DETERMINATION OF WIND OUT-OF-PLANE FAILURE CAPACITY OF PLYWOOD AND OSB-CLAD WALL SYSTEMS

By

JASON MARTIN LOPEZ

A THESIS PRESENTED TO THE UNDERGRADUATE SCHOOL
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To my sweetie, Sara, to whom has been by my side this entire journey.

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Jason Martin Lopez

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The wind uplift resistance of wood roof sheathing panels has been the subject of many wind engineering studies due to the high probability of being subjected to large uplift loads during intense wind occurrences. Meanwhile, few studies focus on wall sheathing resistance, resulting in the assumption that their wind resistance matches the same capacity of roof sheathing panel constructed of similar materials. The study will determine the static out-of-plane wind resistance of wall sheathing on wood framed construction and evaluate whether the current assumption, that the capacity of a wall sheathing panel is similar to that of a roofing sheathing panel, is true. Structural tests were conducted on 20 wall specimens fabricated of 13 mm (½ in.) thick OSB and plywood sheets fastened to spruce-pine-fir wood framing using nails. Using a monotonic-increasing static pressure step-and-hold test sequence, the mean out-of-plane wind resistance capacity attained was 4.21 kPa (88 psf), and we found no statistical difference between plywood and OSB wall panels. When the results are compared against results for roof panels from previous tests, it was found that the out-of-plane capacity of wall panel systems was approximately 17% higher than that of roof panels.

1 INTRODUCTION

In the United States, 90% of single family residential structures consist of light-framed wood structural systems (LFWS) in which the roof structures and external walls are sheathed with structural wood sheathing panels (van de Lindt and Dao 2009). These panels have dual purposes, 1) to resist in place forces through diaphragm/shear wall action; 2) serving as flexural members in resisting the out-of-plane forces due to wind and gravity loads on the roofs and wind suctions and pressures acting on the walls. The exterior walls (sheathed wood-stud walls) in LFWS act as columns to support the vertical loads of the roof structure, and as shear walls for transferring lateral forces collected by the roof diaphragm to the foundation (Figure 1 - 1). They also resist out-of-plane loads induced by wind pressures and provide protection from wind-borne debris to the occupants. Thus, the exterior walls in LFWS are subjected to both in-plane and out-of-plane lateral loads and are critical to maintaining structural integrity and occupant safety during extreme wind events.

While the in-plane shear capacity of walls (Standohar-Alfano et al. 2017) and roof diaphragms (Lee and Rosowsky 2005) have been studied, and several studies have documented the out-of-plane structural (wind uplift) behavior of roof sheathing panels (Datin et al. 2011; Hill 2009; Kopp and Gavanski 2012), little work has been done on the out-of-plane capacity for exterior wood wall systems. In numerical fragility models the default value of the out-of-plane capacity for exterior walls has been the same as the roof sheathing system, despite the fact that the support of the two systems are different and the material properties are not the same.

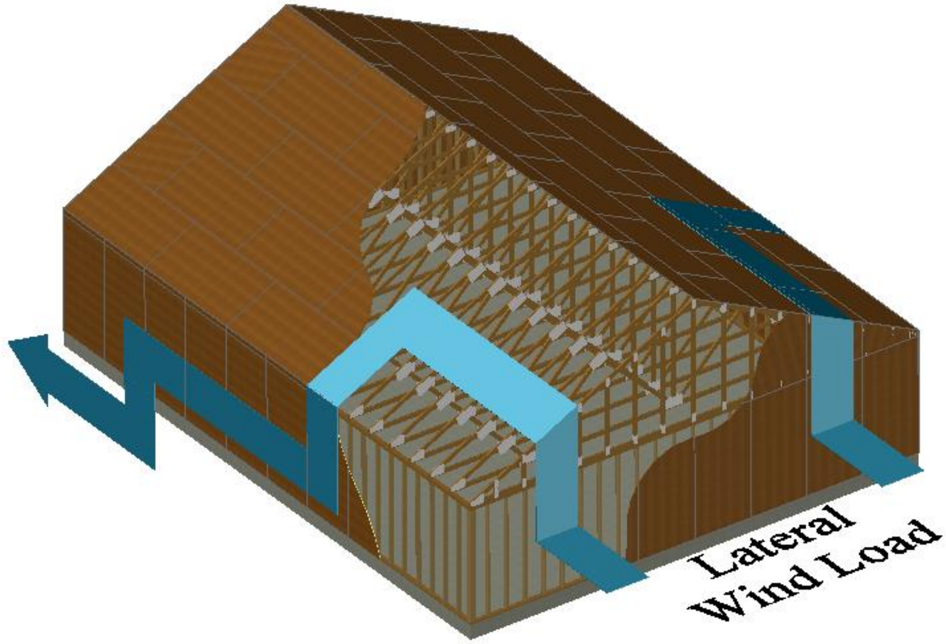


Figure 1 - 1. Shear load transfer due to a lateral wind load.

The need for a more accurate value of the out-of-plane failure capacity for wall sheathing arose while the third author was developing a probabilistic computer model used to predict the tornado-induced damage ratios to light-framed wood residential structures (Peng et al. 2016; Prevatt et al. 2016). A literature review revealed previous numerical models of wood framed buildings (Kasal et al. 1994; Kopp and Gavanski 2012; Li and van de Lindt 2012; Martin et al. 2011; Thampi et al. 2011) used the same wind uplift capacity for wall systems as for roof sheathing panels. Intuitively this should not be the case, since typical wall framing panels typically have more closely spaced framing (406 mm (16 in.) versus the 610 mm (24 in.) spacing used for roof sheathing panels. Further, wall sheathing panels have blocking along the top and bottom edges of panels, which provides additional fastening locations for the panels. Also, in Florida the framing material for wall sheathing is spruce pine fir (SPF) SG of 0.42, while typically southern yellow pine (SYP) SG of 0.55, framing is used in roof trusses and rafters (AWC 2017).

In their numerical model for tornado damage, Prevatt et al. (2016) used out-of-plane mean capacity from Henderson et al. (2013) of 4.44 kPa (92.7 psf) and a coefficient of variance (COV) of 0.15. The predicted damage ratios of wall sheathing was about 50% at the tornado center line, a much lower percentage than the observed damage ratios of 75% found in the Garland Rowlett tornado (Bhusar 2017). It is the authors' belief that using an exceedingly high structural failure capacity for wall sheathing is responsible for this anomalous result.

2 BACKGROUND

A typical wood structural panel fabricated as plywood or oriented strand board (OSB) measures 2.44 m x 1.22 m (8 ft by 4 ft). For use as roof sheathing, the panels are supported transversely on wood framing oriented along the short dimension of the sheets (parallel to the 1.22 m (4 ft) dimension) at 610 mm (24 in.) on center. Assuming a code minimum 150 mm /300 mm (6 in./12 in.) fastener array from the 2017 Florida Building Code – Residential, 6th Edition (FBCR 2017), 33 fasteners are required. In contrast, for wall sheathing systems, the structural panels are installed with their long dimensions oriented vertically and parallel to the direction of framing members. Here, the panels are supported longitudinally by the wood studs, placed spaced 406 mm (16 in.) apart. In addition, wood structural panels are typically fastened to blocking (wall plates) along the short edges of the panel at the top and bottom of each sheet (assuming the exterior wall is 2.4m (8 ft) in height). As a result, wall sheathing panels in a typical house construction will have nearly twice as many fasteners to attach the wood structural panel to the framing members, which suggests its out-of-plane capacity should be higher that a roof sheathing panel, Table 2 - 1.

Given the current drive to develop performance-based design approaches the use of these values may be too conservative and therefore provide incorrect results. In particular, for developing tornado-resilient structural design methods, a realistic fragility function developed using an accurate probabilistic model of the wind loads and representative structural capacities of all components involved. To this point, the wind uplift capacity values of wood roof sheathing has been erroneously used to represent the wind uplift capacity of wall sheathing panels although the structural configurations of these two systems are different.

Table 2 - 1. Materials and nail spacing used for a typical roof and wall system.

House Component	Structural Framing	Exterior Structural Sheathing	Nail Spacing	Nail Type	Number of Nails Per Panel
Roof	Southern Yellow Pine (SYP)	Plywood or OSB	152/305 mm (6/12 in.)	8d common	33
Wall	Spruce Pine Fir (SPF)	Plywood or OSB	152/305 mm (6/12 in.)	6d common	62

3 LITERATURE REVIEW

Wall Wind Out-of-Plane Tests

Kopp and Gavanski (2012) presented an experimental study to determine the ultimate capacities of exterior sheathing on wood-framed wall systems. Table 3 - 1 shows the various wall types tested in the Kopp and Gavanski study. Ten samples of each wall type were tested with five samples tested under ramp loading and five under fluctuating loading. Only one of five test samples (Wall 2, vertical studs with OSB sheathing) resembles the structural system used in residential walls in the United States housing. Even though the Wall 1 sample had a similar mean failure capacity as the Wall 2 sample, Wall 1 is more like a roof section than a wall section.

The study used ramp loads to determine a baseline failure pressure to compare against a realistic fluctuating wind load. The ramp rate loading was 1.92 kPa/min (40 psf/min) with an average test on wood panels lasting about 75 seconds. The full-scale fluctuating pressure load time history, P_t, was created by using

$$P_t = \frac{1}{2}\rho V^2 Cp_t \quad (1)$$

where V^2 is the mean hourly wind speed taken at the mean roof height with a flat uniform terrain, Cp_t is the pressure coefficient taken from an equivalent full-scale 15-min segment from wind tunnel data, and ρ is the density of air. Using equation (1) with an initial wind speed that is likely to not cause damage to a test sample, a 15-minute pressure time history was created. If failure does not occur within the first 15 minutes, the wind speed is scaled up by 2.2 m/s (5 mi/h) to create a new pressure time history. The process is continued until failure has occurred in a continuous cycle with no pause in-between the wind scaling. An OSB test panel under fluctuating load can take 80 minutes before failure occurs.

Table 3 - 1. Wall Configurations used by Kopp and Gavanski (2012) in exterior sheathing tests.

Label	Stud framing Orientation	Sheathing Type	Sheathing Fastener	Vinyl Siding	Siding Nails	Fastener Count
Wall 1	Parallel to Short Edge	11 mm OSB	6d common nail	No	No	43 nails
Wall 2	Parallel to Long Edge	11 mm OSB	6d common nail	No	No	52 nails

The differences in methodology used in the current study versus that used by in Kopp and Gavanski (2012) is shown in Table 3 - 2. The difference in nails in Wall 1 can be accounted for because of a different orientation of the studs. Wall 1 has studs that are installed perpendicular to the 2.4 m (8 ft) length where Wall 2 and the current study used studs installed parallel to long edge of sheathing panel. The difference in nails in Wall 2 comes from the top and bottom plates not being fully nailed every 152mm (6 in.) on center. This study will only use step-and-hold loading instead of ramp or fluctuating loading. Kopp and Gavanski tested five samples of each loading type (ramp and fluctuating) per wall section. Their results indicated that there was no statistical significance between ramp and fluctuating loads, which allows for conclusions to be draw that ramp loading and fluctuating loading can be treated as one group. Both studies use a nailing pattern of 152/305 mm (6/12 in.) on center spacing, but this study attaches all edges of the sheathing panel to the studs with nails every 152mm (6 in.) on center.

Table 3 - 2. Comparison of the differences in walls samples between current study and that of Kopp and Gavanski (2012).

	Current Study		Kopp and Gavanski (2012)	
Panel Material	Plywood	OSB	Wall 1-OSB	Wall 2-OSB
Top Plate	Double	Double	Single	Single
Number of Nails	62	62	43	52
Panel Orientation	2.4 m edge Parallel to Studs	2.4 m edge Parallel to Studs	2.4 m edge Perpendicular to Studs	2.4 m edge Parallel to Studs
Nail Length	60.3 mm (2.37 in.)	60.3 mm (2.37 in.)	50.8 mm (2 in.)	50.8 mm (2 in.)
Number of Specimens per Loading Type	10-Step and Hold	10-Step and Hold	5-Ramp 5-Fluctuating	5-Ramp 5-Fluctuating

Wind Uplift Testing of Roof Panels

Currently, no consensus exists for determining the wind-uplift or out-of-plane capacity of wood sheathing panels. Hill (2009) developed an approach, used subsequently in Datin et al. (2011) to evaluate the out-of-plane capacities of wood roof panels. Using a 152 mm x 1.26 m x 2.49 m (6 in. x 4.15 ft x 8.19 ft) steel chamber and pressure loading actuator, structural panel test specimens were subjected to either uniform static pressures Method A – Static Pressure or to Method B – Dynamic Pressure. Figure 3 - 1 shows the test specimen and fastener arrangement. Sealing of the chamber is achieved by a plastic sheet placed between framing members and the structural panel and taped to the side of the chamber.

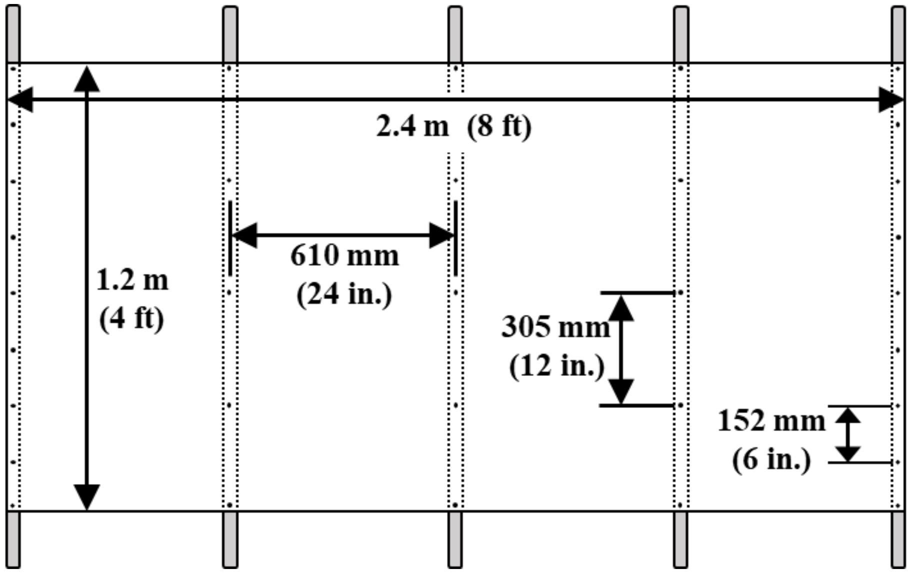


Figure 3 - 1. Typical construction for roof up-lift test samples. Nailing pattern shown is typical code minimum 152/305 mm (6/12 in.) This layout results in 33 nails per panel, with 9 nails on edges and 5 nails in the field.

Failure Mechanisms

An investigation into the failure mechanism from Datin et al. (2011), Kopp and Gavanski (2012), and Henderson et al. (2013), resulted in a trend various nail failures. The common failure mechanisms observed were: nail pull through, nail withdraw, nail head failure, shear failure of nail connection between top/bottom plate and stud, fracture in framing member, or sheathing panel fracture. A test sample was not limited to a single failure type, e.g. several experiments resulted in multiple failures occurring in the same panel, but a single fastener connection within the panel is restricted to a single failure type.

4 EXPERIMENTAL TASKS

Test Setup

A nominal 2.4 m 1.2 m (8 ft x 4 ft) steel chamber used to test the wood specimens is a box with five sides where the test sample is the sixth side (top side) and acts like a lid to the chamber (Figure 4 - 1). A plastic sheet is draped over the sides of the chamber to ensure an airtight seal between the panel and the chamber. The steel chamber has inner dimensions of 152 mm x 1.26 m x 2.49 m (6 in. x 4.15 ft x 8.19 ft) which is slightly larger than the sheathing panels being tested; this allows for the wood sheathing panel to fit within the chamber without touching the sides of the steel chamber. The depth of the box allows the test specimen enough room for unimpeded deflection throughout the testing processes of applied suction pressure. The uniform pressure is applied solely to the structural sheathing and is transferred directly to the framing members through the mechanical connection of the nails. The load on the framing members then proceeds through the bottom and top plates to the outside rim of the chamber where the top and bottom plates rest.

The steel pressure chamber connected to a Pressure Loading Actuator (PLA) powered by a 40 HP, 3-phase 460 V centrifugal blower rated at 10 kPa at a peak airflow of 1.44 m^3/s (3050 CFM). The pressure difference maintained across the sheathing panel is set by the valve position of PLA, which is controlled by a servo motor. The apparatus is computer-controlled using a PID feedback loop via a custom interface developed in LabVIEW. Development and full-scale application of the PLAs can be found in Kemp (2008) and Kopp et al. (2012) respectively.

Figure 4 - 1. Test setup for wall tests – wood wall sample installed on steel test chamber. The plastic sheathing draped over sides of steel chamber was placed between sheathing and wood framing and the edges are taped to chamber wall creating air-tight seal.

Instrumentation

Pressure Measurements

The pressure time history was taken using a Pressure Transducer (PT) installed on the side of the steel chamber. The PT used was an Omegadyne, Model # PX243A-2.5BG5V.

Displacement Measurements

Displacement measurements were taken using two Celesco string potentiometers (SP) with a measurement range of 120 mm (4.75”) and 0.25 % accuracy of full stroke with repeatability of 0.02%. The two SP were placed side-by-side to measure the displacement of the local area (Figure 4 - 2). One SP measured the displacement of the framing member, and the adjacent SP measured displacement of sheathing panel. For convenience, the SP on the framing member is referred to as SP1 and the SP on the sheathing panel is referred to as SP2. The attachment points of SP1 to the stud and SP2 to the panel is located a distance of 1.22 m (4 ft) from the bottom plate of the test specimen. SP1 was attached to stud B and SP2 was located a projected distance of 15.9 mm (5/8 in.) to side of SP1. The difference between the SP2 and SP1 measurements gives the amount of sheathing separation from framing member. All SP measurements are taken simultaneously during the testing phase, therefore the load vs. displacement can be determined for each test sample.

Figure 4 - 2. Installation of two string potentiometers to wood framing member and sheathing. The relative displacement of sheathing under suction pressure is obtained as difference of the two measurements.

Test Procedure & Pressure Trace

Since no testing standard exists for determining the wind-uplift or out-of-plane capacity of wood sheathing panels, the same procedure developed by Hill (2009) was used to test out-of-plane capacities of the laboratory-fabricated wall sections. For this experiment, UF-WRSUT Method A - Static pressure is used to determine the out-of-plane capacity for structural wall sheathing panels. The pressure trace developed for this method is a step-and-hold approach that increases pressure monotonically by increments of 0.48 kPa (10 psf) and held for 60 seconds (Figure 4 - 3). This cycle is repeated until the wall specimen fails or the Pressure Loading Actuator (PLA) capacity is reached.

Absolute peak pressure values at the time of failure, the type of failure, and location of failure were recorded. Failure is defined as the separation of the panel from the framing member resulting from one of the nail failure mechanisms or from the fracture of specimen, as indicated above. Any type of these failures will cause a sudden spike in pressure (indicating failure) which will cause the PLA to exceed its capacity then shut off.

Wall-Section Test Sample

The wall sections that will be tested are representative of typical wood frame residential structures found in practice built in Florida in accordance to the current 2017 Florida Residential Building Code (FBCR 2017). Care was taken to use representative construction techniques reflecting typical wood stud wall systems used in Florida. A wall panel consists of 2.32 m (91.5 in.) wall studs of nominal size 51 by 102 mm (2 by 4 in.) spruce pine fir (SPF) and spaced 410 mm (16 in.) apart that are attached to a single bottom plate; 51 mm by 102 mm (2 in by 4 in.) SPF placed flat on one end and a double top plate (two 51 mm by 102 mm (2 in by 4 in.)) SPF members placed flat on the other end. The overall height of the wall panel is 2.4m (96 in.). Each stud is fastened to the wall plates using two 76 mm (3 in.) smooth-shank full-round pneumatic-gun nails. Both top and bottom wall plates extend beyond the sides of the panel so they can rest on side walls of the steel chamber, as shown Figure 4 - 1. In all, ten wall panels were fabricated using plywood sheeting (11.45 mm (0.451 in.) thick sheets) and ten using oriented strand board (OSB) sheathing (10.61 mm (0.418 in.) thick sheets).

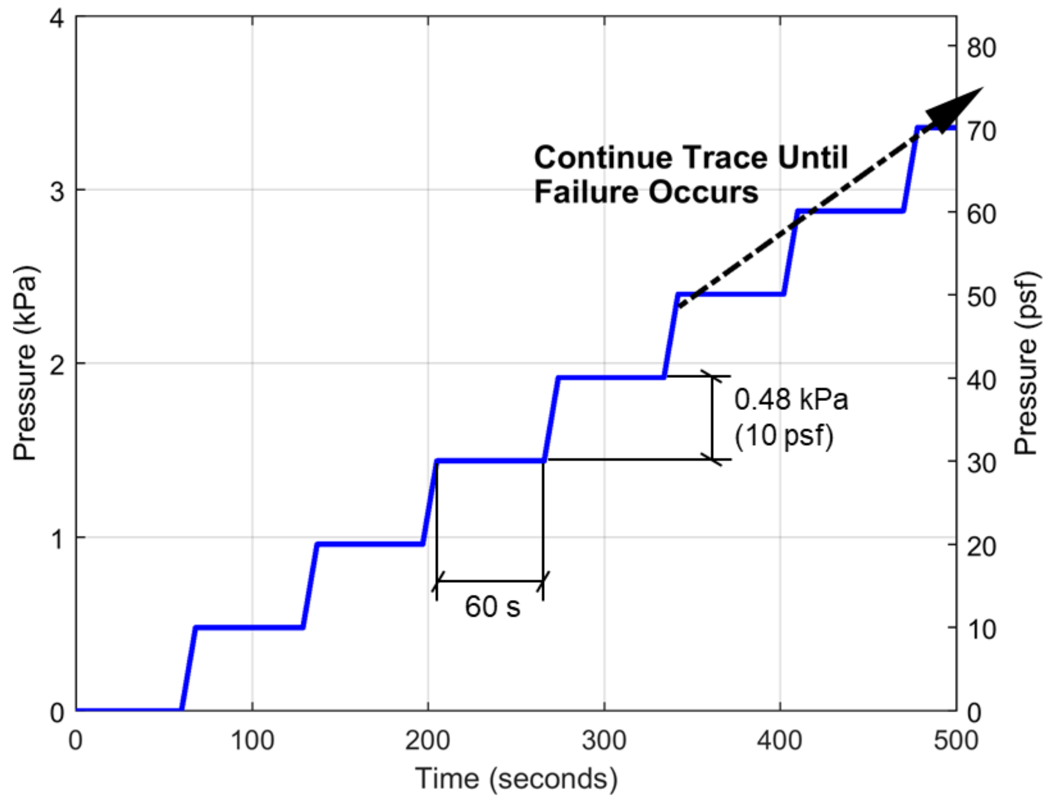


Figure 4 - 3. Pressure trace used to test wall.

The intention of the test is that the wall section being tested is only supported by the top and bottom plates that rest on the outside rim of the steel chamber. Once the framing members are nailed together, an over-sized 4 mils thick plastic sheet is laid over the studs before the sheathing is installed. The plastic sheet is used to seal the assembly by attaching it to the side walls. The methodology used here is similar to methods used in Datin et al. (2011) and Henderson et al. (2013) while testing wind-uplift capacities for roof sheathing panels.

Figure 4 - 1 presents a summary of the components used to fabricate the testing samples. The sheathing is attached using a 152/305 mm (6/12 in.) nailing pattern, as shown in Figure 4 - 4. 152/305 mm (6/12 in.) nailing pattern signifies, nails along the edges of the sheathing are spaced 152 mm (6 in.) on center and 305 mm (12 in.) on center on interior studs, i.e., studs that land in the field of the sheathing panel. Nails are off-set a distance of 9.5 mm (3/8 in.) from the edge of the panel and each panel will have a total of 62 nails per panel (Figure 4 - 4).

Table 4 - 1. Nail schedule and dimensions used for wall samples tested.

Panel Type	Number of Samples	Nail Type[a]	Number of Nails	Nail Use	Nailing Pattern[b]	Shank Diameter mm (in)	Nail Head Diameter mm (in.)	Nail Length mm (in.)
OSB	10	6d	62	Sheathing	152/305 mm (6/12 in.)	2.87 (0.113)	7.11 (0.280)	60.3 (2.37)
		12d	24	Framing	2 per stud	3.05 (0.120)	7.94 (0.313)	76.2 (3.00)
Plywood	10	6d	62	Sheathing	152/305 mm (6/12 in.)	2.87 (0.113)	7.11 (0.280)	60.3 (2.37)
		12d	24	Framing	2 per stud	3.05 (0.120)	7.94 (0.313)	76.2 (3.00)

[a]Nail types are Bright, Non-Coated, Smooth Shank, Full Round Head for Pneumatic Nail Guns.
[b]Nailing Pattern indicated spacing on edge/interior framing members.

Moisture Content & Specific Gravity

Datin et al. (2011) recommended, when performing UF-WRSUT testing protocol, to record the moisture content and specific gravity of the wood framing members. For this experiment, the Moisture Content (MC), density, and Specific Gravity were tested using the methods specified in ASTM D2395 “Standard Test Methods for Density and

Specific Gravity (Relative Density) of Wood and Wood-Based Materials" (ASTM 2014). The "Test Method A - Volume by Measurement" from ASTM D2395 (ASTM 2014) was used because the test specimens are regular in shape, smooth, and sufficient measurements can be made to easily determine the volume.

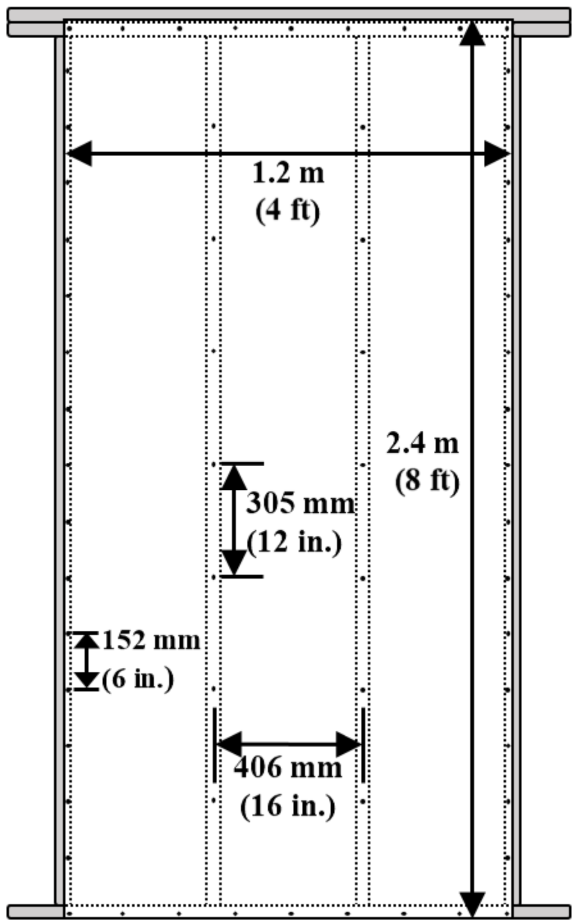


Figure 4 - 4. Typical 152/305 mm (6/12 in.) nailing pattern (62 nails) used to attach the 1.2 x 2.4 m (4 x 8 ft) wood sheathing panel to the framing members that are spaced at 406 mm (16 in.) on center.

To obtain a representative value of MC for the wood frame, density, and SG, five samples of 25.4 mm (1 in.) in length were cut from each of the framing members (Figure 4 - 5). The samples were taken roughly in equally spaced intervals. Because wood has a high variability of defects, samples cannot be taken at exact intervals; ASTM D2395 requires the wood samples be free of knots or other infiltrates. Also, to ensure a sample was not affected by exterior conditions near end grains, the samples taken near the ends of the framing members were a minimum of 152 mm (6 in.) away from the edge. Each framing member in a wall section was individually labeled from A-D and each wood specimen cut from a framing member was labeled 1-5, with1 being closet to the top plane and 5 near the bottom plate (Figure 4 - 6). The samples were labeled with the wall section type (Ply (short for Plywood), OSB), test number (1-10), a designated framing member letter (e.g. A-D), and a position number in the framing member (1-5), (i.e. 1 OSB A1, 1 OSB A2, 1 OSB A3, … ,10 Ply D5).

The moisture content M in the wood was determined from equation (2):

$$M = \frac{m_M - m_O}{m_O} \times 100 \qquad (2)$$

where:

M = the moisture content in the wood specimen as a percentage.

m_M = the initial mass of the wood specimen

m_O = the mass of the oven dried wood specimen

Density (ρ) of the wood specimen at the moisture content M was found by using equation (3).

$$\rho_M = \frac{m_M}{V_M} \qquad (3)$$

where:

ρ_M = the density of the wood specimen at the moisture content M

V_M = is the volume of the wood specimen at the moisture content M

The specific gravity SG_M was determined by using equation (4).

$$SG_M = \frac{Km_O}{V_M} \qquad (4)$$

where:

SG_M = is the specific gravity of the wood specimen at the moisture content M

K = is a constant which is determined by the units in which the mass and volume are measured.

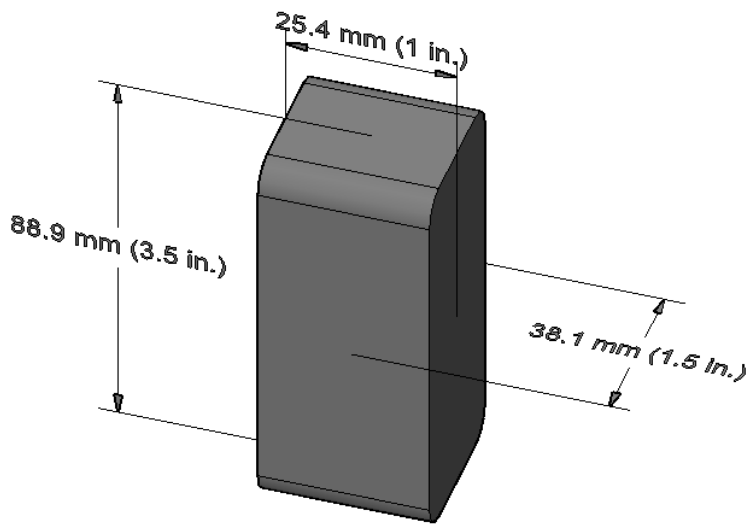


Figure 4 - 5. Wood samples used to determine moisture content and specific gravity of wood framing member. Five samples wood member and the average value is used in calculation.

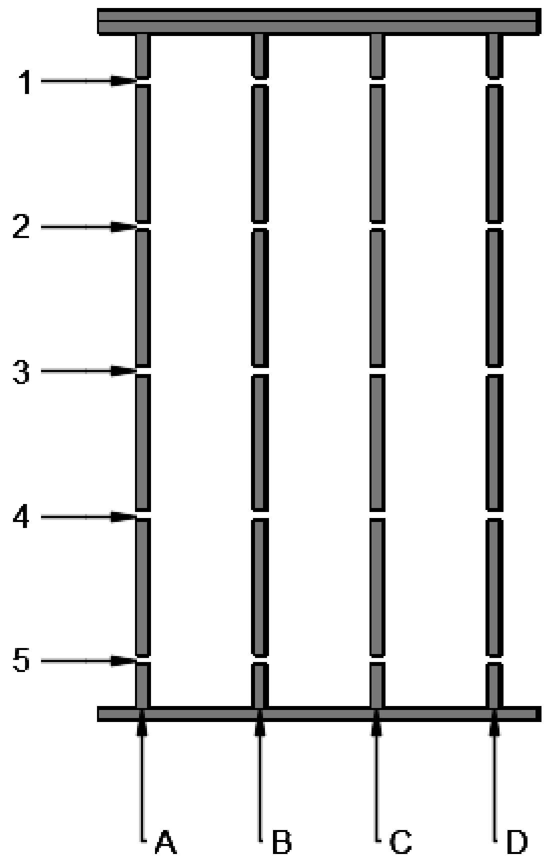


Figure 4 - 6. Locations and nomenclature of wood samples nomenclature cut from the framing members.

5 RESULTS

Structural Sheathing Panels

Table 5 - 1 provides a summary of results for the 10 plywood and 10 OSB wall panels tested. Figure 5 - 1 details observations of failure progression typically seen throughout testing. The failure in test panels always initiated along either a single center stud or both center studs together. 90% of the samples had complete failure of both center members which then progressed to failure of the top/bottom plate and side framing members, or various combinations of the aforementioned. Two of the test panels failed because of nail withdrawal from the stud to bottom plate connection (Figure 5 - 2).

Table 5 - 1. Summary of ultimate capacity, moisture content, density, and specific gravity for Spruce Pine Fir (SPF) test samples.

Panel Type	---	Failure Pressure kPa (psf)	COV	Moisture Content of lumber	COV	Density (ρ) of lumber kg/m^3 (lb/ft^3)	COV	Specific Gravity of lumber	COV
OSB	Mean	4.11 (85.9)	0.109	10.8%	0.065	484 (30.2)	0.087	0.436	0.084
	Max	4.79 (100.1)		12.4%		586 (36.6)		0.523	
	Min	3.31 (69.2)		9.5%		401 (25.0)		0.363	
Plywood	Mean	4.31 (90.1)	0.130	11.3%	0.064	488 (30.5)	0.065	0.439	0.062
	Max	5.21 (108.7)		13.2%		557 (34.8)		0.502	
	Min	3.31 (69.1)		9.6%		407 (25.4)		0.367	
OSB & Plywood	---	4.21 (88.0)	0.106	11.10%	0.073	486 (30.4)	0.08	0.438	0.078

The performance of the OSB panels were tested using monotonic step-and-hold pressure trace with a static wind pressure (Figure 5 - 3 (a)). Displacement measurements of the sheathing panel and the stud (Figure 5 - 3 (b)) were taken simultaneously with pressure reading using two string potentiometers side by side (Figure 4 - 2). The relative displacement of the sheathing panel (e.g., the separation of the sheathing panel from the stud) was determine by taking the difference between the structural sheathing panel displacement and the stud displacement (Figure 5 - 3 (b)). The peak failure pressures were determined to be the max absolute value obtained in each test prior to failure of panel.

After the experimental tests were completed the failure mechanisms and locations of failure were recorded. It was observed that of the ten OSB specimens tested, seven of the tests resulted in at least one nail pull through and a max of four nails pulled through in one specimen. Whereas, out of the ten plywood test specimens, there was only one nail pull-through.

Figure 5 - 1. View of wall panel during testing. The OSB sheathing is pulled away from framing members, with maximum displacements observed at the two middle studs. Initial separation of OSB at both center studs at the same time. OSB test 7.

Subsequently, five 25.4 mm (1 in.) samples were cut from each stud (Figure 4 - 5, Figure 4 - 6). The samples were weighed and measured to determine their volume. The samples were dried in and oven at 102 °C for 24 hours and weighed again. The samples were dried again for another 24 hours and reweighed to ensure practical equilibrium is reached (such that no more than 0.2% change in mass occurs over the drying period). The values obtained for the MC, density, and SG fall in the range of typical values that would be expected for SPF lumber.

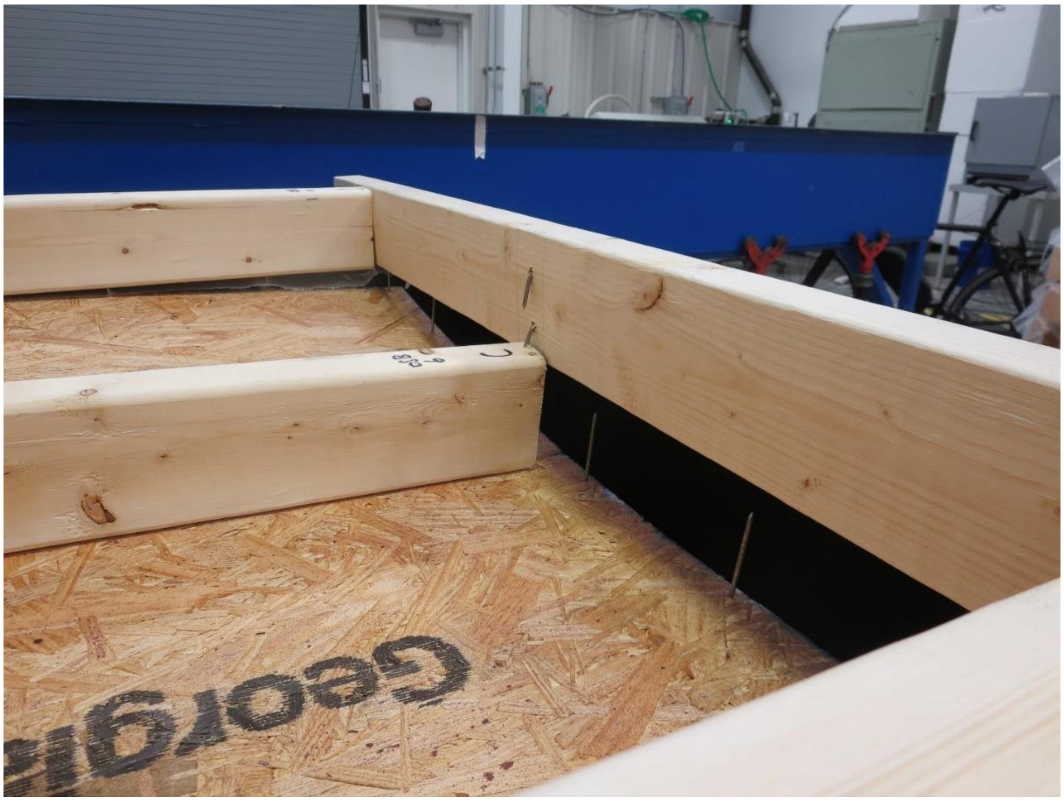


Figure 5 - 2. Failure of wall panel by nail withdrawal from along the bottom wall plate

Statistical Analysis

The Wilcoxon Rank Sum (WRS) test was used to determine if the distributions of the failure capacities between plywood and OSB tests were equal. WRS was chosen because of the relatively small sample size of each group. The WRS is a nonparametric test that assumes the two samples (e.g. plywood group and OSB group) are independent of one another and have equal variance. Using a confidence level of 95%, the WRS tested the null hypothesis of no difference between the two, sample means. The analysis showed, with a p-value = 0.52, that the mean failure pressures for the plywood and OSB panels were not significantly different. This implies that there is a failure to reject the null hypothesis, that the mean failure pressures come from the same distribution. Table 5 - 1 gives a summary of the results of the plywood and OSB tests as one group.

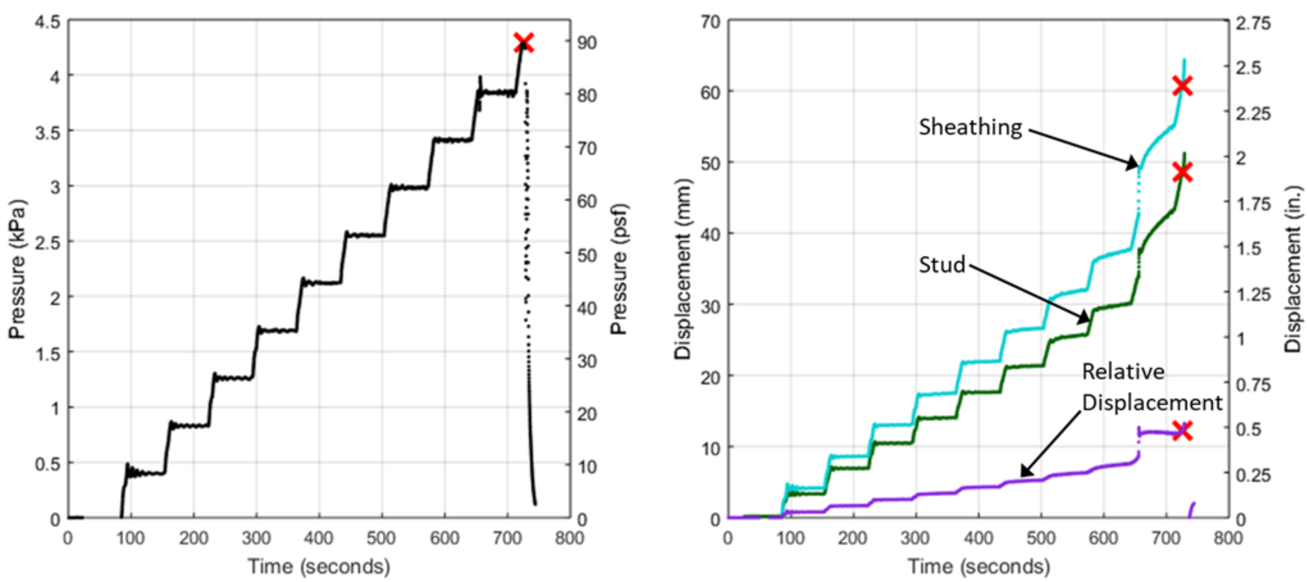


Figure 5 - 3. Typical recorded results (5th Plywood test). ✕, indicates point at which failure occurred. (a) Pressure time history, (b) Time history of the separation between the structural sheathing panel from the stud, displacement time history of sheathing panel, displacement time history of stud.

Distribution

The Akaike information criterion (AIC) (Sakamoto et al. 1986) was used to rank the relative quantality of different statistical distribution models (e.g. normal, lognormal, Weibull, etc.) for the given data set. This method estimates the quality of the different models tested and ranks them from best to worst based on the goodness to fit statistic and the number of parameters associated with the model. The AIC method was also used to determine the best fit distribution for Moisture Content (MC) and SG was lognormal and normal respectively. Figure 5 - 4 shows the normalized histogram of the data collected for MC and SG with the Probability Density Function (PDF) that best represents the distribution of the data collected form the experiments.

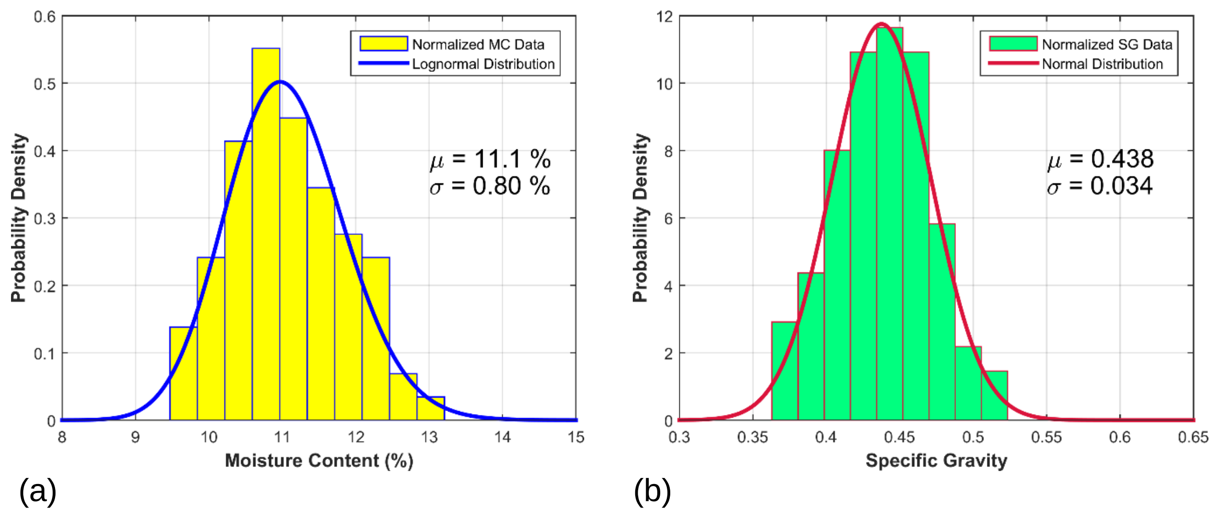
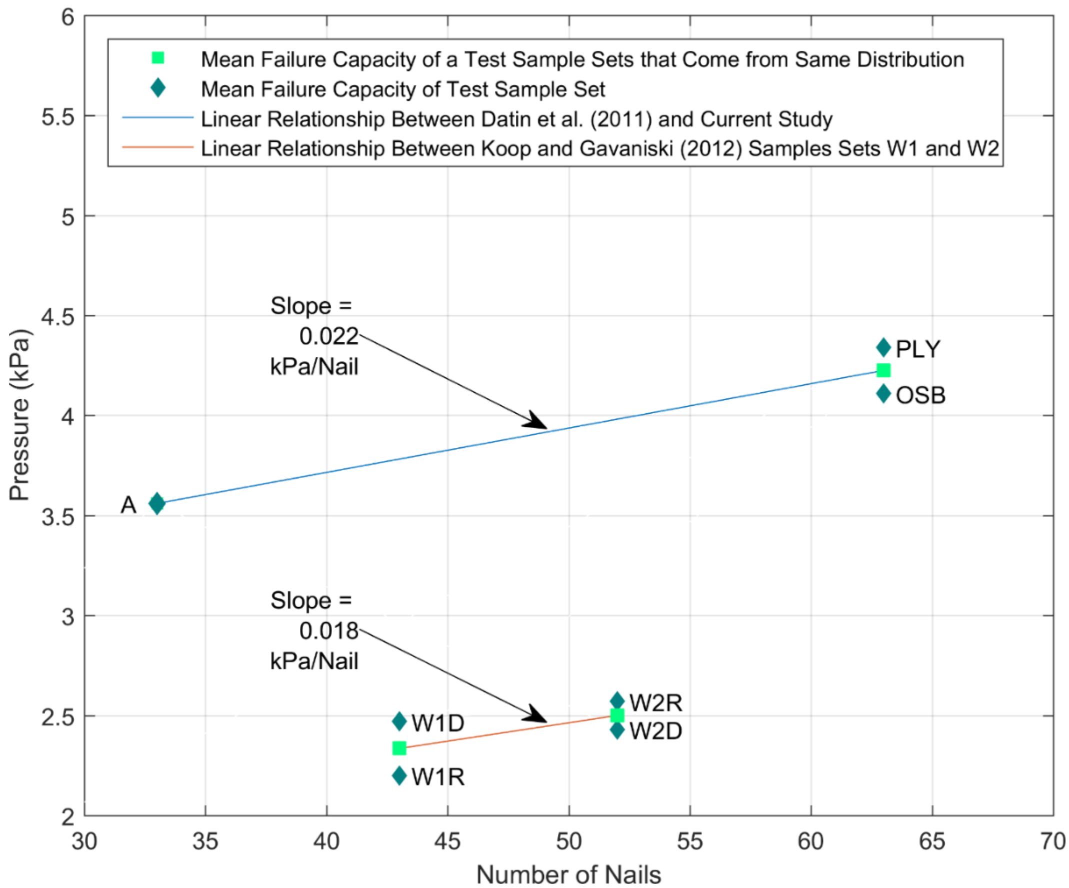


Figure 5 - 4. Represents the normalized histograms from the Moisture Content and Specific Gravity data collected with the Probability Distribution Function that best fits the data: (a) Lognormal Distribution for MC, (b) Normal Distribution for SG.

6 DISCUSSION

When comparing the results of tests performed at the University of Florida versus the tests conducted at the University of Western Ontario of perpendicularly orientated studs with respect to the long edge of the sheathing and studs oriented parallel to the long edge, there is clear relationship of an increase of nails results in an increase in pressure (Figure 6 - 1).



Note:
PLY, OSB – Current Study
A – Datin et al. (2011) Performed at the University of Florida
W1D, W1R, W2D, W2R – Kopp and Gavanski (2012) Performed at the University of Western Ontario
A, PLY, OSB – Used 2 3/8” smooth shank nails to attach sheathing
W1D, W1R, W2D, W2R – Used 2” nails to attach sheathing

Figure 6 - 1. Relationship of the increase in failure capacity of a test sample with respect to the increase in the number of nails used to attach the sheathing panel the studs.

The out-of-plane capacities obtained for the structural wood sheathing panels were not in agreement to previous wall capacity studies that also examined structural wood sheathing panels (Kopp and Gavanski 2012) (Figure 6 - 2). An increase in ultimate capacities found in this study versus the previously mentioned study could be accounted for by the following:

- The increase in the number of nails.
- The use of a slightly longer nail to connect the sheathing to the framing member; [60.4 mm (2 3/8 in.) current study vs. 50.8 mm (2 in.) Kopp and Gavanski (2012)].
- Different support end conditions: This study used double top plates where the previous study only used a single top plate. The bottom and top plates for this study spanned the 1.2 m (4 ft) direction of the steel chamber and were simply supported at the ends.
- This study used a monotonic step-and-hold approach to apply pressure to the structural panels whereas as the previous study used ramp and fluctuating loads.

The mean failure capacities for plywood and OSB panels were 4.31 kPa (90.1 psf) with a COV of 0.123 and 4.11 kPa (85.9 psf) with a COV of 0.103 respectively. The next task, set out to determine if there was a significant difference between the capacities of the plywood and OSB sheathing types. Using the Wilcoxon Rank Sum analysis of the mean values from each of experimental sample groups, it was determined that there was no significant difference between the two sheathing types. This also implies that the two test groups come from the same distribution. Therefore, the mean failure capacity of the entire population was determined to be 4.21 kPa (88.0 psf) with a COV of 0.101.

The wall sheathing panels tested used a 152/305 mm (6/12 in.) nailing pattern, with the orientation of the sheathing parallel to the framing members, therefore the wall sheathing contained a total of 62 nails. Whereas, roof sheathing, generally has a 152/305 mm (6/12 in.) nailing patter as well, but it will have nine nails on the outer edges and five nails on the inner members giving it a total of 33 nails per panel. This change in orientations leads to a 61% increase in nails on the wall sheathing panels. In spite of this, relatively large increase in nails, there is only a 17% percent increase in mean failure capacity for wall sheathing panels. This suggests that the tributary area of each fastener is more important to the capacity of the panel than the total number of nails. The failure mechanism is controlled by the local behavior of the sheathing around a fastener.

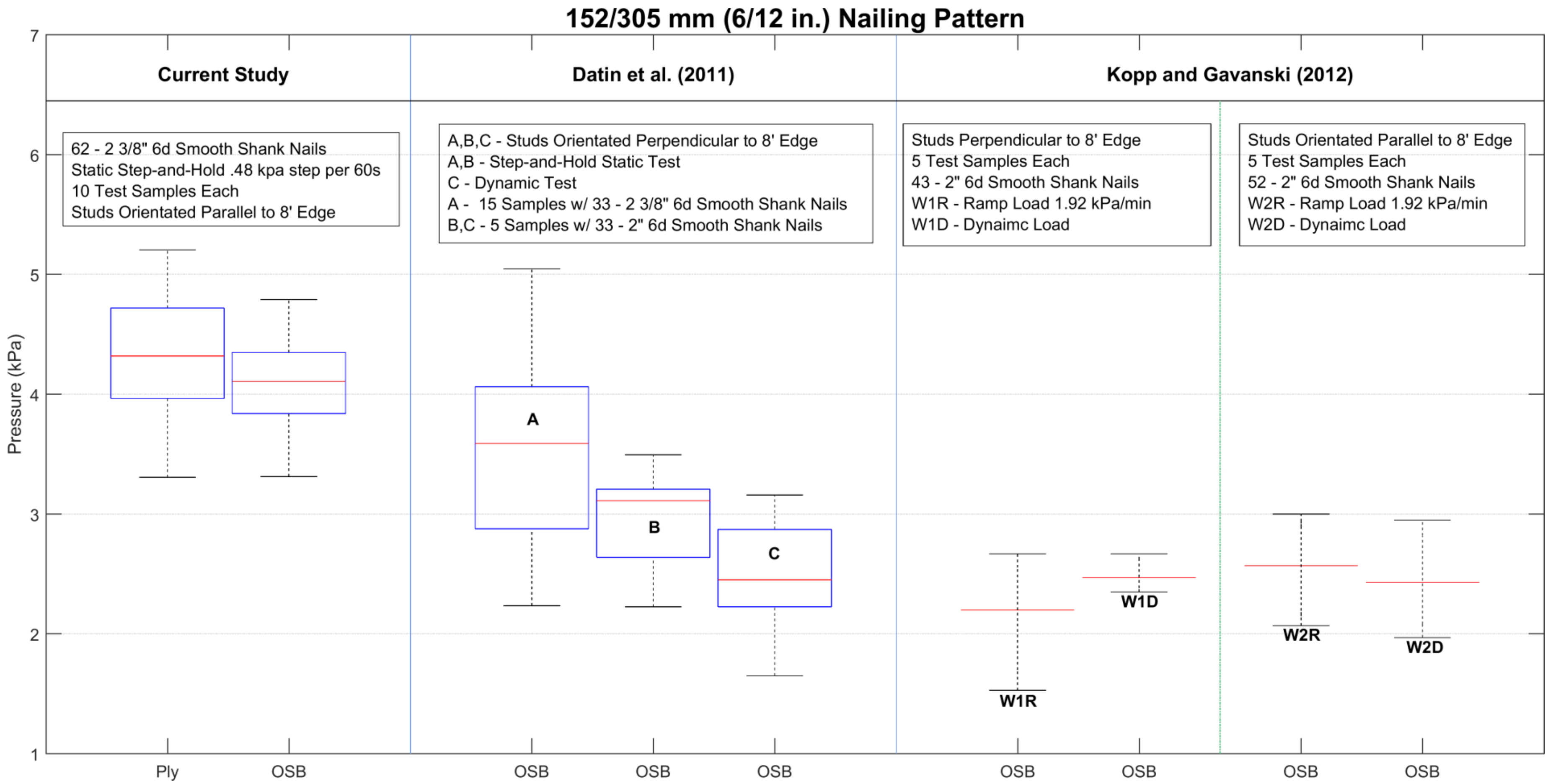


Figure 6 - 2. Box Plot to compare mean capacity failures.

7 CONCLUSION

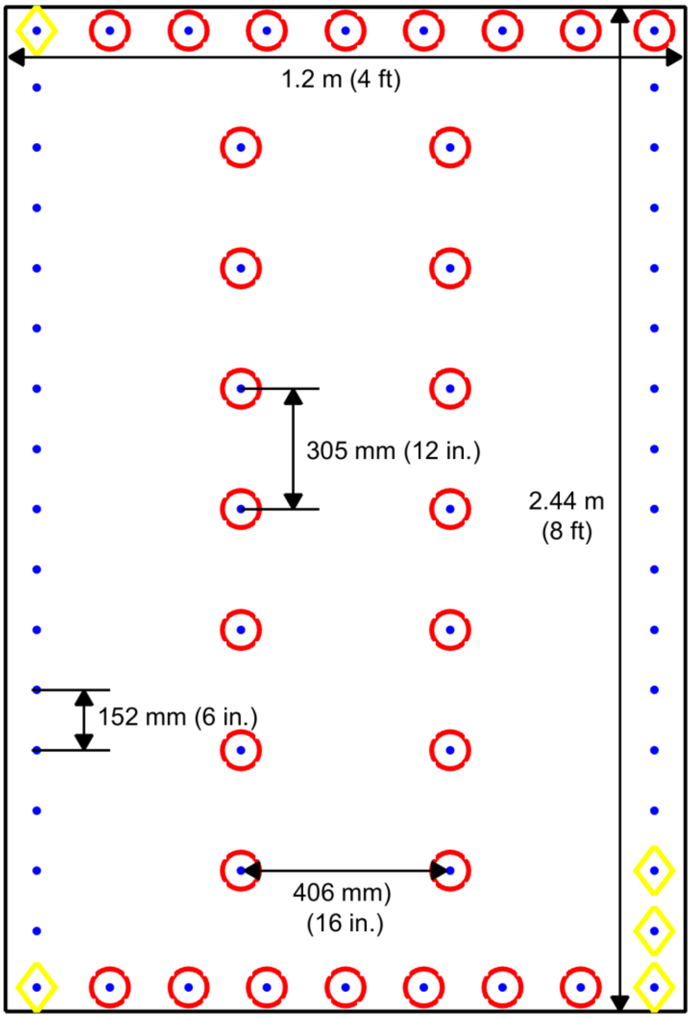
For this experiment, two samples types, plywood and OSB sheathing, were tested in order to determine the ultimate capacities of each sheathing type. The pressure is increased monotonically in a step-and-hold approach. The pressure is stepped in increments of 0.48 kPa (10 psf) and held for 60 seconds and repeated until failure of test specimen. Failure occurs once the panel separates from the wood framing and the blower can no longer maintain a constant air pressure. The failure pressure is taken as the maximum absolute pressure maintained by the system prior to the panel giving way and the system losing pressure.

Because of the failure to reject the null hypothesis, it was determined that the ultimate failure capacity is not significantly affected by the sheathing type. However, failure type between the plywood and OSB sheathing was noticeably different. OSB test specimens are more prone to pull through failures than plywood test specimens. The most common failure mechanism of both test samples was nail withdraw in the two center studs. This failure mechanism eventually led to ultimate failure of the panel at one or multiple edges.

The ultimate capacities from the plywood and OSB sheathing were tested under a monotonic step-and-hold approach using static wind pressures. 18 of the 20 tests conducted, initial failure (e.g. separation of sheathing from framing member) began with either one or both center two framing members. In two of the test specimens there was a shear failure connection of the nails between the bottom plate and the studs.

APPENDIX A

FULL FAILURE MODE AND LOCATION



3.97 kPa (82.8 psf)	SG: 0.471	Ply #1
MC: 11.7%	527 kg/m^3 (32.9 lb/ft^3)	
PT: 0	CPO: 29	PPO: 5

Plywood
10 Samples
Mean: 4.31 kPa (90.1 psf)
Max: 5.21 kPa (109 psf)
Min: 3.31 kPa (69.1 psf)
STD: 0.53 kPa (11.1 psf)
COV: 0.123

OSB
10 Samples
Mean: 4.11 kPa (85.9 psf)
Max: 4.79 kPa (100 psf)
Min: 3.31 kPa (69.2 psf)
STD: 0.43 kPa (8.89 psf)
COV: 0.103

Plywood & OSB
Mean: 4.21 kPa (88.0 psf)
STD: 0.49 kPa (10.3 psf)
COV: 0.101

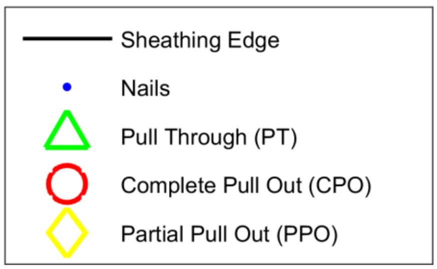
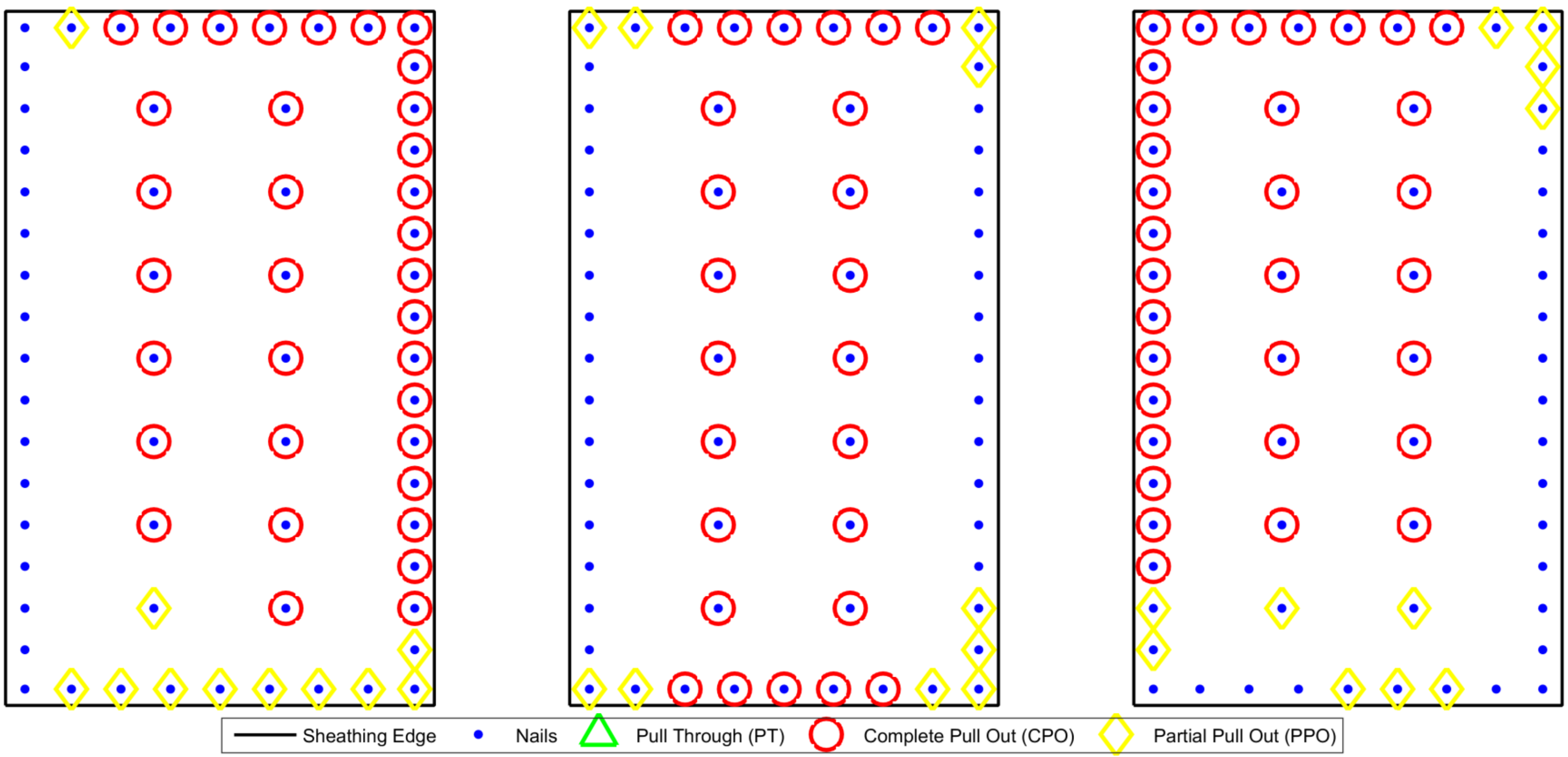


Figure A - 1. Failure mode and location for plywood sample test 1. Test statistics from the plywood group, OSB group, and both groups treated as one group.

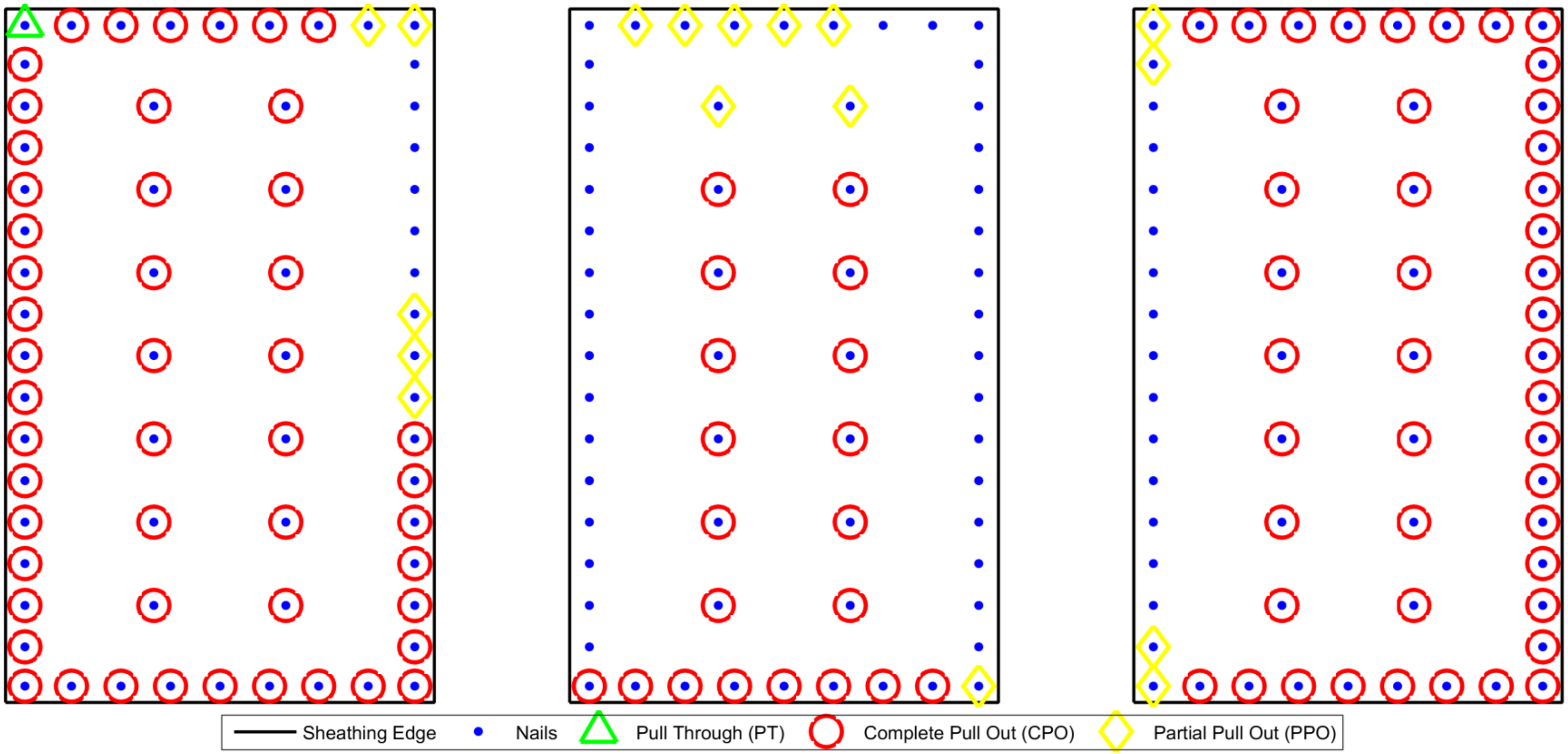


4.35 kPa (90.8 psf)	SG: 0.441	**Ply #2**
MC: 10.0%	486kg/m^3 (30.3lb/ft^3)	
PT: 0	CPO: 34	PPO: 11

4.66 kPa (97.3 psf)	SG: 0.406	**Ply #3**
MC: 10.9%	450kg/m^3 (28.1lb/ft^3)	
PT: 0	CPO: 25	PPO: 10

4.08 kPa (85.1 psf)	SG: 0.453	**Ply #4**
MC: 11.3%	504kg/m^3 (31.5lb/ft^3)	
PT: 0	CPO: 32	PPO: 11

Figure A - 2. Sample statistics, failure mode, and location for plywood samples 2, 3, and 4.

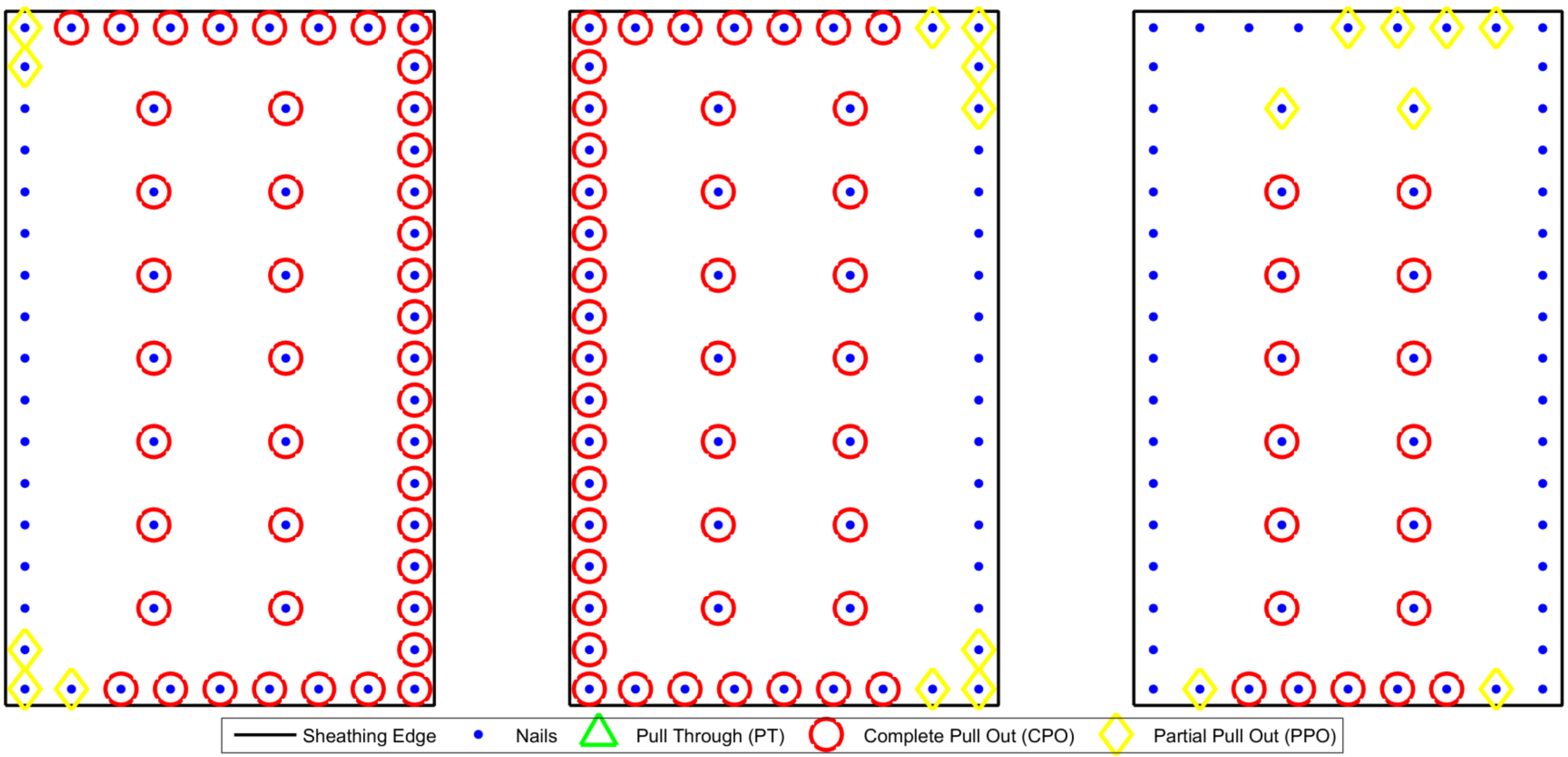


4.29 kPa (89.7 psf)	SG: 0.444	**Ply #5**
MC: 11.7%	496kg/m^3 (31.0lb/ft^3)	
PT: 1	CPO: 50	PPO: 5

3.76 kPa (78.5 psf)	SG: 0.428	**Ply #6**
MC: 11.4%	478kg/m^3 (29.8lb/ft^3)	
PT: 0	CPO: 20	PPO: 8

4.72 kPa (98.6 psf)	SG: 0.445	**Ply #7**
MC: 12.4%	501kg/m^3 (31.3lb/ft^3)	
PT: 0	CPO: 45	PPO: 4

Figure A - 3. Sample statistics, failure mode, and location for plywood samples 5, 6, and 7.

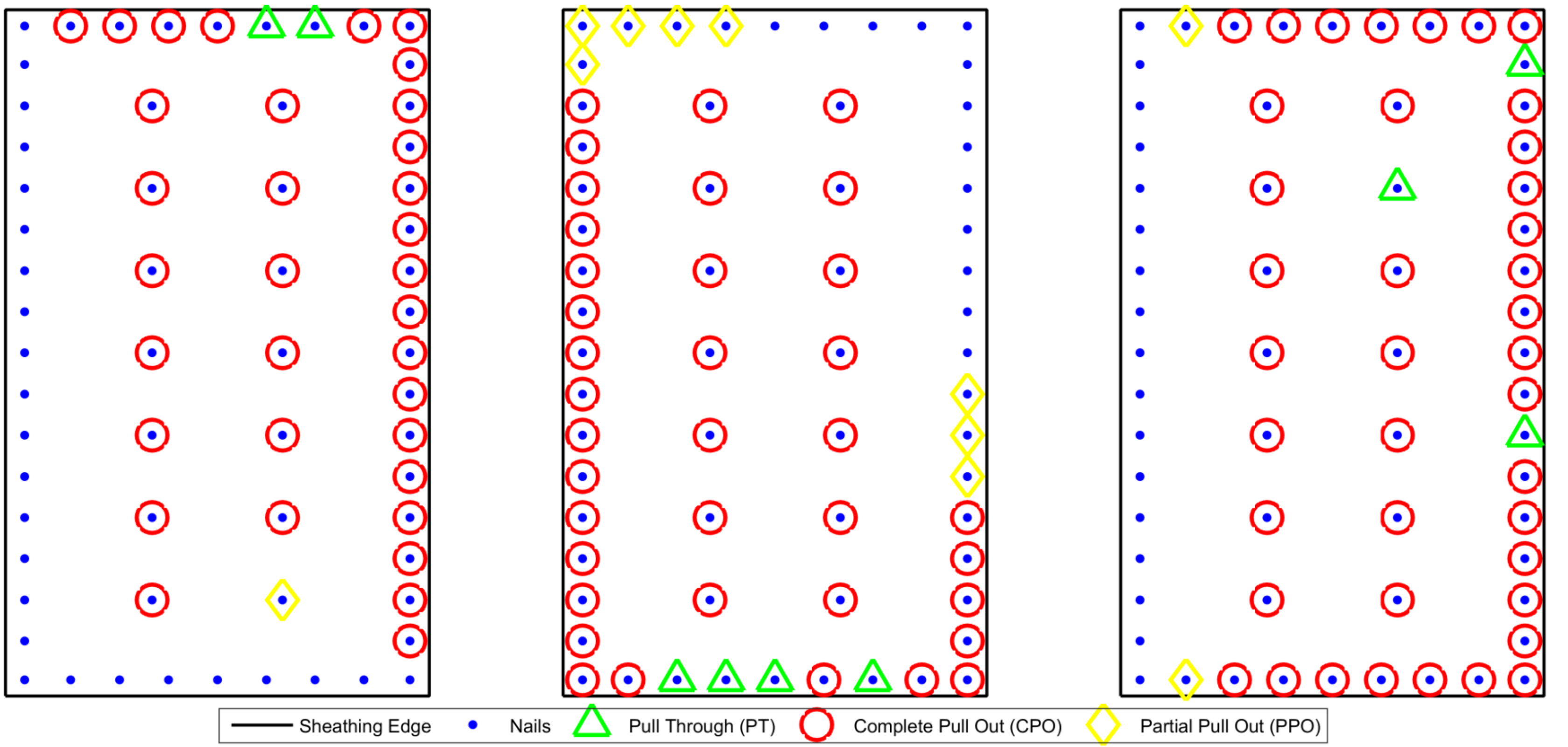


5.21 kPa (109 psf)	SG: 0.422	**Ply #8**
MC: 11.2%	470kg/m^3 (29.3lb/ft^3)	
PT: 0	CPO: 44	PPO: 5

4.79 kPa (100 psf)	SG: 0.444	**Ply #9**
MC: 11.5%	496kg/m^3 (31.0lb/ft^3)	
PT: 0	CPO: 43	PPO: 7

3.31 kPa (69.1 psf)	SG: 0.441	**Ply #10**
MC: 10.5%	478kg/m^3 (39.9lb/ft^3)	
PT: 0	CPO: 17	PPO: 8

Figure A - 4. Sample statistics, failure mode, and location for plywood samples 8, 9, and 10.

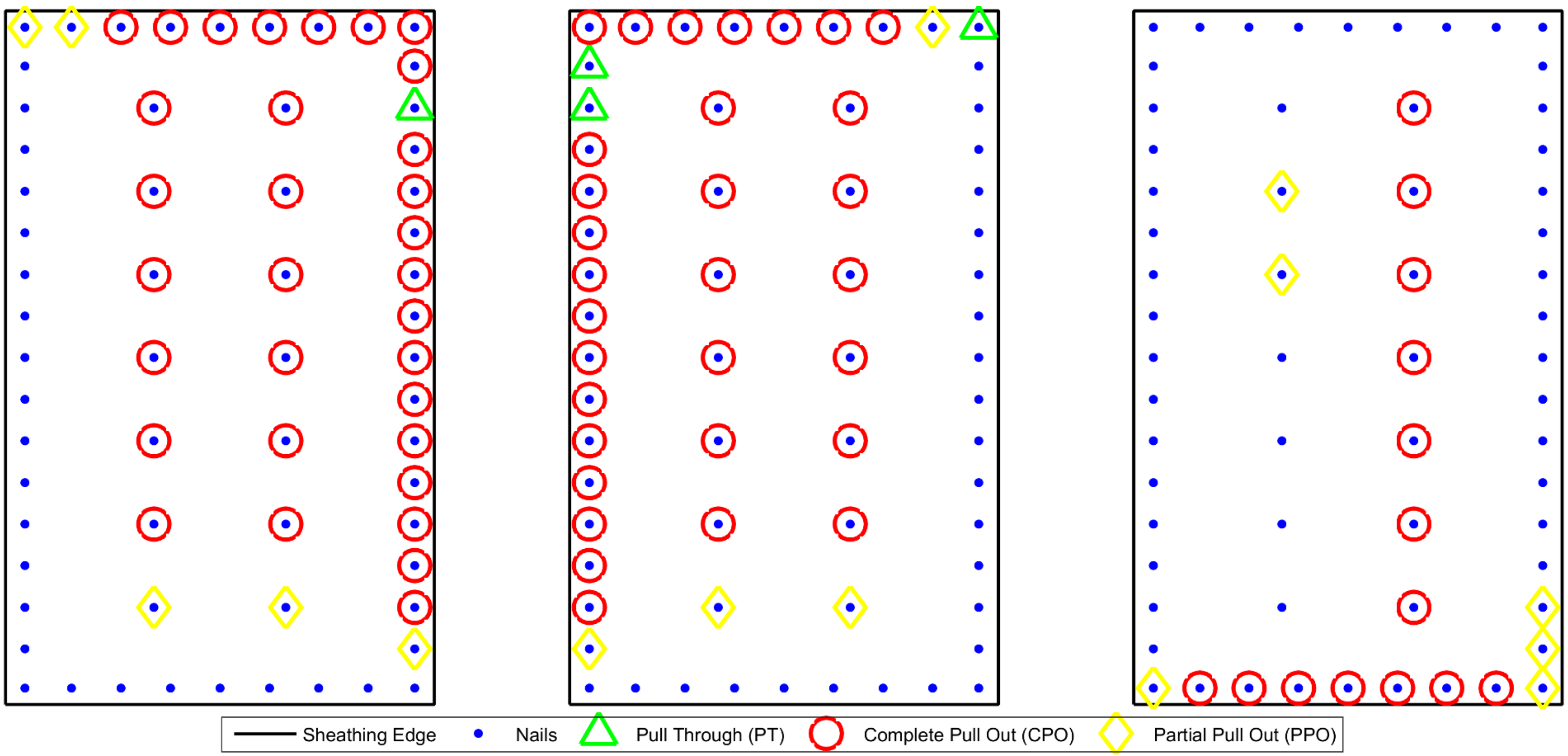


4.35 kPa (90.8 psf)	SG: 0.438	**OSB #1**
MC: 10.1%	483kg/m^3 (30.2lb/ft^3)	
PT: 2	CPO: 34	PPO: 1

3.84 kPa (80.2 psf)	SG: 0.416	**OSB #2**
MC: 10.3%	458kg/m^3 (28.6lb/ft^3)	
PT: 4	CPO: 37	PPO: 8

4.35 kPa (90.9 psf)	SG: 0.424	**OSB #3**
MC: 10.6%	469kg/m^3 (29.3lb/ft^3)	
PT: 3	CPO: 40	PPO: 2

Figure A - 5. Sample statistics, failure mode, and location for OSB samples 1, 2, and 3.

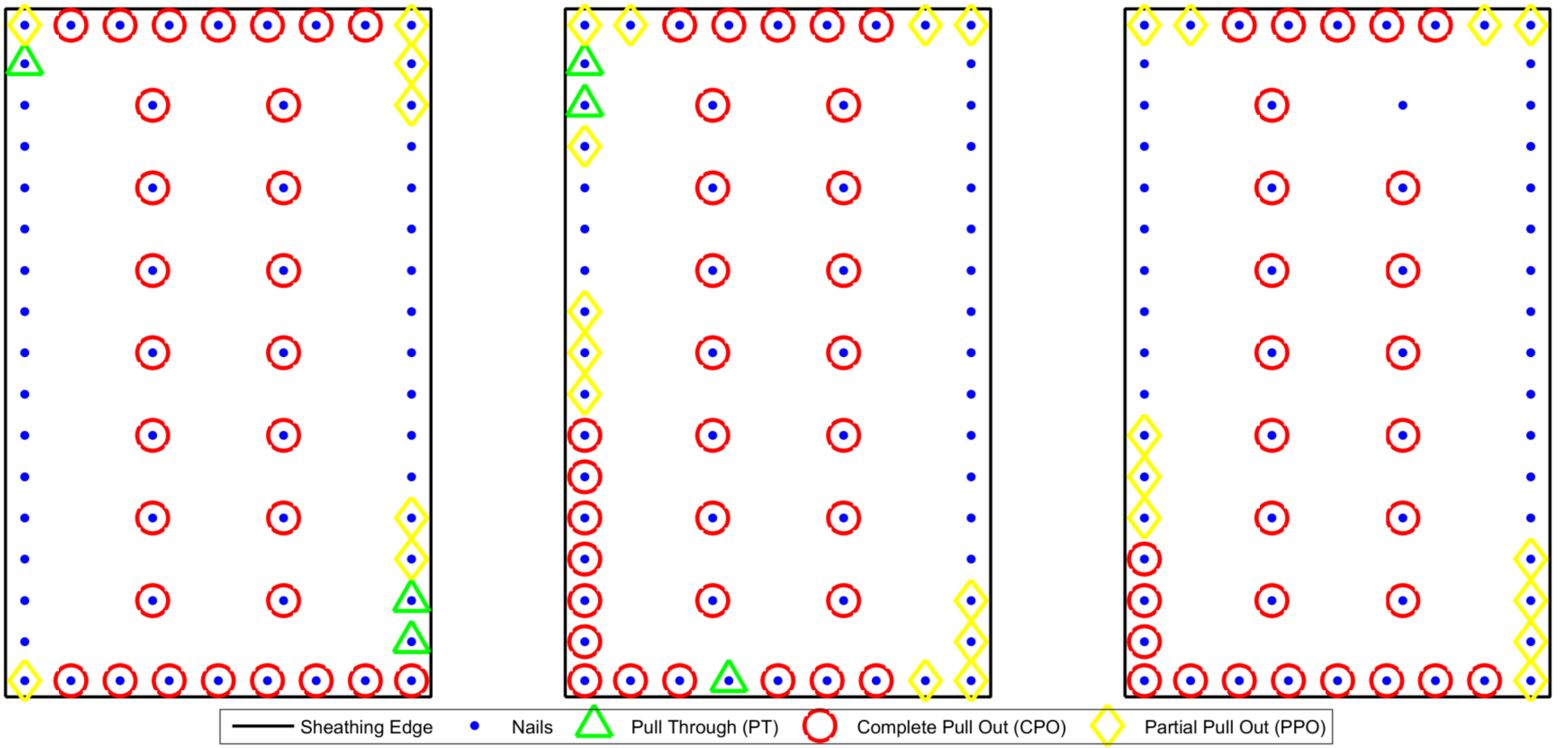


3.62 kPa (75.6 psf)	SG: 0.433	**OSB #4**
MC: 11.6%	484kg/m^3 (30.2lb/ft^3)	
PT: 1	CPO: 32	PPO: 5

3.31 kPa (69.2 psf)	SG: 0.420	**OSB #5**
MC: 11.5%	468kg/m^3 (29.3lb/ft^3)	
PT: 3	CPO: 31	PPO: 4

4.32 kPa (90.2 psf)	SG: 0.471	**OSB #6**
MC: 11.4%	524kg/m^3 (32.8lb/ft^3)	
PT: 0	CPO: 14	PPO: 6

Figure A - 6. Sample statistics, failure mode, and location for OSB samples 4, 5 and 6.

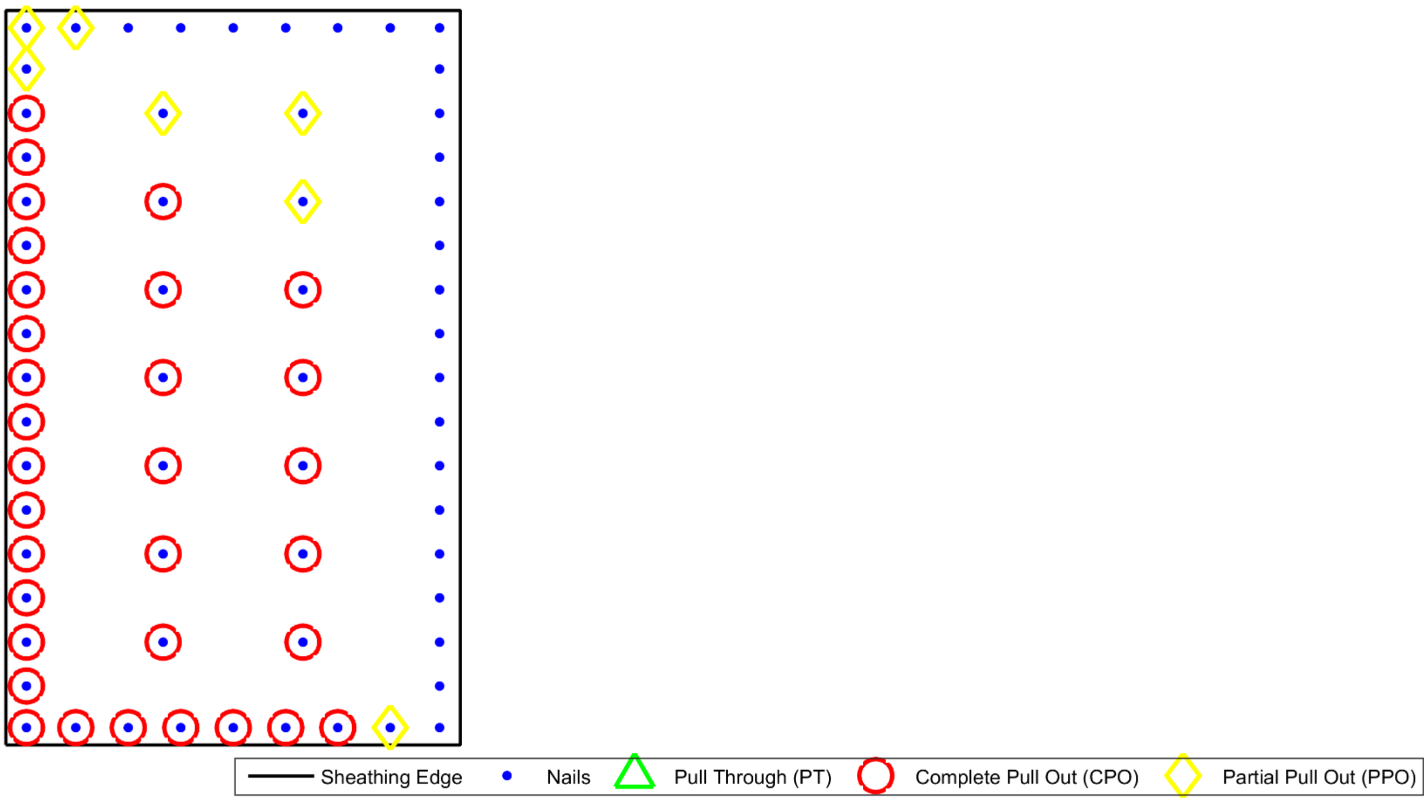


4.79 kPa (100 psf)	SG: 0.462	**OSB #7**
MC: 11.2%	514kg/m^3 (32.1lb/ft^3)	
PT: 3	CPO: 29	PPO: 7

4.13 kPa (86.2 psf)	SG: 0.416	**OSB #8**
MC: 10.3%	459kg/m^3 (28.7lb/ft^3)	
PT: 3	CPO: 31	PPO: 12

4.02 kPa (84.0 psf)	SG: 0.448	**OSB #9**
MC: 10.8%	497kg/m^3 (31.0lb/ft^3)	
PT: 0	CPO: 30	PPO: 11

Figure A - 7. Sample statistics, failure mode, and location for OSB samples 7, 8, and 9.



4.09 kPa (85.4 psf)	SG: 0.435	**OSB #10**
MC: 10.6%	480kg/m^3 (30.0lb/ft^3)	
PT: 0	CPO: 32	PPO: 7

Figure A - 8. Sample statistics, failure mode, and location for OSB sample 10.

APPENDIX B
FULL TEST RESULTS FOR PLYWOOD PANELS

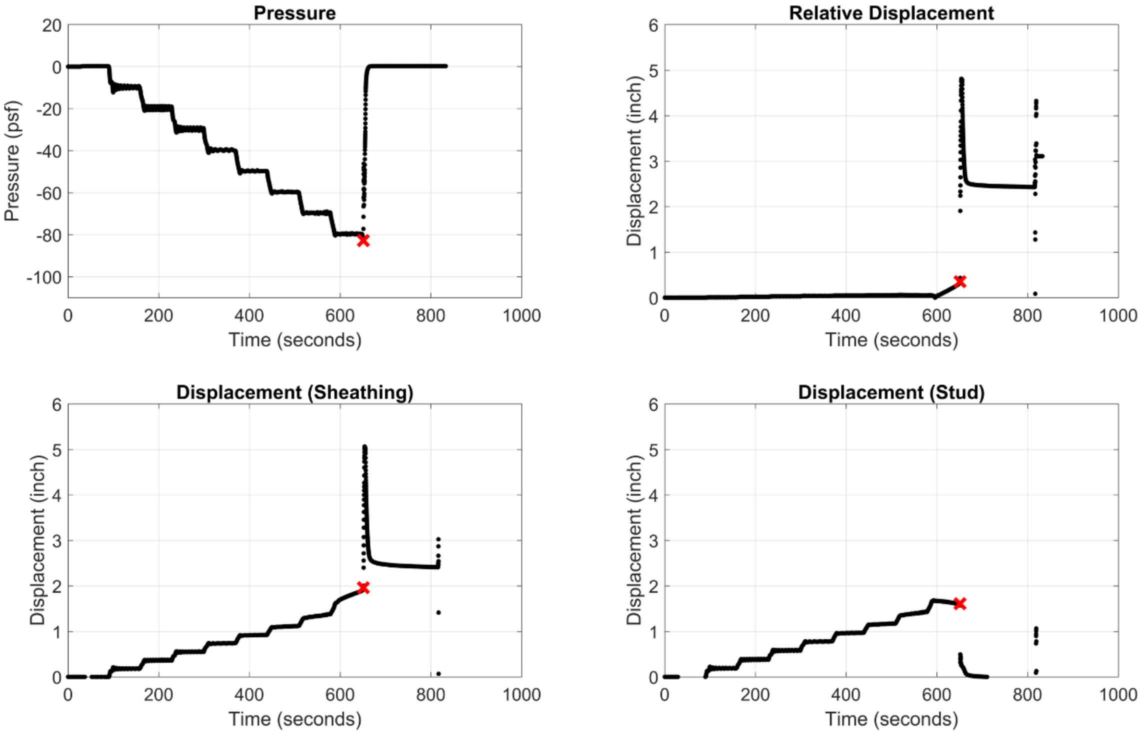


Figure B - 1. Plywood Test Sample 1 Pressure and Displacement Time-History.

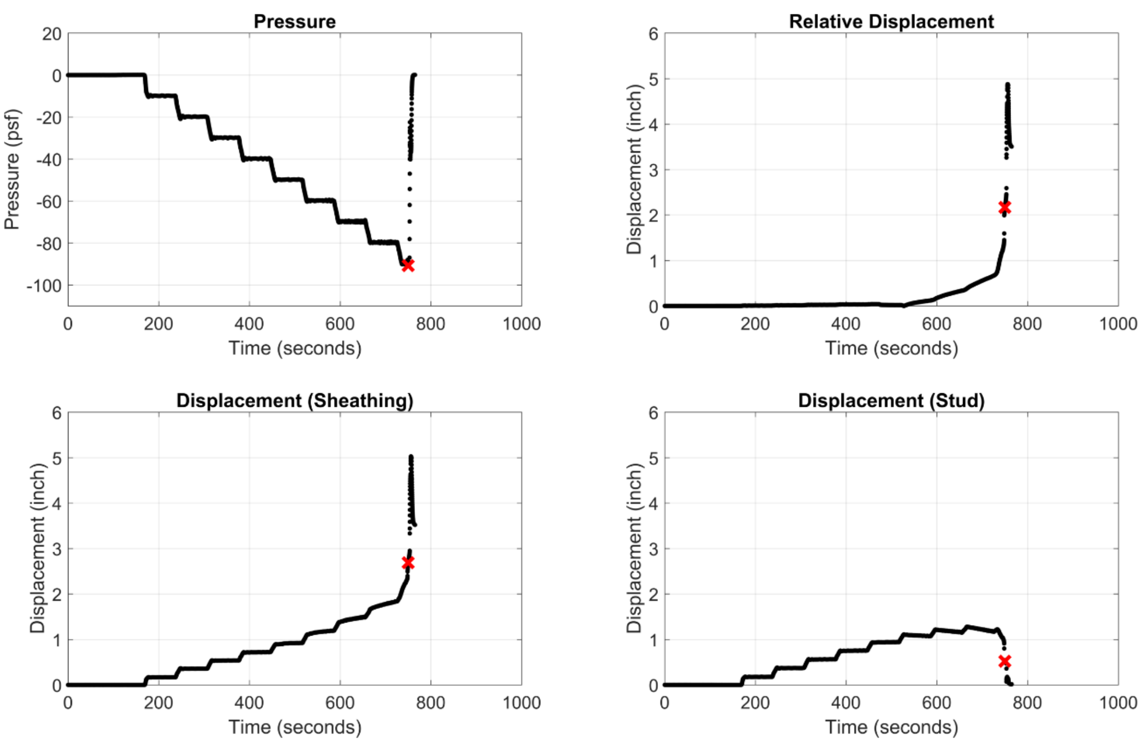


Figure B - 2. Plywood Test Sample 2 Pressure and Displacement Time-History.

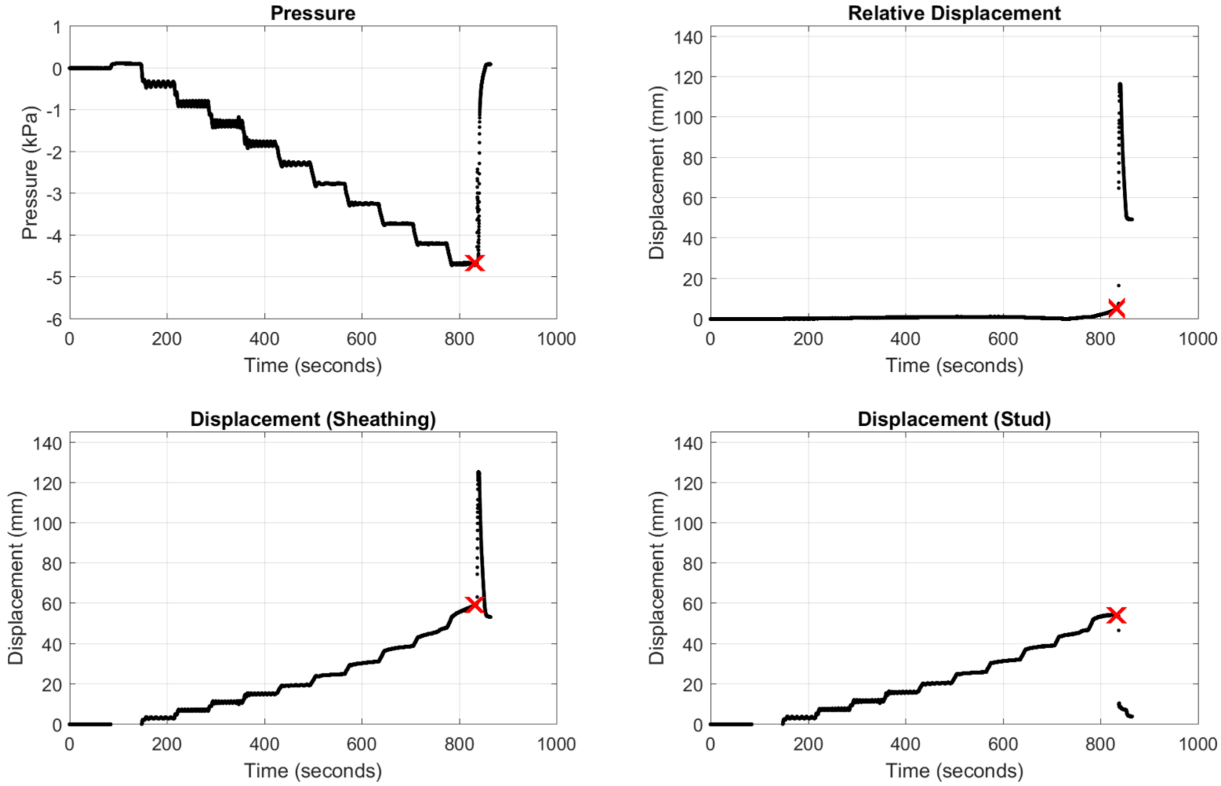


Figure B - 3. Plywood Test Sample 3 Pressure and Displacement Time-History.

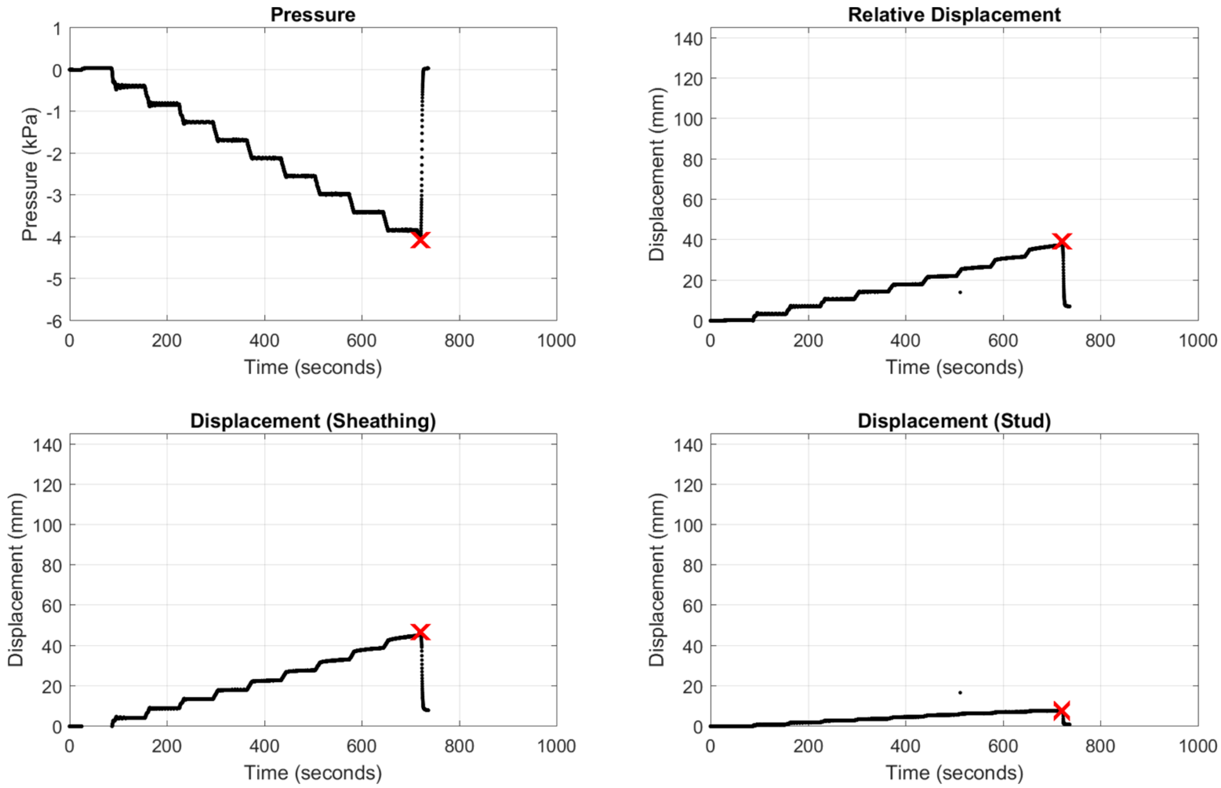


Figure B - 4. Plywood Test Sample 4 Pressure and Displacement Time-History.

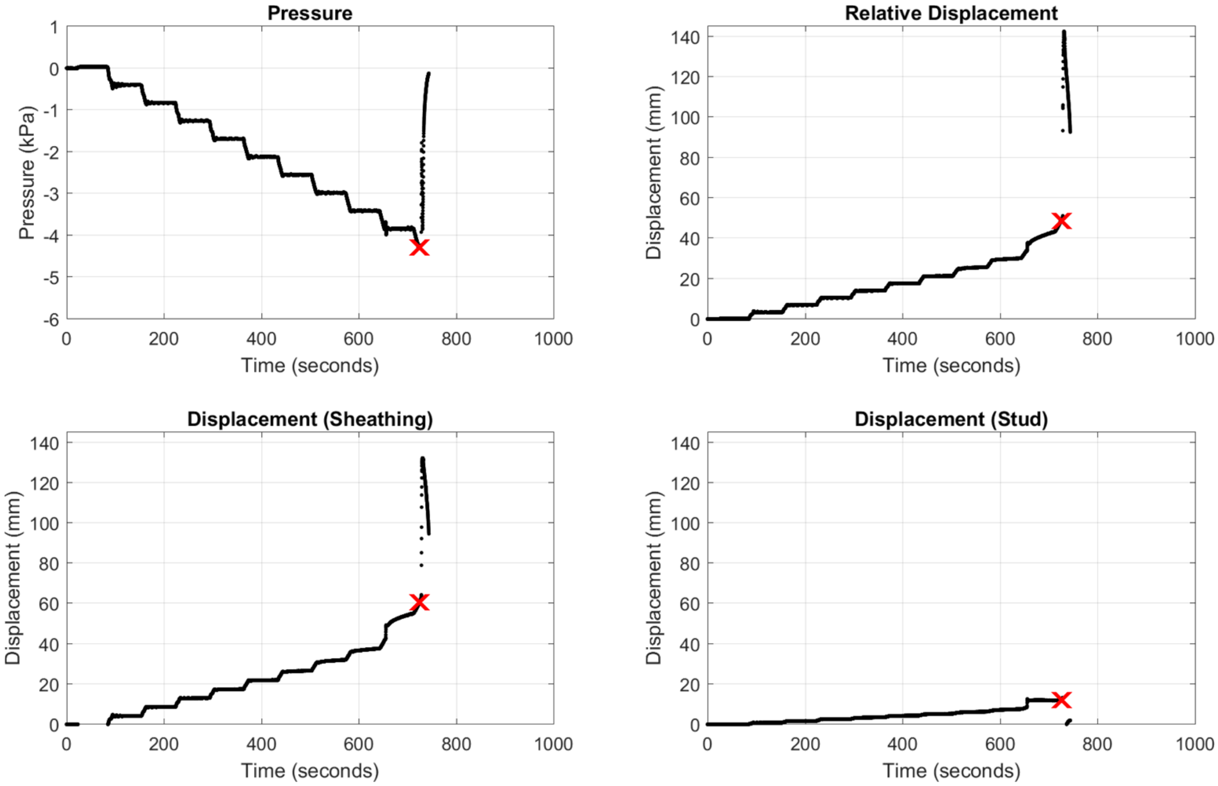


Figure B - 5. Plywood Test Sample 5 Pressure and Displacement Time-History.

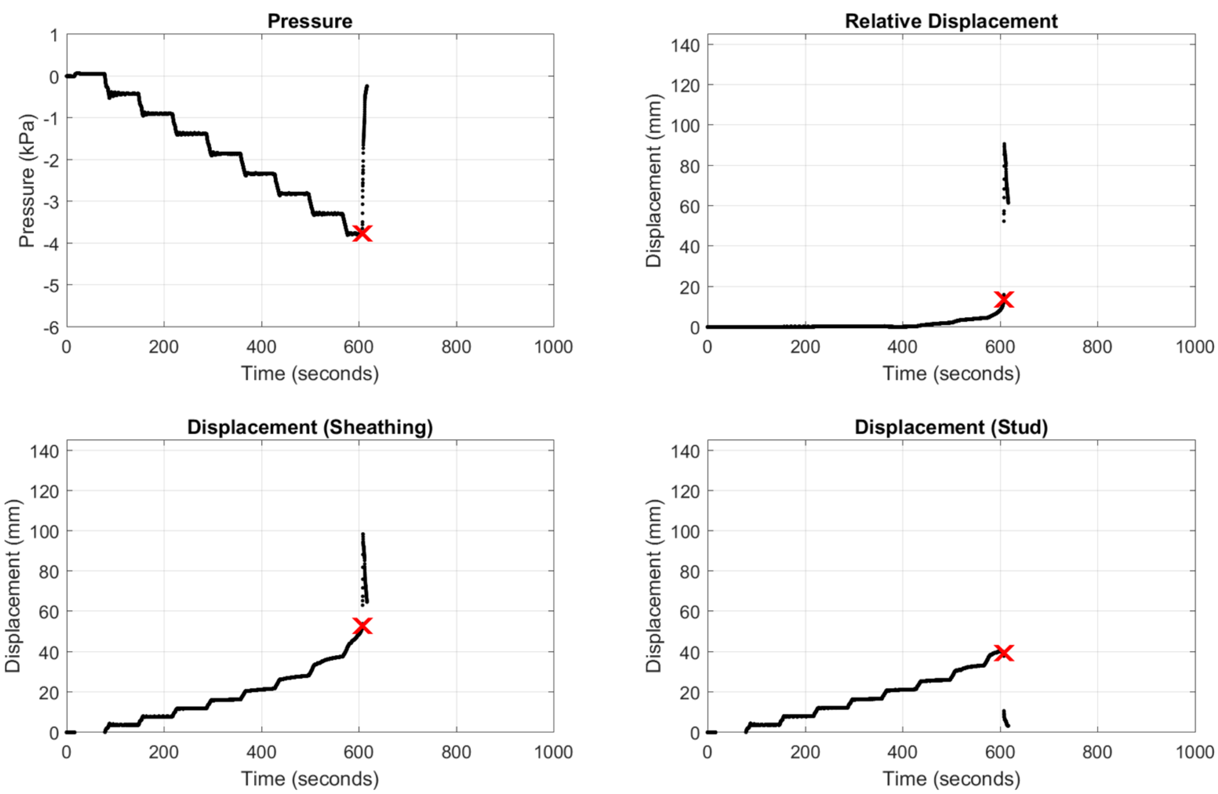


Figure B - 6. Plywood Test Sample 6 Pressure and Displacement Time-History.

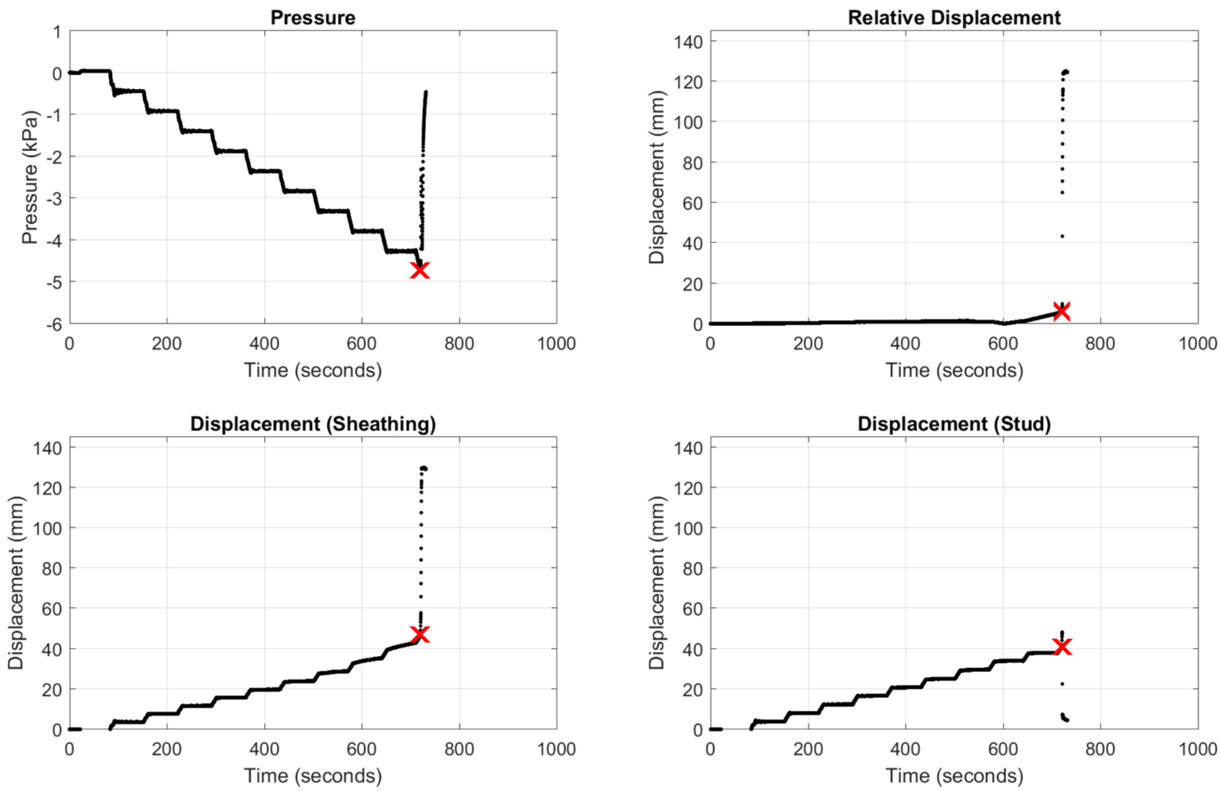


Figure B - 7. Plywood Test Sample 7 Pressure and Displacement Time-History.

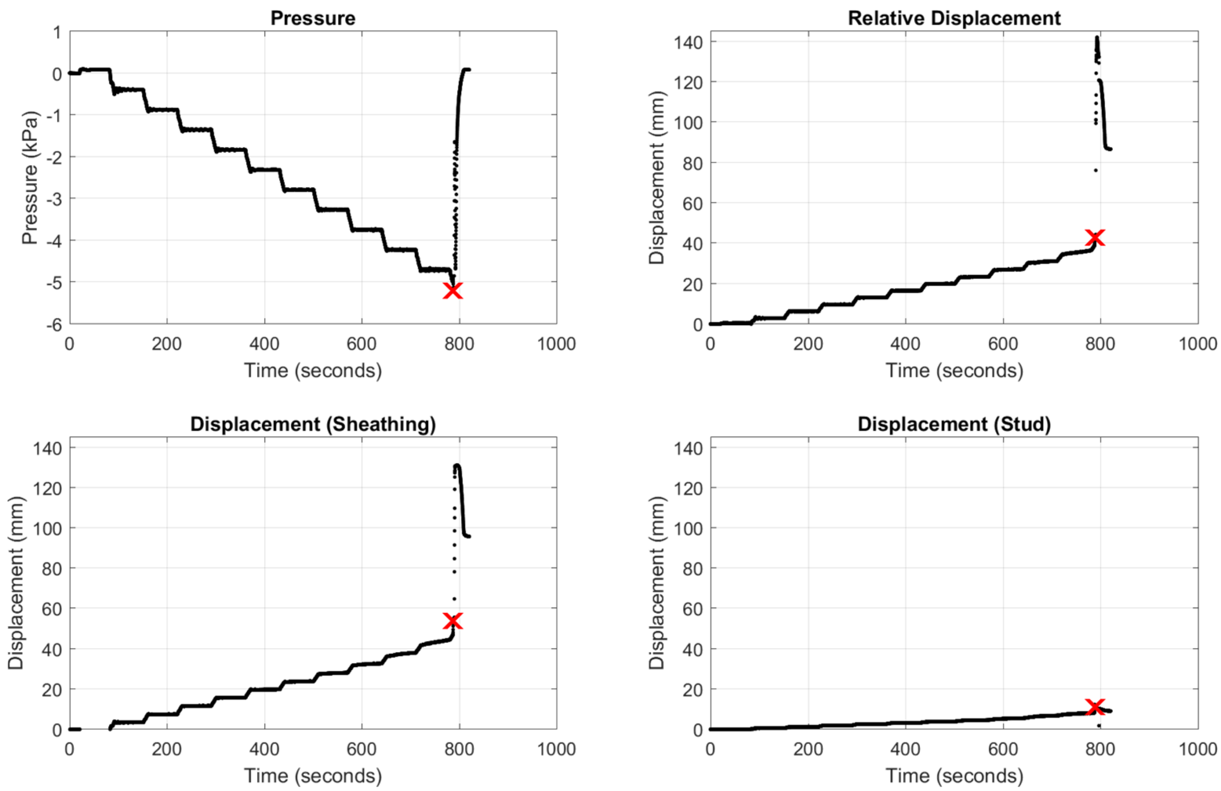


Figure B - 8. Plywood Test Sample 8 Pressure and Displacement Time-History.

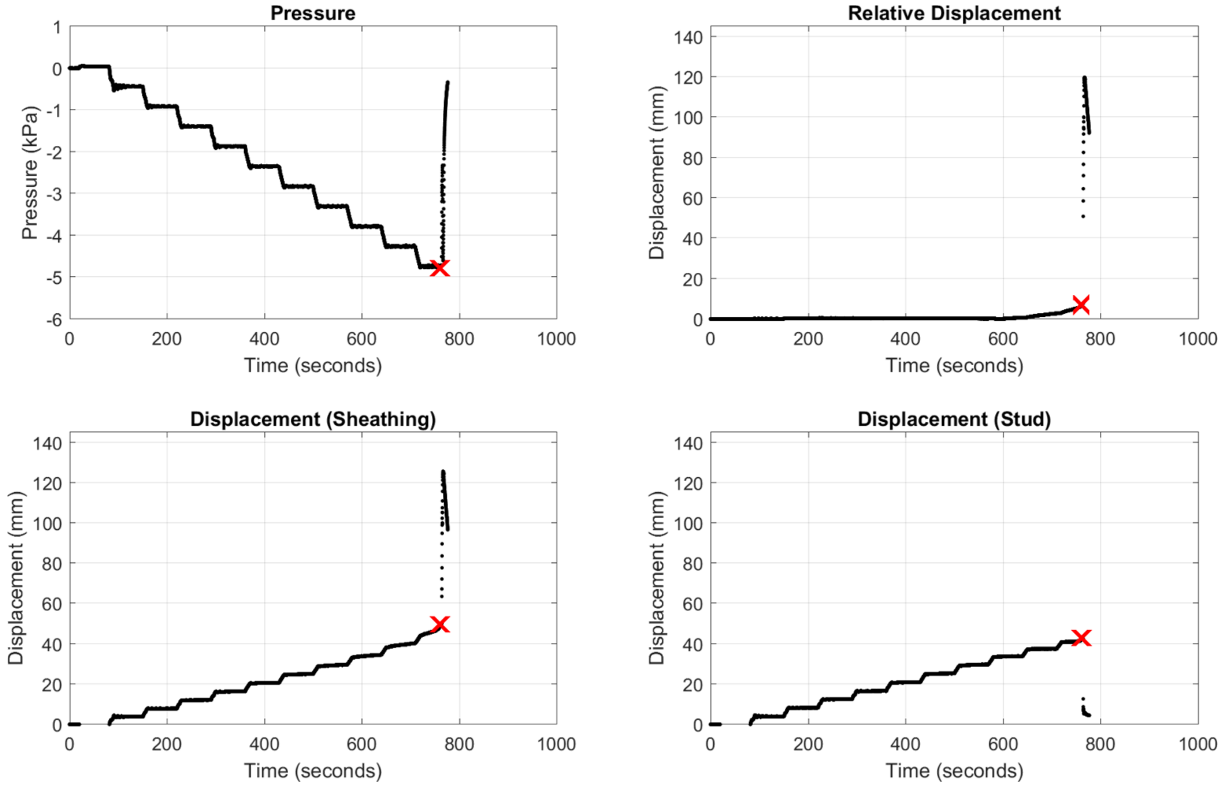


Figure B - 9. Plywood Test Sample 9 Pressure and Displacement Time-History.

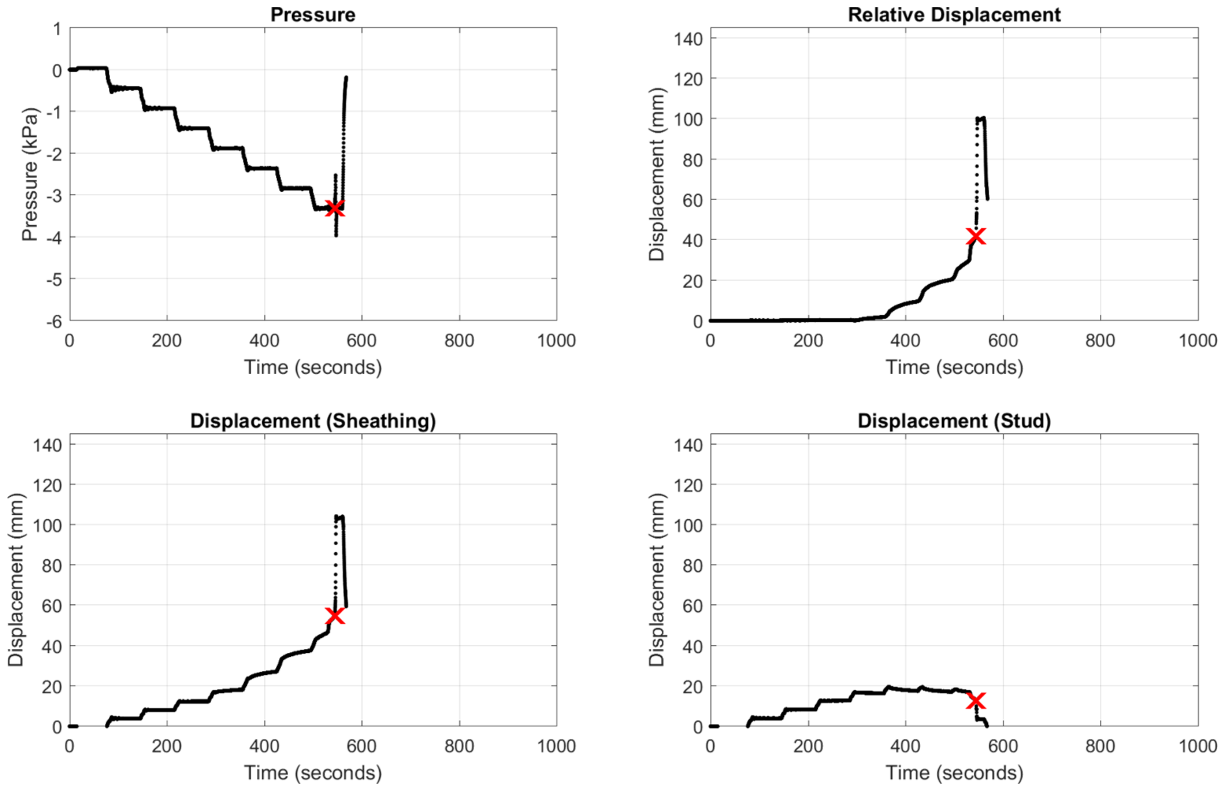


Figure B - 10. Plywood Test Sample 10 Pressure and Displacement Time-History.

APPENDIX C

FULL TEST RESULTS FOR OSB PANELS

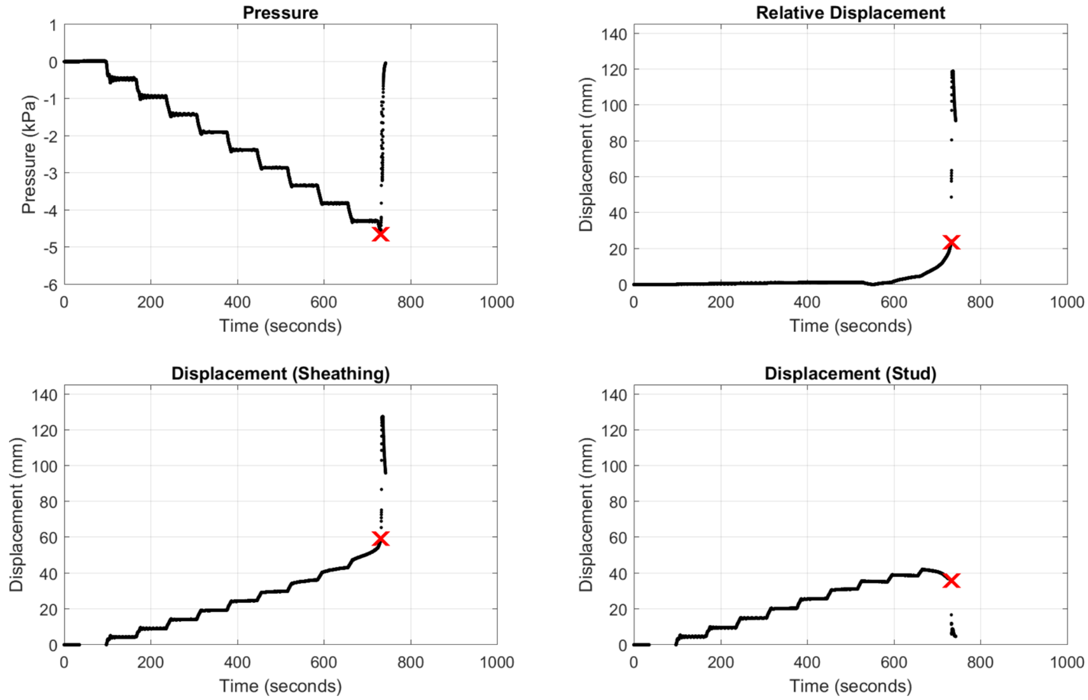


Figure C - 1. OSB Test Sample 1 Pressure and Displacement Time-History.

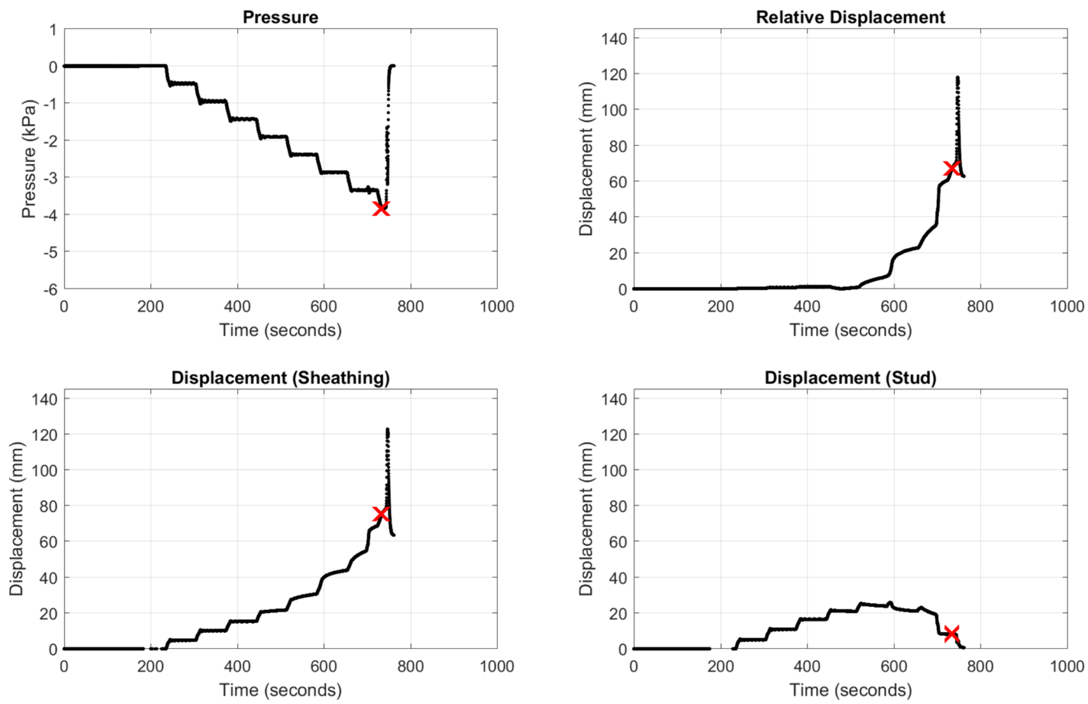


Figure C - 2. OSB Test Sample 2 Pressure and Displacement Time-History.

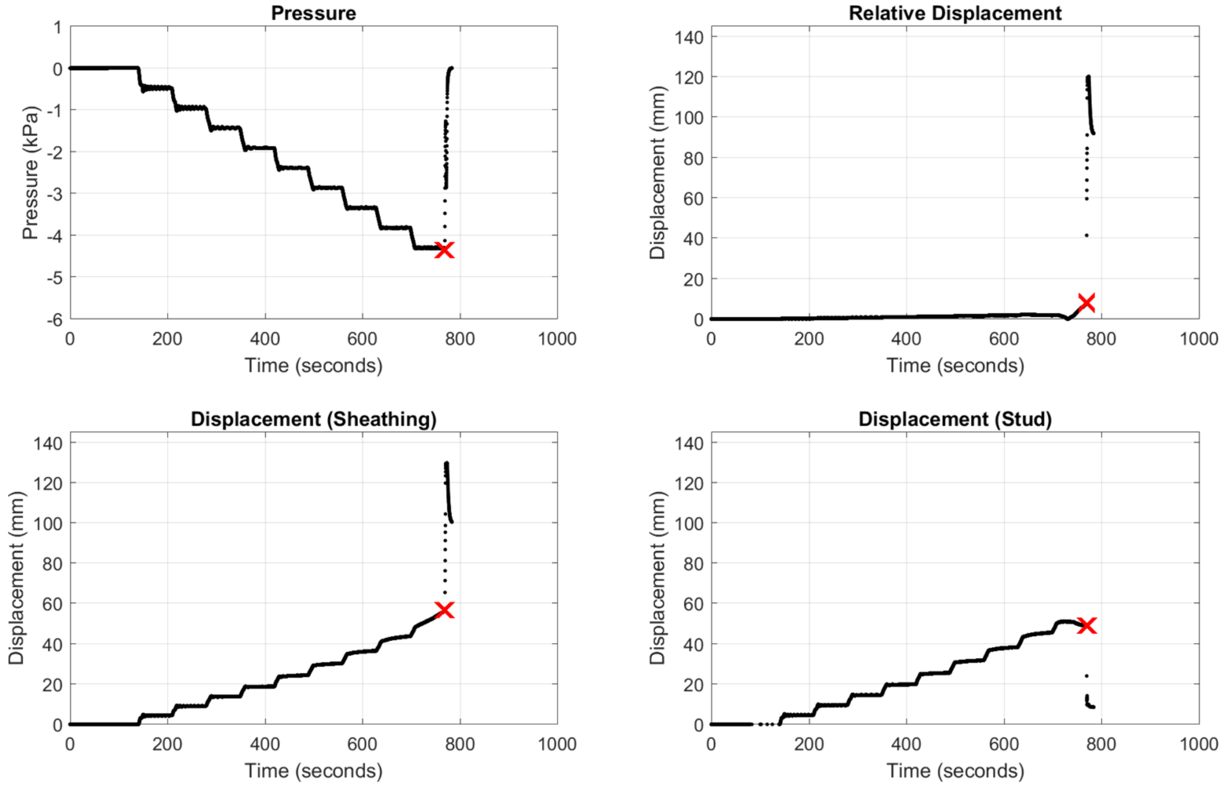


Figure C - 3. OSB Test Sample 3 Pressure and Displacement Time-History.

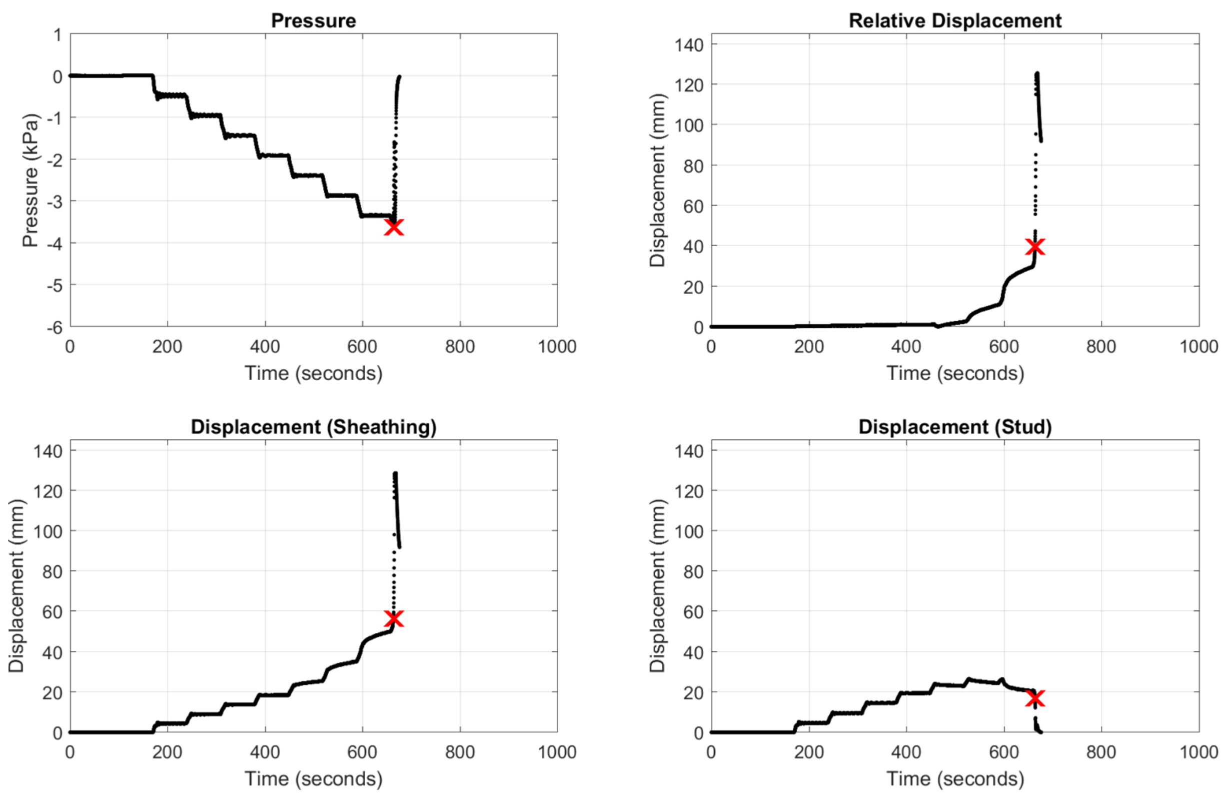


Figure C - 4. OSB Test Sample 4 Pressure and Displacement Time-History.

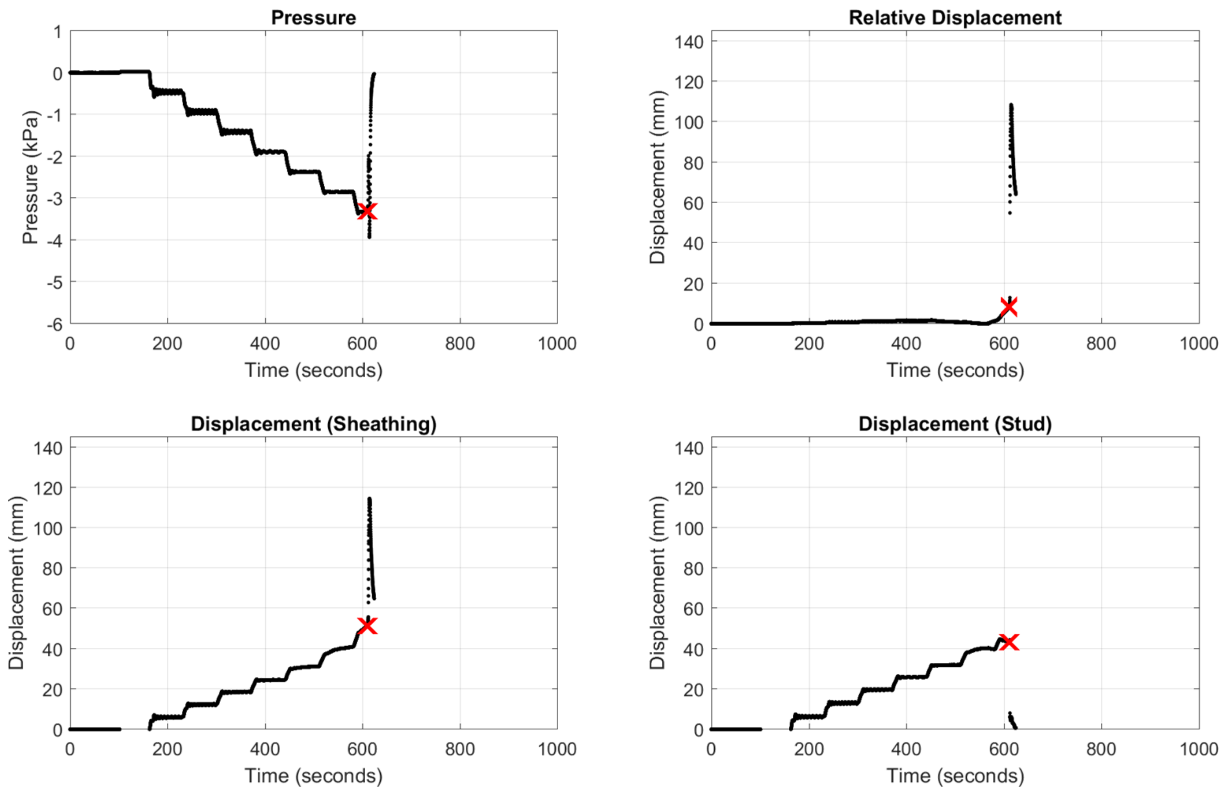


Figure C - 5. OSB Test Sample 5 Pressure and Displacement Time-History.

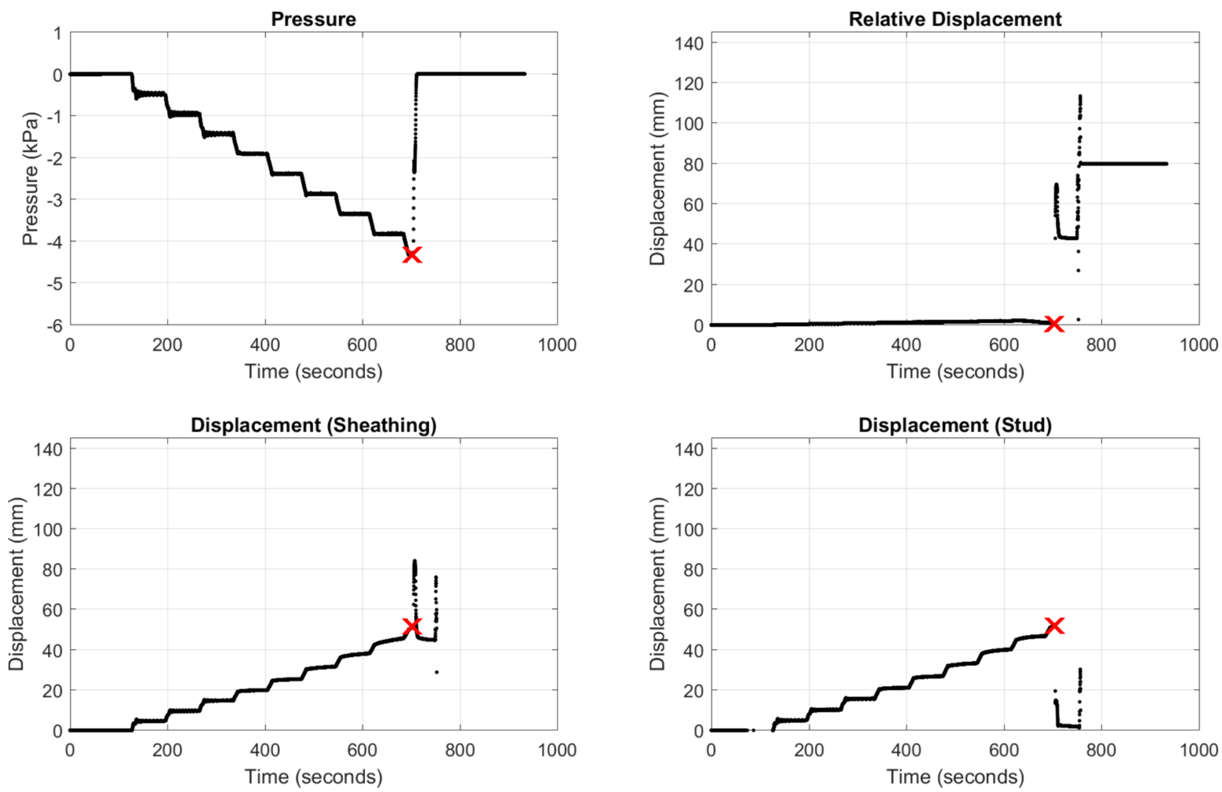


Figure C - 6. OSB Test Sample 6 Pressure and Displacement Time-History.

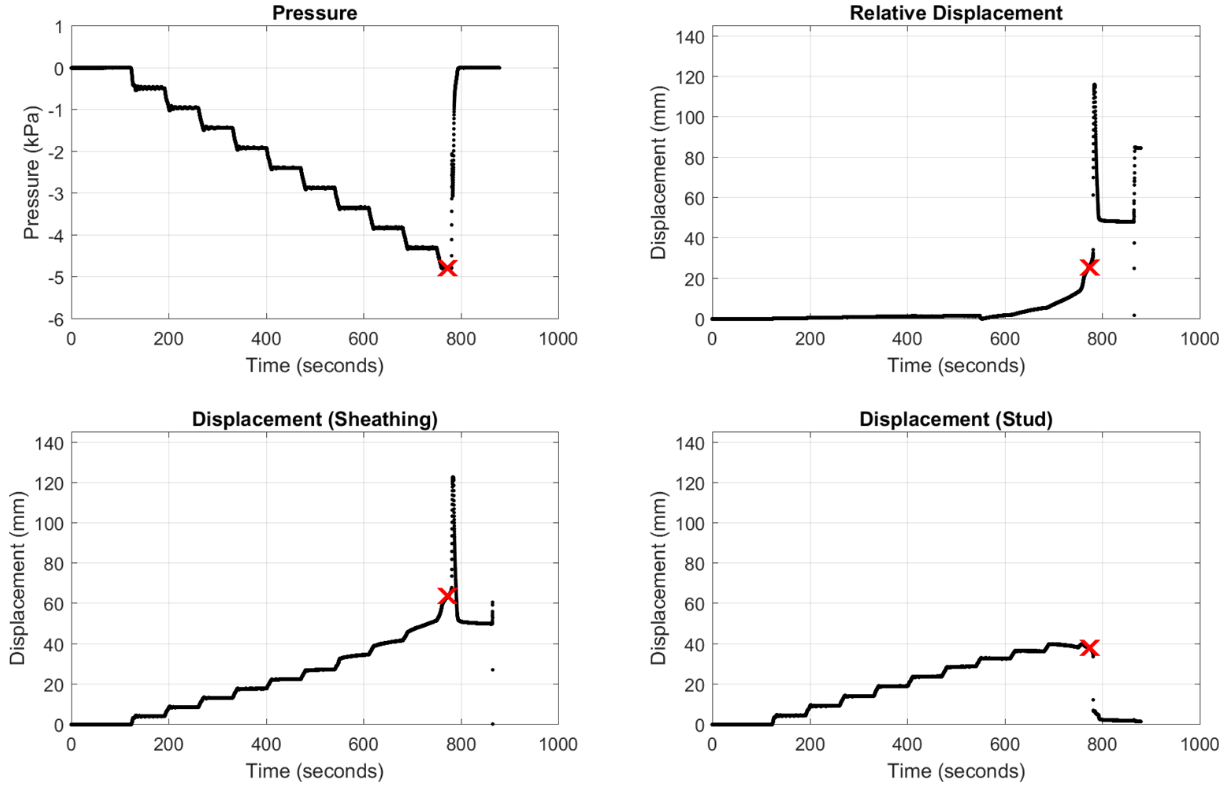


Figure C - 7. OSB Test Sample 7 Pressure and Displacement Time-History.

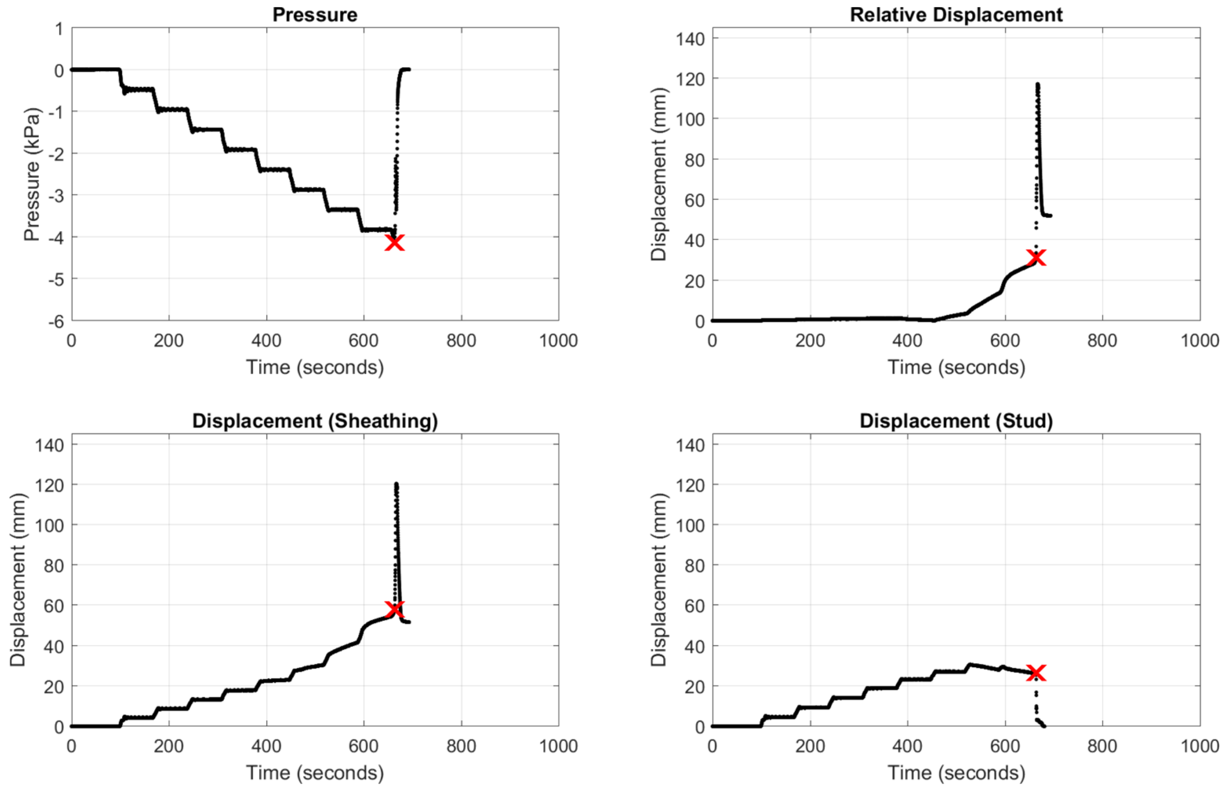


Figure C - 8. OSB Test Sample 8 Pressure and Displacement Time-History.

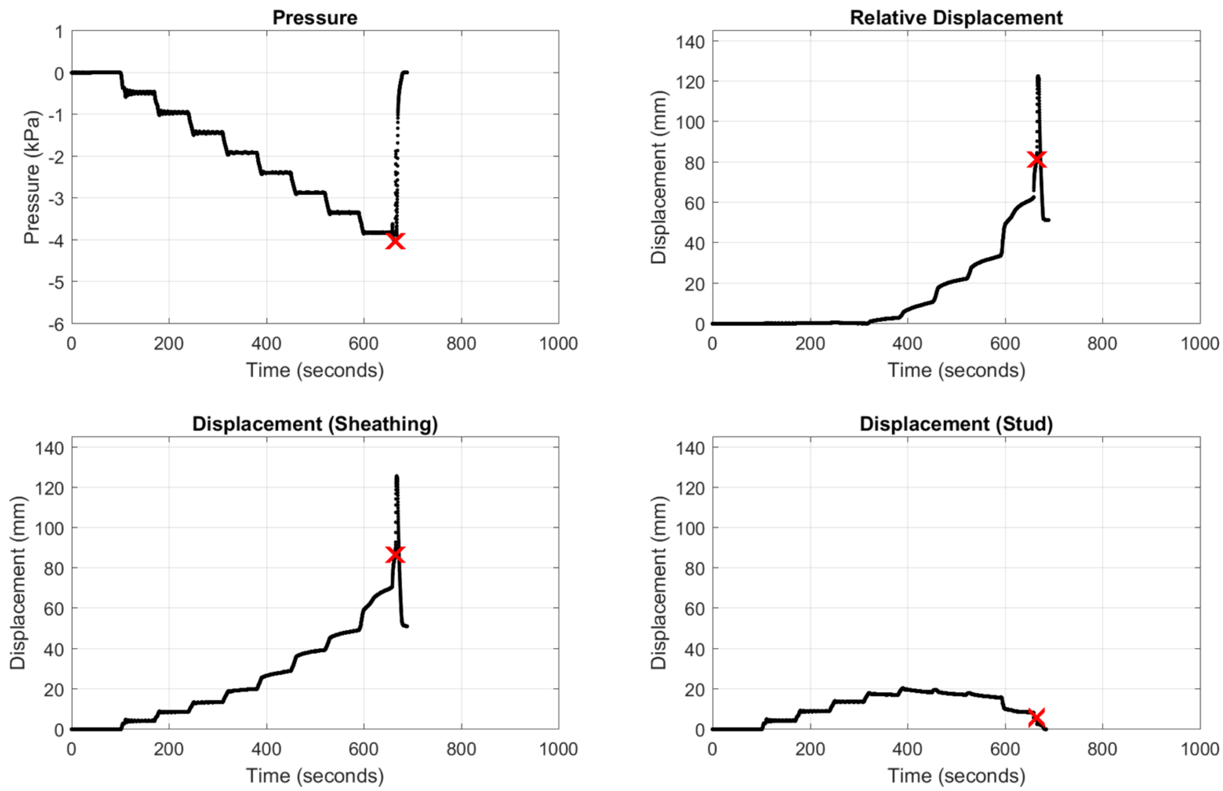


Figure C - 9. OSB Test Sample 9 Pressure and Displacement Time-History.

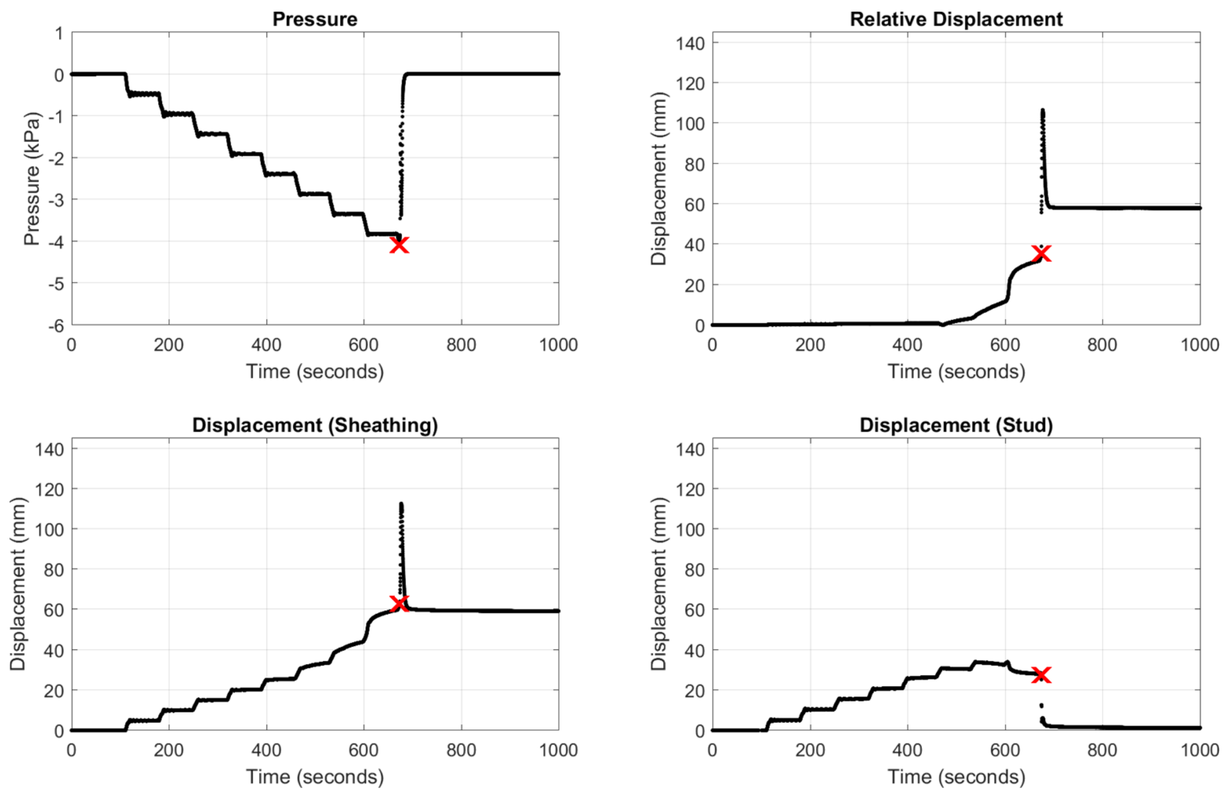


Figure C - 10. OSB Test Sample 10 Pressure and Displacement Time-History.

APPENDIX D
STIFFNESS OF LINEAR ELASTIC REGION OF SHEATHING AND STUD

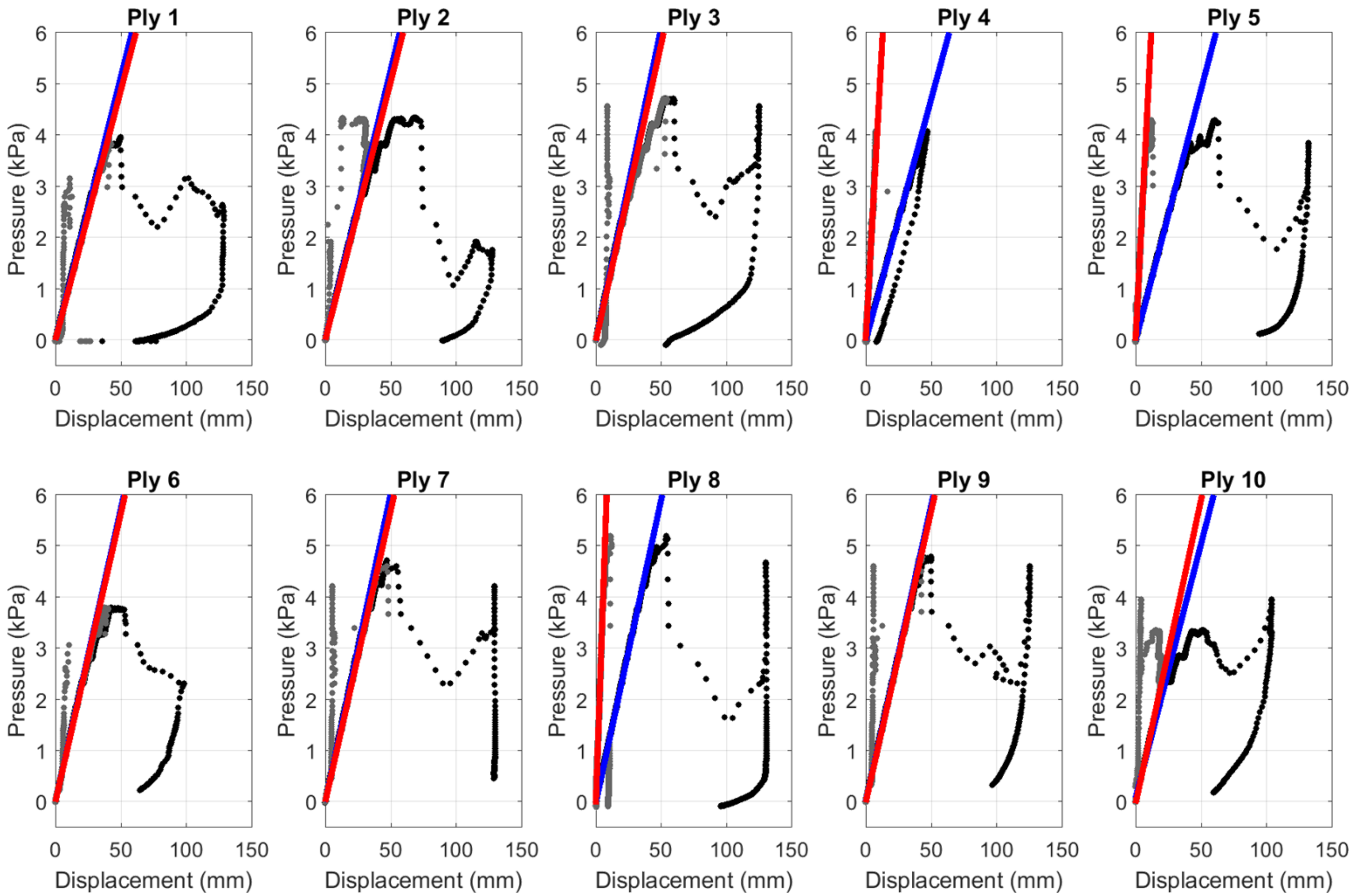


Figure D - 1. Plywood test samples 1 – 10. Red line coincides with stiffness of stud and blue line with sheathing panel.

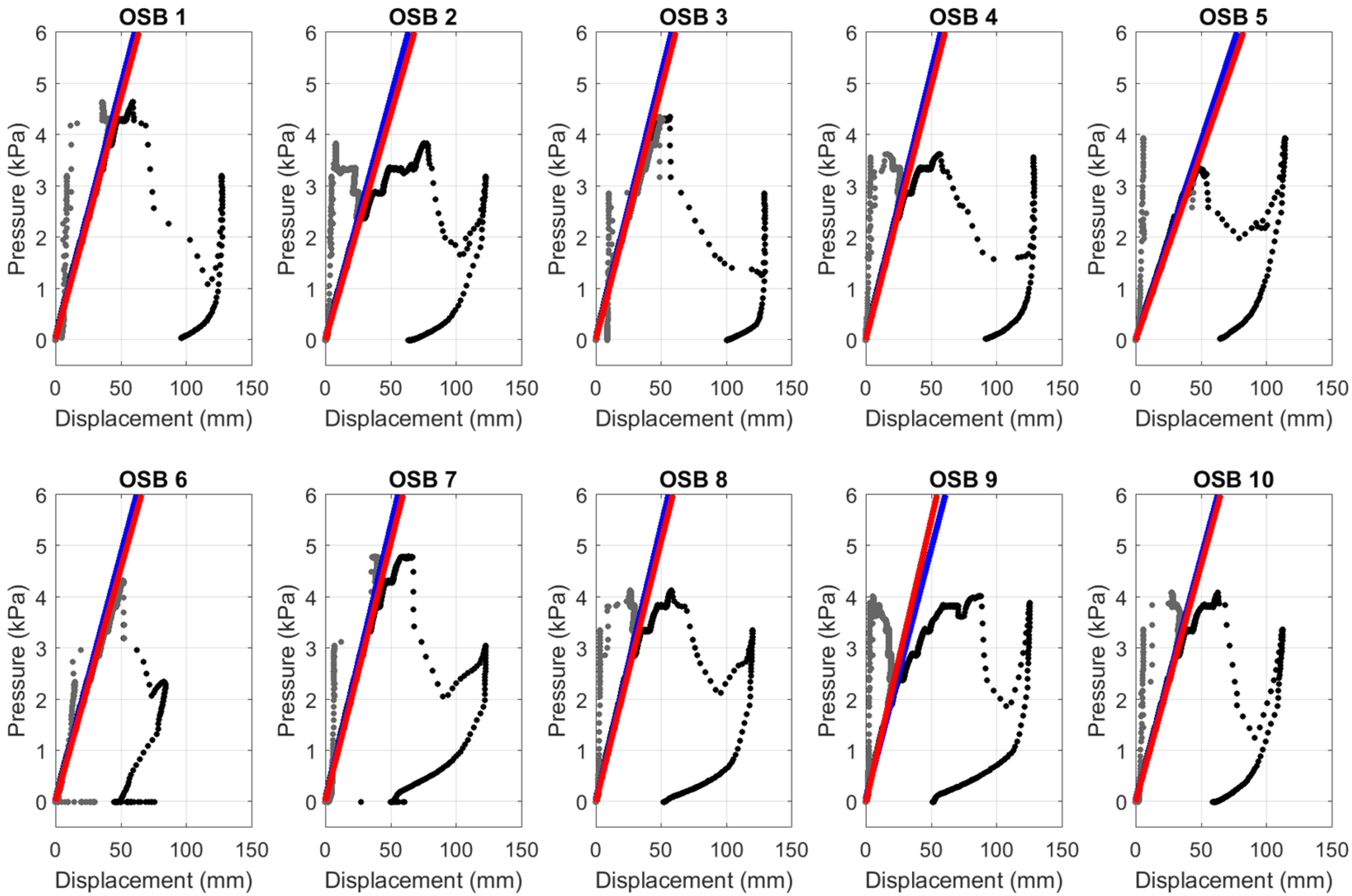


Figure D - 2. OSB test samples 1 – 10. Red line coincides with stiffness of stud and Blue line with sheathing panel.

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