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Wind Pressure Testing of Tornado Safe Room Components Made from Wood

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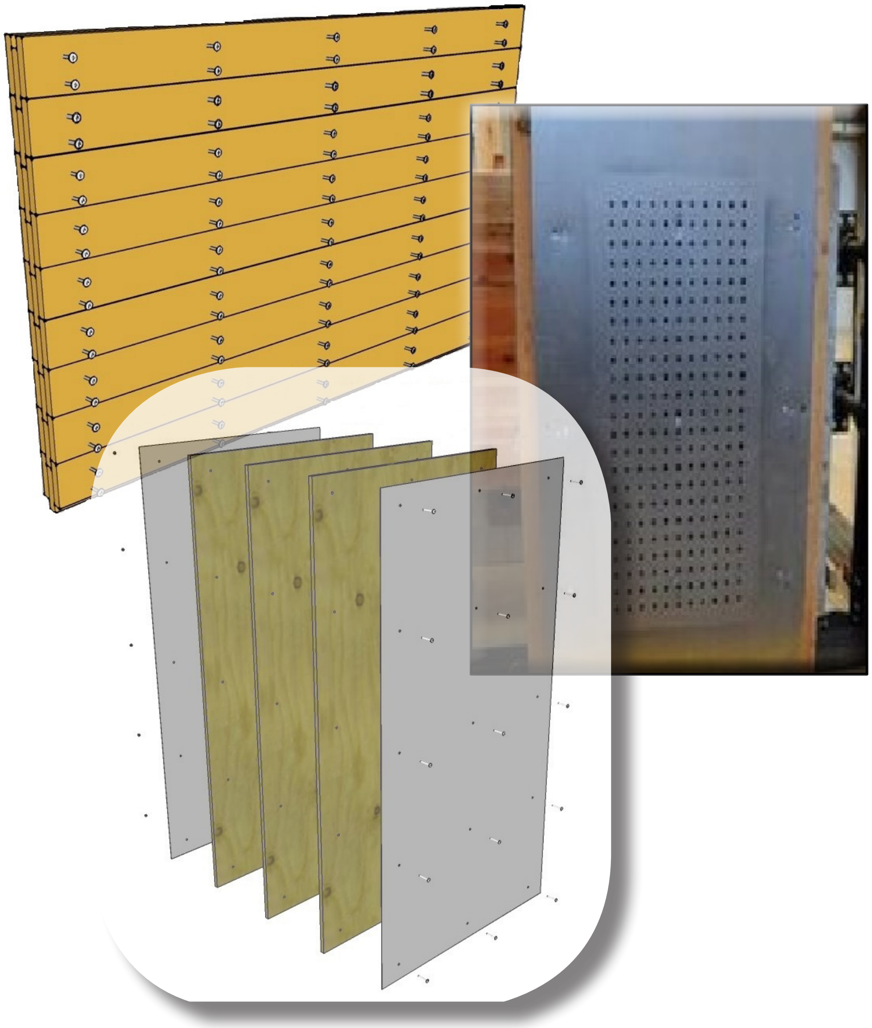

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Abstract

To evaluate the ability of a wood tornado safe room to resist wind pressures produced by a tornado, two safe room components were tested for wind pressure strength. A tornado safe room ceiling panel and door were static-pressure-tested according to ASTM E 330 using a vacuum test system. Results indicate that the panels had load capacities from 2.4 to 3.5 times that required by the wind pressure calculations of ASCE 7. The panels sustained no damage at these elevated load levels.

Keywords: wood, tornado, safe room, door, testing, ASTM E 330

Contents

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Wind Pressure Testing of Tornado Safe Room Components Made from Wood

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Introduction

In addition to resisting impact loads generated by wind-blown debris, a safe room must be able to withstand high wind forces from tornados. The American National Standards Institute's Standard for the Design and Construction of Storm Shelters (ICC-500; ICC–NSSA 2014) stipulates that wall, roof, and door assemblies are pressure-tested according to ASTM E 330 (ASTM 2014) and ASTM E 1886 (ASTM 2013) to simulate the required wind loads. ASTM E 330 deals with static testing, and ASTM E 1886 describes methodology for cyclic testing. ASCE/SEI 7-10 (ASCE 2013) is used to calculate wind pressure loads.

In this study, two wood safe room components previously impact-tested were tested for wind pressure strength. A tornado safe room ceiling panel (Falk and others 2015) and door (Falk and Bridwell 2016) were static-pressure-tested according to ASTM E 330 using a vacuum test system developed by PFS TECO (Cottage Grove, Wisconsin).

Materials and Methods

Test Specimens

Previous research (Falk and others 2015) summarized impact testing of wood walls constructed of nail-laminated nominal 2 by 8 (standard 38- by 184-mm) lumber and wood sheathing. For these walls, three 2 by 8s were nailed together to form a beam with a tongue and groove configuration (Fig. 1). The beams were then stacked and interlocked to create a wall (Fig. 2). The 2 by 8 wall was then sheathed with a wood-based panel (oriented strandboard (OSB) or plywood). The roof of the safe room was constructed the same way but was sheathed only on the interior (ceiling) surface. This asymmetrical design was necessary because fastening the sheathing to the roof surface would be difficult if the safe room was built in a basement with limited headroom. Because the roof panel was only sheathed on one side, it was deemed the weakest of the safe room panels and therefore chosen for pressure testing. Also, as will be seen in the load calculation section of this report, the calculated loads on this panel were greater than those on the wall sections.

The 8- by 8-ft (2.4- by 2.4-m) panel tested as a ceiling was similar in construction to Wall No. 8 of Falk and others (2015, appendix). Construction adhesive was applied between each layer of 2 by 8s, between each nail-laminated wall panel beam, and to the 23/32-in. (18.26-mm) plywood sheathing.

Also tested was a tornado safe room door (Fig. 3), which was constructed according to the diagram in Figure 4. The door was 43 by 84 in. (1.1 by 2.1 m) (to fit across a 36-in.- (0.9-m-) wide door opening) and was constructed of three layers of 23/32-in. (18.26-mm) plywood sheathing and faced front and back with a sheet of 18-gauge (0.05-in.- (1.27-mm-) thick) hot rolled steel. The layers of the door were held together with 1/4-in. bolts as shown in Figure 5 and as described in Falk and Bridwell (2016).

Wind Load Calculation

According to ASCE/SEI 7-10, for a main wind-force resisting system (MWFRS) low-rise building, velocity pressure is calculated as q_z:

$$q_z = 0.00256\, K_z K_{\mathrm{zt}} K_{\mathrm{d}} V^2$$

ICC-500 assumes that the topographic effects factor, K_{zt}, and the wind directionality factor, K_{d}, are equal to 1. The basic wind speed for an EF-5 tornado is equal to 250 mph (402.3 km/h).

$$K_{\mathrm{zt}} = 1.0$$

$$K_{\mathrm{d}} = 1.0$$

$$V = 250 \text{ mph}$$

From ASCE/SEI 7-10, chapter 28, table 28.3.1, and assuming the height of the structure, z, is less than 15 ft (4.6 m),

$$K_z = 2.01\,(15/Z_g)^{2/\alpha}$$

According to table 26.9-1, Exposure C,

$\alpha = 9.5$

$Z_g = 900$

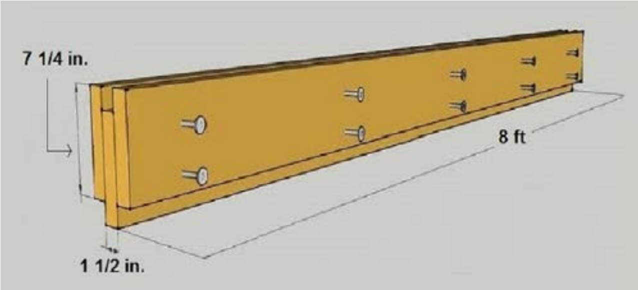

Figure 1. Nail-laminated wall panel beam.

therefore

$$K_z = 2.01\,(15/900)^{2/9.5}$$
$$= 0.85$$

and

$$q_z = 0.00256(0.85)(1.0)(1.0)(250)^2$$
$$= 136\ \text{lb/ft}^2\ (6.5\ \text{kPa})$$

Furthermore, the design wind pressure, p, is calculated from

$$p = qGC_p - q_i(GC_{pi}) \qquad \text{(ASCE /SEI 7-10, table 27.4-1)}$$

assuming the tornado shelter is an enclosed rigid building. For a windward wall,

L/B = 1.0 for an 8 by 8 tornado shelter

C_p = 0.8 from ASCE/SEI 7-10, table 27.4-1

GC_{pi} = ±0.55 per ICC-500, section 304.7 (exception)

$q = q_z$

$q_i = q_h$

$G = 0.85$

Figure 2. Assembled wall panel (without sheathing).

Figure 3. Safe room door.

The most critical case occurs when the internal pressure coefficient (0.55) is negative:

$$p = 136(0.85)(0.8) - 136\,(-0.55)$$
$$= 167\ \text{lb/ft}^2\ (8\ \text{kPa})$$

For a flat roof,

L/B = 1.0 for an 8 by 8 tornado shelter

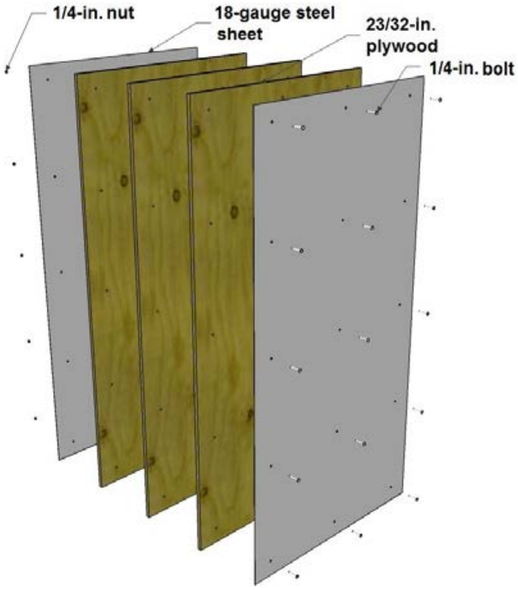

Figure 4. Safe room door construction (1 in. = 25.4 mm; 18 gauge is 0.05 in. (1.27 mm) thick).

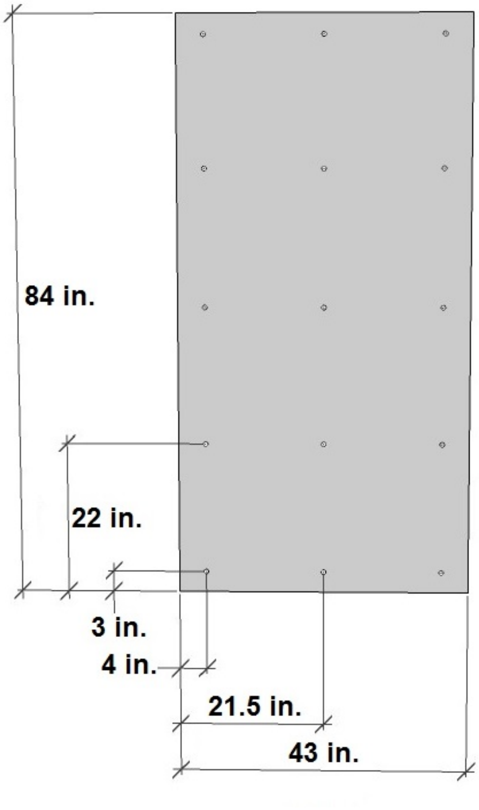

Figure 5. Safe room door bolt pattern (1 in. = 25.4 mm).

$C_p = -1.3$ from ASCE/SEI 7-10, table 27.4-1

$GC_{pi} = \pm 0.55$ per ICC-500, section 304.7 (exception)

Therefore

$q = q_h$

$q_i = q_h$

$G = 0.85$

The most critical case occurs when the internal pressure coefficient (0.55) is positive:

$$p = 136(0.85)(-1.3) - 136(0.55)$$
$$= -225 \text{ lb/ft}^2 \text{ (10.8 kPa)}$$

Test System

PFS TECO, a building materials test laboratory in Cottage Grove, Wisconsin, has developed a vacuum-based panel test system that will allow static pressure testing of panels according to ASTM E 330 loading sequence. This system can exert up to 700 lb/ft^2 (33.5 kPa) of static pressure on panels up to 8 by 24 ft (2.4 by 7.3 m) and can hold pressure to within 1 lb/ft^2 (0.05 kPa). This system uses a large vacuum pump connected to a steel I-beam frame that is sealed to the laboratory floor. The panel specimen is laid on the steel frame and supported such that a plastic membrane can be laid over the top of the specimen to seal it for testing. A computer controls the vacuum pump and the loading sequence (Fig. 6).

Figure 6. Vacuum test system.

Test Setup and Procedure

According to ICC-500, the wall panel specimen (section 806.2) and the door specimen (section 806.3) shall be loaded to at least 1.2 times the wind load calculated from ASCE/SEI 7-10.

As indicated earlier, the ceiling panel tested was asymmetrical in design because it had plywood glued and nailed to only one side. For this reason, the panel was tested twice, once with the plywood on the compression side and once with the plywood on the tension side. Figure 7 shows the test setup for the ceiling panel. The panel was supported

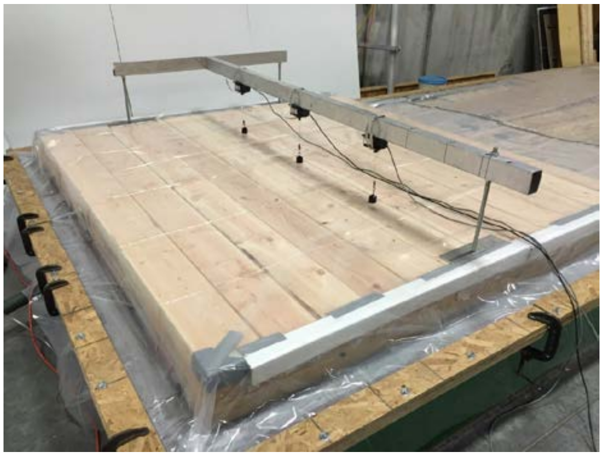

Figure 7. Ceiling panel test configuration (in this case, the plywood is on the tension side).

along each bottom edge on a 5.5-in. (139.7-mm) support beam to simulate the support provided in a safe room by adjoining walls.

For the first test, the panel was tested with the plywood on the tension side. In accordance with ASTM E 330, the panel was preloaded to stabilize the vacuum test system at a load of 20 lb/ft^2 (0.96 kPa). The load was then applied in ten 30-lb/ft^2 (1.44-kPa) increments (30–300 lb/ft^2 (1.44–14.36 kPa)). The load was held at each load level for 5 minutes and then the load was removed. The panel was allowed to relax for 1 minute between loading increments. After the last load increment, the load was increased to the maximum possible.

For the second test, the panel was oriented with the plywood on the compression side. The panel was again tested at increasing load increments. However, to decrease testing time, four 50-lb/ft^2 (2.39-kPa) load increments were used (50–200 lb/ft^2 (2.39–9.58 kPa)). The loading and unloading sequence was the same as the previous test. After the last load increment, the load was increased to the maximum possible.

Panel deflection was monitored using three cable-extension transducers with a range of 20 in. (508 mm) and an accuracy of 0.15%. These were placed along the midline of the panel at quarter points. For the door, deflection was measured at the geometric center of the door, at the middle of the door at the unsupported threshold, and at a quarter point near the top of the door.

For the door, the test setup and system were similar to that of the ceiling panel (Fig. 8). However, the door was supported on only three sides. The bottom of the door was unsupported to simulate the threshold of the door. The other edges of the door were supported on a 2.5-in. (63.5-mm) ledge to simulate the overlay of the door on the opening of the safe room wall. As with the ceiling panel, the door was preloaded to stabilize the vacuum test system. The load was then applied in nine 30-lb/ft^2 (1.44-kPa) increments (30–270 lb/ft^2 (1.44–12.93 kPa)). After the last load increment, the load was increased to the maximum the system would deliver. The loading and unloading sequence was the same as the ceiling panel tests.

Figure 8. Door test configuration.

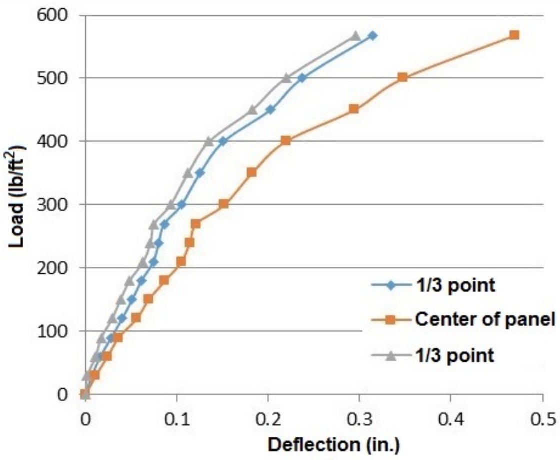

Figure 9. Load and deflection for tested ceiling panel with plywood on tension side (1 lb/ft^2 = 47.9 Pa; 1 in. = 25.4 mm).

Results

Figures 9 and 10 show the results of wind pressure testing of the ceiling panel. Load–deflection curves were generated for each test.

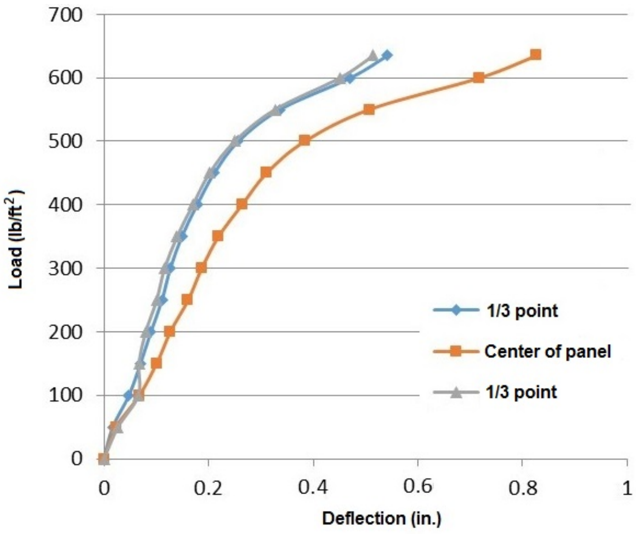

Figure 10. Load and deflection for tested ceiling panel with plywood on compression side (1 lb/ft^2 = 47.9 Pa; 1 in. = 25.4 mm).

Figure 9 shows the load–deflection data for the ceiling panel with the plywood on the tension side. The panel in this orientation withstood the capacity of the test system (568 lb/ft^2 (27.2 kPa)) and deflected 0.47 in. (11.9 mm) at the center of the panel. Deflection of the panel at the 1/3 points was less (as expected) at about 0.30 in. (7.62 mm).

Similar results were found when testing the panel with the plywood on the compression side. However, the maximum load reached was 635 lb/ft^2 (30.4 kPa) with a defection of 0.83 in. (21.1 mm). As expected, the maximum deflection was at the center of the panel farthest from any support. Again, the test system limited maximum load and the panel did not fail.

For the safe room door, a maximum load of 575 lb/ft^2 (27.5 kPa) was reached and the door deflected 0.25 in. (6.35 mm) at the threshold (Fig. 11). Deflection at the midpoint of the door was 0.17 in. (4.3 mm), and at the 1/4 point (from top of the door), the deflection was 0.11 in. (2.8 mm). As with the ceiling panel tests, the test system limited the maximum load and the door did not fail.

For both the ceiling panel and door tests, there was no reduction of load carrying capacity at the incremental load levels and the specimens did not exhibit any distress caused by the loading and unloading at each incremental load.

Discussion

As is expected with wood building components, the load–deflection data exhibited nonlinear behavior with deflection increasing with greater loads. Unfortunately, the ultimate load of the panel and door could not be determined because the capacity of the test system was reached. Although the test system has successfully produced loads up to 700 lb/ft^2 (33.5 kPa), each test is limited by the level of vacuum that can be achieved for a given test setup. The level of vacuum is affected primarily by the number of small leaks that result from the plastic film being compressed over nail heads and other protrusions. Although every effort was made to cushion sharp corners and obvious protrusions, inevitably leaks occur, which limits the load level achieved.

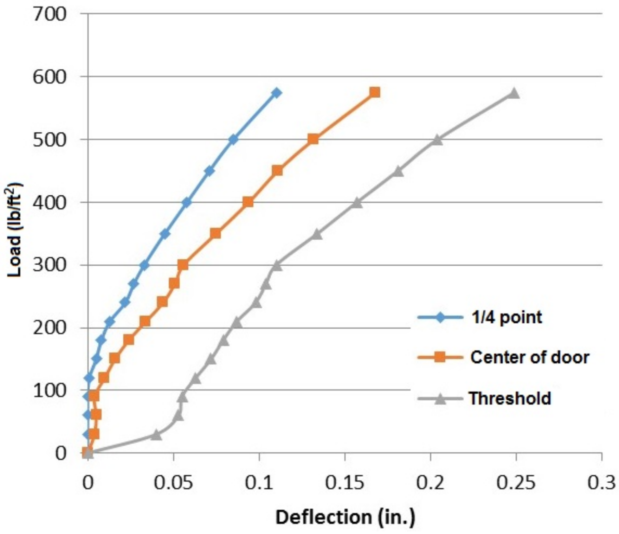

Figure 11. Load and deflection for tested door (1 lb/ft^2 = 47.9 Pa; 1 in. = 25.4 mm).

Despite these leaks, the test system was able to exert loads on the panel and door well in excess of that required. In the case of the ceiling panel with the plywood on the tension side, the load reached was 2.5 times the wind load pressure (and internal suction forces) required by ASCE/SEI 7-10 and ICC-500. Similarly, the ceiling panel with the plywood on the compression side reached a load 2.8 times the wind load pressure.

The door exhibited even greater load capacity with a maximum load reached more than 3.4 times that required.

Conclusions

The results of the wind pressure testing on a wood tornado safe room ceiling panel and door indicated that these components can withstand the calculated wind loads for an EF-5 tornado (250 mph (402.3 km/h)) with a large margin of safety. The ceiling panel withstood more than 2.5 times the design load and the door withstood more than 3.4 times the design load with no damage, distress, or excessive deflection of the component. It is likely that the components could have withstood much greater loading. However, the capacity of the vacuum test system was reached before specimen failure.

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