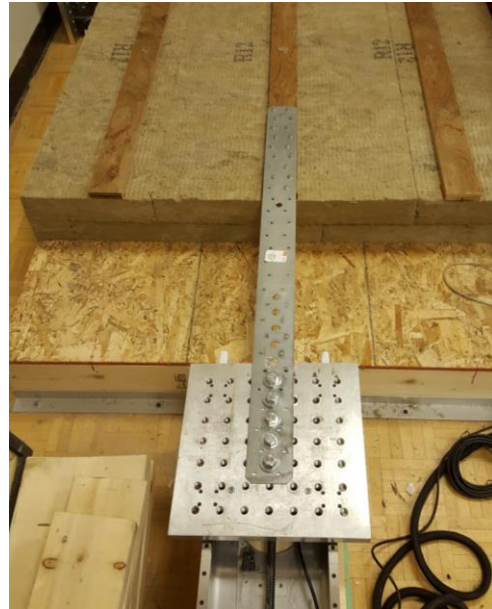


*Please note that as of 2018, ROXUL® and its product lines have been rebranded to ROCKWOOL™ with its respective product names. For more information regarding a specific product found in the report please visit [www.rockwool.com](http://www.rockwool.com) or email [contactus@rockwool.com](mailto:contactus@rockwool.com).*



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# Appendices

## Appendix A Additional Plots

# 1 Introduction

## 1.1 Background

As the construction industry moves toward more energy-efficient buildings, installing exterior insulation is an effective solution to increasing thermal performance of wall assemblies. Previous research and in-situ performance has shown that using long screws to attach cladding directly through an exterior insulation layer without the use of clips or girts is a thermally and structurally efficient solution for lightweight cladding (~2.5psf or ~12.2kg/m<sup>2</sup>, e.g., vinyl, metal, wood siding) with relatively small thicknesses of exterior insulation (~1-1/2" or ~38mm). However, there is still significant skepticism regarding supporting cladding with screws only when using thicker exterior insulation or supporting heavy claddings. These concerns—though largely unsupported by existing research—are creating a barrier to the widespread adoption of this cladding attachment method, in particular with exterior mineral wool insulation, which is perceived as insufficiently rigid in comparison to competing foam plastic insulations such as extruded polystyrene insulation (XPS).

## 1.2 Objective and Scope

To address this gap in industry knowledge and familiarity, various studies have been conducted in this area, including recent work performed by the University of Waterloo and others as part of the Building America program and by the New York State Energy Research and Development Authority. The previous work in this area has focused on evaluation of screw bending and the evaluation of potential truss action created by the screw and compression of the insulation; however, the objective of this study is to build on this existing research with specific focus on the performance of these systems to evaluate the impact of:

- Different densities of insulation
- Very thick insulation
- Screw arrangements
- Screw head types

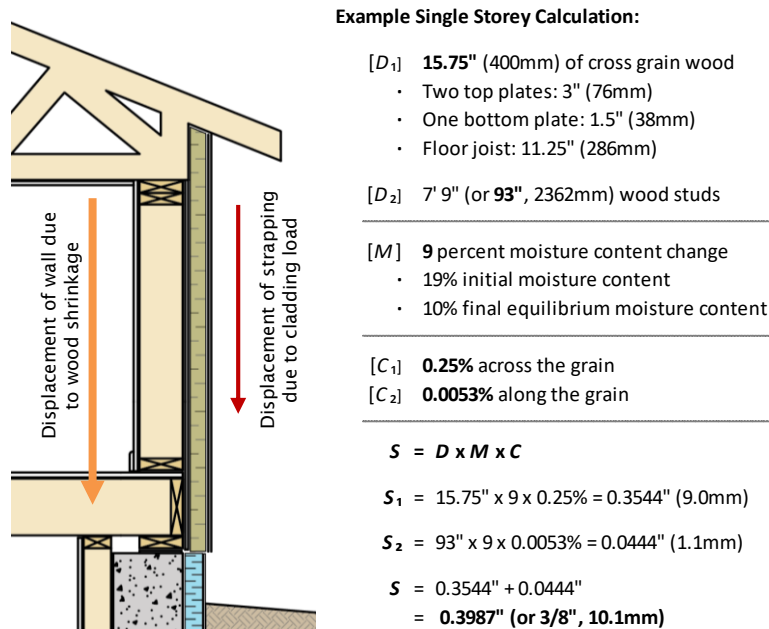
Deflection of strapping that supports the cladding system is a top design consideration; however, little research has been done to define what is allowable deflection for each of the cladding types. It should be noted that a wall assembly in a wood-frame construction is also subject to other types of displacements such as shrinkage of wood material (e.g., top and bottom plate). Figure 1.1 illustrates possible displacement that might occur in a wall assembly due to wood shrinkage as a reference and a baseline for comparing magnitude of displacement. Note that shrinkage of sawn dimensional lumber was calculated using the following equation:

$$S = D \times M \times C$$

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$M$  = percentage of moisture content change (%) i.e., the difference between the initial moisture content and the service equilibrium moisture content.

$C$  = shrinkage coefficient of wood members (percentage per 1% change in moisture content). For most S-DRY softwood lumber, average shrinkage is 0.25% across the grain and 0.0053% along the grain for each 1% change in moisture content



*Figure 1.1 A simple diagram and calculation illustrating possible displacement of wall due to wood shrinkage as a reference and a baseline for comparing magnitude of displacement*

This calculation of potential moisture shrinkage in one storey of typical wood-frame construction indicates that approximately 3/8" (10 mm) shrinkage could potentially be anticipated.

Previous testing performed by others suggests that the majority of deflection with systems using only long screws to attach cladding directly through an exterior insulation layer occurs during the initial loading. Additionally, this cladding support system has not previously been tested to mechanical failure. This is understandable since significant deflection would likely be considered failure of the system, which would likely occur before the point of ultimate failure. Therefore, this study presented in this report also investigated:

- If a method of preloading (seating) the strapping would minimize initial deflection for this type of system.
- The mechanical failure mechanism of this type system by performing test to its load limit. This might be helpful to cladding engineers since understanding the system limits allows for design alternations to address the particular failure mechanism and improve the strength of the system.

Table 1.1 provides summary of 16 test wall arrangements tested as part of this evaluation. Note that the angle in degrees provided after the type of screw head denotes the screw installation angle to the strapping.

TABLE 1.1 TEST WALL ARRANGEMENTS		
Test Wall ID	Insulation Type and Screw Arrangement	Insulation Thickness
		<b>6" (152mm)</b>
1	Roxul ComfortBoard 80 <sup>1</sup> – Countersunk @90°	Two 3-inch layers
2	Roxul ComfortBoard 110 <sup>2</sup> – Countersunk @90°	Two 3-inch layers
3	Roxul ComfortBoard 110 over ComfortBoard 80 – Countersunk @90°	One 3-inch layer of 110 over one 3-inch layers of 80
4	Roxul ComfortBoard 80 – Countersunk @45°	Two 3-inch layers
5	Roxul ComfortBoard 80 – Pan Head @90°	Two 3-inch layers
6	Roxul ComfortBoard 80 – Countersunk @90° <i>Preloaded Strapping</i> <sup>3</sup>	Two 3-inch layers
7	Roxul ComfortBoard 80 – Countersunk @90° <i>One screw, Test to Mechanical Failure</i>	Two 3-inch layers
8	Owens Corning FOAMULAR C-200 XPS – Countersunk @90°	Three 2-inch layers <sup>4</sup>
9	Roxul ComfortBoard 80 – Countersunk @80.5° (1 in 6 slope)	Two 3-inch layers
10	Roxul ComfortBoard 80 – Countersunk (Truss System)	Two 3-inch layers
		<b>9" (229mm)</b>
11	Roxul ComfortBoard 80 – Countersunk @90°	Three 3-inch layers
12	Roxul ComfortBoard 110 – Countersunk @90°	Three 3-inch layers
13	Roxul ComfortBoard 110 over ComfortBoard 80 – Countersunk @90°	One 3-inch layer of 110 over two 3-inch layers of 80
		<b>12" (305mm)</b>
14	Roxul ComfortBoard 80 – Countersunk @90°	Four 3-inch layers
15	Roxul ComfortBoard 110 – Countersunk @90°	Four 3-inch layers
		<b>3" (76mm)</b>
16	Roxul ComfortBoard 80 – Countersunk <sup>5</sup> @90°	One 3-inch layer

<sup>1</sup> ComfortBoard 80 formerly ComfortBoard IS (Insulated Sheathing)

<sup>2</sup> ComfortBoard 110 formerly ComfortBoard CIS (Commercial Insulated Sheathing)

<sup>3</sup> Strapping in this context is a building material used to secure insulation in position, sometimes referred to as "furring."

<sup>4</sup> Due to unavailability of 3" XPS, 3 layers of 2" XPS was used instead to make up a total insulation thickness of 6"

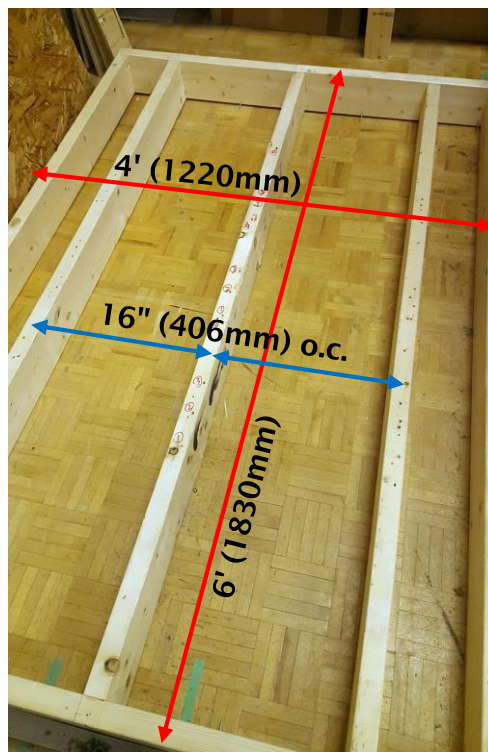
<sup>5</sup> Test wall with 3" (76mm) of insulation was performed with screws different from all other test wall arrangements

## 2 Methodology

This section provides an overview of test wall construction, screw selection, testing apparatus, and testing procedure as well as discussion on testing variables and limitations.

### 2.1 Test Wall

To test the performance of wall assemblies, a 4' x 6' (1220mm x 1830mm) backup wall was constructed with 2x6 SPF framing at 16" (406mm) on centre (o.c.) complete with top and bottom plates. The centre stud was installed in the centre of the backup wall as shown in Figure 2.1. Then the backup wall framing was securely fixed to a concrete slab with L-angles attached to the top and the bottom plate.



*Figure 2.1 4' x 6' backup wall framed at 16" (406mm) o.c. stud spacing and secured to concrete floor with L-angles*

The backup wall framing was then sheathed with 7/16" oriented strand board (OSB) and Tyvek HomeWrap membrane was stapled on to the OSB as in a typical wood frame construction (Figure 2.2). Although the backup wall was 6' (1830mm) tall, the insulation arrangements tested were 4' (1220mm) in height (Figure 2.3). This was done so that by staggering the insulation arrangements along the height, by at least 1-1/2" (38mm), the backup wall could be re-used with screws for the next test arrangement, penetrating the unused portion of the framing and the sheathing as shown in Figure 2.4 and Figure 2.5.





Figure 2.2 Backup wall framing sheathed with OSB and Tyvek HomeWrap stapled to OSB

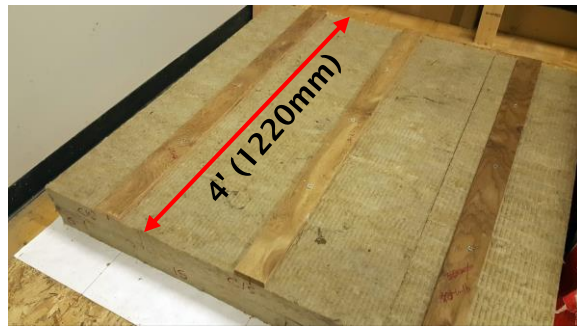


Figure 2.3 6" (2 layers) of mineral wool insulation with 3/4"x3" plywood strapping at 16" (406mm) o.c. spacing

Note that each strapping was secured with three screws at 12" (300mm) spacing

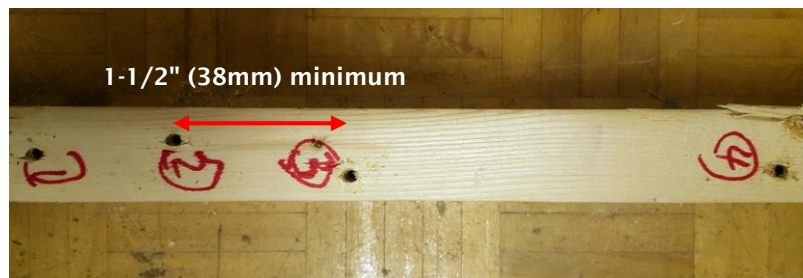


Figure 2.4 A photo of a centre stud after four sets of tests. Test arrangements were staggered along the height of the wall by at least 1-1/2" (38mm) so that the backup wall framing could be re-used without screws penetrating the same location.

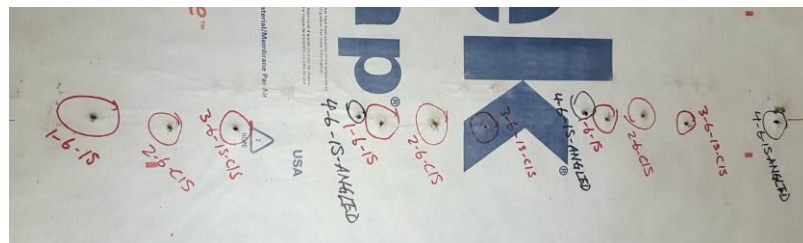
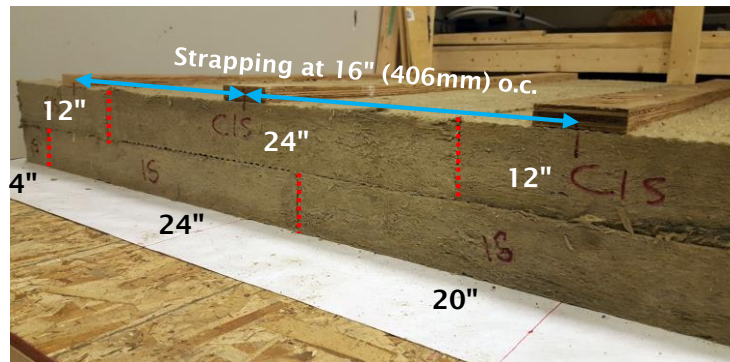


Figure 2.5 An overview along the centre line of a 6-foot-long backup wall after four sets of tests.

Note that each test was staggered at least 1-1/2" (38mm).

Insulation—typically 2' x 4' (610mm x 1220mm)—was placed in staggered layers as shown in Figure 2.6 and secured with 3/4"x3" plywood strapping and 3 screws per strapping. Strapping was installed at 16" (406mm) o.c. to match the stud spacing so that the screws can penetrate into the backup wall framing. In general, 3" (76mm) or less insulation thickness makes it fairly easy to hit the studs but it gets more difficult as the insulation thickness increases up to the 6" to 12" (152mm to 305mm) range. In a laboratory condition with the test wall situated in a horizontal position, it was possible to ensure that the screws penetrated the backup wall framing; however, ensuring screw penetration into backup wall framing members is more difficult in real-world applications, and there is a potential for missing the framing members. For this reason, the structural capacity of the fasteners when only installed into sheathing is of interest, and was

included in this testing. Note that the portion of the test wall that was loaded (centre strapping, centre screws, and centre layers of insulation) was replaced after each set of tests (each test involved two loadings).



*Figure 2.6 An example of staggered insulation installation*

*From left, top layer: 12" (305mm), 24" (610mm), and 12" (305mm) width of ComfortBoard 110 insulation*

*From left, bottom layer: 4" (102mm), 24" (610mm), and 20" (508mm) width of ComfortBoard 80 insulation*

*Note that insulation joints are indicated with red dashed lines*

## 2.2 Screw Selection

The screws used in this testing were selected based on which manufacturer offered a length between 9" and 15.0" (229mm and 380mm) in the same thread and shank diameter and mechanical properties (e.g., bending resistance, tensile strength). Having the same mechanical and physical properties (with exception of length) was the determining factor because having the screws as one of the constants in the test wall assemblies was vital to isolate and evaluate the other factors affecting the stiffness of the wall assemblies. Three different lengths of HECO-TOPIX screws by HECO-Schrauben GmbH & Co. KG, shown in Figure 2.7, were selected for this testing.



*Figure 2.7 HECO-TOPIX 8.0x screws used in this testing*

Physical and mechanical properties of the HECO-TOPIX screws, obtained from the manufacturer's technical datasheet, are summarized in Table 2.1.



TABLE 2.1 PHYSICAL AND MECHANICAL PROPERTIES OF HECO-TOPIX 8.0x SCREW	
Nominal Length, in. (mm)	9.4, 11.8, and 15.0 (240, 300, and 380)
Head Diameter, in. (mm)	~0.58 (~14.8)
Thread Diameter, in. (mm)	~0.31 (~8.0)
Shank Diameter, in. (mm)	0.20~0.21 (5.05~5.45)
Yield Moment, ft-lb (Nm)	14.8 (20.0)
Tensile Strength, lb (kN)	4496 (20)
Withdrawal Capacity <sup>6</sup> , psi (N/mm <sup>2</sup> )	1711.4 (11.8)
Head Pull-Through Capacity <sup>7</sup> , psi (N/mm <sup>2</sup> )	1363.4 (9.4)

The structural capacity of the screw is impacted by its penetration depth (embedment), and BC Building Code (2012) for Part 9 buildings requires that the fasteners for cladding other than shakes and shingles penetrate at least 1" (25mm) into the framing (or penetrate through the fastener-holding base). In this test, given the screw lengths available, the screws were selected so that the penetration depth, excluding the tapered tip, is more than 1" (25mm). The estimated screw penetration into framing for test arrangements is summarized in Table 2.2.

TABLE 2.2 ESTIMATED SCREW PENETRATION INTO FRAMING	
Insulation Thickness and Screw Arrangement	Estimated Penetration Depth <sup>8</sup> inch (mm)
6" (152mm) insulation 9.4" (240mm) screws installed 90° to the strapping (for both countersunk and pan head screw)	1.8 (46)
6" (152mm) insulation 11.8" (300mm) screws installed 45° to the strapping	1.1 (30)
6" (152mm) insulation 9.4" (240mm) screws installed at 1 in 6 slope (upward angle of 9.5° or 80.5° to the strapping)	1.7 (43)
9" (229mm) insulation 11.8" (300mm) screws installed 90° to the strapping	1.1 (29)
12" (305mm) insulation 15.0" (380mm) screws installed 90° to the strapping	1.3 (33)

The screws were installed at 12" (300mm) spacing with an effective supporting area of 1.33ft<sup>2</sup> (0.124m<sup>2</sup>) per screw. The screws were installed so that the head of the screw was fully countersunk into the strapping (flush), except for the pan head screws, which were installed so that the screw head flange (underside) was flush to the strapping. A torque wrench was used to measure how tightly screws were installed. Generally, torque of about 45in-lb (~5Nm) was applied to install the screws with very little pre-compression of the insulation layers. Also note that new screws were used on the centre strapping for each set (first and second loading) of the test.

<sup>6</sup> Based on wood density of 22lb/ft<sup>3</sup> (350kg/m<sup>3</sup>). As a reference, Canadian Standards Association (CSA) 086 standard defines density of Spruce-Pine-Fir (SPF) group to be 26lb/ft<sup>3</sup> (420kg/m<sup>3</sup>).

<sup>7</sup> For wood panel products with minimum thickness of ~3/4" (20mm).

<sup>8</sup> Penetration depth into framing does not include tapered tip which is ~7/16" (~11mm).

## 2.3 Testing Apparatus

The cladding gravity load was imitated by mechanically applying a load on the centre strapping of a test wall assembly using a custom-built testing apparatus capable of logging displacement and load at 0.5-second intervals. This testing apparatus is equipped with a servomotor, a worm drive with 30:1 ratio, and a S-type load cell<sup>9</sup> rated to 1000lb (~454kg). The servomotor allowed for precise control of linear position and speed of the mechanical stage with a motor linked to sensors for position and load feedback. The mechanical stage is connected to a 12-turn-per-inch (TPI) threaded rod (via S-type load cell), which is turned by 30-tooth worm wheel connected to a worm that is driven by a motor with 2000 steps per turn. The following equation provides the resolution of this setup.

$$\text{Resolution} = \frac{2000 \text{ steps}}{1 \text{ turn (worm)}} \times \frac{30 \text{ turn (worm)}}{1 \text{ turn (worm wheel)}} \times \frac{12 \text{ turn (worm wheel)}}{1 \text{ inch}} = 720,000 \text{ steps/inch}$$

This setup provided 720,000 steps-per-inch, or about 28,346.5 steps per millimeter, and the displacement was logged in millimeters to 2 decimal places. An overview of the testing apparatus is provided in Figure 2.8.

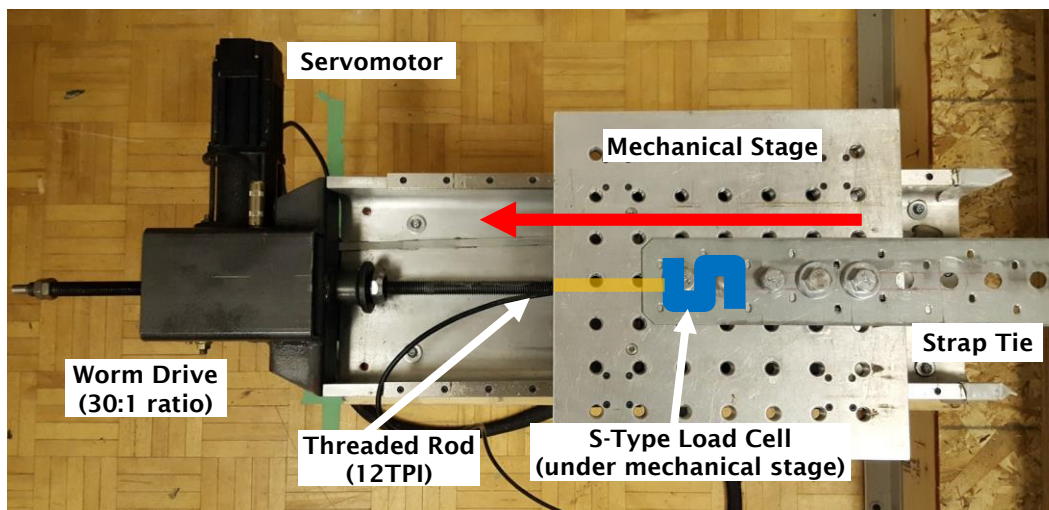


Figure 2.8 Overview of testing apparatus with key components labelled

Note that the direction the test wall strapping was loaded is indicated by the red arrow and the orange line indicates the threaded rod connected to the load cell under the mechanical stage.

The interface that controlled the servomotor with feedback from the sensors (position and load) was written in a load-based programming. This means that the load instead of position (displacement) determined movement of the mechanical stage, allowing the tests to be performed in such a way that the apparatus would displace until a specified load is reached and hold that load for a specified duration. If the strapping were to deflect (or sag), the programming would cause the mechanical stage to move/compensate to ensure that the specified load is applied consistently as gravity would.

<sup>9</sup> The load cell was configured to read at 10Hz (i.e., a reading every 100 millisecond) but the load was logged at 0.5s interval and the accuracy of the reading depended on the accuracy of the load cell and the 24-Bit analog-to-digital converter (ADC) for weigh scales.

In order to apply load to the centre strapping, the load was transferred from the testing apparatus (mechanical stage) to the plywood strapping using a Simpson Strong-Tie's steel strap tie. The height of the mechanical stage was adjusted to match the height of the plywood strapping in order to load it as axially as possible. However, as the strapping was loaded, insulation experienced some compression due to bending of the screws and, consequently, load was being applied at a slight angle. This is discussed in more detail in Section 2.5: Testing Variables and Limitations.

## 2.4 Test Procedure

Each test setup was loaded twice in the order as follows:

- Loaded to 101lb (46kg) and the load was held for 2 hours then released
- Loaded to 899lb (408kg) and the load was held for 120 seconds then released

With 16" (406mm) o.c. framing and 12" (300mm) screw spacing (which gives a total supporting area of 4ft<sup>2</sup> (0.372m<sup>2</sup>) between three screws) the first loading was meant to be representative of very heavy cladding (25psf or 122.1kg/m<sup>2</sup>). For a reference, the weight range of typical cladding types is summarized in Table 2.3 and are indicated in load-displacement plots provided in this report.

TABLE 2.3 TYPICAL CLADDING WEIGHT		
Cladding Type	Typical Area Density Range psf (kg/m <sup>2</sup> )	Equivalent Load per Strapping 4ft <sup>2</sup> (0.372m <sup>2</sup> ) lb (kg)
Vinyl, Metal, and Wood Siding	0.3 – 2.5 (1.5 – 12.2)	1.2 – 10.0 (0.5 – 4.5)
Stucco	10 – 11 (48.8 – 53.7)	40.0 – 44.0 (18.1 – 20.0)
Thin Stone Veneer	13 – 15 (63.5 – 73.2)	52.0 – 60.0 (23.6 – 27.2)
Thick Stone Veneer and Very Heavy Cladding	15 – 18+ (73.2 – 87.9+)	60 – 72+ (27.2 – 32.7+)

The second loading, at 899lb (408kg) distributed between three screws, exceeded the weight of the heaviest cladding system typically used. The intent was to evaluate limits of these systems in order to evaluate impacts of different insulation and screw arrangement, which might not be evident at a lower load.

In both tests, the strapping was displaced at 0.118"/min or 3mm/min (0.002"/s or 0.05mm/s) until the specified load was reached—at which point the testing apparatus maintained the load by either holding the position or pulling/pushing the strapping for 2 hours for the first loading and 120 seconds for the second loading. The apparatus then released the load at the same displacement rate until load returned to zero. Note that in most cases the strapping did not return to the original location, and the second loading was initiated after the completion of the first without re-setting the strapping to the original location.

## 2.5 Testing Variables and Limitations

Note that this study evaluated only the cladding load on the wall system and that, typically, wall systems are subject to other loading (e.g., wind) that needs to be taken into design consideration.

Insulation and screw arrangements were tested with a wood frame backup wall, and because wood is a natural material, some inconsistency is to be expected (e.g., knots). However, this study being a laboratory test, the best effort was made to provide consistency with the components that were not being evaluated.

Since the screws used had a specific length, the screw penetration depth varied between different insulation thickness and screw installation angles. However, a report by BSC dated August 16, 2011, *ComfortBoard Insulating Sheathing (IS)<sup>10</sup> Deflection Testing*, concluded through their testing that the embedment made no significant differences at loads less than approximately 20psf (97.6kg/m<sup>2</sup>) cladding weight.

Additionally, considering the mechanical properties of the screws used, it was more likely for the screws to bend than to withdraw from the framing, to stretch due to tensile force, or for the screw head to pull through the plywood strapping when load was applied. Because the testing apparatus and mechanical stage were fixed flush with the strapping, as the screws were loaded, the strapping compressed the insulation as the screws started to bend and, consequently, this allowed a slightly out of plane load to be applied to the strapping. Table 2.4 provides the estimated compression of the insulation at 101lb (46kg) and 899lb (408kg) and the angle at which the load was estimated to be applied. Note that the numbers provided are for ComfortBoard 80 and that no withdrawal of screws from the framing, lengthening of screws due to tensile force, or screw head pull-through from the plywood strapping were assumed.

TABLE 2.4 ESTIMATED DECREASE IN INSULATION THICKNESS AND LOADING ANGLE				
Applied Load on Strapping	Nominal Insulation Thickness	Decrease in Insulation Thickness		Loading Angle <sup>11</sup> (degrees)
		1/1000" (mm)	%	
101lb (46kg)	6" (152mm)	0.27 (0.007)	<0.1	<0.1
	9" (229mm)	0.17 (0.004)	<0.1	<0.1
	12" (305mm)	0.16 (0.004)	<0.1	<0.1
899lb (408kg)	6" (152mm)	315.00 (8.000)	5.2	0.8~1.5
	9" (229mm)	369.00 (9.400)	4.1	0.9~1.8
	12" (305mm)	362.00 (9.200)	3.0	0.9~1.7

<sup>10</sup> Currently known as ComfortBoard 80

<sup>11</sup> Assuming the distance between the mechanical stage and strapping to be 1'~2' (305mm~610mm)

# 3 Results and Discussion

As mentioned in the objectives, this work builds on existing research with specific focus on the performance of wall systems using thick mineral wool insulation. The test wall assemblies and screw arrangements were chosen so that by cross-comparison, we could evaluate the impact of insulation thickness, type (compressive strength), and screw types and arrangement on stiffness (load-displacement relationship) of wall assemblies. Additionally, the impact of preloaded (seated) strapping was evaluated and two wall assemblies were tested to mechanical failure.

The data obtained from the testing apparatus was the load applied on one strapping fastened with 3 screws (6 screws for Truss System); however, the load-displacement plots presented in this section are representative of load per screw, with the exception of the Truss System, in which case the plot is representative of one truss (two screws).

Additionally, the load-displacement plots in this section are compared to the weight of typical cladding types illustrated by bands of shaded area. The weight range of thick stone veneer and very heavy cladding, thin stone veneer, stucco, and various light weight sidings (vinyl, metal, wood) are represented in red, orange, yellow, and green respectively. The cladding weights are provided as pounds per square-foot (psf) and this is representative of a screw with a supporting area of 1 ft<sup>2</sup>.

## 3.1 Evaluation of Insulation Types

This section contains the results and discussion of the impact of insulation types. One of the concerns regarding installation of thick mineral wool insulation without the used of clips or girts is that this type of insulation (semi-rigid) may not be sufficiently rigid, whereas the foam insulation typically used in this application is more rigid. Two mineral wool insulations and one XPS insulation were compared. Table 3.1 summarizes compressive strength of insulations tested, obtained from manufacturer's product data sheet.

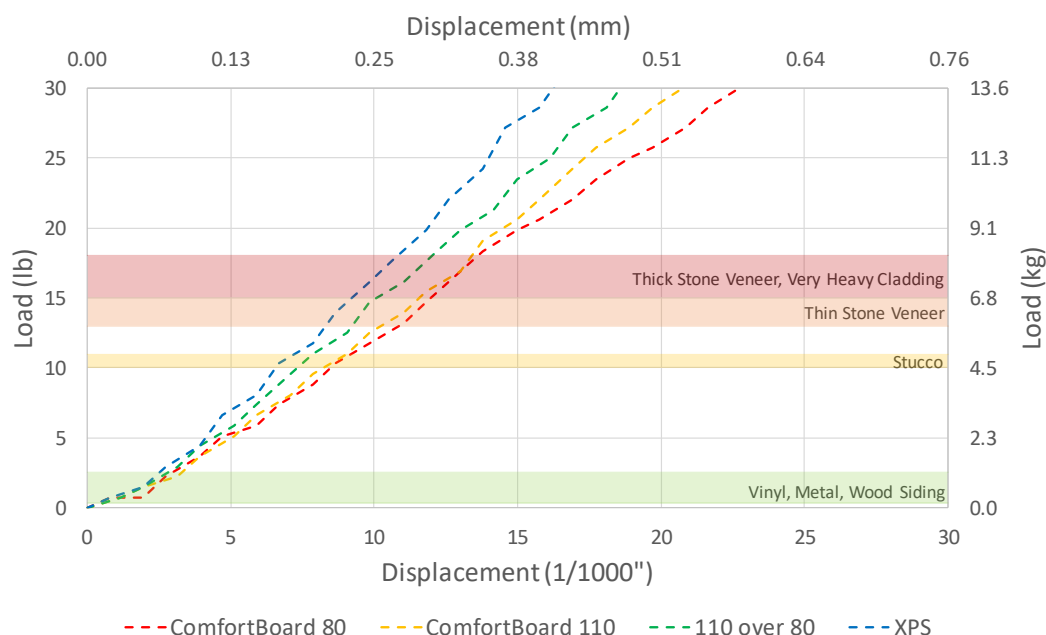
TABLE 3.1 COMPRESSIVE STRENGTH OF INSULATION		
Insulation Type	ASTM C-165, psf (kPa)	
	at 10%	at 25%
Roxul® ComfortBoard™ 80	439 (21)	1065 (50)
Roxul® ComfortBoard™ 110	584 (28)	1566 (75)
	ASTM D-1621, psf (kPa)	
Owens Corning FOAMULAR C-200 XPS	2880 (140)	

Figure 3.1 plots the load-displacement relationship for test wall assemblies with 6" (152mm) of insulation and compares the different insulation arrangements tested. The plots provided are from the second loading for each assembly and the bands of shaded area correspond to the weight of typical cladding types per square foot.

As illustrated, the graph is relatively linear—though there is a slight difference in the slopes, which corresponds to stiffness of the wall assemblies. However, these differences are very small. When a screw is loaded at 25lb (9.1kg), the difference in displacement



between XPS assembly (0.014" or 0.35mm) and ComfortBoard 80 (0.019" or 0.48mm) was only 0.005" (0.13mm).



*Figure 3.1 Load-displacement plot comparing different insulation arrangements at 6" (152mm) thickness with countersunk head screws installed at 90° to the strapping*  
*The plot provided is for second loading of each setup. The plot for first loading is provided in Appendix.*

Figure 3.2 provides load-displacement data for a much higher test load range. Note that the plot range shown in Figure 3.1 is highlighted in red. As illustrated in the Figure 3.2, between 40lb (18kg) and 90lb (41kg) on a screw, the load-displacement plots start to present a varying degree of curvature and the difference in the stiffness between the insulation types becomes more evident, though this amount of load on a screw is unlikely in an actual construction. It is interesting to note that the ComfortBoard 80 and ComfortBoard 110 hybrid wall assembly produced a similar result up to 100lb range and slightly stiffer at load above 100lb (45kg) compared to the wall assembly with only ComfortBoard 110.

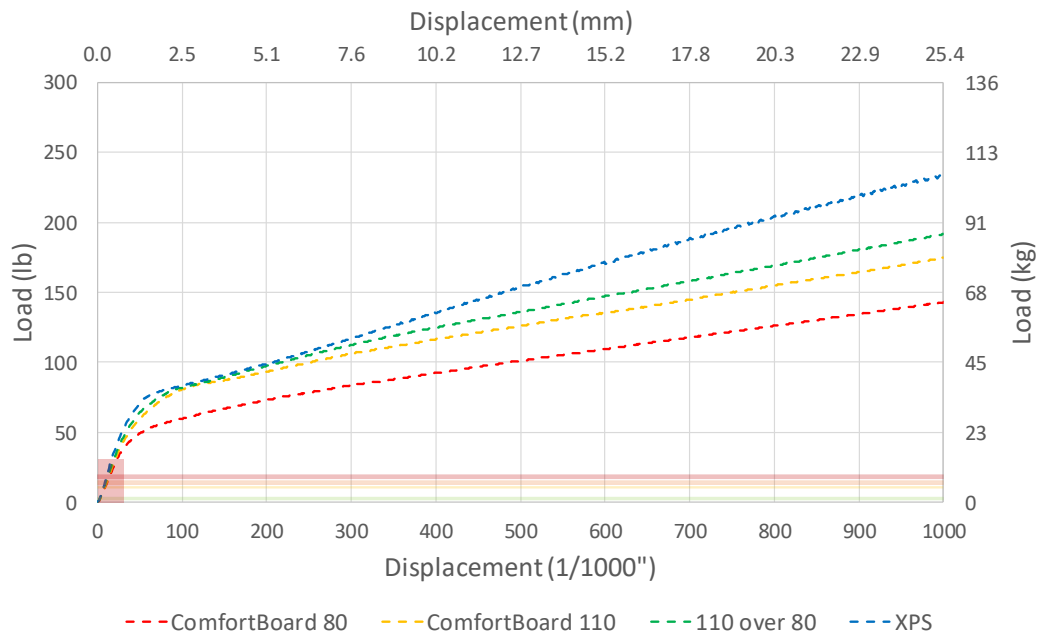


Figure 3.2 Load-displacement plot comparing different insulation arrangements at 6" (152mm) thickness with countersunk head screws installed at 90° to the strapping

The plot provided is for the second loading of each setup. Note that the plot range shown in Figure 3.1 is highlighted in red box.

### 3.2 Evaluation of Insulation Thickness

This section contains the results and discussion of the impact of insulation thickness on the stiffness of the wall assemblies. Both Roxul ComfortBoard 80 and ComfortBoard 110 were tested at three different total thicknesses:

- 6" (2 layers, 152mm) with 1.8" (46mm) estimated screw penetration into framing
- 9" (3 layers, 229mm) with 1.1" (29mm) estimated screw penetration into framing
- 12" (4 layers, 305mm) with 1.3" (33mm) estimated screw penetration into framing

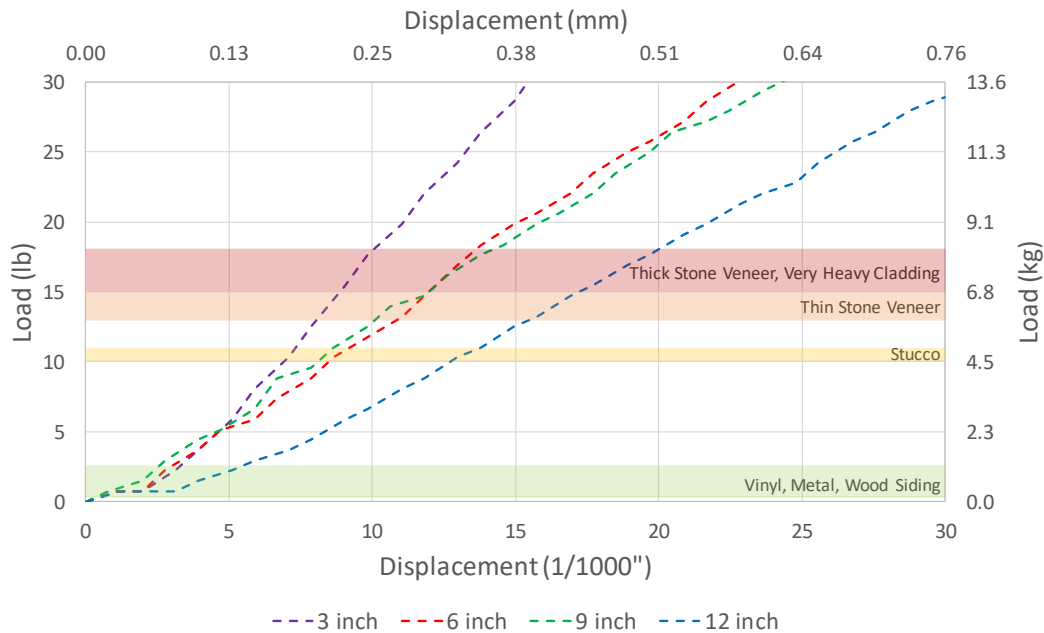
Additionally, ComfortBoard 80 was also tested at 3" (76mm) insulation thickness with GRK R4 #12/14 x 5-5/8" screw<sup>12</sup> with 0.9" (23mm) estimated screw penetration into framing. Note that all screws were installed at 90° to the strapping.

As mentioned, previous testing in this area with relatively thin amounts of insulation (~1-1/2" or ~38mm) has shown that screws through strapping are sufficient to support lightweight cladding (~2.5psf or ~12.2kg/m<sup>2</sup>, e.g., vinyl, metal, wood siding). Comparison of the load-displacement relationships of the systems was made with specific focus on the performance of these systems when using thick insulation.

Figure 3.3 plots the load-displacement relationship for the test walls with 3", 6", 9", and 12" (76mm, 152mm, 229mm, and 305mm) Roxul ComfortBoard 80 insulation. The plot comparing different thicknesses of ComfortBoard 110 was similar to ComfortBoard 80 and is provided in the Appendix. Note that the plots provided are from the second loading for each assembly and the bands of shaded area correspond to the weights of typical cladding types per square foot.

<sup>12</sup> Overall length: 5-1/2" (139.7mm), Thread Diameter: 0.238" (6.0mm), Shank (Root) Diameter: 0.172" (4.4mm)

As illustrated, while 6" and 9" (152mm and 229mm) thickness of insulation had a very similar stiffness, the test wall with 12" (305mm) of insulation experienced slightly more deflection; however, these differences are very small. When the screw is loaded at 25lb (9.1kg), the difference in displacement between the test wall with 6" (152mm) of insulation (0.019" or 0.48mm) and 12" (305mm) of insulation (0.026" or 0.66mm) was only 0.007" (0.18mm). As suspected, assemblies with 3" (76mm) of insulation experienced the least deflection of 0.014" or 0.35mm when the screw is loaded at 25lb (9.1kg).



*Figure 3.3 Load-displacement plot comparing Roxul ComfortBoard 80 insulation at 3", 6", 9" and 12" (76mm, 152mm, 229mm, and 305mm) thickness with countersunk head screws installed at 90° to the strapping*

*The plot provided is for the second loading of each setup. The plot for first loading is provided in Appendix.*

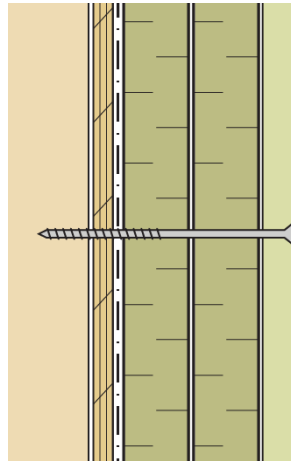
### 3.3 Evaluation of Screw Arrangements and Head Types

This section contains the results and discussion of the impact of screw arrangements and head types. Countersunk head screws are the preferred choice from constructability considerations because the screw head can be embedded into the strapping and not interfere with cladding materials, unlike pan head screws (Figure 3.4).

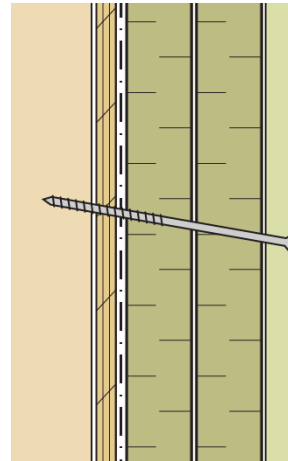


*Figure 3.4 Photo comparing countersunk and pan head screws*

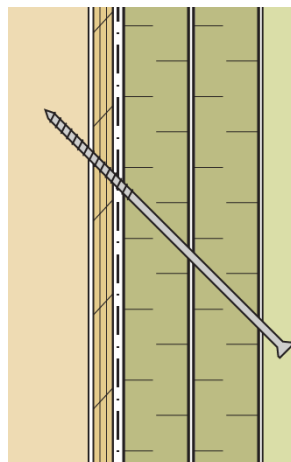
In this section both the testing data from countersunk and pan head screws were evaluated. Additionally, the technique to install screws at an upward angle to take advantage of the truss action was evaluated at two angles, 45° and 1 in 6 slope (upward angle of 9.5° or 80.5° to the strapping). A full Truss System was evaluated as well, as illustrated in Figure 3.5.



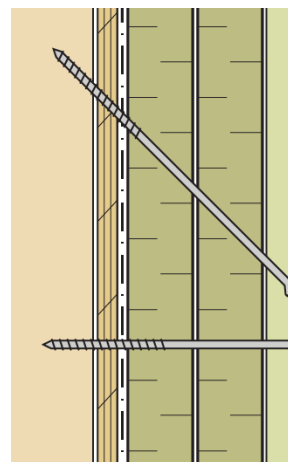
Screw at 90° to the strapping



Screw at 1 in 6 slope (80.5° to the strapping)



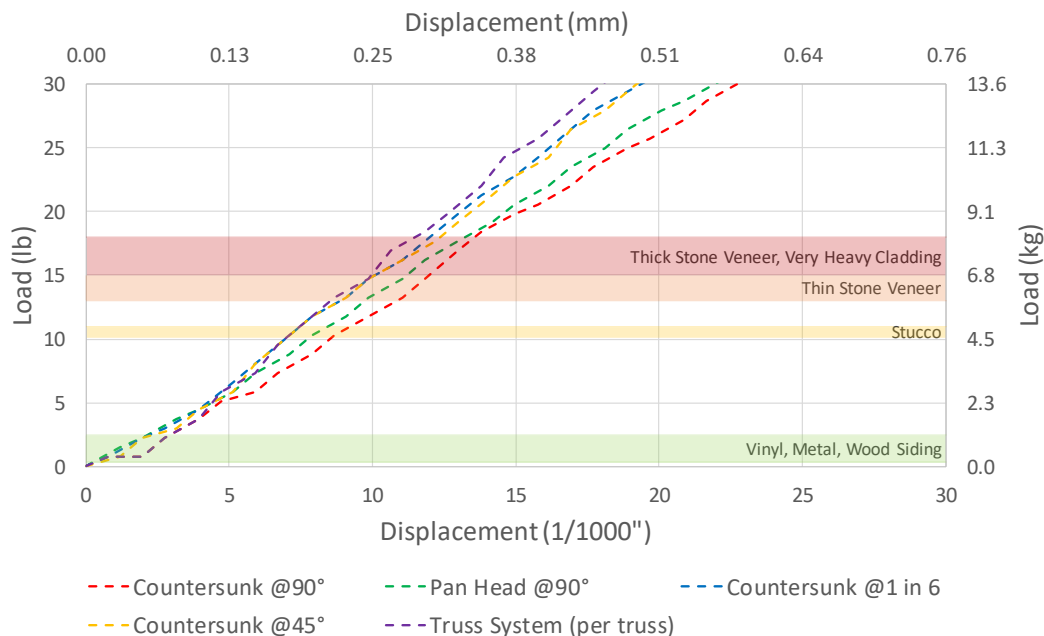
Screw at 45° to the strapping



Truss System (90° + 45°)

*Figure 3.5 Illustration of screw arrangements tested*

All test walls were constructed similarly with 6" (two 3" layers) of Roxul ComfortBoard 80 insulation. Figure 3.6 compares the load-displacement relationship of the test wall assemblies discussed above. As shown in the figure, load-displacement curves are relatively linear for the first 30lb (13.6kg)—though there is a slight difference in the slopes, which corresponds to the stiffness of the wall assemblies. However, these differences are very small. When the screw is loaded at 25lb (9.1kg), the difference in displacement between the stiffest Truss System (0.015" or 0.38mm) and the least stiff assembly with countersunk head screw at 90° (0.019" or 0.48mm) is only 0.004" (0.10mm). The plots provided are from the second loading for each assembly and the bands of shaded area correspond to the weight of typical cladding types per square foot.



*Figure 3.6 Load-displacement plot comparing screw types and arrangements with 6" (152mm) ComfortBoard 80 insulation*

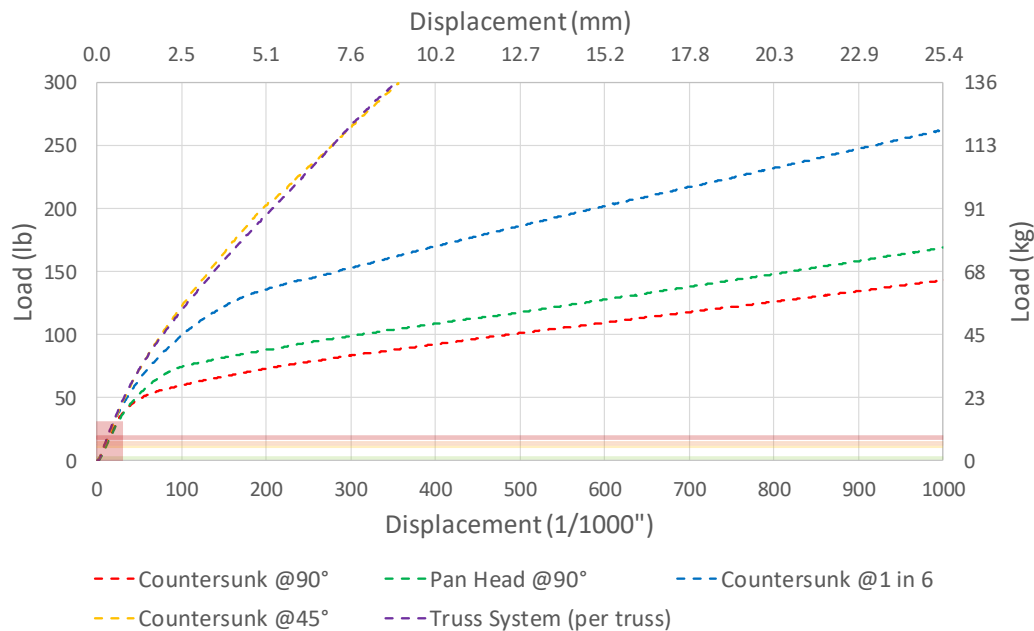
*The plot provided is for the second loading of each setup. The plot for first loading is provided in Appendix.*

Figure 3.7 provides load-displacement data for a much higher test load range. Note that the plot range shown in Figure 3.6 is highlighted in red. As illustrated in the Figure 3.7, between 50lb (23kg) and 100lb (45kg) load per screw (and per truss) the load-displacement plots start to present a varying degree of curvature, and the difference in the stiffness of the screw arrangements becomes more evident—though this amount of load on a screw is unlikely in actual construction.

Steel works best in tension, and—theoretically—by installing screws in an upward angle, the system engages screws to support the gravity load of the cladding in tension more readily and compresses the insulation to take advantage of truss action, whereas screws installed at 90° to the strapping depend more on screw's bending resistance and friction of the layers between the strapping and the sheathing to resist the gravity load. This can be seen at the higher loads where screws are installed at angles, greatly reducing the displacement of the system. The single screw installed at 45° and the Truss System (2 screws) produced very similar results, which indicates that the screw installed at 90° to strapping in the Truss System does very little to support the gravity load. That being said,



the main consideration in this study was performance of cladding support system (e.g., strapping, screw) to resist cladding weight and screws installed at 90° to the strapping in the Truss System might provide support for other loads a wall is subject to such as wind.



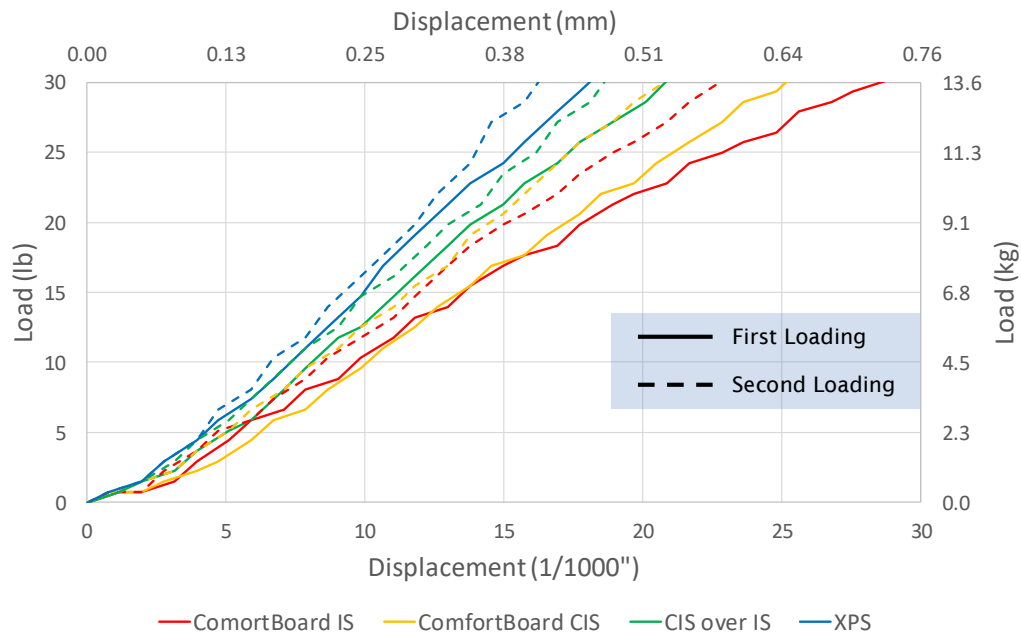
*Figure 3.7 Load-displacement plot comparing different screw types and arrangements with 6" (152mm) ComfortBoard 80 insulation*

*The plot provided is for the second loading of each of the setup. Note that the plot range shown in Figure 3.6 is highlighted in red box.*

### 3.4 Preloading and Mechanical Failure Mechanism

This section contains the results and discussion relating to tests performed on preloaded strapping and tests performed to mechanical failure of these wall systems. Previous testing performed by others suggests that the majority of deflection with this type of system occurs during the initial loading. The purpose of this testing was to investigate if preloaded (seated) strapping would provide a system that experiences less initial deflection. Additionally, two wall assemblies were tested to mechanical failure. This information will be helpful to cladding engineers because understanding the system limits allows for design alternations to address particular failure mechanism and to improve the strength of the system.

As mentioned in Test Procedure, each set of tests involved first (101lb or 46kg for 2 hours) and second (899lb or 408kg for 120 seconds) loading. The load-displacement relationships for all 6" (152mm) insulation arrangements with screws installed at 90° to the strapping are compared in Figure 3.8. The first loading data is provided with a solid line and the second loading with a dashed line. The test data for the second loading consistently displayed less displacement than the first, and it is clear that the test wall assemblies became slightly more resistant to deflection (stiffer) after the first loading. This confirms previous findings that less deflection is experienced after the initial loading and that it is likely due to the seating of the strapping. That said, the amount of deflection observed in the first loading is still relatively small with the maximum shown in Figure 3.8 being 0.029" (0.73mm) at 30lb (13.6kg) on a screw.



*Figure 3.8 Load-displacement plot comparing first and second loading by insulation arrangements*

*All insulation arrangements are 6" (152mm) thickness with countersunk head screws installed at 90° to the strapping. The first loading plot is provided with solid line and the second loading with dashed line*

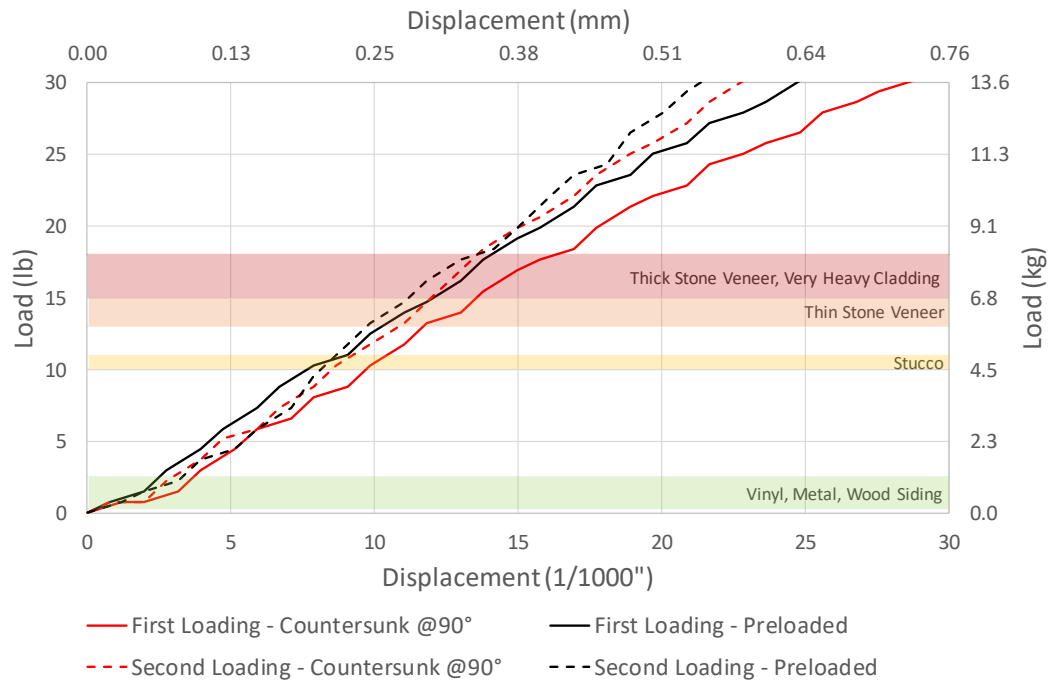
To avoid having this larger initial deflection affect the cladding system, the effectiveness of preloading each strapping to intentionally cause this initial deflection (i.e., seat the strapping on the insulation) prior to performing the test was investigated. To do this, the strapping was preloaded from the top by a hammer until strapping started to compress the insulation slightly. This typically resulted approximately  $\sim 3/4"$  (19mm) of deflection of the strapping.



*Figure 3.9 Preloaded strapping*

*Top of the strapping was struck with a 20oz hammer in the direction of gravity until the strapping started to compress the insulation slightly.*

The plot provided in Figure 3.10 compares the load-displacement relationship of preloaded and as-installed wall assemblies, both having 6" (152mm) ComfortBoard 80 with screws installed at 90° to the strapping. Note that the first loading of each test wall is provided with solid line and the second loading with dashed line. Also, the bands of shaded area correspond to the weight of typical cladding types per square foot. The figure illustrates that the preloaded system experienced slightly smaller deflection on its first loading, which is comparable to the second loading of a similar wall assembly.



*Figure 3.10 Plot comparing load-displacement relationship of a similar test wall system with strapping on one of the systems preloaded prior to the first loading*

*In both assemblies incorporated total of 6" (152mm) ComfortBoard 80 insulation with countersunk head screws installed at 90° to the strapping. The first loading plot is provided with solid line and second loading with a dashed line.*

It should be noted that when cladding is being attached, strapping is incrementally loaded, which might act similarly to preloading the strapping and consequently experience some deflection before the whole cladding system is installed.

Deflection of strapping that supports the cladding system is likely one of the top design considerations for these systems, especially for those cladding systems that are sensitive to movement (e.g., stucco). Since there has been little research into defining what is allowable deflection for each of the cladding types, the intention of this test was to load the screws via strapping to its limit and observe the mechanical failure mechanism of these systems. The types of mechanical failure related to the screw are identified below and accompanied with an illustration provided in Figure 3.11.

- Excessive permanent **bending** of screw
- **Tensile failure** of screw
- Screw thread **withdrawal** from 2x framing member
- Screw head **pull-through** from 3/4"x3" plywood strapping

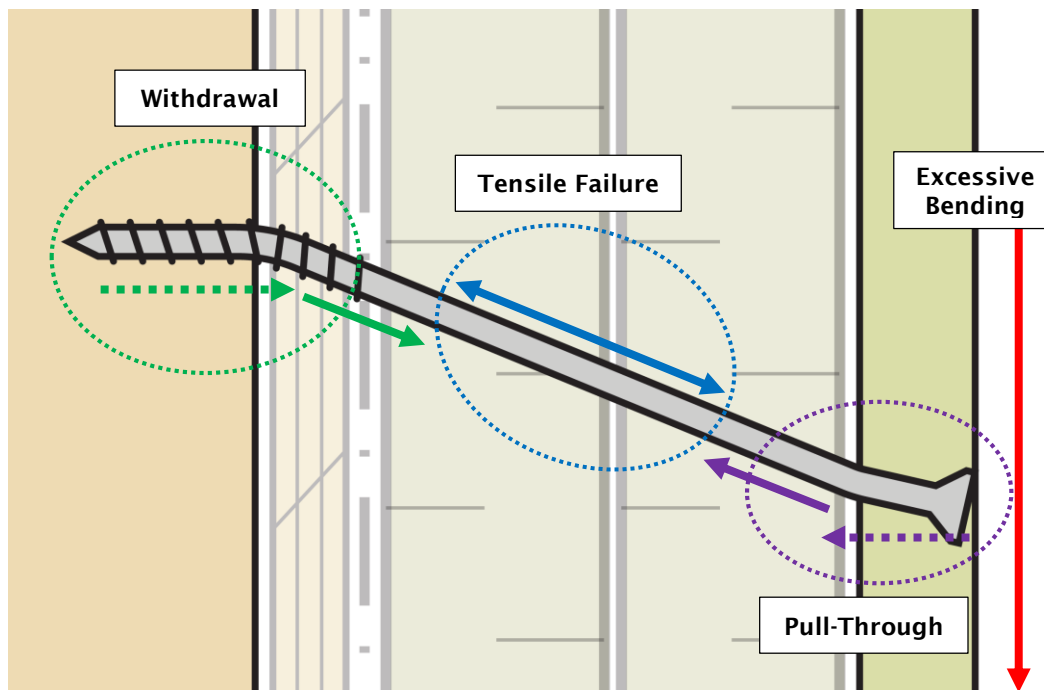


Figure 3.11 Illustration of possible mechanical failures relating to a screw securing a strapping

None of the mechanical failures listed above was observed with the test walls with three screws securing the centre strapping, which is likely due to the size of the screws used for the testing (~5/16" or 8.0mm thread diameter screw). Therefore, this mechanical failure test had to be performed with a reduced number of screws securing the centre the strapping. Only one screw was installed at the centre of the strapping, this was done in order to apply a load in excess of 300lb (136kg). Two test walls with 6" (2 x 3", 152mm) ComfortBoard 80 with one HECO-TOPIX 8.0x240 securing the centre strapping were tested and both systems failed at the plywood strapping (Test Walls #7-1 and #7-2). Table 3.2 provides a summary of test data at the point of failure. As already mentioned, this test was performed to evaluate mechanical failure and, due to the stiffness of the system, the strapping had to be displaced in excess of 3" (76mm)—which is significantly beyond what would be considered acceptable deflection.

TABLE 3.2 SUMMARY OF TEST TO MECHANICAL FAILURE			
Test Wall ID	Failure Mechanism	Displacement inch (mm)	Load per Screw lbs (kg)
Test Wall #7-1	Plywood Strapping	4.786 (121.56)	864 (392)
Test Wall #7-2	Plywood Strapping	3.169 (80.48)	690 (313)

In both tests, the screw experienced bending beyond its yielding point (permanent deformation) as shown in Figure 3.12. The penetrated area of the OSB sheathing had minor bearing damage, but it was no more enlarged/deformed than those tested to 300lb (136kg) per screw while no visual bearing damage was observed at the backup wall framing screw penetration.

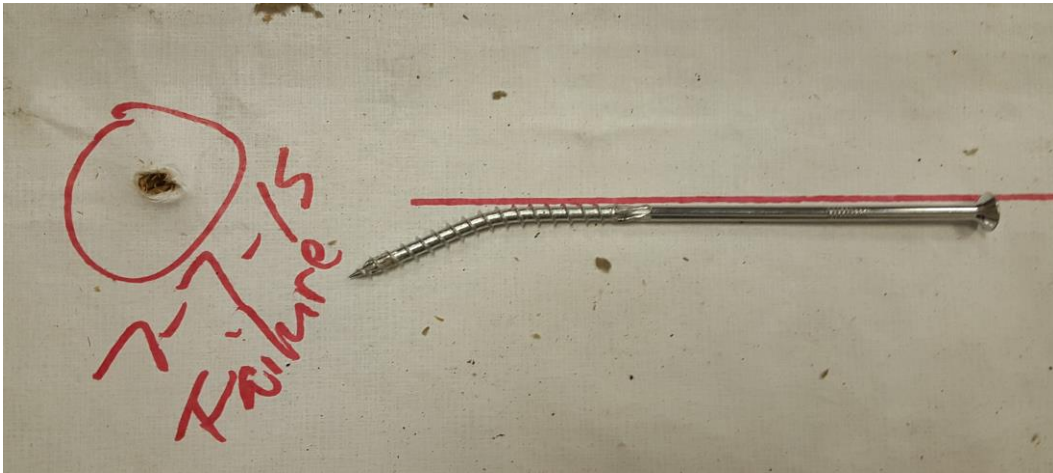


Figure 3.12 HECO-TOPIX 8.0x240 screw from Test Wall #7-1 after loaded to ~660lb (~300kg)

Both test walls failed similarly at the plywood strapping. Figure 3.13 provides photos of Test Wall #7-1 moments before the failure. As the screw bent and engaged more in tension, the countersunk head pulled-through 4 out of 6 plies of the 3/4" plywood strapping and broke the last 2 plies.



4.5" (115mm) displacement @807lb (366kg)



An overview of photo on the left



5.2" (131mm) displacement @719lb (326kg)



5.2" (133mm) displacement

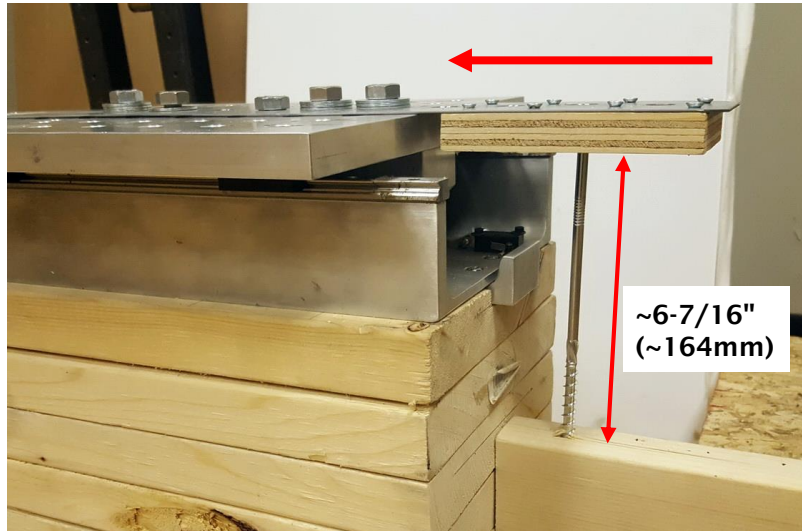
Figure 3.13 Mechanical failure at plywood strapping during Test Wall #7-1 test

It should be noted that because this test was performed with only one screw, the plywood strapping experienced significant bending at the location of the screw and did not compress the insulation evenly.

To further understand the mechanics of these wall systems, a bending test was performed on the HECO-TOPIX 8.0x240 screw alone. The test was set up so that the load would be applied to the screw via strapping, in the same manner as other test walls were tested;

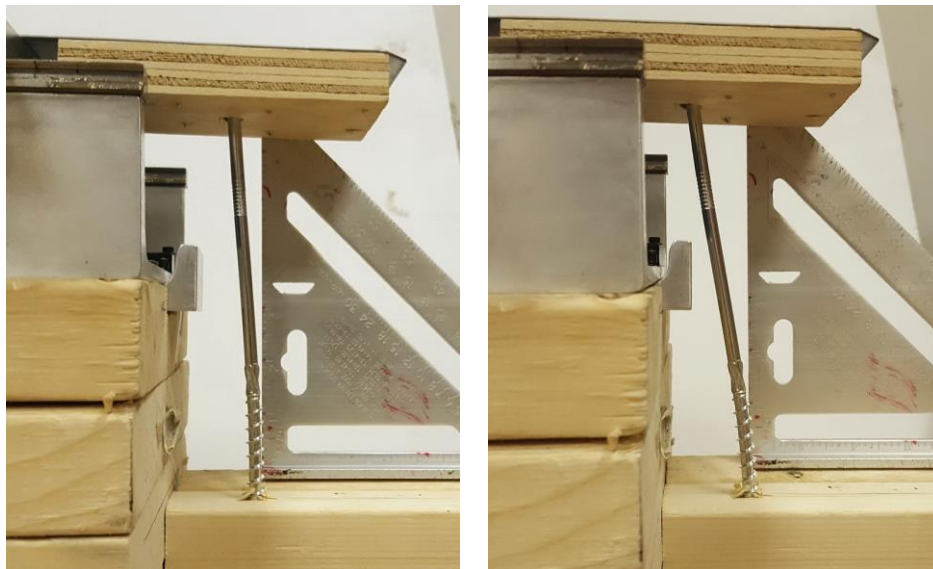


however, this screw bending test was performed without the insulation and OSB sheathing, as shown in Figure 3.14. The screw penetrated ~2.24" (~57mm) into the 2x framing including the tapered tip and the screw head was countersunk into the 3/4" plywood, leaving ~6-7/16" (~164mm) of gap between the framing and plywood strapping. The screw bending was assumed to take place at the face of the 2x framing lumber since there was slightly more bearing damage from the screws typically seen at the OSB penetration compared to 2x backup wall framing lumber; therefore, OSB sheathing was also excluded from this test.



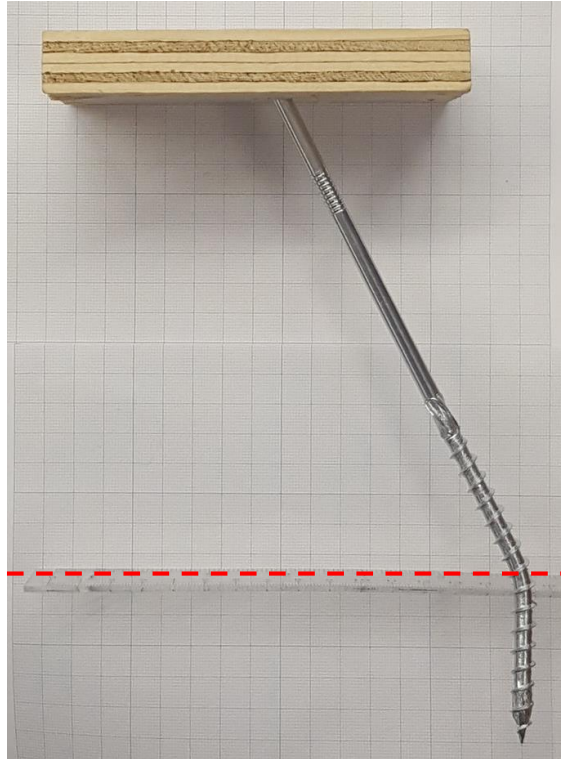
*Figure 3.14 HECO-TOPIX 8.0x240 bending test with ~6-7/16" (~164mm) gap instead of insulation (6" or 152mm) and OSB sheathing (7/16" or 11mm) between the strapping and the 2x framing*

The screw bending test showed that, without a compressible insulation layer, the force applied to the strapping went directly into bending the screw as shown in lapse photos taken during a screw bending test provided in Figure 3.15.



*Figure 3.15 Lapse photos taken during a screw bending test*

The intent was to perform this screw bending test in a similar manner as tests performed on the test walls with insulation; however, due to significant bending of the screws, three trials of screw bending test had to be stopped at 73lb (33kg), 260lb (118kg), and 152lb (69kg) load at which point the apparatus logged deflection of 1.475" (38.7mm), 4.532" (120.4mm), and 2.477" (65.7mm) respectively. Figure 3.16 provides a photo of HECO-TOPIX 8.0x240 screw after a screw bending test. As shown in the photo, the screw underwent a permanent deformation. The red dashed line represents face of backup wall framing lumber, and coincidentally indicates where the bending took place.



*Figure 3.16 HECO-TOPIX 8.0x240 screw after screw bending test*

The photos provided in Figure 3.17 are close-ups of the screw penetration holes in the backup wall framing lumber after the screw bending test (screws were carefully driven out). As shown in the photos, the framing lumber experienced no visual bearing damage.



*Figure 3.17 Close-up photos of backup wall framing at screw penetrations after screw bending test*

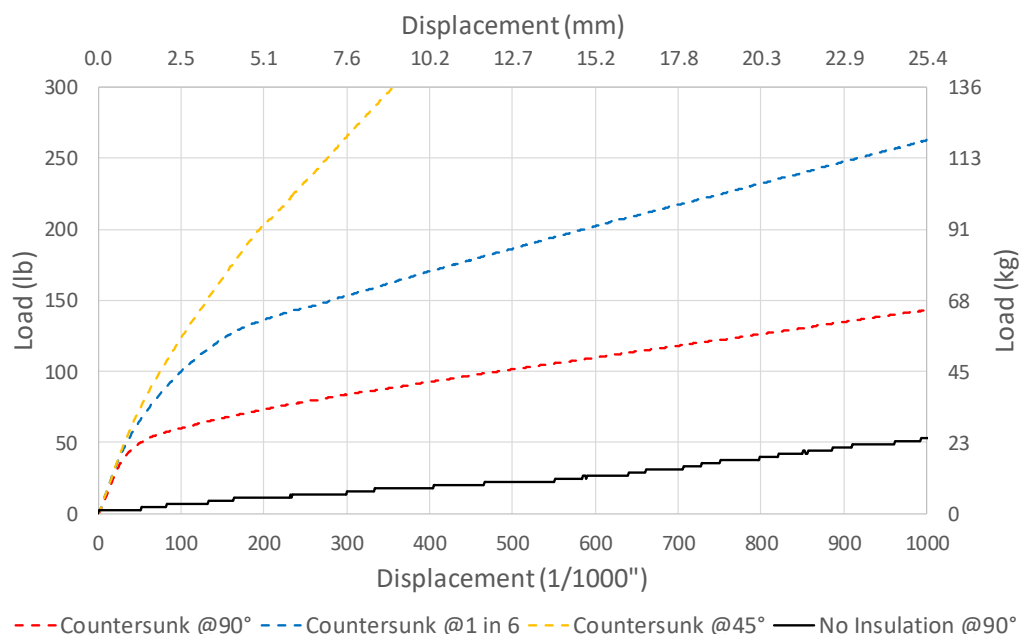
*Note that after screws were carefully driven out, no visible bearing damage was observed.*

The photos provided in Figure 3.18 are close-ups of the 3/4" plywood strapping at a screw penetration after the screw bending test. As shown in the photos, the countersunk head had deformed the penetration hole.



*Figure 3.18 Close-up photos of 3/4" plywood strapping at a screw penetration  
Note the slight bearing damage on the strapping.*

The results of the screw bending tests are provided in Figure 3.19 along with load-displacement relationship of different screw arrangements with 6" (152mm) insulation for comparison. As illustrated in the figure, screws on their own provide significantly weaker performance than do the systems with insulation, resulting in much greater displacement as shown in the figure. As a result, it can be concluded that the stiffness of these systems relies significantly on the compressible insulation layer and the truss action provided by both the screw and the insulation.



*Figure 3.19 Load-displacement plot comparing three screw installation angles with 6" (152mm) ComfortBoard 80 insulation and HECO-TOPIX 8.0x240 installed at 90° to the strapping with a gap between plywood strapping and 2x framing instead of insulation and OSB sheathing*

*Note that the load provided is per screw.*

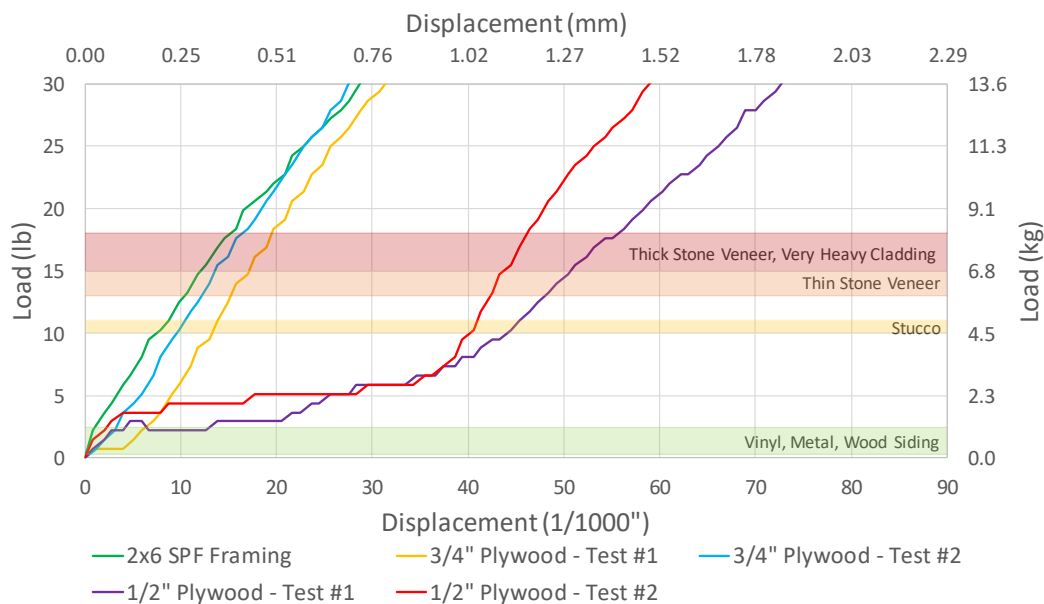
### 3.5 Screw Penetration into Non-Framing Member Only

In this study, the objective was to investigate the performance of exterior-insulated wall assemblies with an assumption that the screws securing the insulation and attaching the cladding penetrate into the backup wall framing. In a laboratory condition, it was possible to ensure that the screws penetrated the backup wall framing; however, due to the nature of attaching thick amounts of insulation to the exterior of the wall, ensuring screw penetration into backup wall framing member is difficult in real-world application, and the potential for missing the framing members is high. Therefore, the importance of screws penetrating the backup wall framing member and how screws missing the stud affects the performance of these types of wall system were investigated.

Long screw tests with screws not penetrating the backup wall framing were performed with 9" (229mm) of Roxul ComfortBoard 80 insulation, HECO TOPIX 8.0x280 screws and either 1/2" or 3/4" plywood. In these cases, the screws penetrate only the plywood sheathing layer, and do not penetrate the stud framing.

The screws which only penetrate a sheathing layer do not have as much embedment as screws which penetrate the framing. This arrangement is likely to allow for the screw to more easily rotate at the embedment point, more similar to a pin connection than to a moment connection. In this configuration, the screw is able to rotate more freely instead of bending the screw, and larger amounts of deflection occur.

This screw rotation at the penetration hole in the 1/2" plywood sheathing deformed the holes (bearing damage) and eventually lead to withdrawal of the screws from the sheathing. Figure 3.20 compares load-displacement relationship of assemblies when screws penetrate 2x6 SPF framing, 3/4" plywood only, and 1/2" plywood only. The plot provided is for the first loading of each setup and all test assemblies are with 9" (229mm) of ComfortBoard 80 insulation and HECO-TOPIX 8.0x installed at 90° to the strapping.



*Figure 3.20 Load-displacement plot comparing stiffness of assemblies when screws penetrate 2x6 framing, 3/4" plywood only, and 1/2" plywood only.*

*All test assemblies are with 9" (229mm) of ComfortBoard 80 insulation and HECO-TOPIX 8.0x installed at 90° to the strapping. The plot provided is for the first loading of each setup*

The results of this testing reveal that 3/4" plywood provides similar performance to assemblies where the screw penetrates the framing members; however, all three tests performed with 1/2" plywood ended in withdrawal failure (pull out from sheathing, only first and second test results shown). It should be noted that the assemblies with 1/2" plywood stiffened around 0.040" (1.02mm) displacement. It is likely that the truss action created between compressive resistance of insulation and tensile strength of screws started to contribute to the stiffness of the assemblies at this point.

As the sheathing only results illustrate, when thicker sheathing is used (e.g., 3/4" plywood) the plywood sheathing can provide similar load resistance to the framing, as long as the plywood is adequately secured back to the studs. With thinner more common sheathings (e.g., 1/2" plywood) the system less stiff and experienced larger deflections. However, given that some load capacity does exist with these thinner more common sheathing, it is likely that when a small number of fasteners unintentionally miss the framing, that the overall strength of the system is still sufficient to support the cladding loads. In practice when these types of systems have been used, this is likely why failures are uncommon, and is also why it is common to recommend at least two fasteners per strapping member to provide redundancy. Further testing is needed to investigate a reasonable tolerance for missing the studs (e.g., 10% of fasteners missing the studs provides acceptable performance).

One additional consideration for the screws through sheathing only arrangement is that the HECO-TOPIX 8.0x screw has ~0.236" (~6mm) between the threads which would mean that with 1/2" plywood, it is likely that the screw had only one good thread biting the wood (or two threads in best case scenario). While with 3/4" plywood, the screws had 3 threads biting the wood. One interesting side note is that a smaller diameter fastener would likely have tighter thread spacing (i.e., higher thread density) which may work better for thin sheathing since the pull-out resistance may be improved. However, it is likely that a smaller diameter fastener would have less bending resistance, and thus the compressive strength of the insulation would potentially have a larger impact. This suggests that there might be an advantage in this arrangement to using smaller screws, though further testing is needed to confirm.

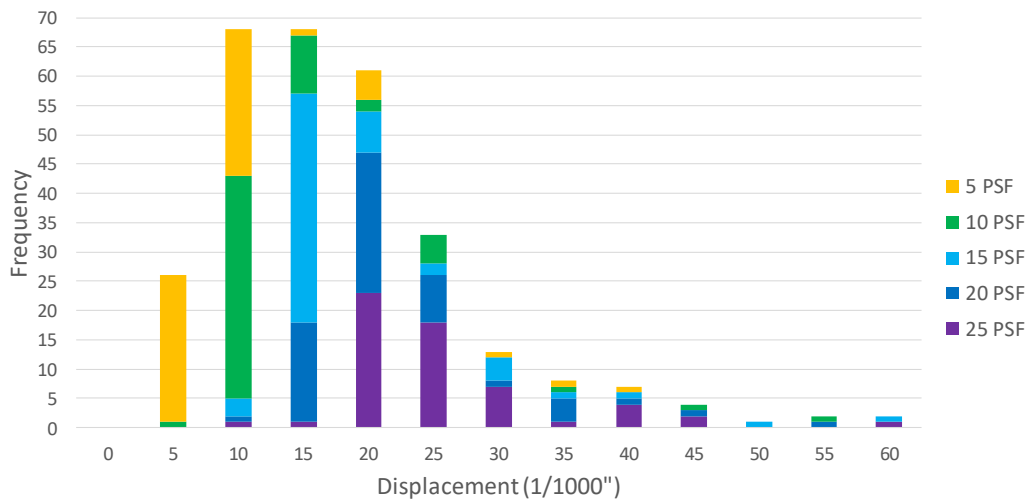
### **3.6 Statistical Analysis and Summary**

A total of 30 test assemblies were tested instead of the previously mentioned 15 (Table 1.1). This was largely due to difficulties experienced with the load-based programming at high loads (>880lb or >400kg). The results up to 25lb (11.3kg) per screw for all tests performed were statistically analyzed as a frequency plot and are provided in Figure 3.21. Displacements at loads of 5lb, 10lb, 15lb, 20lb, and 25lb (2.3kg, 4.5kg, 6.8kg, 9.1 kg, and 11.3kg) per screw were tabulated in 0.005" (0.127mm) increments and the frequency of displacement at a given load was plotted. This resulting distribution is representative of how much deflection can be expected regardless of insulation type or screw arrangement when the supporting area of a screw is 1ft<sup>2</sup> with cladding areal density of 5psf, 10psf, 15psf, 20psf, and 25psf (24.4kg/m<sup>2</sup>, 48.8 kg/m<sup>2</sup>, 73.2 kg/m<sup>2</sup>, 97.6 kg/m<sup>2</sup>, and 122.1 kg/m<sup>2</sup>) when HECO-TOPIX 8.0x screws (or similar) are used. Overall, the distribution works to characterize the scatter present in the results.

As illustrated in Figure 3.21, most of the systems experienced displacement between 0.005" to 0.025" (0.127mm to 0.635mm) at provided cladding loads. Naturally, the lighter

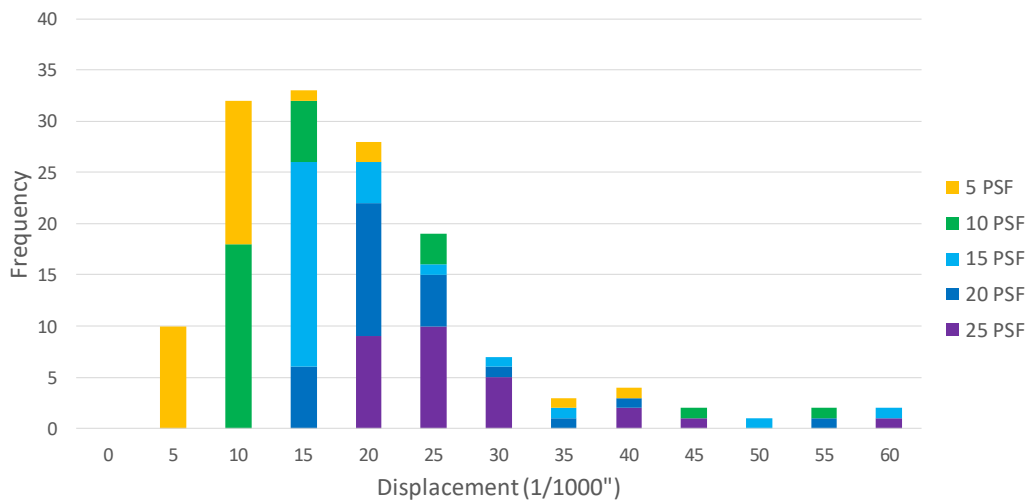


the load, the system experienced the lower end of displacement and the higher the load, the higher the displacement.

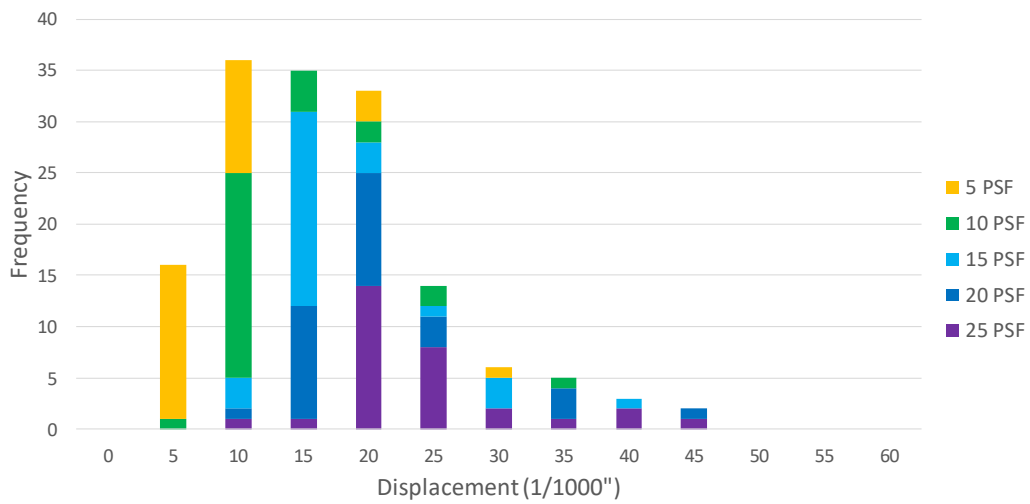


*Figure 3.21 Frequency plot providing displacement at provided cladding weights with HECO-TOPIX 8.0x screw (or similar) supporting 1ft<sup>2</sup>*

Figure 3.22 and Figure 3.23 provide the same information provided in Figure 3.21 separated into first and second loading respectively. These plots confirm the observation that initial displacement is typically larger than the second loading, though the difference is relatively small.



*Figure 3.22 Frequency plot providing displacement at provided cladding weights with HECO-TOPIX 8.0x screw (or similar) supporting 1ft<sup>2</sup> on **first loading***



*Figure 3.23 Frequency plot providing displacement at provided cladding weights with HECO-TOPIX 8.0x screw (or similar) supporting 1ft<sup>2</sup> on **second loading***

## 4 Findings and Conclusions

The intention of this study was to evaluate the impact of insulation type and thickness, screw head type, and screw arrangement on the performance of exterior-insulated wall assemblies to resist cladding load. Additionally, the method of preloading the strapping and the ultimate failure mechanism of this type of wall assembly were evaluated. This study found that:

- The impact of compressive strength of insulation materials on the overall stiffness of the test wall assembly was negligible when screws were loaded to 25lb (9.1kg), which is indicative of common cladding loads. The difference in deflection between rigid foam insulation (XPS) typically used in this application and ROXUL ComfortBoard 80 (semi-rigid mineral wool) was 0.005" (0.13mm) at 25lb (9.1kg). However, at a higher load, insulation material with a higher compressive strength was shown to provide a stiffer wall assembly.
- Insulation thicknesses of 6" and 9" (152mm and 229mm) provided very similar overall stiffness of the test wall assembly when the screw was loaded to 25lb (9.1kg). Although test wall assemblies with 12" (305mm) insulation deflected slightly more, the difference in deflection was relatively small (0.007" or 0.18mm) at 25lb (9.1kg) and would likely not be of importance in most common applications.
- The impact of the screw head type (countersunk and pan-head) on the overall stiffness of the test wall assembly was negligible when the screw was loaded to 25lb (9.1kg). However, the pan head screw was shown to provide a slightly stiffer wall assembly at higher loads.
- Angles at which screws are installed also made negligible difference in stiffness of up to 25lbs (9.1kg) of load on a screw; however, when a screw is loaded beyond 45lb (20kg), there's a clear advantage to installing screws at an upward angle, which engages the screw to resist the load in tension more readily.
- Each test wall was loaded twice, and it was observed that more deflection was consistently experienced on initial loading, which confirms findings from previous studies done by others.
- The strapping, which provide support for the cladding material, were preloaded prior to testing. The idea behind preloading the strapping is to seat the strapping into the insulation and to reduce the initial deflection. The strapping was preloaded by up to ~3/4" (~19mm) in displacement and on its initial loading, the preloaded test walls provided a very similar performance as the walls that had already been loaded once through the testing.
- Overall, all test walls performed similarly within the range of typical cladding loads. The impact of insulation type and thickness, screw head type, and screw arrangement on the performance of an exterior-insulated wall assembly to resist a cladding load became more evident at loads above 45lb (20kg) per screw; however, these loads are uncommon for most typical cladding arrangements. For these levels of loads, gravity supported systems such as shelf-angles (i.e., for brick) would likely be more applicable.

- Between typical cladding loads of 5psf to 20psf (24.4kg/m<sup>2</sup> to 97.6kg/m<sup>2</sup>) with the screw supporting an area of 1ft<sup>2</sup> (0.0929m<sup>2</sup>), test walls typically deflected between 0.005" to 0.025" (0.13mm to 0.64mm) using HECO-TOPIX 8.0x screws.
- In a laboratory condition with test wall situated in a horizontal position, it was possible to ensure that the screws penetrated the backup wall framing; however, ensuring screw penetration into backup wall framing members would likely be more difficult in real-world applications, and there is potential for missing the framing members. Long screw tests with screws not penetrating the backup wall framing reveal that:
  - 3/4" plywood provided similar performance to assemblies where the screw penetrates the framing members and can provide significant load resistance as long as the plywood is adequately secured back to the studs.
  - With thinner more common sheathings (e.g., 1/2" plywood) the system was less stiff and experienced larger deflections; however, it is likely that in cases where studs are unintentionally missed, sufficient capacity would still exist when combined with the resistance of adjacent fasteners that successfully embedded in the framing.

Areas for further testing:

- Investigate allowable deflection for typical cladding materials.
- Evaluate the performance of similar systems for use in exterior-insulated light-gauge steel stud wall system.
- Further investigation could be completed to assess alternate screw diameters and screw penetration depths to further optimize design.

Yours truly,



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# Appendix A

## Additional Plots

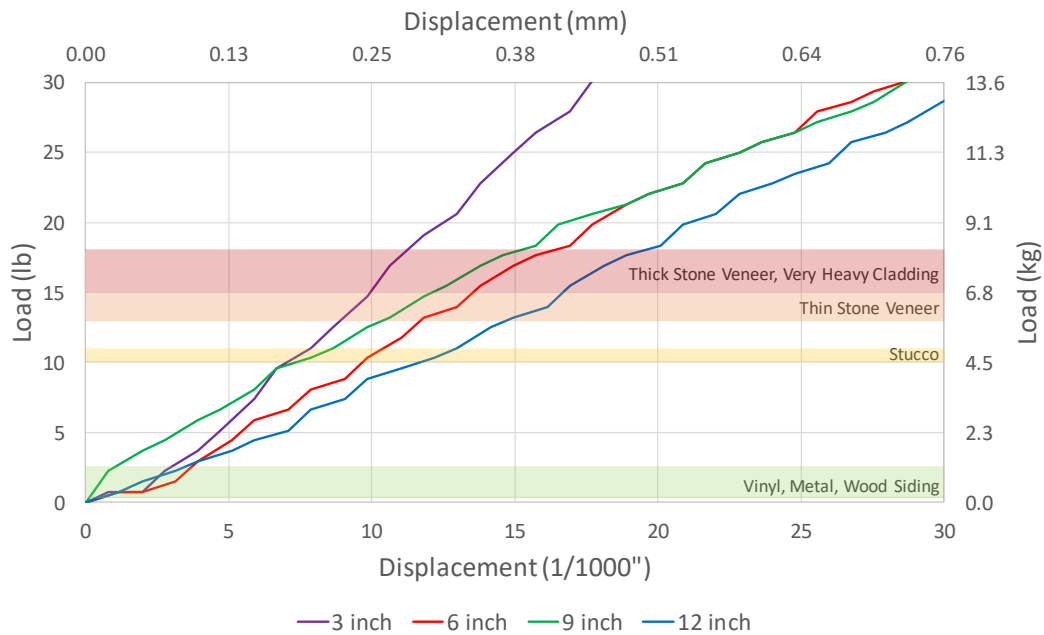


Figure 4.1 Load-Displacement plot comparing Roxul ComfortBoard 80 insulation at 3", 6", 9" and 12" (76mm, 152mm, 229mm, and 305mm) thickness with countersunk head screws installed at 90° to the strapping.

The plot provided is for **first loading** of each of the setup.

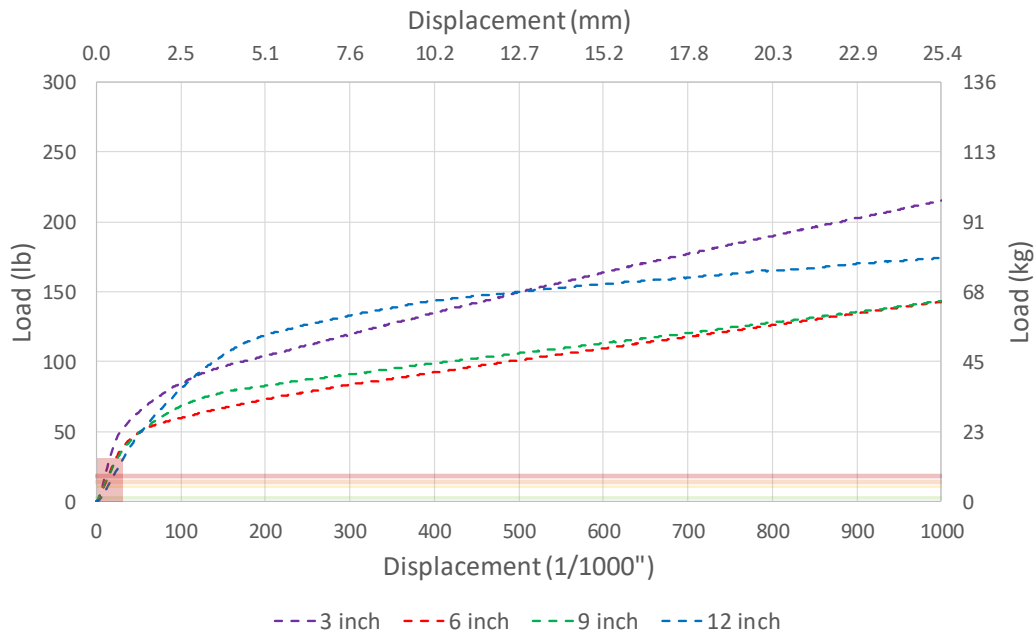


Figure 4.2 Load-Displacement plot comparing Roxul ComfortBoard 80 insulation at 3", 6", 9" and 12" (76mm, 152mm, 229mm, and 305mm) thickness with countersunk head screws installed at 90° to the strapping.

The plot provided is for **second loading** of each of the setup. Note that the plot range shown in Figure 3.3 is highlighted in red box.



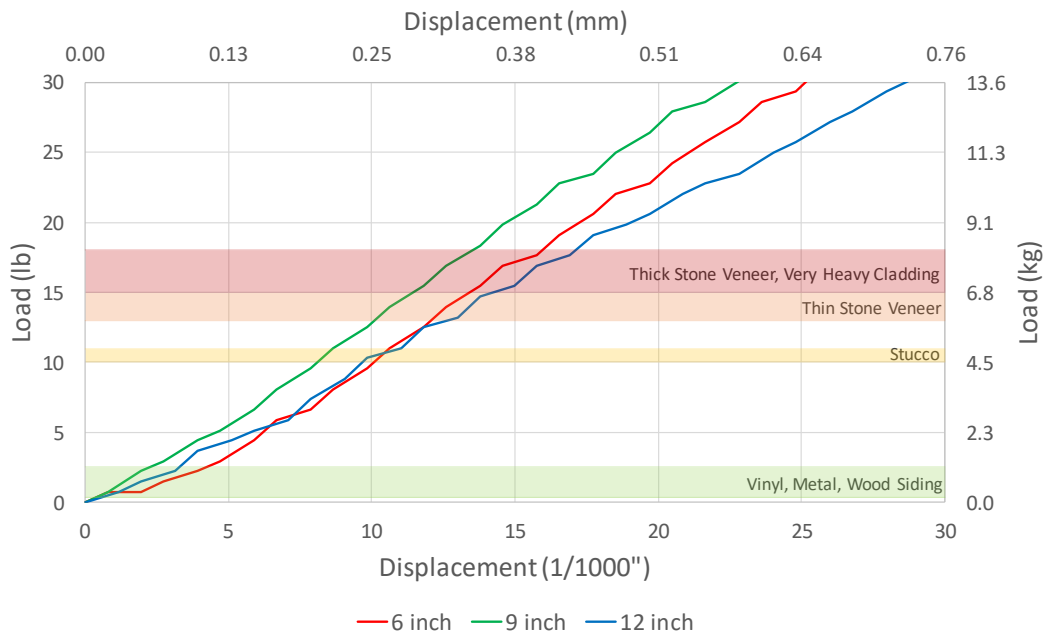


Figure 4.3 Load-Displacement plot comparing Roxul ComfortBoard 110 insulation at 6", 9" and 12" (152mm, 229mm, and 305mm) thickness with countersunk head screws installed at 90° to the strapping.

The plot provided is for **first loading** of each of the setup.

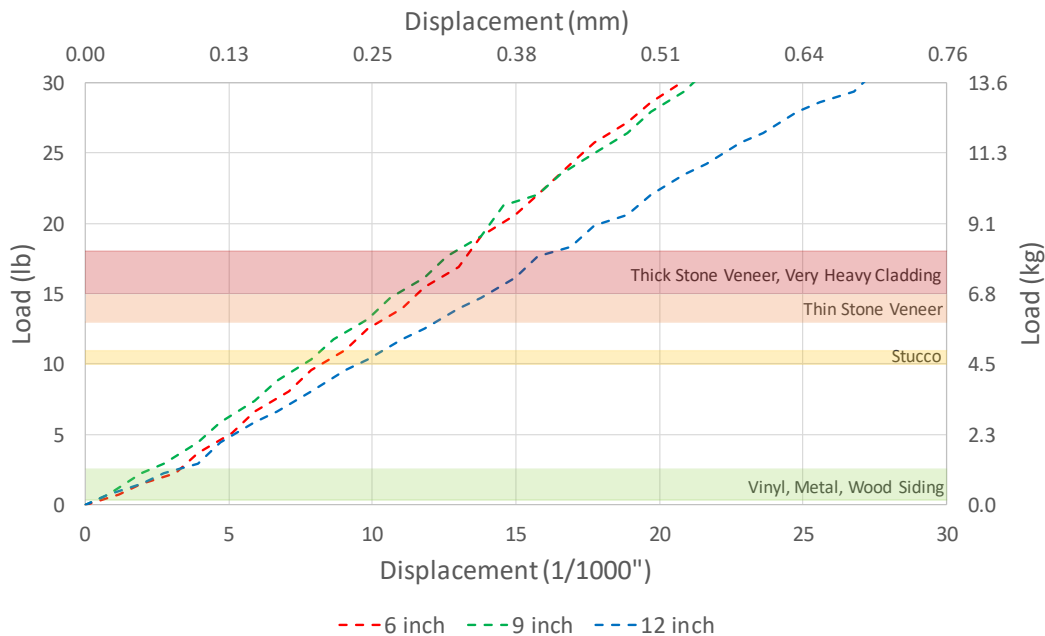


Figure 4.4 Load-Displacement plot comparing Roxul ComfortBoard 110 insulation at 6", 9" and 12" (152mm, 229mm, and 305mm) thickness with countersunk head screws installed at 90° to the strapping.

The plot provided is for **second loading** of each of the setup.

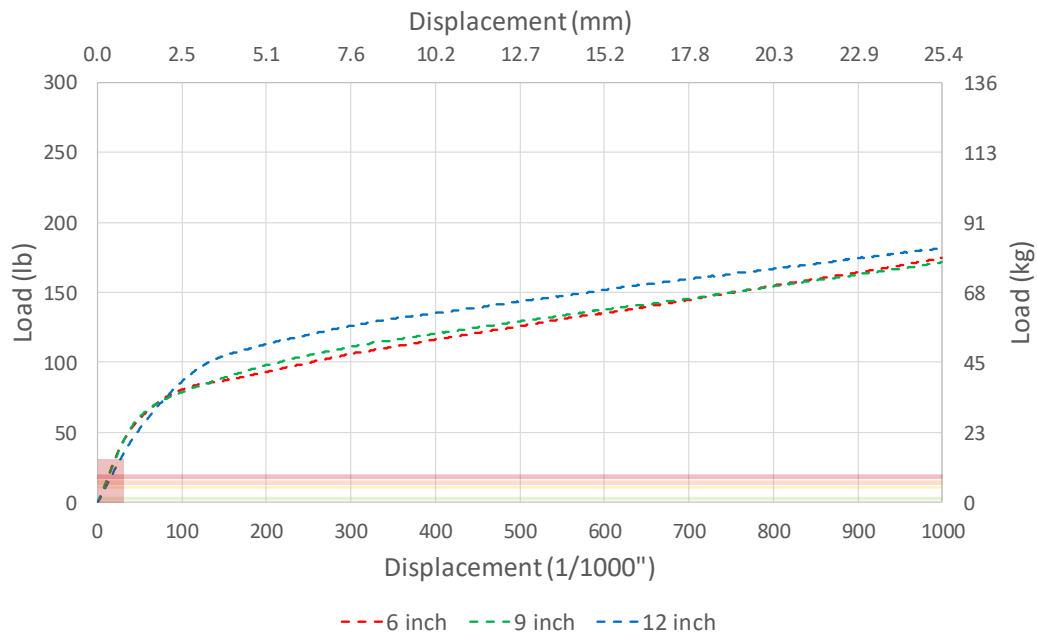


Figure 4.5 Load-Displacement plot comparing Roxul ComfortBoard 110 insulation at 6", 9" and 12" (152mm, 229mm, and 305mm) thickness with countersunk head screws installed at 90° to the strapping.

The plot provided is for **second loading** of each of the setup. Note that the plot range shown in Figure 4.4 is highlighted in red box.

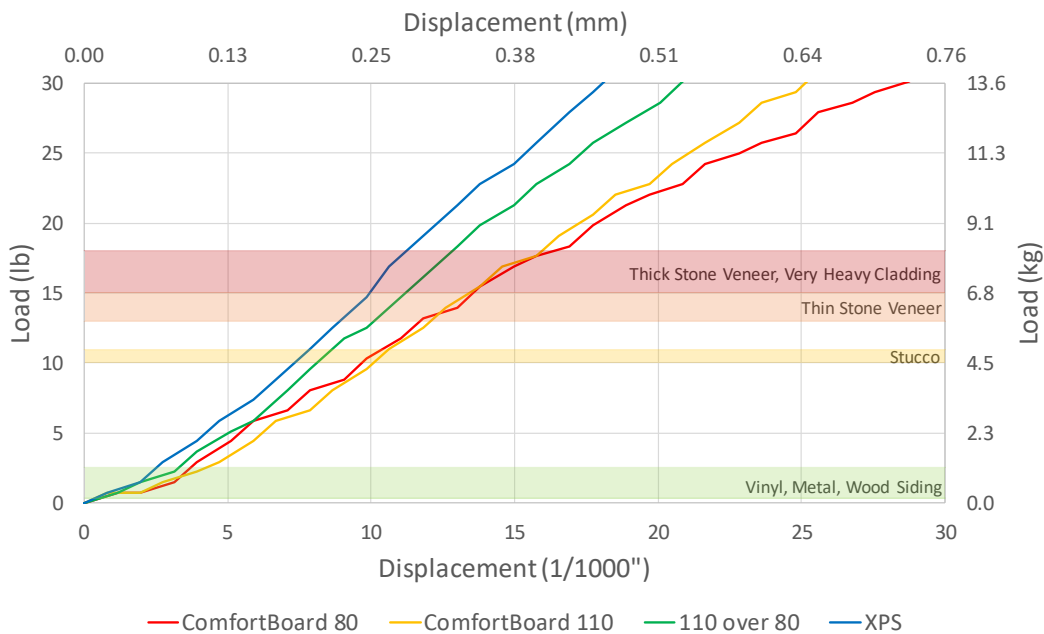
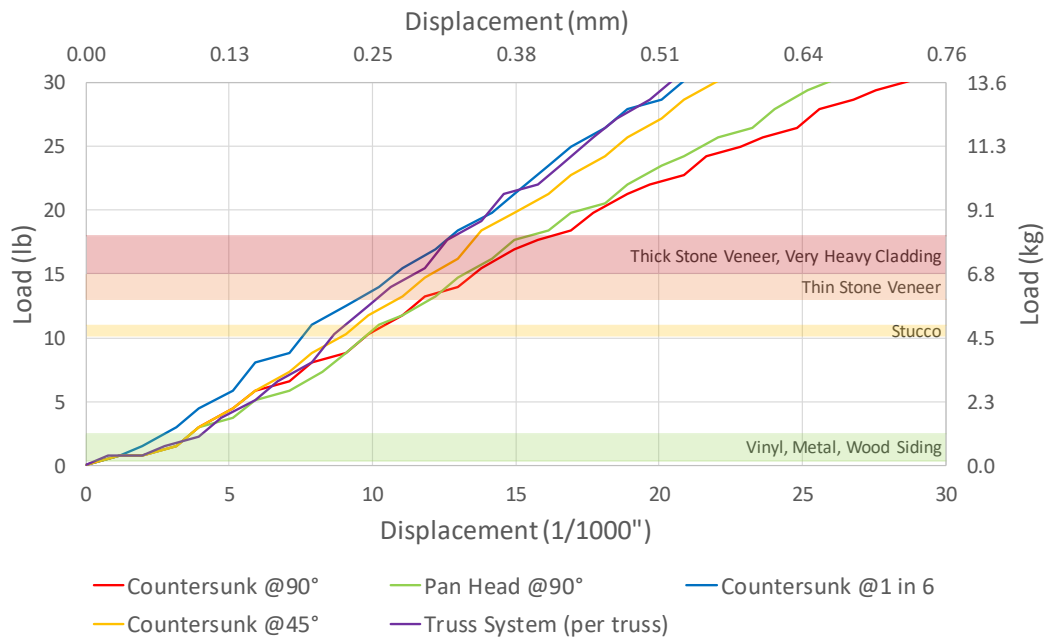


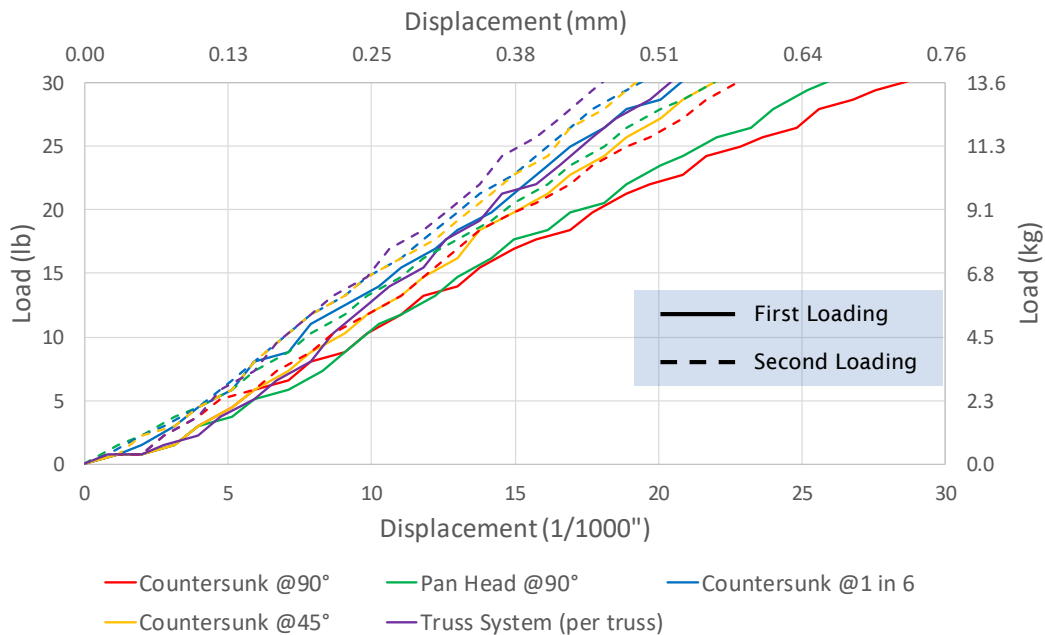
Figure 4.6 Load-Displacement plot comparing insulation arrangements at 6" (152mm) thickness with countersunk head screws installed at 90° to the strapping.

The plot provided is for **first loading** of each of the setup.



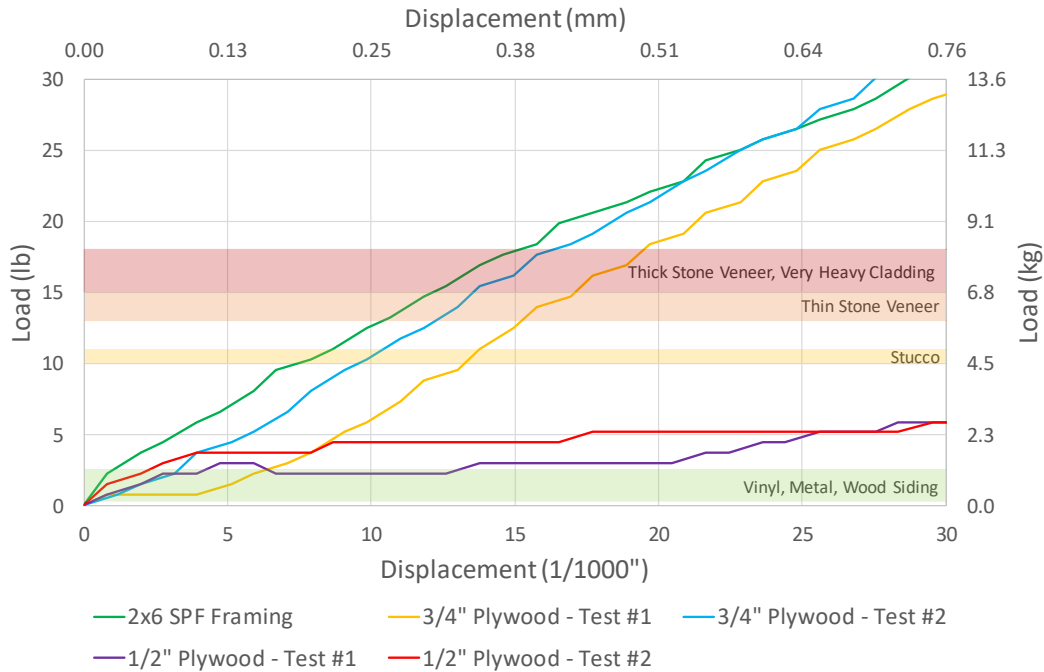
**Figure 4.7 Load-Displacement plot comparing screw types and arrangements with 6" (152mm) of ComfortBoard 80 insulation.**

*The plot provided is for **first loading** of each of the setup.*



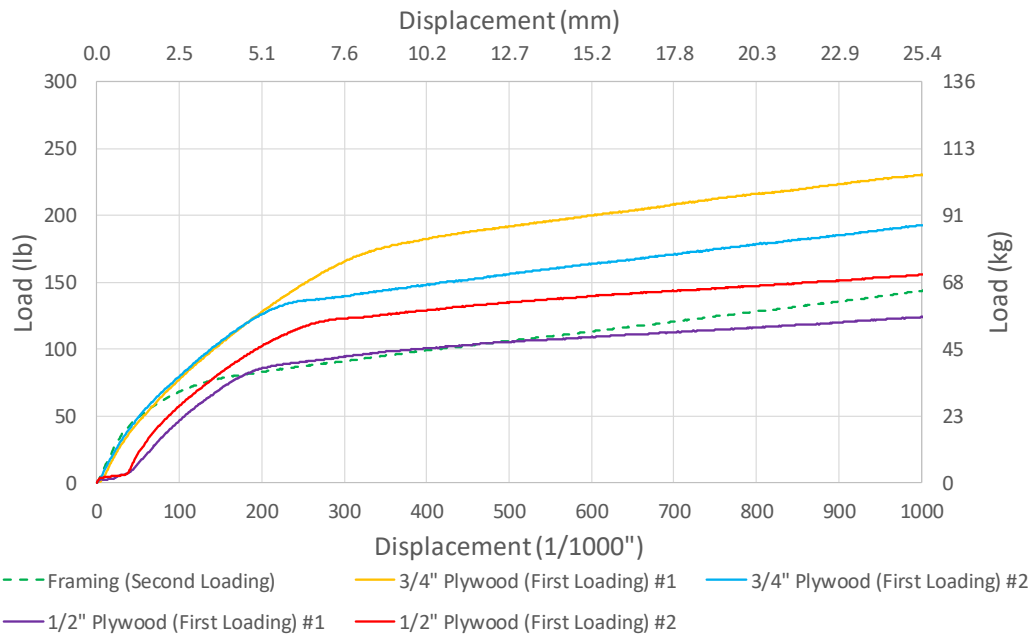
**Figure 4.8 Load-displacement plot comparing first and second loading by screw type and arrangements.**

*All arrangements are with 6" (152mm) of ComfortBoard 80. The first loading plot is provided with solid line and the second loading with dashed line.*



**Figure 4.9 Load-displacement plot comparing stiffness of assemblies when screws penetrate 2x6 framing, 3/4" plywood only, and 1/2" plywood only.**

All test assemblies are with 9" (229mm) of ComfortBoard 80 insulation and HECO-TOPIX 8.0x installed at 90° to the strapping. The plot provided is for the first loading of each setup



**Figure 4.10 Load-displacement plot comparing stiffness of assemblies when screws penetrate 2x6 framing, 3/4" plywood only, and 1/2" plywood only.**

All test assemblies are with 9" (229mm) of ComfortBoard 80 insulation and HECO-TOPIX 8.0x installed at 90° to the strapping.