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ENABLE THE USE OF MASS TIMBER PRODUCTS FOR NON-RESIDENTIAL BUILDINGS IN HIGH VELOCITY HURRICANE ZONES

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ABSTRACT: The wind design requirements for all regions designated as wind-borne debris regions are governed by the International Building Code (IBC). In Florida, stricter requirements apply to regions with high hurricane wind speeds, referred to as High Velocity Hurricane Zones (HVHZ). For non-residential buildings, the building products for the entire building envelope must be evaluated and meet the requirements of Section 1626 in the Florida Building Code (FBC). While there are construction assemblies deemed to comply with these requirements. Cross-Laminated Timber (CLT) is yet proven to be qualified. The goal of this project is to enable the use of CLT in HVHZ through experimental testing including windborne debris impact and cyclic pressure testing. The experimental results show that 3-ply CLT with a thickness of approximately 105 mm (4.125 in) satisfactorily passed all tests conducted with very little damage indicating that CLT is suitable for applications in HVHZ.

KEYWORDS: Cross-Laminated Timber, High Velocity Hurricane Zones, Debris Impact Test, Cyclic Wind Pressure Loading Test

1 INTRODUCTION

After Hurricane Andrew ripped through Florida in 1992, it exposed shortcomings of the current building codes. In September 1992, the Federal Emergency Management Agency's (FEMA) Federal Insurance Administration (FIA) assessed buildings' damages caused by Hurricane Andrew (FIA, 1992). It was observed that the damages differ significantly between neighbourhoods of proximity which were mainly due to the construction details and building products for the building envelope, shown in Figure 1.1. As a result, the FBC published the first version of enhanced wind provisions in 2001. Additionally, it was further enhanced following the damages due by Hurricanes Charley, Frances, Jeanne, Katrina, and Wilma in 2004 and 2005. Similar to Hurricane Andrew, FEMA's Mitigation Assessment Team's (MAT) building damage assessment caused by Hurricane Katrina showed excessive building envelope damage which was due to inadequate wind resistance and damage from windborne debris impact (FEMA, 2006). "In part, the building envelope failure problem is due to lack of high-wind design guides for envelope assemblies and various types of rooftop equipment.", says MAT. The most recent FBC requires the entire building envelope to be impact resistant in HVHZ. Studies, conducted by Bridwell et al. in 2013 and Falk et al. in 2015, show the ability of 5-ply CLT to resist a 6.8 kg (15 lb) 2x4 lumber missile with a velocity of approximately 44.7 m/s (100 mph) with minimal damage. In 2020, the capacity of 3-ply CLT to resist debris impact loads was investigated at Clemson University and showed that there is a 26% probability of failure for missiles expected in an EF-2 tornado (50 m/s – 60 m/s) and a 54% probability of failure in an EF-5 tornado (89+ m/s) (Stoner, 2020). In addition, recent experiments conducted at the Forest Products Laboratory (FPL) have shown that a 4-ply CLT wall, a 3-ply CLT roof, and a 4-ply CLT door can meet the requirements of ICC-500, the standard for the design and construction of storm shelters published jointly by the International Code Council (ICC) and the National Storm Shelter Association (NSSA) (Falk et al., 2019). While the ICC-500 and the HVHZ standard share some similarities, the specifications for the two necessary experiments, debris impact and cyclic wind pressure loading tests, are different for HVHZ.

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Figure 1.1: Building performance difference between manufactured homes (outlined in the center) and conventional residential buildings (lower left) (FIA, 1992).

There are several construction assemblies listed in Section 1626.4 of FBC, which have been proven to meet HVHZ requirements, including exterior concrete masonry walls, exterior wood-frame walls, and exterior reinforced concrete elements. This project presents the experimental test results, explaining the performance of CLT under HVHZ testing criteria. The main objective of this project is to qualify PRG-320 compliance CLT panels for HVHZ standards.

2 EXPERIMENTAL TESTING

To qualify CLT for HVHZ, debris impact test and cyclic wind pressure loading test must be conducted in compliance with Section 1626 of FBC, Testing Application Standard (TAS) 201-94, and TAS 203-94. CLT panels will be deemed to comply with HVHZ standards if three test specimens reject missile impacts without penetration and resist the cyclic pressure loading with no crack forming longer than 127 mm (5 in) and 1.6 mm (1/16 in) wide through which air can pass during cyclic wind pressure loading test.

2.1 DEBRIS IMPACT TEST

A total of three CLT test specimens will be tested in compliance with Section 1626 of FBC and TAS 201-94. In accordance with FBC's Section 1626, the test specimens must undergo large missile and small missile impact tests. However, it is specified in TAS 201-94 that any specimen that passes the large missile impact test with no opening that a 4.8 mm (3/16 in) sphere can pass through need not be tested for the small missile impact test. From preliminary testing, it was observed that CLT can resist the large missile without opening, therefore it is concluded that the small missile impact test is not necessary for this project. Figure 2.1 shows the test setup for the large missile tests while Figure 2.2.a shows a high-speed camera used to calibrate the missile velocity at a frame rate of 2000 fps. The description of the large missile impact test is summarized in Table 2.1. The missile is propelled using a 33-gallon compressed air tank, shown in Figure 2.2.b.

Table 2.1: *A summary description of a large missile impact test*

Missile	2" x 4" #2 surface dry Southern Pine 4 kg (9 lb)
Missile Velocity	24.4 m/s (80 ft/s or 54.5 mph)
Target	Within a 127 mm (5 in) radius circle having its center on the midpoint of the test specimen Within a 127 mm (5 in) radius circle in a corner having its center at 152.4 mm (6 in) away from supporting members
Test Specimen	1.2 m x 2.4 m (4-ft x 8-ft) PRG-320 compliance CLT panel
Fail Criterion	Openings ≥ 4.8 mm (3/16 in) (Exemption for small missile test)

Figure 2.1: *Test setup for large missile impact test*

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Figure 2.2.a: *Missile speed calibration with a high-speed camera*

Figure 2.2.b: *33-gallon compressed air tank used to propel missiles*

2.2 CYCLIC WIND PRESSURE LOADING TEST

Following the debris impact test, the CLT specimens go through the cyclic wind pressure loading test in conformity with Section 1626 of FBC and TAS 203-94. The assumptions for wind loads are determined using the Directional Procedure in ASCE 7-22, shown in Table 2.2. Additionally, the loading schedule for the cyclic test is shown in Table 2.3. Figure 2.3 shows the test setup for the cyclic pressure loading test.

Table 2.2: *Assumptions for wind loads*

Exposure Category	C
Building Height, H, m (ft)	18.3 (60)
Design Wind Speed, V, m/s (mph)	89.4 (200)
Directionality Factor, K_d	0.85
Exposure Coefficient, K_z	1.13
Topographic Factor, K_{zt}	1.00
Ground Elevation Factor, K_e	1.00
Gust Factor, G	0.85
Ultimate Design Load, P, kPa (psf)	5.79 (121)
Max. Cyclic Pressure, $P_{max,}$ kPa (psf)	3.5 (73)

Table 2.3: *Loading schedule for cyclic test*

Number of Cycles	Minimum Pressure kPa (psf)	Maximum Pressure kPa (psf)
600	0 (0)	1.77 (37)
70	0 (0)	2.11 (44)
1	0 (0)	4.55 (95)

Figure 2.3: *Test setup for cyclic pressure loading test*

The cyclic pressure protocol was achieved using a large fan which was connected to a bi-polar valve shown in Figure 2.4. The location and control of the valve allowed for air to be forced into the chamber (positive pressure) or taken out of the chamber (negative pressure). For all tests in this study, negative pressures were achieved through the calibration of the pressure to the location of the bi-polar valve. Positive pressures were avoided to test the

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panel independent of the connection between the panel and the supporting elements. Prior to each test, calibration of the relationship between the location of the bi-polar valve and the pressure was performed. An example of this calibration is shown in Figure 2.5 and was dependent on the seal between the CLT panel and the pressure chamber.

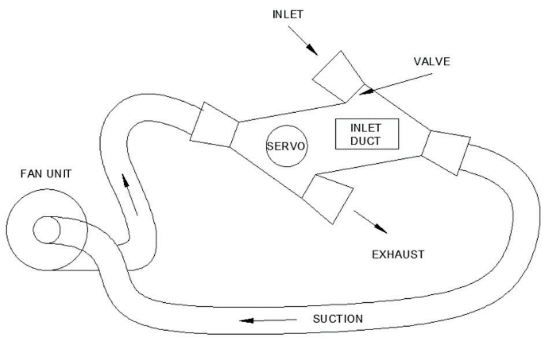

Figure 2.4: *Pressure controlled with a bi-polar valve*

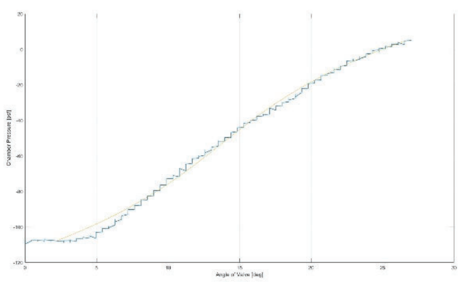

Figure 2.5: *Calibration curve, shown in yellow*

3 TEST RESULT

3.1 LARGE MISSILE IMPACT TEST

A CLT panel specimen was tested for the large missile. It received two impacts at the center and corner 152.4 mm (6 in) away from supporting members, shown in Figure 2.4. Table 2.4 shows the summary result of missile indentation for the test while Figure 2.4 shows their corresponding pictures. There were indentations of 6.35 mm (0.25 in) and 12.7 mm (0.5 in) at the center and corner, respectively. This corresponds to 6% and 12% of the CLT panel thickness (105 mm or 4.125 in), respectively which are minimal damages to the panel.

Table 2.4: *A summary result for missile indentation*

Impact Location	Missile Weight kg (lb)	Missile Length m (in)	Missile Speed m/s (mph)	Indentation Depth mm (in)
Center	4 (9)	2.17 (85.25)	29.5 (66)	6.35 (0.25)
Corner	4 (9)	2.17 (85.25)	31.7 (71)	12.7 (0.50)

(a) Center (b) Corner

Figure 2.4: *Missile penetration depth of large missile test*

3.2 CYCLIC WIND PRESSURE TEST

A specimen was tested for cyclic wind pressure loading test with the loading schedule, shown in Table 2.3. The maximum deflection was measured to be 2.845 mm (0.112 in) throughout all three loading cycles with a permanent deformation of 0.686 mm (0.027 in). No crack or opening formed during or after the experimental test. Figures 3.1, 3.2, and 3.3 show the pressure loads and deflection for several cycles of the three loading cycles respectively (Table 2.3). The CLT specimen remains elastic during the cyclic test, as shown in Figure 3.4.

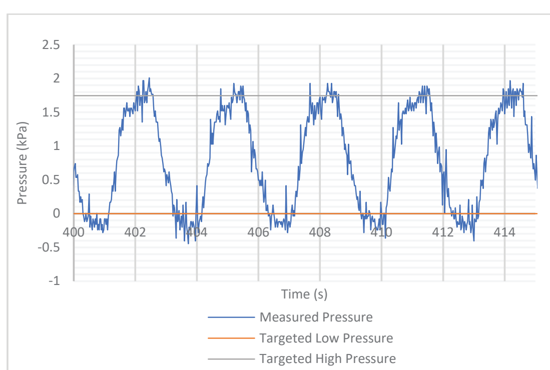

Figure 3.1.a: *Measured pressure for 5 cycles of 0-1.77 kPa*

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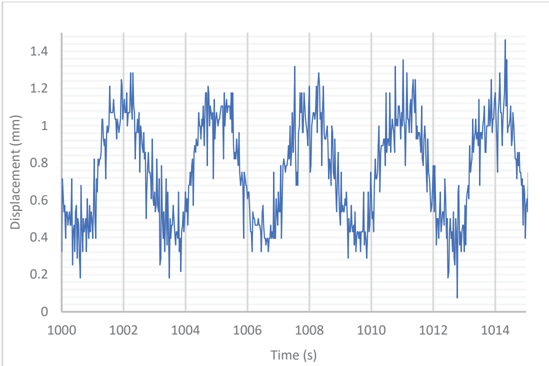

Figure 3.1.b: *Measured deflection for 5 cycles of 0-1.77 kPa*

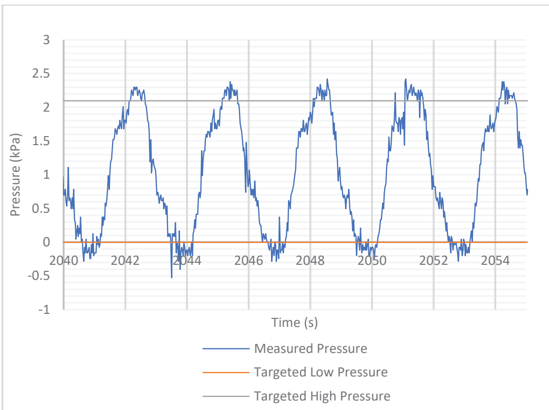

Figure 3.2.a: *Measured pressure for 5 cycles of 0-2.11 kPa*

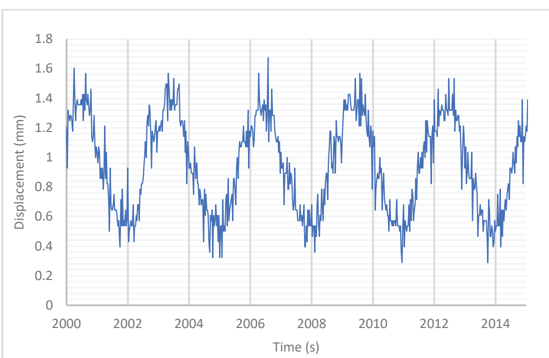

Figure 3.2.b: *Measured displacement for 5 cycles of 0-2.11 kPa*

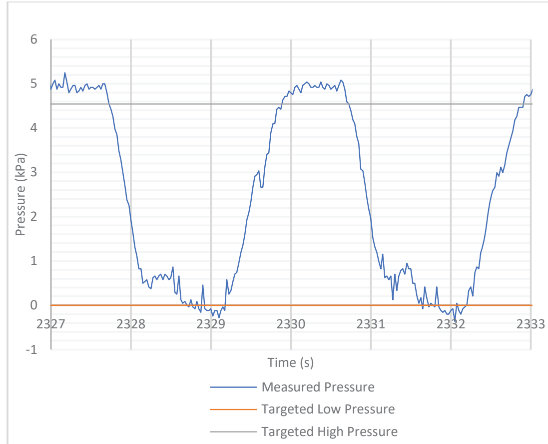

Figure 3.3.a: *Measured pressure for 5 cycles of 0-4.55 kPa*

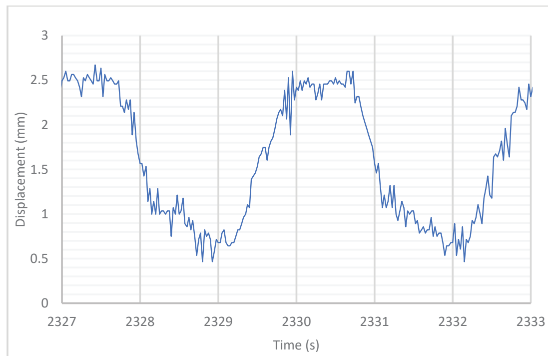

Figure 3.3.b: *Measured displacement for 5 cycles of 0-4.55 kPa*

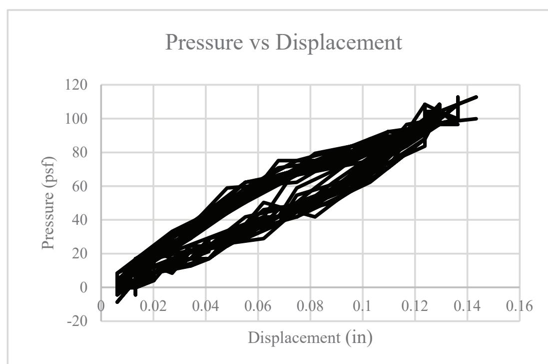

Figure 3.4: *Result from the preliminary test*

The measured pressures in the chamber were consistent with the targets outlined in Table 2.3. Deviation of the pressures from the target value was limited to 11% for the testing shown. Such deviation was the result of the pressure cycles which approached 0 Pa as they had the potential to interrupt the seal. Efforts were made to minimize deviation through the testing protocol such as placing a plastic film over the panel and using clamps around the panel edges to ensure that if a positive pressure was experienced by the panel, it would not cause the panel to lift off the test chamber.

Overall, the results of the experimental testing indicate little damage to the CLT panel from the debris impact and cyclic pressure. Additional testing could be performed to determine the point at which 3-ply CLT panels would begin to experience more significant damage from such events.

4 CONCLUSIONS AND FUTURE WORK

As part of this study, the 3-ply CLT test specimen underwent debris impact and cyclic wind pressure loading test in accordance with FBC requirements. The results of the two tests indicate that 3-ply CLT can withstand such impacts and pressure testing with little to no permanent damage. It is recommended that CLT be included as a qualified construction assembly listed in FBC 1626.4. Moving forward, two additional CLT specimens will be tested, and a test report will be drafted, describing the performance of CLT under the HVHZ condition. This report will aim to serve as support for engineers and contractors seeking to implement CLT as a construction material in HVHZ.

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