CIB-W18/46-15-7

**INTERNATIONAL COUNCIL FOR RESEARCH AND INNOVATION
IN BUILDING AND CONSTRUCTION**

WORKING COMMISSION W18 - TIMBER STRUCTURES

WIND TUNNEL TESTS FOR WOOD STRUCTURAL PANELS USED AS NAILABLE SHEATHING

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MEETING FORTY SIX

VANCOUVER

CANADA

AUGUST 2013

Wind Tunnel Tests for Wood Structural Panels Used as Nailable Sheathing

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Abstract

Wood structural panels, defined as plywood and oriented strand board (OSB), have been occasionally used as a nail-base in light-frame wood construction. The demand for improved energy conservation in the building construction recently has promoted the construction of the so-called "advanced framing", which requires the stud spacing be increased from the typical 406 mm (16 in.) on center to 610 mm (24 in.) on center to align with the roof trusses or framing. In some climate zones, foam plastic insulation of 25 to 51 mm (1 to 2 in.) is installed outside of the wood structural panel sheathing (i.e., between wood structural panels and exterior wall cladding) to provide the needed thermal insulation required by the energy conservation code, which makes the installation of exterior wall cladding challenging due to the difficulties in accurately hitting the studs with nails that are required to be longer than typical. As a result, there is an interest by the construction industry to use wood structural panels as nailable sheathing, which can serve as the nail-base to facilitate the installation of exterior wall cladding at wider stud spacing without the concern on missing nails into wood studs when installing exterior wall cladding.

APA – The Engineered Wood Association has undertaken a series of studies to investigate the use of wood structural panels as nailable sheathing for lap siding, which includes an engineering analysis using single nail withdrawal capacity from wood studs and nailhead pull through capacity from the lap siding. However, due to the small thickness of the wood structural panel sheathing, there is a concern whether the single-nail withdrawal capacity could accurately predict the performance of walls subject to dynamic wind forces. To confirm the engineering calculation under wind dynamics, APA sponsored a study at the Insurance Institute for Business & Home Safety (IBHS) Research Center in South Carolina in September 2012 to provide full-scale wind tunnel test results. This paper describes the test details and results obtained from the study.

1. Introduction

In the wall applications, light-frame wood buildings in North America are typically sheathed with wood structural panels that are directly attached to wood studs with nails. By definition of the U.S. building codes, the term of wood structural panels is referred to plywood and oriented strand board (OSB). The exterior wall cladding, such as wood lap siding or vinyl siding, is then attached to wood studs over water-resistive barriers and wood structural panels. Rarely is the exterior wall cladding attached directly to wood structural panels as a nail-base, or so called "nailable sheathing" even though such practice exists in attaching roof shingles to roof sheathing and is permitted for wall applications in the U.S. building codes.

In recent years, the demand for improved energy conservation in the building construction has promoted the construction of light-frame wood construction with the so-called "advanced framing", which requires the stud spacing be increased from the typical 406 mm (16 in.) on center to 610 mm (24 in.) on center to align with the roof trusses or framing. In some climate zones, foam plastic insulation of 25 to 51 mm (1 to 2 in.) is installed outside of the wood structural panel sheathing (i.e., between wood structural panels and exterior wall cladding) to provide the needed thermal insulation required by the energy conservation code, which makes the installation of exterior wall cladding challenging due to the difficulties in accurately hitting the studs with nails that are required to be longer than typical. As a result, there is an interest by the construction industry to use wood structural panels as nailable sheathing, which can serve as the nail-base to facilitate the installation of exterior wall cladding at wider stud spacing without the concern on missing nails into wood studs when installing exterior wall cladding.

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2. Objectives

The main objectives of this study were to compare the engineering calculation with wind-tunnel test results when wood structural panels are used as nailable sheathing under wind loads at critical angles. Both the ultimate load and allowable load designs were to be examined.

3. Methods and Materials

3.1 Wind Tunnel Test Facility

The IBHS is a non-profit organization, which is wholly supported by the property insurance industry to conduct scientific research for identifying and promoting effective actions that strengthen homes, businesses, and communities against natural disasters and other causes of loss. The Research Center is a state-of-the-art, multi-hazard applied research and training facility in Richburg, South Carolina. The core facility at the center is a specially-designed open-jet wind tunnel, as shown in Figure 1, with an exceptionally large test chamber of 44 m (145 ft) wide by 44 m (145 ft) long with a clear interior height of 18 m (60 ft). The test chamber is large enough to subject full-scale, one- or two-story structures to a variety of wind-related or wind-influenced natural perils.

Figure 1. IBHS wind tunnel test facility

The unique wind flow capabilities inside the large test chamber are produced by 105 vane-axial fans. These 1.7 m (5.5 ft) diameter fans with 260 kW (350 hp) medium voltage electric motors push air through a 15-tube contraction structure. The flow through each tube in the structure is independently controlled using Rockwell medium voltage variable frequency drives, with active front-ends that allow precise control of acceleration and deceleration of the fans and hence the flow. The fans and controls are designed to allow simulation of gross flow characteristics of a variety of wind events including Category 1, 2 and 3 hurricanes, extra-tropical windstorms, and thunderstorm frontal winds. An illustration of a typical one-story structure in the test chamber identifying the location of the reference anemometer in relation to the fans, test structure on the turntable, and the direction of wind flow in the chamber is provided in Figure 2.

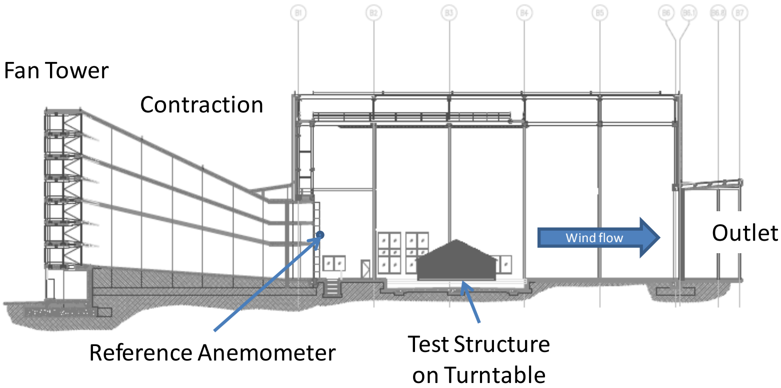

Figure 2. Elevation view of typical structure in test chamber; showing relative location of fans, contraction, outlet, and reference anemometer

Wind conditions for the testing conducted in this study consisted of a mean wind speed profile and turbulence characteristics profile typical of open country terrain, defined as Exposure C in ASCE 7-10 [1]. Validation of the Research Center's capability to replicate surface wind pressures on typical structures was accomplished by testing a replica of the Texas Tech Wind Engineering Research Field Laboratory building. Results of these validation studies are provided in Morrison, et al. [2].

3.2 Building Layout and Design

The test building consisted of a single-story steel foundation frame to which wall sections and a roof were attached. The roof on the test building had a 6 on 12 pitch with one gable end and one hip end. The structure was 9.1 m (30 ft) wide by 12.2 m (40 ft) long, with an additional 305 mm (1 ft) overhang on the roof. The mean roof height was 5.2 m (17 ft). Eight different wall assemblies were constructed for concurrent test programs, as shown in Figure 3. Two of the eight wall segments, i.e., Walls 5 and 6, were selected for this study.

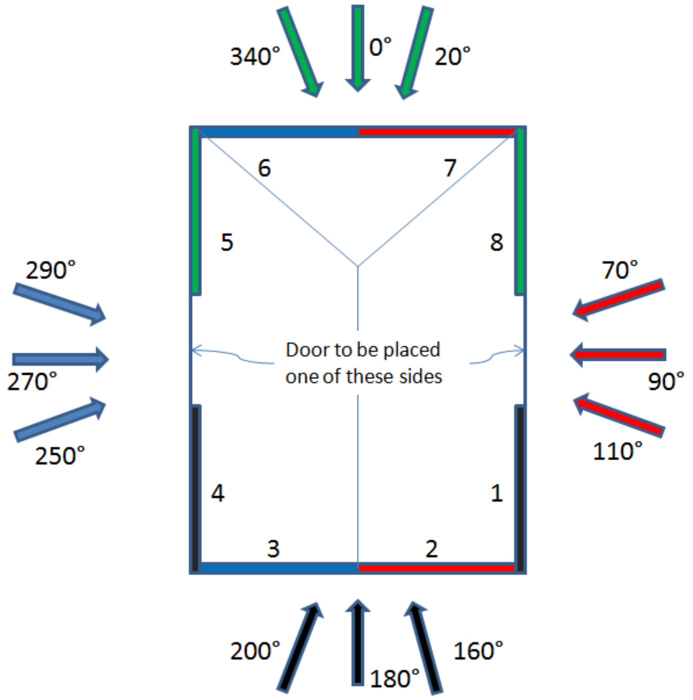

Figure 3. Sketch of wind angles and test wall locations

Based on previous wall pressure studies using this same frame and roof structure, IBHS researchers identified critical angles for each wall section as the wind direction parallel to the wall and 20 degrees from parallel. In the earlier studies, there was no discernible difference in external pressures or net loads across wall segments adjacent to the hip end versus the gable end. The location of the eight walls and critical wind angles are shown in Figure 3, where the wind directions in green are the most critical for Walls 5 and 8, and the wind directions in light blue are the most critical for Walls 3 and 6. As mentioned earlier, the walls used for this study were Walls 5 and 6. Hard stops were installed between Walls 4 and 5 on the side wall and between Walls 6 and 7 on the hip end wall to separate these configurations.

Wall 5 was used to evaluate the ultimate load capacities, i.e., the wall was designed to fail at a peak wind speed of 47 m/s (105 mph) in the wind tunnel, while Wall 6 was designed to sustain the same peak wind speed without failure by adjusting the nail spacing with a factor of safety. The peak wind speed of 47 m/s (105 mph) was selected as it is close to the 49 m/s (110 mph) covered in the U.S. residential code and based on the limitations of other materials used for the same building in the test plan. This wind speed is expected to impose a wind load of 1.8 kPa (37 psf) in Exposure C conditions (open terrain with scattered obstructions) based on the U.S. code.

Smooth-shank nails with 7.5 mm (0.297 in.) head diameter, 2.9 mm (0.113 in.) shank diameter, and 63.5 mm (2-1/2 in.) long were selected in conjunction with 2x4 (38 mm x 89 mm) Spruce-Pine-Fir studs spaced at 406 mm (16 in.) on center and 11 mm (7/16 in.) thick 1220 mm x 2440 mm (4 ft x 8 ft) OSB sheathing. The wall cladding was constructed with commercially available non-veneer lap siding of 11 mm (7/16 in.) thick, 203 mm (8 in.) wide, and 4.9 m (16 ft) long. The lap siding is overlapped with the next siding of 28.6 mm (1.125 in.). A house wrap was used as the water resistive barrier applied over the OSB sheathing. Commercially available R-13 unfaced fiber glass batt insulations were installed in the wall cavities between studs. Gypsum wall boards of 13 mm (1/2 in.) in thickness were installed in the interior of the building with seams taped and mudded. Figure 4 shows the wall-to-roof construction details.

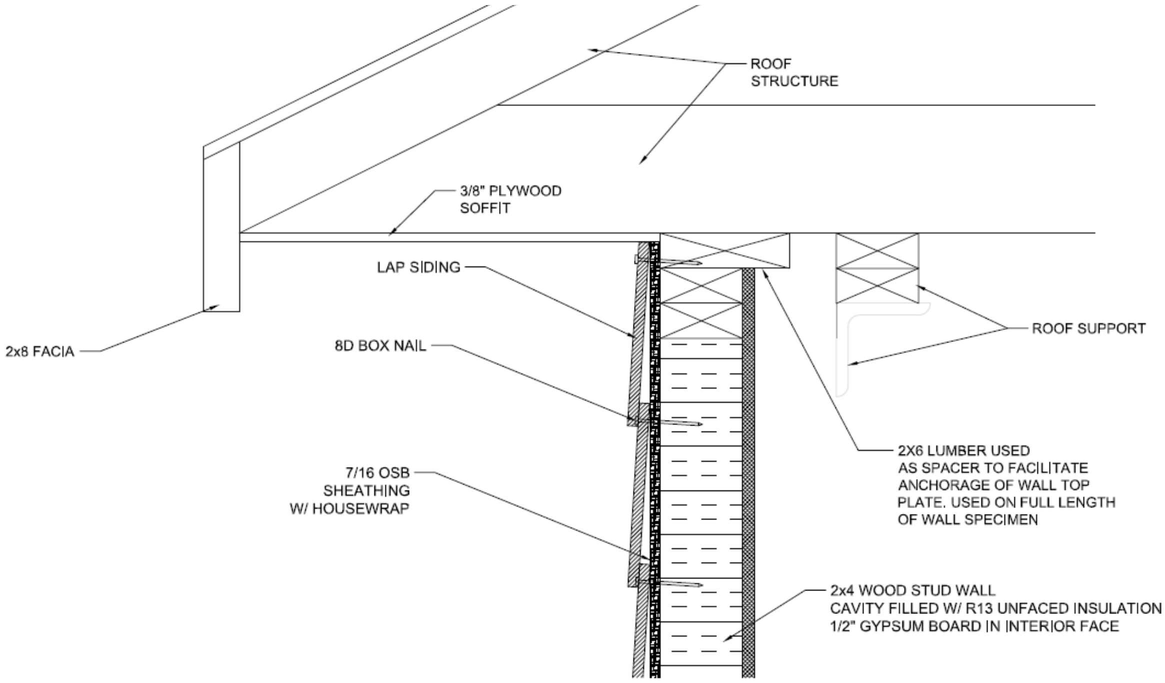

Figure 4. Wall-to-roof construction details (1 in. = 25.4 mm)

3.3 Nailing Spacing and Installation

For the experimental design, the engineering calculation for single nail withdrawal capacity under wind load was performed based on American Wood Council's National Design Specification for Wood Construction (NDS) [3]. According to APA Panel Design Specification (PDS) [4, 5], the "equivalent specific gravity" for wood structural panels is 0.40 for the purpose of determining the nail withdrawal resistance, which results in the average nail withdrawal capacity of about 246 N (55 lbf) when adjusting the published allowable nail withdrawal resistance in the NDS by a factor of 5 for 11 mm (7/16 in.) thick OSB sheathing under wind load duration (the load duration factor is 1.6 in accordance with the NDS). However, to ensure Wall 5 would fail at the expected peak wind speed of 47 m/s (105 mph), the experimental design took the upper bound of the equivalent specific gravity" for wood structural panels at 0.50, which resulted in the average nail withdrawal capacity of about 430 N (96 lbf).

This nail withdrawal capacity is substantially lower than the nailhead pull through capacities of the lap siding, as determined in accordance with ASTM D1037 [6] and published in APA Technical Topics TT-070, *Nailhead Pull-Through Strength of Wood Structural Panels* [7]. It is also lower than the lap siding bending and shear strength at the expected maximum nail spacing of 838 mm (33 in.). Therefore, this nail withdrawal capacity was used as the basis for the design of nailing schedules for Walls 5 and 6. For Wall 5, which was intended to fail at the peak wind speed of 47 m/s (105 mph), the calculated nail spacing was 838 mm (33 in.). For Wall 6, which was designed to sustain the same peak wind speed with a factor of safety, the calculated nail spacing was 254 mm (10 in.). In a simplistic way, this means that there is a factor of safety of 3.3 for Wall 5, as compared to the ultimate capacity from Wall 6.

The exposed height of the siding is 175 mm (6.875 in.) for both Walls 5 and 6. For Wall 6, the nail spacing of 254 mm (10 in.) on center results in a tributary area for each nail of 0.045 m^2 (0.48 ft^2). For Wall 5, the nail spacing of 838 mm (33 in.) on center for expected nail withdrawal failure results in a tributary area for each fastener of 0.15 m^2 (1.58 ft^2).

Figure 5 shows the installation details of the walls. Note that all nails for the lap siding were designed to directly attach to the OSB sheathing by intentionally missing the lumber studs except for the starter nails from each end of every lap siding run. The end joints of the lap siding were butted and staggered between lap siding runs.

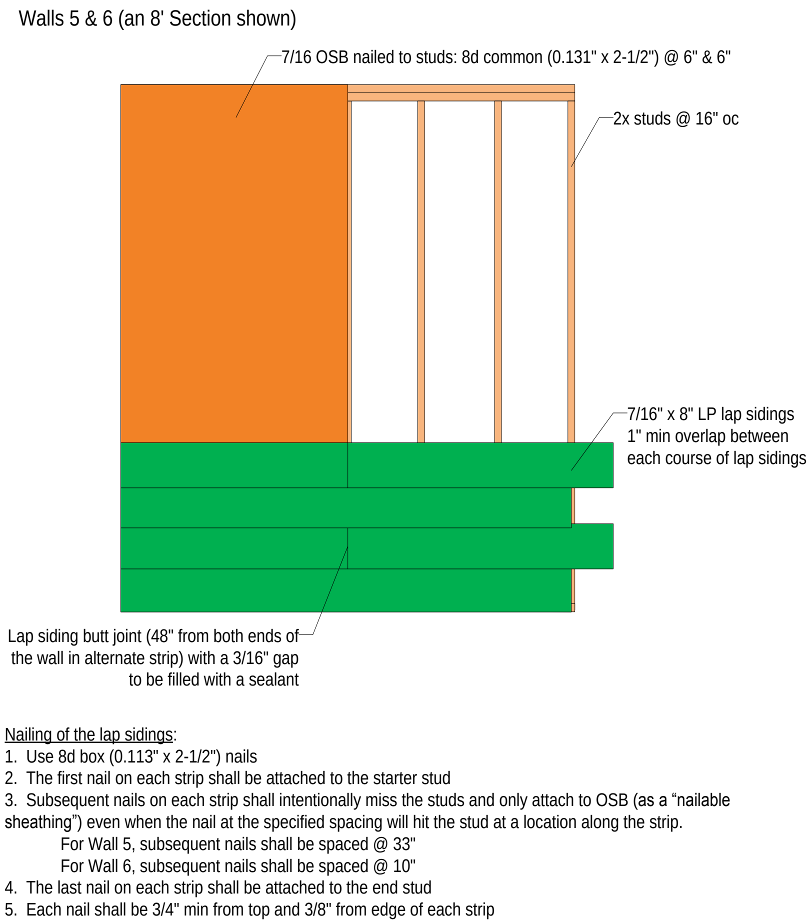

Figure 5. Installation details for the wall construction (1 in. = 25.4 mm)

3.4 Instrumentation

The test plan included measurement of wind pressures on the external wall surface, between each of the wall layers, and inside the test building. Each measurement location had three pressure taps installed, as shown in Figure 6. The pressure tap identified as P_1 in Figure 6 was mounted with its opening flush with the outside surface of the lap siding. P_2 was mounted to the inside surface of the lap siding such that it measures the pressure in the cavity between the siding and sheathing. P_3 was mounted such that it measures the pressure in the fiberglass-batt-filled cavity between the sheathing and the interior gypsum wallboard. Finally, internal pressures inside the building were measured at locations behind each of the wall segments. Pressure taps were strategically located on each wall. Pressure data was sampled at 100 Hz and filtered to 10 Hz to remove noise. The instrumentation was designed to facilitate the determination of the so-called “pressure equalization effect,” which is a phenomenon that occurs in multi-layer systems because openings in various layers allow the external wind pressures to be transmitted to interior layers, reducing the net wind loads across layers where equalization occurs, for the wall assemblies. Results of the pressure equalization effect expressed as the “pressure equalization factor” will be reported in a separate paper.

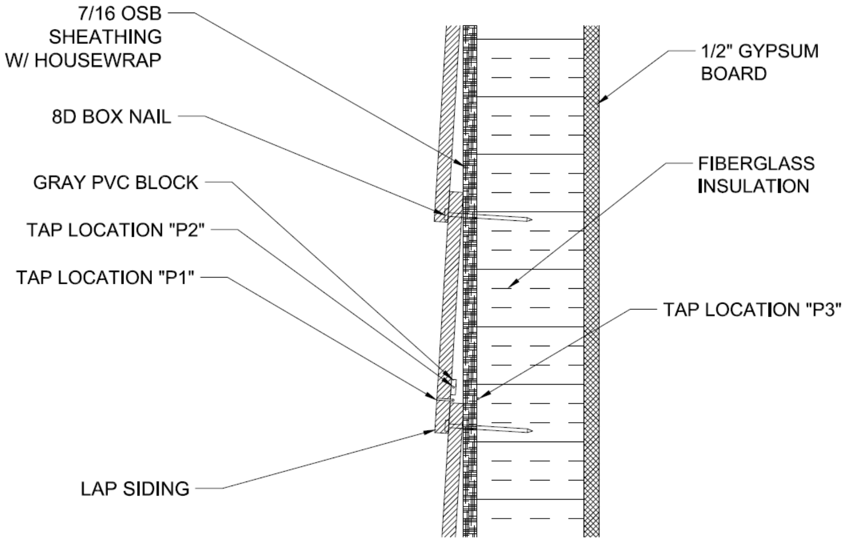

Figure 6. Configuration of pressure tapes in exterior wall system (1 in. = 25.4 mm)

3.5 Testing

Wall assemblies were tested at the critical angles identified to produce the worst wind loading effects from previous testing. These angles are shown in Figure 3 and Table 1. Wind pressure data are collected using an automated data acquisition system reading the output from the pressure sensors attached to each of the pressure taps. The test sequences in multiple-step wind speeds are described in Table 1. For each wind speed and wind angle combination, a 15-minute time history was applied. As these walls were part of the building that was subject to different wind angles, the overall cumulative test duration was about 2 hours at each wind speed.

Table 1: Test Sequence in Critical Wind Directions

Building rotation[1]		Gust wind speeds		
Wall #		Target gust at 5.5 m (18 ft)	Recorded gust[2] at 5.5 m (18 ft)	Equivalent gust at 10 m (33 ft)
5	6			
340°, 0°, 20°	250°, 270°, 290°	25 m/s (55 mph)	27 m/s (61.5 mph)	30 m/s (66.7 mph)
		34 m/s (77 mph)	35 m/s (78.8 mph)	38 m/s (85.4 mph)
		42 m/s (95 mph)	43 m/s (95.8 mph)	46 m/s (103.8 mph)
		48 m/s (108 mph)	49 m/s (110.5 mph)	54 m/s (119.8 mph)

1) Zero degrees is defined as the hip roof side of the building facing the fan inlet, and 180 degrees is defined at the gable end side of the building facing the fan inlet.
2) The same wind record results in slightly different maximum gust wind speeds in the test facility as a result of atmospheric conditions and variable frequency drive performance characteristics.

The achieved gust for each run varied slightly as a result of atmospheric conditions surrounding the test facility and variable frequency drive performance, thus a range of achieved gust wind speeds are reported with the results. The target values and typical 3-second peak gust wind speeds measured during the tests are provided in Table 1. Corresponding open country 3-second gust wind speeds at 10-m (33-ft) elevation in open terrain are also reported in Table 1.

4. Results

4.1 Siding Failure on Wall 5

Wall 5 was specifically designed with a nail spacing at the ultimate nail withdrawal capacity by assuming the full external wind pressure at the peak wind speed of 47 m/s (105 mph). However, during testing for wind speeds at a target gust of 42 m/s (95 mph) at 5.5 m (18 ft), a single piece of lap siding on Wall 5 experienced partial nail withdrawal. If testing had continued, the lap siding would have blown off. Upon inspection, it was noted that a single nail was omitted during construction from this piece of siding, leaving a 1676 mm (66 in.) nail spacing on this length of siding, instead of the designed spacing of 838 mm (33 in.) on center. The measured peak wind pressures experienced by this lap siding varied between approximately 0.9 kPa (19 psf) and 1.1 kPa (23 psf), depending on the wind direction.

Despite the fact that the nail was missing, this lap siding was still somewhat restrained by the siding directly above and the adjacent nails. For a 2515 mm (99 in.) long and two-panel tall segment of the lap siding centered on the location where the nail was missing, there were 5 nails providing restraint where 6 should have been installed. The area of these two siding would be 0.88 m^2 (9.45 ft^2) and the total peak wind load would have been between about 800 N (180 lbf) and 965 N (217 lbf). This would result in a peak wind load on each of the 5 nails of between 160 N (36 lbf) and 191 N (43 lbf), assuming the nail withdrawal loads were uniformly distributed among nails.

A review of the earlier sequence of tests with target gust wind speeds of 34 m/s (77 mph) that the wall survived without any observed withdrawal of the fasteners reveals that this section of siding would have been exposed to extreme peak wind pressures of between 0.62 kPa (13 psf) and 0.77 kPa (16 psf). The corresponding extreme loads on the nails using the same load distribution arguments discussed in the previous paragraph would have been between 111 N (25 lbf) and 133 N (30 lbf). It is possible that a longer duration of testing at the 34 m/s (77 mph) target wind speed might have resulted in withdrawal of nails in this area of the wall due to the missing nail.

Having encountered the failure reported in the previous section, the lap siding pieces in the area of the failure and above were removed and re-installed with nails shifted about 51 mm (2 in.) laterally to ensure that the new attachment points were not affected by the old attachment points. Testing was then resumed. The building was subjected to two tests where the target gust wind speed was 42 m/s (95 mph) without failure. This was followed by the sequence of testing with the target gust wind speed of 48 m/s (108 mph). During the first direction tested with the 48 m/s (108 mph) target gust wind speed, one lap siding was blown off the wall. Subsequent testing with wind records having a target gust of 48 m/s (108 mph) at 5.5 m (18 ft) resulted in a loss of the majority of lap siding on Wall 5. Failure of additional individual pieces of siding occurred during the 0° and 20° testing, as shown in Figure 7.

Figure 7. Wall 5 failure during testing at 20° with target gust speed of 48 m/s (108 mph)

At a nail spacing of 838 mm (33 in.) on center, the tributary area for each nail on Wall 5 was 0.15 m^2 (1.6 ft^2). The testing at a target gust wind speed of 42 m/s (95 mph) created peak loads between 0.9 kPa (19 psf) and 1.1 kPa (23 psf). The corresponding withdrawal forces on the nails would be peak values between 133 N (30 lbf) and 165 N (37 lbf). Consequently, it is likely that the two tests conducted with target 3-second gust winds of 42 m/s (95 mph) began to loosen up the re-attached lap siding. When the first test with a target wind speed of 48 m/s (108 mph) was conducted, the building was not oriented at the most critical wind direction for loading on this portion of the wall and the peak cyclic loads were likely once again weaken the over-stressed nailed joints in withdrawal. Therefore, the overall estimate of the Wall 5 performance at the failure between 42 m/s (95 mph) and 48 m/s (108 mph) must take the load duration and repeated loading history into account. Since the nail withdrawal is usually designed at a wind load that is about 1/3 of the ultimate withdrawal capacity, it is not expected that the accumulative damage experienced from these extreme wind load sequence will occur in reality.

4.2 Siding Performance on Wall 6

The siding installed on Wall 6 did not experience any signs of damage or nail backing out, despite of the repeated wind loads and long load duration, as compared to the assumed 10-minute load duration. It was exposed to a full battery of simulated open country winds with target peak gust wind speeds of 25 m/s (55 mph), 34 m/s (77 mph), 42 m/s (95 mph), and 48 m/s (108 mph). The simulated open country winds with a target of 48 m/s (108 mph) are expected to have applied peak wind pressures of between 1.2 kPa (25 psf) and 1.5 kPa (32 psf) to most areas of the siding on Wall 6.

The tributary area of the exposed siding with nails at 254 mm (10 in.) spacing is 0.045 m^2 (0.48 ft^2). The corresponding peak withdrawal forces on the nails would have been between 53 N (12 lbf) and 67 N (15 lbf). These forces are on the order of the allowable nail withdrawal resistance based on the APA Panel Design Specification (equivalent specific gravity of 0.40) with the load duration factor of 1.6. This confirms that the current design methodology for using wood structural panels as nailable sheathing can be justified under the wind loads at the most critical wind angles. It is also comfortable to confirm from these wind tunnel tests that the design methodology can be applied to wood structural panels with small nail penetration under the repeated wind loads at the full design wind speed from various wind angles.

5. Summary and Conclusions

The results obtained from this study clearly support the use of wood structural panels as nailable sheathing, which can be designed with single nail withdrawal resistance, even though the sheathing thickness might be small. On this basis, APA has published the Technical Topics TT-109, *Wood Structural Panels Used as Nailable Sheathing* [9], for use by design professionals. When the load duration factor of 1.6 is applied, the allowable withdrawal capacities used in the U.S. assure that the peak nail withdrawal loads at a design wind speed will be less than about 1/3 of the average ultimate nail withdrawal capacity (the allowable withdrawal capacity adjusted for the load duration is actually 1.6/5 = 32% of the average ultimate withdrawal capacity). Based on the IBHS wind tunnel tests provided in this report, an adequate factor of safety has been provided for the attachment of siding in real wind events.

6. Acknowledgements

This study is a joint research project of APA – The Engineered Wood Association, the Insurance Institute for Business & Home Safety (IBHS), and the USDA Forest Products Laboratory. This research was supported in part by funds provided by the USDA Forest Products Laboratory and the Engineered Wood Technology Association (EWTA), which is greatly appreciated.

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