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Design and Performance Testing of a Skylight in Qatar

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Abstract. The current paper deals with a case study on façade industry with the purpose to be useful for the engineers involved in the structural and architectural design of curtain walls.

The research activity has been based on both the structural calculation and the experimental test on the Le Boulevard skylight in Doha (Qatar), measuring 36m by 18m in plan, located at a height of about 42 m and subjected to a wind load of 1.7 KPa. The skylight, composed of steel rectangular curved tubes, glass and aluminium sandwich panels, is designed for a basic wind speed of 25 m/s as per Qatar Construction Standards. Two types of steel frames have been designed, one to support both the glazing and aluminium sandwich panel, and another to transfer all the loads to the main structure.

Subsequently, a performance testing on a specimen extracted from the skylight has been performed. The test was carried out by Aluminium Technology Auxilliary Ind. (ALUTEC) on a specimen having length and width of 6.625 m and 3.315 m, respectively. The assessment procedures have been carried out following the “ASTM E283”, “ASTM E331” and “ASTM E330” standards. The results of the test have been found within the acceptable limits for the skylight components specified by the standards and required by the project specification.

The case study

Skylights are light transmitting fenestration forming all or a portion of a building space for day lighting purposes. The case study herein presented is a skylight specimen designed for the Le Boulevard building in Doha (Qatar) having plan dimensions of 6.625 m x 3.315 m. It is composed by 2 mm thick top and bottom aluminium metal sandwich panels (honey comb) with 33 mm insulating material interlayer, which have been combined with a roof glazing area of 13.52 mm (lite) laminated glass +16 mm (gap) + 8 mm (lite) fully tempered glass.

Aluminium 1100 H14 with proof stress of 135 MPa [1, 2] has been used for aluminium sandwich panels. The permissible deflection of such components under dead and wind load is span/90, whereas the same deflection under dead and imposed load is span/200 [3].The primary supporting structure is composed of 300 x 200 x 12 steel rectangular hollow tubes, whereas the secondary structure is composed of 60 x 60 x 5 square steel hollow tubes connected to the main structure. Steel grade S275 having yield strength of 275 MPa [4, 5] has been adopted for steel members. The glass is double glaze unit having 13.52mm outer laminated sheet with 1.52mm PVB, 16mm air gap and 8mm clear inner sheet. The allowable bending stress for glass is equal to 50 MPa. The respect of the serviceability limit state check for glass is guaranteed for a maximum deflection of span/60, whereas the same check for steel framing elements is satisfied whit a permissible deflection of span/200 [4].

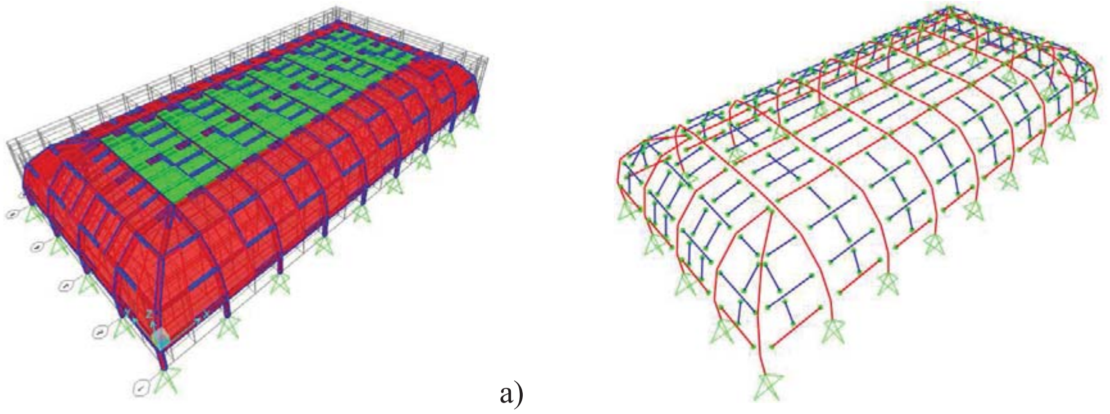
The structural analysis and design

The FEM model. The skylight has been modelled with the SAP2000 analysis program (Fig 1a).

With reference to the structural modelling, the transversal frames are assumed to be as continuous systems, since they are the main load bearing structures, while the longitudinal frames are considered as secondary frames, therefore pinned connected to the transversal frames (Fig. 1b). All the frames are pinned supported at their bases. Furthermore, conservatively, the slop of the skylight in the transversal direction is ignored, so to have the maximum bending effect and, consequently, the maximum deflections in the frame elements.

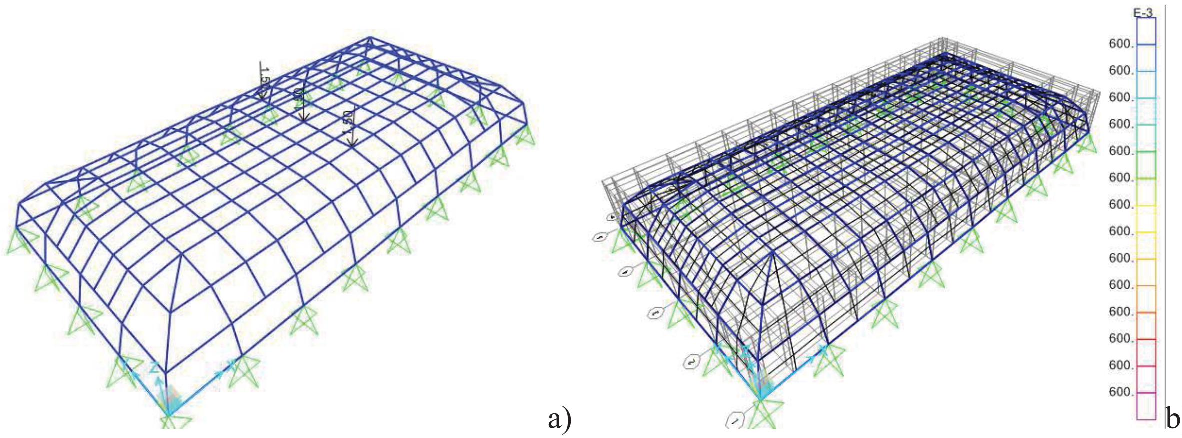
Dead Loads (DL) of tempered glasses, aluminium panels and structural elements have been automatically considered by the software, whereas two non-concurrent cases of Live Loads (LL) on the inaccessible roof, as established by the British Standards [6], have been considered, namely a concentrated load of 1.5 kN applied at most critical locations (LL 1, Fig. 2a) and a uniform load of 0.6 kN/m^2 (LL 2, Fig. 2b). Finally, the Wind Load (WL) has been set equal to 1.7 kPa for 25 m/s wind speed, as defined in the British and QCS 2014 standards [7, 8].

The design load combinations have been defined according to the BS 5950-2000 code [4].



a) b)

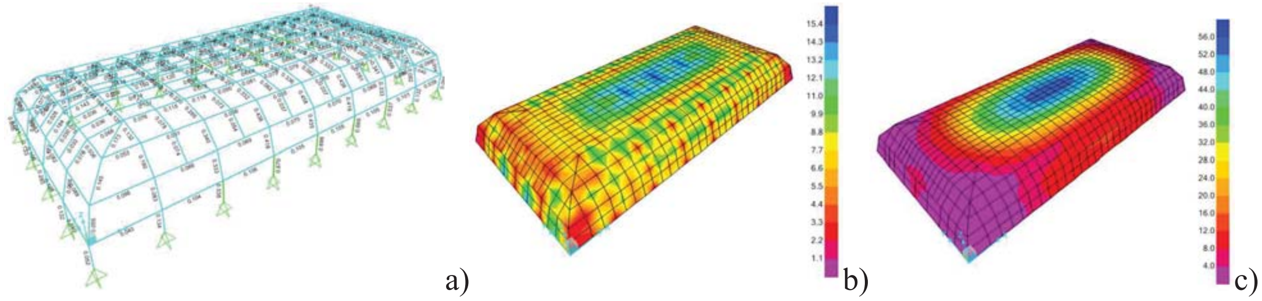
Figure 1. The FEM model with glass (red) and aluminium (green) panels setup with SAP2000 (a) and the frame element releases (b)



a) b)

Figure 2. Concentrated live loads [kN] (a) and uniform live loads [kN/m^2] applied on the roof (b)

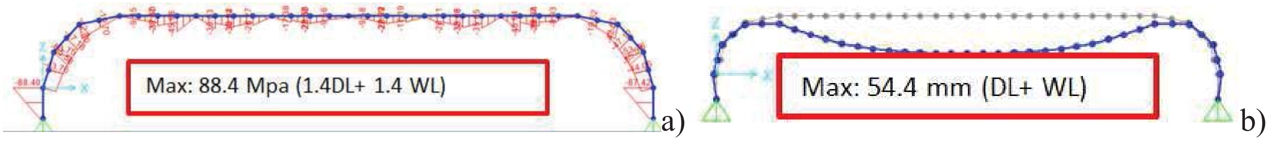
Structural checks. For each load combinations, the demand-to-capacity ratios have been evaluated for each frame member, as shown in Figure 3, where it is evident that the maximum value of such a ratio is 0.52, corresponding to the load combination 1.2•(DL+WL+LL1+LL2). In addition, the maximum stresses and deflections of shell elements corresponding to the worst loading combinations at ULS (1.2 • (DL+WL+LL1+LL2)) and SLS (DL + WL), respectively, have been indicated in the same figure.



a) b) c)

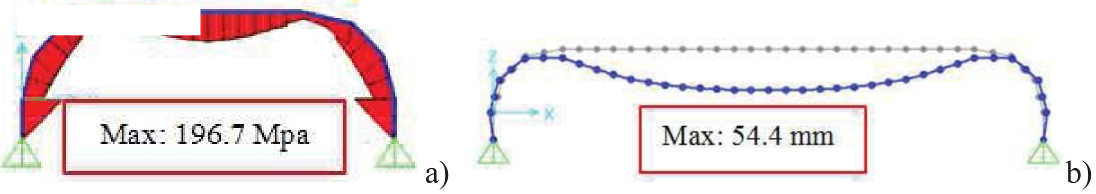
Figure 3. Demand-to-capacity ratios into frame elements (a) and maximum stresses at ULS (b) and maximum deflections at SLS (c) into roof shells

In particular, the maximum stresses and deflections into longitudinal and transverse frames are depicted in Figures 4 and 5, respectively.



a) b)

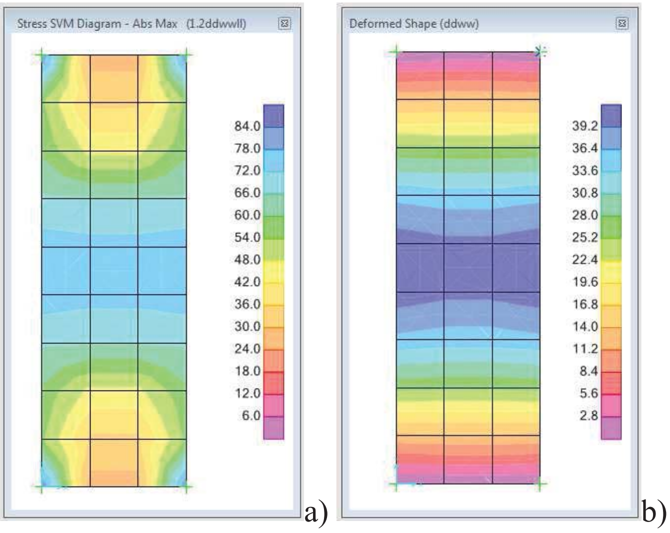
Figure 4. Maximum stresses (a) and deflections (b) of the longitudinal frame



a) b)

Figure 5. Maximum stresses (a) and deflections (b) of the transverse frame

Aluminium sandwich panels with thickness of 37 mm, placed on beam grids of 4500 x 1500 mm, have been checked initially for strength and deflection.

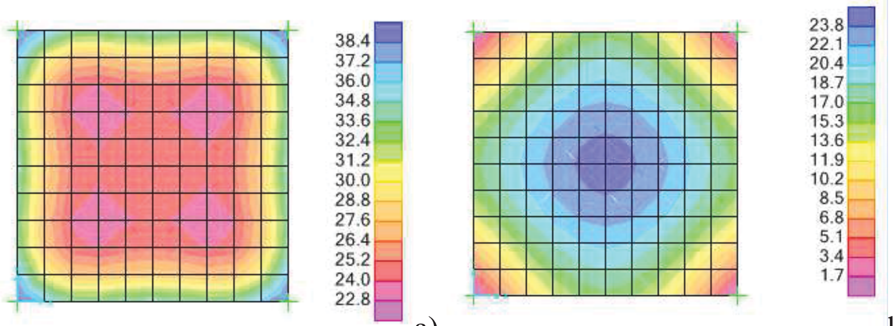


a) b)

Figure 6. Stress distribution under the worst load combinations at ULS (1.2 DL + 1.2 WL + 1.2 LL) (a) and maximum deflections at SLS (DL + WL) (b) for aluminium panels

The sandwich panels have maximum stresses of about 84 MPa (Fig. 6a), which are compatible with their maximum bending resistance (125 MPa). Moreover, considering that the allowable deflection of aluminium sandwich panel, equal to 4500/90 = 50 mm, is greater than the maximum displacement achieved under the design loads (39 mm, see Fig. 6b), also the serviceability check is fulfilled.

On the other hand, the tempered glass panels with thickness of 21.52 mm (13.52 mm + 16 mm (space) + 8 mm) are applied on beam grids of 1500 x 1500 mm. Conservatively, they are assumed to be without the air gap and, furthermore, they are considered to be flat instead of curved, in this way maximizing stresses and deflection. From the analysis it is noticed that the glass has a maximum stress of about 38.4 MPa < 50 MPa (see Fig. 7a). The maximum deflection is 23.8 mm, which is less than the allowable one (span/60 = 2250/60 =37.5 mm) (see Fig 7b).

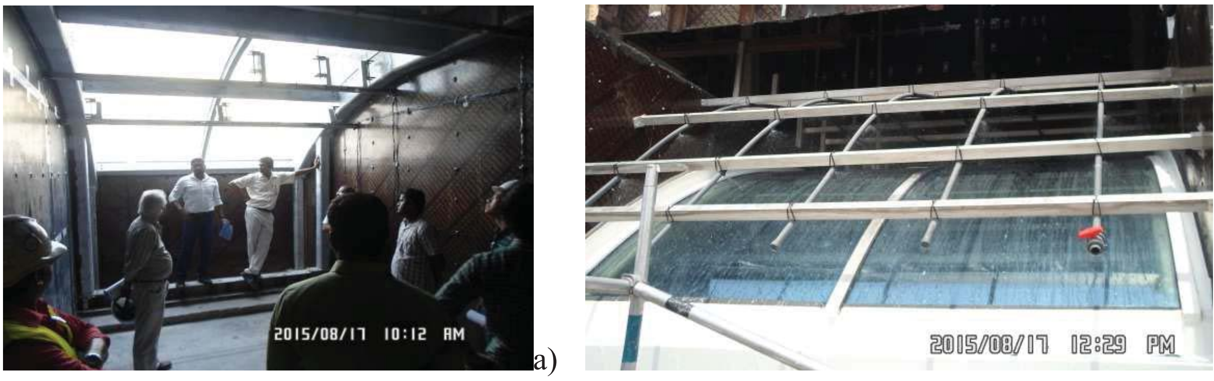


a) b)

Figure 7. Stress distribution under the worst load combinations at ULS (1.2 DL + 1.2 WL + 1.2 LL) (a) and maximum deflections at SLS (DL + WL) (b) for glasses

Performance testing

The performance test, which was supervised by Thomas Bell-Wright International Consultants (TBWIC), started with the air infiltration / exfiltration of the mock up witnessed by specialists. Initially, for the air infiltration / exfiltration test, the blower has been set to produce a negative chamber pressure of approximately 300 Pascal [9]. Testing was conducted using the chamber method for uniformly distributed loading. Each test frame was secured in a horizontal uniformly distributed load testing apparatus. The air within the test chamber was evacuated using a vacuum pump, inducing a uniformly distributed load to the sample (see Fig. 8).



a) b)

Figure 8. Inside view of the mock up (a) and specimen subjected to water pressure (b)

With regard to the structural performance test, ASTM E 330-02 [10] criteria were adopted. Nine Linear Displacement Transducers (LDTs) were positioned (See Figure 8) in place along internal side of the specimen to measure deflection values of steel tubes (LDTs 1, 2 and 3), glass (LDTs 4, 5 and 6) and aluminum sandwich panels (LDTs 7, 8 and 9). The test was initially carried out in the positive wind load direction with a negative chamber pressure (765 and 1530 Pascal at 50% and 100 % of its maximum capacity, respectively). In the process with the whole pressure application, the load was held for 10 seconds at the maximum value and deflections were recorded. After a recovery period of 1 minute, residual deformations were taken. There was no visual failure noted and, therefore, the test result was positive. Then, the negative wind load direction was considered with a pressure value equal to 1530 Pascals (100 % of the positive chamber pressure). After the test completion, there was no adverse effect or any kind of failure noted on the specimen and the test was recorded as successfully. The LDT displacements achieved during the test are summarized in Figure 10.

The actual deflections of the center of the steel member, glass panel and aluminium sandwich panel were obtained by taking the average value of the most outer LDT minus the results from the middle LDT. About aluminium sandwich panels, the actual deflection under positive loading at their center obtained from LDTs was equal to 5.88 mm (Fig. 11a). Similarly, under negative loading, the obtained deflection from the LDTs for aluminium sandwich panels was 7.43 mm (Fig. 11b).

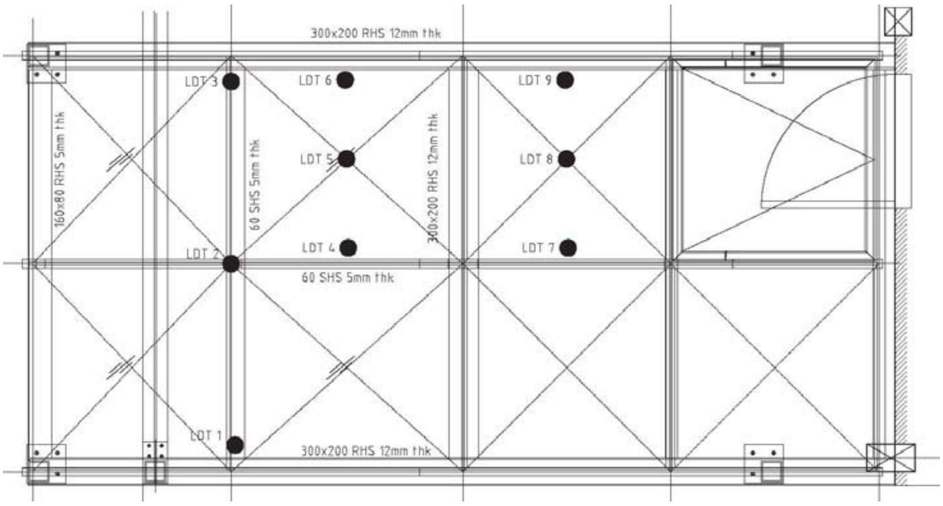


Figure 9. Linear displacement Transducer (LDT) location for experimental tests

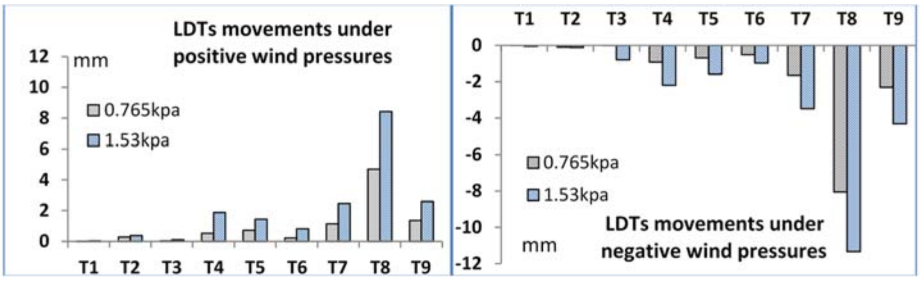


Figure 10. LDTs measured movements under positive (a) and negative (b) wind pressures

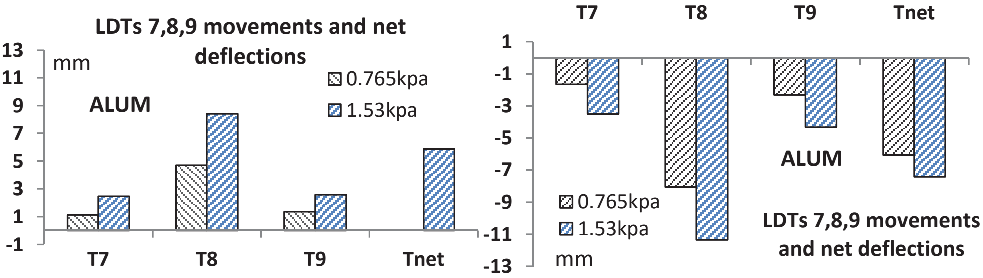


Figure 11. LDTs measured net deflection for aluminium sandwich panels under positive (a) and negative (b) wind pressures

In the case of post structural – static water penetration test, the spray rack set-up was the same as in the previous water test, positioned in accordance with standard requirements and rotameter gauges, controlling the water volume flow. Also in this case, a differential test pressure of 1000 Pa with duration of 15 minutes was applied. No water leakage was observed in any part along internal side of the specimen during the test and so the test was recorded as successfully passed among the witnesses. After the seal degradation, the external weather seals of the panel were removed to simulate degradation of seals with the passage of time. A water test at 1000 Pa for 10 minutes followed after removing the seals and the result did not show evidence of water leakage inside and around the glass panel, showing the adequacy of the adopted system.

Lastly, for the structural proof load test, the same nine LDTs were kept in the positions already indicated (Figure 8). The test was firstly carried out in the positive wind load direction, with negative chamber pressures of 1147 Pa and 2295 Pa, respectively equal to 75% and 150% of the maximum pressure allowable by the specimen. At the peak pressure before mentioned, the pressure was held for 10 seconds and deflections were recorded. After a recovery period of 1 minute, residual deformations were taken. There was no visual failure noted and so the test was recorded as passed.

Finally, the test procedures were carried out with the negative wind load direction by applying 1147 Pa and 2295 Pa, which corresponded to 75% and 150 %, respectively, of the positive allowable pressure sustainable by the specimen. The test pressure at the maximum value was sustained by the specimen without showing any crack or adverse effect to constitute failure and so the test was judged successfully. Therefore, the specimen was dismantled with the record of the system components.

Concluding remarks

In the paper numerical analyses and experimental tests on a skylight mock-up made of steel frames, aluminium sandwich panels and fully tempered glasses have been presented. About design checks, all the components have been found to be safe at Ultimate and Serviceability Limit States. Also, under the applied water penetration test, carried out before the structural performance test, the mock-up satisfied the limitations prescribed by ASTM standards, proving the adequacy of the system as well the sealant used. The mock-up was subjected to a proof load as well. The structural performance test under proof load equivalent to ULS was successfully performed, thus recommending using the same arrangement, as the one installed for the mock up, in order to have a useful life of the structural system under service condition. By the visual controls done after dismantling the testing sample, it was observed that glass, sandwich panels, brackets and fasteners did not undergo any damage. Therefore, the adopted mock-up can be considered suitable to successfully act as a curtain wall system.

References

[1] BS 8188-1, Structural use of aluminium, Part 1: Code of Practice for Design, 1991.

[2] BS 8188-2, Structural use of aluminium, Part 2: Specification for materials, workmanship and protection, 1991.

[3] BS 5427-1, The use of profiles sheet for roof and wall cladding on buildings, 1996.

[4] BS 5950-1, Structural use of steelwork in building, 2000.

[5] BS 5950-2, Specification for materials, fabrication and erection — Rolled and welded sections, 2001.

[6] BS 6399-3, Loading for buildings, Part 3: Code of practice for imposed roof loads, 1988.

[7] BS 6399-2, Loading for buildings, Part 2: Code of practice for wind loads, 1997.

[8] QCS 2014-2010, Qatar Construction Specifications, 2014.

[9] C. Lopez et al., Water penetration resistance of residential window and wall systems subjected to steady and unsteady wind loading, Building and Environment 46 (2011) 1329-1342.

[10] ASTM E330 / E330M - 14, Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference, 2014.