figure 14).

**Brackets checking**

The central Bracket is subjected to a total Tension of 51.9KN due

to wind suction and a shear of 24.55KN due to dead load of the curtain wall. These forces are obtained under Ultimate Limit States. The Bracket is realized in Robot structural analysis software<sup>3</sup> see Figure 15. Since 4 # M10 Stainless Steel bolts are used, therefore the forces are divided by 4 and applied at the center of the bolts in the numerical model (Figure 15). The loads are obtained from the Ultimate Limit State and are applied by default in dead load case. Maximum Induced Stress in the 12mm-thick Plate is 63.16MPa<275MPa (Figure 16), shows that the bracket is safe.

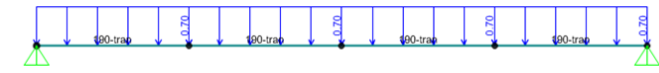


Figure 12 Numerical model of transoms with the dead load of glass.

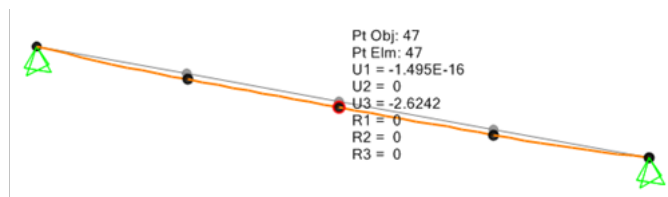


Figure 13 Induced deflection in transom=2.62mm < 3.5mm.



Figure 14 Stresses in the transoms=29.45MPa < 160Mpa.

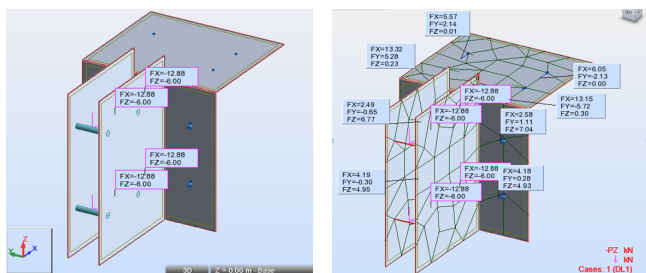


Figure 15 Numerical model of bracket with loading (left) and meshing of the numerical model with reactions on anchors (right).

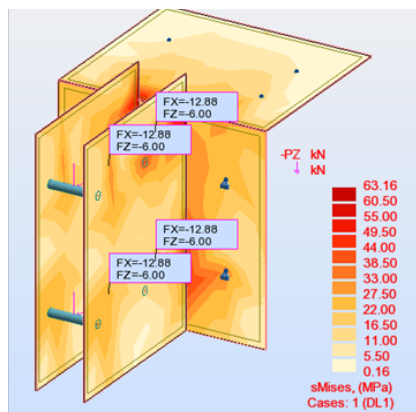


Figure 16 Stresses in the mild steel bracket.

## Conclusion

The here presented paper dealt with the structural design of a complex curtain wall. Curving rectangular tubes to achieve double

curvature mullions is generally not possible therefore mullions are built-up members fabricated from Aluminium sheets. The maximum glass panel is 3000mm x 1980mm for which the double glazed glass unit [8+(14 Air gap)+6] is adopted, that satisfy the strength and deflection. All anchors used are M12 of grade 8.8 with appropriate chemical in reinforced concrete having minimum embedment of 140mm. 12mm thick mild steel welded brackets are used and found safe for transferring the applied loads. 6mm-fillet weld (throat thickness 4.2mm) of E35 Electrode is used for the mild steel brackets. The through stainless steel bolts holding the mullions in the brackets are M10 of property class 70. For the composite panels which are only 4mm thick Aluminium tubes 40x40x3mm are used as stiffeners and are spaced at 600mm center to center. The paper shows that the design of such curtain walls should take into account different practical issues such as the deflection and strength limitations of the glass under high wind loads, transoms strict deflection limitations to support the dead load of huge glass panels without breakage, mullion deflection limitations, and anchors to satisfy the minimum edge distances from the concrete face. The paper is believed to be beneficial for the technicians involved in the structural design of curtain walls.

## Acknowledgements

None.

## Conflict of interest

The author declares no conflict of interest.

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