EFFECTS OF THROUGH-SHEATHING INSTALLATION AND TEST METHOD ON PREDICTED NAIL WITHDRAWAL CAPACITY

By

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To my mother and Michael-Paul

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Roof to wall connections are important when preventing damages to light framed wood homes during windstorms. Failures in roof sheathing connections, primarily nails, can cause a chain effect leading to the destruction of the entire structure.

Nail withdrawal capacities are tested in accordance to the ASTM D1761; ultimate and design values are predicted using equations in the National Design Standard for Wood Construction. A previous study suggested that installation through the sheathing may cause loss in capacity which is not addressed in the ASTM D1761 method.

This research seeks to determine whether through-sheathing installation affects withdrawal capacity. The University of Florida developed field investigations to determine the withdrawal capacity of nails installed in wood roof structures in which the sheathing had to be locally removed which motivated this research.

The previous study concluded sheathing removal contributed to nail withdrawal strength reduction. This study investigates whether the loss in strength is caused by driving the nail through the sheathing itself. If this is the case the results will have implications on the method which nail strength is typically tested and for the

interpretation of ultimate failure wind speeds based on forensic evidence of roof sheathing failures.

Based on the reduction in nail withdrawal strengths when driven through-sheathing it was recommended that a reduction factor between 0.6 and 0.8 should be used with the nail withdrawal capacity results per ASTM D1761 to represent a more accurate prediction of nail withdrawal capacities in a wood-framed roof of an existing residential building.

CHAPTER 1
INTRODUCTION

The damage caused by windstorms on residential structures are of great concern in Florida, especially the damage in older structures. In many occasions, the failure of the roof occurs first, exposing the house to the elements and making it extremely vulnerable to a plethora of other types of damage, including complete destruction of the home. In his 1991 paper, (Sparks 1991) stated that about 60% of all wind storm damages occurred in wood residential buildings. In addition 95% of economic losses to those structures are due to roof failures (Baskaran and Dutt 1997). Many of these roof failures can be attributed to the sheathing to truss fasteners which are primarily nails.

National Design Standard (Empirical Equation)

The design strength of nails is provided by the American Forest and Paper Association based upon extensive testing done on nail withdrawal capacity According to the National Design Standard (NDS) equation (AFPA 2005) that predicts nail withdrawal capacities, only the specific gravity of the framing member, and the diameter and length of the nail affect the immediate withdrawal capacity of the nails. Through-sheathing installation is not accounted for in this equation. The equation for the ultimate capacity is shown below:

$$W = 6900DG^{2.5}\ (W = 47.6DG^{2.5}) \qquad (1\text{-}1)$$

Where W is the ultimate withdrawal capacity in lb/in (N/mm) (capacity of nail in lb (N) per inch (mm) that is embedded in the framing member), D is the diameter of the nail in inches (mm) and G is the specific gravity of the framing member. This equation was based on research done by Kurtenacker in 1931 which was later revised and published in 1965 (Kurtenacker 1965a) The design values are calculated with a Kw (shown below) coefficient after being multiplied by 1/6 for a factor of safety and then multiplied by 1.2 (10% for a change from permanent to normal loading and 10% for experience) (AFPA 2005).

$$K_w = 1.2*6900/6 \ (K_w = 1.2*47.6/6) \qquad (1\text{-}2)$$

This then gives the equation for design values as follows:

$$W = K_w D G^{2.5} \qquad (1\text{-}3)$$

ASTM D1761 Test Protocol

The current testing procedure used to determine the peak nail withdrawal of nail out of wood is the ASTM D1761 (ASTM 2006a). In this testing the nail is installed directly into a framing member then withdrawn axially at 0.1 in/min (25.4 mm/min) using a gripping device able to fit around the nail head. This is slightly different from the 0.075 in/min withdrawal rate used in the Kurtenacker research which the NDS values are based on.

Nail Withdrawal for In-situ Condition

Sutt and Rosowsky (2000) were one of the first to investigate nail withdrawal in the field. They developed the portable nail extractor (PNE) which was able to withdraw nails from the roofs in field. This was the gateway to the Shreyans study (Shreyans et al. 2012). Shreyans investigated both in-situ conditions and laboratory testing. The goal was to determine a way to use the laboratory testing results to predict how the nail would react in the field; a modified PNE was used for this testing. Through-sheathing installation was investigated however only direct withdrawal was performed. The sheathing would first be removed locally around the nail to allow the mPNE to grip the nail. This however added another variable, the method that was used to remove the sheathing (reciprocating blade, hole-saw or circular saw), which later proved to also have an effect on the withdrawal strength.

It was concluded that the reciprocating blade had the least effect on withdrawal strength. The ASTM D1761 method was non-conservative in its withdrawal capacities predictions and it was recommended a 0.5 to 0.7 factor be applied to the ASTM D1761 results for the situation of 6D Nails installed in southern yellow pine.

Objectives

The goal of this research is to address the effect that through-sheathing installation has on the peak withdrawal capacity of nails. Though the reason for this is not entirely clear it is important to understand how the nail will behave. It is theorized that when a nail is being installed through-sheathing it is either deformed and/or the force at which it enters the framing member is reduced which then reduces the hold it has in the framing member. If this is true then knowing how the nail will perform based on how it is installed in the field is extremely important when determining the forces it will be able to resist in addition to being able to forensically determine failure loads after windstorms and other natural disasters. Currently there is no standard testing procedure that addresses through-sheathing installation. The ASTM D1761 as explained above only tests nails installed directly into framing member which is not a realistic representation of what is going on in the field. The objectives of this study are as follows:

- Determine how much of a reduction through-sheathing installation has on nail withdrawal capacities.
- Investigate withdrawal methods that will best isolate the effects of sheathing.
- Determine whether these effects are constant over time.

- Establish a factor to be applied to the ASTM D1761 results that will account for through-sheathing installation.

The results of this testing will affect the way the ASTM D1761 values are used when predicting in field strengths. The test method may need to be modified to better reflect through-sheathing installation effects or have a factor applied to the results that more accurately predict the performance of nails in the field.

CHAPTER 2
LITERATURE REVIEW

The current equation that is found in the National Design Standard for Wood Construction (AFPA 2005) is based on a technical note written in 1931 by R.S. Kurtenacker. The technical note was revised in 1958 and then released as a research note titled “Nail Withdrawal Resistance in American Woods” (Kurtenacker, 1965a). The paper states that the resistance of the nail is directly related to the density or specific gravity of the wood, the diameter of the nail and the depth of penetration. More specifically the withdrawal capacity increases with all three. The relationship between these variables and the ultimate withdrawal load is shown in Figure 2-1.

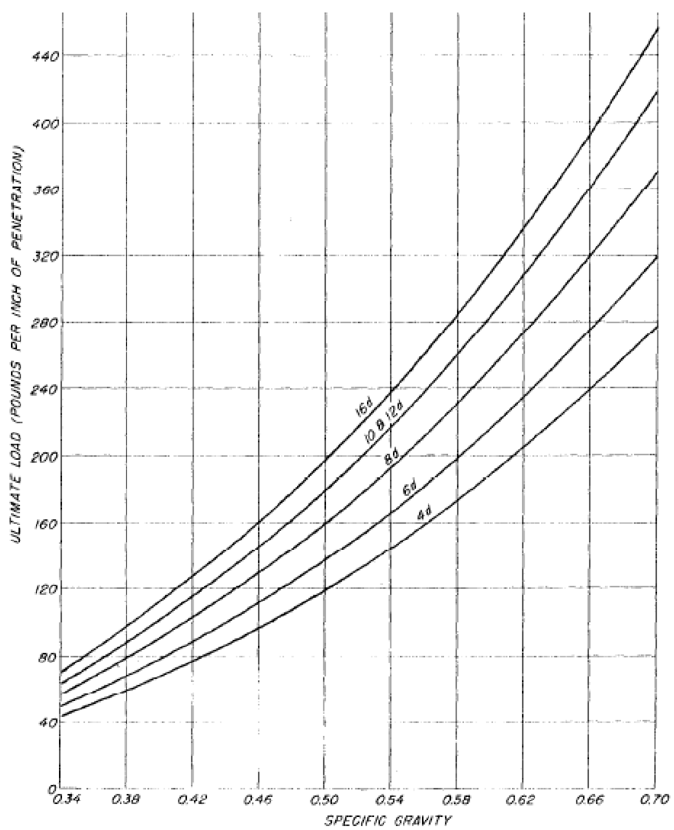


Figure 2-1. Graph comparing Ultimate Load (lb/in) of different types of nails to the Specific Gravity of the wood is was withdrawn from. Source: Kurtenacker, R.S. (1965a). “Nail-holding power of American woods” *Forest Products Laboratory, U.S. Forest Service,* Madison, WI.

After this R.S. Kurtenacker went on to research the effect time had on the withdrawal resistance various types in his paper “Performance of Container Fasteners Subjected to Static and Dynamic Withdrawal” (Kurtenacker 1965b). Fifteen fastener types were tested, twelve replicates each, from nails to staples, each having different sizes and coatings. These nails were installed into douglas fir wood through both ¼ in. plywood and ¾ in white pine. The plywood was used with 2 inch nails and the white pine was used with 2.5 inch nails; the purpose of these was to control the embedment depth into the douglas fir keeping them both at 1.75 inch. Douglas fir wood according to the NDS has a specific gravity of 0.50 as opposed to southern pine which has a specific gravity of 0.55. Wood was stored indoors at a constant temperature of 73 ^{o}F and 50% Humidity except for one set which was stored outdoors. Of the specimens stored indoors tests were performed the same day and then 2, 6.5, 13, 26 and 52 weeks after installation while the specimens stored outdoors were tested only at the 52 week mark. From these tests it was concluded that smooth shank uncoated fasteners have marked decrease in withdrawal capacity after as little as two weeks except for nylon coated and helically threaded fasteners.

Figure 2-2 summarizes the results and Figure 2-3 shows the result for the 6D and 8D common bright nails (graph generated based on the Kurtenacker data for this paper for clarity) As it can be observed within the first two weeks there is as much as a 30% to 70% decrease within the first two weeks and more specifically about a 62% decrease for both 6D and 8D common bright nails.

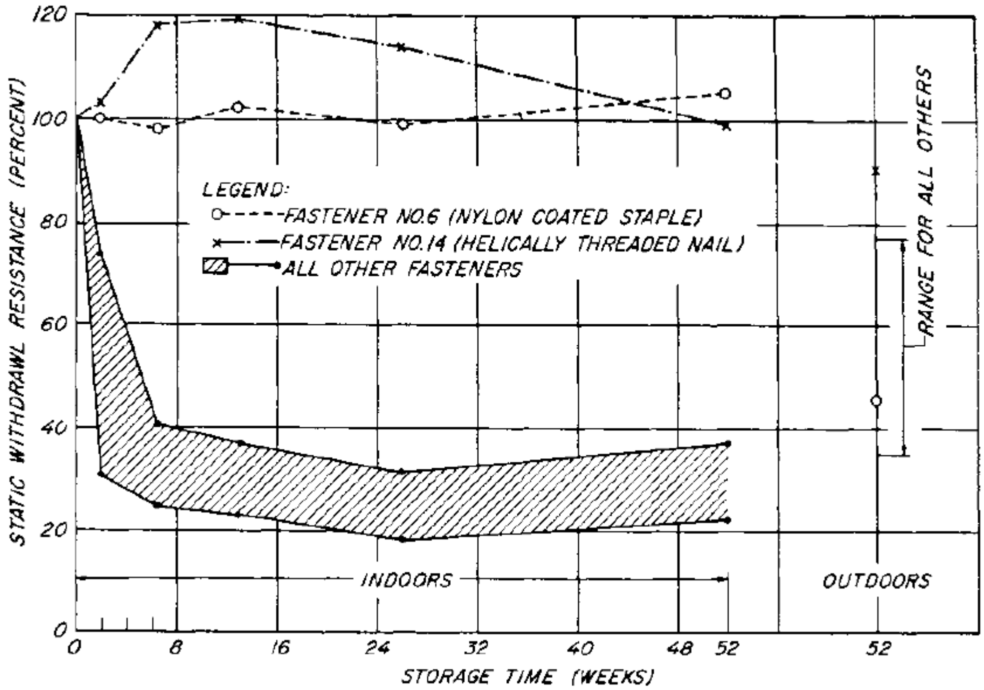


Figure 2-2. Static Withdrawal Resistance of Various Fasteners over time. Source: Kurtenacker, R. S. (1965b). "Performance of Container Fasteners Subjected to Static and Dynamic Withdrawal*." Forest Products Laboratory, USDA Forest Service,* Madison, WI.

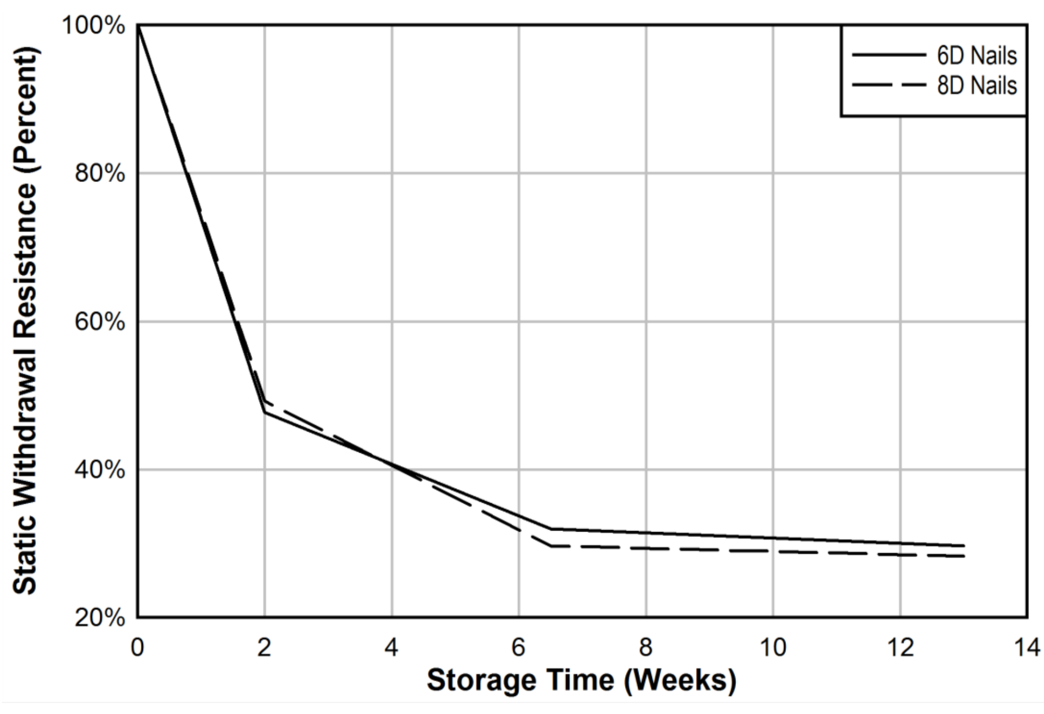


Figure 2-3. Average withdrawal for 6D and 8D common bright nails taken from the Kurtenacker results (Kurtenacker 1965b).

Today the NDS bases their equation for nail withdrawal strength on this research. The equation to predict the design strength of a nails is as follows:

$$W = K_w G^{1.5} D \qquad (2\text{-}1)$$

where:

W = nail or spike design value per inch of penetration in main member, (lb (N))

K_w = 1380 (9.52)

G = specific gravity of main member based on ovendry weight and volume, where $0.31 < G < 0.73$

D = shank diameter of the nail or spike (in (mm)), where 0.0999 (2.54) (< D <0.375 (9.53)

The equation for K_w is as follows:

$$K_w = 1.2(6900/6)\ (K_w = 1.2(47.6/6)) \qquad (2\text{-}2)$$

The 20% increase was introduced as a part of the World War II emergency increase in wood design values, 10% for change from permanent to normal loading and 10% for experience. Therefore when this and the factor of safety of 6 are taken out the ultimate load ends up being as follows:

$$W = 6900G^{1.5}D\ (W = 47.6G^{1.5}D) \qquad (2\text{-}3)$$

After this several studies have tried to isolate each variable that may affect the decrease in withdrawal capacity of nails both in the field and in a laboratory setting (Herzog and Yeh 2006; Pye 1995; Shreyans et al. 2012; Sutt and Rosowsky 2000; Swane and Vagholkar 1968) These included heat, humidity, cyclic loading, racking, time and other environmental factors for in field factors and withdrawal rate for laboratory factors.

In 1995 Pye researched the effects of In-Service conditions (Pye 1995). These included racking, humidity, heat and a combination of heat and humidity. Various nail coatings and nail shanks were used and the method of driving the nails and type of wood were also explored. Pye concluded with the following:

- Power driven fasteners proved to have higher capacities than hand driven fasteners.
- Ring Shank fasteners had higher withdrawal capacities
- Heat series had the most dramatic decreases.

The heat and humidity series also explored withdrawal strength at different times after installation. Under this series there were three subsets; the specimens were stored in a small outdoor shed meant to simulate roof attic conditions, the specimens were stored indoor under controlled ambient condition (70ºF and 55% Humidity) and lastly the specimens were rotated weekly between each environment. The ambient conditions have values at 1 week, 3 week and 10 week. Summary of this data can be found in Table 2-1.

Table 2-1. Pye Data (1995): Withdrawal Capacities for Specimens Stored Indoor Under Ambient Conditions (lb/in (N/mm))

		Time after Installation		
Nail Type	Wood	1 week	3 week	10 Week
1HSF	SYP	169 (29.6)	270 (47.3)	257 (45.0)
1HSF	SPF	243 (42.6)	-	292 (51.1)
2HRF	SYP	342 (59.9)	360 (63.0)	388 (67.9)
4PSF	SYP	263 (46.1)	289 (50.6)	293(51.3)

As shown above for all series in stored in Indoor ambient temperature the nail withdrawal capacity increases over time which is not was has been observed in previous studies. The reason for this was however not the focus of this paper and was not addressed.

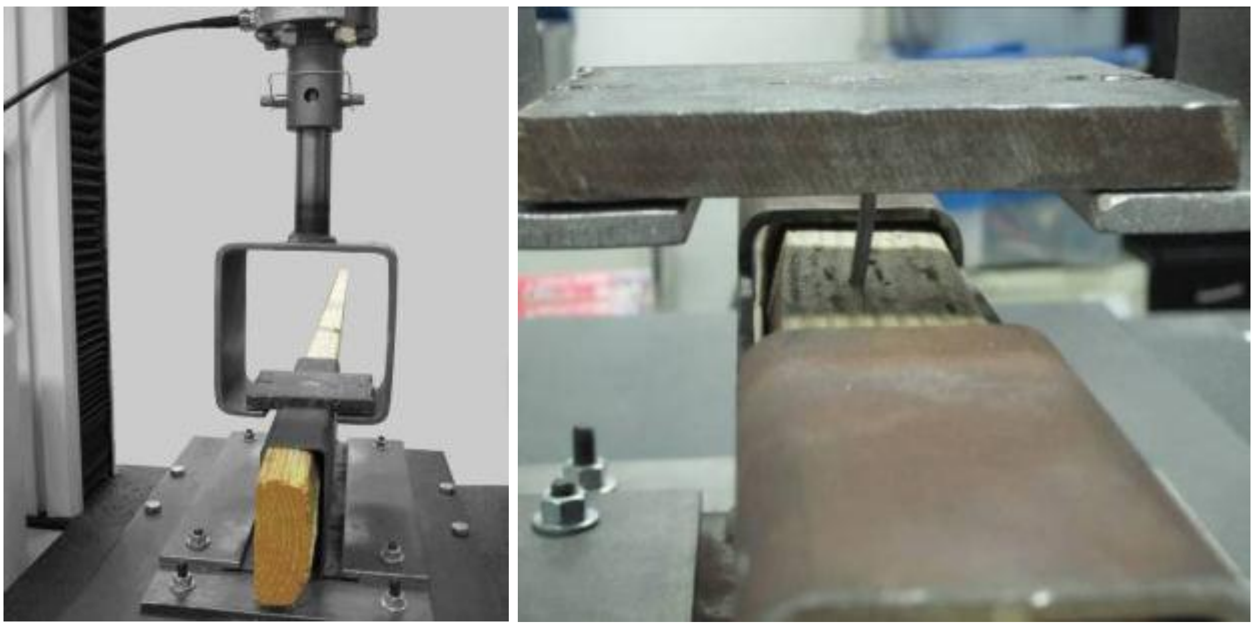
In the end he determined that the design values were too conservative for ring shank nails, however they overestimated capacity of smooth shank fasteners subjected to heat and the factor used when smooth shank fasteners were subject to change in moisture content was too conservative

Up until this point however there has not been any testing of nails in the field, all testing were laboratory setups trying to imitate in field conditions.

Sutt and Rosowsky (2000) published a paper which focused on the effect of in-situ conditions on nails withdrawal capacities. For this research he developed what was called a fastener extractor which then evolved into what is now known as a Portable Nail Extractor (PNE). It was a device with a self-contained load cell that was able to withdraw fasteners in the field. The load was applied manually with levers on either side. One of the concerns of this device was the variability in withdrawal rate between operators, however Sutt stated this was shown to not have and effects on 8D nails based on previous studies. Sutt investigated the nails on a home that was constructed between 1972 and 1983 that was subject to a fire and had a renovated area that was constructed in 1996.The testing was performed in 1999. A holesaw was used to remove the sheathing form around the nail in the field.

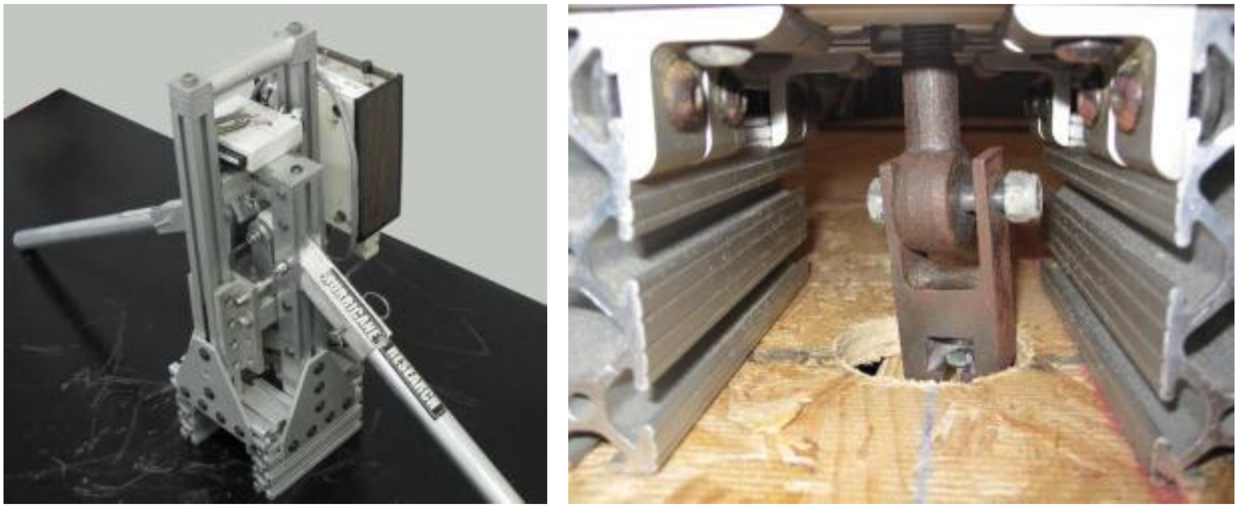
Sutt concluded that there is a reduction in capacity of a nail subjected to in-situ conditions therefore design values may be non-conservative. In addition the test values were lower than the design values used 1.0 and 1.6 for the load duration factors.

In Shreyans et al. (2012) reported a study evaluating the in-situ and laboratory withdrawal strength capacities of typical nails used to install plywood and OSB sheathing in roofs of existing Florida homes. In the field sheathing was removed locally with various methods and withdrawn with a modified version of Sutt’s PNE, the modified Portable Nail Extractor (mPNE) In addition nails were withdrawn using the ASTM D1761 method using a Universal Testing Machine (Figure 2-4) and compared to installing nails through-sheathing in the lab and removing them similarly to those in the field with the mPNE (Figure 2-5) so as to isolate the through-sheathing effects on the nails and compare them to the standard test method. The results of the laboratory studies are shown in Figure 2-6.



A B

Figure 2-4. UTM set up. A) UTM Machine, B) Close up of nail being withdrawn. Source: Shreyans, S., Kerr, A., Prevatt, D. O., and Gurley, K. R. (2012). "In-Situ Nail Withdrawal Strengths in Wood Residential Roofs." *ATC&SEI Advances in Hurricane Engineering,* Miami, FL.



A B

Figure 2-5. mPNE set up. A) mPNE, B) Close up of nail being withdrawn after sheathing has been removed. Source: Shreyans, S., Kerr, A., Prevatt, D. O., and Gurley, K. R. (2012). "In-Situ Nail Withdrawal Strengths in Wood Residential Roofs." *ATC&SEI Advances in Hurricane Engineering,* Miami, FL.

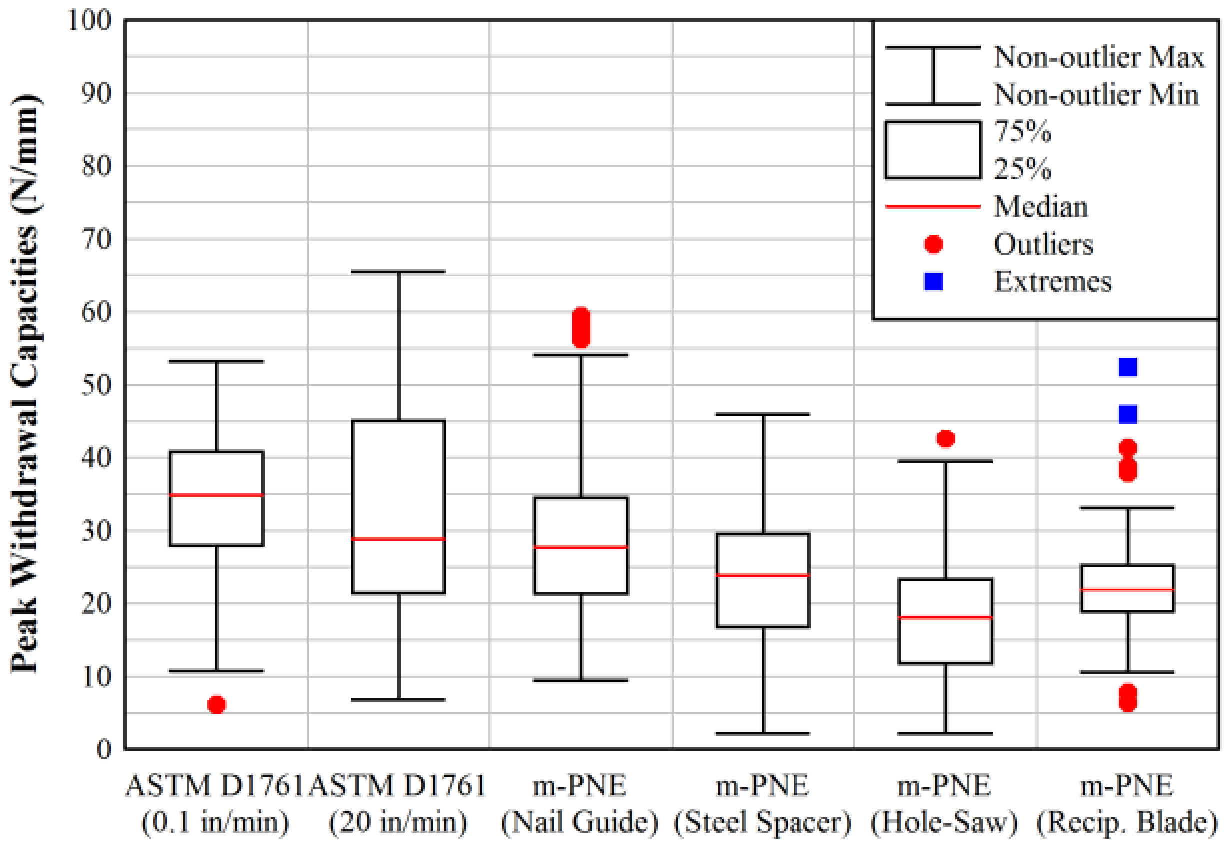


Figure 2-6. Boxplot of Shreyans et al. Data. Source: Shreyans, S., Kerr, A., Prevatt, D. O., and Gurley, K. R. (2012). "In-Situ Nail Withdrawal Strengths in Wood Residential Roofs." *ATC&SEI Advances in Hurricane Engineering,* Miami, FL.

It was concluded that through-sheathing installation had an effect on nails withdrawal capacities. The reciprocating blade was determined to be more suited for removal of local sheathing. It was recommend that a suggested reduction factor between 0.5 and 0.7 be applied to the ASTM D1761 result to account for installation through-sheathing and the results were non-conservative and an improved test method was needed for predicting withdrawal strengths in wood roofs.

CHAPTER 3
MATERIALS AND METHODS

Materials and Equipment

Two types of Nails were tested: 6D smooth shank, hot-dipped galvanized nails (Length 2 in (50.8mm) and diameter 0.113 in (2.87 mm)) and 8D smooth shank, hot-dipped galvanized nails (length 2.5 in (63.5 mm) and diameter 0.131 in (3.33 mm). The 6D nails were tested in summer 2012 and the 8D nails were tested in Spring/Summer of 2013.

Nails were installed using a Stanley Bostitch F21PL Nail Gun. Framing members used were No. 2 Southern Yellow Pine nominal 2 in x 4 in, 8 ft long (38 mm x 89 mm x 2438 mm) and for through-sheathing tests both 7/16 in (1.11 mm) oriented strand board and 15/32 in (11.91 mm) plywood were used for 6D nails and 1 in (2.54 mm) OSB for the 8D nails. Tests were performed on a 33,721 lbf (150 kN) Instron Universal Testing Machine (UTM), Model Number 3384.

ASTM Standard Test Methods

The control testing method followed the ASTM D1761 specification “Test Methods for Mechanical Fasteners in Wood” (ASTM 2006a), which states that the fastener should be withdrawn with a gripping device able to fit the base of the fastener head while positioned to allow true axial loading. In addition it states that nails should be withdrawn at a constant rate of 0.1 in/min (2.54 mm/min). This withdrawal rate was used for all test methods.

In addition for each board the specific gravity and moisture content was determined for each 2x4 per the ASTM D2395 specification “Test Methods for Specific Gravity of Woods and Wood-Based Materials (ASTM 2006b) and the ASTM 4442 specification “Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials” (ASTM 2006c). The Specific Gravity and Moisture Content Tests were done on five evenly spaced 1 inch segments from the 2x4s, the first and the last being 6 inches from the edge, for the 6D Nails and nine 1 inch segments from the 2x4s used in the 8D nail testing.

Test Setup

Tests were set up on the UTM using the ASTM D1761 as a guideline. The 2x4 member was held to the place with a fabricated steel apparatus pictured (Figure 3-1).

Nails were then withdrawn with a head attachment connected to a load cell following one of the withdrawal methods detailed in the “Withdrawal of Nails” section below.

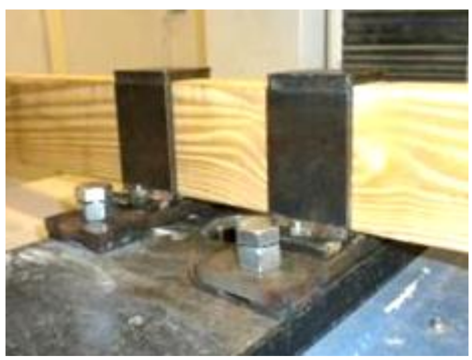


Figure 3-1. Apparatus used to anchor the 2x4 member to base of UTM for testing. July 2012. Courtesy of Ashlie Kerr.

Installation and Withdrawal of Nails

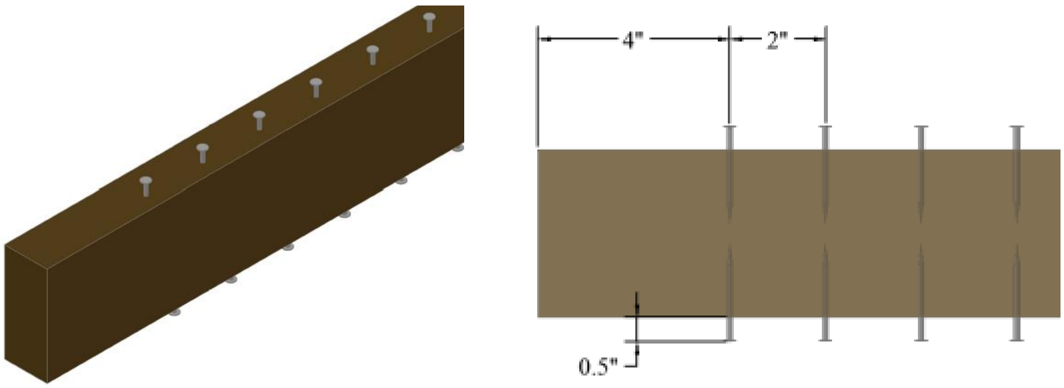
Nails were installed two ways for the 6D Nails. First was using a ½ inch (12.7 mm) nail guide which was used to give a consistent embedment depth of 1.5 in (38.1 mm) (Figure 3-2). This depth was chosen because it is the typical thickness of roof sheathing. The second installation method was through a 3.5 in (88.9 mm) by 5 in (127 mm) strips of OSB or Plywood depending on test method (Figure 3-3).

Figure 3-2. Installation of nail using nail guide. July 2012. Courtesy of Shelly Dean.

Figure 3-3. Nail installed through-sheathing. July 2012. Courtesy of Shelly Dean.

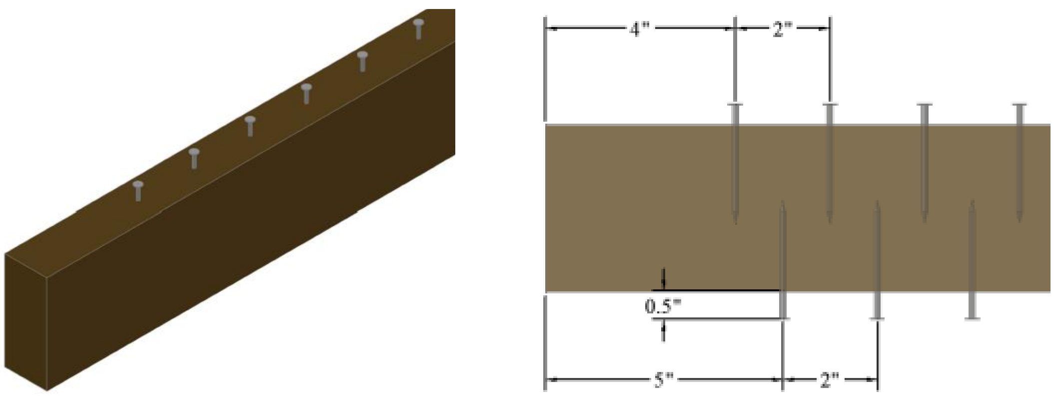
For the 6D the nails were installed 2 in (50.8 mm) o.c. (on center) on both narrow faces of the 2x4 with first and the last nail being at least 4 in (101.6 mm) from the edge (Figure 3-4).For 8D the nails were also installed 2 in (50.8 mm) o.c. however on one narrow face the first nail was installed 4 in (101.6 mm) from the edge and the opposite face was offset by 1 in (25.4 mm) so the first nail was installed 5 in (127.0 mm) from the edge (Figure 3-5)

Once installed nails were withdrawn either directly by using the nail head apparatus shown in Figure 3-6 or the indirect method using the C-Channel in Figure 3-7.



A B

Figure 3-4. 6D Nail Spacing in 2x4 Member. A) Isometric View, B) Side View.



A B

Figure 3-5. 8D Nail Spacing in 2x4 Members. A) Isometric View, B) Side View

Figure 3-6. Direct Withdrawal Method. July 2012. Courtesy of Shelly Dean.

A B

Figure 3-7. Indirect Withdrawal Method. A) Withdrawal setup in with C-Channel, B) Withdrawal with Styrofoam cube placed in C-Channel to prevent bending of sheathing strip. July 2012. Courtesy of Shelly Dean.

Test Methods and Test Matrix for 6D Nails

Six different Test Methods were explored with the 6D nails each using a different combination of the above installation and withdrawal methods. Each of these methods is detailed below.

a) ASTM D1761

1. Nail is installed using the nail guide from Figure 3-3.
2. Nail is then withdrawn directly from the 2x4 wood member using the Direct Withdrawal Method (Figure 3-6).

b) Steel Plate

1. Nail is installed using the nail guide from Figure 3-3.
2. A slotted Steel plate (Figure 3-8) is then slipped around the nail and withdrawn using the C-Channel in the Indirect Withdrawal Method.

Figure 3-8. Slotted Steel Plate set up. July 2012. Courtesy of Shelly Dean.

c) OSB/Indirect Withdrawal

1. Nail is installed directly through-sheathing as shown in Figure 3-3.
2. Nail is then withdrawn using the indirect withdrawal with Styrofoam cube in Figure 3-7B.

d) Plywood/Indirect Withdrawal

1. Same as above but with Plywood sheathing instead of OSB.

e) OSB/Reciprocating Blade

1. Nail is installed directly through the OSB as shown in Figure 3-3.
2. Sheathing is removed from around the nail with a reciprocating blade as shown in Figure 3-9.
3. Nail is then withdrawn using the direct withdrawal method shown in Figure 3-.6.

f) Plywood/Reciprocating Blade

1. Same as above but with Plywood sheathing instead of OSB.

A breakdown of the number of nails tested is given in Table Table 3-1 and the moisture content and specific gravity per board in Table 3-2.

Table 3-1. Number of nails tested per board per method (6D nails)

Board	ASTM D1761	Steel Plate	OSB/ Indirect	Plywood/ Indirect	OSB/Recip. Blade	Plywood/ Recip. Blade
AA	24	19	19			
AB	48	20		18		
AC	37		20	20		
AD	19	18	15		20	
AE			19	18	20	18
AF			18	19	20	20

Table 3-2. Test Matrix for 6D nails with specific gravity and moisture content

Board	Specific Gravity	Moisture Content	Test Method[a]	# of Nails per Test Method
AA	0.47	14.0%	a/b/c	24/19/19
AB	0.48	14.4%	a/b/d	48/20/18
AC	0.44	14.7%	a/c/d	37/20/20
AD	0.57	13.6%	a/b/c/e	19/18/15/20
AE	0.43	13.3%	c/d/e/f	19/18/20/18
AF	0.50	14.5%	c/d/e/f	18/19/20/20
Average	0.48	14.1%		

[a]Test method letter designations are as follows:
(a) ASTM D1761 (b) Steel Plate (c) OSB/ Indirect Pull (d) Plywood/ Indirect Pull (e) OSB/ Recip. Blade (f) Plywood/ Recip. Blade

Test Methods and Test Matrix for 8D Nails

Initially four different Test Methods were explored with the 8D nails each using a different combination of the above installation and withdrawal methods. Each of these methods is detailed below.

a) ASTM D1761

1. Nail is installed using the nail guide from Figure 3-2.
2. Nail is then withdrawn directly from the 2x4 wood member using the Direct Withdrawal Method (Figure 3-6).

b) OSB/Indirect Withdrawal

1. Nail is installed directly through-sheathing as shown in Figure 3-3.
2. Nail is then withdrawn using the indirect withdrawal with Styrofoam cube in Figure 3-7B.

c) OSB/Reciprocating Blade

1. Nail is installed directly through the OSB as shown in Figure 3-3.

2. Sheathing is removed from around the nail with a reciprocating blade as shown in Figure 3-9.

3. Nail is then withdrawn using the direct withdrawal method shown in Figure 3-6.

A B

Figure 3-9. Sheathing being removed using reciprocating blade. A) Reciprocating Blade in use, B) After Sheathing is removed. July 2012. Courtesy of Shelly Dean.

d) Slotted OSB

1. Nail was withdrawn using the nail guide from Figure 3-2.

2. A slotted OSB (Figure 3-10) similar to the Steel plate from the 6D nails testing was slipped around the nail and withdrawn using the indirect withdrawal method.

Figure 3-10. Slotted OSB. April 2013. Courtesy of Ashlie Kerr.

Once the testing for the above testing commenced it was observed that all the slotted OSB testing and a majority of the OSB/Indirect Withdrawal had pull through failures. Pull through occurs when instead of the nail being withdrawn out of the 2x4 member it instead stays anchored in the 2x4 member and rips through the OSB sheathing. The peak load when this occurred was recorded and will be referred to as "OSB Pull Through". In addition those same nails were then withdrawn from the wood member using the direct pull method (Figure 3-6); these results will be referred to as "OSB Pull Through/Direct Pull". As a result of this unanticipated failure pattern a modified test method was necessary to measure the nail withdrawal capacity. This involved installing a ¾ inch diameter and 0.07 in. thick steel washer between the nail head and top surface of sheathing to minimize likelihood of pull-though failure which is detailed below.

e) OSB/washer

1. Nail installed through-sheathing with the nail going through the center of a 0.07 in thick and ¾" (19.05 mm) washer (Figure 3-11)
2. Nail withdrawn using the indirect withdrawal method.

A breakdown of the number of nails tested is given in Table 3-3 and specific gravity and moisture content per board is given in Table 3-4.

Figure 3-11. 8D Nail installed through center of washer into sheathing. May 2013. Courtesy of Ashlie Kerr

Table 3-3. Number of nails testing per board per method (8D Nails)

Board	ASTM D1761	OSB/Indirect Withdrawal (Pull Out/Pull Through)	OSB/ Reciprocating Blade	Slotted OSB (Pull Out/ Pull Through)	OSB Washer
BA	26	29 (8/21)	29		
BB	21	22		29 (3/26)	
BC	44		43		
BD	31	30 (4/26)	26		
BE	27		26		30
BF	44		21		21
BG	25		33		25
BH	26		31		26
BI	23		32		30
BJ	26		33		27

Table 3-4. Test Matrix for 8D nails with specific gravity and moisture content

Board	Specific Gravity	Moisture Content	Test Method[b]	# of Nails per Test Method	OSB Pull Out/ OSB Pull Through[a]
BA	0.51	11.8%	a/b/c	26/29/29	8/21
BB	0.53	12.5%	a/b/d	21/22/29	3/26
BC	0.42	12.1%	a/c	44/43	-
BD	0.50	11.5%	a/b/c	31/30/26	4/26
BE	0.47	10.8%	a/c/e	27/26/30	-
BF	0.54	11.7%	a/c/e	44/21/21	-
BG	0.45	11.6%	a/c/e	25/33/25	-
BH	0.46	11.8%	a/c/e	26/31/26	-
BI	0.54	11.6%	a/c/e	23/32/30	-
BJ	0.51	11.3%	a/c/e	26/33/27	-
Average	0.49	11.7%			

[a] For the OSB method when the nail did not pull out the 2x4 it is said to be a pull-through and was then pulled out using the direct pull method. For the slotted OSB all nails were pull-through.

[b]Test Method letter designations are as follows:

(a). ASTM D1761	(b). OSB/Indirect Pull	(c). OSB/Recip. Blade	(d). Slotted OSB	(e). OSB w washer

Effects of the Washer on Withdrawal Capacity

When it was decide that a washer would be needed to test with the 8D nails to prevent pull-through there was a question of whether or not the washer size would have an effect on the withdrawal capacity; a test matrix was developed to determine this. Both the 6D nails and 8D nails were tested because for consistency in the time-dependent testing both the 6D and 8D nails used washers despite the fact that pull-through was not an issue with 6D nails. Table 3-5 shows a brief summary of the results for the 6D Nails.

Table 3-5. Summary of Washer Test Data

	6D Nails		
Washer Diameter	None	0.5 in (12.7 mm)	0.75 in (19.05 mm)
Sample Size	24	29	27
Mean of Withdrawal Capacities lb/in (N/mm)	138 (24.2)	131 (22.0)	124 (21.8)
Standard Deviation lb/in (N/mm)	33 (5.8)	39 (6.9)	23 (4.1)
CoV	24.2%	28.9%	19.0%

A Wilcoxon Test was performed comparing the data and based on a 5% confidence level we can reject the null hypothesis which assumes that the sample sets come from different populations. The p values are shown in Table 3-6 and based on the previous statement we can conclude that the three test method results can be said to come from the same population.

For the 8D nails a majority of the nails had pull-through failure with the 0.5 in (12.7mm) diameter washer. This was another reason to stick with the 0.75 in (19.05 mm) washer in addition to the results from the 6D nails.

Table 3-6. Statistical Analysis Summary of Washer Test

Washer Sizes Compared	P value	Percent Difference
No Washer and 0.5 in (12.7 mm)	0.48	5.2%
0.5 in (12.7 mm) and 0.75 (19.05 mm)	0.48	5.6%
No Washer and 0.75 in (19.05 mm)	0.06	10.8%

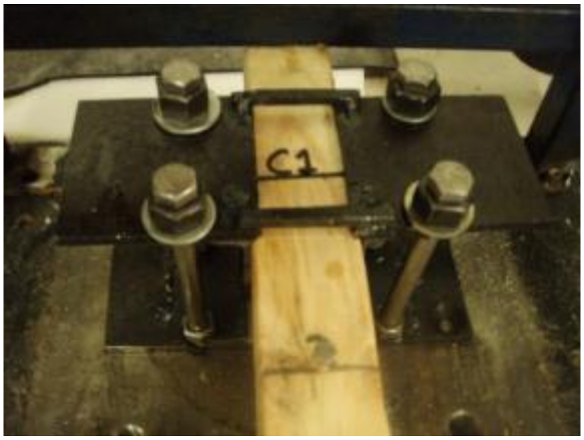
Time Dependent Testing

The last set of testing was done to compare the withdrawal strength of nails over time. It has already been determined that over time nails lose withdrawal capacity over time as determined in (Kurtenacker 1965b) study nail withdrawal strength is decreased over time with as much as a 70% decrease over time after two weeks . The objective of the time-dependent testing was to determine whether through-sheathing installation has the same behavior over time.

For this testing both 6D and 8D nails were tested These nails came from the same batch as the ones used in the tests described in the previous sections. From our results it was determined that the ASTM D1761 and the OSB with washer methods would be the ones used for this testing.

Test Setup

The apparatus for the test setup had to be changed to accommodate all the nails being installed in the 2x4 at one time. The spacing of the nails had to be adjusted as well to accommodate the change in apparatus. The nails tested per the ASTM D1761 method were spaced 3 in (76.2 mm) apart o.c. and the nails tested per the OSB with washer method were spaced 7 in (177.8 mm) apart o.c. to leave space for the apparatus. Figure 3-12 and Figure 3-13 show both these setups. The method of withdrawing the nails remained the same.



A

B

Figure 3-12. Test apparatus to anchor 2x4 to UTM for ASTM D1761 Method for Time dependent testing. A) Top View, B) Angled Side View. September 2013. Courtesy of Ashlie Kerr.

A B

Figure 3-13. Test apparatus to anchor 2x4 to UTM for OSB w/washer method for Time dependent testing. A) Front View, B) Angled Side View. September 2013. Courtesy of Ashlie Kerr.

Test Matrix

For the time-dependent testing 30 nails were tested per method per time period. The nails were tested immediately, 2 weeks, 6 weeks and will be tested 12 weeks after installation. Table 3-7 and Table 3-8 show the number of nails tested per test method per time period and the complete text matrix respectively.

Table 3-7. Nails tested per method per time period

	6D Nails		8D Nails		
Time after Installation	ASTMD1761	OSB with Washer	ASTM D1761	OSB with Washer	
Immediately	30	30	30	30	120
2 weeks	30	30	30	30	120
6 Weeks	30	30	30	30	120
12 weeks	30	30	30	30	120

Table 3-8. Time Dependent Testing Test Matrix

Board	Specific Gravity	Moisture Content	Withdrawal Time	Nail Type	Test Methods	# of Nails
CA	0.46	11.5%	Immediate	6D	Both	30 per method
CB	0.48	11.4%	Immediate	8D	Both	30 per method
CC	0.40	10.3%	2 week	6D	ASTM	30
CD	0.49	11.3%	2 week	6D	OSB	12
CE	0.47	11.6%	2 week	6D	OSB	12
CF	0.48	11.6%	2 week	Both	OSB	6 per type
CG	0.37	13.4%	2 week	8D	OSB	12
CH	0.42	12.0%	2 week	8D	OSB	12
CI	0.47	12.1%	2 week	8D	ASTM	30
CJ	0.45	12.9%	6 week	6D	ASTM	30
CK	0.42	12.5%	6 week	6D	OSB	12
CL	0.53	13.1%	6 week	6D	OSB	12
CM	0.56	12.0%	6 week	Both	OSB	6 per nail type
CN	0.57	11.6%	6 week	8D	OSB	12
CO	0.47	10.9%	6 week	8D	OSB	12
CP	0.46	10.9%	6 week	8D	ASTM	30
CQ	0.49	9.6%	12 week	6D	ASTM	30
CR	0.50	11.4%	12 week	6D	OSB	12
CS	0.46	11.8%	12 week	6D	OSB	12
CT	0.56	11.9%	12 week	Both	OSB	6 per nail type
CU	0.44	11.4%	12 week	8D	OSB	12
CV	0.57	12.3%	12 week	8D	OSB	12
CW	0.39	10.9%	12 week	8D	ASTM	30
Average	0.47	11.6%				

CHAPTER 4
RESULTS AND DISCUSSION

6D Nail Results

For each test the maximum withdrawal capacity was recorded. From there depending on how much of the nail was embedded in the framing member that peak force was divided by the embedment length to give results in load per unit length as it does in the NDS. A Summary of the results is shown in Table 4-1

Table 4-1. Summary of results for 6D Nails

Test Method	ASTM D1761	Steel Plate	OSB Indirect Pull	Plywood Indirect Pull	OSB Recip. Blade	Plywood Recip. Blade
Sample size	134	59	97	76	60	40
Mean[a]	141 (24.7)	147 (25.7)	124 (21.8)	121 (21.2)	94 (16.4)	83 (14.6)
Median[a]	140 (24.5)	146 (25.6)	125 (21.8)	123 (21.5)	91 (16.0)	79 (13.8)
Std. Dev[a]	34 (5.9)	39 (6.8)	24 (4.2)	26 (4.62)	29 (5.0)	25 (4.40
5% Non-Exceedance[a]	91 (16.0)	85 (14.8)	85 (14.8)	78 (13.6)	54 (9.4)	52 (9.1)
Minimum[a]	60 (10.4)	79(13.8)	72 (12.7)	67 (11.7)	50 (8.8)	47 (8.3)
Maximum[a]	314 (55.0)	263 (46.1)	181 (31.8)	191 (33.5)	149 (26.1)	169 (29.7)
CoV (%)	23.9	26.4	19.4	21.8	30.4	30.2
Mean SG per method[b]	0.49	0.51	0.48	0.47	0.50	0.47
Boards averaged for SG[b]	AA, AB, AC, AD	AA, AB, AD	AA, AC, AD, AE, AF	AB, AC, AE, AF	AD, AE, AF	AE, AF

[a]Load per length of nail shank in lb/in (N/mm)
[b]The Specific Gravity is a weighted average of the boards that the methods were tested on (See Table 3-2)

Histograms are plotted of the data sets to determine if there was a common distribution among them in addition to determining the best way to analyze the data (Figure 4-1, Figure 4-2, Figure 4-2, Figure 4-4, Figure 4-3, Figure 4-5, Figure 4-6) with common probabilistic modes layered over them. In light of the fact that we are dealing with failure loads and design loads are of concern more interest was placed on the lower values. Therefore a 5% exclusion values was determined for each data set and plotted as bar graphs (Figure 4-8) as well as the means (Figure 4-7).

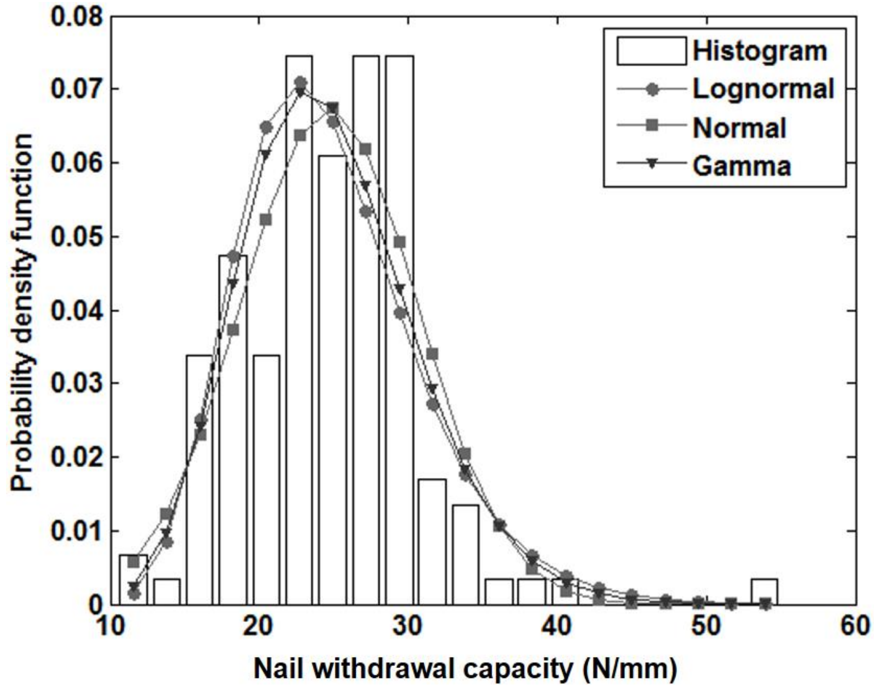


Figure 4-1. Histogram of ASTM D1761 Data and Probabilistic Modes (6D Nails)

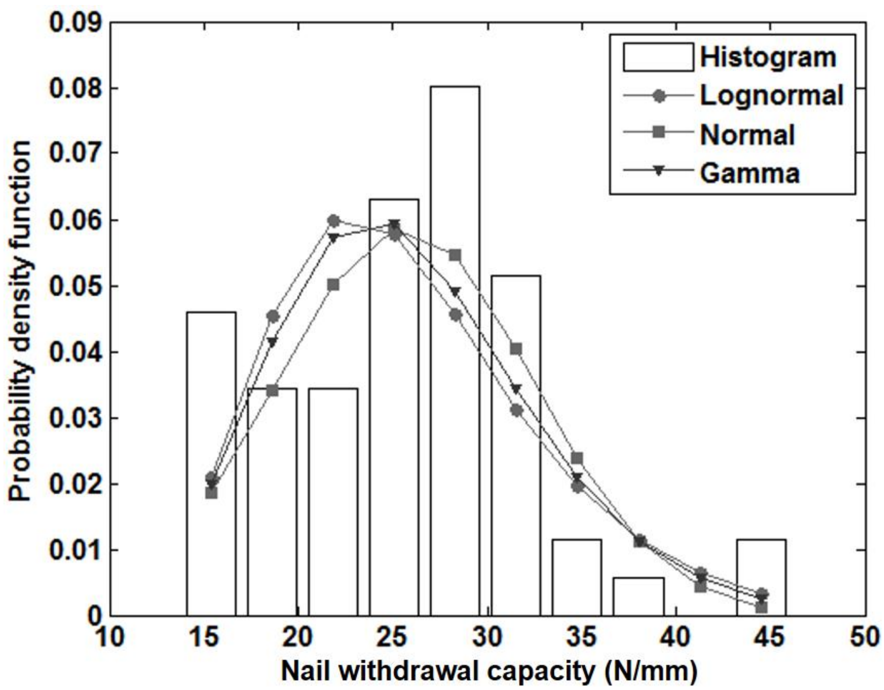


Figure 4-2. Histogram of Steel Plate Data and Probabilistic Modes (6D Nails)

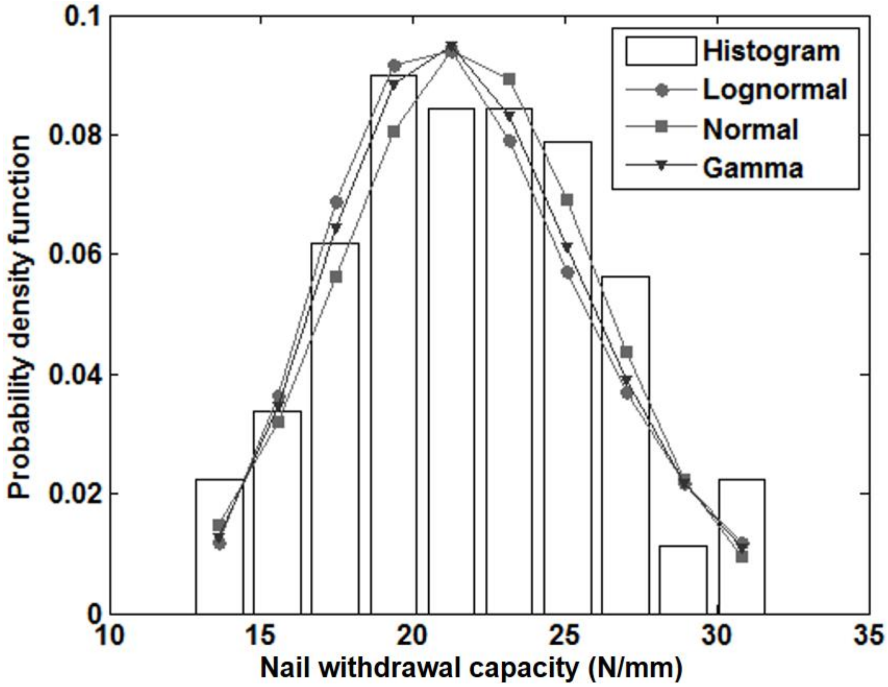


Figure 4-3. Histogram of OSB Indirect Pull Data and Probabilistic Modes (6D Nails)

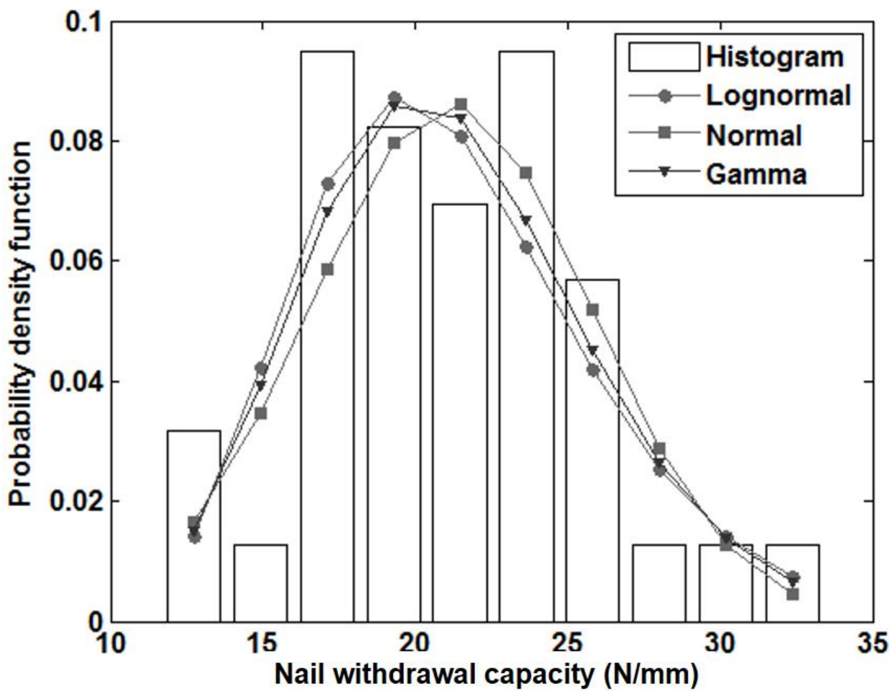


Figure 4-4. Histogram of Plywood Indirect Pull Data and Probabilistic Modes (6D Nails)

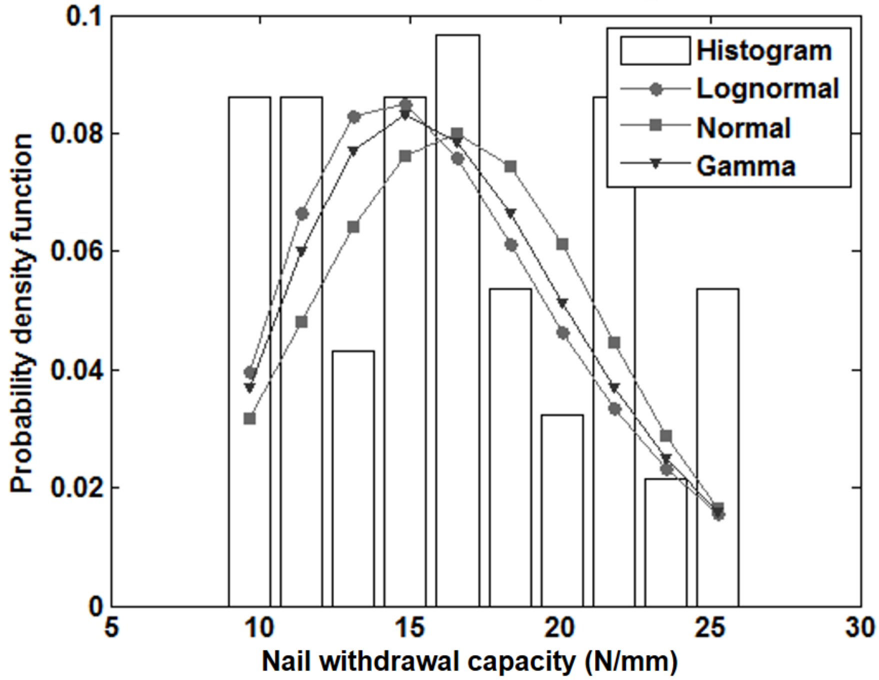


Figure 4-5. Histogram of OSB Reciprocating Blade Data and Probabilistic Modes (6D Nails)

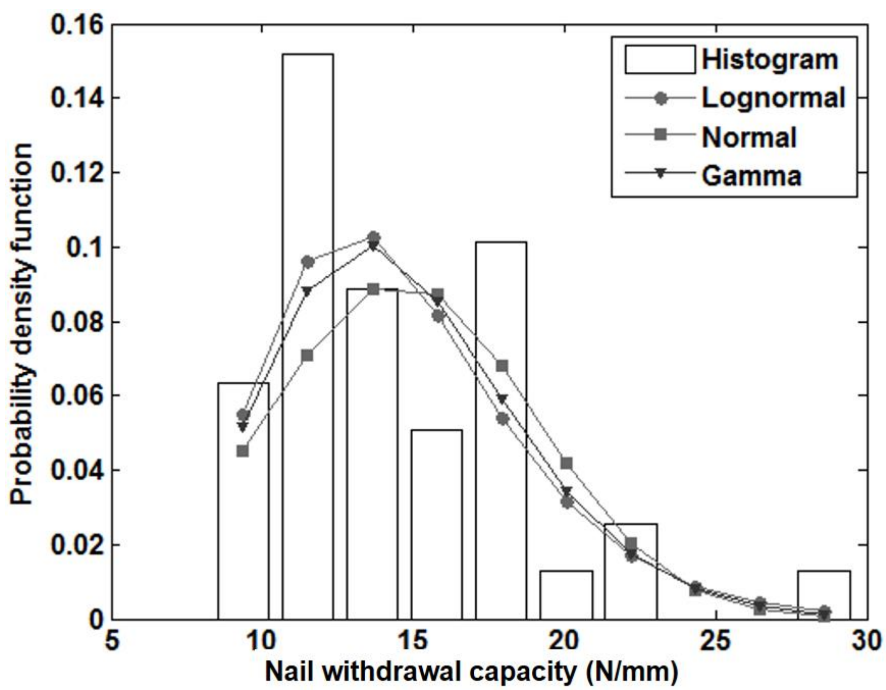


Figure 4-6. Histogram of Plywood Reciprocating Blade Data and Probabilistic Modes (6D Nails)

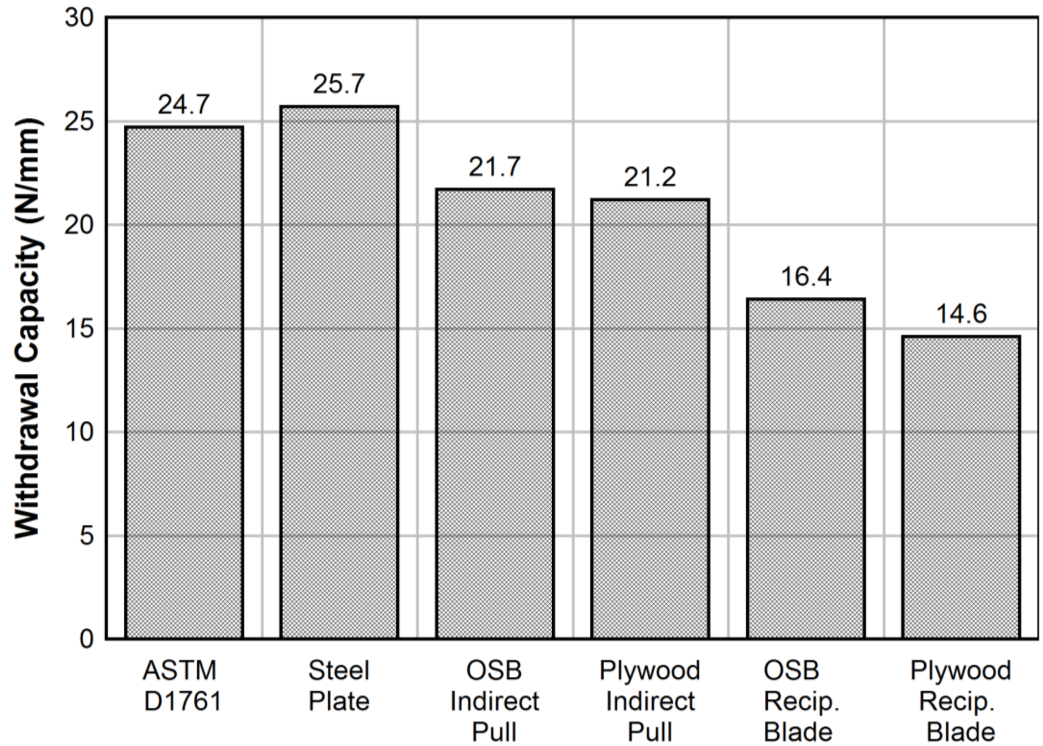


Figure 4-7. Mean Withdrawal Capacities (6D Nails)

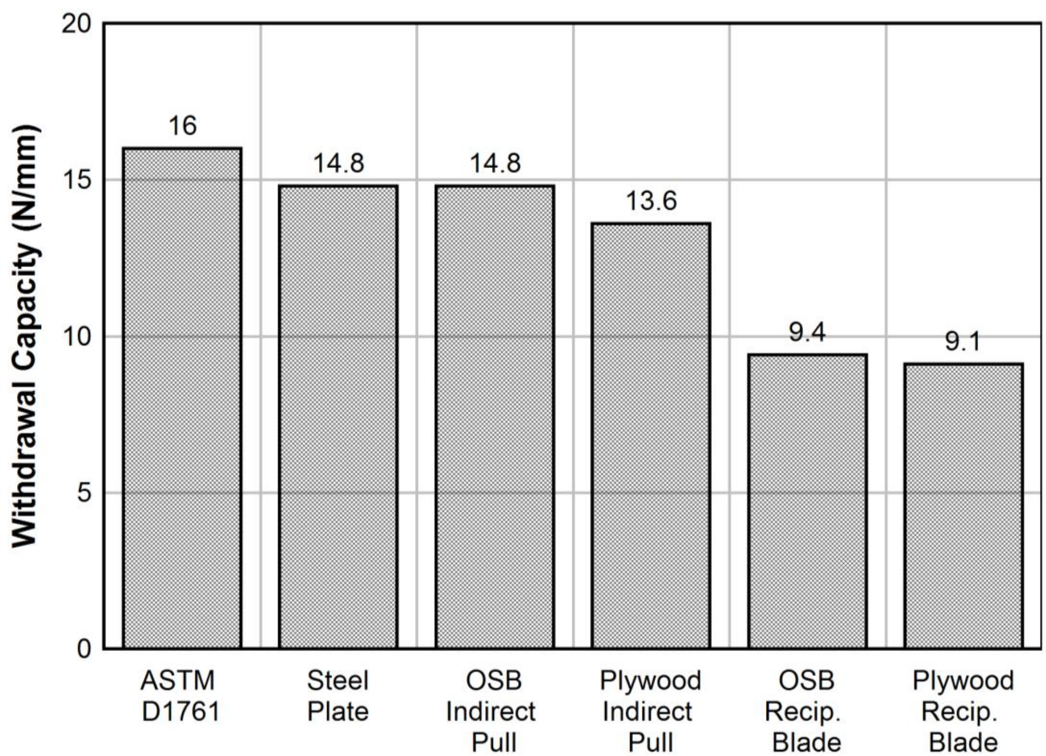


Figure 4-8. 5% Non-Exceedance Capacities (6D Nails)

Wilcoxon test was determined to be the most suited because unlike many similar statistical analysis tests it does not assume normally distributed data. In general assumes that the data is non-parametric (has no distributive characteristics) and can be used to compare data sets of unequal sample sizes (Wilcoxon, 1945). This comparison was done using the statistical software R Studio (Version 0.97.449 © 2009-2012 RStudio, Inc.) which gives a p values. The p-value represents the probability that the null hypothesis can be rejected. The null hypothesis in this case being that the data sets compared can be said to come from two different populations. For the purposes of this study we reject the hypothesis at a p-value above 0.05. Hence if the p-value is less than 0.05 we can say the data sets come from separate population and if the p-value is above 0.05 we can say the data sets can be said to come from the same population. The p-values are reported in Table 4-2 along with the percent difference between the mean and 5% non-exceedance of those data sets.

Table 4-2. Wilcoxon Test p-values and Mean & 5% Non-Exceedance Percent Differences (6D Nails)

Test Method	ASTM D1761	Steel Plate	OSB Indirect Pull	Plywood Indirect Pull	OSB Recip.Blade	Plywood Recip. Blade
ASTM D1761	1	0.24 (3.9%) (7.6%)	3.2E-5 (12.7%) (8.5%)	5.6E-6 (15.4%) (19.2%)	5.6E-16 (40.4%) (50.7%)	7.1E-16 (49.8%) (58.9%)
Steel Plate		1	5.2E-5 (16.6%) (0.9%)	2.3E-5 (19.3%) (11.7%)	5.5E-12 (44.2%) (43.6%)	1.8E-12 (55.2%) (51.9%)
OSB/ Indirect Pull			1	0.38 (2.8%) (10.8%)	1.7E-9 (28.1%) (42.7%)	1.2E-12 (39.5%) (8.5%)
Plywood/ Indirect Pull				1	3.3E-7 (23.4%) (32.3)	5.0E-10 (36.8%) (40.9%)
OSB/ Recip. Blade					1	0.085 (11.7%) (8.8%)
Plywood/ Recip. Blade						1

According to the p-values the 6 data sets above can be combined and reduced to 3 data sets:

1. ASTM D1761 and Steel Plate
2. OSB Indirect Pull and Plywood Indirect Pull
3. OSB Reciprocating Blade and Plywood Reciprocating Blade.

Based on this the following can be said:

- The Steel Plate Test Method has no effect on the withdrawal strength of the nails.
- Installing through-sheathing reduces the withdrawal strength of the nails from as little as 13% (ASTM D1761 and OSB Indirect Pull) and to as much as 55% (Steel Plate and Plywood Reciprocating Blade) when comparing means.
- The method used to withdraw the nails once the sheathing is installed (Indirect Pull vs. Reciprocating Blade) has an effect on the withdrawal strength.
- The type of sheathing (OSB vs. Plywood) has no effect on withdrawal strength.

Table 4-3 show the new results once the data sets are combined and Table 4-4 shows the p-values and percent differences between these new combined sets to further iterate the differences. In addition to the bar graphs comparing the mean and 5% non-exceedance values (Figure 4-9 and Figure 4-10)

Table 4-3. Combined Data Sets Results for 6D Nails

Test Method	ASTM D1761 & Steel Plate	OSB & Plywood Indirect Pull	OSB & Plywood Recip.Blade
Sample size	193	193	100
Mean[a]	143 (25.0)	123 (21.5)	90 (15.7)
Median[a]	141 (24.7)	124 (21.7)	84 (14.7)
5% Non-Exceedance[a]	87 (15.2)	78 (13.6)	53 (9.2)
Std. Dev[a].	35 (6.2)	25 (4.4)	28 (4.8)
Minimum[a]	60 (10.4)	67 (11.7)	47 (8.3)
Maximum[a]	314 (55)	191 (33)	169 (30)
CoV (%)	24.7	20.5	30.8
Mean SG per method[b]	0.49	0.48	0.50
Boards Averaged for SG[b]	AA, AB, AC, AD	AA, AB, AC, AD, AE, AF	AD, AE, AF

[a]Load per length of nail shank in lb/in (N/mm)
[b]The Specific Gravity is a weighted average of the boards that the methods were tested on (Table Table 3-2)

Table 4-4. Wilcoxon p-values and Mean and 5% Non-Exceedance Percent Differences for Combined Data Sets for 6D Nails

Test Method	ASTM D1761 & Steel Plate	OSB & Plywood Indirect Pull	OSB & Plywood Recip. Blade
ASTM D1761 & Steel Plate	1	2.0E-9 (15.1%) (10.7%)	<2.2E-16 (45.9%) (48.6%)
OSB & Plywood Indirect Pull		1	<2.2E-16 (31.3%) (38.4%)
OSB & Plywood Recip. Blade			1

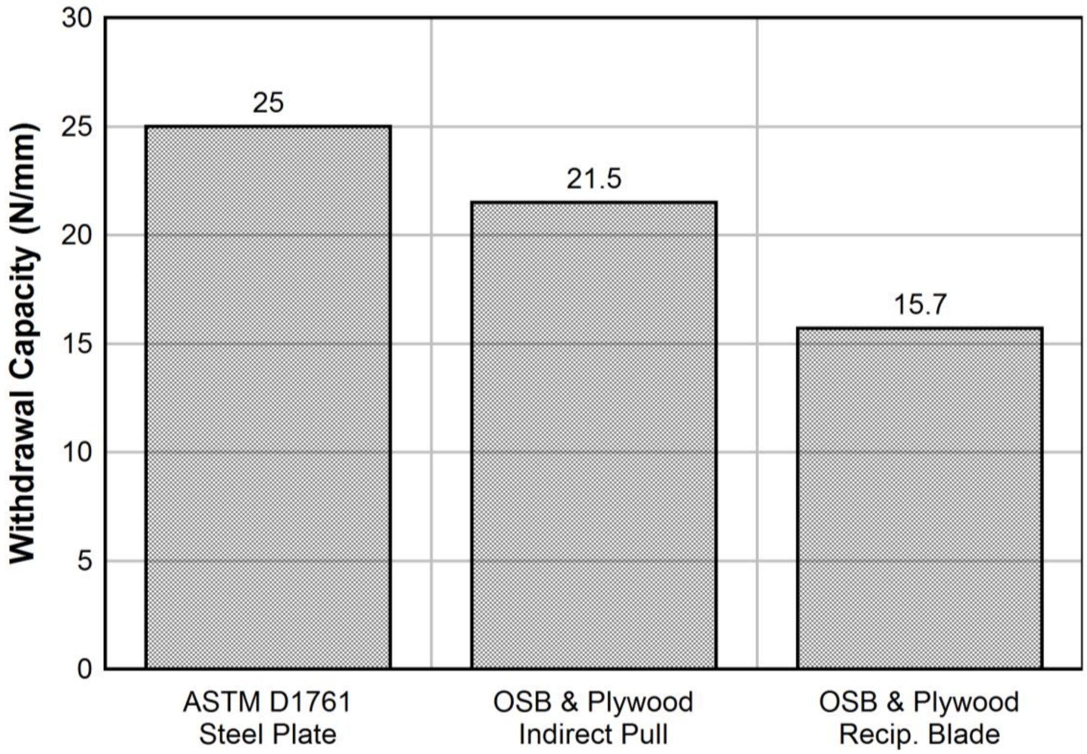


Figure 4-9. Mean Withdrawal Capacities (Combined Test Methods for 6D Nails)

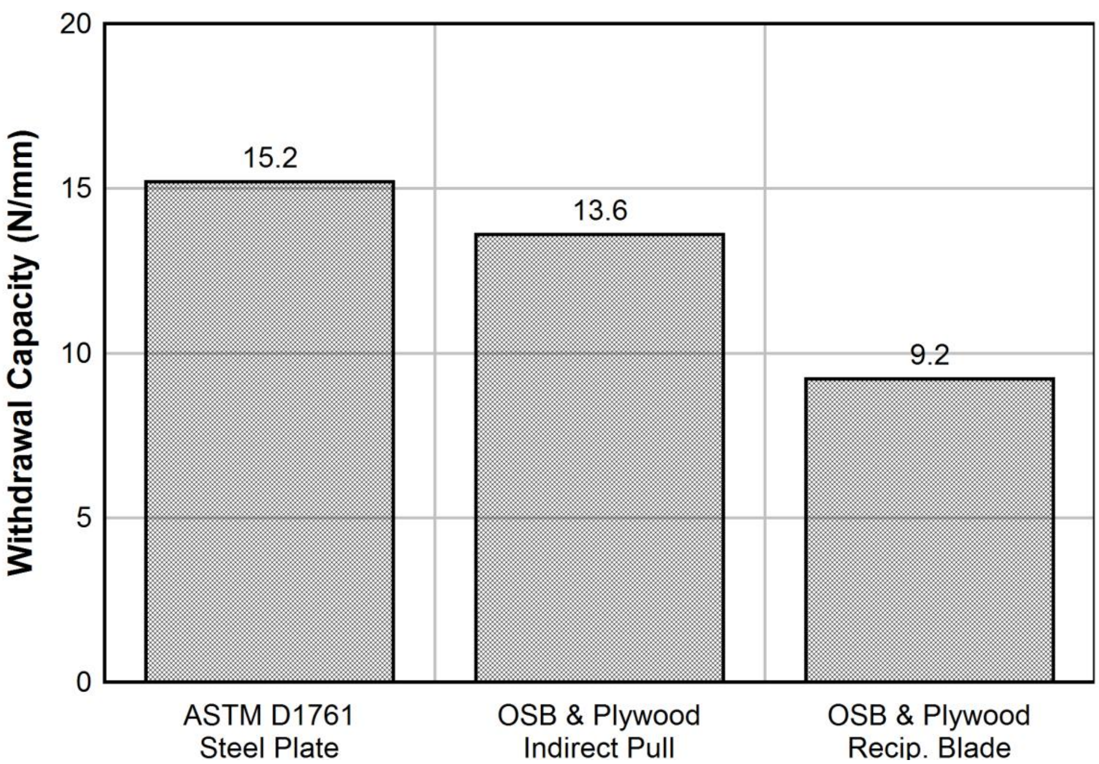


Figure 4-10. 5% Non-Exceedance Withdrawal Capacities (Combined Test Methods for 6D Nails)

As seen above there is a larger difference between the ASTM D1761 Test Results and the Reciprocating Blade results than between the ASTM and the Indirect Pull Results. It is speculated that the vibrations form the reciprocating blade as the sheathing is being removed may affect the nail thus being the reason for the reduction in the withdrawal capacity. The theory was suggested in a previous study as the same phenomena occurred in (Shreyans et al., 2012)

The 6D nail data was compared to Shreyans data (Figure 411). The only similarities found was when comparing the mPNE nail guide from Shreyans test results to the current ASTM D1761 test method which had a p value of 0.9 (Table 4-5).

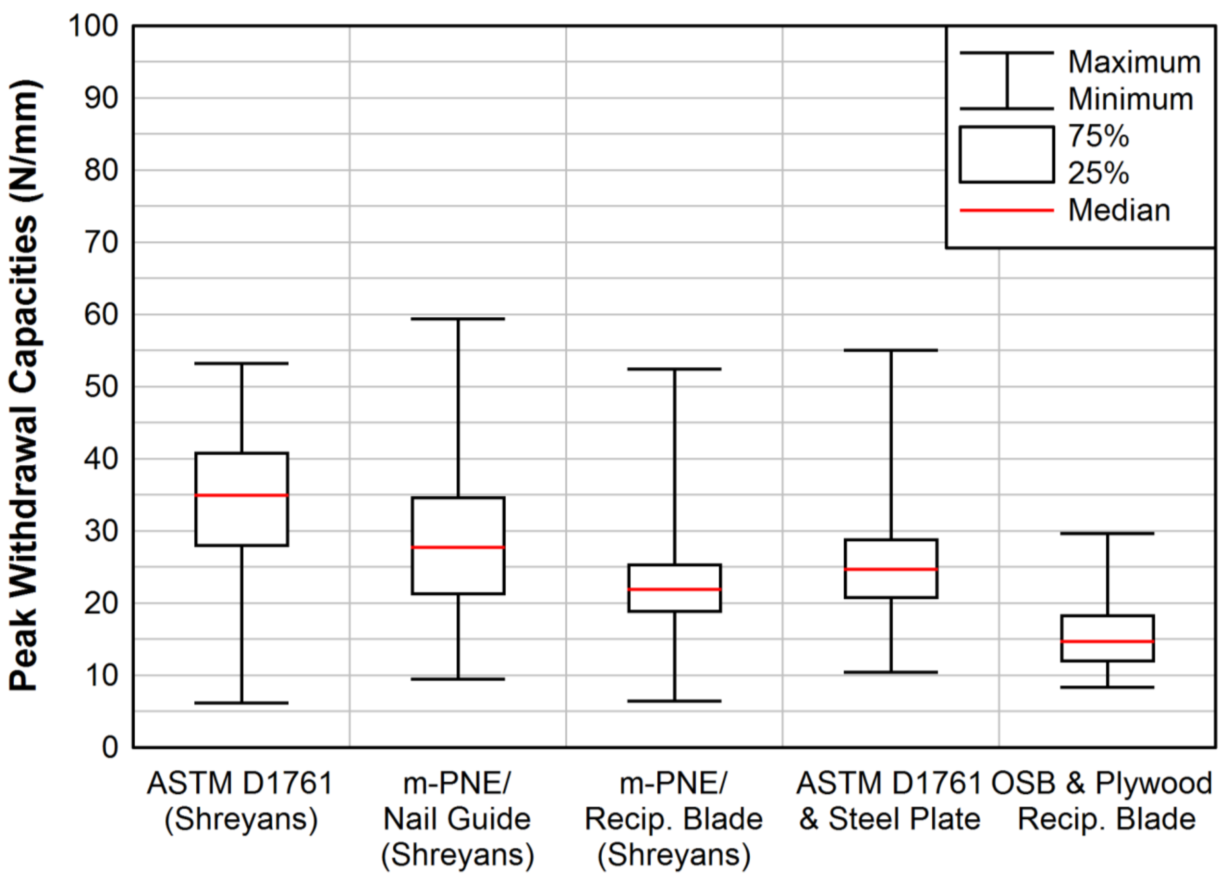


Figure 4-11. Comparison of Data to Shreyans et al. (2012)

Table 4-5. Mean Percent Differences comparing to Shreyans et al. (2012) Data

	Mean Percent Difference
ASTM D1761 (Shreyans) and ASTM D1761/Steel Plate	33.7%
mPNE/Nail Guide and ASTM D1761/Steel Plate	1.3%
mPNE/Recip. Blade and OSB/Plywood Recip. Blade	33.8%

The last thing that was investigated was the effects of specific gravity on the withdrawal results. As mentioned in the Methods and Materials section above five 1 inch (25.4 mm) sections were cut from each board to determine specific gravity and moisture content. This was averaged to determine the specific gravity of each board and these values were plotted against the mean peak withdrawal capacity for each method on that board. These results are show Figure 4-12 along with the ultimate withdrawal strength calculated according to the NDS ultimate withdrawal equation (Equation 1-1) Based on the graph above there is no observable pattern between the peak nail withdrawal capacities and the specific gravity. In addition the majority of the mean peak nail withdrawal capacities for the results through-sheathing are below the expected ultimate withdrawal capacity.

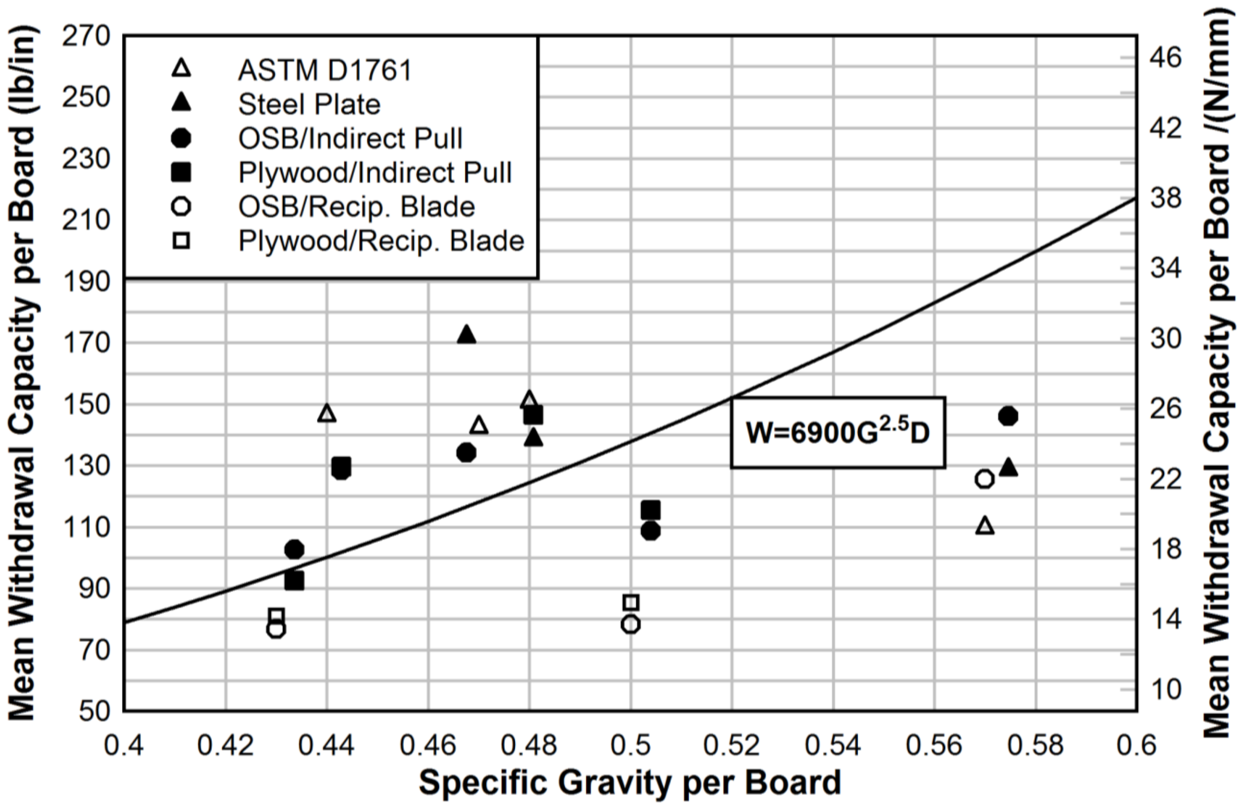


Figure 4-12. Mean Withdrawal Capacity vs. Specific Gravity per Board (6D Nails)

8D Nail Results

Histograms with probabilistic modes were plotted just as with the 6D nails (Figure 4-13, Figure 4-14, Figure 4-15, Figure 4-16, and Figure 4-17). The theory that installing nails through-sheathing reduces withdrawal capacity is further reinforced in the 8D nail withdrawal results (Table 4-6, Figure 4-18, Figure 4-19). However unlike the 6D nails the 8D nails do not seem to be affected by the use of the reciprocating blade to remove the local sheathing. In fact the reciprocating blade results are higher than the washer method, which is comparable to the 6D nails indirect pull method, however it is only a 5.6% difference in the means and are the same for the 5% non-exceedance values. In addition when pull through occurred and the nails were then directly withdrawn from the framing member there was only a 4.78% difference in means between these results and the ASTM D1761.

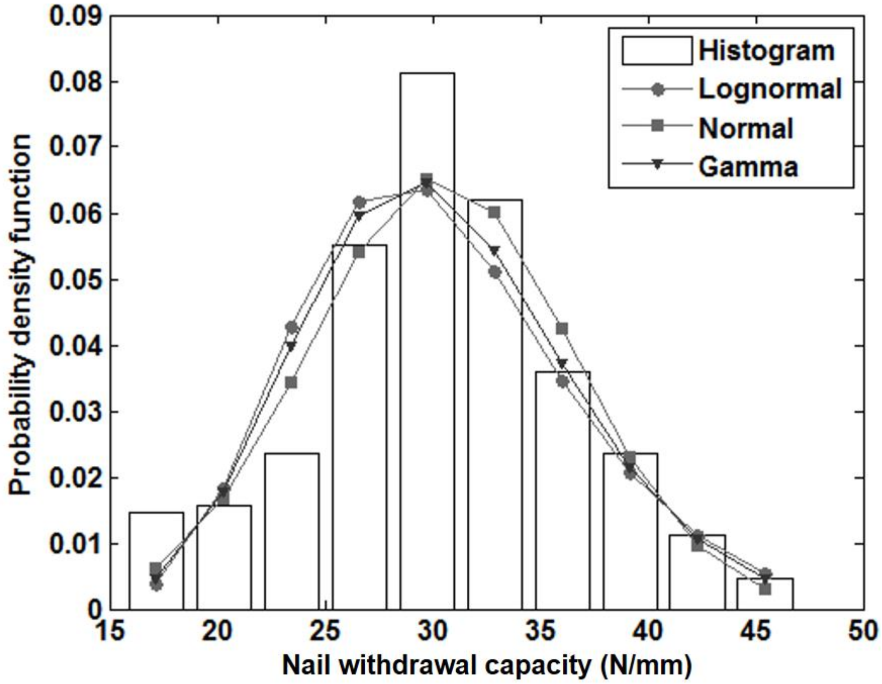


Figure 4-13. Histogram of ASTM D1761 Data Set and Probabilistic Modes (8D Nails)

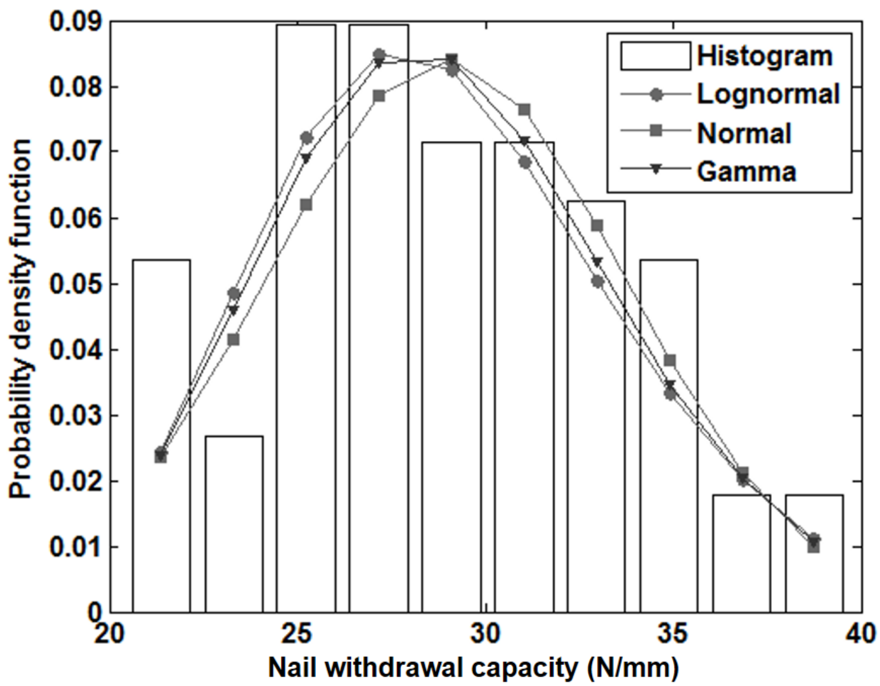


Figure 4-14. Histogram of OSB Pull Through Direct Pull Data Set and Probabilistic Modes (8D Nails)

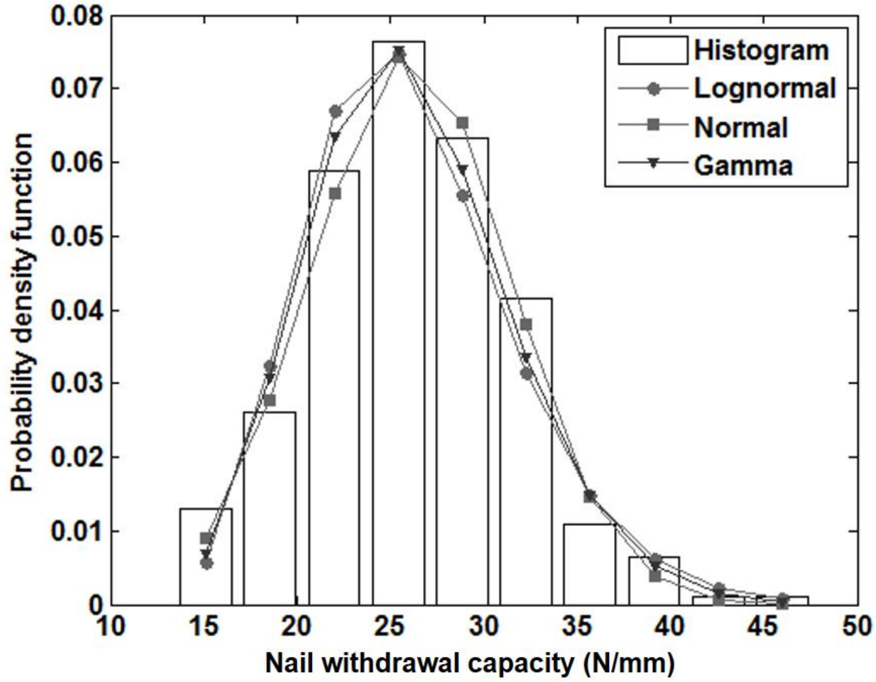


Figure 4-15. Histogram of OSB Reciprocating Blade Data Set and Probabilistic Modes (8D Nails)

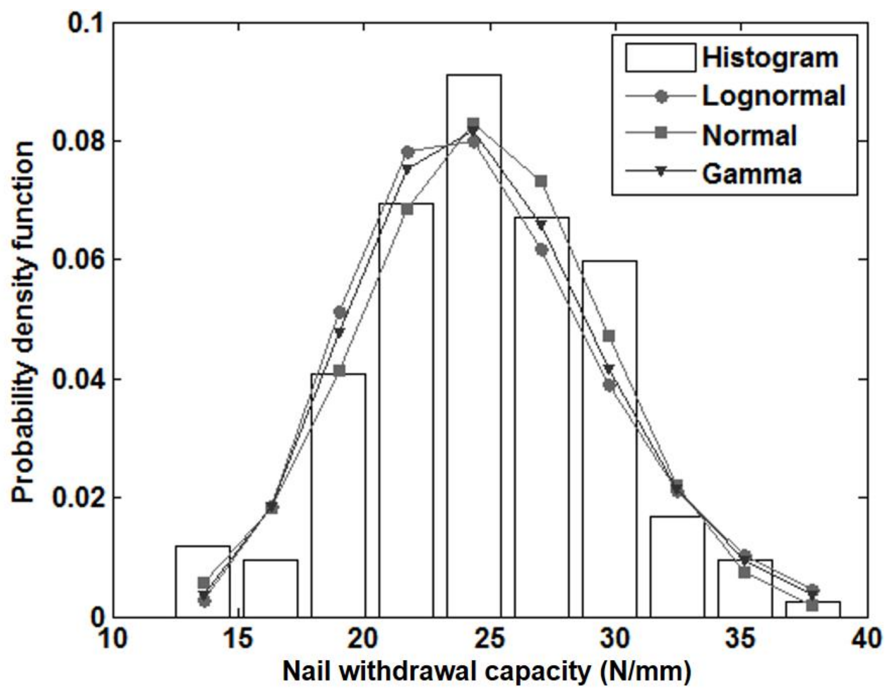


Figure 4-16. Histogram of OSB w/Washer Data Set and Probabilistic Mode (8D Nails

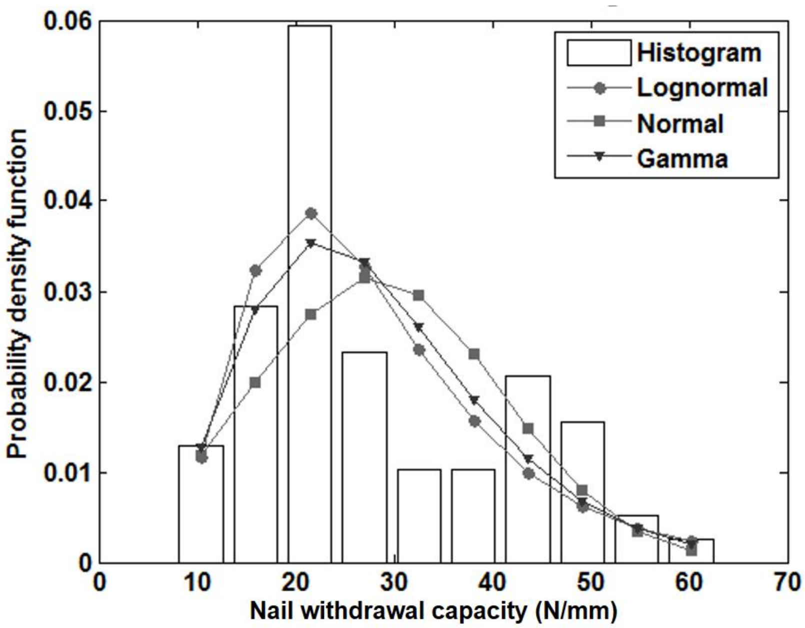


Figure 4-17. Histogram of OSB Pull Through Data Set and Probabilistic Modes (8D Nails)

Table 4-6. Summary of results for 8D Nails

Test Method	ASTM D1761	OSB Pull Through Direct Pull[c]	OSB Recip. Blade	OSB w/Washer	OSB Pull Through
Sample size	291	62	274	158	73
Mean[a]	173	165	149	141	160
	(30.4)	(28.9)	(26.1)	(24.7)	(28.1)
Median[a]	171	165	145	141	133
	(30.0)	(28.9)	(25.4)	(24.6)	(23.2)
5% Non-Exceedance	112	122	98	96	67
	(19.6)	(21.4)	(17.2)	(16.8)	(12.7)
Std. Dev[a].	35	27	31	27	73
	(6.1)	(4.7)	(5.3)	(4.8)	(12.7)
Minimum[a]	89	116.6	76.6	69.9	43.8
	(15.6)	(20.4)	(13.4)	(12.3)	(7.7)
Maximum[a]	269	227	272	224	360
	(47.0)	(39.7)	(47.7)	(39.2)	(63.0)
CoV (%)	20.1	16.4	20.5	19.5	45.1
Mean SG per method[b]	0.49	0.52	0.49	0.49	0.51
Boards Averaged for SG	BA, BI	BA, BB, BD	BA, BC, BI	BE, BI	BA BB, BD

[a]Load per length of nail shank in lb/in (N/mm)
[b]The Specific Gravity is a weighted average of the boards that the methods were tested on (Table 3-4)

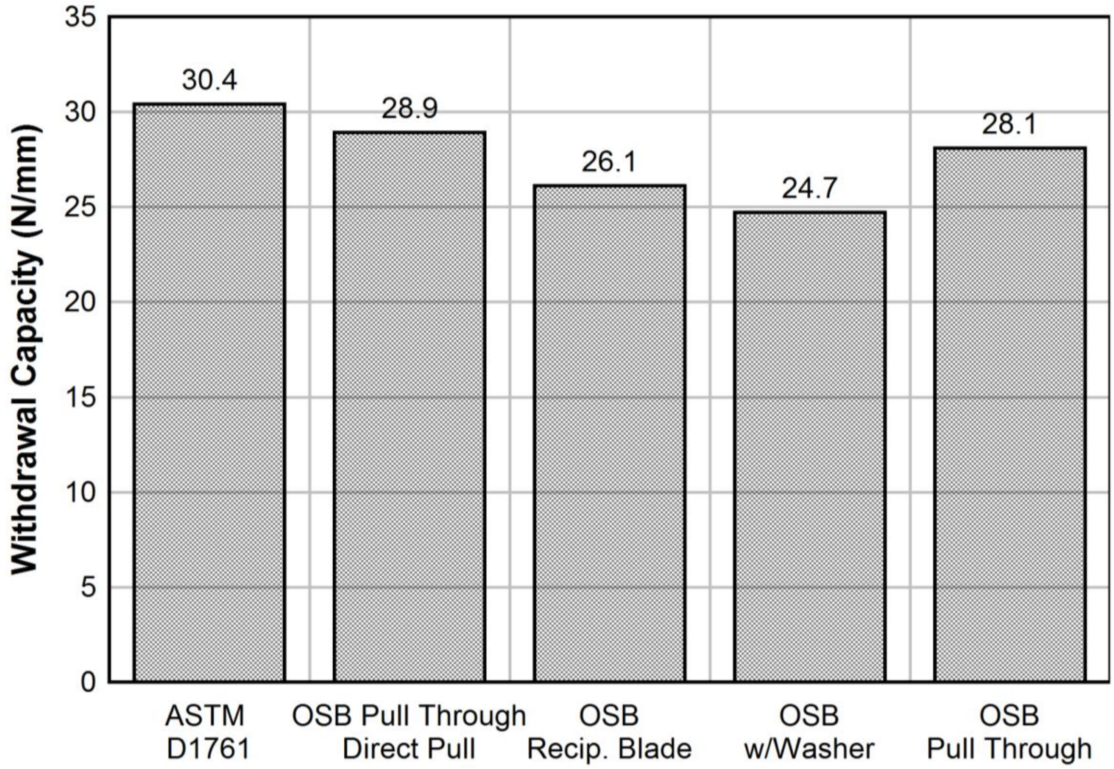


Figure 4-18. Mean Withdrawal Capacities (8D Nails)

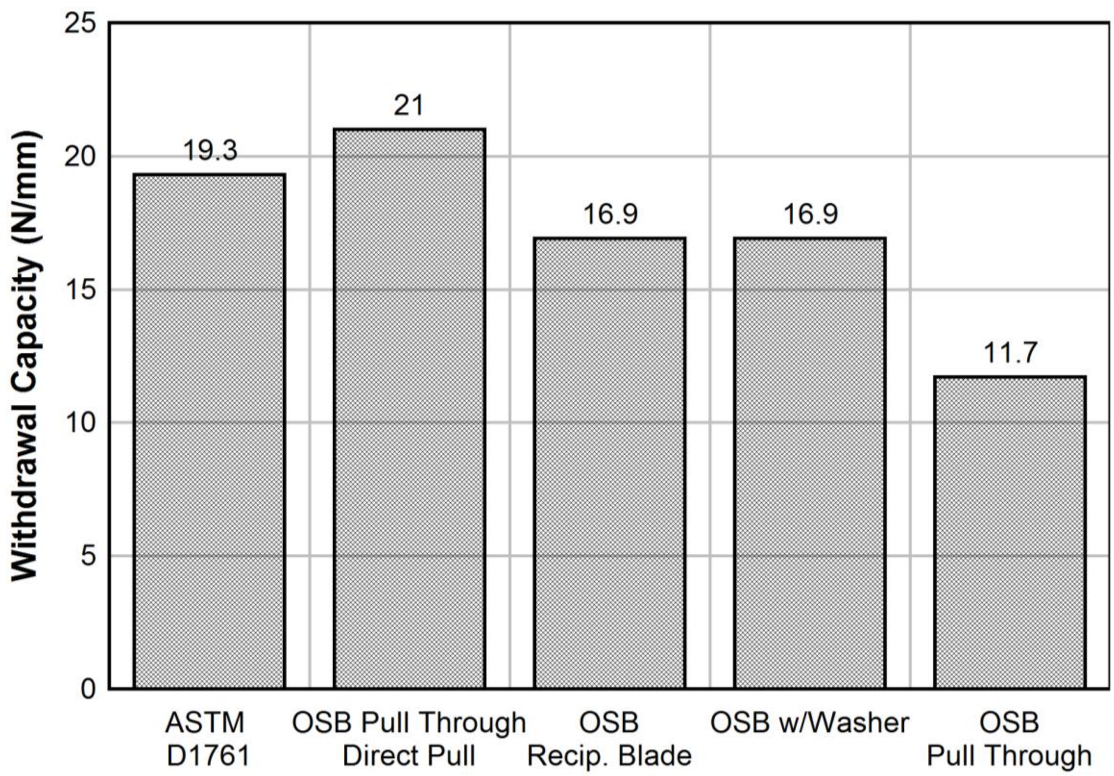


Figure 4-19. 5% Non-Exceedance Capacities (8D Nails)

In addition to this the Wilcoxon test rejected the null hypothesis meaning that they can be said to come from the same population (Table 4-7). These small differences could be a result in the increase diameter of the nails. The vibrations of the reciprocating blade and the stress from the pull-through are not enough to reduce the withdrawal capacity drastically because the 8D nail has a stronger hold in the wood. However based on testing it is more likely that the 8D nails will fail in pull though before any pull out from the framing member occurs. In comparison to the ASTM D1761 pull through failure loads were lower by 8%.

Table 4-7. Wilcoxon Test p-values and Mean and 5% Non-Exceedance Percent Differences (8D Nails)

Test Method	ASTM D1761	OSB Pull Through Direct Pull	OSB Recip. . Blade	OSB w/Washer	OSB Pull Through
ASTM D1761	1	0.06 (4.8%) (8.7%)	<2.2E-16 (15.2%) (13.1%)	<2.2E-16 (20.7%) (13.2%)	0.0005 (7.8%) (49.1%)
OSB Pull Through/Direct Pull		1	8.8E-5 (10.4%) (21.8%)	5.9E-8 (16.0%) (21.9%)	0.02 (3.0%) (57.2%)
OSB/ Recip. Blade			1	0.01 (5.6%) (0.1%)	0.34 (7.5%) (36.5%)
OSB w/Washer				1	0.9 (13.0%) (36.5%)
OSB Pull Through					1

Figure 4-20 shows the results plotted against the specific gravity. The results are calculated and plotted with the same method as the 6D nails. The only difference is for each board nine 1 inch (25.4mm) samples were taken instead of five. Once again there is no observable pattern with regards to specific gravity. In addition above a specific gravity above 0.5 majority of the results fall below the predicted NDS Ultimate Withdrawal Capacity values, including the ASTM D1761 values.

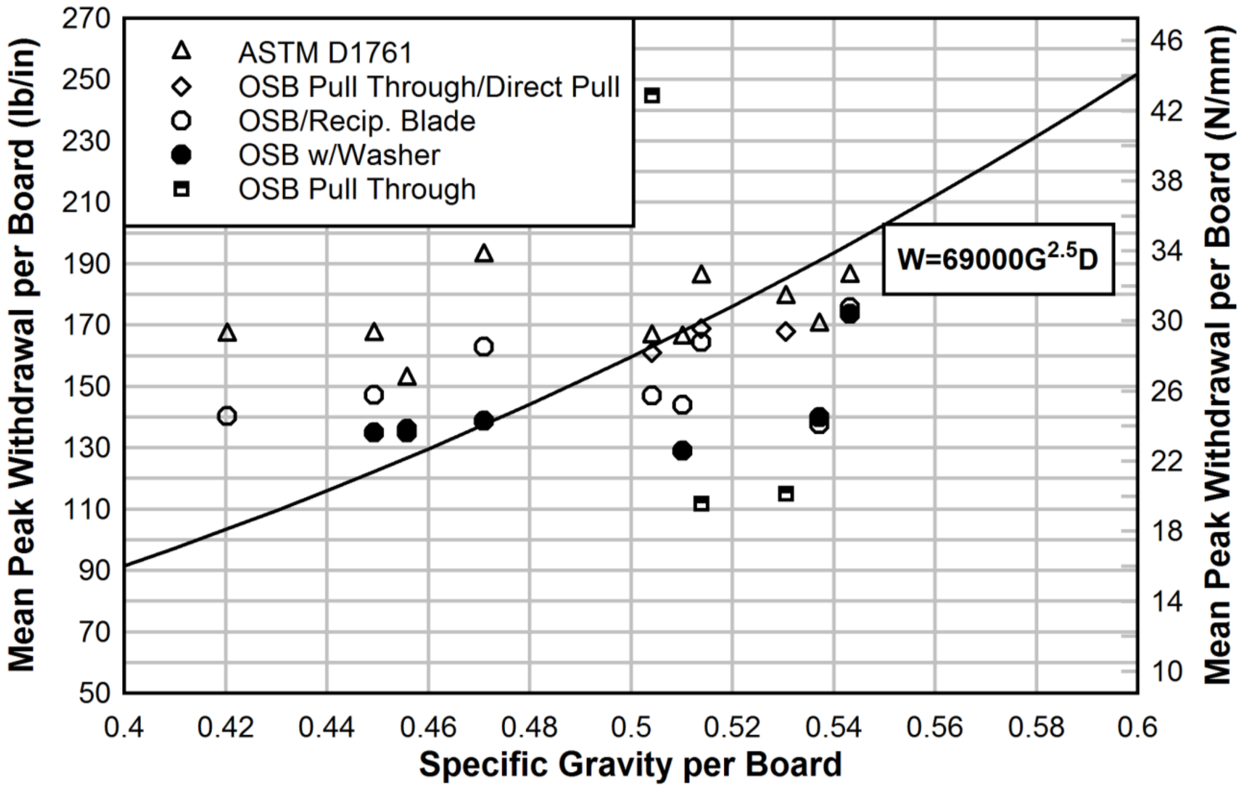


Figure 4-20. Mean Withdrawal Capacity vs. Specific Gravity per Board (8D Nails)

Time Dependent Testing

Based on the results so far it can be said than installation through-sheathing affects the immediate peak nail withdrawal strength. However the next question is: How does time affect the peak nail withdrawal capacities? From this three outcomes were theorized:

1. The peak nail withdrawal capacity would decrease at the same rate over time. Hence if the difference between the immediate peak withdrawal capacities with and without sheathing starts out at x% then it would continue to be a difference of that same x% over time (Figure 4-21)

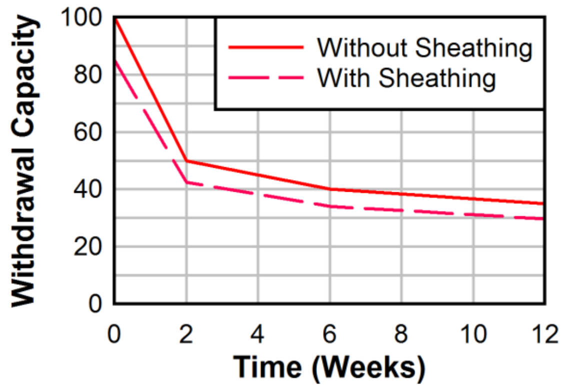


Figure 4-21. Graph of Theory 1

2. The difference of the peak nail withdrawal capacity of between nails installed with and without sheathing would decrease until they leveled out at the same value. Hence if the difference between the immediate peak nail withdrawal capacities with and without sheathing starts out at x% over time the difference would decrease to 0% or close to it, therefore over time the withdrawal capacities between the two installation methods converge (Figure 4-22)

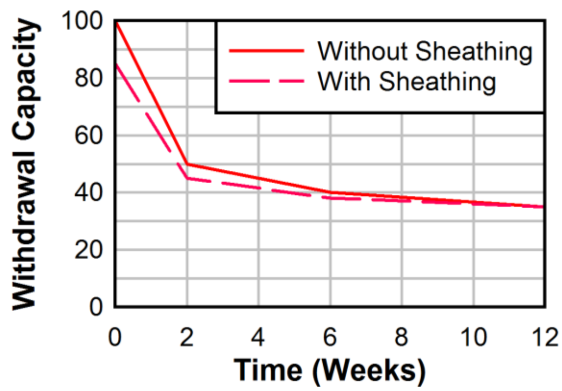


Figure 4-22. Graph of Theory 2

3. The last possible outcome is that the withdrawal would decrease at noticeable different rates so in the end the percent difference would be different whether positive of negative. Hence if the difference between the immediate peak withdrawal capacities with and without sheathing was x% in the end it would be a different y% with the reciprocating blade decreasing faster and having a larger percent difference at the end or the slower and being higher than the ASTM values in the end (Figure 4-23)

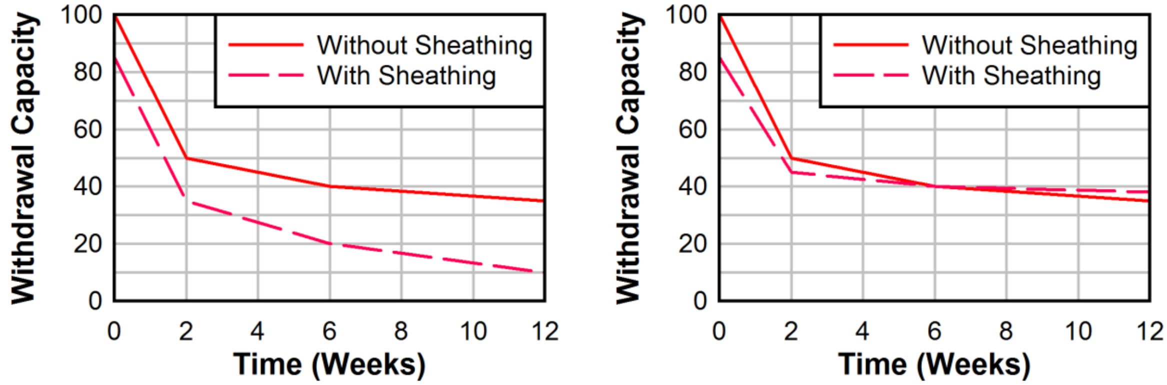


Figure 4-23. Possible Outcomes of Theory 3

As discussed in the Chapter 3 for the indirect pull the 8D nails would pull-through for the majority of the tests. The washer was used to prevent this in the 8D Nails. Further testing was done to determine whether the washers affected the withdrawal strength and it was determined it did not according to statistical analysis. Although pull-through was not a problem with 6D Nails for the time dependent testing washers were used for the sake of consistency.

In the case of the 6D nails there is a decrease over time in withdrawal capacity, with the exception of the 6 week data (Table 4-8 and Figure 4-24). The withdrawal capacity however does not decrease as rapidly as in the Kurtenacker 1965 paper which states the biggest loss in strength happens in the first two weeks. On average there is a 11% and 3% difference in the first two weeks for the ASTM D1761 (Table 4-9) and OSB (Table 4-10) test methods respectively and after 12 weeks there is a difference of 44% and 29%. It can then be said that the loss in strength over time is lower when installed through-sheathing for 6D Nails.

Table 4-8. Summary of results for Time Dependent Testing for 6D Nails

Test Method	ASTM D1761				OSB w/Washer			
Time of Withdrawal	Immediate	2 wk.	6 wk.	12 wk.	Immediate	2 wk.	6 wk.	12 wk.
Sample size	30	30	30	30	30	30	30	30
Mean[a]	126	113	108	80	106	84	117	79
	(22.0)	(19.8)	(19.0)	(14.0)	(18.5)	(14.7)	(20.4)	(13.8)
Median[a]	121	118	103	77	89	86	119	82
	(21.1)	(20.6)	(18.0)	(13.5)	(15.6)	(15.1)	(20.8)	(14.3)
Std. Dev[a].	30	26	18	26	42	31	28	12
	(5.2)	(4.5)	(3.2)	(4.6)	(7.3)	(5.4)	(4.8)	(2.2)
Minimum[a]	85	48	87	38	71	39	53	53
	(14.8)	(8.4)	(15.2)	(6.7)	(12.4)	(6.8)	(9.3)	(9.3)
Maximum[a]	182	159	150	170	282	151	170	109
	(31.9)	(27.9)	(26.3)	(29.8)	(49.3)	(26.5)	(29.8)	(19.1)
CoV (%)	23.6	22.7	16.9	33.1	39.5	36.7	23.6	15.6
Mean SG per method[b]	0.46	0.40	0.45	0.49	0.46	0.48	0.50	0.51
Boards Averaged for SG	CA	CC	CJ	CQ	CA	CD, CE, CF	CK, CL, CM	CR, CS, CT

[a]Load per length of nail shank in lb/in (N/mm)
[b]The Specific Gravity is a weighted average of the boards that the methods were tested on (See Table 3-8)

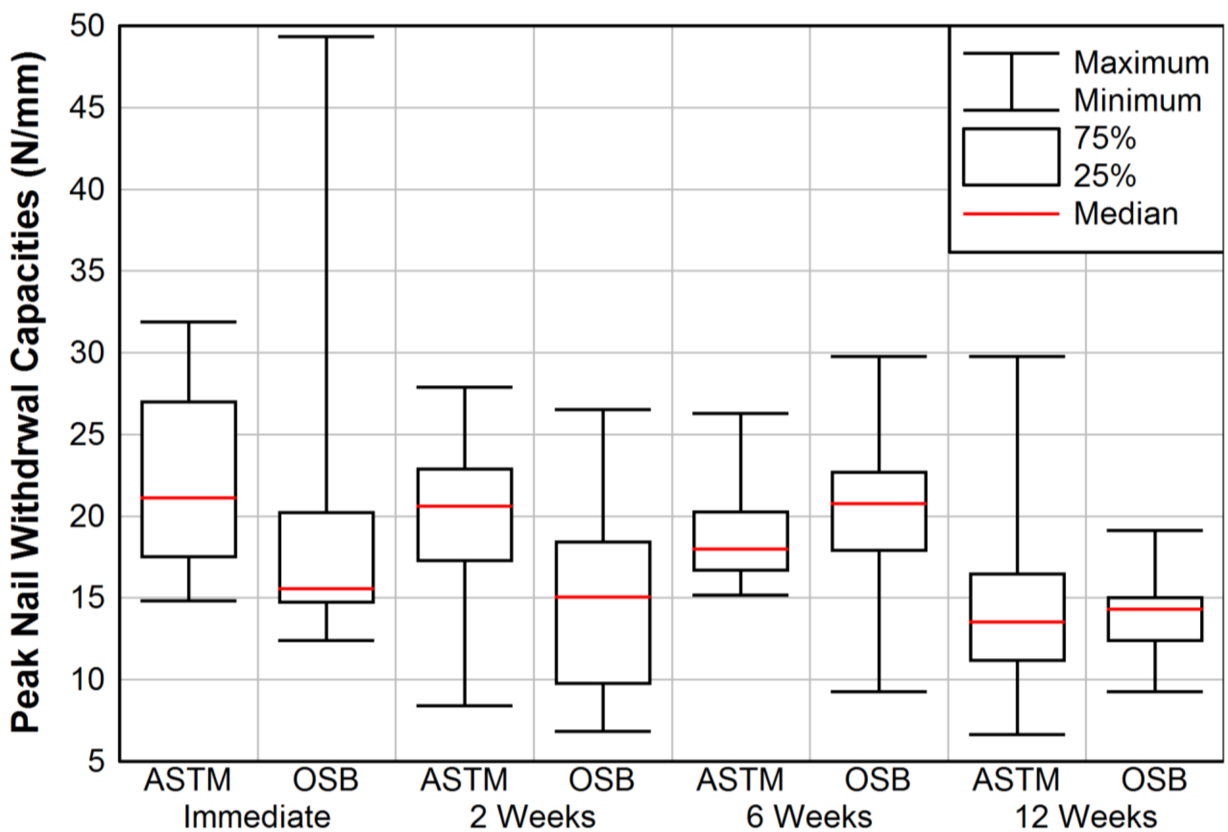


Figure 4-24. Boxplot of 6D Nail Withdrawal Method per Method Over Time

Table 4-9. Wilcoxon Test p-values and Mean and Median Percent Differences (6D ASTM D1761)

	Immediate	2 Weeks	6 Weeks	12 Weeks
Immediate	1	0.18 (10.8%) (2.5%)	0.03 (15.0%) (16.1%)	1.71E-7 (44.9%) (43.8%)
2 Weeks		1	0.24 (4.2%) (13.6%)	9.8E-6 (34.5%) (41.4%)
6 Weeks			1	3.0E-6 (30.4%) (28.2%)
12 Weeks				1

Table 4-10. Wilcoxon Test p values and Mean and Median Percent Differences (6D OSB w/Washer)

	Immediate	2 Weeks	6 Weeks	12 Weeks
Immediate	1	0.08 (23.0%) (3.4%)	0.01 (-10.1%) (-28.7)	1.0E-3 (29.2%) (8.5%)
2 Weeks		1	7.6E-5 (-32.9%) (-32.0%)	0.37 (6.3%) (5.1%)
6 Weeks			1	1.0E-7 (40.0%) (40.0%)
12 Weeks				1

The same phenomenon is observed with the 8D OSB w/Washer test series (Table 4-11 and Figure 4-25) at 6 weeks as with the 6D nails. The mean withdrawal capacity is higher than the other test series in the time line. This also happens at the 2 week mark for the ASTM D1761 for 8D Nails. After further analysis of the 8D ASTM D1761 test series the Immediate, 6 week and 12 week can all be said to come from the same population according to the p-values obtained from the Wilcoxon Test (Table 4-12). The 2-week results for the 8D ASTM D1761 has an average difference of 21% from the means of the Immediate, 6 week and 12 week.

Table 4-11. Summary of Results for Time Dependent Testing for 8D Nails

Test Method	ASTM D1761				OSB w/Washer			
Time of Withdrawal	Immediate	2 wk.	6 wk.	12 wk.	Immediate	2 wk.	6 wk.	12 wk.
Sample size	30	29	30	30	30	29	29	30
Mean[a]	148 (25.9)	179 (31.3)	146 (25.6)	141 (24.7)	133 (23.2)	132 (23.0)	135 (23.6)	99 (17.3)
Median[a]	145 (25.4)	176 (30.7)	145 (25.4)	140 (24.5)	127 (22.3)	124 (21.7)	134 (23.5)	97 (17.1)
Std. Dev[a].	20 (3.5)	18 (3.2)	17 (2.9)	22 (3.9)	20 (3.5)	30 (5.3)	33 (5.7)	24 (4.3)
Minimum[a]	113 (19.8)	136 (23.7)	110 (19.3)	90 (15.8)	107 (18.7)	88 (15.4)	75 (13.1)	55 (9.6)
Maximum[a]	215 (37.6)	211 (36.9)	175 (30.6)	202 (35.4)	178 (31.2)	193 (33.8)	192 (33.7)	154 (27.0)
CoV (%)	13.3	10.1	11.3	15.7	15.1	23.0	24.2	24.6
Mean SG per method[b]	0.48	0.47	0.46	0.39	0.48	0.42	0.53	0.53
Boards Averaged for SG	CB	CI	CP	CW	CB	CF, CG, CH	CM, CN, CO	CT, CU, CV

[a]Load per length of nail shank in lb/in (N/mm)
[b]The Specific Gravity is a weighted average of the boards that the methods were tested on (See Table 3-8)

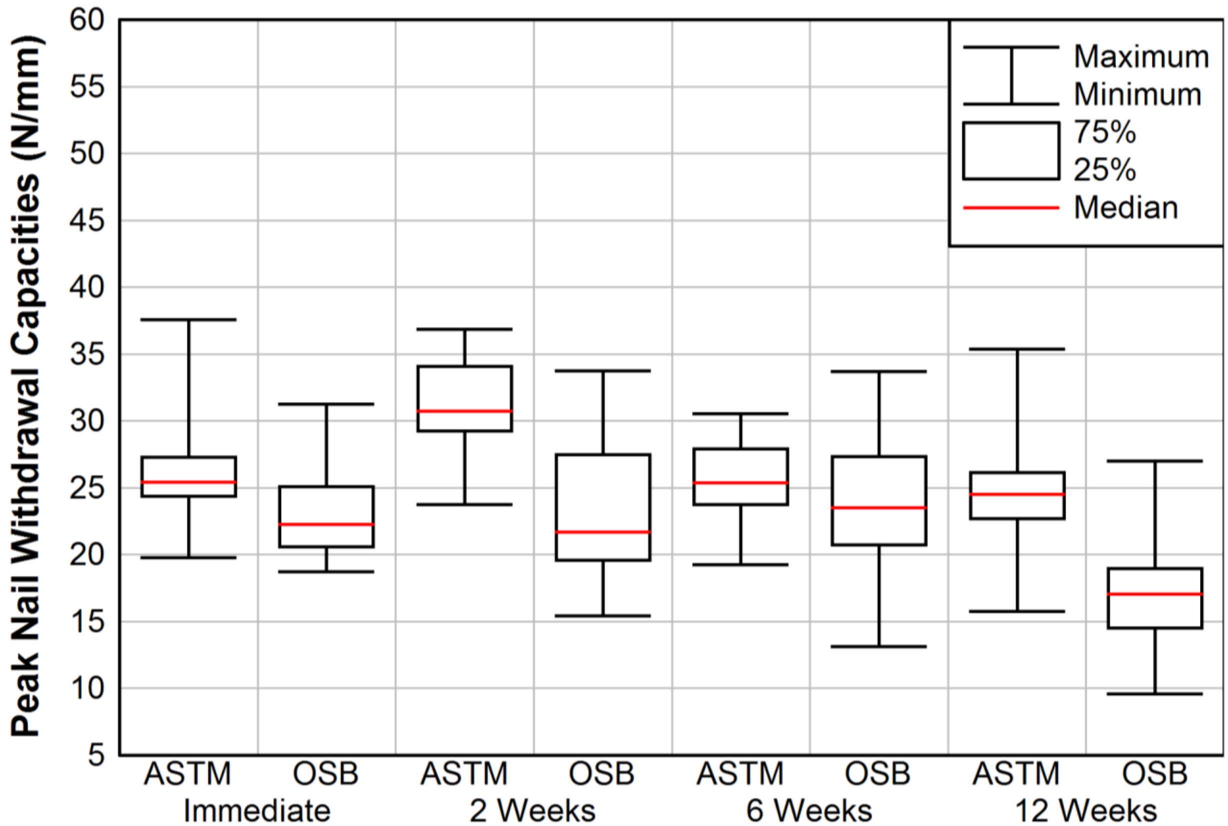


Figure 4-25. Boxplot of 8D Nail Withdrawal Capacities per Method Over Time

Table 4-12. Wilcoxon Test p-values and Percent Differences (8D ASTM D1761)

	Immediate	2 Weeks	6 Weeks	12 Weeks
Immediate	1	5.4E-7 (-18.6%) (-18.9%)	0.79 (1.5%) (0.2%)	0.14 (4.9%) (3.7%)
2 Weeks		1	6.2E-8 (20.1%) (19.0%)	6.7E-8 (23.4%) (22.5%)
6 Weeks			1	0.21 (3.4%) (3.5%)
12 Weeks				1

In the case of the 8D OSB w/Washer results (Table 4-13) the Immediate, 2 week and 6 week results can be said to come from the same population. The 12 week is lower with 30% average difference from the means of the Immediate, 2 week and 6 week results.

The mean ratio of the withdrawal capacity over time in comparison to the immediate withdrawal per method is graphed below in Figure 4-26.

Table 4-13. Wilcoxon Test P values and Percent Differences (8D OSB w/Washer)

	Immediate	2 Weeks	6 Weeks	12 Weeks
Immediate	1	0.64 (0.9%) (2.8%)	0.44 (-1.4%) (5.3%)	8.5E-7 (29.5%) (26.6%)
2 Weeks		1	0.59 (-2.3%) (-0.1%)	6.5E-5 (29.6%) (23.8%)
6 Weeks			1	9.7E-5 (30.9%) (%31.8)
12 Weeks				1

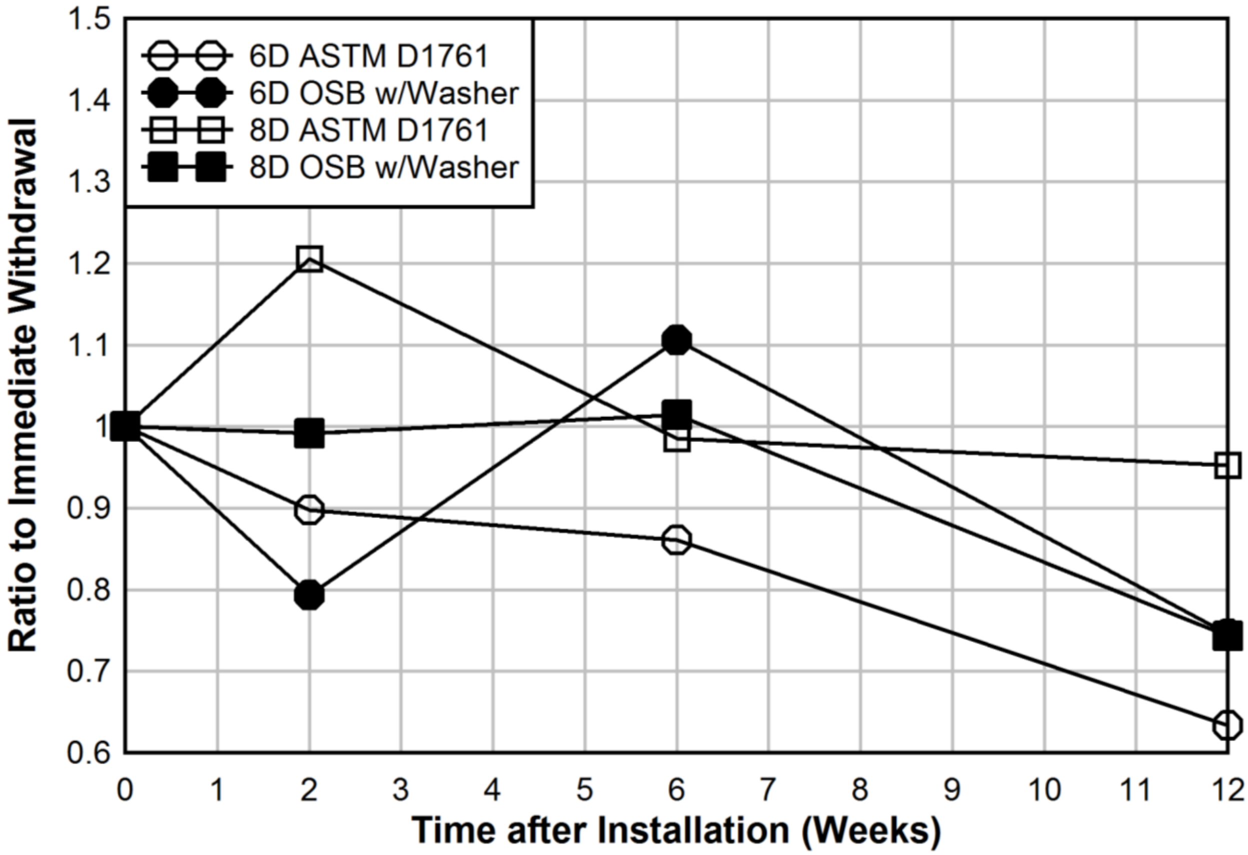


Figure 4-26. Peak Withdrawal Capacities as a ratio of the Immediate Withdrawal Over Time (6D and 8D nails)

As shown in the graph and after statistical analysis (Table 4-14 and Figure 4-27) it can be seen that ASTM D1761 and OSB w/Washer values converge starting at 6 weeks, however for the 8D nails converge at 6 weeks but separate again at 12. Weeks. Another observation was that over time the reduction of the through-sheathing method had the same percent reduction over time between 6D and 8D nails, which was not observed for ASTM D1761 test methods over time.

Table 4-14. Wilcoxon P Values and Percent Difference between Test Methods (ASTM D1761 vs. OSB w/Washer)

	6D Nails		8D Nails	
Time of Test	P Value	Percent Difference	P Value	Percent Difference
Immediate	0.0008	17.6 %	2.5E-3	11.0%
2 Weeks	0.0004	29.7%	2.9E-8	30.3%
6 Weeks	0.0574	7.5%	0.19	8.2%
12 Weeks	0.9000	1.3%	2.9E-11	35.5%

Table 4-15. Wilcoxon P values and Percent Difference between Nail Types (6D vs. 8D)

	ASTM D1761		OSB w/Washer	
Time of Test	P Value	Percent Difference	P Value	Percent Difference
Immediate	3.0E-3	16.3%	3.2E-5	22.8%
2 Weeks	1.0E-10	45.0%	1.0E-6	44.3%
6 Weeks	3.1E-8	22.7%	0.03	14.2%
12 Weeks	1.2E-9	55.6%	3.0E-11	22.5%

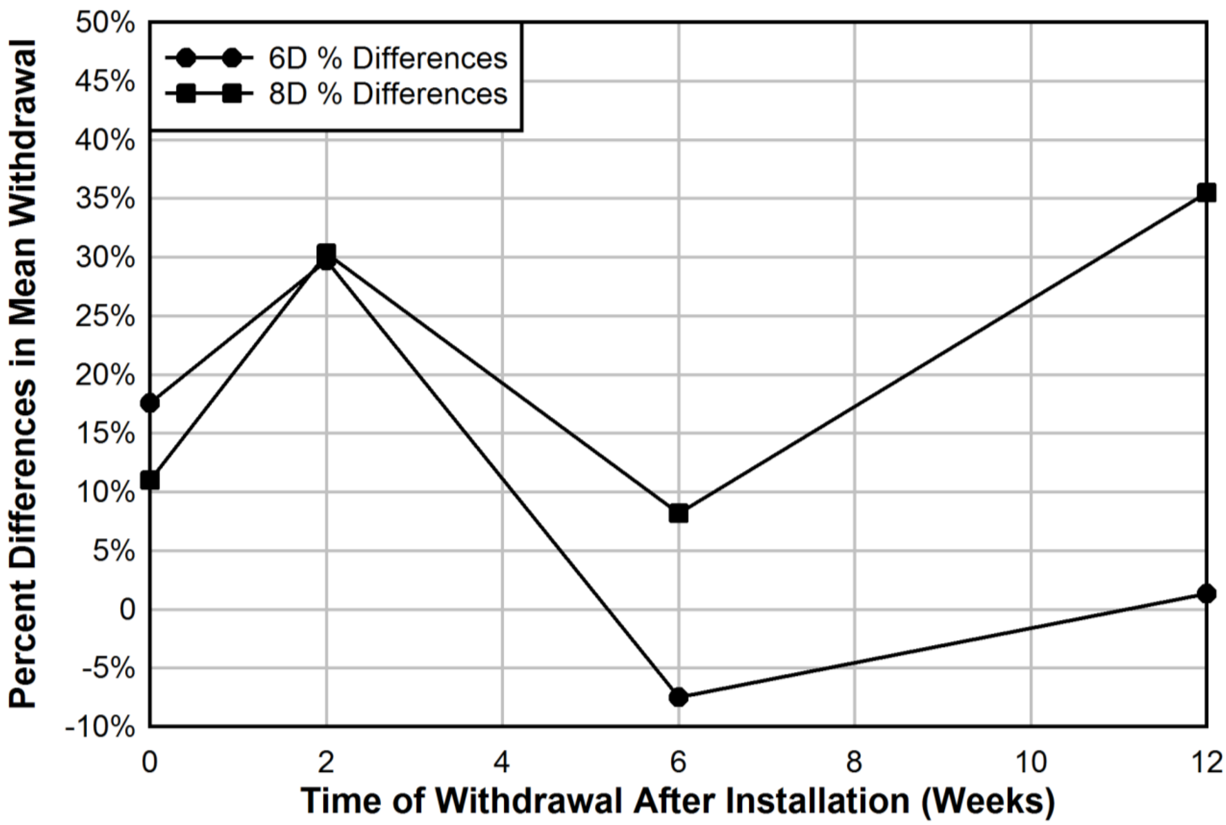


Figure 4-27. Percent Differences of Mean between ASTM D1761 and OSB w/Washer Test Methods per nail type

Temperature was also a concern when performing these tests. Temperature and Humidity data were collected by a LogTag Analyzer Device and imported using the LogTag Analyzer Software (Version 2.3 © 2002-2013 LogTag Recorders). The device was placed beside the test specimens to get a log of the temperature and humidity in the room they were stored in over time. The data was graphed over time and compared to atmospheric temperatures obtained from the National Weather Service Website and shown below (Figure 4-28 and Figure 4-29). There are also graphs where the data over the time is graphed over the two day period in which both the six week and twelve week test groups were performed (Figure 4-30, Figure 4-31 and Figure 4-32). There is not data for Immediate and 2 week as the LogTag Device was not available at that time.

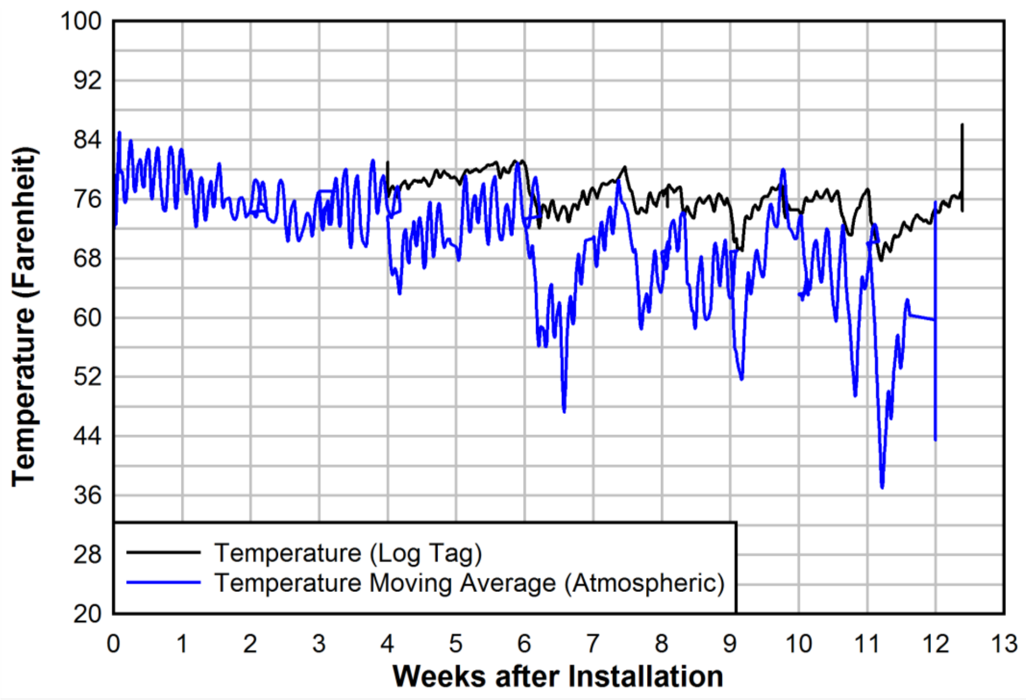


Figure 4-28. Temperature over time

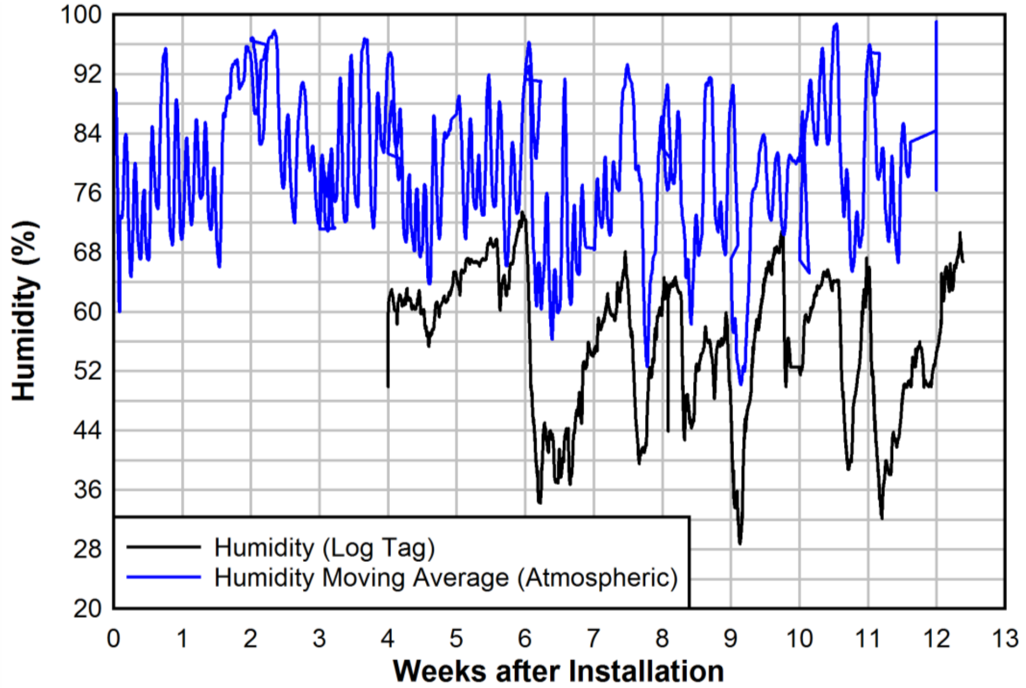


Figure 4-29. Humidity over time

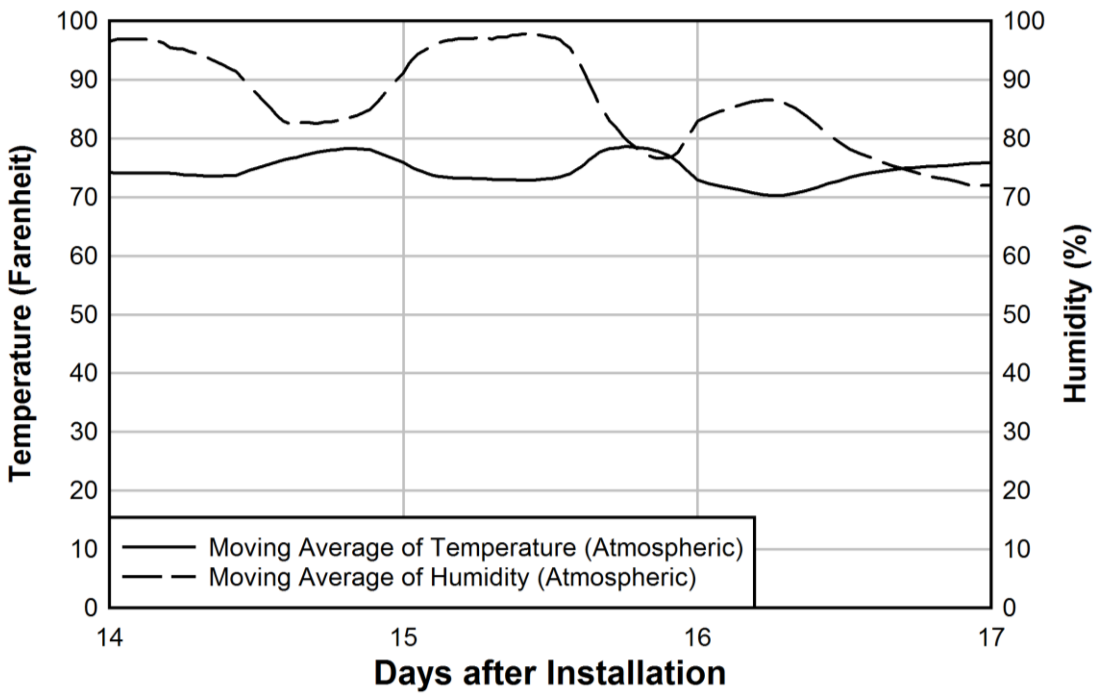


Figure 4-30. Temperature and Humidity over time during the 2 day period in which 2 week tests were performed. (Atmospheric Only)

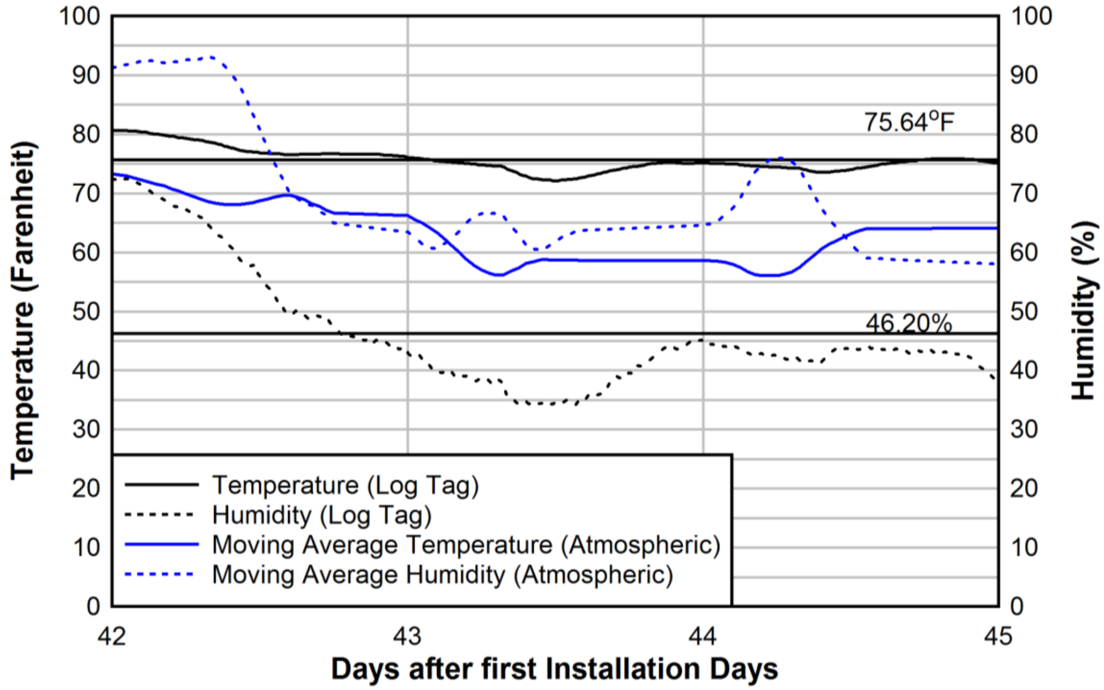


Figure 4-31. Temperature and Humidity over time during the 2 day period in which the 6 week tests were performed (Line represents mean value of log tag data over time period).

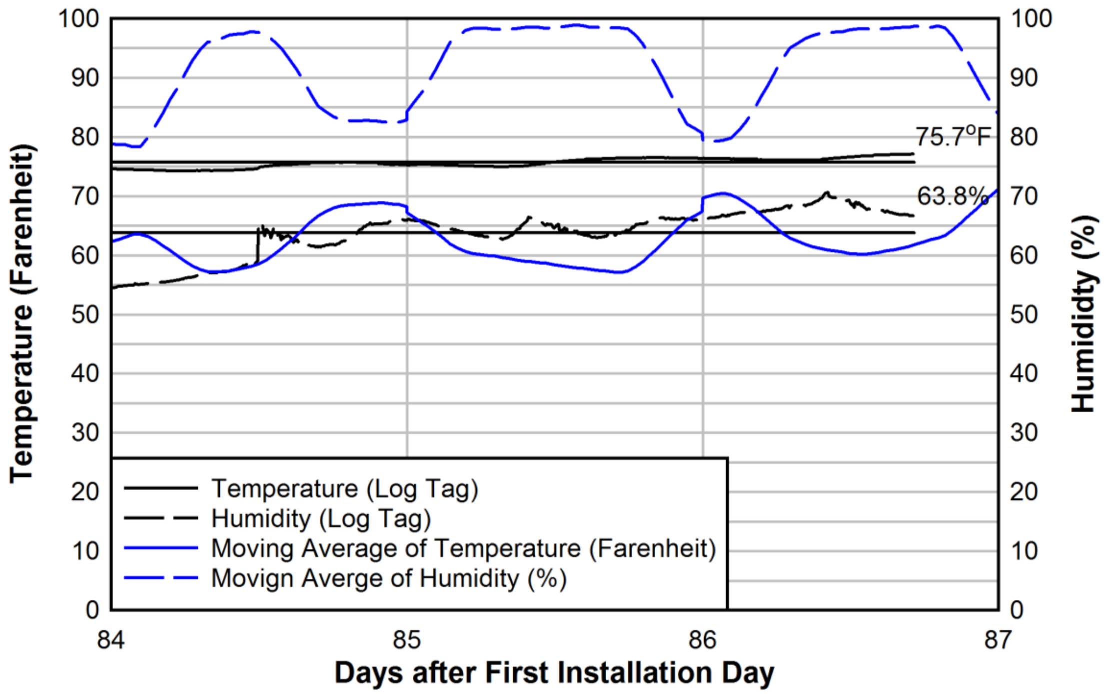


Figure 4-32. Temperature and Humidity over time during the 2 day period in which the 12 week tests were performed (Line represents mean value of log tag data over time period).

As shown above the temperature remains fairly stable over time averaging at 75.3^{o} F with a minimum of 67.7^{o} F and a maximum of 86.1^{o} F. The humidity however has large spikes with a minimum of 28.7% and a maximum of 86.4% averaging at 55.2%. One of these large spike occurs during the time the 6 week testing was being performed which is when the withdrawal capacities for OSB increase instead of decreasing as expected. It could be said that the lower humidity caused the withdrawal to be higher however there is not enough data to substantiate this observation.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

The main objective of this study was to determine the nature in which through-sheathing installation affects nail withdrawal capacities and to develop an accurate method for testing nails installed through-sheathing in the laboratory. As shown in the results above there is a definite difference in the results obtained using the standard ASTM D1761 test method and the modified test method in which nails were installed through-sheathing. The following conclusions can be made from the above results:

- Driving a nail through wood sheathing (regardless of sheathing type), reduces its withdrawal capacity as compared with similar nails driven directly into the wood framing member. This is evident by the difference in withdrawal capacity of nails between the ASTM D1761 test method and methods in which the nails are driven through-sheathing.

- The reciprocating blade and indirect pull test methods (both through sheathing installation methods) caused a reduction in nail withdrawal capacity. These were 46% and 16% reduction respectively for 6D Nails and 15% and 21% reduction respectively for 8D Nails.

- The indirect pull method is determined as a more appropriate test method to isolate the effects of sheathing as it causes less of a reduction in capacity in 6D nails.

- Over time the difference between the ASTM D1761 and through-sheathing installation methods is reduced for 6D nails but there is almost no change for 8D nails. However due to the unexpected jump in mean capacity at the 6 week mark no definite conclusion can be made. This jump however could be attributed to the drop in humidity during that time period.

- A reduction factor ranging from 0.6 to 0.85 should be used with the immediate nail withdrawal capacity determined by the ASTM D1761 procedure in estimating the strength of 6D nails (through-sheathing installed) in-situ. The reduction factor for 8D nails is 0.85.

- Directly using the NDS-specified values of nail withdrawal strength (without the above-reduction factors) to estimate the failure loads and wind speeds from roof damage observations will over-estimate the failure wind speed and is non-conservative.

In this testing it was determined that through-sheathing installation causes a decrease in nail withdrawal capacities, however the reason for this loss in strength is unclear. One theory is that as the nail goes through the sheathing there may be a greater chance for deformation of the tip of the nails however on inspection this did not seem to be the case. Another theory is that the nail is resisted and slowed as it goes through the sheathing so the force and speed at which it enters the framing member is less than when there is no obstruction however there is no way to test this at this point.

The results of this study affect the way the results of the ASTM D1761 test method are currently interpreted when determining how a nail will behave in the field. Having a better understanding of this is helpful when it comes to forensic engineers as often they may need to back calculate to determine failure wind speed. If the data gathered for the nails is not accurate this could lead to incorrect assumptions in the field. However on the design side despite these findings the NDS design predictions should not be affected due to the various reduction factors applied to the ultimate prediction to before arriving at a the design value.

It is recommended that more testing be conducted to verify the strength reduction factor, using a wider sample of nails, and wood species. The conditioning of the wood samples was insufficient to fully eliminate fluctuations in temperature and humidity over the 12-week period. Still, these results do not support the substantial (over 50%) loss in nail withdrawal strength observed in the Kurtenacker (1965a, b) studies of the late 1960s, as reported earlier.

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BIOGRAPHICAL SKETCH

Ashlie Kerr started the University of Florida in 2007 as a civil engineering major. During her time as an undergraduate student she was highly involved in various organizations including the American Society of Civil Engineers student chapter, Society of Women Engineers, the American Concrete Institute student chapter and the Jamaican American Student Association.

Ashlie became involved in research as an undergraduate and gained a position as a research assistant in her final year of her undergraduate degree program. Ashlie graduated with her Bachelor of Science in civil engineering in December 2011 after which she immediate began her graduate degree program in structural engineering.

Ashlie continued with research through the graduate program and completed her graduate degree program in May 2014 earning her Master of Engineering in civil engineering.

In February of 2014 Ashlie joined the consulting engineering firm Botkin, Parssi and Associates of Lake Worth, FL as a Structural Engineer, where she is working on the restoration and remodeling of condominiums and custom homes.