STRUCTURAL TESTING OF SCREWS THROUGH THICK EXTERIOR INSULATION

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ABSTRACT

Using long screws directly through an exterior insulation layer to provide cladding attachment without the use of clips or girts has been shown to be a thermally and structurally efficient solution for more energy-efficient wood-frame buildings. However, there is still significant scepticism regarding supporting cladding with only screws when using thicker exterior insulation (>38 mm or >1-1/2"), supporting heavy claddings (>48.8 kg/m² or >10 psf, e.g., stucco, stone veneer), or in particular, using exterior mineral wool insulation, which is perceived as insufficiently rigid in comparison to competing foam plastic insulations such as extruded polystyrene insulation (XPS).

Various studies have been conducted to address this gap in industry knowledge and familiarity to help promote adoption of this cladding attachment method. To build on this existing research, which focused on evaluation of screw bending and potential formation of a truss (created by the screw and compression of the insulation), this study focuses on the impact of the compressive strength of the insulation, large thicknesses of insulation (~305 mm or ~12"), and fastener embedment depth (framing member vs. sheathing only) on the structural performance of these systems. The impact of these parameters was evaluated in a laboratory condition using a custom-built apparatus to mechanically imitate cladding (gravity) load in an isolation from other factors such as various other forces building is subject to. The test specimens were selected so that the impact of these parameter can be evaluated by cross comparison. This study found that when 8.0 mm (5/16") fasteners, fully embedded in to the structural framing, were subjected to common cladding load (9.1 kg or 25 lb per fastener) the deflection observed was typically less than 0.64 mm (0.025"), which is likely insignificant considering potential moisture shrinkage that could be anticipated in a typical one-storey wood-frame construction (10 mm or 3/8").

INTRODUCTION

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 directly through an exterior insulation layer to provide cladding attachment without the use of clips or girts is a thermally and structurally efficient solution for lightweight cladding (~12.2 kg/m² or ~2.5 psf, e.g., vinyl, metal, wood siding) with relatively small thicknesses of exterior insulation (~38 mm or ~1-1/2"). 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).

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 (Smegal & Straube, 2011; Lepage, 2013; Baker & Lepage, 2014). As an example, research by Baker and Lepage (2014) focused on the mechanisms and the relative magnitude of forces that work to resist the deflection of the system and whether deflection can be reliably calculated using mechanic equations as well as evaluation of the impact of long-term environmental exposure on these types of system. Their research found that mechanism such as friction between layers of the assembly may provide more load resistance than the bending resistance of the fasteners. It was noted that further study of mechanics is needed and that models based on theorized mechanics did not sufficiently predict the measured deflection. Baker and Lepage (2014) also found that long-term exposure testing with 102 mm (4") of exterior insulation subjected to loads representative of lightweight cladding measured low amount of deflection. Although their long-term test with heavier load showed good resistance to movement, the research noted that more study is needed to investigate potential for long-term creep for these assemblies.

The primary objective of this study is to evaluate the vertical load resistance of long screws through insulation as a cladding attachment technique with specific focus on relatively thick insulation layers which have not previously been rigorously investigated. In particular, the performance of these systems when using mineral wool insulation is investigated. As part of this investigation various parameters are to be assessed as to their impact on the load-deflection response of the system. These parameters include:

- Compressive strength of insulation (mineral wool in different densities and XPS)
- Insulation thickness (76 mm, 152 mm, 229 mm, and 305 mm or 3", 6", 9", and 12")
- Fastener penetration in to substrate (impact of embedment in framing member vs. sheathing only)

In assessing the results of the testing, specific consideration is given to allowable deflection for different cladding types. As there is limited information available regarding allowable deflection, comparisons will be made to known dimensional movements from other factors such as wood drying shrinkage. The results and analysis presented in this paper form a portion of the work performed as part of a larger study (Tatara & Ricketts, 2017) assessing various factors impacting the performance of attaching cladding through insulation with long screws.

METHODOLOGY

This section provides an overview of test wall construction, fastener selection, testing apparatus arrangement, and testing procedure.

Test Walls

To test the performance of this cladding attachment system, a 1220 mm x 1830 mm (4' x 6') backup wall was constructed with 38 mm x 140 mm (2x6) SPF framing at 406 mm (16") on centre (o.c.) complete with top and bottom plates as shown in Figure 1. The backup wall framing was securely fixed to a concrete slab with L-angles attached to the top and the bottom plates.

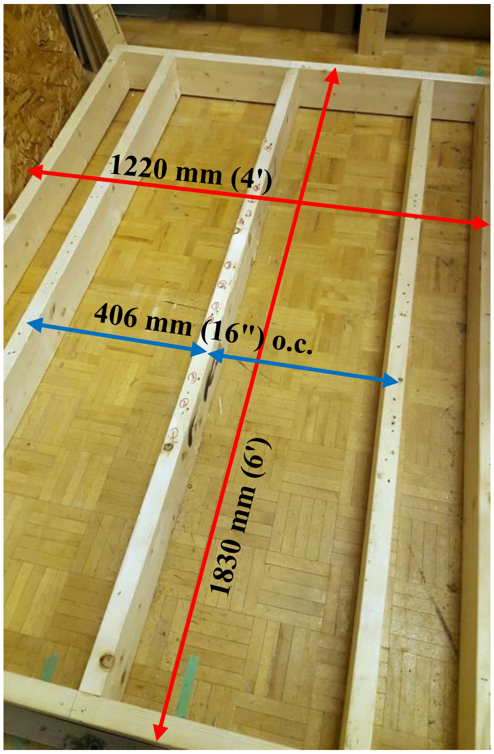

Figure 1: 1220 mm x 1830 mm (4' x 6') backup wall framed at 406 mm (16") o.c. stud spacing and secured to concrete floor with L-angles.

As shown in Figure 2, the backup wall framing was then sheathed with 11 mm (7/16") oriented strand board (OSB) and spunbonded polyolefin house wrap membrane was stapled on to the OSB as is common for wood frame construction. Although the backup wall was 1830 mm (6') tall, the insulation arrangements tested were 1220 mm (4') in height to allow for repositioning of the test area on the back-up wall to test multiple samples using the same framing members.

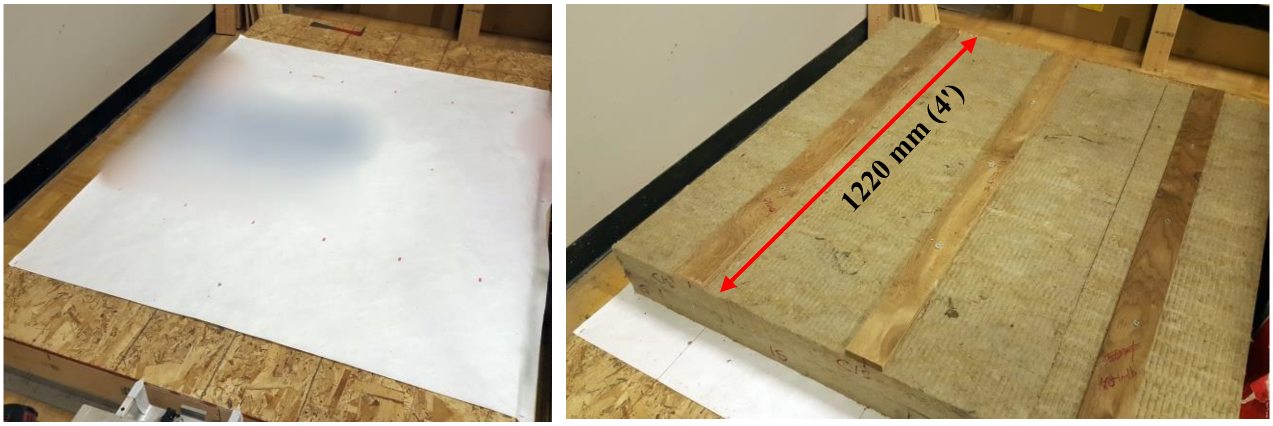

Figure 2: Backup wall framing sheathed with OSB and spunbonded polyolefin house wrap membrane stapled to OSB (left). 152 mm or 6" (2 layers) of mineral wool insulation with 19 mm x 76 mm (3/4"x3") plywood strapping at 406 mm (16") o.c. spacing (right). Note that each strap was secured with three screws at 300 mm (12") spacing.

Insulation—typically in 610 mm x 1220 mm (2' x 4') boards—was placed in staggered layers as shown in Figure 3 and secured with 19 mm x 76 mm (3/4"x3") plywood strapping with 3 screws per strap. Strapping was installed at 406 mm (16") o.c. to match the stud spacing so that the screws can penetrate into the backup wall framing. In general, 76 mm (3") or less insulation thickness makes it fairly easy to reliably embed the fasteners in to the studs but it becomes more difficult as the insulation thickness increases up to a range of 152 mm to 305 mm (6" to 12"). In a laboratory condition with the test wall situated in a horizontal position, it was possible to ensure that the screws penetrated in to the backup wall stud framing; however, ensuring screw penetration in to 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 strap, centre screws, and centre layers of insulation) was replaced after each set of tests (each test involved two loadings as described in later sections of this paper).

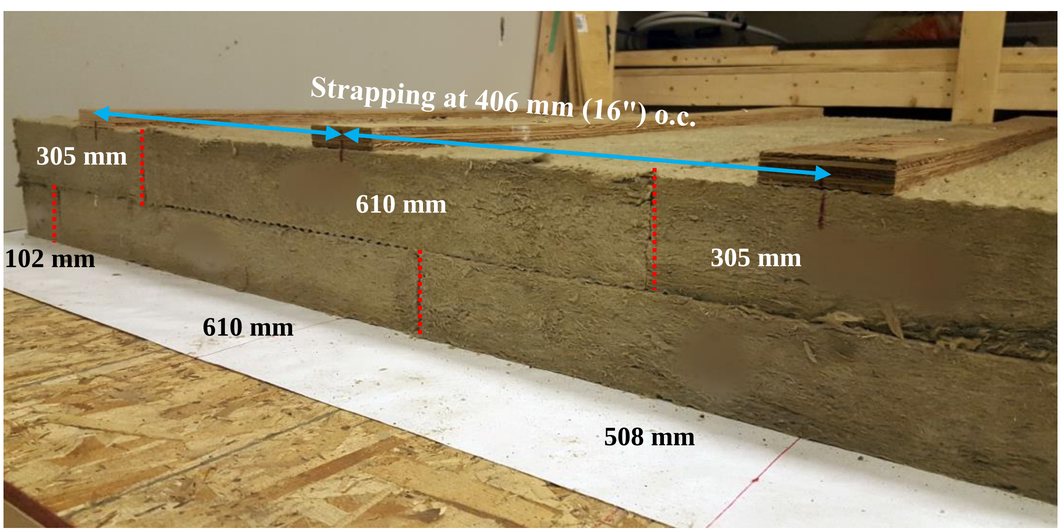

Figure 3: An example of staggered insulation board installation.
From left, top layer: 305 mm (12"), 610 mm (24"), and 305 mm (12") width of 176 kg/m³ (11 lb/ft³) mineral wool insulation.
From left, bottom layer: 102 mm (4"), 610 mm (24"), and 508 mm (20") width of 128 kg/m³ (8 lb/ft³) mineral wool insulation.
Note that insulation joints are indicated with red dashed lines.

Table 1 provides a summary of the 8 test wall arrangements tested as part of this evaluation. Note that all fasteners were installed 90° to the strapping for this testing[1]. These test wall arrangements were selected specifically to address the previously stated objective. In particular:

- the impact of compressive strength of insulation was evaluated by comparing the performance of Test Walls 2, 3, and 4 with the only difference between these specimens being insulation type,
- the impact of insulation thickness was evaluated by comparing the performance of Test Walls 1, 2, 5, and 8 with the only difference between the specimens being thickness of insulation, and
- the impact of fastener embedment in to the structure (e.g., framing member versus sheathing only) was evaluated by comparing the performance of Test Walls 5, 6, and 7.

Table 1: Test Wall Arrangements

Test Wall ID	Insulation Type	Insulation Thickness & Layer Arrangements
		76 mm (3")
1	**Mineral Wool (128 kg/m³ or 8 lb/ft³)**	**One 76 mm (3") layer**
		152 mm (6")
2	**Mineral Wool (128 kg/m³ or 8 lb/ft³)**	**Two 76 mm (3") layers**
3	**Mineral Wool (176 kg/m³ or 11 lb/ft³)**	**Two 76 mm (3") layers**
4	**XPS**	**Three 51 mm (2") layers[2]**
		229 mm (9")
5	**Mineral Wool (128 kg/m³ or 8 lb/ft³)**	**Three 76 mm (3") layers**
6	**Mineral Wool (128 kg/m³ or 8 lb/ft³) – Fastened to 19 mm (3/4") Plywood Sheathing Only**	**Three 76 mm (3") layers**
7	**Mineral Wool (128 kg/m³ or 8 lb/ft³) – Fastened to 13 mm (1/2") Plywood Sheathing Only**	**Three 76 mm (3") layers**
		305 mm (12")
8	**Mineral Wool (128 kg/m³ or 8 lb/ft³)**	**Four 76 mm (3") layers**

Fastener Selection

The fasteners used in this testing were selected based primarily on the availability of lengths between 229 mm and 380 mm (9" and 15") in the same thread and shank diameter and mechanical properties (e.g., bending resistance, tensile strength) to allow for consistency in the fastener properties in all testing such that the other variables can be isolated. Three different lengths of fasteners with 8.0 mm (5/16") thread diameter, shown in Figure 4, were selected for testing with 152 mm, 229 mm, and 305 mm (6", 9", and 12") of insulation. Note that 6.0 mm x 142.9 mm (#12/14 x 5-5/8") fasteners and 8.0 mm x 280 mm (5/16" x 11.0") fasteners were selected for the test wall assembly with 76 mm (3") of insulation and

[1] Strapping in this context is a building material used to secure insulation in position, sometimes referred to as "furring".
[2] Due to a lack of availability of 76 mm (3") XPS, 3 layers of 51 mm (2") XPS was used instead to make up a total insulation thickness of 152 mm (6").

sheathing-only test respectively (both not shown in Figure 4). All screws used have a countersunk head type.

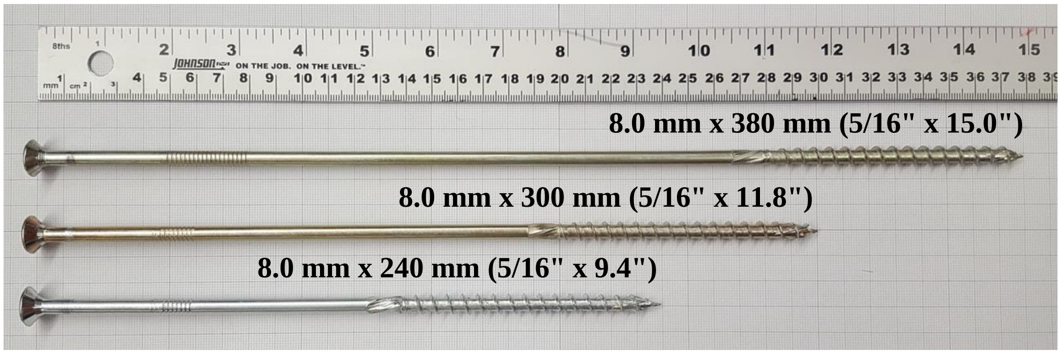

Figure 4: Three different lengths of 8.0 mm (5/16") fasteners used in this testing.

Physical and mechanical properties of 8.0 mm (5/16") and 6.0 mm (#12/14) fasteners, obtained from the manufacturers' technical datasheets (European Organisation for Technical Approvals, 2012; GRK FASTENERS™ ÜberGrade™, 2015), are summarized in Table 2.

Table 2: Physical and Mechanical Properties of 8.0 mm (5/16") and 6.0 mm (#12/14) Fastener

Property of Fasteners	
8.0 mm (5/16") Fastener	
Nominal Length	**240 mm, 280 mm, 300 mm, and 380 mm (9.4", 11.0", 11.8", and 15.0")**
Head Diameter	**~14.8 mm (~0.58")**
Thread Diameter	**~8.0 mm (~0.31")**
Shank Diameter	**5.0 5 mm ~ 5.45 mm (0.20" ~ 0.21")**
Yield Moment	**20.0 Nm (14.8 ft-lb)**
Tensile Strength	**20 kN (4496 lb)**
Withdrawal Capacity[i]	**11.8 N/mm^2 (1711.4 psi)**
Head Pull-Through Capacity[ii]	**9.4 N/mm^2 (1363.4 psi)**

[i] Based on a wood density of 350 kg/m^3 (22 lb/ft^3). As a reference, Canadian Standards Association (CSA) 086 standard defines density of Spruce-Pine-Fir (SPF) group to be 420 kg/m^3 (26 lb/ft^3) **(Standards Council of Canada, R2006)**.
[ii] For wood panel products with minimum thickness of 20 mm (~3/4").

6.0 mm (#12/14) Fastener	
Nominal Length	**142.9 mm (5 5/8")**
Thread Diameter	**6.0 mm (0.238")**
Shank Diameter	**4.4 mm (0.172")**
Bending Yield Strength	**974.6 N/mm^2 (141,350 psi)**
Tensile Strength	**5.0 kN (1134 lb)**
Withdrawal Capacity[i]	**8.8 N/mm^2 (1273 psi)**
Head Pull-Through Capacity[ii]	**18.0 N/mm^2 (2608 psi)**

[i] For specific gravity of 0.67. Fastener withdrawal value obtained in accordance with American Society for Testing

and Materials (ASTM) D1761 **(ASTM International, 2012)**.
[ii] For specific gravity of 0.67. Fastener pull-through value obtained in accordance with ASTM D1037 **(ASTM International, 2012)**.

The structural capacity of the screw is impacted by its penetration depth (embedment). BC Building Code (Province of British Columbia, National Research Council, 2012) for Part 9 buildings requires that the fasteners for cladding other than shakes and shingles penetrate at least 25 mm (1") in to 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 greater than 25 mm (1"). The estimated screw penetration in to the framing for the test arrangements is summarized in Table 3.

Table 3: Estimated Screw Penetration into Framing

Insulation Thickness and Screw Arrangement	Estimated Penetration Depth, mm (inch)
76 mm (3") insulation **6.0 mm x 142.9 mm (#12/14 x 5-5/8") screws installed 90° to the strapping**	**23 (0.9)**
152 mm (6") insulation **8.0 mm x 240 mm (5/16" x 9.4") screws installed 90° to the strapping**	**46 (1.8)**
229 mm (9") insulation **8.0 mm x 300 mm (5/16" x 11.8") screws installed 90° to the strapping**	**2.9 (1.1)**
305 mm (12") insulation **8.0 mm x 380 mm (5/16" x 15.0") screws installed 90° to the strapping**	**33 (1.3)**

The screws were installed at 300 mm (12") spacing with an effective supporting area of 0.124 m² (1.33 ft²) per screw. The screws were installed so that the head of the screw was fully countersunk into the strapping (flush). A torque wrench was used to measure how tightly screws were installed. Generally, torque of approximately ~5 Nm (45 in-lb) was applied to install the screws with minimal pre-compression of the insulation layers.

Testing Apparatus

The cladding gravity load was imitated by mechanically applying a load on the centre strap of a test wall assembly. Mechanical loading was selected rather than gravity loading to allow for application of constant strain rate or constant load during the testing. Previous testing by others has largely been performed using gravity loading by attaching weights to the strapping; however, a continuous load-displacement curve was desired, and mechanical loading better suited this objective.

Loading and measurements of deflection were completed 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[3] rated to ~454 kg (1000 lb). The servomotor allows for

[3] 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

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, or ~0.47244-turn-per-millimeters) 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.

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

This setup provided 720,000 steps-per-inch (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 5.

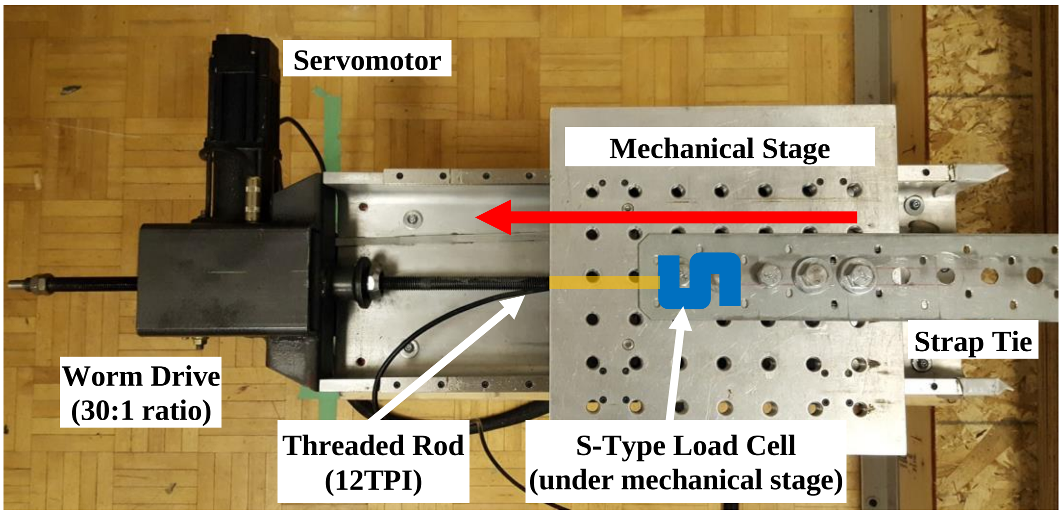

Figure 5: Overview of testing apparatus with key components labelled.
Note that the direction the test wall strapping was loaded is indicated by the red arrow and the orange line indicates the threaded rod connected to the load cell under the mechanical stage.

The interface that controlled the servomotor with feedback from the sensors (position and load) was written in 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.

In order to apply load to the centre strap, the load was transferred from the testing apparatus (mechanical stage) to the plywood strapping using a steel strap. 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, the insulation experienced some compression due to bending of the screws and, consequently,

converter (ADC) for weigh scales.

the load was being applied at a slight angle[4].

The test arrangements were constructed with 3 straps and insulation to allow for improved simulation of actual wall conditions with respect to insulation layer staggering. It was assumed for this testing that negligible resistance is provide by this neighbouring straps to the load applied to the centre strap, as it the apparatus as configured for this testing was not able to load all three straps simultaneously while only measuring load on the middle strap. Future testing should be completed to validate this assumption.

Test Procedure

Each test wall specimen was loaded twice in the following order:

1) Loaded to 46 kg or 101 lb (15.3 kg or 33.8 lb per fastener) and the load was held for 2 hours then released
2) Loaded to 408 kg or 899 lb (136 kg or 299.8 lb per fastener) and the load was held for 120 seconds then released

Two loading cycles were applied so that the initial load displacement response could be evaluated using a load representative of a relatively heavy cladding, and then the load displacement response under second loading could be measured to assess the impact of a "seating" of the strapping in to the insulation. For reference, the weight range of typical cladding types is summarized in Table 4 and are indicated in load-displacement plots provided in this paper.

Table 4: Typical Cladding Weight

Insulation Thickness and Screw Arrangement	Typical Range of Area Density, kg/m² (psf)	Equivalent Load per Strapping[i], kg (lb)
Vinyl, Metal, and Wood Siding	**1.5 – 12.2 (0.3 – 2.5)**	**0.5 – 4.5 (1.2 – 10.0)**
Stucco	**48.8 – 53.7 (10 – 11)**	**18.1 – 20.0 (40.0 – 44.0)**
Thin Stone Veneer	**63.5 – 73.2 (13 – 15)**	**23.6 – 27.2 (52.0 – 60.0)**
Thick Stone Veneer and Very Heavy Cladding	**73.2 – 87.9+ (15 – 18+)**	**27.2 – 32.7+ (60 – 72+)**

[i] Strapping with supporting (tributary) area of 0.372 m² (4 ft²)

In both tests, the strapping was displaced at a rate of 3 mm/min or 0.118"/min (0.05 mm/s or 0.002"/s) until the specified load was reached—at which point the testing apparatus maintained the load for 2 hours for the first loading, and 120 seconds for the second loading. A longer duration was selected for the first loading to evaluate if any displacement would continue to occur under continued loading, whereas the shorter duration for the second test was selected primarily to evaluate the upper limits of performance under short-

[4] More detail discussion is provided in report Structural Testing of Screws through Thick Exterior Insulation **(Tatara & Ricketts, 2017)**

duration high-load events. The apparatus then released the load at the same displacement rate until the measured 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.

RESULTS AND DISCUSSION

The data obtained from the testing apparatus was the load applied on one strap fastened with 3 screws; however, the load-displacement plots presented in this section provide the load per screw for ease of interpretation. 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 shaded in red, orange, yellow, and green respectively.

Evaluation of Insulation Types

This section contains the results and discussion of the impact of insulation types on the load-deflection response of the tested assemblies. Two mineral wool insulations off different densities and one XPS insulation were tested. Table 5 summarizes the compressive strength of the insulation products that were tested as obtained from manufacturers' product data sheets (ROXUL®, Revised 2013; ROXUL®, Revised 2015; Owens Corning®, 2013). Note that compression resistance of these products was not available in directly comparable formats.

Table 5: Compressive Strength of Insulation

Insulation Type	ASTM C165[i], kPa (psf)	
	At 10%	At 25%
Mineral Wool (128 kg/m³ or 8 lb/ft³)	21 (439)	50 (1065)
Mineral Wool (176 kg/m³ or 11 lb/ft³)	28 (584)	75 (1566)
	ASTM D1621[ii], kPa (psf)	
XPS	140 (2880)	

[i] **(ASTM International, Reapproved 2012)**.
[ii] **(ASTM International, 2016)**.

Figure 6 plots the load-displacement relationship for test wall assemblies with 152 mm (6") of insulation and with different insulation types. The plots provided are from the second loading for each assembly. Results from the first loading are not presented but are similar, though typically are slightly less stiff. Use of either set of results does not alter the general conclusions drawn by this study.

As illustrated, the load-displacement responses of the three systems are relatively linear, though there is a slight difference in the slopes, which corresponds to stiffness of the wall assemblies. However, these differences are relatively minor in terms of absolute additional displacement. When a screw is loaded at 9.1 kg (25 lb), the difference in displacement between XPS assembly (0.35 mm or 0.014") and 128 kg/m³ (8 lb/ft³) mineral wool (0.48 mm or 0.019") is approximately 0.13 mm (0.005"). For a comparison, moisture shrinkage of the wood-framing members in a one-storey house would be on the order of 10 mm (3/8")[5] (BC Housing and the Building Safety and Standards Branch, 2011), at least one order of magnitude larger than the displacements measured due to cladding load. This suggests that the vertical displacement of the cladding in these three arrangements is likely acceptable.

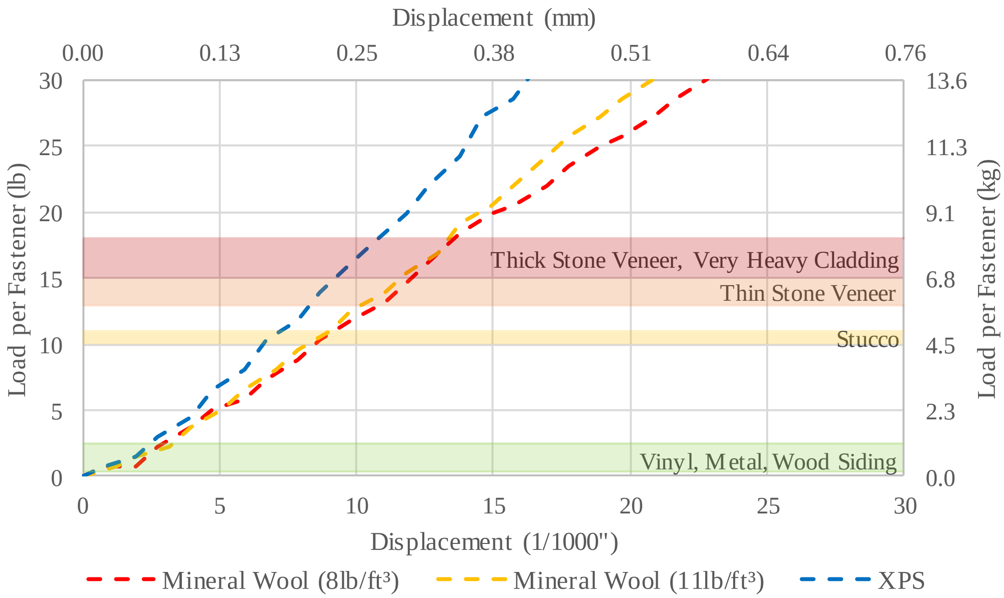

Figure 6 Load-displacement plot comparing different insulation types at 152 mm (6") thickness with countersunk head screws installed at 90° to the strapping. The plot provided is for second loading of each arrangement.

Figure 7 provides load-displacement data for a much higher test load range well beyond that typically applied by cladding gravity loads. Note that the plot range shown in Figure 6 is highlighted in red. As illustrated in the Figure 7, between 18 kg (40lb) and 41 kg (90lb) on a screw, the load-displacement plots start to present a varying degree of curvature and the difference in the response of the systems becomes accentuated. This is likely because as the screws bend, the increased compressive resistance of the insulation creates a truss with the screw and provides a larger proportion of the total load resistance of the system. While this finding does illustrate an expected difference in response, the load applied is well beyond likely in-service cladding loads, so is unlikely to have a meaningful impact on the in-service performance of these systems.

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[5] Assuming 38 mm (2x) framing with double top plates, single bottom plate, 38 mm x 286 mm (2x12) floor joist, and 2362 mm (93") studs. As well as 9% change and moisture content with shrinkage coefficient of 0.25% across the grain and 0.0053% along the grain.

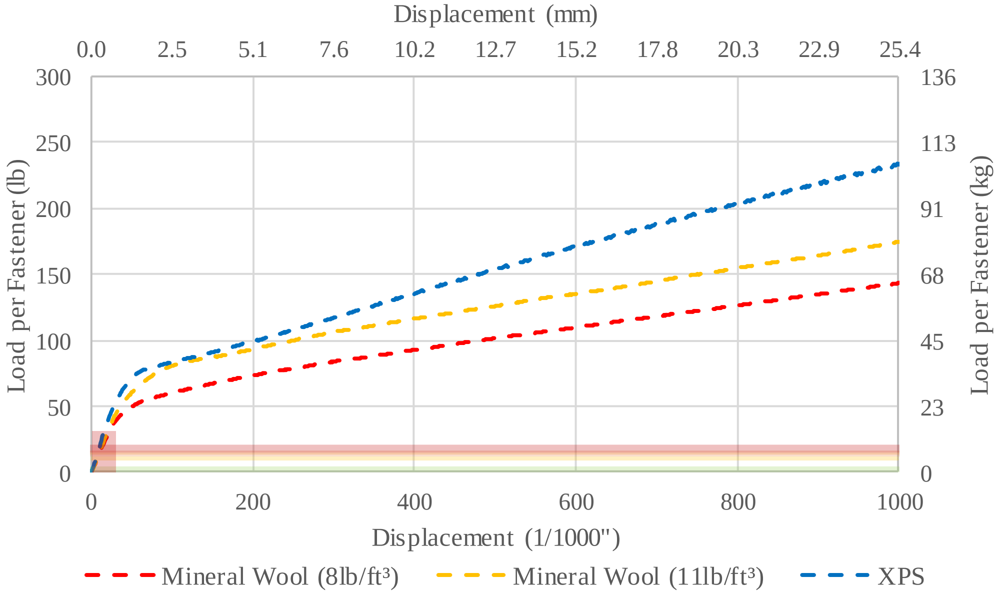

Figure 7: Load-displacement plot comparing different insulation types at 152 mm (6") thickness with countersunk head screws installed at 90° to the strapping. The plot provided is for the second loading of each arrangement. Note that the plot range shown in Figure 6 is highlighted in red box.

Evaluation of Insulation Thickness

This section contains results and discussion regarding the impact of insulation thickness on the load-deflection response of the different wall assemblies. 128 kg/m³ (8 lb/ft³) mineral wool insulation was tested at four different total thicknesses:

1) 76 mm (1 layer, 3") with 23 mm (0.9") estimated screw[6] penetration into framing
2) 152 mm (2 layers, 6") with 46 mm (1.8") estimated screw[7] penetration into framing
3) 229 mm (3 layers, 9") with 29 mm (1.1") estimated screw[7] penetration into framing
4) 305 mm (4 layers, 12") with 33 mm (1.3") estimated screw[7] penetration into framing

Figure 8 plots the measured load-displacement response for these test walls. Note that similar to the plots provided with regards to insulation type, 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.

Figure 8 illustrates that in general, the thicker the insulation the greater deflection that was measured, though the absolute differences in deflection are small and unlikely to cause a meaningful difference in in-service performance. When the screw is loaded to 9.1 kg (25 lb), the difference in displacement between the test

[6] 5.3 mm/6.1 mm x 142.9 mm (#12/14 x 5-5/8") screw installed at 90° to the strapping

[7] 8.0 mm (5/16") screws at 240 mm, 300 mm, and 380 mm (9.4", 11.8", and 15.0") lengths installed at 90° to the strapping

wall with 152 mm (6") of insulation (0.48 mm or 0.019") and 305 mm (12") of insulation (0.66 mm or 0.026") is approximately 0.18 mm (0.007"). As one would expect, assemblies with 76 mm (3") of insulation experienced the smallest deflection of 0.35 mm or 0.014" when the screw is loaded at 9.1 kg (25 lb).

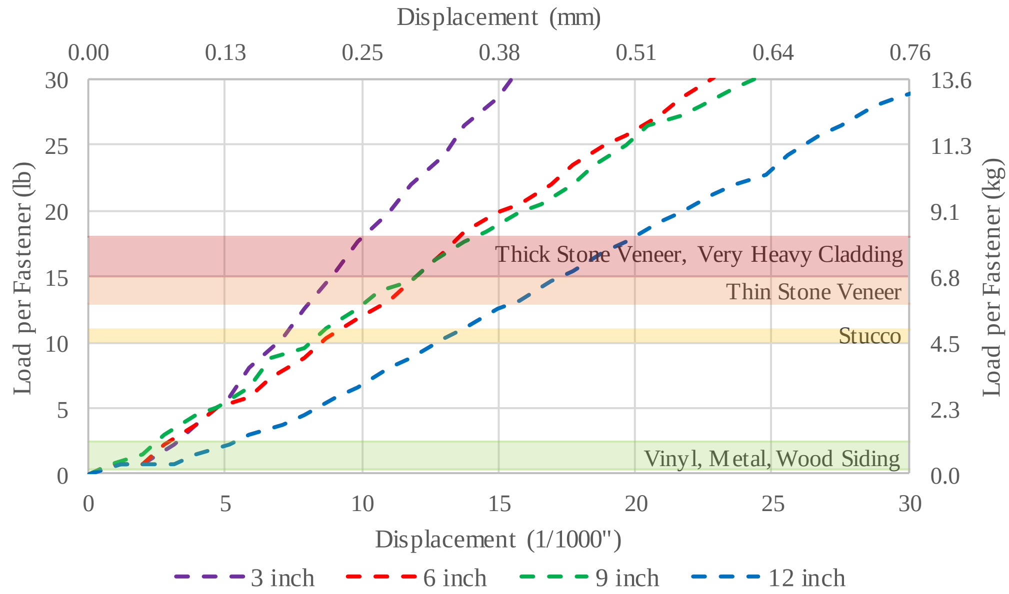

Figure 8: Load-displacement plot comparing 128 kg/m³ (8 lb/ft³) mineral wool insulation at 76 mm, 152 mm, 229 mm, and 305 mm (3", 6", 9" and 12") thickness with countersunk head screws installed at 90° to the strapping. The plot provided is for the second loading of each arrangement.

Screw Penetration into Sheathing Only

Tests with screws penetrating only into the sheathing but not into the backup wall framing were performed with 229 mm (9") of 128 kg/m³ (8lb/ft³) mineral wool insulation, 8.0 mm x 280 mm (5/16" x 11.0") screws and either 13 mm or 19 mm (1/2" or 3/4") plywood sheathing. 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.

When tested, the screw rotation at the penetration hole in the 13 mm (1/2") plywood sheathing deformed the holes (bearing damage) and eventually lead to withdrawal of the screws from the sheathing. Figure 9 compares load-displacement relationship of assemblies when screws penetrate 38 mm x 140 mm (2x6) SPF framing, 19 mm (3/4") plywood only, and 13 mm (1/2") plywood only. The plot provided is for the first loading of each arrangement and all of the test assemblies used 229 mm (9") of mineral wool (128 kg/m³ or 8 lb/ft³) insulation and fasteners installed at 90° to the strapping.

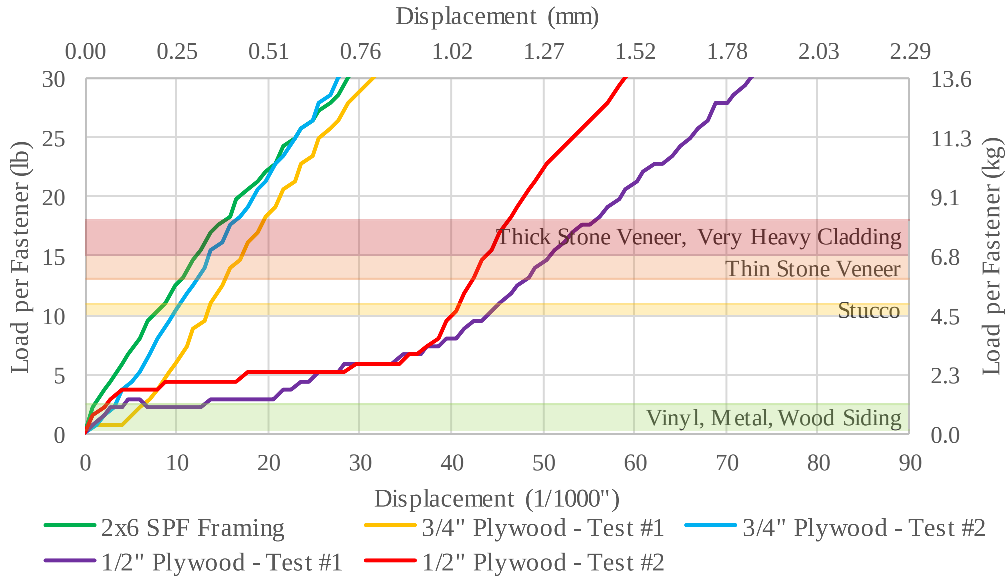

Figure 9: Load-displacement plot comparing stiffness of assemblies when screws penetrate 38 mm x 140 mm (2x6) framing, 19 mm (3/4") plywood only, and 13 mm (1/2") plywood only. All test assemblies used 229 mm (9") of mineral wool (128 kg/m³ or 8 lb/ft³) insulation and fasteners installed at 90° to the strapping. The plot provided is for the first loading of each setup.

As the sheathing-only results illustrate, when thicker sheathing is used (e.g., 19 mm or 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., 13 mm or 1/2" plywood), the system was 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, the overall strength of the system is still sufficient to support typical cladding loads without large amounts of deflection. When these types of systems have been used in practice, 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., perhaps 10% of fasteners missing the studs provides acceptable performance).

One additional consideration for the screws through sheathing-only arrangement is that the fasteners used for this testing had a relatively coarse thread spaced at ~6 mm (~0.236"), which would mean that with 13 mm (1/2") plywood, it is likely that the screw had only one or two thread(s) biting in to the sheathing while with 50% thicker 19 mm (3/4") plywood, more threads would be able to bite in to the wood. As such, a finer threaded fastener may provide improved withdrawal resistance, though if a smaller diameter fastener were used, this may lead to increased deflection at lower in-service loads. Further testing is needed to confirm the potential impact using a more finely threaded fastener.

FINDINGS AND CONCLUSIONS

The intention of this study was to evaluate the impact of insulation type, insulation thickness, and fastener embedment (sheathing vs. studs) on the load-deflection response of claddings attached via strapping using long screws through exterior insulation. Key conclusions are summarized below.

1) The arrangements where fasteners were installed embedded in to the wood framing were measured to provide relatively small amounts of deflection (when loaded within the range of typical cladding loads) as compared to other potential sources of movement such as moisture shrinkage of the wood framing due to drying. This finding suggests that the amount of deflection that would be expected with these types of systems is generally within the acceptable range.
2) Arrangements which included larger thickness of exterior insulation typically experienced more deflection than did arrangements with smaller thickness of insulation; however, the impact of insulation thickness on the overall stiffness of the test wall assemblies was insignificant when screws were loaded to 9.1 kg (25 lb), which is indicative of common cladding loads.
3) The systems with the fasteners installed in to 19 mm (3/4") plywood sheathing provided similar load-deflection response to systems with the fasteners embedded minimum 25 mm (1") in to the stud framing.
4) The systems with the fasteners installed in to 13 mm (1/2") plywood sheathing were measured to have increased deflection as compared to when the fasteners are embedded minimum 25 mm (1") in to the stud framing. It is likely that in cases where fasteners are unintentionally not installed in to the stud framing that sufficient capacity would still exist when combined with the resistance of adjacent fasteners that successfully embedded in to the framing.

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