Structural Design Proposal for the Le Boulevard Sky light Doha Qatar

MUHAMMAD TAYYAB NAQASH
Aluminium Technology Auxiliary Industries W.L.L.P.O Box 40625, Doha, Qatar
Email: tayyab@alutecqatar.com

Abstract: The here presented report deals with the structural calculation of Le Boulevard skylight 36m by 18m in plan, located at a height of about 42m, subjected to a wind load of 1.7kPa[1] in Doha Qatar. The skylight is composed of rectangular curved tube and is designed for a basic wind speed of 25m/s as per Qatar Construction Standards[2]. It is having Aluminium metal sandwich panels (honey comb) of 2mm top and bottom thickness with 33 mm insulating material on top , whereas on the rest of the roof area glazing of 13.52 (lite) laminated +16 (gap)+8(lite) fully tempered glass is used. Two types of steel frames have been designed, one to support the glazing and Aluminium sandwich panel whereas other steel framing system has to transfer all the loads to the main structure[3-5].

Stresses and deflection checks obtained from the numerical model [6]have been carried out for glass, Aluminium sandwich panel, primary and secondary steel framing elements. The connections especially among the primary structural system, secondary system and the base plate are realized and checked for the induced forces. All the structural system has been found SAFE according to different acceptance criterion[7]. This report will give an overview to the technicians involve in the façade industry.

Keywords: Skylight, steel structures, structural glass, Aluminium sandwich panels

Introduction:
Skylights are light transmitting fenestration forming all or a portion of a building’s space for day lighting purposes. Here a skylight is designed using Sap 2000 numerical model (See Fig 1) for Le Boulevard building located in Doha Qatar.

With reference to the structural modelling, the transversal frames are rigid and the longitudinal frames are pinned, the secondary members that are resting on the primary structure are pinned connected. The base support is pinned, therefore does not allow the transformation of moments. In all frames both longitudinal and transversal, frame E (the transversal one located at the symmetric point) govern the design, both for ultimate limit state and serviceability limit state.

The modelling assumption are such that the transversal frames are assumed to be the main load bearing frames, hence all are rigid frames, whereas the longitudinal frames are working as secondary frames. Therefore, they are released (pinned connected with the transversal frames), and therefore only transferring the shear (See Fig 2). Furthermore, conservatively, the slope of the skylight in the transversal direction is ignored, so that to haven maximum bending effect and consequently the deflections in the frame elements.

Aluminium100 H14, proof stress 135Mpa[8, 9] for Aluminium sandwich panel having 2mm top and bottom thicknesses with a 33mm insulated interlayer is used.

Steel grade S275 having yield strength 275Mpa [10, 11] is adopted for the steel members. The allowable Stress for glass is, f_allow equals 50 Mpa as bending stress. The glass is Double Glaze Unit having 13.52mm outer laminated sheet having 1.52mm PVB with 16mm air gap and 8mm clear inner sheet.

The Primary Structure is composed of 250 x 200 x 12 rectangular hollow tubes, whereas the Secondary Structure is composed of 150 x 150 x 10 square hollow tubes connected to the primary structure using channel brackets. The secondary elements are connected to the primary structural members, therefore an equivalent profile is adopted for the primary structural system, and the property of the profile is mentioned below. The equivalent profile has the same area and same moment of Inertia in the strong axis; hence contribute in increasing the overall inertia.

The serviceability limit state, the glass permissible deflection equals Span/60 whereas Steel framing elements permissible deflection = span/200[10], Aluminium sandwich panel permissible deflection under dead and wind load is span/90[12], Aluminium sandwich panel permissible deflection under dead and imposed load is span/200 [12].

Loading and combinations:
The dead load comprised of Glass, Aluminium panel and structural elements, the deal load is calculated by the software (SAP 2000)
The wind load is Calculated as 1.7 kPa for 25m/s wind speed as per British Standard and QCS 2014 [1, 2]. The live load is the minimum imposed load on roof with no access is considered as per British Standards [13], the following two cases are considered: (a) Live Load1: 1.5 kN (Concentrated Load applied at most critical locations) (b) Live Load2:0.6 kN/m² (Uniform Load), these live loads are assumed to be non-concurrent.

The design load combinations are the various combinations of the load cases for which the model needs to be checked. According to the BS 5950-2000
MUHAMMAD TAYYAB NAQASH

As the structure is subjected to dead load (DL), live load (LL) and wind load (WL), and considering that wind force is reversible, the following load combinations may need to be considered (See Fig. 3 and Fig. 4).

1.4 DL, 1.4 DL + 1.6 LL, DL ± 1.4 WL, 1.4 DL ± 1.4 WL, 1.2 DL + 1.2 LL ± 1.2 WL.

Dynamic pressure is 1.669 Kpa. Conservatively, a dynamic pressure of 1.669 kpa is considered. Net wind pressure is considered to be the maximum value among all zones, i.e. 1.7 Kpa.

Figure 1: Numerical Model in SAP 2000

Figure 2: Frame releases definitions

Figure 3: Concentrated Point load (left) applied at the most critical positions and uniform live load (right)

Figure 4: Uniform wind load (left) and model (right)

Figure 5: Glass (Red) and Aluminum (Green) shell elements

Checking of aluminum sandwich panel:

Aluminium sandwich panel (2mm + 33 mm (space) + 2mm = 37 mm) resting on beam grid of (4500 x 1500 mm) as shown below is checked initially for strength and deflection.

The sandwich panel has maximum stresses about 84.3 Mpa < 125Mpa (See Fig 7). The deflection in aluminium sandwich panel is reported here, being the allowable Deflection under DL + WL = Span/90 = 4500/90 = 50 > 39.2 (See Fig 8). --OK

Figure 6: Imposed loading (left) and wind loading (right) on aluminum shell elements

Figure 7: Maximum stresses under 1.4 DL + 1.4 WL (Left) and under 1.2 DL + 1.2 WL + 1.2 LL (Right)
Allowable Deflection under DL = Span/500 = 4500/500 = 9mm > 2.24mm ----OK
Allowable Deflection under DL + LL = Span/200 = 4500/200 = 22.5mm > 15.4mm ----OK
The Aluminium Sandwich panels are Safe for both ultimate limit states and serviceability limit states.

Checking of glass panel for strength and deflection:
The glass panel (13.52mm + 16mm(space) + 8mm = 21.52mm) resting on beam grid of (1500x1500mm) as shown in Fig 9 is checked initially for strength and deflection. Conservatively, it is assumed to be without the air gap and furthermore, it is considered to be flat although in real situation it is curved, therefore in real scenario will have reduced stresses due to membrane action as well deflection. The glass has maximum stresses of about 38.4 Mpa < 50 Mpa (See Fig 10) -Hence Safe
Allowable Deflection under any the adopted load combination equals Span/60 = 2250/60 = 37.5 mm > 23.8 mm (See Fig 11)
The design is carried out taking into account all the loading combinations and the Demand to Capacity ratios has been checked, as shown below.

Under the assumed load combinations, the Demand to Capacity ratio as shown in Fig 12 has been observed. It is evident that the ratios are less than 0.6, which seems that all the sections are satisfied for strength. The maximum demand to capacity ratio is found 0.52.

This shows that the most critical load combination is 1.2(DL+WL+LL1+LL2), hence, together with 1.4(DL + WL) load combination the stresses are shown also for this load combination.
Low stresses has been observed under combinations other than the above two combinations.

Fig 12: Obtained Demand to Capacity ratios

Fig 13: Stresses in shell elements under 1.4DL+1.4WL (left) and under 1.2(DL+LL1+LL2+WL) (right)

Fig 14: Overall model deflection (left) under dead and imposed, (right) under dead and wind load
In the following section, the strength and deflection checks of longitudinal frames are addressed.

**Stresses and Deflections in Longitudinal Frames**

Maximum allowable stress = 275Mpa > 88.4 Mpa ------Hence Safe Enough (See Fig 15).
Allowable deflection = Span/200 = 27000/200 = 135mm > 54.4mm, Hence Safe Enough (See Fig 16).

**Stresses and deflections in transversal frames:**
Frame E govern the design, both for ultimate limit state and serviceability limit state. Maximum allowable stress = 275Mpa >196.7 Mpa, Hence Safe Enough

Allowable deflection = span/200 = 12000/200 = 60mm >54.4mm Hence Safe Enough
In Secondary elements the relative displacement is very small and it is normally less than 2mm, as an example, see the figure below for one of an element where the relative displacement under SLS is only 1.7mm. Also the stresses are generally too small. Limiting allowable displacement is span/200 = 1500/200 = 7.5mm
Frame to frame connection:

It is to be noted that longitudinally there is no moment at the joints as in the longitudinal direction the members are released and therefore do not transfer moment but can only transfer shear. In figure below, the shear force diagram is shown, the maximum shear force at the joint is observed to be 61.8 kN. Hence the connections are designed for this shear force. \(V_u\) (Shear) =61.8kN, the connections of the primary structural elements will follow these forces

Shear capacity of M20 bolt = 91.9 kN > 62/4 = 15.5 kN— Safe. Provide a channel to fit in between the main tube welded with through 6mm fillet weld (throat thickness 4.2mm) using E35 electrode and bolted to the main transversal frames. Use 4 M20 bolts. The channel profile will be bolted on one side and welded on the other side. The design of bolted side is as follows, Use 4 M20 bolt (minimum) and Use 6mm fillet weld (throat thickness equals 4.2mm) E35 Electrode for the cleats

For connecting the secondary members to the main frame members in longitudinal as well is the transversal direction, the maximum shear induced is 22 kN (approx.), therefore a cleat angle is provided, here the bolt has to transfer shear of 22kN to the main tube. Therefore M16 bolts will be enough. Use 2 M16 bolt and double angle cleat or a channel tube.
From the above results, the Bracket is subjected to the following. Maximum reactions due to Ultimate limit state $V= 22\text{KN}$, Assume Stainless Steel M16 bolts and therefore it is found safe.

**Sleeve connection:**
Since it is difficult to transport the transversal frame as one member, therefore, sleeve connections are made. These connections are located at a distance of 750mm from the joint where the curve member meets. The maximum shear at this point is about 41KN, a bending moment of 73 KN-m is recorded. The proposed connection is as shown below. Since six bolts are considered on one side, Axial Tension / Compression due to bending moment on group of bolts is $73/0.3 = 243 \text{KN}$, Vertical shear $= 41 \text{KN}$. Therefore, net axial shear in bolts will be $243 + 41 = 284 \text{KN}$. Shear capacity of M20 grade 8.8 bolts $= 71 \text{KN}$, Bolts required $= 284/71 = 3.9$ Say 6 bolts (for safety allowance) Use 6 M20 bolts (minimum)

**Checking the connection for shear,**
Shear area of the sleeve $(220 \times 170 \times 12) = 220 \times 12 \times 2 = 5280\text{mm}^2$

$$P_v = 0.6 P_y A_v = 0.6 (275) (2x 200x)12/1000 = 792\text{KN} \gt 284 \text{KN} \rightarrow OK$$

Maximum reactions under 1.4 (DL + WL) are $Fx = 22 \text{KN}$ (Shear), $Fy = 108 \text{KN}$ (Shear) and $Fz = 182 \text{KN}$ (Vertical compression), whereas Maximum reactions under 1.2 (DL + WL+ LL1+ LL2) are $Fx = 23 \text{KN}$ (Shear), $Fy = 112 \text{KN}$ (Shear) and $Fz = 187.7 \text{KN}$ (Vertical compression)

Provide 6mm fillet weld (throat thickness 4.2mm) all around the tube. Perimeter of the weld will be $250\times 2 + 200\times 2 = 900\text{mm}$ and Area of weld is $900\times 4.2 = 3780 \text{mm}^2$

Maximum $Fx = 23 \text{KN}$ (Shear), $Fy = 112 \text{KN}$ (Shear) and $Fz = 187.7 \text{KN}$ (Vertical compression), Resultant shear is 114KN and therefore the stresses in weld were found to be 30 Mpa < 220 Mpa, hence 6mm fillet weld (throat thickness 4.2mm) of E35 Electrode around the tube is recommended.

The base plate dimensions are calculated as per British Standards and found that using 400 x 300 x 20 (mm), thick steel base plate with s275 (yield strength 275 Mpa) is safe enough. The HIT-HY 200 M16 or any equivalent anchors bolts are recommended being conservatively with the assumption of Cracked Concrete [14] with very wide reinforcement. The anchor bolts are designed for the following loads. Maximum $Fx = 23 \text{KN}$ (Shear), $Fy = 112 \text{KN}$ (Shear) and $Fz = 187.7 \text{KN}$ (Vertical compression).

Hilti SAFEset HIT-Z anchor with HIT-HY 200 injection mortar with 96 mm embedment $h_{ef}$, M16, Steel galvanized, Hammer drilled installation per ETA 12/0028 or any other equivalent anchors are recommended.

**Conclusions:**
Aluminium metal sandwich panels having 2mm top and bottom thickness with 33 mm insulating material is Safe both for Ultimate Limit States and Serviceability Limit States and therefore shall be used as minimum. Fully tempered glass of 21.52mm thickness is Safe both for Ultimate Limit States and Serviceability Limit States and therefore shall be used as minimum 150 x 150 x 10 Hollow steel tube of S275 steel grade for the supporting structure for transferring loads to the main frame is Safe both for Ultimate Limit States and Serviceability Limit States and therefore shall be used as minimum.
250 x 200 x 12 hollow steel tube of S275 steel grade for the main structure for transferring loads to the base plate is Safe both for Ultimate Limit States and Serviceability Limit States and shall be used as minimum
M16 bolt of grade 8.8 and cleat angle or a channel tube 80x80x8 (minimum)mild steel of S275 steel grade on one side and 6mm fillet weld (throat thickness 4.2mm) on the other side of cleat for connecting the secondary members shall be used as minimum
M20 bolt of grade 8.8 with a channel of mild steel of S275 steel grade on one side and 6mm fillet weld (throat thickness 4.2mm) on the other side for connecting the longitudinal frame with the transversal frame shall be used as minimum
M20 bolt of grade 8.8 shall be used for the sleeve connection
M16 stainless steel bolt class 80 shall be used as minimum for bracket connection
400 x 300 x 20 mm thick base plate of S275 steel grade shall be used
Hilti SAFEset 4 numbers of HIT-Z anchor with HIT-HY 200 injection mortar with 96 mm embedment h_ef, M16, Steel galvanized, Hammer drilled installation per ETA 12/0028 shall be used as minimum

Acknowledgement:
The Author acknowledged the support of his employer ALUTEC W.L.L, Qatar’s largest Aluminium and glazing company, specializing in architectural Aluminium and glass products, Aluminium doors, windows, skylights, cladding projects and unitized as well in standard curtain walls systems.

References: