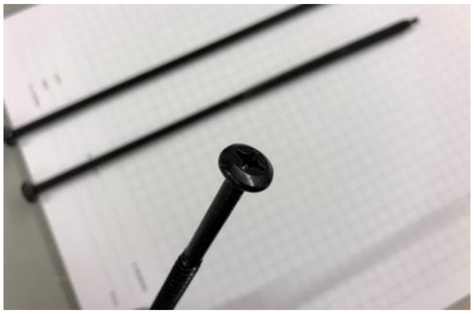
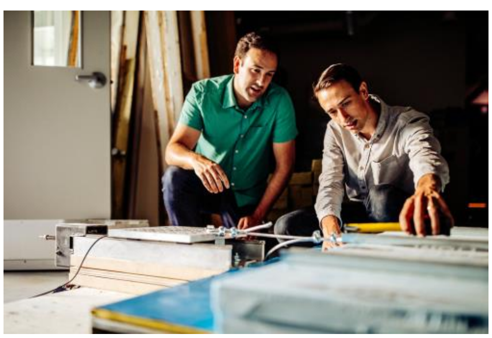
Structural Testing of Screws through Exterior Stone Wool Insulation for Steel-Frame Walls

Project 7119.009





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1 Introduction

1.1 Background

As the construction industry moves toward more energy-efficient buildings, exterior insulation has been recognized as an effective solution for increasing the thermal performance of wall assemblies. Previous research and in-situ performance have shown that using only screws directly through exterior insulation to provide cladding attachment is a thermally and structurally efficient solution for wood-frame walls. For steel-frame walls, however, there is still scepticism regarding this method of cladding support, and cladding attachment clips are currently the more common solution.

This study focuses on the impact of density and thickness of insulation materials on the structural performance of a cladding attachment system where the exterior insulation is installed and held in place using only screws and steel furring fastened in to a steel stud back-up wall. In particular, this study investigates the use of exterior stone wool insulation, which may be perceived as insufficiently rigid in comparison to competing foam plastic insulations such as extruded polystyrene insulation (XPS) for this type of insulation and cladding installation approach.

Previous testing performed on wood-frame walls suggests that the majority of deflection occurs during the initial loading; therefore, this study also investigates preloaded furring and pre-compressed insulation as techniques to minimize initial deflection. In addition to the structural performance, airtightness, water penetration, and constructability considerations of this system are also discussed.

Overall the study aims to provide important information for the industry as to the viability of the screws through exterior insulation cladding attachment approach in steel stud wall applications to facilitate the expanded use of exterior insulation as part of non-combustible wall assembly design.

1.2 Objective and Scope

In this study, a series of tests were performed similarly to the study which investigated structural performance of attaching cladding using long screws through thick exterior insulation for wood frame construction[1], but instead of plywood strapping and a wood-frame backup wall, non-combustible materials such as steel stud and tracks, and gypsum sheathing were used. The viability of the screws through exterior insulation cladding attachment approach in steel stud wall applications was of interest since in the steel frame construction, the steel stud to fastener connection will likely act as a pin-type connection and consequently, will resist cladding loads in a different way than in wood-frame construction where a moment type connection is more likely to be achieved.

A pin-type connection refers to a connection which does not resist bending moment (i.e., rotation). Alternatively, a moment-type connection does resist moment. The embedment of the fastener in to the wood is likely to provide increased moment resistance as compared to the fastener in to the steel stud. Inherently, while moment connections only require one support to be stable, pin-type connections require bracing to be stable. Therefore, attaching cladding to steel-studs using long screws theoretically

[1] Structural Testing of Screws through Thick Exterior Insulation Report dated June 13, 2017

relies more on the truss action created by the compression of the insulation than the same system when installed in to wood-frame construction.

The work was divided into 5 tasks. These tasks corresponded with the specific parameters to be evaluated.

→ Task 1: Evaluation of Insulation Types
(e.g., ROCKWOOL COMFORTBOARD™ 80, XPS)

→ Task 2: Evaluation of Insulation Thickness (i.e., 3", 6", and 9")

→ Task 3: Evaluation of Preloading and Pre-compression

→ Task 4: Evaluation of Fastener Missing the Stud Framing

→ Task 5: Evaluation of Fastener Penetration into Horizontal Metal Straps

In this study, an insulation thickness of 6" was used as a baseline, and 3" and 9" insulation arrangements were also tested in some cases. Table 1.1 provides summary of 12 test wall arrangements tested as part of this evaluation.

TABLE 1.1 TEST WALL ARRANGEMENTS

Insulation Type and Screw Arrangement (Screws were installed at 90˚ to the sheathing)	**Indication of Insulation Layers to Achieve Total Insulation Thickness**		
	3"	**6"**	**9"**
ROCKWOOL COMFORTBOARD™ 80	1 x 3"	2 x 3"	
ROCKWOOL COMFORTBOARD™ 110	1 x 3"	2 x 3"	3 x 3"
ROCKWOOL COMFORTBOARD™ 110 over ROCKWOOL CAVITYROCK®			1 x 3" + 1 x 6"
XPS Insulation	3" (total)[i]	6" (total)[i]	
ROCKWOOL COMFORTBOARD™ 80 – Preloaded		(2 x 3") x 2	
ROCKWOOL COMFORTBOARD™ 80 – Pre-compressed		(2 x 3") x 2	
ROCKWOOL COMFORTBOARD™ 80 – One Fastener to Miss Stud Framing		(2 x 3") x 2	
ROCKWOOL COMFORTBOARD™ 80 – Fastener Penetration into Horizontal Metal Strap		(2 x 3") x 2	

[i] A total insulation thickness of 3" and 6" may be obtained by layering 1.5",2", or 3" thicknesses depending on material availability.

2 Methodology

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

2.1 Test Wall

To test the performance of the wall assemblies, a 4' x 6' (1220mm x 1830mm) backup wall was constructed with 18-gauge 3-5/8"x1-1/4" steel framing at 16" (406mm) on centre (o.c.) complete with an 18-gauge top track and 20-gauge bottom track. 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 platform constructed with 1-1/2"x1-1/2"x1/4" hollow structural steel sections (HSS), 2"x2" lumber, and plywood sheathing.

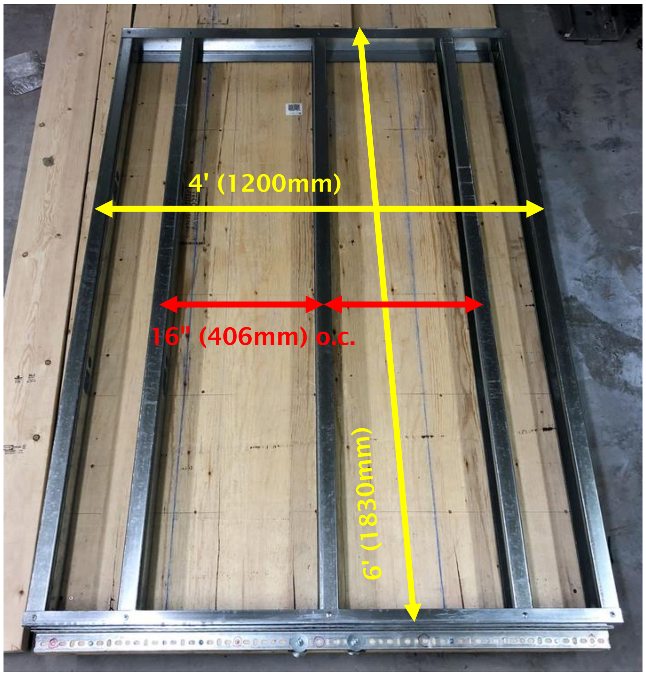

Figure 2.1 4' x 6' steel backup wall framed at 16" (406mm) o.c. stud spacing and secured to a platform constructed with HSS, 2"x2", and plywood sheathing.

The steel backup wall framing was then sheathed with 1/2" DensGlass Gold exterior gypsum board sheathing and Henry Blueskin SA self-adhered membrane applied with Henry Blueskin primer per typical steel frame construction (Figure 2.2 and Figure 2.3). Although the backup wall was 6' (1830mm) tall, the insulation arrangements tested were 4' (1220mm) in height (Figure 2.4). This was done so that by staggering the insulation arrangements along the height, by approximately 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 2.5 and Figure 2.6. As shown in the photos, the intent was to stagger each test wall by 1-1/2" (38mm) but even in laboratory setting, installing the screws precisely is difficult.

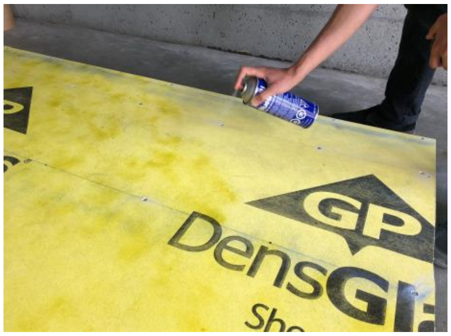

Figure 2.2 Backup wall framing sheathed with DensGlass Gold and Blueskin SA primer being applied.

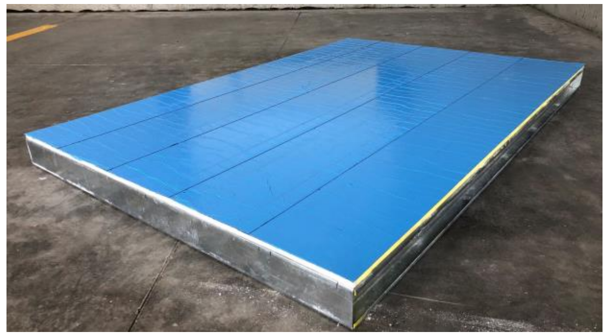

Figure 2.3 Backup wall with Blueskin SA self-adhered membrane applied.

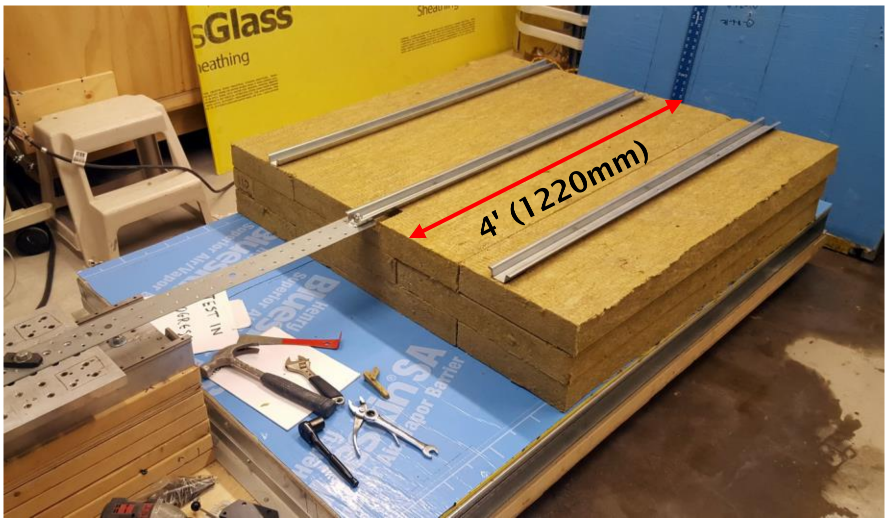

Figure 2.4 9" (3 Layers) of stone wool insulation with 20-gauge 7/8"x1-1/4" steel furring at 16" (406mm) o.c. spacing.

Note that each steel furring (hat track) was secured with three screws at 12" (300mm) spacing.

Figure 2.5 A photo of a centre stud after 8 sets of tests. Test arrangements were staggered along the height of the wall by approximately 1-1/2" (38mm) so that the backup wall framing could be re-used without screws penetrating the same location.

The intent was to stagger each test wall by 1-1/2" (38mm) but even in laboratory setting, installing the screws precisely was difficult, and in some cases the spacing varied.

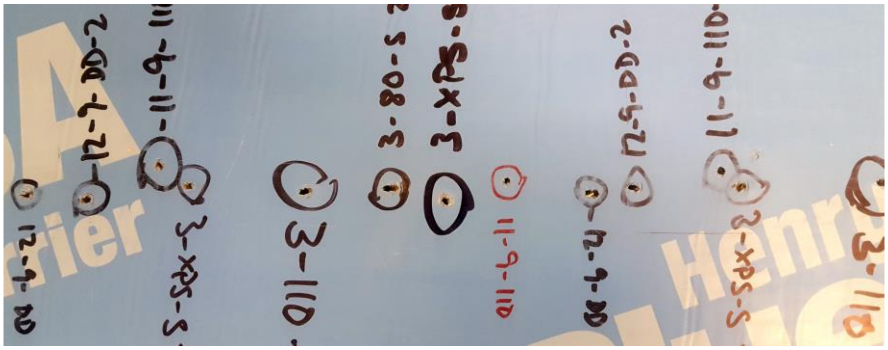

Figure 2.6 An overview along the centre line of a 6-foot-long backup wall after 8 sets of tests.

The intent was to stagger each test wall by 1-1/2" (38mm) but even in laboratory setting, installing the screws precisely was difficult, and in some cases the spacing varied.

Insulation—typically 2' x 4' (610mm x 1220mm)—was placed in staggered layers as shown in Figure 2.7 (9" of ROCKWOOL COMFORTBOARD™ 110 shown) and secured with 20-gauge 7/8"x1-1/4" steel furring (hat track) and 3 screws per furring. Furring was installed with flanges away from the insulation at 16" (406mm) o.c. to match the stud spacing so that the screws can penetrate into the backup wall framing. Similar to wood frame construction, 3" (76mm) 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 9" (152mm to 229mm) range, even with self-drilling fasteners. 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 at 90˚; however, ensuring screw penetration into backup wall framing members is more difficult in real-world applications as self-drilling fasteners work best when installed at 90˚ to the face of substrate, and there is a potential for missing the framing members. For this reason, the structural capacity of the system when not all fasteners penetrate the steel stud is of interest and was included in this evaluation. Note that the portion of the test wall that was loaded (centre furring, centre screws, and centre layers of insulation) was replaced after each set of tests (each test involved two loadings).

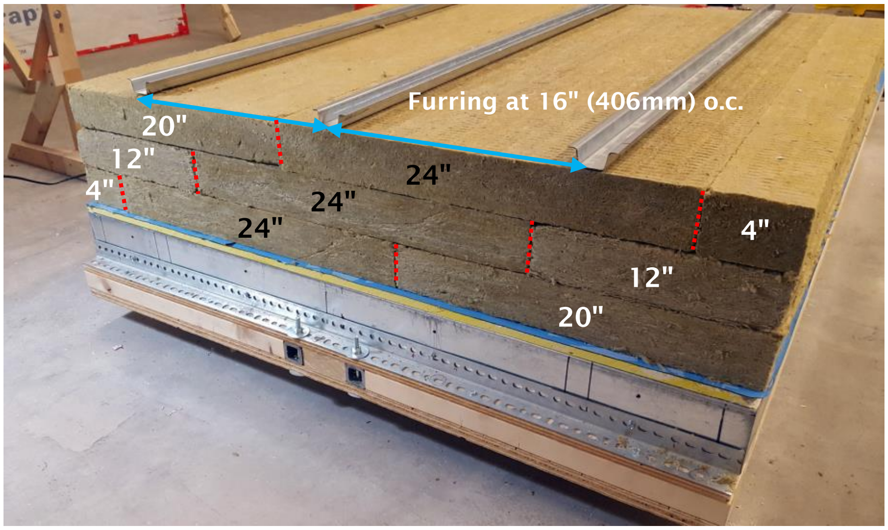

Figure 2.7 An example of staggered insulation installation (9" of ROCKWOOL COMFORTBOARD™ 110 shown)

Top layer, from left: 20" (508mm), 24" (610mm), and 4" (102mm),
Middle layer, from left: 12" (305mm), 24" (610mm), and 12" (305mm),
Bottom layer, from left: 4" (102mm), 24" (610mm), and 20" (508mm).

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 5" and 11" (127mm and 280mm) in the same thread and shank diameter and mechanical properties (e.g., tensile strength, pullout resistance). 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 strength and stiffness of the wall assemblies. Three different lengths of TRUFAST #14 HD Roofing Fasteners by Altenloh, Brinck & Co. U.S., Inc., shown in Figure 2.8, were selected for this testing. Note that these are self-drilling pan head screws intended to secure insulation, coverboards, base sheets and single-ply roof membrane systems to corrugated metal steel, wood, and concrete substrates.

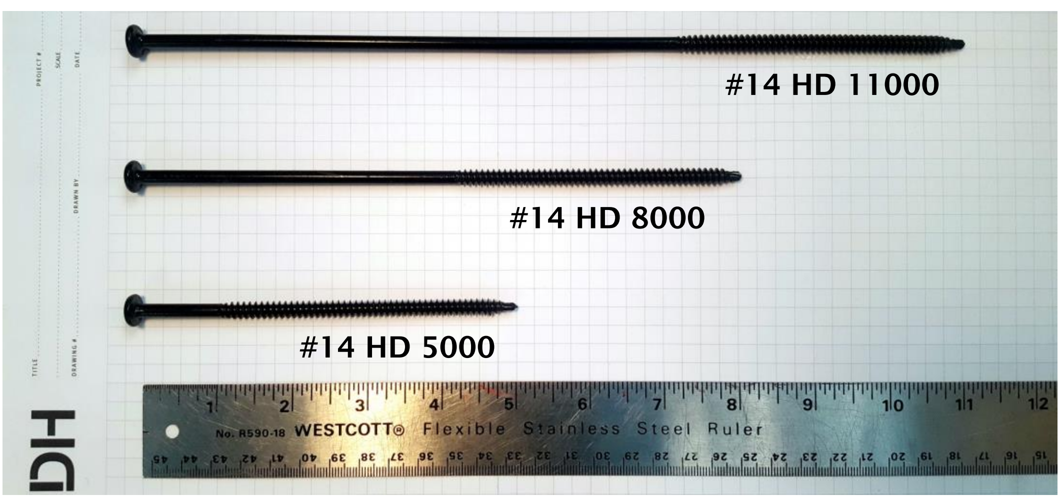

Figure 2.8 TRUFAST #14 HD Roofing Fasteners used in this testing

Physical and mechanical properties of the TRUFAST #14 HD fasteners, obtained from the manufacturer's technical datasheet, are summarized in Table 2.1.

TABLE 2.1 PHYSICAL AND MECHANICAL PROPERTIES OF TRUFAST #14 HD FASTENER	
Nominal Length, in. (mm)	5, 8, and 11 (127.0, 203.2, and 279.4)
Head Diameter, in. (mm)	0.438 (~11.1)
Thread Diameter, in. (mm)	0.237 (~6.0)
Shank Diameter, in. (mm)	0.180 (~4.6)
Thread Density, Threads per Inch (TPI)	13
Fastener Tip Characteristic	#2 Drill Point, 0.130" (3.3mm) Diameter
Tensile Strength, lbf (kN)	3200 (~14.2)
Shear Strength, lbf (kN)	2200 (~9.8)
Pullout Capacity[i], lbf (kN)	675 (~3.0)

[i] Based on 18-gauge steel substrate with yield strength of 33.0ksi (227.5MPa)

Pan head screws are the preferred choice for steel frame construction from constructability considerations as the screw head flange (underside) can be installed flush to the steel furring. Also, in this case the steel furring (hat track) was installed with the flanges away from the insulation which allows for cladding materials to be installed without interfering with the screw head. A close-up photo of the head of TRUFAST #14 HD fastener is provided in Figure 2.9.

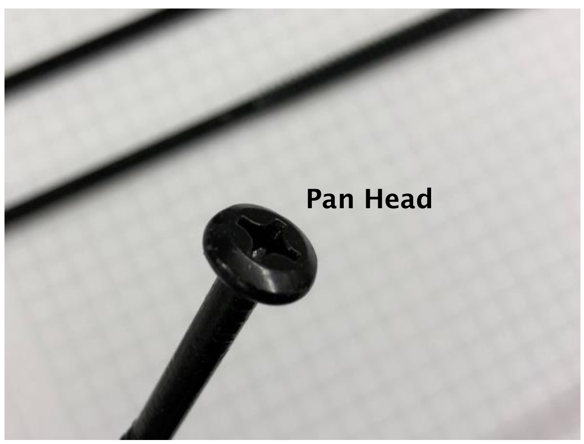

Figure 2.9 Photo of pan head screw

Due to the nature of steel framing and self tapping (drill point) screws, the screws in all the insulation arrangements tested were installed at 90° to the steel furring as shown in the schematic drawing provided in Figure 2.10.

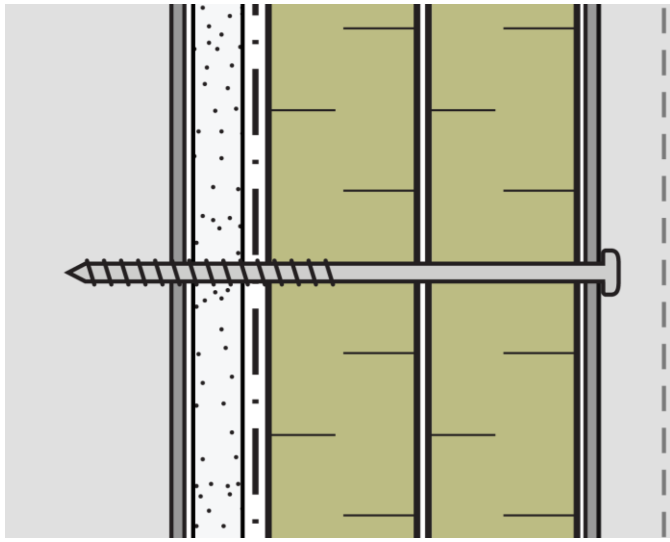

Figure 2.10 A schematic drawing of steel frame test wall assembly from left: Steel stud, gypsum sheathing, air and vapour membrane, insulation (2 layers, stone wool shown), and furring (hat track)

In steel frame construction, the structural capacity of the screw is impacted by the screw's thread density and the gauge and yield strength of the intended fastening substrate (steel framing). In this test, given the screw lengths available, the screws were selected to penetrate at least 3/4" (~19mm) into the steel framing to ensure that the major diameter (threaded part) would be well in contact with the steel framing. The screws were installed at 12" (300mm) spacing with an effective tributary area of 1.33ft² (0.124m²) per screw. The pan head screws were installed so that the screw head flange (underside) was flush to the furring. A torque wrench was used to measure how tightly the screws were installed. Generally, torque of approximately 20in-lb (~ 2.3Nm) was applied to install the screws with qualitatively very little pre-compression of the insulation layers. Also, note that new screws were used on the centre furring for each set (first and second loading) of the test.

2.3 Testing Apparatus

The cladding gravity load was imitated by mechanically applying a load on the centre furring 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[2] 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.

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

[2] The load cell was configured to read at 10Hz (i.e., a reading every 100 millisecond) but the load was logged at 0.5s intervals 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.

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 2.11.

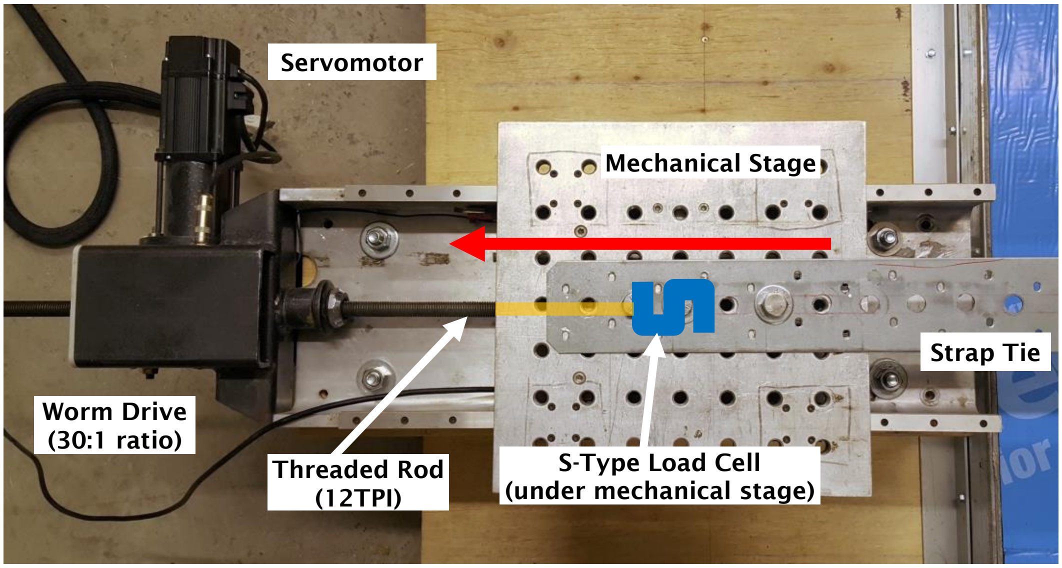

Figure 2.11 Overview of testing apparatus with key components labelled

Note that the direction the test wall furring 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 furring 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.

In order to apply load to the centre furring, the load was transferred from the testing apparatus (mechanical stage) to the steel furring using a Simpson Strong-Tie's steel strap tie. The height of the mechanical stage was adjusted to match the height of the steel furring in order to load it as axially as possible. However, as the furring was loaded, the 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

The test was performed with test wall situated horizontally to isolate the cladding load applied by the test apparatus while ignoring the self-weight of the insulation as various density of insulation materials were used in this testing.

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 4ft² (0.372m²) between three screws) the first loading was meant to be representative of very heavy cladding (25psf or 122.1kg/m²). For reference, the weight range of typical cladding types is summarized in Table 2.2 and are indicated in load-displacement plots provided in this report.

TABLE 2.2 TYPICAL CLADDING WEIGHT

Cladding Type	**Typical Area Density Range** psf (kg/m²)	**Equivalent Load per Furring** 4ft² (0.372m²) 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, significantly exceeds the weight of the heaviest cladding systems typically used. The intent was to evaluate limits of these systems in order to evaluate impacts of different insulation, which might not be evident at a lower load.

After connecting the steel furring to the testing apparatus (mechanical stage), mechanical stage was pulled away from the test wall to eliminate any slack in the load transferring mechanism. This was done by displacing the mechanical stage until the smallest measurable load was registered, then quickly moving the stage back to release the load. Typically, this resulted in 0.5mm to 1.5mm of displacement before the test was performed.

In both tests, the furring 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 furring 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 furring did not return to the original location, and the second loading was initiated after the completion of the first without re-setting the furring 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.

Considering the mechanical properties of the screws used, it was more likely for the screws to rotate around the steel frame penetration point than to pullout from the framing, to stretch due to tensile force, or for the screw head to pull through the steel furring when load was applied. Because the testing apparatus and mechanical stage were fixed flush with the furring, as the screws were loaded, the furring compressed the insulation as the screws started to rotate and, consequently, this allowed a slightly out of plane load to be applied to the furring. A plunger type deflection gauge was used to measure the compression of the insulation approximately at the centre of the furring (near the middle fastener) when furring was loaded to 101lb (46kg) and 899lb (408kg) as shown in Figure 2.12.

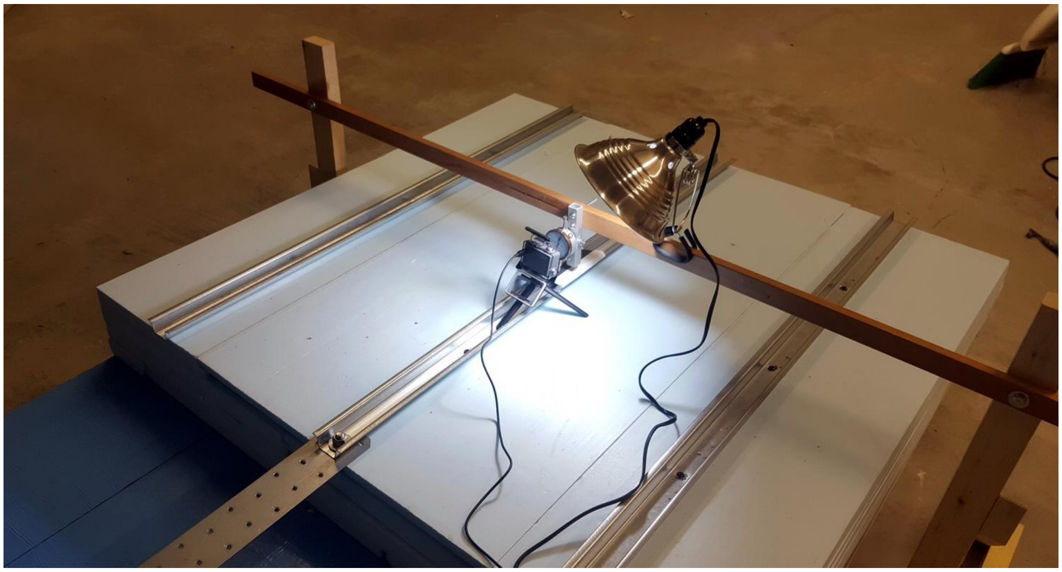

Figure 2.12 Overview of test setup complete with plunger type deflection gauge attached to a cross beam that is independent of the test wall assembly with GoPro and lighting to capture lapse photos of the displacement (6" XPS insulation test shown).

The estimated angle at which the load was applied was calculated and provided in Table 2.3 based on the displacement measurements. The values provided for this exercise are all obtained from test performed on COMFORTBOARD™ 110 as this insulation was the only insulation type tested at all three thicknesses. It should be noted that the decrease in the insulation thickness for COMFORTBOARD™ 80 and COMFORTBOARD™ 110 over CAVITYROCK® was more than for the COMFORTBOARD™ 110. At 6" insulation thickness, COMFORTBOARD™ 80 decreased in its thickness approximately three time more than COMFORTBOARD™ 110 and consequently, the angle at which the load was applied was proportionally larger. The measured decrease in COMFORTBOARD™ 80 insulation thickness and the loading angle is also provided in the table for comparison (row shaded in grey). Also note that no pullout of screws from the framing, lengthening of screws due to tensile force, or screw head pull-through from the steel furring were assumed.

TABLE 2.3 MEASURED DECREASE IN COMFORTBOARD™ 110 INSULATION THICKNESS AND ESTIMATED LOADING ANGLE				
Applied Load on Furring	Nominal Insulation Thickness	Decrease in Insulation Thickness		Loading Angle[i] (degrees)
		1/1000" (mm)	%	
101lb (46kg)	3" (76mm)	2 (0.051)	<0.1	<0.1
	6" (152mm)	2.5 (0.064)	<0.1	<0.1
	6" (152mm)[ii]	7.5 (0.191)	<0.1	<0.1
	9" (229mm)	4 (0.102)	<0.1	<0.1
899lb (408kg)	3" (76mm)[iii]	N/A	N/A	N/A
	6" (152mm)	227 (5.766)	3.8	0.5~1.1
	6" (152mm)[ii]	640.5 (16.269)	10.1	1.5~3.1
	9" (229mm)	287 (7.290)	3.2	0.7~1.4

[i] Assuming the distance between the mechanical stage and furring is 1'~2' (305mm~610mm)

[ii] This row provides measured decrease in COMFORTBOARD™ 80 insulation thickness and estimated loading angle

[iii] The decrease in COMFORTBOARD™ 110 insulation thickness at 3" was not measured during the second loading at 899lb due to deflection gauge malfunction

2.6 Disclaimer

Please note that the testing is intended to demonstrate feasibility of this type of system in steel frame construction only. In particular, these tests were performed and analyzed only for simulated cladding dead load, and the system was not evaluated with respect to other forces that building enclosures and cladding systems are subjected to in-service.

Cladding attachment system design is the responsibility of the design professional for a specific project. It is the responsibility of the licensed architect, designer, specifier, and/or builder to ensure that the construction details are suitable for the intended application of the project.

Commercially reasonable business efforts were made to ensure the accuracy of this testing; however, it is possible that non-material errors or omissions could remain.

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 stone wool insulation. The test wall arrangements were chosen so that by cross-comparison, the impact of insulation thickness and type (compressive strength) on the stiffness (load-displacement relationship) of wall assemblies could be evaluated. Additionally, the impact of preloaded (seated) furring, pre-compression of insulation, and the load-displacement response when not all screws penetrate the steel stud framing were evaluated.

The data obtained from the testing apparatus was the load applied on one steel furring (hat track) fastened with 3 screws; however, the load-displacement plots presented in this section are representative of load per screw. 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 claddings, 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 1ft^2.

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 stone wool insulation without the use 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. Three ROCKWOOL stone wool insulations and one XPS insulation were compared. Table 3.1 summarizes compressive strength and density of the insulations tested, obtained from manufacturer's product data sheet where available.

TABLE 3.1 COMPRESSIVE STRENGTH AND DENSITY OF INSULATION

Insulation Type	**ASTM C-165**, psf (kPa)		**ASTM C-303,** lbs/ft³ (kg/m³)
	at 10%	**at 25%**	
COMFORTBOARD™ 80	439 (21)	1065 (50)	8 (128)
COMFORTBOARD™ 110	584 (28)	1566 (75)	11 (176)
CAVITYROCK® (6")	-	-	6.2 (100) outer layer and 4.1 (65) inner layer
	ASTM D-1621, psf (kPa)		-
XPS (Type 3)	2880 (140)		-

While deflection of strapping that supports the cladding system is a key design consideration, little research has been done to define what is allowable for different cladding types and cladding manufacturers are not typically providing this information. For the purposes of comparison, it is possible to compare the measured deflection of the furring to the typical design movement allowances for deflection of concrete floor slab. As the primary structure of the building experiences variety of loading including short-term live loads and long-term creep. The cladding support system or cladding itself must be designed to allow for this relative movement. Typically, the primary structural engineer of record will provide an upper limit for deflection allowance so that this movement can be accommodated in finishes and non-structural wall system (e.g., with deflection heads for infill steel stud walls). This deflection allowance is also taken into account for cladding system design such that no unintended load will be imposed on the cladding and cladding system by the deflection of the primary structure. Typical deflection allowances for this type of primary structure deflection is in the range of ~20mm (~13/16") and this value can be used as a reference and a baseline for comparing magnitude of displacement observed in this study.

Figure 3.1 plots the test result for wall assemblies with 6" (152mm) of insulation and compares load-displacement response of ROCKWOOL COMFORTBOARD™ 80, ROCKWOOL COMFORTBOARD™ 110, and XPS insulation. The plots provided are from the first loading for each assembly and the bands of shaded area correspond to the weight of typical cladding types per square foot.

As illustrated, the load-displacement response is relatively linear, showing very little differences in stiffness between the wall assembly types; however, as expected, the most rigid insulation (XPS) appears to be the stiffest and the insulation with the least compressive strength (ROCKWOOL COMFORTBOARD™ 80) deflects the most.

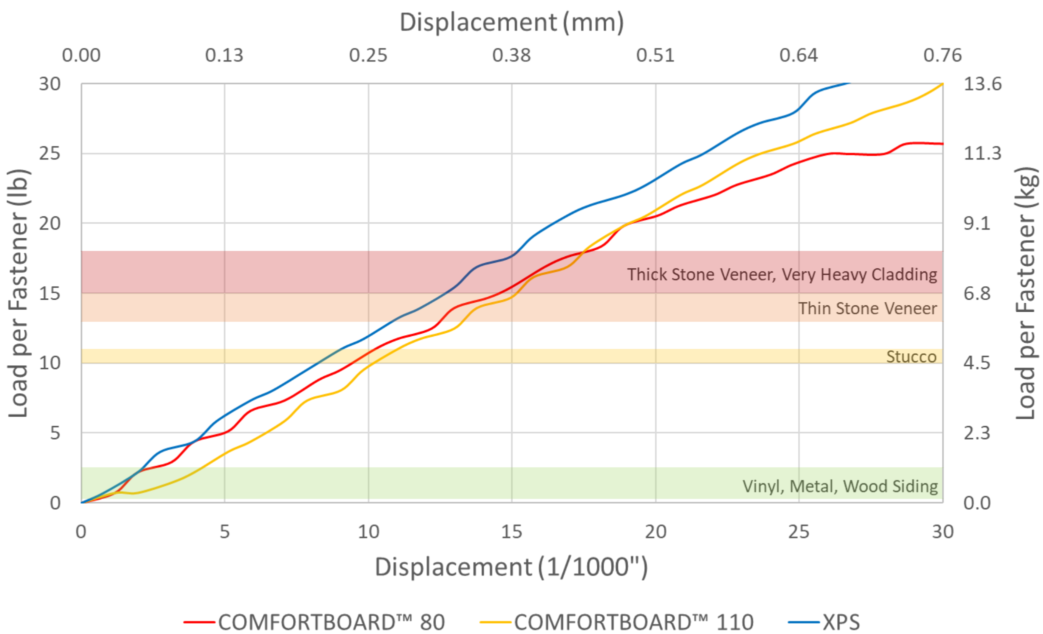

Figure 3.1 Load-displacement plot comparing different insulation arrangements at 6" (152mm) thickness.

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

Figure 3.2 plots the load-displacement relationship of the same test wall assemblies but during the second loading for each assembly. Note that the bands of shaded area correspond to the weight of typical cladding types per square foot.

The graph shows even smaller differences in stiffness between the wall assembly types than during the first loading. When a screw is loaded at 25lb (9.1kg), the difference in displacement between the XPS assembly (0.021" or 0.53mm) and COMFORTBOARD™ 80 (0.022" or 0.56mm) was negligible. A similar result was observed for these assemblies with 3" of insulation installed. The plots for the first and the second loading for the 3" insulation are provided in Appendix.

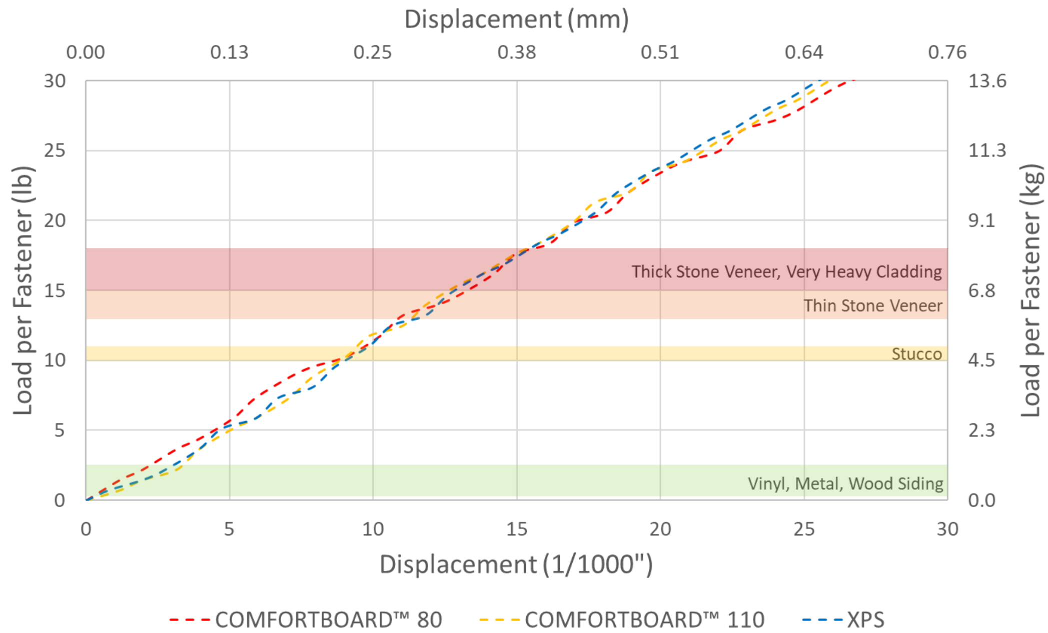

Figure 3.2 Load-displacement plot comparing different insulation arrangements at 6" (152mm) thickness.

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

Figure 3.3 provides the load-displacement data for a much higher test load range during the second loading. Note that the plot range shown in Figure 3.2 is highlighted with a red box. As illustrated in the Figure 3.3, between 30lb (14kg) and 60lb (27kg) on a screw, the load-displacement plots of the XPS and COMFORTBOARD™ start to present a varying degree of slope and the difference in the stiffness between the insulation types becomes more evident, though these loads on a screw are well beyond typical cladding dead loads anticipated in-service. It is interesting to note that the COMFORTBOARD™ 80 and COMFORTBOARD™ 110 wall assemblies produced a similar result up to the 60lb range and then diverge.

For comparison, Figure 3.3 also includes data from Structural Testing of Screws through Thick Exterior Insulation[3] for wood frame construction for the same insulation thickness and types. From this comparison it is evident that the steel stud walls are initially less stiff than the comparable wood-stud assemblies; however, at higher amounts of displacement the steel stud and wood stud load-deflection responses are relatively similar. This is likely a result of the fasteners in to wood studs providing some moment resistance due to embedment of the fasteners, whereas the steel stud assembly does not have this embedment and thus likely acts more as a pin connection and allows more initial displacement. However, once initially displaced, the compression of the insulation can contribute a larger portion of the load resistance of the systems, and the wood stud and steel stud assemblies provide more similar load-deflection responses.

[3] Structural Testing of Screws through Thick Exterior Insulation Report dated June 13, 2017

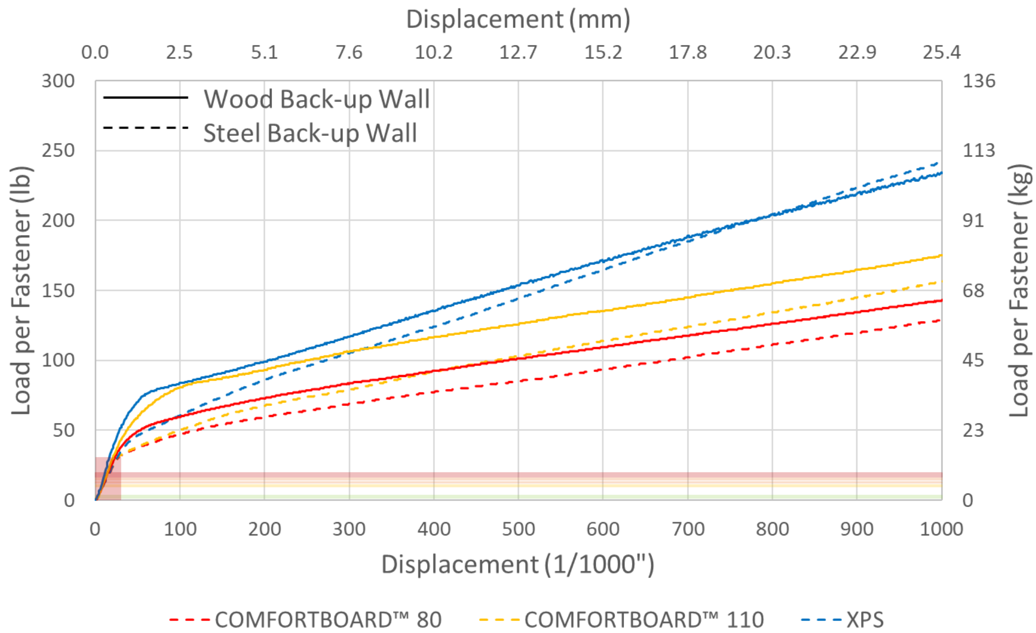

Figure 3.3 Load-displacement plot comparing different insulation arrangements at 6" (152mm) thickness.

The plot provided in dashed line is for the ***second loading*** *of each setup (steel back-up wall) and the load-displacement data from tests performed for wood frame (second loading) is provided in solid line. Note that the plot range shown in Figure 3.2 is highlighted by a red box.*

Figure 3.4 plots the load-displacement relationship for test wall assemblies with 9" (229mm) 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.

Similar to the data provided for the assemblies with 6" of insulation, the graph is relatively linear; however, it does show an increased difference in stiffness between the wall assembly with COMFORTBOARD™ 110 and the other assemblies with 3" of COMFORTBOARD™ 110 over 6" of CAVITYROCK®. This is understandable as CAVITYROCK® is approximately half as dense as COMFORTBOARD™ 110.

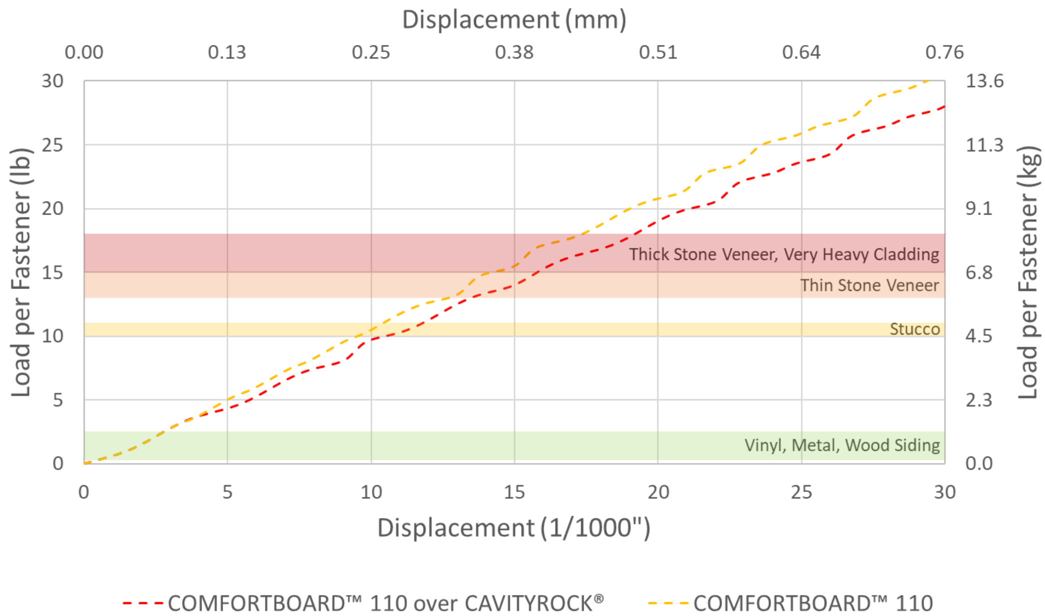

Figure 3.4 Load-displacement plot comparing different insulation arrangements at 9" (229mm) thickness.

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

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 assembly cladding support. ROCKWOOL COMFORTBOARD™ 110 was tested at 3" (1 layer, 76mm), 6" (2 layers, 152mm), and 9" (3 layers, 229mm) total insulation thicknesses and COMFORTBOARD™ 80 was tested at 3" and 6" total insulation thicknesses.

Previous testing in this area has shown that even at 9" insulation thickness, screws through strapping are sufficient to support lightweight cladding (~2.5psf or ~12.2kg/m², e.g., vinyl, metal, wood siding) in wood frame construction.

Figure 3.5 plots the load-displacement relationship for the test walls with 3", 6", and 9" (76mm, 152mm, and 229mm) ROCKWOOL COMFORTBOARD™ 110 insulation. The plot comparing different thicknesses of COMFORTBOARD™ 80 (3" and 6") was similar to COMFORTBOARD™ 110 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.

As illustrated, assemblies with 3" (76mm) of insulation experienced the least deflection (0.012" or 0.30mm) when the screw is loaded at 25lb (9.1kg) while 6" and 9" (152mm and 229mm) thickness of insulation had a very similar load-displacement response up to this load. When the screw is loaded at 25lb (9.1kg), the difference in displacement between the test wall with 6" (152mm) of insulation (0.022" or 0.55mm) and 9" (229mm) of insulation (0.024" or 0.61mm) was only 0.003" (0.06mm). The difference in load-displacement response due to changing insulation thicknesses is more apparent than the differences observed as a result of changes in insulation type (compressive strength).

In steel frame construction, it is theorized that this cladding attachment method relies more on the rotation of screws at the penetration (pin connection) that leads to the compression of the insulation layer by the steel furring, creating a truss action to resist the load. The shorter screws need to travel less distance compared to longer screws to create the same amount of rotation. Thus, the insulation in the system with shorter screws will be compressed and engage in resisting the load in a shorter displacement than system with longer screws, resulting in a stiffer response consistent with that shown in the measured results.

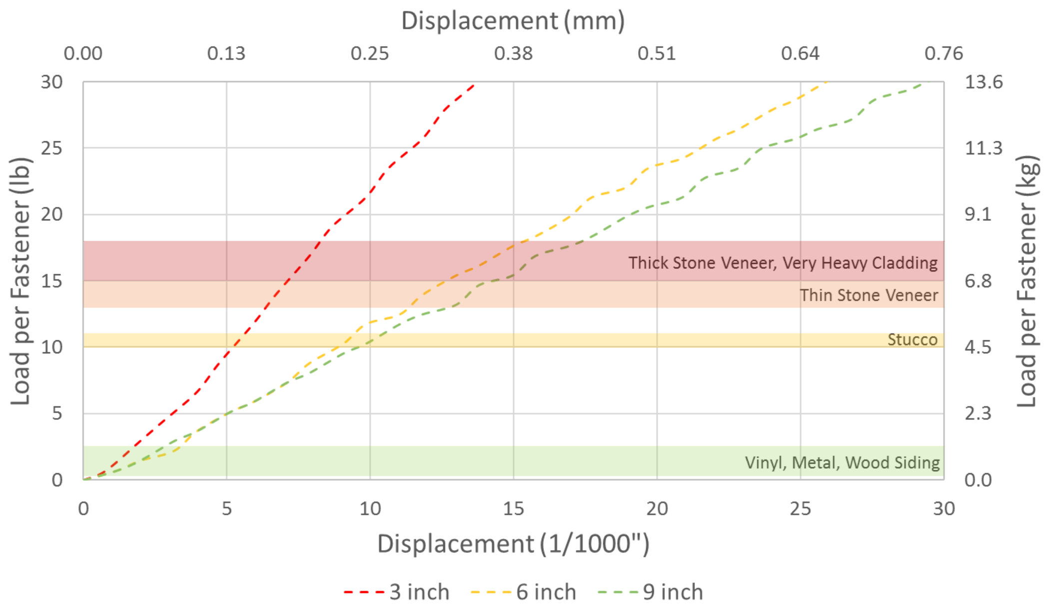

Figure 3.5 Load-displacement plot comparing ROCKWOOL COMFORTBOARD™ 110 insulation at 3", 6", and 9" (76mm, 152mm, and 229mm) thicknesses.

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

3.3 Evaluation of Preloading and Pre-Compression

Previous testing has shown that the majority of deflection with this type of system occurs during the initial loading and preloading (seating) the strapping was found to provide a system that experiences less initial deflection in wood frame construction. Based on this, the effectiveness of preloading and pre-compression in steel frame construction was investigated. This section contains the results and discussion relating to tests performed on a wall system with preloaded furring and tests performed on a wall system with pre-compressed insulation.

As mentioned in Section 2.4: 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 are compared in Figure 3.6. 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 sagging (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 furring. That said, the differences in the stiffness between the first and second loadings is relatively small, and unlikely to be significant with respect to adequately supporting wall cladding.

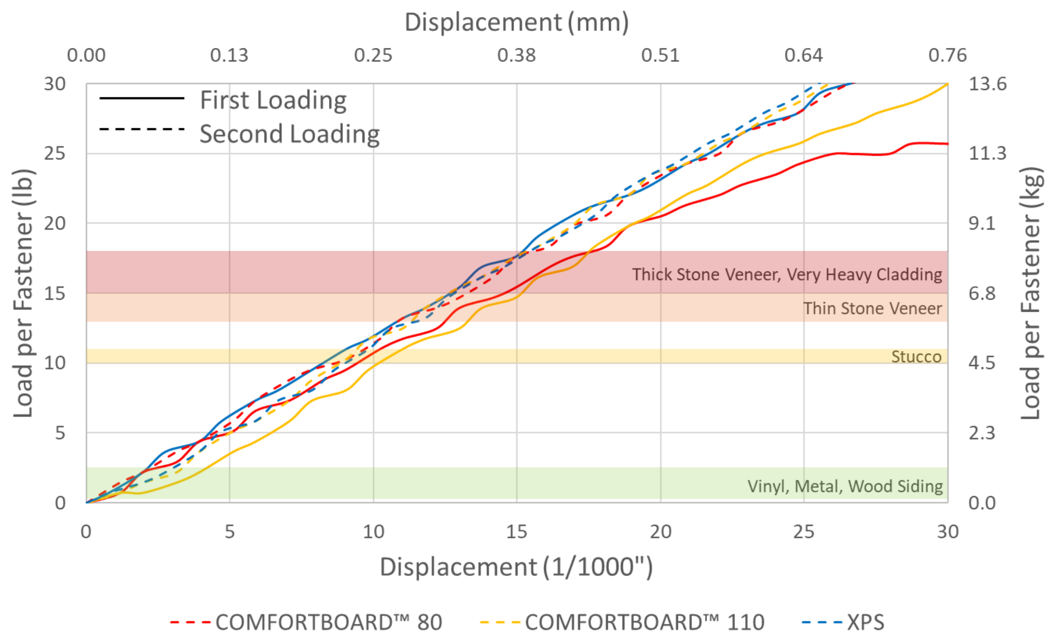

Figure 3.6 Load-displacement plot comparing first and second loading by insulation arrangements

All insulation arrangements are 6" (152mm) thickness. The first loading plot is provided with solid line and the second loading with dashed line.

Given these findings, to mitigate the initial deflection which is typically the largest, the effectiveness of preloading the furring (i.e., seat the furring on the insulation) prior to performing the test was investigated. The idea is to intentionally cause this initial deflection by preloading the furring from the top, in the direction of the simulated gravity load with a hammer until the furring started to compress the insulation slightly. To achieve this preloading, the furring was initially installed approximately 1/4" (6mm) offset from the top edge of the insulation and the furring was struck until it became flush with the insulation as shown in Figure 3.7.

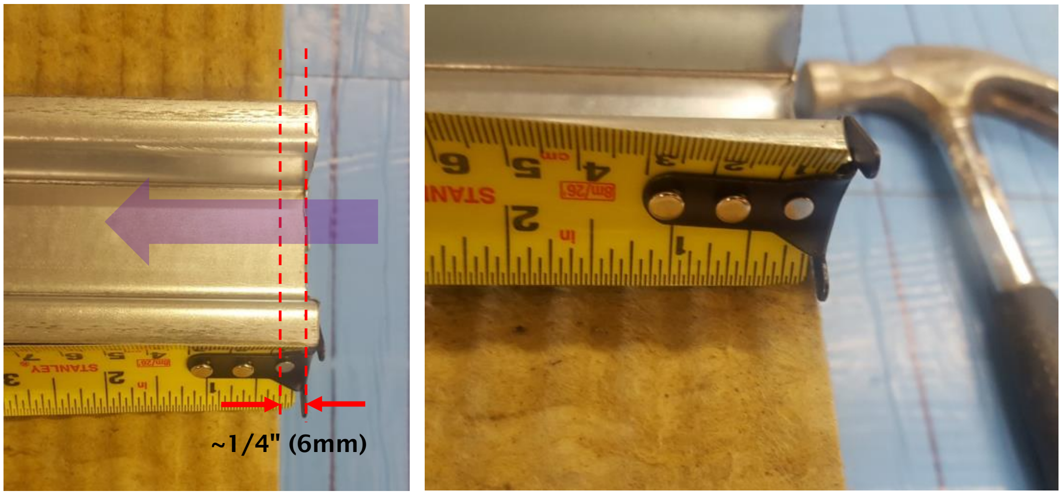

Figure 3.7 Preloaded furring

The furring was initially installed approximately 1/4" (6mm) offset from the edge of the insulation (left) and the furring was struck with a 20oz hammer in the direction of the simulated gravity load until the furring became flush with the insulation and started to compress the insulation slightly (right).

The plot provided in Figure 3.8 compares the load-displacement relationship of preloaded and as-installed wall assemblies, both having 6" (152mm) COMFORTBOARD™ 80. 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 almost no change in the load-displacement response on its first loading compared to the as-installed system, and only at load ranges above 22lb (~10.0kg) did preloaded system appears to be slightly stiffer. Interestingly, the as-installed wall system on its second loading experienced slightly less deflection than did the preloaded system, and the difference in stiffness between the first and second loadings was greater for the as-installed system than it was for the pre-loaded system.

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

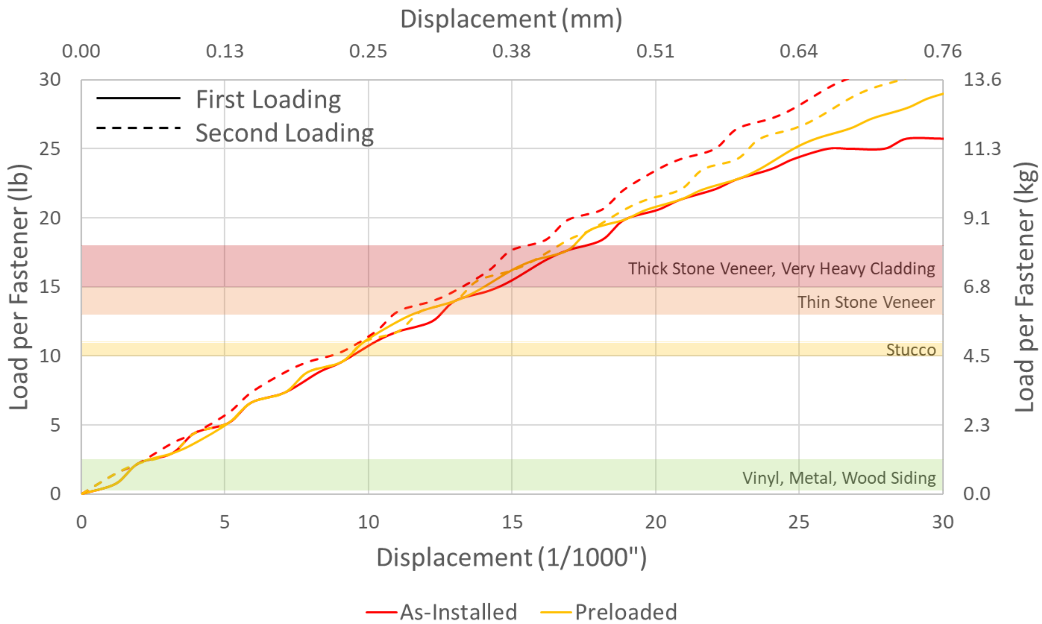

Figure 3.8 Plot comparing load-displacement relationship of a similar test wall systems with furring on one of the systems preloaded in the direction of loading (gravity) prior to the first loading

Both assemblies incorporated a total of 6" (152mm) COMFORTBOARD™ 80 insulation. The first loading plot is provided with a solid line and second loading with a dashed line. The plot for the higher range for second loading is provided in the Appendix.

The load resistance of this cladding attachment system can be provided by a number of different mechanisms. As previously discussed, when fasteners are installed in the wood studs, there is embedment of the fastener in to the wood which provides some amount of moment resistance. Consequently, bending resistance of the fastener and the moment resistance of this connection were found to contribute significantly to the overall load-deflection response of the cladding attachment system. Figure 3.9 illustrates possible mechanical failure mechanisms relating to a screw securing strapping in wood-frame construction.

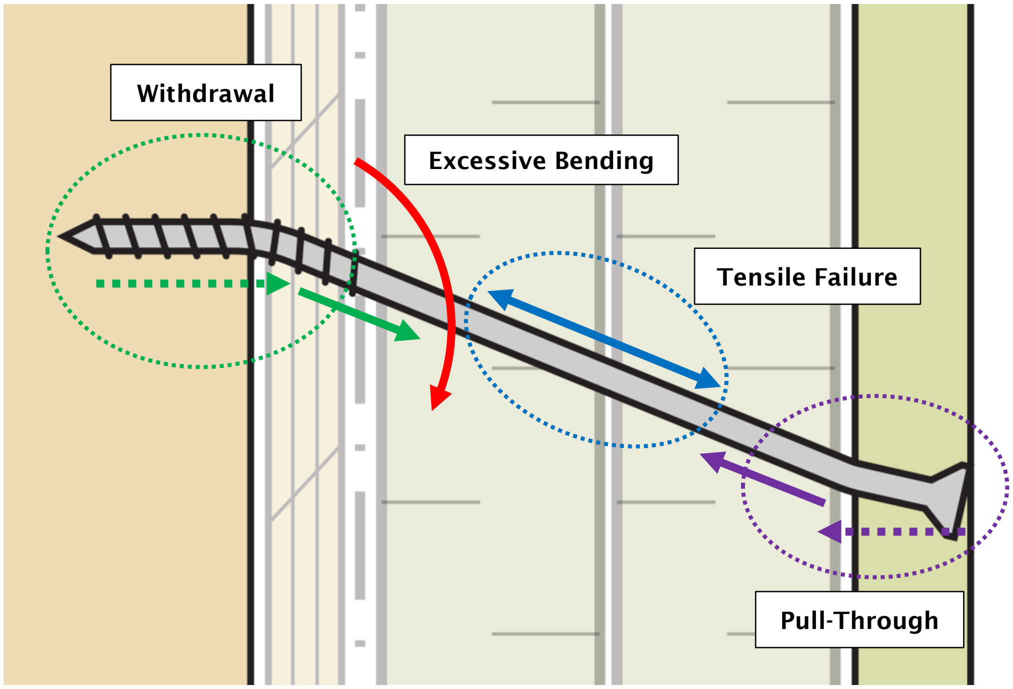

Figure 3.9 Illustration of possible mechanical failures relating to a screw securing a strapping in wood-frame construction

By comparison, it is likely that a fastener installed into steel stud framing will provide less moment resistance than it would when installed in to wood, and thus act more similarly to a pin-type connection. When this connection acts more similarly to a pin-type connection, the contribution of the truss action created by compression of the steel furring against the face of insulation is likely to become a more substantial component of the overall load-displacement response of the system, and the fasteners are very unlikely to experience significant bending. Figure 3.10 illustrates mechanical properties of fastener and steel framing and furring likely to help to resist cladding dead load for this type of system in steel frame construction.

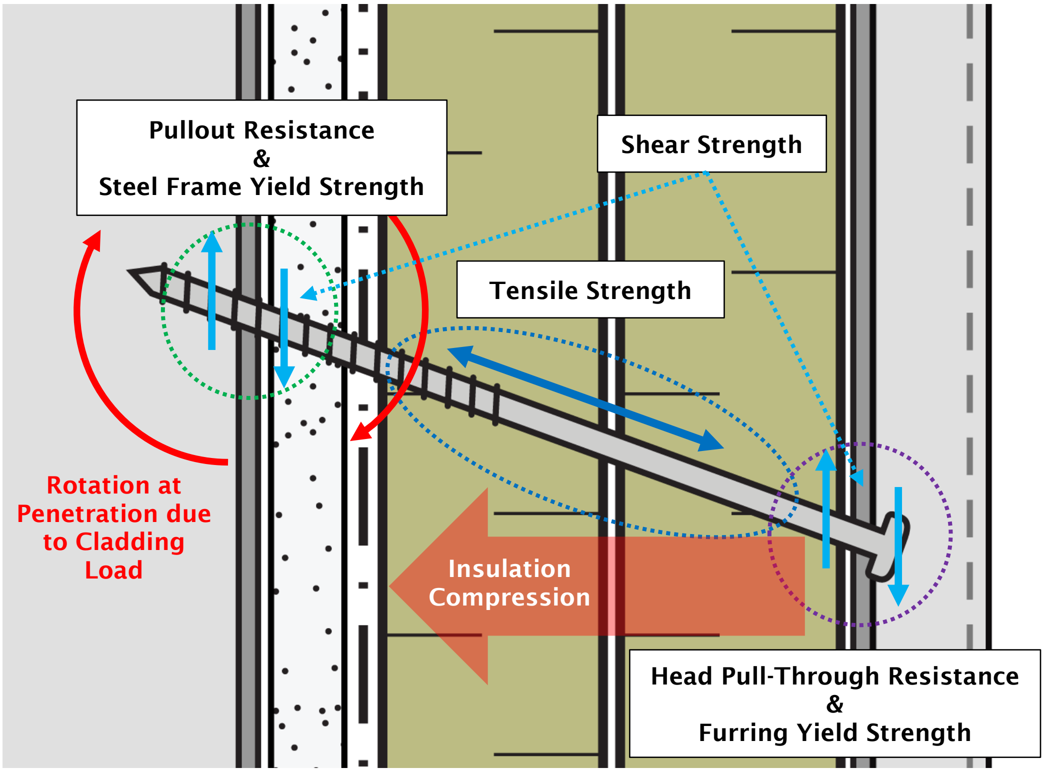

Figure 3.10 Illustration of mechanical properties of fastener and steel framing and furring relating to resisting gravity load in steel frame construction

The test result in Section 3.2: Evaluation of Insulation Thickness showed that the shorter screws needed to travel less distance compared to longer screws to create the same amount of rotation and thus the insulation in the system with shorter screws was compressed and engaged in resisting the load in a shorter displacement than system with longer screws, resulting in a stiffer response. The idea behind pre-compression of the insulation is so that by pre-compressing the insulation, the furring would not need to first deflect vertically prior to engaging the insulation in compression and forming a truss system to resist the cladding dead load. This pre-compression can be provided by installing the furring such that it slightly compresses the insulation, rather than installing the furring flush to the face of the insulation. The effectiveness of pre-compressing the insulation was investigated by pre-compressing COMFORTBOARD™ 80 by installing the screws through the furring until the furring was embedded approximately ~1/4" (6mm) into the insulation as shown in Figure 3.11.

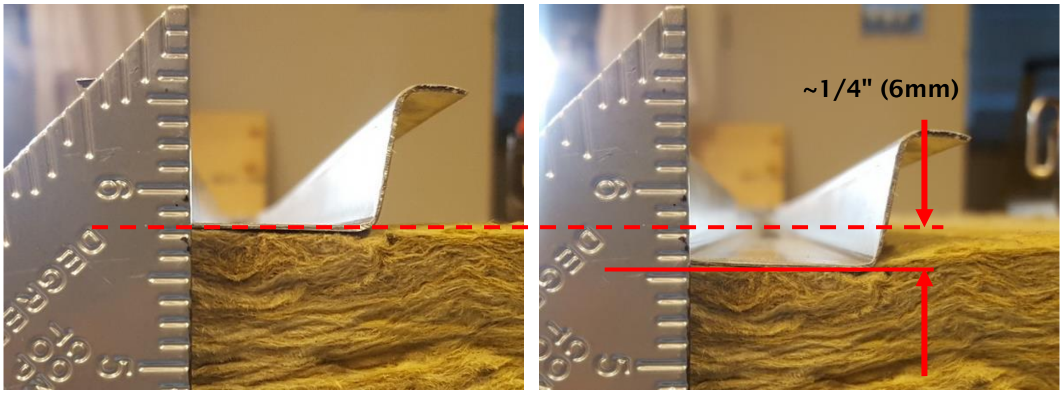

Figure 3.11 Pre-compressing insulation

Fasteners were installed and tightened until the furring was embedded approximately 1/4" (6mm) into the insulation

The plot provided in Figure 3.12 compares the load-displacement relationship of pre-compressed insulation and as-installed (furring flush with insulation) wall assemblies, both having 6" (152mm) COMFORTBOARD™ 80. 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 pre-compressed system experienced slightly less deflection on its first loading than the as-installed wall assembly above 20lb (9.1kg), but the difference at the lower loading range was negligible. The same could be seen with the plot for the second loading, the pre-compressed and as-installed wall assemblies had similar performance and the difference in displacement between them was negligible. This suggests that even when the furring is installed so that it slightly compresses the insulation, a relatively small amount of deflection of the furring is required before it engages the insulation in compression.

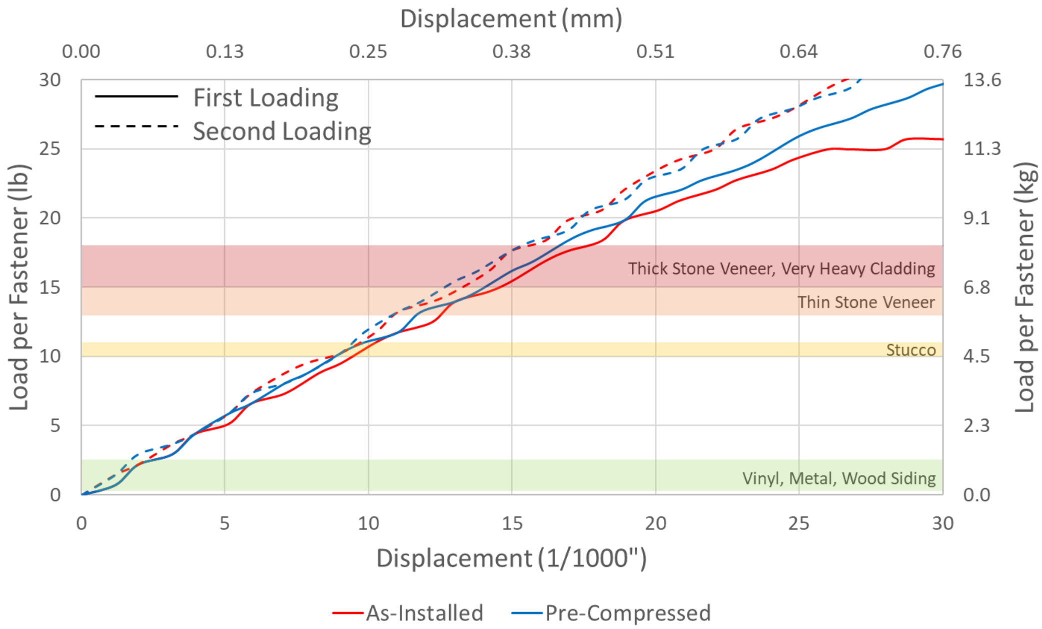

Figure 3.12 Plot comparing load-displacement relationship of similar test wall systems with furring on one of the systems pre-compressing the insulation prior to the first loading

Both assemblies incorporated a total of 6" (152mm) COMFORTBOARD™ 80 insulation. The first loading plot is provided with a solid line and second loading with a dashed line. The plot for the higher range for the second loading is provided in the Appendix.

The plot provided in Figure 3.13 compares the load-displacement relationship of pre-compressed insulation and preloaded furring wall assemblies, both having 6" (152mm) COMFORTBOARD™ 80. Note that the first loading of each test wall is provided with a solid line and the second loading with a dashed line. Also, the bands of shaded area correspond to the weight of typical cladding types per square foot. The figure illustrates that the pre-compressed system experienced slightly less deflection on its first loading than the preloaded wall assembly. Naturally, the load-displacement response of these two techniques are even more similar (compared to the as-installed test result), as compression of the insulation is engaged slightly earlier in both cases. However, with respect to constructability considerations, pre-compression may be easier to execute in real-world application with a driver set at a torque or with an insulation depth gauge rather than hammering each piece of furring from the top. Overall, the difference in load-displacement response between the as-installed case and the preloaded and pre-compressed cases is sufficiently negligible that it is unlikely to be worth using either of these strategies.

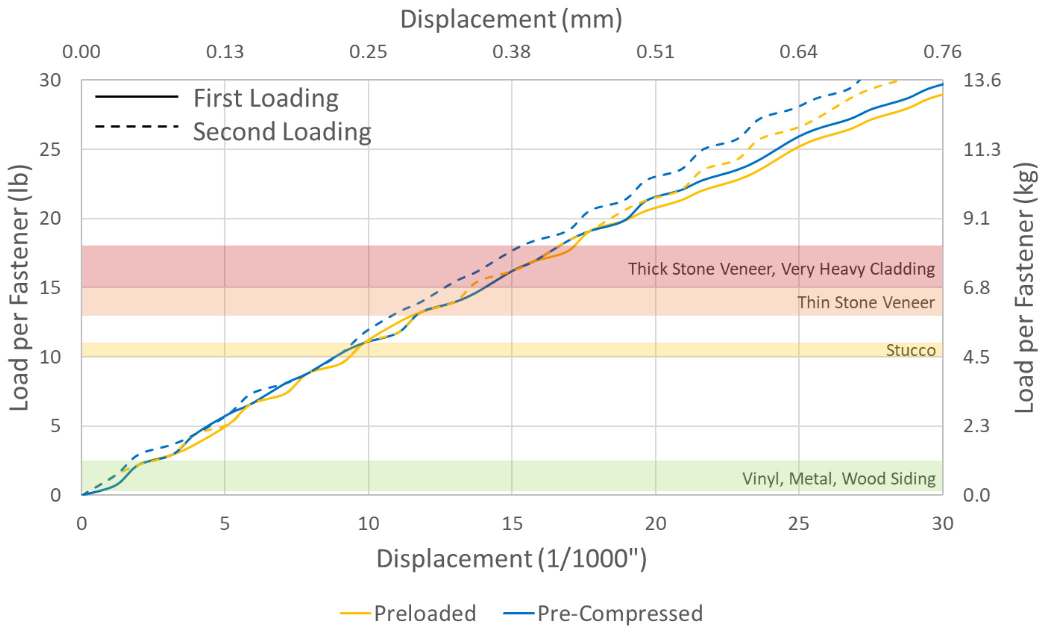

Figure 3.13 Plot comparing load-displacement relationship of similar test wall systems with furring on one of the systems preloaded in the direction of loading (gravity) and furring on the other pre-compressing the insulation prior to the first loading

Both assemblies incorporated a total of 6" (152mm) COMFORTBOARD™ 80 insulation. The first loading plot is provided with a solid line and second loading with a dashed line. The plot for the higher range for second loading is provided in Appendix.

3.4 Evaluation of a Fastener Missing the Stud Framing

In this study, the objective was to investigate the performance of exterior-insulated wall assemblies with the 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 90˚ screw penetration into backup wall framing member is difficult in real-world application, and the potential for missing the framing members is high, especially as the insulation thickness increases. Therefore, the importance of screws penetrating the backup wall framing member and how screws missing the studs affects the performance of these types of wall system were investigated.

To assess the implications of missing a stud, a test was performed with 6" (152mm) of ROCKWOOL COMFORTBOARD™ 80 insulation, TRUFAST #14 HD Roofing Fasteners and 1/2" DensGlass Gold gypsum board sheathing. In this test, one screw penetrates only the gypsum board sheathing layer, and did not penetrate the stud framing, while the remaining two fasteners were both installed securely in to the stud framing. This was achieved by intentionally driving the centre fastener slightly on an angle in a direction perpendicular to the furring. Photos provided in Figure 3.14 were taken after the test and illustrate how far away the centre fastener was installed relative to the stud. The fastener was installed such that it missed the edge of the stud by approximately 3/4" (19mm).

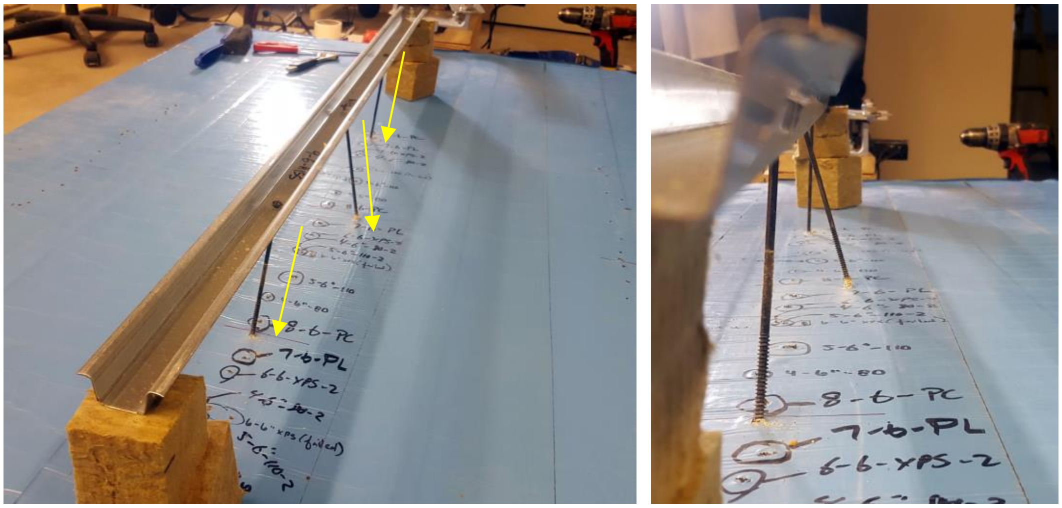

Figure 3.14 Photos of test wall with centre fastener missing the stud taken after the test

The plot provided in Figure 3.15 compares the load-displacement relationship of furring installed with all three screws (as-installed) and the other with one screw not penetrating the framing member, both having 6" (152mm) COMFORTBOARD™ 80. 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 both wall assemblies show almost identical load-displacement response which is different from what one might expect, and also differs from the results of similar tests that were performed with wood backup walls. It is theorized that this system relies primarily on the truss created by the compression of the insulation, and thus the number of fasteners is relatively unimportant so long as the furring is secured sufficiently that it remains in alignment and compresses evenly against the surface of the insulation. By comparison, the wood-frame wall is thought to have relied more heavily on contribution of the moment connection of the fastener to the wood, and thus the number of fasteners would have a more direct impact on the results.

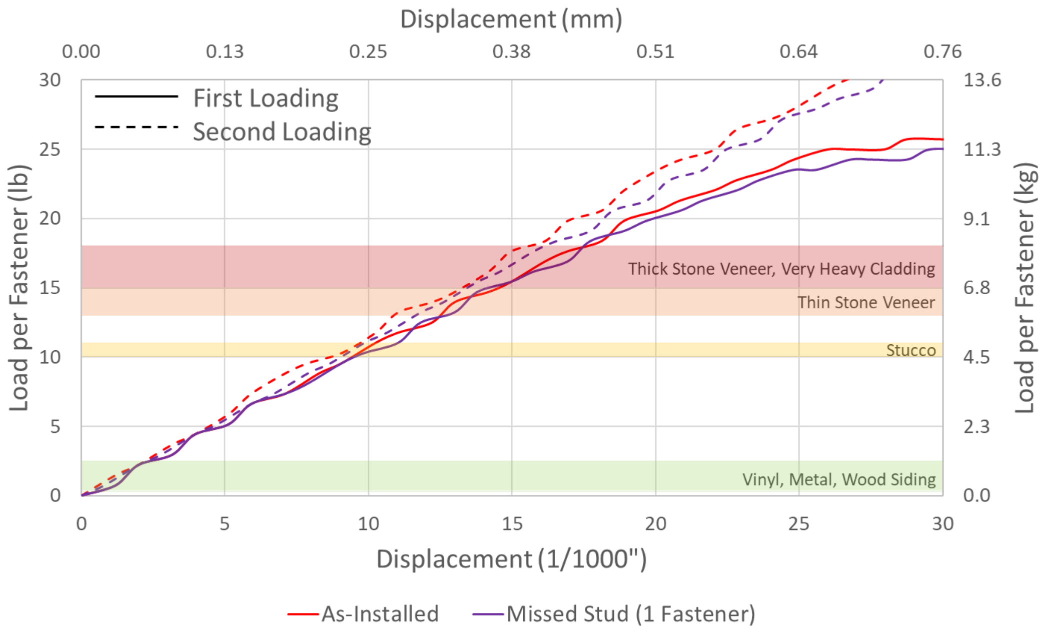

Figure 3.15 Load displacement plot comparing stiffness of assemblies when all fasteners penetrate steel stud framing (As-Installed) and another when one fastener misses framing

Both assemblies incorporated a total of 6" (152mm) COMFORTBOARD™ 80 insulation. The first loading plot is provided with a solid line and second loading with a dashed line.

Figure 3.16 provides load-displacement data for a higher test load range when as fastener has missed the stud. Note that the plot range shown in Figure 3.15 is highlighted with a red box. At the test load range above 40lb (18.1kg), there is a noticeable difference in stiffness between the system with all of the fasteners in to the stud and the system with one faster that missed the stud. However, the difference in these results is relatively small, and suggests that as long as the load is well below the pullout resistance of the fastener connections and the furring is relatively stiff over the span between embedded fasteners, the two system will provide relatively similar load-deflection responses. This is likely because the fasteners which did penetrate in to the stud are sufficient to hold the furring against the insulation and allow for development of insulation compression to support the applied load.

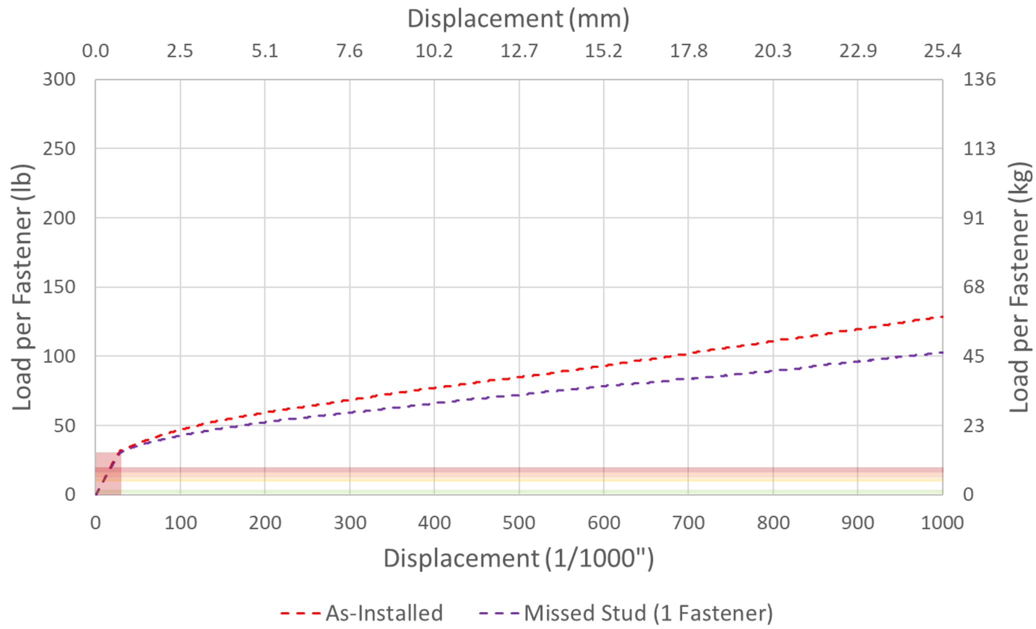

Figure 3.16 Load displacement plot comparing stiffness of assemblies when all fasteners penetrate steel stud framing (As-Installed) and another when one fastener misses framing

Both assemblies incorporated a total of 6" (152mm) COMFORTBOARD™ 80 insulation. Note that the plot range shown in Figure 3.15 is highlighted with a red box.

In addition to the structural considerations, it is also important to consider the air and water control implications of fastening through the sheathing membrane, and this importance is increased for fasteners which miss the structural steel framing. In wood construction, embedment of the fastener in to the surrounding wood framing or sheathing has been shown to assist in the sealing of the penetration, and in most instances is likely to provide sufficient levels of performance. Contrarily, fasteners through sheathing membranes applied over gypsum wall board substrates have been shown to have difficulty self-sealing, and often can substantially damage the gypsum wall board and sheathing membrane as they attempt to self-tap in to the steel stud during installation. To mitigate this when using clip-type cladding attachment systems, sealant is sometimes installed behind the clip to assist in sealing the fastener penetrations. This approach is not possible when using only long screws through the insulation. Furthermore, if a fastener were to miss the stud, the exterior gypsum wall board will not provide a secure connection for the fastener, and thus it is likely that significant damage could be done to the sheathing membrane. If an installer, having realized that the fastener had missed the stud, were to remove the fastener, a hole would be left in the sheathing, and would likely be difficult or impossible to detect from the exterior due to the overlying insulation material. Given this potential for a defect in the sheathing, it is worth considering the relative risks that this may pose to different systems. Particular considerations include the location of the water control layer (i.e., water resistive barrier) on the sheathing, the ability for water to be held, drain, or dry from behind the insulation, and the exposure conditions.

3.5 Evaluation of the use of Horizontal Metal Straps

Horizontal metal strap is often used for laterally bracing steel stud wall. This section investigates structural performance of system where fasteners are installed in the metal strap instead of the framing. Naturally, this setup will add an extra path for the cladding dead load to be carried back to the structure.

As shown in Figure 3.17, unlike other test walls tested in this study, the steel studs were re-framed in a such way that there was no stud installed at the centre of the wall but instead two studs, 8" (203mm) away from the centre line (yellow dash line), were installed at 16" (406mm) spacing. Three 18-gauge 2" metal flat strapping, which are the fastening base for this test, were installed at 12" (305mm) spacing perpendicular to the studs and to the direction of simulated load. It is very unlikely to install lateral bracing at this spacing in actual construction but for the purpose of comparison with other test walls in this study, the fastener spacing for the furring, thus the horizontal strap spacing was kept at the same. The horizontal strapping was fastened at every stud and while efforts were made to ensure that horizontal strapping was installed tight, some slack remained.

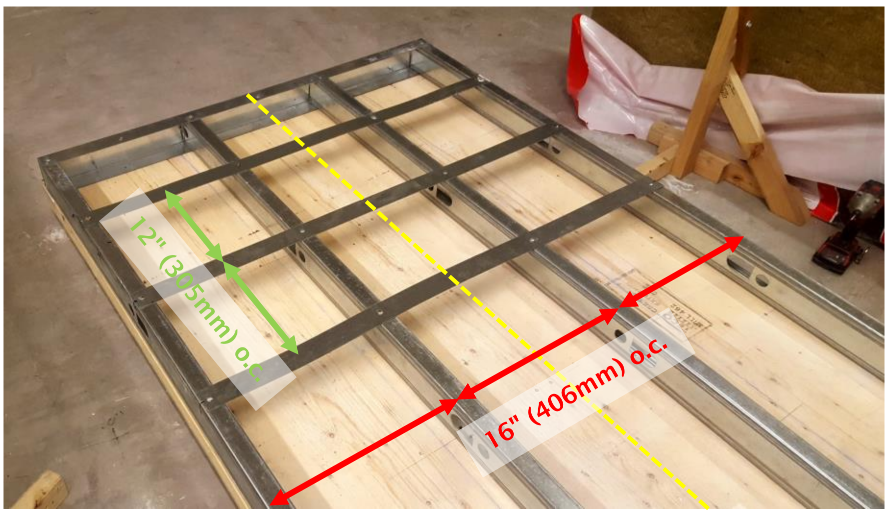

Figure 3.17 4' x 6' steel backup wall was re-framed with two studs 8" (203mm) away from the centre line (yellow dash line), installed at 16" (406mm) spacing.

Three 18-gauge 2" metal flat strapping were installed at 12" (305mm) spacing perpendicular to the studs for fastening base.

Once re-framing and installation of the horizontal straps were complete, the wall was sheathed with 1/2" DensGlass Gold exterior gypsum board sheathing and Henry Blueskin SA self-adhered membrane applied with Henry Blueskin primer in the same manner as all other test walls as shown in Figure 3.18.

Figure 3.18 Backup wall with Blueskin SA self adhered membrane applied.

Approximate locations of the horizontal straps are indicated with yellow dotted lines.

Photos of the test wall with horizontal straps provided in Figure 3.19 and Figure 3.20 are taken from the interior side of the wall after the testing.

Figure 3.19 A photo of the test wall with horizontal straps taken from the interior side after the testing

Note that the three fasteners used to secure each furring (dotted circles in the figure) were driven into the horizontal straps installed between the stud framing and gypsum sheathing at 12" (305mm) spacing. The fasteners in the red dotted circles are slightly on an angle (self-drilling tip is slightly pointing up) as a result of loading from the testing.

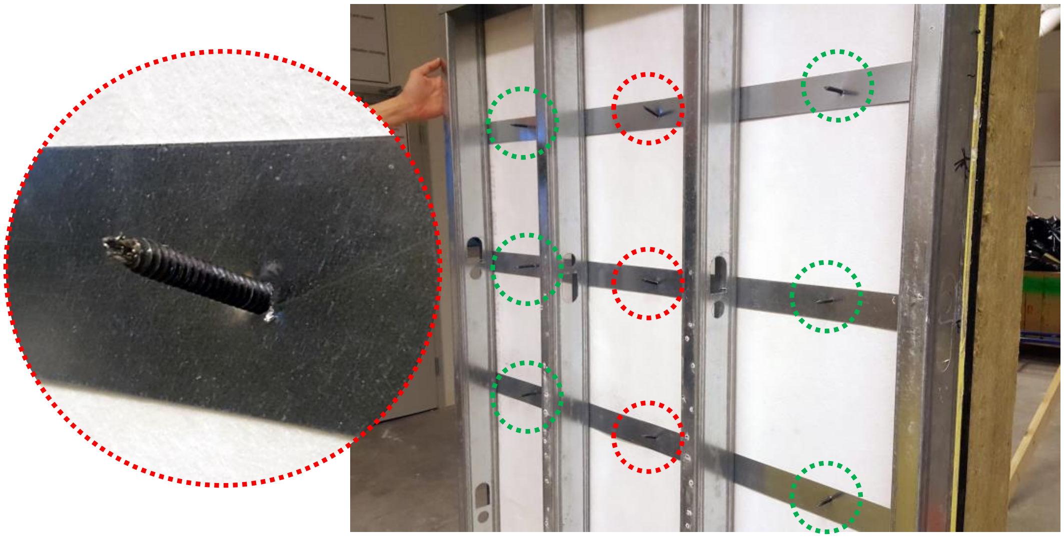

Figure 3.20 Photos of the test wall with horizontal straps taken from the interior side after the testing

Note that the self-drilling tip of centre column of fasteners (indicated in red dotted circles) are slightly pointing up from the testing.

The plot provided in Figure 3.21 compares the load-displacement relationship of furring installed with all three screws penetrating steel framing (as-installed) and the other with screws penetrating the horizontal strapping instead. Note that both test walls incorporated 6" (152mm) of COMFORTBOARD™ 80. The plots provided are from the first loading for each assembly and the bands of shaded area correspond to the weight of typical cladding types per square foot.

As Illustrated, the load-displacement response is relatively linear and horizontal strapping seems to provide comparable fastening base for the screws with respect to stiffness of the system.

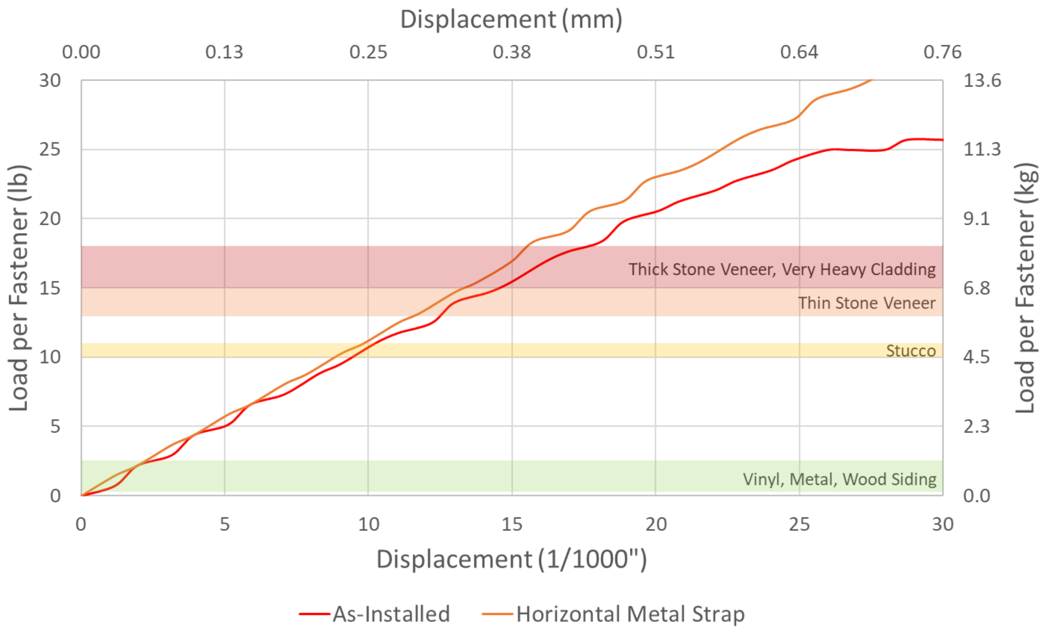

Figure 3.21 Load displacement plot comparing stiffness of assemblies where all fasteners penetrate steel stud framing (As-Installed) and another where fasteners penetrates horizontal strap instead.

*Both assemblies incorporated a total of 6" (152mm) COMFORTBOARD™ 80 insulation. The plot provided is for **first loading** of each setup.*

Figure 3.22 plots the load-displacement relationship of the same test wall assemblies; however, the plot range provided is for a much higher test load during the second loading. Note that the plot range shown in Figure 3.21 is highlighted with a red box. The test data shows that at approximately 50lb (23kg), system with furring fastened to horizontal strap decreases in stiffness. This increased deflection is likely due to horizontal strap being more easily rotated with the fastener in comparison to the stud that runs in the direction of the simulated load.

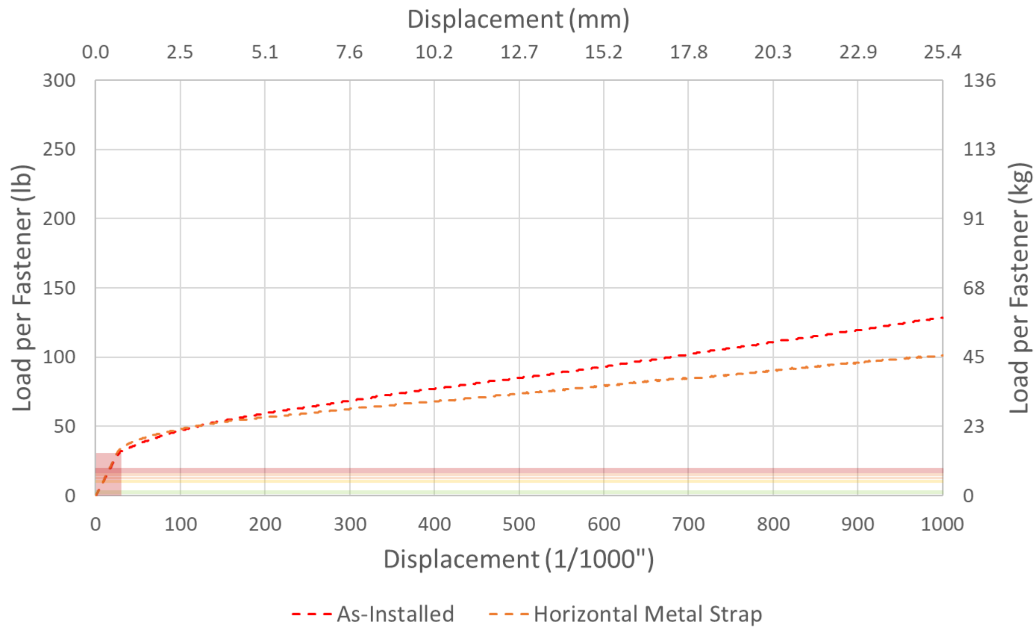

Figure 3.22 Load displacement plot comparing stiffness of assemblies where all fasteners penetrate steel stud framing (As-Installed) and another where fasteners penetrates horizontal strap instead.

Both assemblies incorporated a total of 6" (152mm) COMFORTBOARD™ 80 insulation. Note that the plot range shown in Figure 3.21 is highlighted with a red box.

4 Findings and Conclusions

The intention of this study was to evaluate the impact of various design parameters on the load-deflection response for the dead load support of cladding attached to steel stud with long fasteners installed through exterior insulation. In particular, the impact of insulation type, insulation thickness, preloading the furring, and pre-compressing the insulation were assessed. This study found that:

→ The impact of the compressive strength of the insulation materials on the overall stiffness of the test wall assembly was negligible when screws were loaded up to 25lb (9.1kg), which is indicative of common cladding loads. The difference in deflection between 6" of rigid foam insulation (XPS) and 6" of ROCKWOOL COMFORTBOARD™ 80 (semi-rigid stone wool) was 0.005" (0.13mm) at 25lb (9.1kg) during the first loading.

→ The tests performed on wall assemblies with Insulation thicknesses of 3", 6", and 9" (76mm, 152mm, and 229mm) showed that the wall with 3" of insulation is noticeably stiffer compared to the walls with 6" or 9" of insulation, while the difference between the 6" and 9" was very small. With ROCKWOOL COMFORTBOARD™ 110, when the walls were loaded to 25lb (9.1kg), the deflection of each system was 0.012" (0.30mm), 0.022" (0.55mm), 0.024" (0.61mm) respectively during the second loading. The test result shows that since the cladding load is carried back to the structure via a pin-type connection at the fastener penetration, as expected, the shorter the length between the connection and the cladding, the stiffer the response of the cladding support system.

→ Each test wall was loaded twice, and similar to observations made in the study which investigated structural performance of this type of system for wood frame construction, it was observed that more deflection was consistently experienced on the initial loading.

→ The furring, which provides support for the cladding material, was preloaded prior to testing with the intent of pre-deflecting the furring prior to theoretical loading from the cladding. Preloading of the furring was not found to have a significant impact on initial or total deflection of the furring.

→ To assess whether pre-compression of the insulation by the furring would reduce initial deflection or provide a stiffer system response, the furring was fastened such that it was compressed in to the insulation by 1/4" (6mm). Pre-compressing the insulation was not found to have a significant impact on the initial or total deflection of the furring.

→ Of the parameters evaluated, insulation thickness was found to be the most impactful on the measured load-deflection response of the system; however, the load-deflection response was typically similar and sufficiently strong and stiff within the range of typical cladding weights such that this system would likely be able to provide sufficient cladding support for the insulation thicknesses tested.

→ Test performed on the wall assembly where furring was fastened to horizontal metal strapping instead of directly to the steel stud framing showed that, at the insulation thicknesses tested, metal strapping can likely provide an adequate fastening base for the support of typical cladding dead loads. The use of this strapping may provide a practical method for the installation of furring at locations where studs are not provided, thus providing additional flexibility in the cladding support system design, as well as potential constructability benefits.

→ 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 90˚ 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. This can have meaningful consequences with respect to air and water control, but testing showed that despite having missed the structural framing, the system can still provide similar load resistance with a missed fastener, as long as neighbouring fasteners are installed into the steel framing.

Areas for further testing:

→ Investigate allowable deflection for typical cladding materials.

→ Investigate wide furring as compression of insulation is the primary force resisting the cladding gravity load.

→ Investigate long-term load-displacement response of this type of system in steel frame construction.

→ Investigate self-sealing ability and risk of air/water leaks as results of damage to the sheathing membrane potentially associated with this cladding attachment technique.

We trust that this report meets your needs at this time. Please feel free to contact the undersigned with any question or comments.

Yours truly,

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Appendix A

Additional Plots

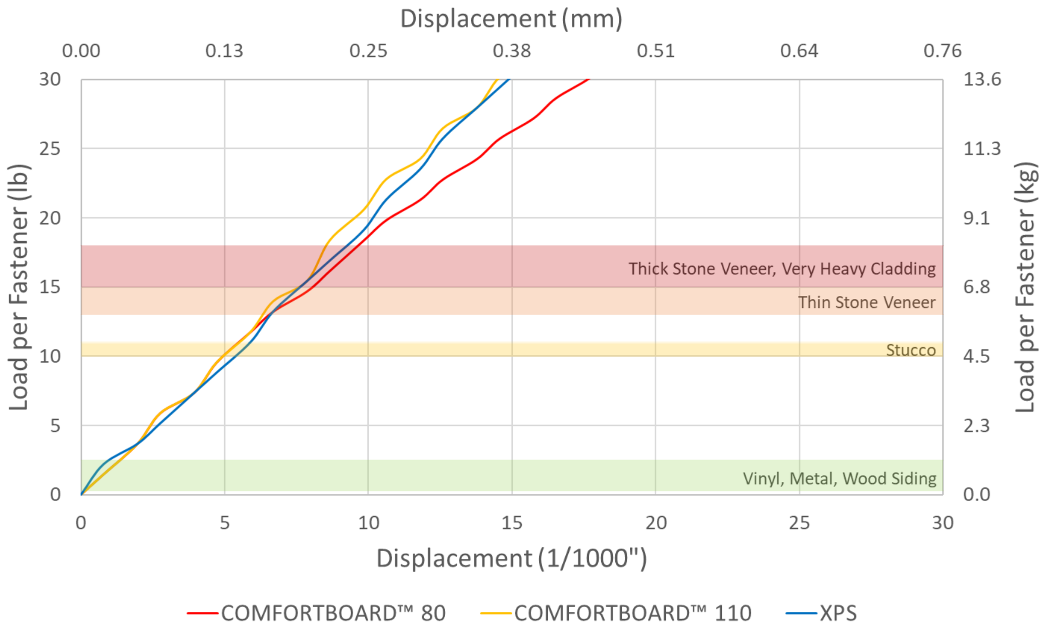

Figure 4.1 Load-displacement plot comparing different insulation arrangements at 3" (76mm) thickness.

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

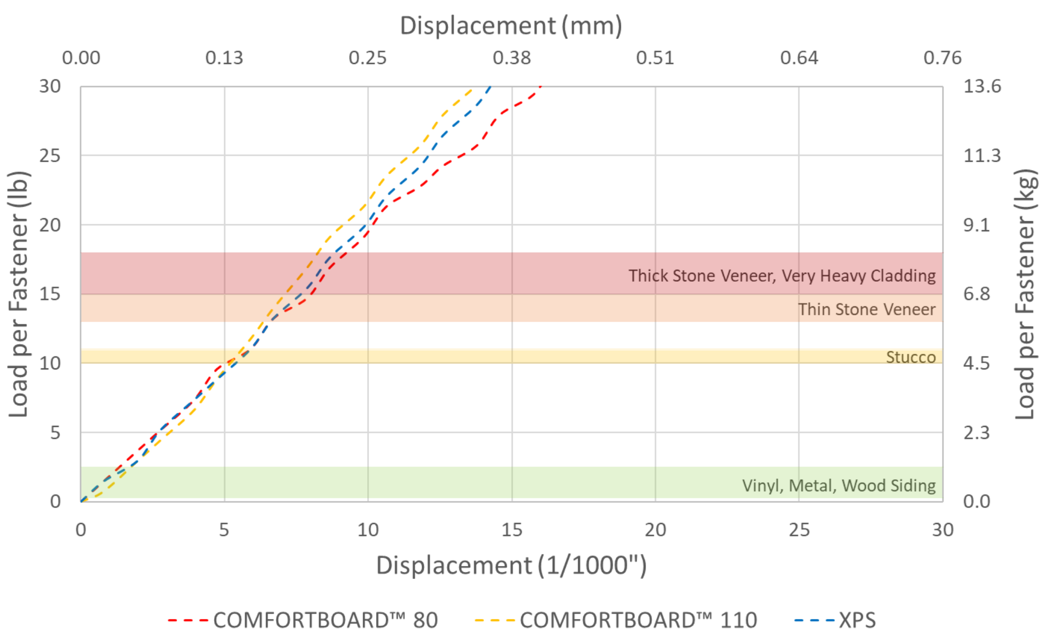

Figure 4.2 Load-displacement plot comparing different insulation arrangements at 3" (76mm) thickness.

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

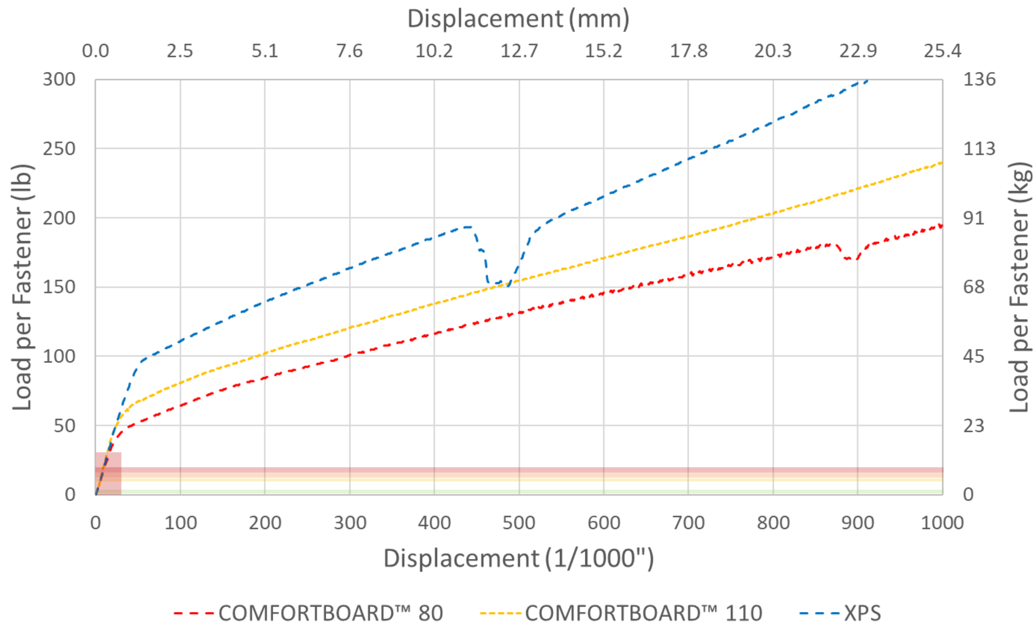

Figure 4.3 Load-displacement plot comparing different insulation arrangements at 3" (76mm) thickness.

*The plot provided is for **second loading** of each setup. The drop in the XPS plot is likely due to slippage of the insulation layers, though this was not confirmed.*

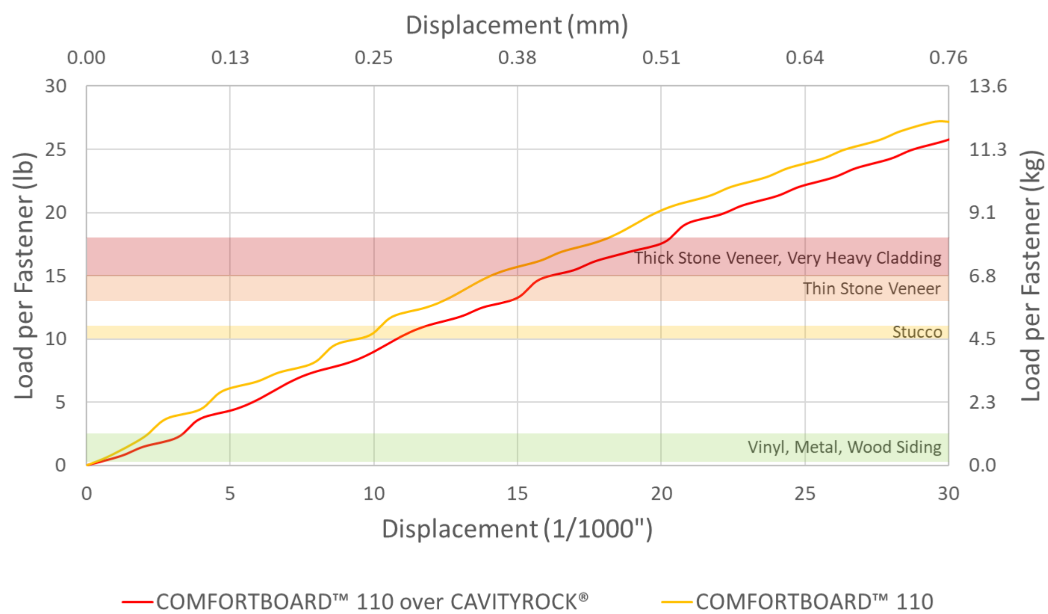

Figure 4.4 Load-displacement plot comparing different insulation arrangements at 9" (229mm) thickness.

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

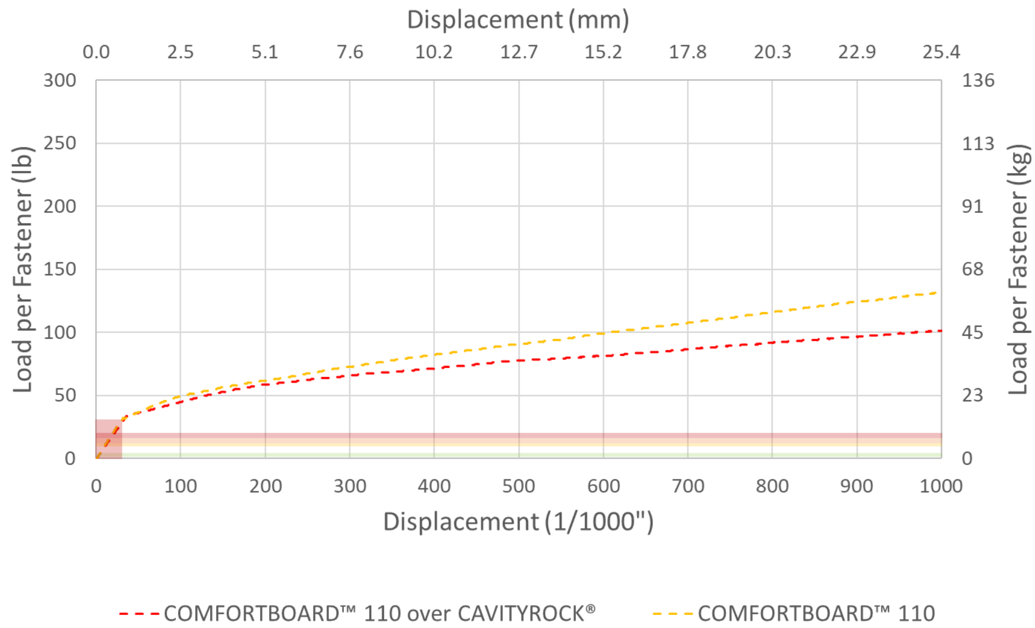

Figure 4.5 Load-displacement plot comparing different insulation arrangements at 9" (229mm) thickness.

*The plot provided is for the **second loading** of each setup. Note that the plot range shown in Figure 3.4 is highlighted with a red box.*

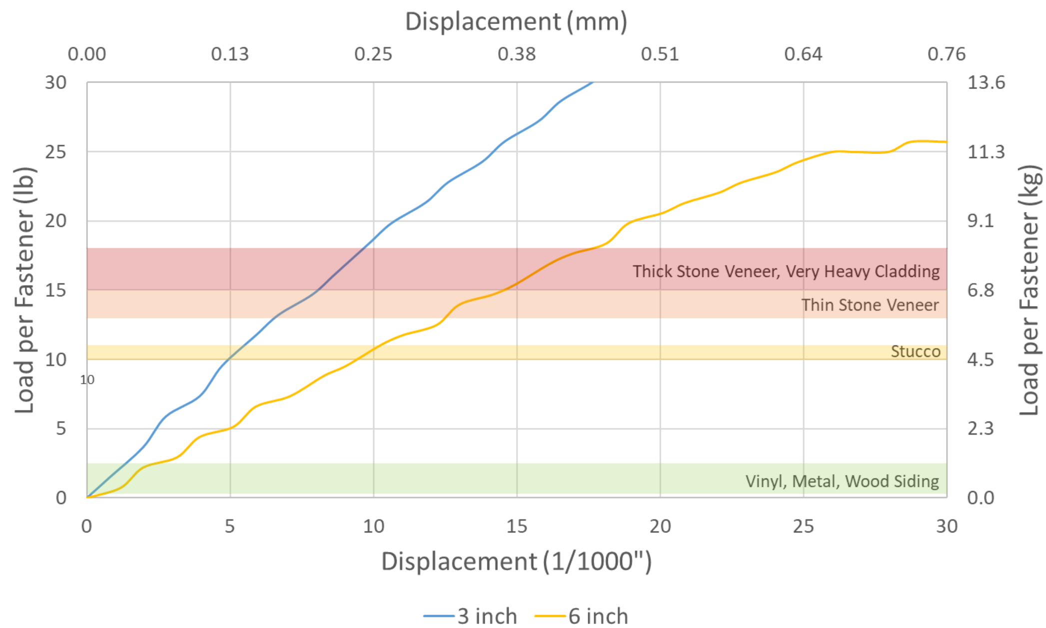

Figure 4.6 Load-displacement plot comparing ROCKWOOL COMFORTBOARD™ 80 insulation at 3" and 6" (76mm and 152mm) thicknesses.

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

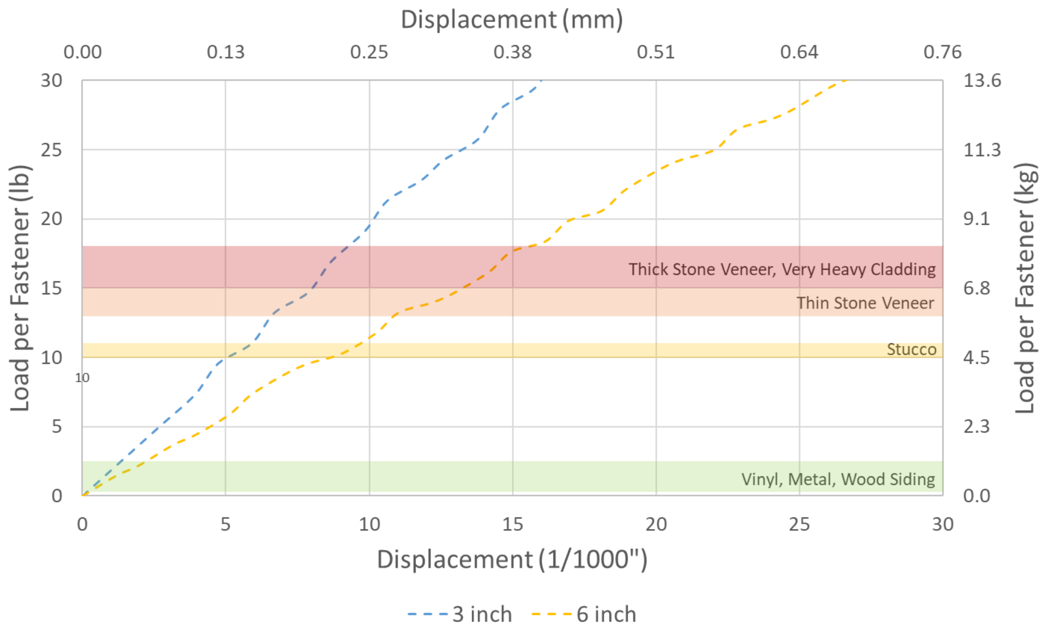

Figure 4.7 Load-displacement plot comparing ROCKWOOL COMFORTBOARD™ 80 insulation at 3" and 6" (76mm and 152mm) thicknesses.

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

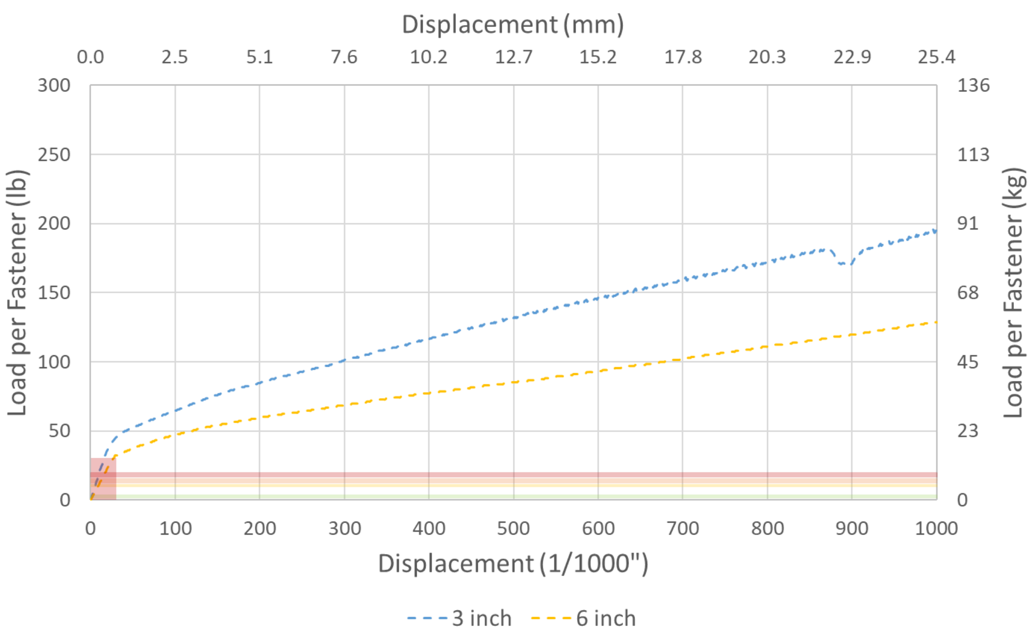

Figure 4.8 Load-displacement plot comparing ROCKWOOL COMFORTBOARD™ 80 insulation at 3" and 6" (76mm and 152mm) thicknesses.

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

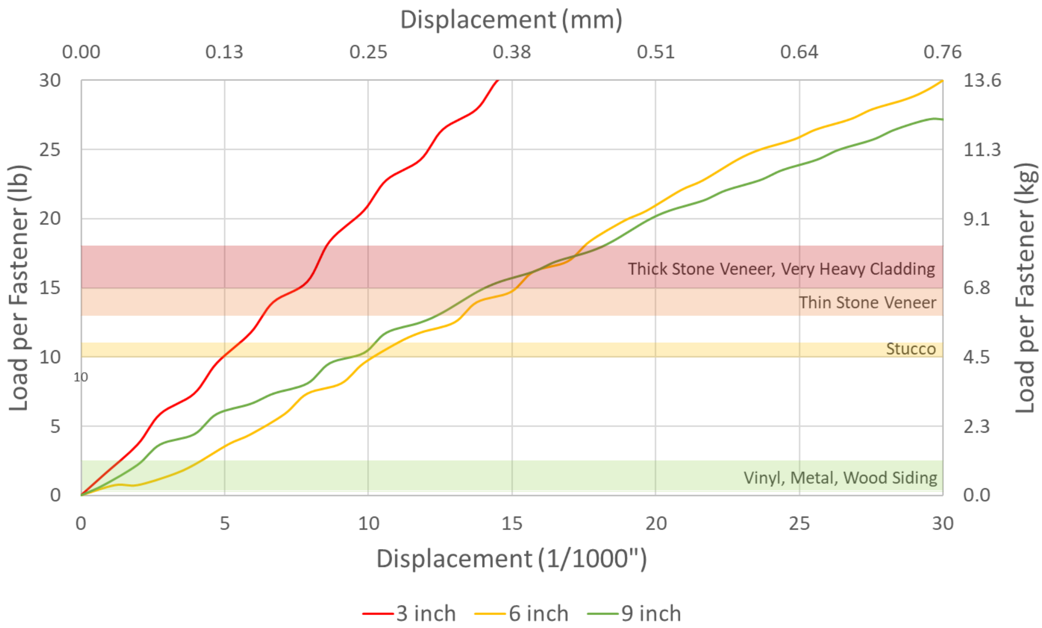

Figure 4.9 Load-displacement plot comparing ROCKWOOL COMFORTBOARD™ 110 insulation at 3", 6", and 9" (76mm, 152mm, and 229mm) thicknesses.

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

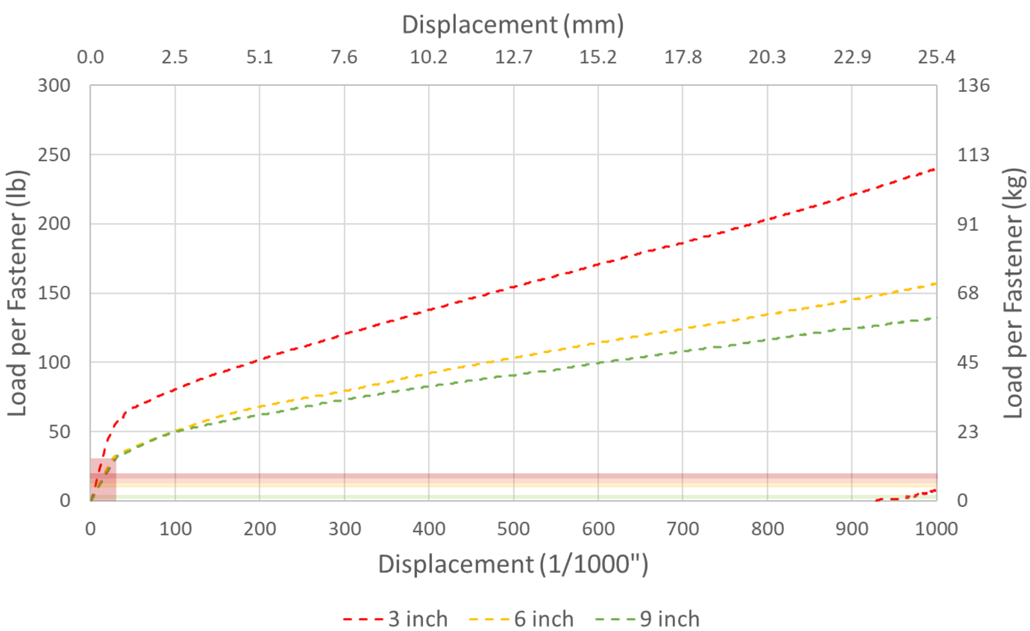

Figure 4.10 Load-displacement plot comparing ROCKWOOL COMFORTBOARD™ 110 insulation at 3", 6", and 9" (76mm, 152mm, and 229mm) thicknesses.

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

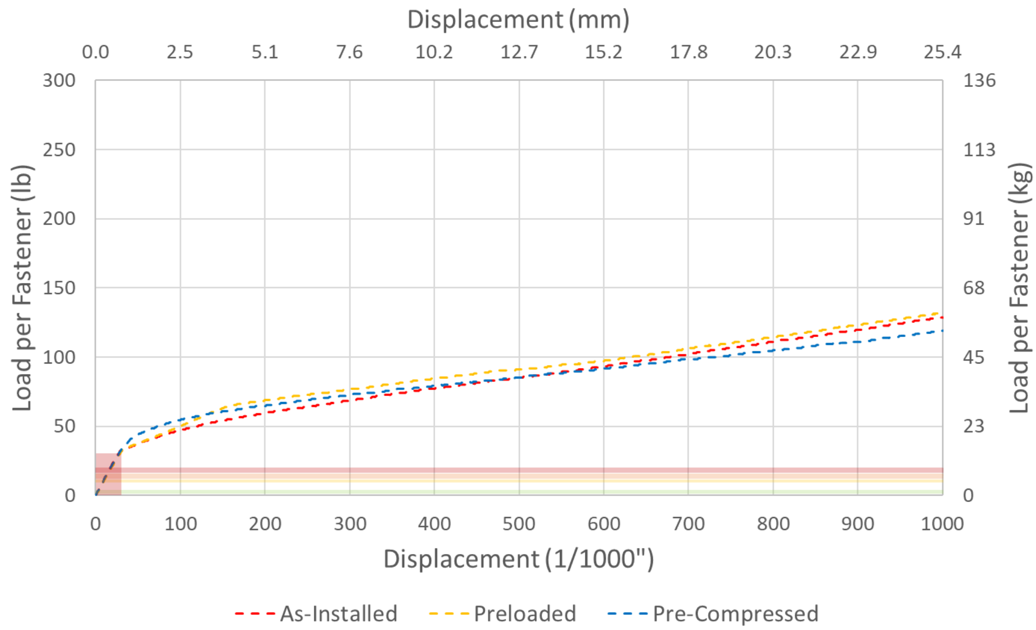

Figure 4.11 Plot comparing load-displacement relationship of a similar test wall systems with furring on one of the systems preloaded in the direction of loading (gravity) and furring on the second pre-compressing the insulation prior to the first loading

Both assemblies incorporated a total of 6" (152mm) COMFORTBOARD™ 80 insulation. The first loading plot is provided with a solid line and second loading with a dashed line. The plot for the higher range for second loading is provided in Appendix.