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# On the deflection of window glass subjected to lateral forces

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**Abstract**: This paper deals with the deflection of double glazed unit made of glass. Some results obtained from the structural testing for deflection only has been mentioned. Structural performance has also been compared with a simplified numerical model of the window in Robot Structural Analysis software. Furthermore for a quick check the glass has been checked following "ASTM E1300" standard using software tool "Window Glass Design", considering it to be rectangular unit. Quite good agreement has been found between the results obtained from the structural testing and numerical model when subjected to pressure. The cause of disagreement in the deflection values when the DGU is subjected to suction and pressure are not dealt in this report.

***Keywords:*** *Structural Testing, Glass, Windows, Façade Engineering, Wind Pressure, Glass Standards*

## Introduction:

The purpose of testing windows, curtain walls and building facades is to ensure that the products will perform as intended, and if not, to find out the reason behind the failure. For mega projects of building structures it is valuable to perform a mock up test (Chew, Wong et al. 1998).

Previously it has been found that when the DGU is subjected to pressure, both of the glazing lites contribute to the deflection, whereas when the unit is subjected to a pull on one lite, the other lite equally deflect inward but does not globally contribute to the deflection and hence slightly deflects more. This is more probably due to the fact that when the glass lite that is subjected to pressure (push in a way), the lite deflect outward, thereby pressing the air gap in between the DGU and finally push the outer lite. In this case it is believed that the two lites of the DGU work equally contribute in a way. The air gap in between the lites helps as a rigid tie. Nevertheless, in the case when the inner lite is subjected to pull (suction), the inner lite deflect inward, the outer lite deflect too but contribute slightly less to the deflection.

The windows of a building must be strong enough to withstand the effects of wind without breakage. The wind pressure may be positive or negative on a window, depending on its location, height and the orientation of the building surface to the wind and this is known as the pressure coefficient. The wind action also affects the barometric pressure inside the building. The here presented paper deals with the experimental activity of a window as shown in Figure 1. The window tested here is subjected to quite high wind load 2.55 Kpa.

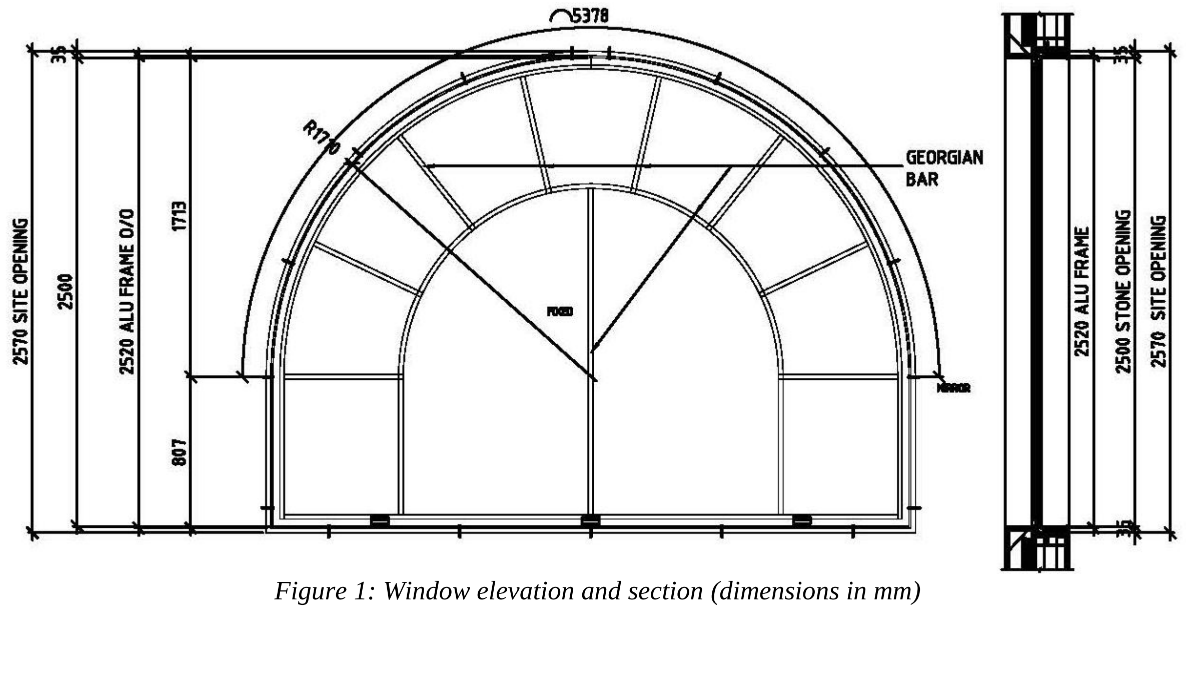


*Figure 1: Window elevation and section (dimensions in mm)*

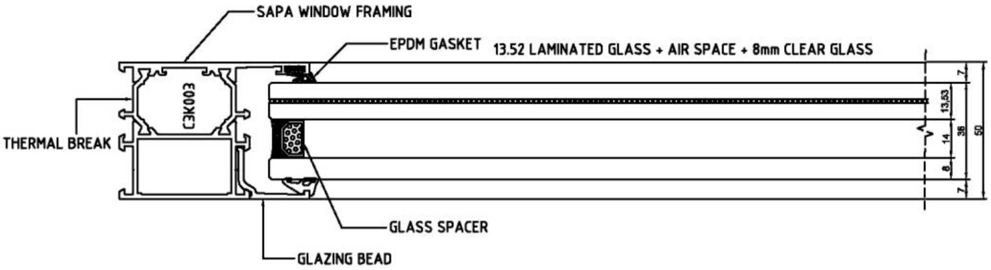


*Figure 2: Double glazed unit for the tested window (in mm)*

ALUTEC W.L.L is a certified IGU glass manufacturer. The IGUs are made as per ASTM E2190 and formed by sealing air or gas (organ etc.) between glass lites. During the sealing process the initial pressure and temperature of the trapped air are the same as atmospheric, and therefore the lites will remain flat if they do not deflect under self-weight. As long as the unit remains sealed, the mass of the air between the panes is constant and obeys Charles Law. If all the boundaries of the air space are perfectly rigid the volume would be constant too, and changes in pressure outside the unit would have no effect on the pressure inside the unit. If the pressure outside the unit increases while the temperature remains the same, pressure differential will cause the glass panes to deflect inward, thus decreasing the volume of confined air and vice versa. This is why, for special applications such as high altitude windows, it is important to consider the air pressure at the time of sealing and the air pressure at the glazing location.

Temperature changes result in pressure and volume changes. An increase in temperature causes outward deflection of the panes, and a decrease in temperature causes inward deflection. The change in pressure induced by a temperature rise of 2.7°C is about the same as that caused by a barometric drop of 1 kPa. Barometric pressure averages 101.3 kPa at sea level and drops by about 1 kPa per 100 m in elevation or altitude. This is why special care must be taken for units glazed at high altitude. Often, pressure equalization is required once the unit is installed, using pressure valves or capillary tubes. Panes of installed IGUs constantly deflect in and out with changes in climate. This puts stress on the edge seals and, if excessive, can shorten their life. It can also create changes in the appearance of transmission and reflection images, especially if the units are made from tinted or reflective glass. If the unit is large and/or square, the airspace may not be wide enough to stop the two panes deflecting in and touching, leading to an effect called ‘Newton’s rings’. The glass is no longer insulating if the panes are touching, and in some cases, the glass surfaces can rub and cause permanent surface damage inside the unit.

When the outer pane of an IGU is subject to external wind pressure it will deflect inward, therefore will push the air space, which acts like a spring and forcing the inner pane deflect as well. Some spring resistance is lost by the air space and thus the inner pane may not deflect the same amount. The actual amount of loss is a complex issue but codes provide load sharing formula to calculate the individual strength of each pane. If the panes of the IGU are the same thickness then it is considered that each pane is sharing the wind load due to the spring effect. This is a simplification as the inner pane may be already be deflecting outward (into the building) due to pressure and temperature changes. To calculate wind load deflection the load is shared and each pane calculated according to it thickness.

For the wind load design of an IGU, charts are generally provided in codes, for each glass type once the load sharing of each pane is calculated. For panes of equal thickness the load sharing factor is 0.625. If different glass types and/or thicknesses are used the calculations are more complex and computer software helps. However, as a simple guide it is conservative and safe to consider both panes to be the thinner and weaker of the glass types used. However, in reality there is a bit of cushioning by the airspace under wind load and the inner pane will deflect a little less, so it is better to have the stiffer glass to the outer pane, if possible but this is not always possible if the outer glass needs to match other windows. Heat treated glass such as toughened or heat strengthened glass may also have inherent bow or roller wave that can add to the apparent deflection in the unit and it is not advisable to use two large square thin panes of toughened glass in an IGU even if they meet the design load requirements. Deflection due to wind load is generally restricted to 1.5 times the airspace thickness, or 20 mm maximum, otherwise it can become visually disturbing. It is always advisable to have a large airspace for large units as the deflection due to pressure change can reduce performance and cause Newton’s Rings.

**Mock Up Description:**

The window is having Double Glazing Unit (DGU, see Figure 2) made up of 8 mm Stopray Vision-60T external lite with 16 mm Air (100%) having powder coated Georgian strips for aesthetic purpose and Stratobel 66.4 (6 mm Planibel Clear+ 1.52 mm clear PVB + 6 mm Planibel Clear) internal lite (ISO 9050 1990; EN 673 1997; EN 410 1998).

The chamber at the facility includes application of both positive and negative pressure having a capacity of about 4000 Pascals. Generally DGU is considered of two lites, external one (exposed to wind pressure) and internal. Under service condition, positive pressure means pushing of the external lite of the DGU by the wind pressure therefore deflecting inward and negative pressure means pushing of the internal lite of the DGU by the wind pressure therefore deflection outward. In the testing chamber, the positive pressure is simulated by producing negative pressure whereas the negative pressure is simulated by inducing positive pressure in the chamber.

*Figure 3: Window subjected to water pressure (Left), Window after the testing (Right)*

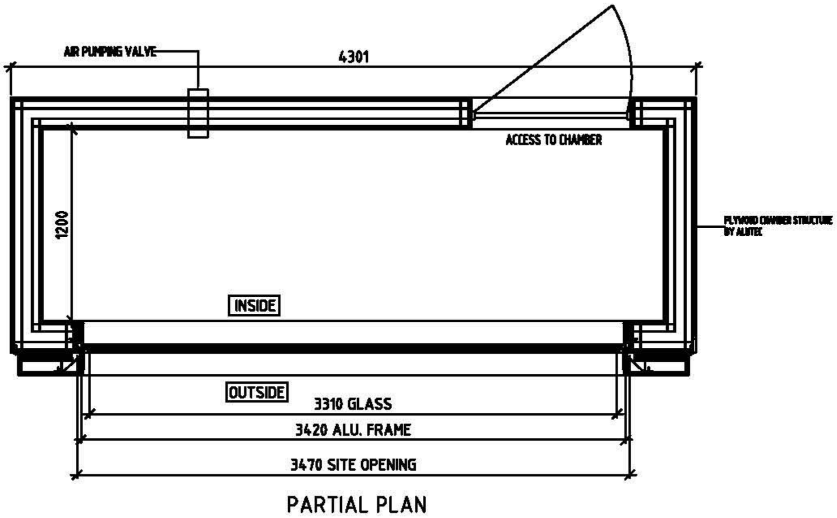


*Figure 4: Partial plan of testing chamber at ALUTEC facility*

**Table 1: Deflection limitations for glass**

| Reference code | Prescribed Deflection limitation | Remarks |
|---|---|---|
| AS 1288-1994 (AS 1288 2006) | L/60 | Deflection of 2, 3 or 4 edge supported glass under design wind loading |
| ASTM E 1300-94 (ASTM E1300 2003) | 19mm | Deflection of glass (not mandatory) |
| BS 5516 (BS 5516 2004) | Hermetically sealed double glazing: minimum of ($S^2$x 1000)/540 or 20mm | Allowable deflection of 2-edge-supported glass where S =span (m) of supporting edge |
| BS 5516 (BS 5516 2004) | Hermetically sealed double glaze unit: minimum of ($S^2$x 1000)/175 or 40mm, | Allowable deflection of the edges of 4-edge-supported glass where S =span (m) of supporting edge |

The permissible stress value under Ultimate limit state for fully tempered glass is adopted as 50 MPa (AS 1288 2006) whereas the deflection limit under serviceability limit state is considered as span/60 or 25mm, whichever is less, this is as per the project specifications, Some codes prescribe the deflection limitation as shown in Table 1.

In the numerical model, the dead load is calculated by the software, whereas wind load of 2.55 kPa is applied as surface pressure. The window is subjected to dead load, and wind pressure. Stresses and deflection from the numerical model have been carried out for glass and found safe according to different acceptance criterion (Leo Chan 1999; prEN 13474-2 2000; AS 1288 2006; prEN 13474-3 2009).

In addition to the numerical model, Window Glass Design tool (Window Glass Design. 2002) has also been used which performs all required calculations to design window glass according to ASTM E 1300-02, considering window to be of rectangular shape. Therefore it has also been used to check and verify the Double Glaze Unit. The applied short duration load of 2.55 kpa (3 sec) resulted in a load resistance for the adopted glass as 8.79 kPa and approximate center of glass deflection as 22.3 mm.

**Performance Test:**

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 positive wind load was simulated by producing a negative chamber pressure (in this case the inner glass was pulling) and similarly positive chamber pressure was produced thus simulate the negative wind load. The air within the test chamber was evacuated using a vacuum pump, inducing a uniformly distributed load to the sample.

With reference to the structural performance test, ASTM E 330-02 (ASTM E330 / E330M - 14 2014) criteria were adopted. About 12 Linear Displacement Transducers (LDTs) were positioned (See Figure 5) in place along internal side of the specimen to measure maximum central deflection value of the window. The test was initially carried out in the positive wind load direction, i.e. negative chamber pressure (2000 Pascals and 2550 Pascals). In the process of 100 % load application, the load was held for 10 seconds and deflections were recorded (See Table 2). After a recovery period of 1 minute, residual deformations were taken. There was no visual failure noted but the deflection values were exceeding the permissible value. Immediately the negative wind load direction followed with a pressure value equal to 2550 Pascals (i.e. positive chamber pressure) was carried out in the same procedure. After completion of the test there were no adverse effect or any kind of failure noted on the specimen and the test was recorded succeeded as the specified maximum, deflection of 25mm was satisfied. The failure of the test under the negative chamber pressure (simulate as positive wind pressure) is due to the fact that the air gap is not working as a tie. On the contrary the DGU window satisfy the performance test under positive chamber pressure (being the window is subjected to push from inside, simulate as suction). It is believed that the air gap work as a rigid link between the two glass lites. Generally in real scenario the windows are not subjected to a direct pull and therefore in order to check them for positive pressures, it is recommended to either utilize an external jet or to reverse the direction of the window being this is considered beyond the scope of the current paper.

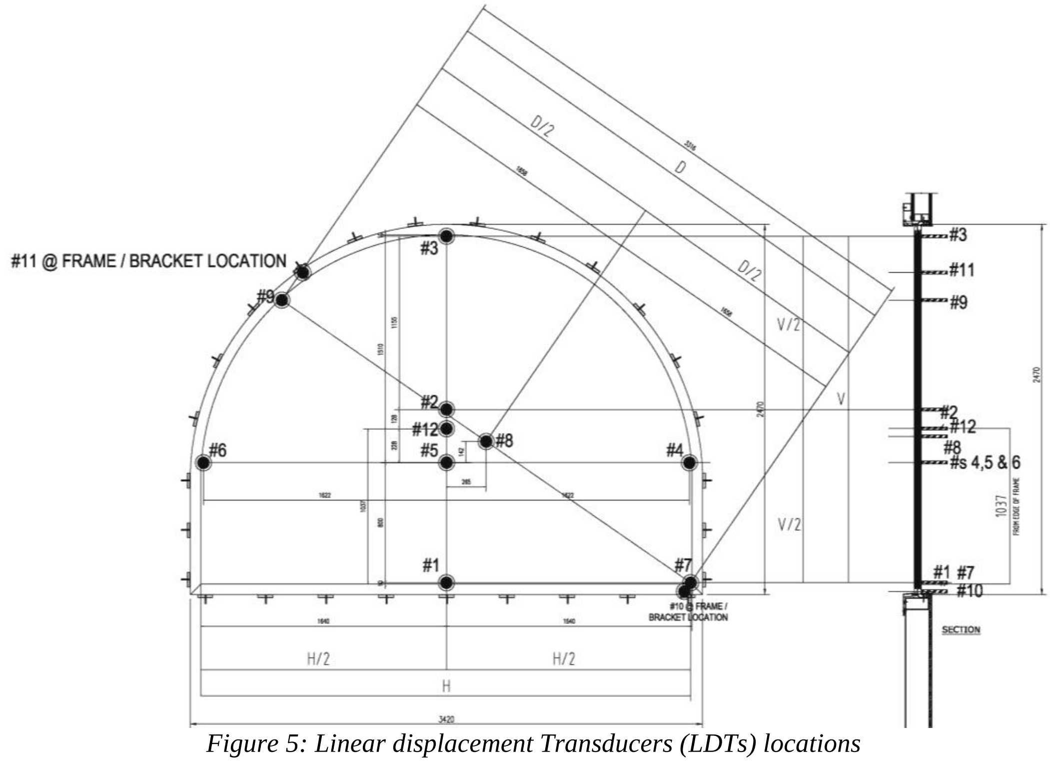


*Figure 5: Linear displacement Transducers (LDTs) locations*

**Table 2: LDTs movements under positive and negative wind pressure**

| *Loading (kPa)* | *Movement of LDTs in mm* | | | | |
|---|---|---|---|---|---|
| | *T1* | *T2* | *T3* | *T4* | *T5* |
| (+) 2.55 | 13.91 | 39.7 | 5.63 | 6.08 | 6.38 |
| (-) 2.55 | -10.18 | -23.98 | -5.38 | -6.65 | -7.35 |

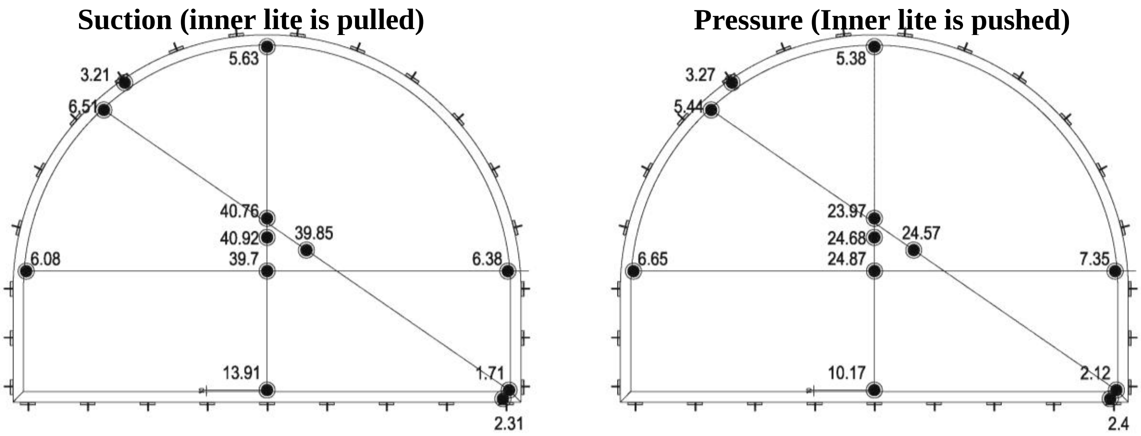


*Figure 6: LDTs movements under positive (left) and negative (right) wind pressure*

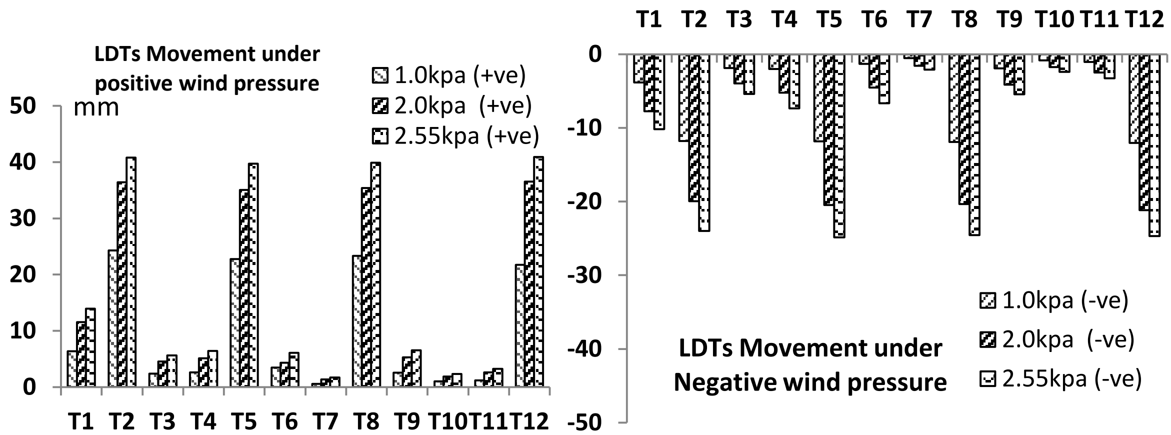


*Figure 7: LDTs movements under positive (left) and negative (right) wind pressure*

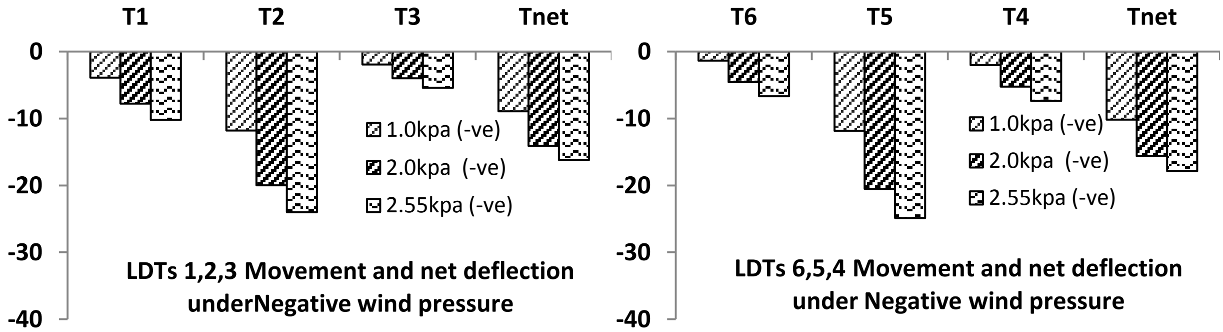


*Figure 8: Movement and net deflection of LDTs 1, 2 & 3 (left) and LDTs 6, 5 & 4 (right) under negative wind pressure*

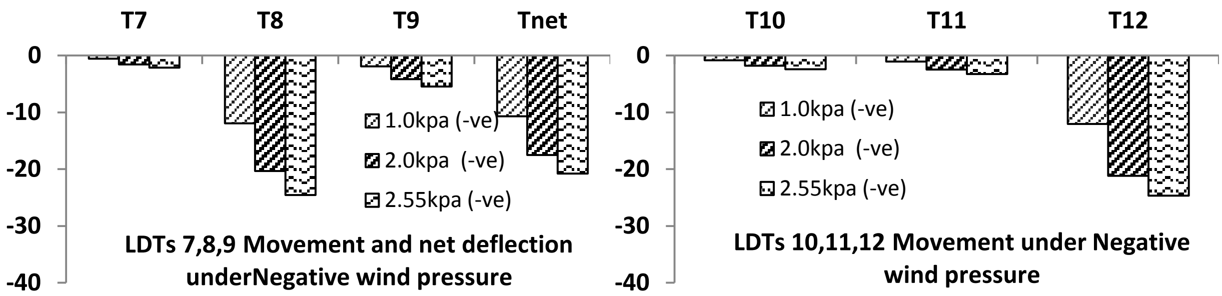


*Figure 9: Movement and net deflection of LDTs 7, 8 & 9 (left) and Movement only of LDTs 10, 11 & 12 (right) under negative wind pressure*

**Table 3: LDTs movements and net deflection under positive and negative wind pressure**

| ***Pressure (kPa)*** | **T1** | **T2** | **T3** | ***Dnet*** | **T6** | **T5** | **T4** | ***Dnet*** | ***T7*** | ***T8*** | ***T9*** | ***Dnet*** | ***T10*** | ***T11*** | ***T12*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (+) 2.55 | 13.91 | 40.77 | 5.64 | 30.99 | 6.08 | 39.7 | 6.38 | 33.47 | 1.71 | 39.85 | 6.52 | 35.74 | 2.31 | 3.22 | 40.93 |
| (-) 2.55 | 10.18 | 23.98 | 5.38 | 16.20 | 6.66 | 24.88 | 7.36 | 17.87 | 2.12 | 24.58 | 5.44 | 20.79 | 2.40 | 3.28 | 24.68 |

It has been observed (See Table 3) that maximum net deflection for the LDTs under negative wind pressure is 20.79mm which is less than 25mm. Nevertheless, the maximum net deflection obtained from the LDTs under positive wind pressure is 35.74mm which reveals that the DGU deflects more under positive wind pressure. The difference needs to be investigated precisely but is believed to be address later, therefore considered beyond the scope of the current paper.

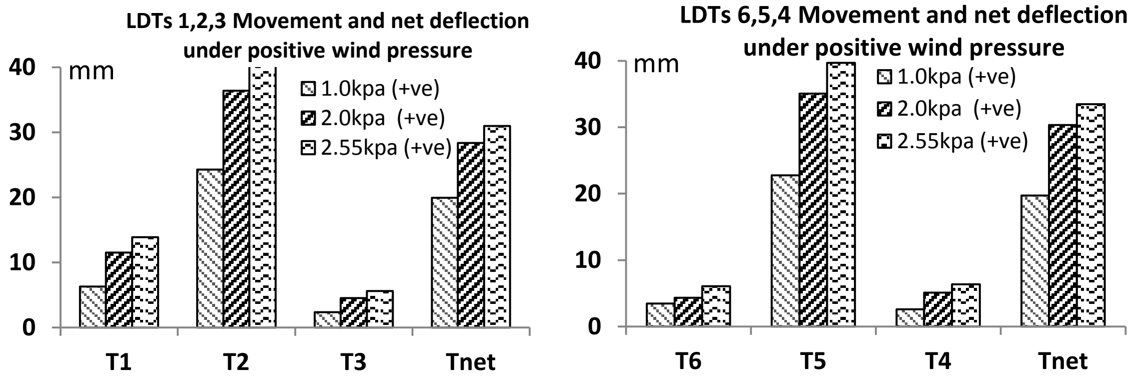


*Figure 10: Movement and net deflection of LDTs 1, 2 & 3 (left) and LDTs 6, 5 & 4 (right) under positive wind pressure*

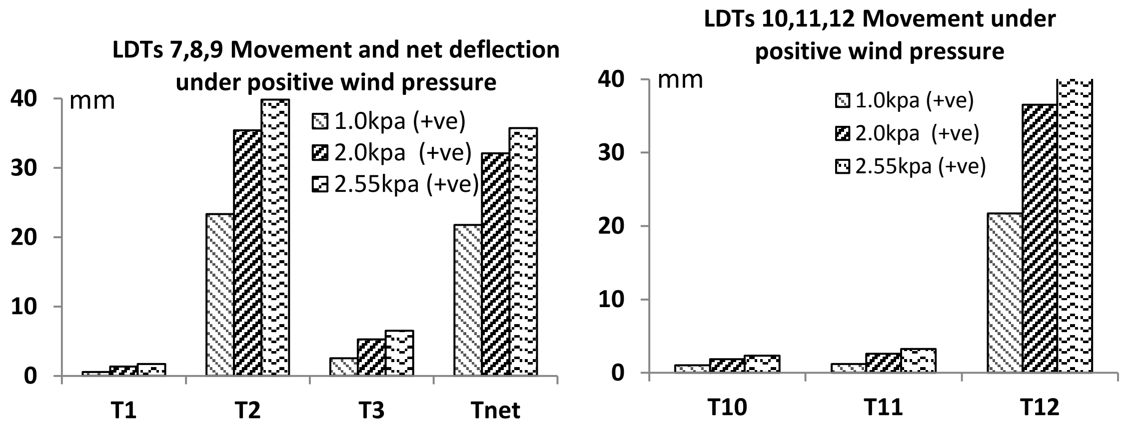


*Figure 11: Movement and net deflection of LDTs 7, 8 & 9 (left) and Movement only of LDTs 10, 11 & 12 (right) under positive wind pressure*

The actual deflection of the center of the glass was obtained by taking average of the outer most LDTs and subtracts the results from the middle LDT.

**Numerical Analysis:**

In this section, numerical model (see Figure 13) has been produced for the window using shell elements. It is assumed that the air gap does not exist and moreover the window is subjected to direct pressure only. The model is subjected to the specified wind pressure of 2.55kPa. The window is restrained at the edges following the same spacing for the brackets (See Figure 13) as used in the mock up.

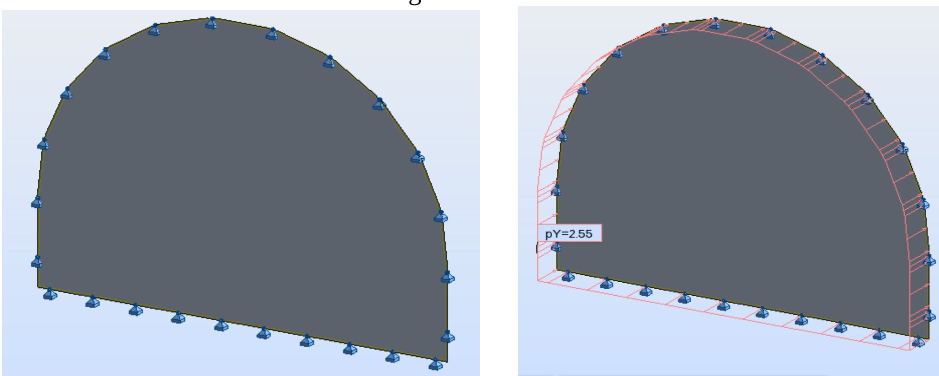


*Figure 12: Numerical Model (Left) and Wind pressure on the Numerical model (right)*

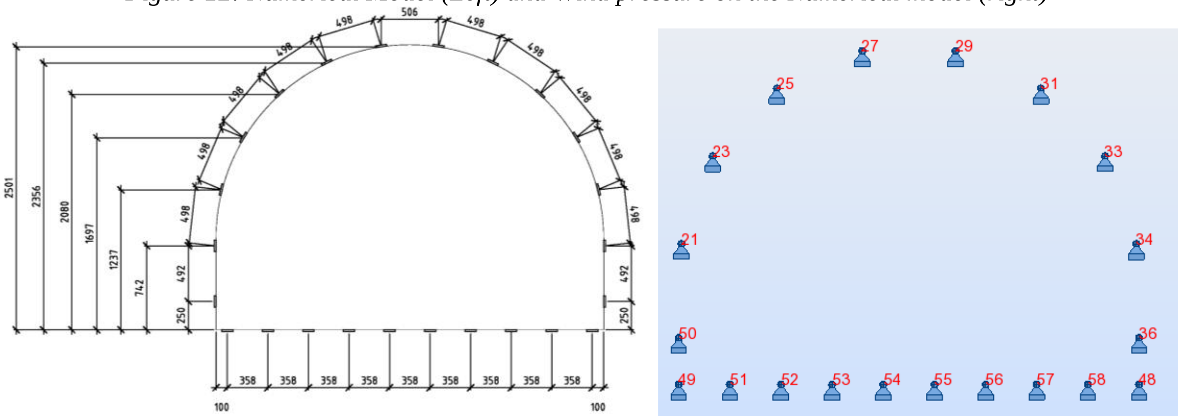


*Figure 13: Mock up showing the bracket locations (left) dimension in mm (right) support numbering*

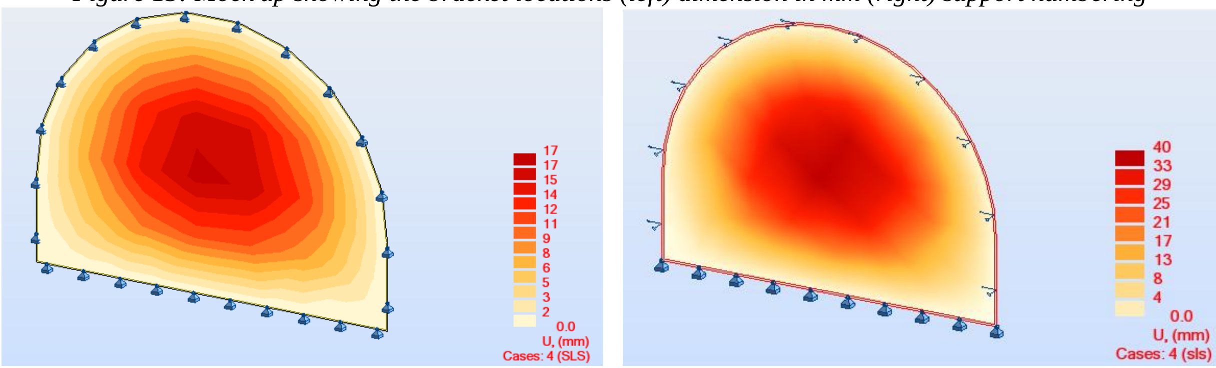


*Figure 14: Induced deflection using 18mm thick glass (right) and using 13.52 mm thick glass under SLS (left)*

Deflections obtained from the numerical model (See Figure 14) have been found within the permissible limit. The stress contour shows high stresses at the mid and at the edges of the glass. The induced center deflection in the glass under serviceability limit states from the numerical model equals 17 mm which is within the acceptable limits and is quite comparable to the one obtained from experimental performance test when subjected to pressure.

**Conclusions:**

- The window mock is found safe structurally as per the experimental mock up test and as per ASTM E1300 criteria.
- It has been observed that maximum net deflection for the LDTs under negative wind pressure is 20.79mm which is less than 25mm. Whereas, the maximum net deflection obtained from the LDTs under positive wind pressure is 35.74mm which reveals that the DGU deflects more under positive wind pressure. This disagreement of the deflection values when the DGU is subjected to suction and pressure are not dealt in this report but aimed to be address later on.
- The numerical model generated for the window as well for the brackets gives satisfactory outcomes as per the acceptance criteria. The numerical results even though with a simplified model show acceptable agreement between the test results and the theoretical calculations of ASTM as per Window Glass Design tool.

**References:**


[1] AS 1288 (2006). "Glass in Buildings: Selection and Installation." Australian Standard.

[2] ASTM E330 / E330M - 14 (2014). Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference. West Conshohocken, PA, 2014,, ASTM International, .

[3] ASTM E1300 (2003). "Standard practice for determining load resistance of glass in buildings." ASTM Standard.

[4] BS 5516 (2004). "Patent Glazing and Sloping Glazing for buildings." British Standard.

[5] Chew, M., C. Wong, et al. (1998). Building Facades: A guide to common defects in tropical climates, World Scientific.

[6] EN 410 (1998). Glass in building - Determination of luminous and solar characterization of glazing, European Committee for Standardization

[7] EN 673 (1997). Glass in building - Determination of thermal transmittance (U-value) - Calculation method, European Committee for Standardization

[8] ISO 9050 (1990). Glass in Building: Determination of Light Transmittance, Solar Direct Transmittance, Energy Transmittance and Ultra-violet Transmittance, and Related Glazing Factors. Geneve, Swizerland.

[9] Leo Chan (1999). "Structural Use of Glass in Buildings." The Institute of Structural Engineers.

[10] prEN 13474-2 (2000). "Glass in building- Design of glass panes-Part 2: Design for uniformly distributed loads." European Standard.

[11] prEN 13474-3 (2009). "Glass in building - Determination of the strength of glass panes - Part 3: General method of calculation and determination of strength of glass by testing." European Standard.

[12] Window Glass Design. ( 2002). Standards Design Group, Inc. 8212 Ithaca, Suite 8, Lubbock, TX 79423-5086.