# Experimental Investigation of Jalousie Type Window Frames Subjected to Static Wind Pressure

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**Abstract –** *Glazing components of a building envelope refer to windows, doors, or any portions made of glass that permit light and provide an outside view of a building. However, in the presence of severe winds, glazing components are prone to failure.This study experimentally investigated the capacity of typical jalousie type window frames against simulated static wind pressures. The static wind pressures were simulated inside an air chamber to create a pressure difference across samples. In this study, five large-scale tests were performed where four of which experienced pull-through failures of the standard aluminum casing and one of which experienced breakage of glass blades. A four-point bending test was also done to measure the capacity of the glass subjected to uniform pressure. It was observed that the governing mode of failure for the window system was the pull-through failure at a mean pressure capacity of 4.218 kPa with a coefficient of variance of 0.23. The capacity of the glass was observed to fail at a higher mean pressure of 6.508 kPa with a coefficient of variance of 0.25. The threshold capacity obtained from this study will be useful for developing fragility curves of buildings in future studies.*

*Keywords—Jalousie, Window frame, Static Wind Pressure*

## I. INTRODUCTION

Glazing components of a building envelope refer to windows, skylights, curtain walls, doors, or any portions made of glass that permit light and provide a scenic view. However, in the presence of severe winds, windows and doors are vulnerable building envelope components. Failure of the glass can occur due to windborne debris and due to wind-induced pressures. The failure of these components allow the entry of wind and rain into the interior of the building and may induce progressive damage. Specifically, water leakage causes corrosion of frames and fasteners. (FEMA).

In the Philippines, there are many typhoon-prone area due to its geographic and meteorological setting (Yonson, 2015). These areas usually have jalousie type window frames used in residential and school buildings. Shown in Figure 1 is an example of a typical Department of Education school building. A jalousie type window frame has horizontal slats wherein it's opening, and closing is operated by a crank. This mechanism creates an unobstructed or obstructed view and provides effective ventilation. This type of window frame is preferred because it is economical and easy to repair (Modernize). Nevertheless, according to Graham (1959), these common flat glass jalousies are fragile and have low resistance to impacts and vibration. Thus, they shatter and break as results of gusts of wind.

**Figure 1.** Example of a one-storey school building (Department of Education)

To assess the vulnerability of the building envelope against wind loading, the standard deviation and mean of resistance capacities must be determined. These threshold values can be determined experimentally or numerically. In experimental methods, researchers may conduct small-scale, large-scale, or full-scale tests to simulate different wind loadings on building components (Mahaarachchi, 2003). These loadings can be in a static or cyclic manner, depending on the limitations of the equipment used (Bisa, 2017).

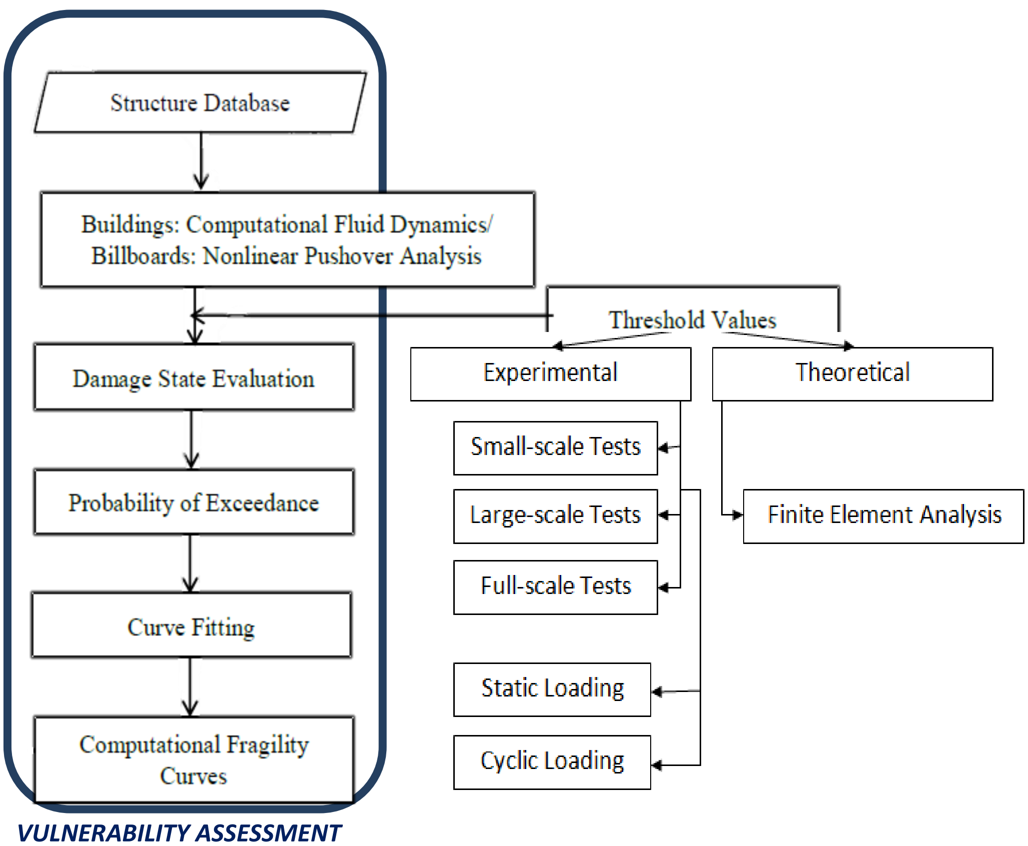


**Figure 2.** Conceptual Framework of the Study

Iizumi, E. and Kopp. G.A (2009) conducted full scale glass breakage tests on annealed glass specimens that were mounted on a steel pressure box. Gavanski, E. and Lopp, G.A. (2011) also conducted full scale glass breakage on 20 monolithic glass specimens for different test series. Failure pressures and failure times were recorded in a high airflow pressure loading actuator (HAPLA) that applied the different loading pattern such as ramp (static) loads, sawtooth loads, and fluctuating (dynamic) loads. They concluded that the threshold capacity of the glass is independent of the loading pattern (whether static or dynamic) used.

Many researches have already been done in the fragility and vulnerability assessment of different buildings. The GMMA-RAP (Greater Metro Manila Area-Risk Analysis Project) by UP Diliman Institute of Civil Engineering (2014) produced different vulnerability curves for different types of buildings. One of the critical assumption in the report was that the governing mode of failure is the breakage of glass. This threshold capacity was then estimated at a value of 3.332 kPa, which was based on a failure probability of 0.008 in accordance of ASTM E1300-02. Another vulnerability model by Tan (2017) used a threshold value of 2.5 kPa based on ASTM E1300-02 "Standard Practice for Determining Load Resistance of Glass in Buildings" for jalousie type windows. The glass jalousie which has 6-mm thickness and 525-mm length was assumed to be "simply supported continuously along two opposite sides." Note that these values used by researchers were design pressures based on a failure probability of 0.008.

As mentioned, previous researches of the Institute have only considered glass breakage as the only possible mode of failure for vulnerability assessments. But according to post-damage surveys of Typhoon Nina (2016), jalousie windows were observed to not only have glass breakage as a mode of failure, but the failure of the aluminum frame was also observed a common mode of failure. As to date, no published researches have been conducted to investigate the capacity of jalousie type windows frames. And the understanding of the behavior and capacity of these building envelopes are important for the vulnerability assessment of low-rise Philippine structures.

## II. EXPERIMENTAL STUDY

This paper investigates the possible modes of failure and determines the threshold capacity of typical jalousie type window frames used in the Philippines. An attachment system was developed to hold test windows in their actual mounting. Large-scale tests of windows were conducted by simulating static wind pressures in an air chamber developed by Bisa (2017). The window specimen was subjected to increasing suction pressure until a mode of failure was observed.

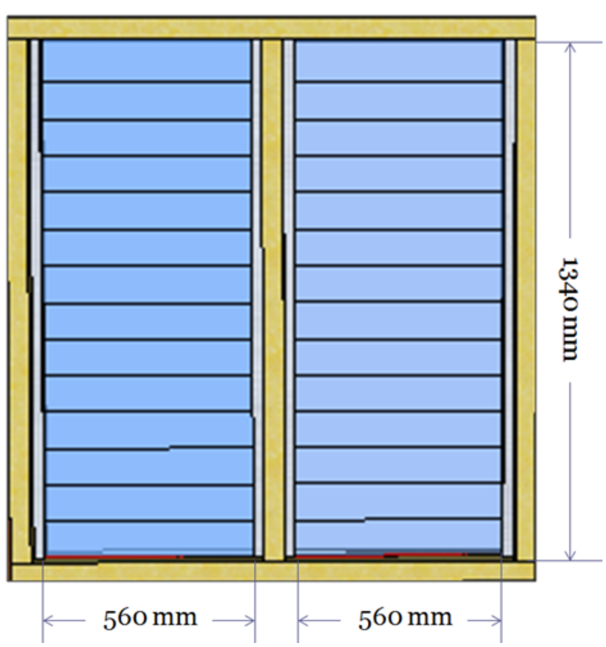


**Figure 3.** Dimensions of the test window

Typical design of window frames recommended by the Department of Public Works and Highways (DPWH) for standard one-story school buildings in the Philippines were investigated. The opening height and width of the panel differ by only 80 mm and 35 mm, respectively, from the standard design due to testing constraints.

*2.1 Specifications of test specimens and attachment system*

The window as shown in Figure 3 consists of 2 panels with 15 blades made of clear glass on each panel. The size of each blade is 22" by 4" by ¼". The frame is made of standard aluminum casing. Screws used as fasteners have diameter of 0.25" and length of 1.5". They are fastened on designated holes of the aluminum casing. The main window jamb is made of wood that has a cross-sectional area of 1.5" by 5.5".

The attachment system (2.6 m x 2.6 m) was designed to resist the simulated wind pressures. The casing is completely made of wood where internal braces have cross-sectional area of 1.5" by 5.5" and braces on edges, 1.5" by 1.5". A plywood of ½" thickness covers the exterior face of the casing. The attachment system with installed test window used in the study is shown in Figure 4.

*2.2 Experimental set up*

To investigate the different modes of failure, two experimental set-ups were used in the study. The first set-up was a large-scale set-up, which made use of the air chamber to subject the whole window unit to static suction pressure. Five Air Chamber (AC) samples for this set-up were investigated and were labeled respectively as AC1, AC2, AC3, AC4 and AC5. This allowed the researches to observed what mode of failure was likely to occur for the whole window unit. The second set-up was a small-scale set-up and was done to isolate and investigate the threshold capacity for the glass panel only. This made use of a universal testing machine and an attachment for a four-point bending test.

**Figure 4.** Attachment system with test window

The test sample (combination of attachment system and test window) was placed on top of the 2.4 m x 2.4 m x 0.4 m air chamber used in the study. To assure that air leaks are minimized, the edges of the attachment system were sealed by using polyethylene sheets and duct tape. The same materials were also used in sealing the test windows.

To simulate the static wind pressure, a 15-kPa blower was used to draw air until failure of the test window was observed. To measure the barometric pressure, a pressure sensor (BMP 180), as shown in Figure 5, was placed inside the air chamber. To measure the displacement of the midpoint of a window panel, a linear variable differential transformer as shown in Figure 6 was installed above the point of interest.

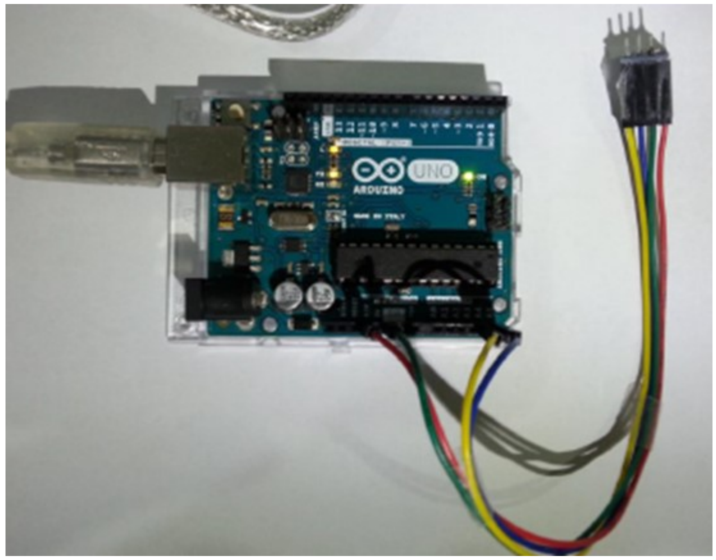

**Figure 5.** Pressure sensor (Bisa, 2017)

**Figure 6.** Linear variable differential transformer (Bisa, 2017)

In addition, a video camera was positioned in such a way that it was able to capture the failure of the test specimen. The complete set up of the experiment is shown in Figure 7.

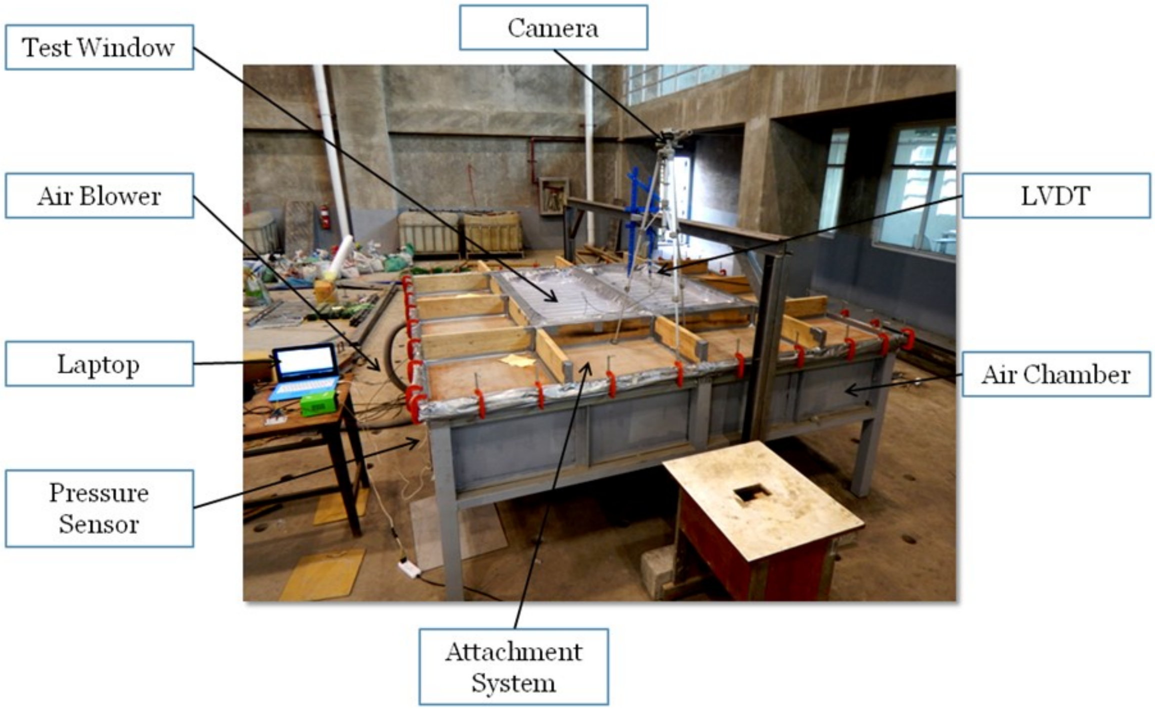


**Figure 7.** Complete set up of the experiment

The four-point bending test on the other hand were based on ASTM D790 and ASTM D7264. The support span and loading span used were 20 inches and 10 inches respectively to replicate the actual support condition of the glass blades. A universal testing machine was then used with a loading rate of 2.67 inches per minute. The set up is shown in Figure 8.

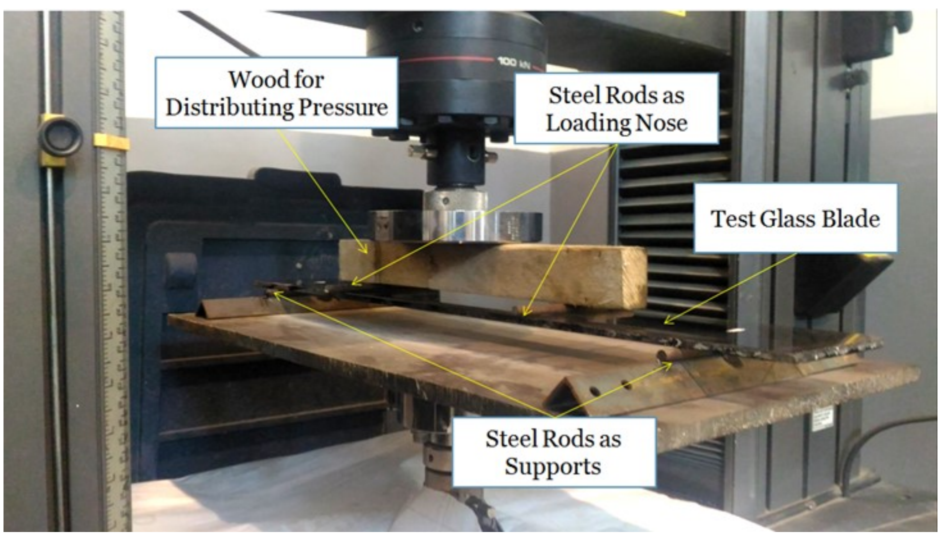


**Figure 8.** Four-point bending set up

## III. TEST RESULTS AND DISCUSSION

### *3.1 Failure Pressures and Failure Modes*

A failure in the set-up was defined as the inability of the test specimen to maintain differential pressure. This simulates the failure of a building envelope to prevent the increase of internal pressure. The failure of a building window envelope would lead to an increase of internal pressure and may lead to a greater differential pressure across the other building envelope components. There are two possible modes of failure observed in the study, namely: pull-through of the aluminum casing and breakage of glass blades. Based on the results, pull-through is more likely to occur when the jalousie type window frame is subjected to static wind pressure.

Pull-through is defined as the aluminum casing detaching from the screws used as fasteners. After the failure, the screws are still attached on the wooden window jambs. Figure 9 shows a test sample that experienced this mode of failure. In addition, the designated holes on the aluminum casing for the screws were damaged because of stress concentration that occurred around the head of screws.

Glass breakage is defined when the glass blades of the test specimen crack and eventually break. The breakage was initiated by a small crack at the middle portion of the panel. This crack then propagated across the adjacent glass blades towards the opposite ends of the panel. Figure 10 shows a test sample that experienced a breakage of glass blades.

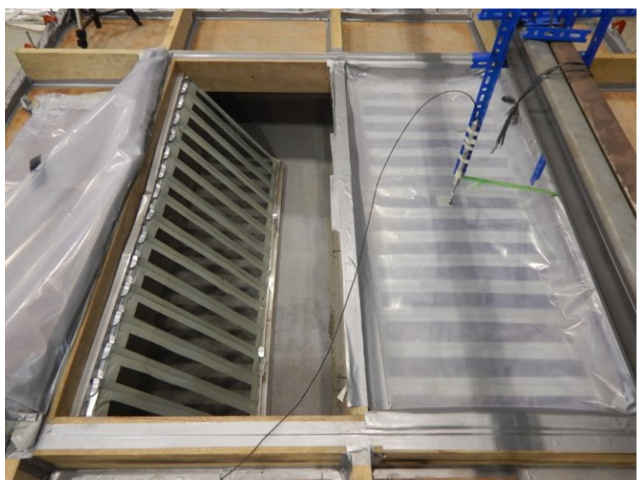

**Figure 9.** Pull-through failure of a sample

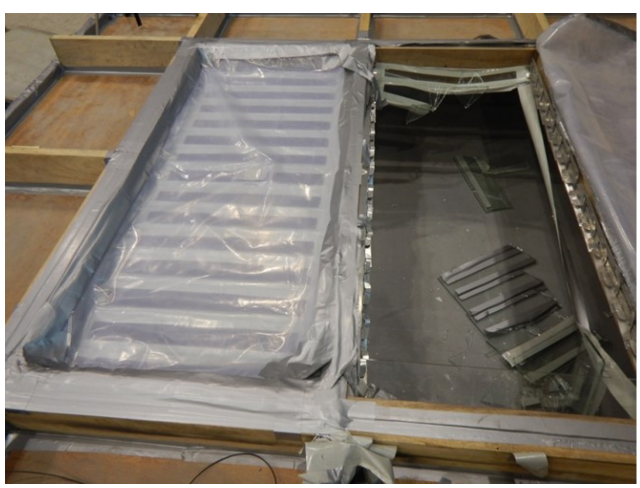

**Figure 10.** Glass breakage of a sample

The pressure-time curves for all the successful tests performed in the study are illustrated in Figure 11. The pressure difference, which is expressed in kilopascal, is calculated by determining the difference between the initial atmospheric pressure and the pressure inside the chamber upon failure. The deflection-time is shown in Figure 12.

The pressures in which failure occurred were identified by using pressure-time curves and recorded videos. As shown in Figure 11, the occurrence of failure can be identified by a sudden drop of pressure. This sudden drop is due to the specimen allowing air leaks and equalization of pressure outside the air chamber. However, a difference (absence of sudden pressure drop) in AC3 can be observed due to the pull-through failure not damaging the seal. The different rates of increase of pressure can be observed in the different tests. This is due to the variability in the sealing of the air chamber which made use of polyethylene sheets. Although it should be noted that Gavanski, E. and Lopp, G.A. (2011) concluded that the strength of the specimen is independent of the loading rate.

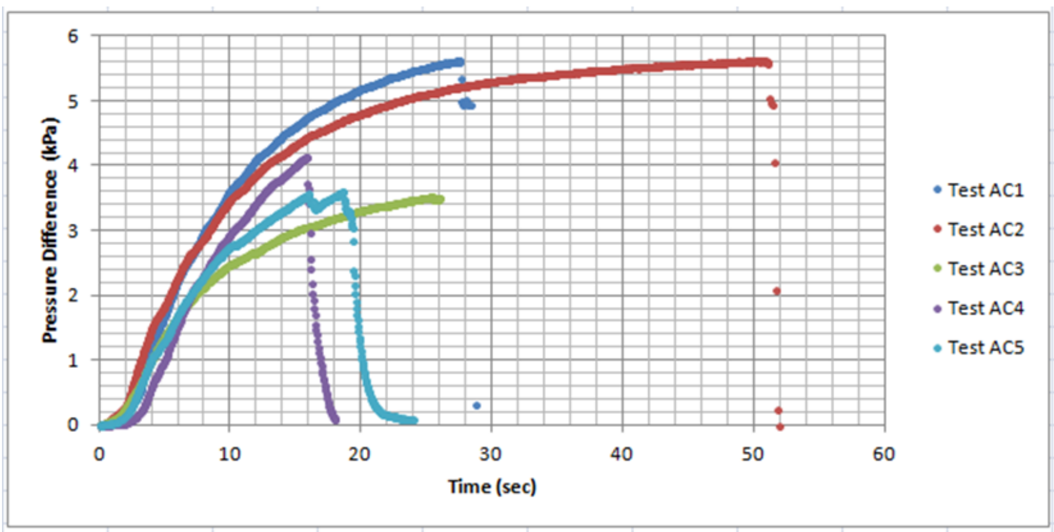


**Figure 11.** Pressure-time curves

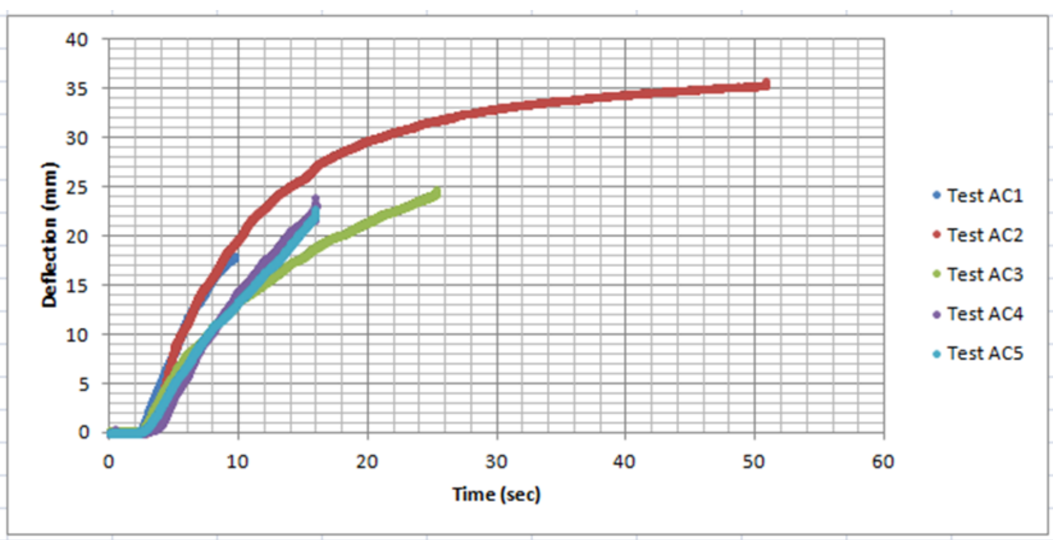


**Figure 12.** Deflection-time curves

In Figure 12, a time vs deflection curve is displayed. Failure is observed when the curve ended with a sudden increase, which is due to the LVDT measuring the panel suddenly falling. In addition, a linear relationship between the pressure difference across the window specimens and the deflection of a panel at midpoint is observed regardless of the loading pattern. The range of the maximum deflection for the failure of the aluminum framing is observed to be between 20 to 25mm. The differences in the measured capacities are due to the probabilistic nature of the strength of materials. The failure pressures and failure modes are summarized in Table 1.

**Table 1.** Failure pressures and failure modes of Air Chamber (AC) Test

| Sample | Failure Pressure [kPa] | Failure Mode |
|---|---|---|
| AC1 | 5.618 | Pull-through |
| AC2 | 5.639 | Glass breakage |
| AC3 | 3.529 | Pull-through |
| AC4 | 4.146 | Pull-through |
| AC5 | 3.577 | Pull-through |

For the four-point bending test, five samples were used to investigate the capacity of the glass panels used for jalousie windows. A summary of the results is presented in Table 2.

**Table 2.** Failure pressures and failure modes of Four-point bending Test (FBT)

| Sample | Failure Pressure [kPa] | Maximum Deflection [mm] |
|---|---|---|
| FBT1 | 6.641 | 6.036 |
| FBT2 | 8.352 | 6.708 |
| FBT3 | 4.031 | 5.152 |
| FBT4 | 7.306 | 6.818 |
| FBT5 | 6.208 | 6.002 |

*3.2 Comparison between glass and aluminum casing*

Table 2 shows the mean capacity of glass as obtained in four-point bending tests and the mean capacity of aluminum casing as obtained in air chamber tests. The glass panels had a mean pressure capacity of 6.508 kPa with a coefficient of variance of 0.246 while the aluminum casing has a smaller mean pressure capacity of 4.218 kPa with a coefficient of variance 0.231. Based on these results, the pull-through failure of the aluminum casing is the critical failure mode between two. No other failure modes were observed to have occurred for this kind of window type.

**Table 3.** Glass versus aluminum casing

| Component | Mean Failure Pressure [kPa] | COV |
|---|---|---|
| Aluminum Casing | 4.218 | 0.231 |
| Glass | 6.508 | 0.246 |

*3.3 Mean capacity and other statistical parameters*

The threshold capacity of the test windows in the study can be determined by calculating the mean failure pressure from the given tests that only experienced pull-through failures in Table 1. The coefficient of variation (COV) is also taken into consideration because of the randomness of how materials like roofing assemblies and glass behave under certain conditions. This randomness is mainly due to differences in production and handling of the materials. In most fragility analysis, the resistance of windows are modelled using a lognormal or Weibull distribution. Thus, statistical parameters were derived for both distributions using different methods. The lognormal parameters were determined using the following equations:

$$\mu = \ln\left(\frac{m}{\sqrt{1+\frac{v}{m^2}}}\right) \tag{1}$$

$$\sigma^2 = \ln\left(1+\frac{v}{m^2}\right) \tag{2}$$

Where  and  are the mean and variance of the non-logarithmized sample values. The Weibull distribution parameters were fitted based on linear regression and expressing the cumulative distribution function as the following equation

$$\ln(-\ln(1-F(x))) = \beta\ln x - \beta\ln\alpha \tag{3}$$

In this form, the coefficients can be found via linear regression. The computed values are shown in the Table below.

**Table 4.** Mean capacity and other statistical parameters

| | |
|---|---|
| Mean Failure Pressure (Normal) | 4.218 kPa |
| Standard Deviation (Normal) | 0.975 kPa |
| COV (Normal) | 0.23 |
| Lognormal Mean | 1.4132 |
| Lognormal Standard Deviation | 0.2281 |
| Weibull Shape Parameter | 4.414 |
| Weibull Scale Parameter | 4.574 |

Figures 13 shows the cumulative lognormal and Weibull distribution. The distribution shows the probability of failure given the local pressure experienced by the jalousie windows.

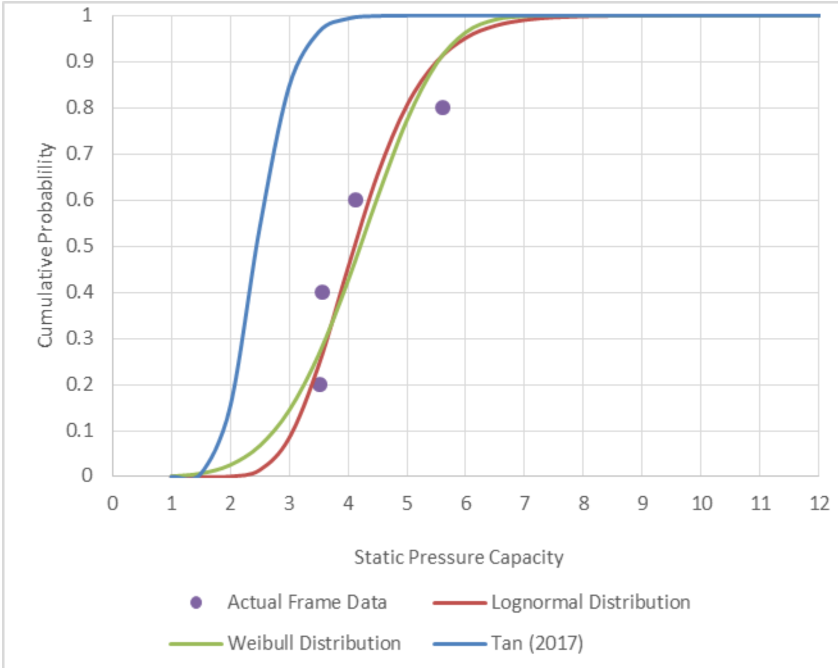


**Figure 13.** Approximation of Statistical Parameters for the Capacity of the Aluminum Frame

The fragility function used in Tan (2017) is also superimposed in figure 13. It can be shown that there is a significant decrease in probability of failure for different values of static pressure capacity. An accurate quantification of the fragility of one building envelope is important because this would affect the total vulnerability of a structure to severe wind loadings. This is because once a window panel fails, the internal pressure inside a building will increase. The total pressure acting across the other building envelops such as the roof panels will consequently increase. Thus, a lower fragility function will result to a more resilient structure against wind loads.

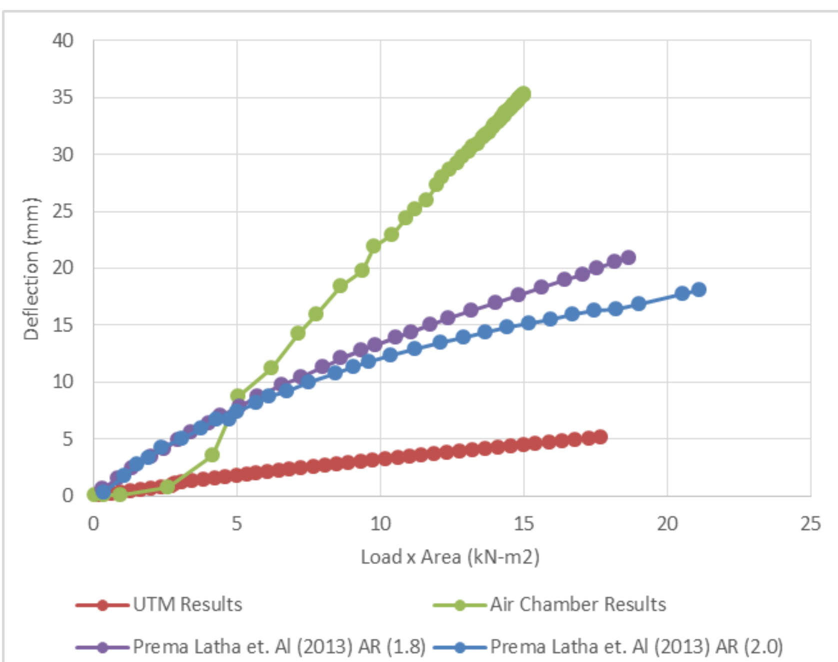


**Figure 14.** Comparison of different test-set ups

The result of the AC2 for glass breakage was superimposed with the four-point bending tests for glass breakage in figure 14. The behavior of the full system and single glass blade can be seen to be identical until 2.59kN-m2. Although the air chamber test and four-point bending test both measured the deflection of the glass blades at the center of each blade, the air chamber test showed greater deflection after 2.59kN-m2. This an be attributed to the deformation of the jalousies that start to occur beyond this point until finally reaching a maximum deflection of 15.01 mm. Prema Latha et. Al (2013) was also able to conduct local experiments in order to propose a chart for glass panels simply supported on four sides having aspect rations varying between 1.0 and 2.0. They were also able to compare their results to the design charts in ASTM E1300-02. Comparing the results of jalousie windows with Indian glass panels, Philippine jalousie windows have a lower threshold capacity.

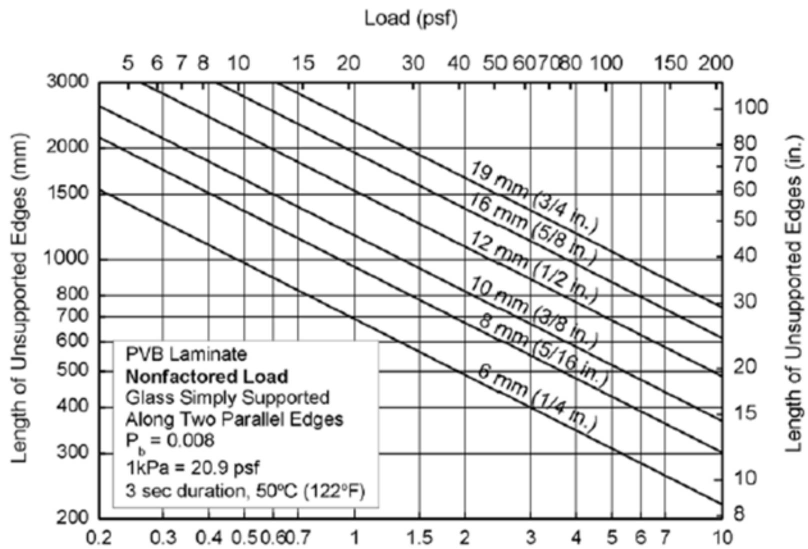


**Figure 15.** Non-factored Load Chat for Laminated Glass Simply Supported Along Two Parallel Edges (ASTM E1300-02)

Based on the type of glass used and glass type factor from ASTM E1300-02, the load resistance for the glass blade specimen, with an unsupported length of 500mm, can be estimated to be 1.5 kPa. The non-factored load chart can be shown in figure 15.

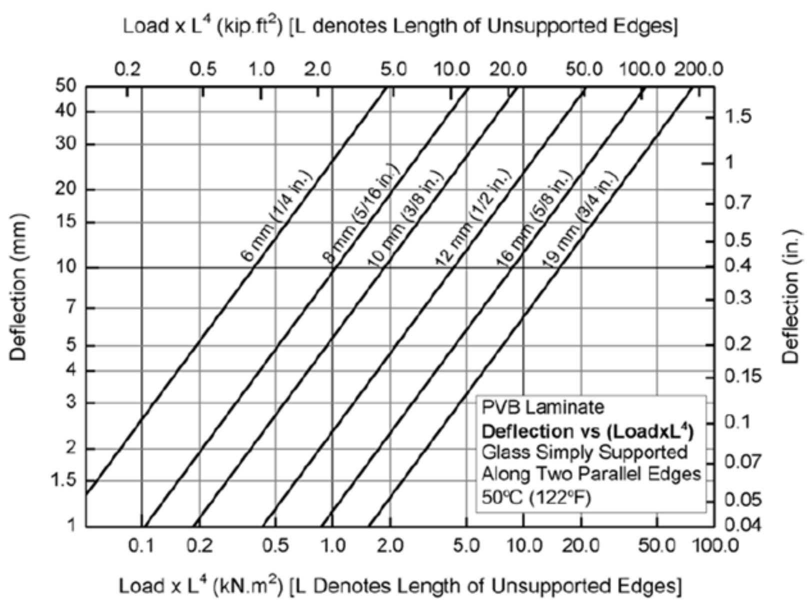


**Figure 16.** Deflection Chart for Laminated Glass Simply Supported Along Two Parallel Edges (ASTM E1300-02)

Correspondingly, the maximum allowable deflection can be estimated to be at 2.7 mm using the charts. The average threshold capacity of 6.507 kPa is 333% higher than that estimated by ASTM E1300-02. The deflection chart used can be shown in figure 16. The average measured deflection of 6.14 mm is 127% higher than that estimated by ASTM E1300-02. This shows that local construction materials should be tested, and local design provisions should be proposed for local window building envelops.

## IV. CONCLUSIONS

In developing fragility curves, it is important to identify the threshold capacity of building components such as roofing assemblies and windows.

Using a Monte Carlo Simulation, these probabilistic resistances are compared to the pressures derived from computational fluid dynamics model to determine the vulnerability/fragility of certain building envelope components. Previous researches on the development of fragility curves of school buildings in the Philippines assumed that jalousie windows have a threshold capacity of 2.5 kPa, which was based on glass breakage alone by using ASTM E1300 (Tan, 2017). However, those values are based on foreign materials and are not applicable to local construction materials. It is observed in the study that such window types have a mean capacity of 4.218 kPa and the governing mode of failure is a pull-through failure of the aluminum casing when subjected to static wind pressure.

The identification of the governing mode of failure is also useful for designers and window installers in improving the resilience of jalousie windows against severe wind loading. Local construction practitioners can focus on improving the attachment of the aluminum casing instead of strengthening the glass panels.

## V. ACKNOWLEDGMENT

The authors would like to acknowledge Structural Engineering Laboratory of Institute of Civil Engineering for the use of the equipment. They would also like to acknowledge J.D. Legaspi Construction, Office of the Associate Dean for Student Affairs, and Office of the Vice Chancellor for Research and Development for the funding of the project.

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