

Determination of Effective Standoff in Standing Seam Roof Systems

RESEARCH REPORT RP18-3

August 2018

Updated September 2019

Committee on Specifications
for the Design of Cold-Formed
Steel Structural Members



American Iron and Steel Institute

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Department of Engineering Technology

Determination of Effective Standoff in Standing Seam Roof Systems

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Executive Summary

This test program was undertaken to better understand the horizontal force transfer between a purlin and standing seam sheathing. Because the purlin and sheathing are separated by a clip, forces must be transferred over the height of the clip. This force transfer is dependent upon the rotational stiffness of the connection between the clip and the purlin and the connection between the clip and the seam of the sheathing. While the overall height of the clip is referred to as the standoff distance, the effective height at which the force is effectively transferred is referred to as the effective standoff. The effective standoff has broad implications on purlin stability as the sheathing provides a degree of lateral support to the purlin.

A series of 25 tests was performed on a variety of clip, panel, seam and insulation configurations to determine both the effective standoff and rotational stiffness of the panel-clip connections. Test specimens were subdivided according to the panel profile; both 24 in. wide trapezoidal panels and 16 in. wide vertical rib profiles were tested. For trapezoidal profiles; fixed, sliding tab and floating clips were tested. For vertical rib profiles; fixed clips and floating clips were tested. For each clip type a "low" clip and a "high" clip were tested. Low clips were tested with either no insulation or 4" of uncompressed insulation and high clips were tested with either 4 in. or 6 in. of uncompressed insulation. The main testing program was for specimens with mechanically crimped seams however several random tests were performed on specimens with un-crimped seams.

The test program is intended to represent a broad sample of systems in use by the industry. Although only one test per configuration was performed, some relationships can be inferred between similar systems. As such, given the variation between tests, only broad generalizations can be inferred from the test data. For trapezoidal systems, the stiffness of the connection between the purlin and clip is typically slightly higher than the connection between the clip and the seam, resulting in an effective standoff slightly above the mid-height of the clip. For vertical rib systems, the stiffness of the connection between the seam and the clip is typically greater than the connection to the purlin, resulting in an effective standoff below the mid-height of the clip. When the seam is un-crimped, the effective standoff is very nearly to the top of the clip.

Background

Standing seam roof systems are commonly supported by cold-formed C- and Z-section purlins spaced at 3 to 5 foot intervals and spanning from 20 to 35 feet between primary framing. Insulation is draped over the purlins and a metal clip is fastened through the insulation into the top flange of the purlin with self-tapping screws. The standing seam sheathing is then attached to the clip via a tab on the clip that interlocks into the seam of the panel. The seam of each panel interlocks with the adjacent panel and is often mechanically crimped. By enclosing the connection to the clip within the seam, penetrations through the sheathing and, thus, potential avenues for leaks, are minimized.

There are two main types of panel profiles: vertical rib and trapezoidal. Vertical rib profiles have a slender vertical rib and typically have widths between seams of 12 in. to 16 in. Trapezoidal panels, as the name implies, are profiled into a trapezoidal shape that increases the stiffness of the seam allowing for longer spans. Trapezoidal profiles are typically 24 in. wide. Each profile utilizes clips specific to the rib profile. Clips may also be provided in two different heights (either *low* or *high*) to account for differing insulation thicknesses. Low clips are used with insulation thicknesses ranging from 0 in. to 4 in. whereas high clips are used with insulation ranging from

2 in. to 6 in. Because these systems are often used to cover large areas, flexibility is designed into the clip connection to allow for thermal expansion/contraction. Clips with built-in flexibility are referred to as *sliding* whereas those without are referred to as *fixed*. Designs for sliding clips can vary widely, however, in surveying the different clips available within the industry, a subcategory of sliding clips was created. Sliding clips were subcategorized as: *sliding tab*, where the main body of the clip has a rigid structure with a sliding tab that fits into the seam (Figure 1(a)), or *floating*, where the clip has a base that is attached to the purlin and the main body of the clip fits into the seam and slides as a unit (Figure 1(b)).



(a) High clip - Sliding tab

(b) High Clip - Floating

Figure 1: Sliding trapezoidal clip profiles

Sheathing provides lateral and torsional restraint to cold-formed C- and Z-section purlins in standing seam roof systems, resulting in strength and stability. C-sections, because of the eccentricity of the shear center are subject to torsion along the length which is partially restrained by the sheathing. In addition to torsion, Z-sections, as a result of the inclined principal axes, are also subject to lateral deflections that are resisted by the sheathing. The restraint provided by the sheathing to the purlin is translated into in-plane diaphragm forces in the sheathing that is extracted from the system through *anchors*.

Quantifying the interaction between the purlin and the sheathing is essential to understanding the stability of the purlin. Displacement compatibility methods are used to define the extent to which the sheathing restrains the purlin (Murray et al., 2009). The sheathing provides restraint through a torsional spring at the top flange representing the rotational stiffness of the connection between the panel and the purlin and a lateral spring representing the diaphragm stiffness of the sheathing as shown in Figure 2(b). Displacement compatibility has been traditionally enforced at the top flange of the purlin – the assumed center of rotation as shown in Figure 2(c). This approximation is reasonable for through-fastened systems but for standing seam systems, forces must be transferred over the height of the clip. The center of rotation is therefore offset from the top of the purlin as shown in Figure 3. This distance is referred to as the effective standoff.

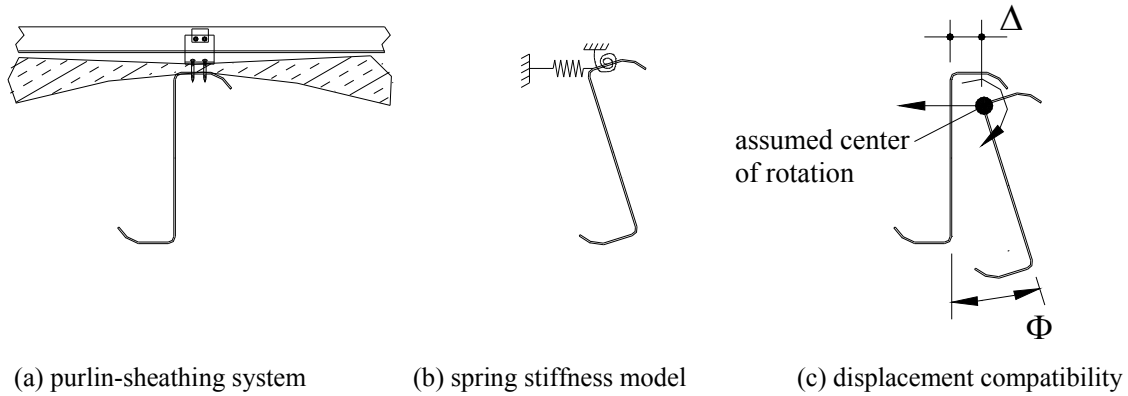


Figure 2: Displacement-compatibility of purlin sheathing system

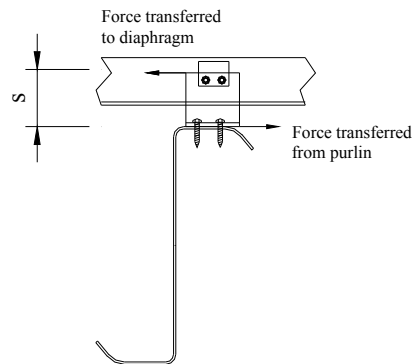


Figure 3: Lateral force transfer through clip

The analytical model used to evaluate the effective standoff is shown in Figure 4. As horizontal forces are transferred from the purlin over the height of the clip, a moment is created. The clip itself is treated as a rigid body but the purlin-clip connection and the clip-sheathing connection both have flexibility and are modeled as springs. If the purlin-clip connection is flexible relative to the clip-sheathing connection, the clip will act rigidly with the sheathing, the center of rotation will shift to near the bottom of the clip and the standoff will be minimized as shown in Figure 4(a). Conversely, if the clip-sheathing connection is flexible relative to the clip-purlin connection, the center of rotation will shift towards the top of the clip as shown in Figure 4(b). In reality, a typical system will fall within these extremes and therefore the effective standoff ranges between zero and the height of the clip as shown in Figure 4(c).

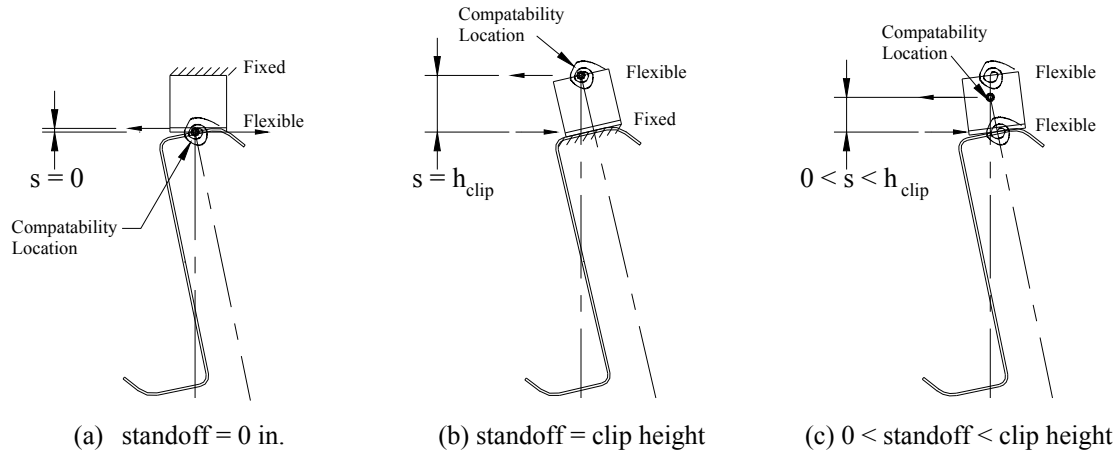


Figure 4: Standoff Range

Test Procedure

The AISI Test Standard S901-13 *Rotational-Lateral Stiffness Test Method for Beam-to-Panel Assemblies* (AISI 2013) outlines the test apparatus and procedure to determine the rotational stiffness of the connection between the purlin and sheathing. To perform the test, a panel subassembly representative of the installed configuration of the purlin and deck is constructed. The subassembly may be constructed as a cantilever assembly (shown in Figure 5(a)) or a simple span assembly (Figure 5(b)). In the test, a force is applied to the free flange of the purlin parallel to the rib of the sheathing as shown in Figure 5. The displacement of the free flange is measured and the rotational stiffness is determined as the moment resisted per unit rotation.

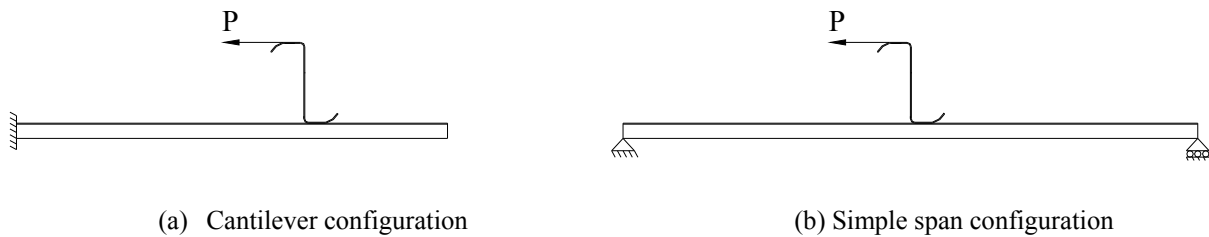


Figure 5: Rotational-Lateral Stiffness Test Configurations

Test Standard S901-13 can be modified with additional instrumentation to determine effective standoff. Because of the difficulty of properly restraining the end of a standing seam panel in a cantilever configuration, it is the opinion of the authors that a simple span assembly is better suited for standing seam systems.

As shown in Figure 6, to determine the total rotation of the purlin, lateral displacements are measured at the free flange, Δ_1 , and the attached flange Δ_2 . To measure the relative rotation between the clip and purlin, displacement transducers are attached to the web of the purlin and measure the relative displacement at each end of the clip, Δ_3 and Δ_4 . The total rotation of the purlin relative to its original orientation, ϕ_{total} , the rotation of the purlin relative to the clip $\phi_{\text{purlin-clip}}$, and the rotation of the clip relative to the seam, $\phi_{\text{clip-seam}}$, are shown in Figure 6 and are calculated:

$$\phi_{\text{total}} = a \sin\left(\frac{\Delta_1 - \Delta_2}{d}\right) \quad (1)$$

$$\phi_{\text{purlin-clip}} = a \sin\left(\frac{\Delta_4 - \Delta_3}{b_{\text{sensor}}}\right) \quad (2)$$

$$\phi_{\text{clip-seam}} = \phi_{\text{total}} - \phi_{\text{purlin-clip}} \quad (3)$$

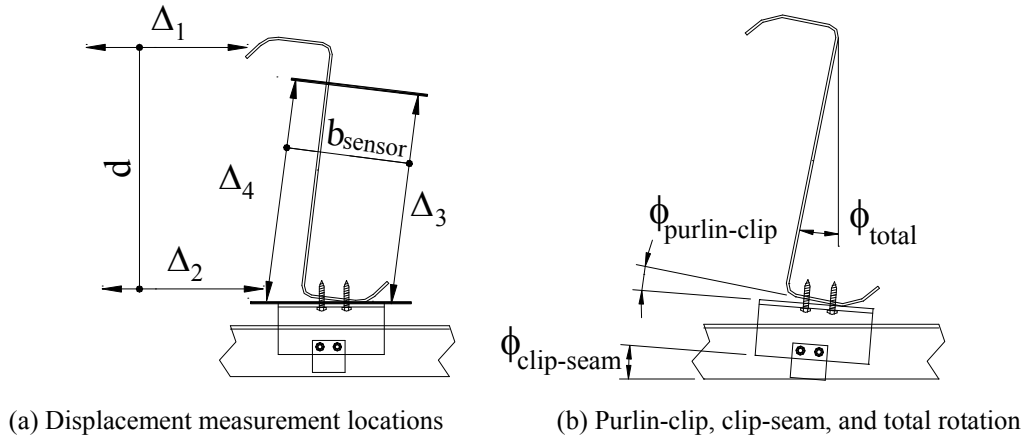


Figure 6: Quantifying rotational deformation

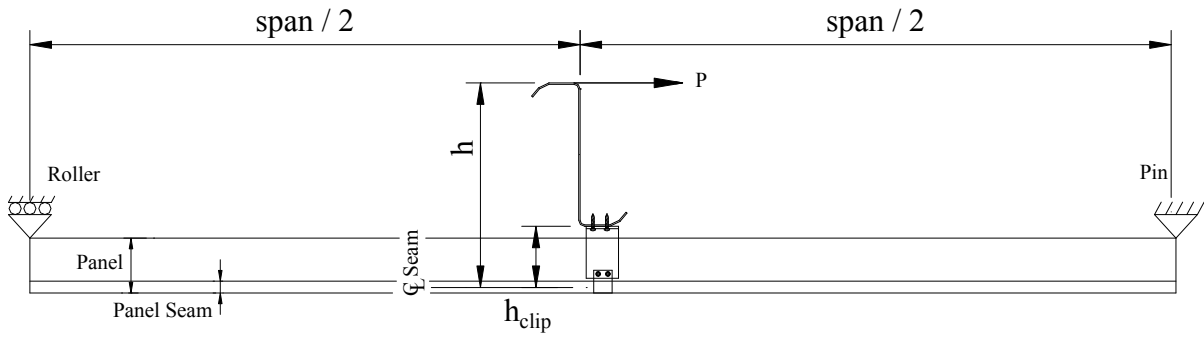


Figure 7: Reported moment from test

To determine the moment-rotation behavior of the connection, the moment is calculated as the horizontal force at the free flange, P , multiplied by the distance from the centerline of the seam to the free flange of the purlin, h , as shown in Figure 7. Typical moment rotation behavior is shown plotted in Figure 8 with rotation plotted along the horizontal axis and the moment plotted along the vertical axis.

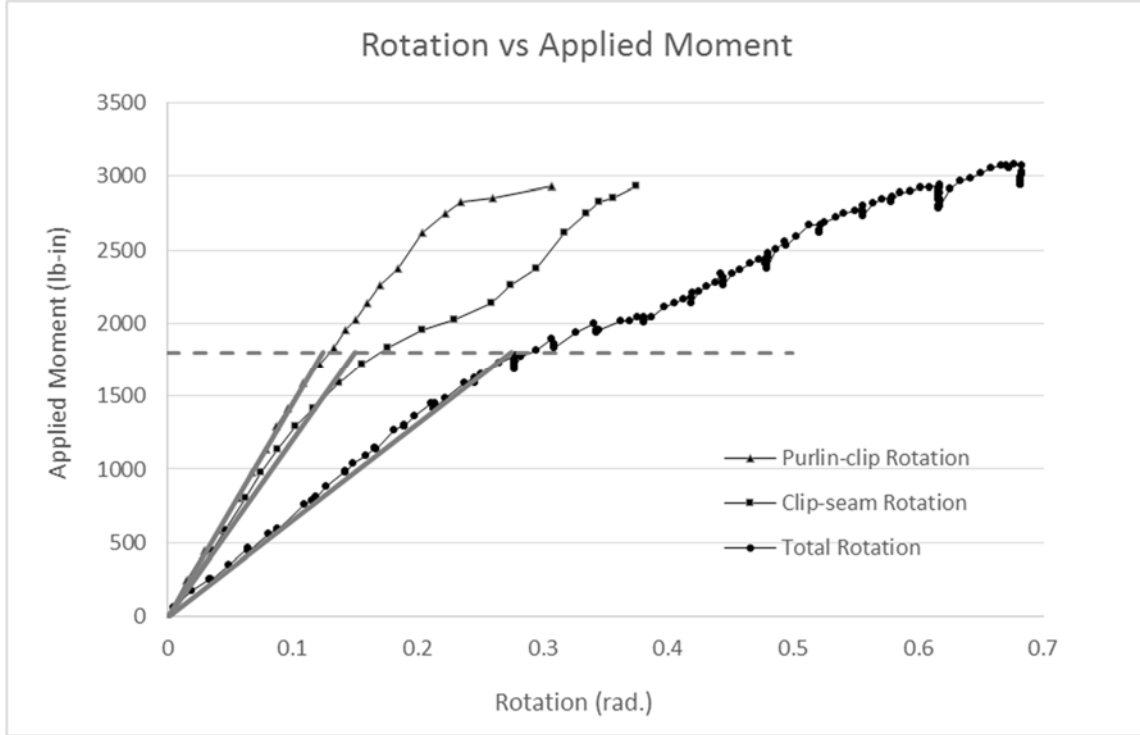


Figure 8: Sample Test Result

In AISI S901, rotational stiffness is calculated at 80% of the peak load. For determining effective standoff, a slightly different approach is used. All tests exhibited an initial linear behavior followed by a reduction in stiffness in the connection between the clip and seam. This point is reported as the peak linear moment, represented by the horizontal dashed line in Figure 8. In many cases, the system exhibited substantial strength beyond the peak linear moment, however this strength was typically accompanied by deformations of the seam. The data beyond this peak linear moment is not considered in the determination of the effective standoff as it is the intent to capture the primary behavior of the connection. The stiffness of the clip-seam connection, $k_{\phi\text{clip-seam}}$, stiffness of the clip-purlin connection, $k_{\phi\text{purlin-clip}}$, and the total stiffness of the connection, k_{ϕ} , are determined from slope of the line that provides the best fit to the data. The unit rotational stiffness of the connection, k_{ϕ} is calculated

$$k_{\phi} = \frac{P \cdot h}{\phi_{\text{total}} \cdot L_{\text{trib}}} \quad (4)$$

where L_{trib} is the length along the purlin tributary to each clip (equal to the clip spacing or the panel width). The rotational stiffness of both the purlin and the clip can be similarly calculated by comparing the moment to the rotation of the clip-seam connection or purlin-clip connection individually. Because the clip-seam stiffness and the purlin-clip stiffness are considered series springs, the total stiffness is related to the clip-seam and purlin-clip stiffness by the following relationship

$$k_{\phi} = \left(k_{\phi\text{clip-seam}}^{-1} + k_{\phi\text{purlin-clip}}^{-1} \right)^{-1} \quad (5)$$

The effective standoff is defined from the ratio of the clip-seam rotation to the total rotation (or ratio of total stiffness to clip-seam stiffness)

$$s = h_{\text{clip}} \frac{\phi_{\text{clip-seam}}}{\phi_{\text{total}}} = h_{\text{clip}} \frac{k_{\phi}}{k_{\phi\text{clip-seam}}} \quad (6)$$

The height of the clip, h_{clip} , is defined differently between vertical rib profiles and trapezoidal profiles. For trapezoidal profiles, the height of the clip is the distance from the base of the clip to the “shoulder” of the clip that fits under the seam plus one-half the height of the seam (Figure 9). For vertical rib profiles, the height of the clip is the distance from the base of the clip to the top edge of the clip that is enclosed in the seam, less one-half the height of the seam (Figure 10).

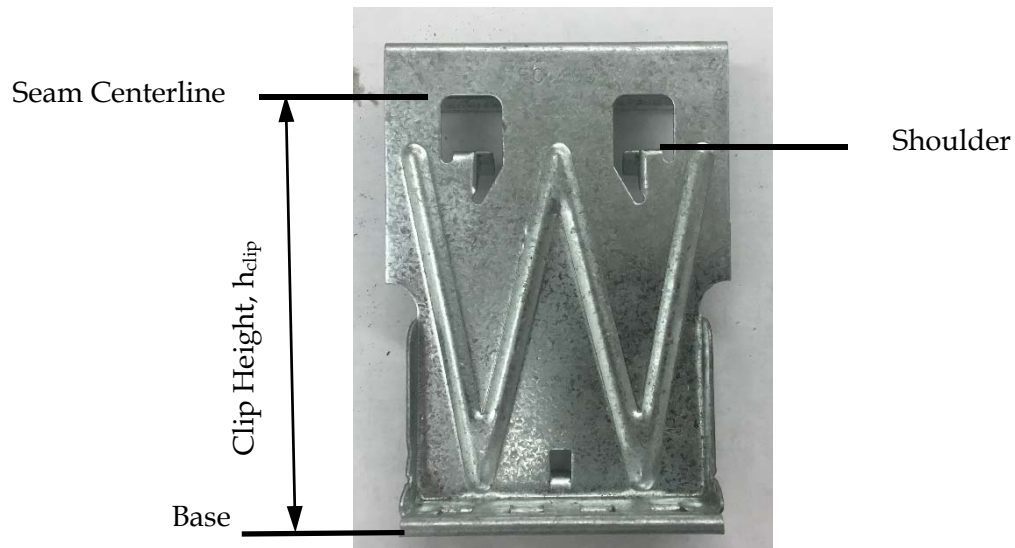


Figure 9: Clip Height for Trapezoidal Clips

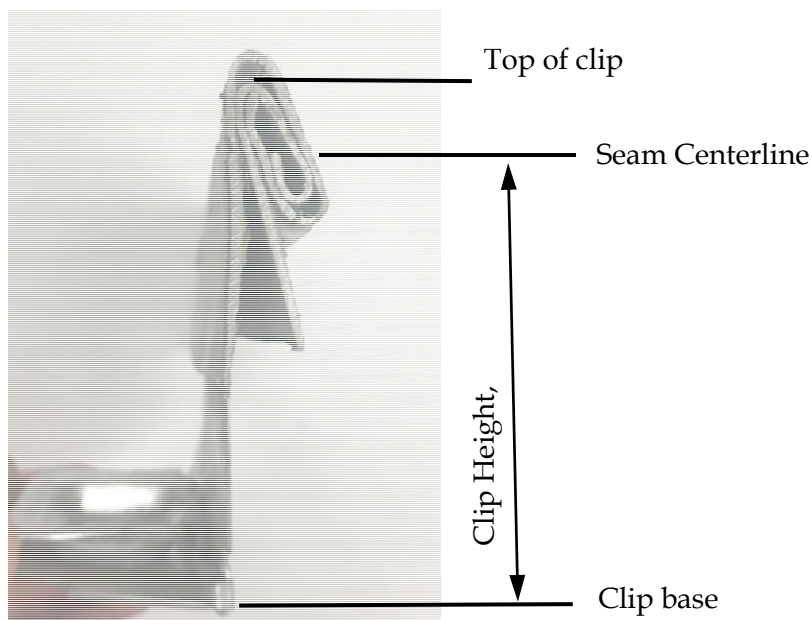


Figure 10: Clip Height for Vertical Rib Clips

Test Program

A survey of clips commonly in use was undertaken to compare and categorize the clips. From the survey of clips, a test program was developed to investigate and compare the categorized systems. Test specimens are subdivided according to the panel profile; both 24 in. wide trapezoidal panels and 16 in. wide vertical rib profiles were tested. For trapezoidal profiles, fixed, sliding tab and floating clips were tested. For vertical rib profiles, fixed clips and floating clips were tested. For each clip type a “low” clip and a “high” clip were tested. Low clips were tested with either no insulation or 4 in. of uncompressed insulation and high clips were tested with either 4 in. or 6 in. of uncompressed insulation. The combinations of parameters resulted in the twenty test configurations shown in Table 1. The main testing program was for specimens with mechanically crimped seams, however several random tests were performed on specimens with un-crimped seams (indicated in Table 1 with a “u” designation). The dimensions of the tested clips are shown in Table 2 and photographs of the clips are shown in Figure 11.

Table 1: List of Configurations Tested

Trapezoidal Profile			Vertical Rib Profile		
Test #	Clip	Insulation	Test #	Clip	Insulation
1	Low Fixed	0”	13	Low Fixed	0”
2 / 2u ¹		4”	14		4”
3 / 3u ¹	High Fixed	4”	15 / 15u ¹	High Fixed	4”
4		6”	16		6”
5	Low	0”	17	Low Floating	0”
6	Sliding Tab	4”	18		4”
7	High	4”	19	High Floating	4”
8	Sliding Tab	6”	20		6”
9	Low	0”			
10 / 10u ¹	Floating	4”			
11 / 11u ¹	High Floating	4”			
12		6”			

¹Seam un-crimped

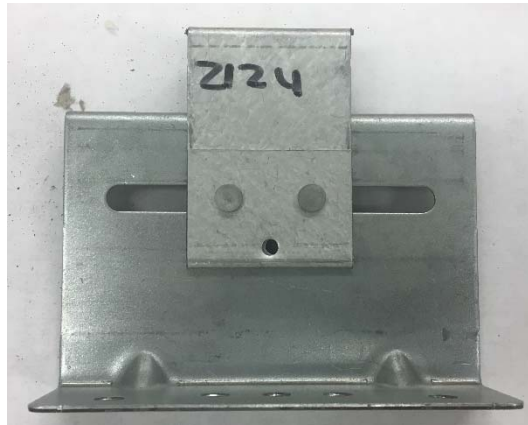
Table 2: Clip Dimensions

Type	Low/ High	ID	Width in Seam (in.)	Shoulder width (in.)	Base Width (in.)	Base to Shoulder Height (in.)	Base Thickness (in.)	Tab Thickness (in.)
Trapezoidal Fixed	Low	FC462	3.25	3.25	2.81	2.375	0.0396	0.0396
	High	FC463	3.25	3.25	2.81	3.375	0.0396	0.0396
Trapezoidal Sliding tab	Low	HW2122	2	5	5	2.351	0.07	0.039
	High	HW2124	2	5	5	3.424	0.069	0.032
Trapezoidal Floating	Low	MPS602	4.3125	4.3125	3.41	2.5	0.0635	0.0396
	High	MPS603	4.3125	4.3125	3.41	3.5	0.0635	0.0396
Vertical Rib Fixed	High	HW224	3	3	3	3.05	0.075	0.037
	Low	HW226	3	3	3	2.415	0.066	0.034
Vertical Rib Floating	Low	HW220	4.3	4.3	2.375	2.515	0.061	0.032
	High	HW222	4.3	4.3	2.375	3.015	0.061	0.032



(a) Trapezoidal Fixed

(b) Trapezoidal Floating



(c) Trapezoidal Sliding



(d) Vertical Rib Floating

(e) Vertical Rib Fixed

Figure 11: Test Clips

A test frame was constructed from steel angles L2x2x3/16 as shown in Figures 12 and 13. Angles running the length of the panels were spaced at 3 feet - 0 in. and were bolted to transverse angles. At the "pin" end, round holes were used to allow rotation of the transverse support angle and at the "roller" end slotted holes were used to allow both translation and rotation. Bolts used in the connections were hand tightened. The panels were attached to the support frame

transverse angles only at the panel ends with self-tapping screws, 2 screws in each panel at each end. No fasteners were applied along the edges of the panel to allow the panel to bend along its span although very little deformation of the panel was observed. A steel bar $\frac{1}{4} \times 1 \times 1'-0''$ was used as a seam strap to simulate the lateral restraint of an adjacent panel and prevent the seam from opening prematurely. The bar was fastened to the pan of the deck with self-tapping screws each side of the seam. A seam strap was located each side of the clip connection approximately 1 feet - 0 in. from the purlin.

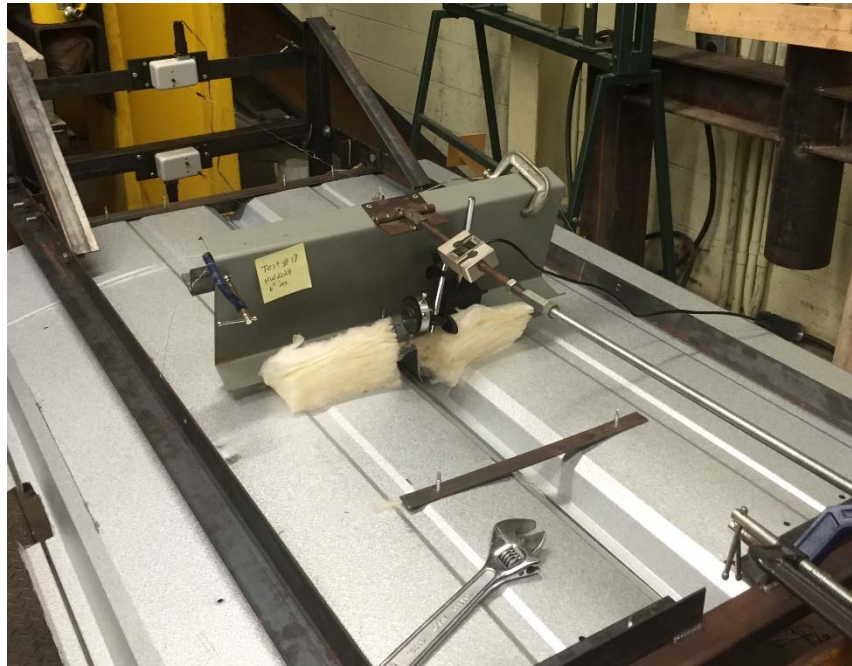


Figure 12: Test Apparatus with Specimen

Each test specimen was constructed with two panel sections, each 5 feet long. Trapezoidal panels were 24 in. wide and vertical rib panels were 16 in. wide. A single clip was attached to the seam and connected to a tributary length of purlin. Where included in the test parameters, a 6 in. wide strip of insulation was sandwiched between the purlin and the clip. For vertical rib panels, the purlin was 16 in. long and for trapezoidal panels, the purlin was 24 in. long. The purlin cross section in each test was 8ZS300x0.100. A heavy gauge purlin was chosen to minimize the purlin deformation and virtually no deformation of the purlin was observed. The seams of the trapezoidal panels were crimped with a single stage hand crimper while the vertical rib panel seams were crimped with a two-stage crimper. The panel seams in the five un-crimped tests were simply snapped into place. Each specimen was constructed in the normal position (sheathing on top of purlin) and then was flipped to the inverted position (purlin on top of sheathing) to facilitate observation of deformations during testing.

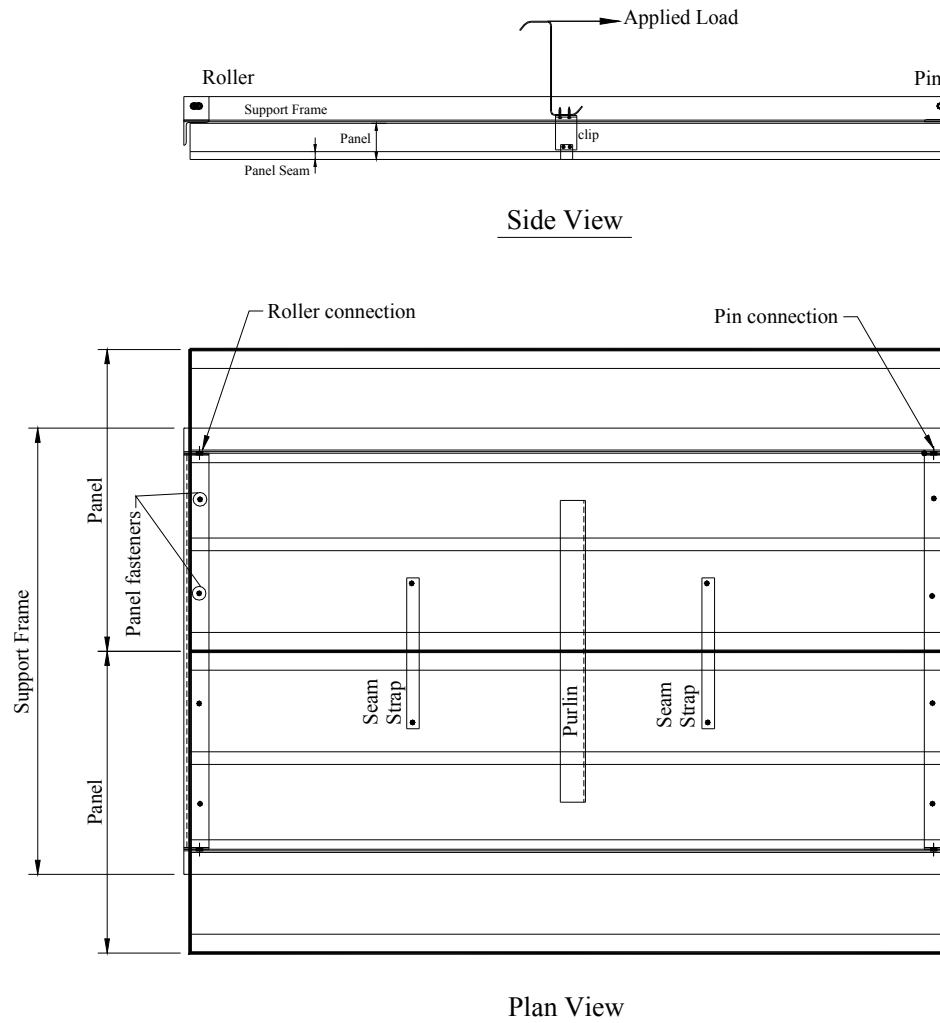


Figure 13: Plan and Elevation of Test Specimen with Support Frame

Load was applied through a ½ in. diameter threaded rod attached to the free flange of the purlin with a hinge and anchored to the support frame as shown in Figure 14. Force was increased by tightening the rod against the anchor point and was measured by a 2-kip S-type load cell. Displacements, Δ_1 and Δ_2 as shown in Figure 6a, were measured by strain gauge based wire potentiometers anchored externally to the support frame. Displacement Δ_4 was measured by a wire potentiometer clamped to the web of the purlin specimen. Displacement Δ_3 was measured in early tests by a dial gauge fixed to the attached flange of the purlin and in later tests a wire potentiometer attached to web of the purlin. For clips that did not extend beyond the flange of the purlin, a small aluminum channel was fastened to the face of the clip as shown in Figure 15. This channel provided the surface to measure displacements of the purlin relative to the clip.

Testing Protocol

Once the specimen was assembled and the instrumentation in place with the load cell finger tightened, all instrumentation was zeroed. Force was applied by tightening the threaded rod against the anchor point. The force was applied in increments and at approximately every 0.50

in. of lateral deflection of the free flange, the test was paused to read the dial gauges, observe changes in the specimen and take pictures. The test was continued until the total rotation reached approximately 0.50 radians. In some cases, the purlin lost significant stiffness before this point and in other cases, although the stiffness softened, the connection showed capacity to continue deforming. Upon reaching the maximum rotation, the system was unloaded and data acquisition terminated.



Figure 14: Application of Force



Figure 15: Rotational-Lateral Stiffness Test Configuration

Test Results

A summary table of all of the test results and data sheets for each test are provided in Appendix 2. In most cases, the system exhibited linear behavior initially followed by deformation of the clip to seam connection that reduced the overall stiffness and the stiffness of the clip-to-seam connection. The moment at this transition point from linear behavior is reported as the peak linear moment. Stiffness of the purlin-clip connection, the clip-seam connection, and the total series stiffness of the two connections is calculated based on the behavior in this linear region.

Trapezoidal Deck – Fixed Clips

Tests 1 through 4 were performed with trapezoidal deck and fixed clips where the clip has a wide interface with the seam. The tests show consistent stiffness values. Total stiffness had a tight range between 0.097 and 0.127 kip-in./rad-in. The clip-seam stiffness ranged between 0.202 and 0.263 kip-in./rad-in. while the purlin-clip stiffness ranged from 0.186 to 0.330 kip-in./rad/in. Because the purlin-clip stiffness is only slightly higher than the clip-seam connection, the effective standoff was slightly higher than the mid height of the clip with a range between 48% and 61% of the clip height. A reasonable estimate of the standoff distance for these types of clips is 50% of the clip height.

Two tests were performed on un-crimped seams, Test 2u with a low fixed clip and Test 3u with a high fixed clip. As expected, the stiffness of the clip connection to the seam is significantly reduced and the standoff distance increased. A reasonable estimate of the standoff distance is 80% of the clip height.

Failure of the clip (loss of stiffness in the system) typically occurred as the “shoulder” of the clip at the bottom of the seam deformed and the side of the clip in compression was wedged into the seam. Compression buckling of the clip side in compression was typically observed and was more pronounced with the taller clips. The peak moment that the clip was able to sustain before substantial deformation occurred is significantly greater for the low fixed clips than the high fixed clips. This difference is largely a result of the buckling of the compression side of the clip. The taller clips have a longer unsupported length but it is also partly the result of the instability of the single-clip test configuration as the clip was more susceptible to lateral rotation.

Trapezoidal Deck – Sliding Tab Clips

Tests 5 through 8 with sliding tab clips displayed a wide variation in stiffness. Total stiffness values ranged from 0.144 to 0.220 kip-in./rad-in which are consistently larger than that for fixed clips. However, the peak moment sustained before stiffness loss is consistently lower for the sliding tab clips than the fixed clips. This difference in peak moment between these two clip types is largely a result of this difference in the extent to which the clip is integrated into the seam. For the fixed clip, the entire width of the clip is integrated into the seam whereas for the sliding tab clips, only the short section of the sliding tab, which is independent of the base, is crimped into the seam. The peak moment and corresponding loss in stiffness occurred as the compression edge of the base of the clip plows into the seam and causes seam separation.

The base of the sliding tab clip is fabricated from heavier gauge material than the sliding tab. Because of this difference in material, the stiffness of the connection to the purlin is greater than for the connection between the seam and the sliding tab. As a result, the standoff distance shifts towards the seam. The tested values ranged widely (from 49% to 88% of the clip height). For sliding tab systems, a reasonable approximation of the standoff distance is between 60% and 70% of the clip height.

A test of a sliding tab clip with an un-crimped seam was not performed. However, a proposed standoff value is given in Table 3 based on the tests of un-crimped trapezoidal deck seams with fixed clips and floating clips. As noted for the crimped tests, the sliding tab clip has a greater purlin-clip stiffness and corresponding standoff distance than the fixed clip or trapezoidal clip. It is inferred that for a sliding tab clip where the seam is un-crimped that this increased stiffness at the base of the clip will result in a higher standoff than for the fixed and floating clips, which have

a standoff of 80% and 70% respectively. As a result, for sliding tab clips with un-crimped seams, a standoff distance of 90% of the clip height was estimated.

Trapezoidal Deck – Floating Clips

Tests 9 through 12 with floating clips exhibit similar behavior to the fixed clips. Stiffness of the purlin-clip connection is slightly more than the clip-seam connection, resulting in a standoff just above mid-height of the clip. It is reasonable to approximate the standoff for floating clips at 50% of the clip height. Compared to the fixed clip, the floating clips exhibited slightly higher stiffness and slightly larger peak moment values. Overall, the tests exhibited consistent results.

Two tests were performed with the seam un-crimped (Tests 10u and 11u). As expected, with the seam un-crimped, the stiffness of the connection between the clip and the seam is reduced resulting in an increase in the standoff distance (approximately 70% of the clip height). It is noted that the decrease in stiffness is accompanied by a decrease in peak moment that is approximately half that of the crimped seam.

Vertical Rib Deck

Comparing vertical rib deck tests to trapezoidal deck tests, in general, the vertical rib tests exhibited higher values for stiffness, but had smaller values for the peak moment. It should be noted that the panel width for the vertical rib deck is 16 inches whereas the trapezoidal deck had a panel width of 24 inches. Therefore, while the vertical rib deck had a smaller peak moment, it is also tributary to a smaller panel width.

Vertical Rib Deck – Fixed Clips

Tests 13 through 16 with fixed clips exhibited consistent results. Stiffness in the connection between the purlin and the clip is close for both low fixed and high fixed clips but there is a significant difference in the clip to seam connection stiffness between the low and high clips. Like with the trapezoidal fixed clips, the large unbraced length of the fixed clips as they extend from the seam created instability in the clip and during the test they had a tendency to roll laterally. This instability can be mitigated with a test configuration that includes at least two clips. For low fixed clips, the effective standoff is approximately 40% of the clip height. For the high fixed clips, the calculated effective standoff is approximately 50% of the clip height. It is the opinion of the authors that this difference is the result of the lateral instability of the clip and it is reasonable to use the effective standoff value of 40% approximated from the low clips.

One test was performed with a high clip and un-crimped seam. As expected and as demonstrated in other un-crimped tests, the stiffness of the connection between the clip and the seam is greatly reduced and the effective standoff was measured at 88% of the clip height. For this one test un-crimped test, the stiffness of the purlin-clip connection was consistently higher than all of the other tests fixed clip tests and therefore may have overestimated the standoff. Using an average value of the purlin-clip stiffness from all of the fixed clip tests, the standoff distance is closer to 80%, which is reported the reported value in Table 3. The standoff value of 80% is also consistent with the standoff value for fixed clips used with trapezoidal profiles.

Vertical Rib Deck – Floating Clips

Tests with floating clips exhibited the largest values for stiffness between the clip and the seam. As a result of this large stiffness, the effective standoff is shifted close to the purlin. Like with the high fixed clips, the specimens with a high floating clip exhibited lateral instability causing a reduction in the stiffness of the high floating clips. This reduction presented itself in the connection between the purlin and the clip as a result of the location of the instrumentation, as opposed to the connection with the seam as was observed in the fixed clips. Therefore, the standoff should be biased towards the low floating clips and a reasonable value for the effective standoff is approximately 25% of the clip height.

No test was performed with a floating clip and an un-crimped seam, however a value of effective standoff is approximated as 80% in Table 3 based on the standoff of fixed clips. Although floating clips exhibit greater flexibility at the base of the clip than the fixed clips and would thus likely have a lower standoff value, the standoff value for floating clips is conservatively set equal to that found for fixed clips.

Previous Reporting of Results

Results from the test program were previously reported in Seek et al. (2017). There are some discrepancies between the values reported there and within this report. The main discrepancy occurs in the way in which values for effective standoff were calculated. In the previous presentation of the data, effective standoff was calculated for the full range of test values, that is, including values beyond the point where behavior was linear. Because softening of the system was a result of reduced stiffness in the clip to seam connection, this created a bias in the data towards an increased standoff distance.

Also in Seek et al., different values for the clip height were used in calculations. For the trapezoidal deck clips, the height of the clip measured from base to the shoulders was used in Seek et al. as opposed to the distance from the base to the center of the seam used in this report. For the vertical rib clips, Seek et al. used the overall height of the clip as opposed to the distance to the center of the seam. In addition, an erroneous value of 4 in. was used in several calculations.

As a result of these differences, the results presented in this report show in general lower standoff values and higher stiffness values. The results presented in this report should supersede the previously presented results.

Test Evaluation

Of the displacement measurements, the most consistent and reliable data is the total rotation measurements. Capturing the deformation of the purlin relative to the clip (displacement measurements Δ_3 and Δ_4) proved challenging and subject to small imperfections. Therefore, more variation is observed in the rotation of the purlin relative to the clip. Because the rotation of the clip relative to the seam is calculated from the rotation of the purlin relative to the clip, this variation in the data is therefore extended to the rotation of the clip relative to the seam.

As previously noted, lateral-rotational instability of the clip (perpendicular to the seam) was observed in the tests, particularly for tall clips. This instability resulted from the test configuration with only a single clip connecting the purlin to the sheathing. This instability can be minimized by modifying the test specimen to include two panel seams and clip connections along the length of the purlin as shown in Figure 16.

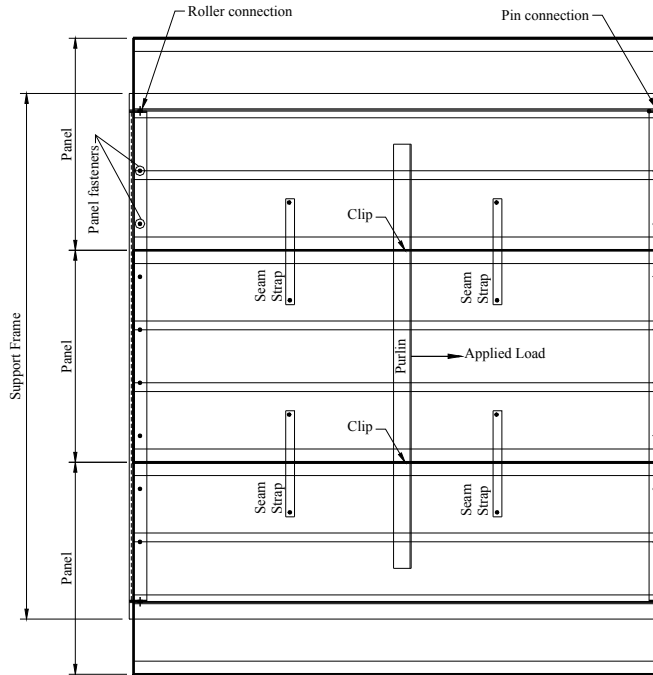


Figure 16: Plan View of Proposed Test Specimen with 2 Clip Connections

Conclusions

This test program has provided a fundamental understanding of effective standoff in standing seam roof systems. Changes in stiffness between the purlin and the clip or between the purlin and the sheathing can affect the location of the standoff distance. In general, the standoff distance is near the mid-height of the clip for systems with a crimped seam and near the top of the clip for un-crimped seams. Given the variation in the purlin-clip and clip-seam rotation data and because only one test per configuration was performed, only broad approximations of the effective standoff and the stiffness of the clip connections can be inferred from the test program.

For different systems, effective standoff can easily be determined with slight modifications to AISI Test Standard S901 whereby additional instrumentation is added to capture the relative rotation between the clip and the purlin. Unless additional test data is acquired, the effective standoff values provided in Table 3 may be used.

A designer should use engineering judgment when applying standoff values to systems different from those presented in this report. Standoff is affected by the stiffness of the seam-clip connections and the stiffness of the purlin-clip connections. At the seam, increasing the length along the seam in which the clip is engaged will increase the stiffness of this connection and as a result, will shift the standoff distance towards the seam. In the connection between the purlin and the clip, the length of the connection between the clip and purlin is limited by the width of the purlin flange and therefore can have little impact on changes in the standoff distance. However, the stiffness of the purlin-clip connection can be affected by changes in the thickness of both the clip and the purlin. An increase in the material thickness in the clip will increase the stiffness of the purlin-clip connection and therefore increase the standoff distance. In the testing, a purlin made from 0.105 in. thick material was used to minimize purlin deformations. If thinner purlins are used, the stiffness of the purlin-clip connection will be reduced resulting in a smaller effective standoff. Different thicknesses of uncompressed insulation were tested. When

sandwiched between the purlin and clip, the insulation was significantly compressed. Although it is expected that the addition of insulation would reduce the stiffness of the purlin-clip connection, no significant trends were observed and it is believed that the differences are small relative to the variability within the testing. The standoff can also be affected by the location of the lateral flexibility built into sliding and floating clips to allow for thermal expansion. This lateral flexibility is typically accompanied by additional rotational flexibility. With the floating clips tested, the lateral flexibility is located at the base of the clip at the purlin, resulting in a lower standoff height. Conversely the lateral flexibility in sliding tab clips was located near the seam of the system, resulting in a higher standoff distance.

Table 3: Recommended Effective Standoff Values

Panel Type	Clip Type	Seam Crimped / Un-crimped	Effective Standoff (% of clip height)
Trapezoidal	Fixed	Crimped	50%
Trapezoidal	Fixed	Un-crimped	80%
Trapezoidal	Sliding Tab	Crimped	60-70%
Trapezoidal	Sliding Tab	Un-crimped ¹	90%
Trapezoidal	Floating	Crimped	50%
Trapezoidal	Floating	Un-crimped	70%
Vertical Rib	Fixed	Crimped	40%
Vertical Rib	Fixed	Un-crimped	80%
Vertical Rib	Floating	Crimped	25%
Vertical Rib	Floating	Un-crimped ¹	80%

¹No test data. Standoff distance estimated.

References

- AISI (American Iron and Steel Institute). (2013) *S901-13 Rotational-Lateral Stiffness Test Method for Beam-to-Panel Assemblies*. Washington, DC.
- AISI (American Iron and Steel Institute). (2012). *North American Specification for the Design of Cold-Formed Steel Structural Members*. Washington, DC.
- Murray, T. M., Sears, J., and Seek, M. W. (2009). *D111-09 Design Guide for Cold-Formed Steel Purlin Roof Framing Systems*. American Iron and Steel Institute. Washington, DC.
- Seek, M. W. and McLaughlin, D. (2017) "Impact of clip connection and insulation thickness on the bracing of purlins in standing seam roof systems." *Conference Proceedings, Structural Stability Research Council Annual Stability Conference*. 2017. Structural Stability Research Council, Chicago, IL.

Appendix 1 Clip Characterization

Table A1.1 Clip Characterization - Trapezoidal Profiles

Member	Type	ID	Width in Seam (in.)	Shoulder width (in.)	Base Width (in.)	Base to Shoulder Height (in.)	Hole Spacing (in.)	Base Thickness (in.)	Tab Thickness (in.)	Slide Range (in.)
1	Sliding tab	SSPC-1	2.5	4.7665	4.7665	2.255	.5,1.25	0.105	0.033	1.307
		SSPC-2T	4.75	4.7515	4.7515	3.6365	.5,1.25	0.105	0.034	1.276
	Sliding tab	S3PC-1	4	6	6	3.544	.5,1.25	0.101	0.033	1.271
		S3PC-2T	4	6	6	2.2	.5,1.25	0.106	0.03	1.303
2	Sliding tab	HW2122	2	5	5	2.351	0,.65,1.75	0.07	0.039	1.348
		HW2124	2	5	5	3.424	0,.65,1.75	0.069	0.032	1.338
		HW2126	2	6	6	2.353	0,.65,1.7	0.106	0.041	2
		HW2128	2	6	6	3.41	0,.65,1.7	0.106	0.036	2
		HW2129	2	5	5	4.012	0,.65,1.75	0.075	0.037	1.322
4	MR-24	MR-1	2.125	3.25	1.75	2.25	0	0.062	0.023	??
		MR-2	1.375	3.25	1.75	2.25	0	0.062	0.023	??
		MR-3	2.125	3.25	1.75	3.3125	0	0.062	0.023	??
		MR-4	1.375	3.25	1.75	3.3125	0	0.062	0.023	??
		MR-5	2.125	3.25	1.75	3.75	0	0.062	0.023	??
		MR-6	1.375	3.25	1.75	3.75	0	0.062	0.023	??

Table A1. 1 Clip Characterization - Trapezoidal Profiles, cont

Member	Type	ID	Width in Seam (in.)	Shoulder width (in.)	Base Width (in.)	Base to Shoulder Height (in.)	Hole Spacing (in.)	Base Thickness (in.)	Tab Thickness (in.)	Slide Range (in.)
3	Fixed	FC461	3.25	3.25	??	2.375	??	0.0396	0.0396	??
		FC462	3.25	3.25	??	2.375	??	0.0396	0.0396	??
		FC463	3.25	3.25	??	3.375	??	0.0396	0.0396	??
		FC 10200	3.25	3.25	??	2	??	0.0336	0.0336	??
		FC 10203	3.25	3.25	??	2.375	??	0.0336	0.0336	??
		FC 10213	3.25	3.25	??	3.375	??	0.0396	0.0396	??
	Floating	MPS602	4.3125	4.3125	??	3.5	??	0.0635	0.0396	??
		MPS603	4.3125	4.3125	??	4.5	??	0.0635	0.0396	??
		MPS602-3	4.3125	4.3125	??	3.5	??	0.0635	0.0396	??
		MPS603-3	4.3125	4.3125	??	4.5	??	0.0635	0.0396	??
		MPS604-3	4.3125	4.3125	??	3.5	??	0.0635	0.0396	??
		MPS604	4.3125	4.3125	??	3.5	??	0.0635	0.0396	??
		MPS605-3	4.3125	4.3125	??	4.5	??	0.0635	0.0396	??
		MPS605	4.3125	4.3125	??	4.5	??	0.0635	0.0396	??
		MC 1203	4.375	4.375	??	2.375	??	0.0635	0.0336	??
		MC 1213	4.375	4.3125	??	3.375	??	0.0635	0.0336	??
		MPS 1213	4.375	4.3125	??	3.375	??	0.0635	0.0396	??
		MPS 1203	4.375	4.3125	??	3.375	??	0.0635	0.0396	??
	Floating	BA 602-6	6	6	??	4.5	??	0.0635	0.0396	??
		BA 602-8	8	8	??	4.5	??	0.0635	0.0396	??
		BA 602-12	12	12	??	3.5	??	0.0635	0.0396	??
		BA 602-16	16	16	??	3.5	??	0.0635	0.0396	??
		BA 603-6	6	6	??	4.5	??	0.0635	0.0396	??
		BA 603-8	8	8	??	4.5	??	0.0635	0.0396	??
BA 603-12		12	12	??	4.5	??	0.0635	0.0396	??	
BA 603-16	16	16	??	4.5	??	0.0635	0.0396	??		

Table A1.1 Clip Characterization - Vertical Rib Profiles

Member	Type	ID	Width in Seam (in.)	Shoulder Width (in.)	Base Width (in.)	Base to Shoulder Height (in.)	Hole Spacing (in.)	Base Thickness (in.)	Tab Thickness (in.)	Slide Range (in.)
1	Sliding Tab	LSEC-1	3	3	3	2.39	0.3	0.05	0.027	0.6
		LSEC-2T	3	3	3	3.51	0.3	0.05	0.027	0.6
	Fixed	SLPC-2	3.5	3.5	3.5	1.867	0.65	0.05	0.05	N/A
2	Floating	HW220	4.3	4.3	2.375	2.515	0.3	0.061	0.032	1.05
		HW222	4.3	4.3	2.375	3.015	0.3	0.061	0.032	1.021
	Fixed	HW224	3	3	3	3.05	0,.75	0.075	0.037	N/A
		HW226	3	3	3	2.415	0,.75	0.066	0.034	N/A
		SSR-2	7.5	7.5	1.75	2.875	0,.375,1.25,2.25	0.059	0.042	??
		SSR-3	7.5	7.5	1.75	3.375	0,.375,1.25,2.25	0.059	0.042	??
		SSR-4	7.5	7.5	1.75	3.875	0,.375,1.25,2.25	0.059	0.042	??

Appendix 2 Test Results

Table A2.1 Summary of Test Results

Test	Test ID	Clip Stiffness, $k_{\phi\text{clip-seam}}$ (kip-in./rad-in.)	Purlin Stiffness, $k_{\phi\text{purlin-clip}}$ (kip-in./rad-in.)	Total Stiffness, k_{ϕ} (kip-in./rad-in.)	Max Linear Moment (lb-ft)	Clip Height (in.)	Clip Base to Seam CL, h_{clip} (in.)	Effective Standoff (in.)	Effective Standoff Ratio
1	T-LF-0	0.263	0.239	0.126	1582	2.50	3.00	1.44	0.48
2	T-LF-4	0.202	0.277	0.117	1979	2.50	3.09	1.79	0.58
2u	T-LF-4u	0.098	0.240	0.070	478	2.50	3.09	2.20	0.71
3	T-HF-4	0.206	0.330	0.127	1050	3.50	4.09	2.53	0.61
4	T-HF-6	0.204	0.186	0.097	1060	3.50	4.13	1.98	0.48
3u	T-HF-4u	0.100	0.589	0.086	298	3.50	4.09	3.53	0.86
5	T-LS-0	0.204	1.396	0.178	645	2.35	2.85	2.50	0.88
6	T-LS-4	0.228	0.571	0.163	891	2.35	2.94	2.10	0.72
7	T-HS-4	0.341	0.618	0.220	1056	3.35	3.94	2.54	0.64
8	T-HS-6	0.297	0.277	0.144	946	3.35	3.98	1.93	0.49
9	T-LFo-0	0.427	0.587	0.246	1671	2.50	3.00	1.74	0.58
10	T-LFo-4	0.499	0.603	0.273	1897	2.50	3.09	1.69	0.55
10u	T-LFo-4u	0.209	0.590	0.154	821	2.50	3.09	2.10	0.68
11	T-HFo-4	0.543	0.560	0.276	1280	3.50	4.09	2.08	0.51
12	T-HFo-6	0.537	0.487	0.256	1519	3.50	4.13	1.96	0.48
11u	T-HFo-4u	0.276	0.669	0.196	671	3.50	4.09	2.90	0.71
13	V-LF-0	0.873	0.524	0.328	676	2.375	2.00	0.75	0.38
14	V-LF-4	0.745	0.477	0.291	604	2.375	2.09	0.82	0.39
15	V-HF-4	0.452	0.549	0.251	648	3.00	2.72	1.51	0.56
16	V-HF-6	0.493	0.481	0.244	597	3.00	2.75	1.36	0.50
15u	V-HF-4u	0.089	0.608	0.078	254	3.00	2.72	2.38	0.88
17	V-LFo-0	1.288	0.659	0.437	906	2.50	2.13	0.72	0.34
18	V-LFo-4	1.49	0.449	0.345	768	2.50	2.22	0.52	0.23
19	V-HFo-4	0.943	0.195	0.162	633	3.00	2.72	0.47	0.17
20	V-HFo-6	1.166	0.195	0.198	559	3.00	2.75	0.47	0.17

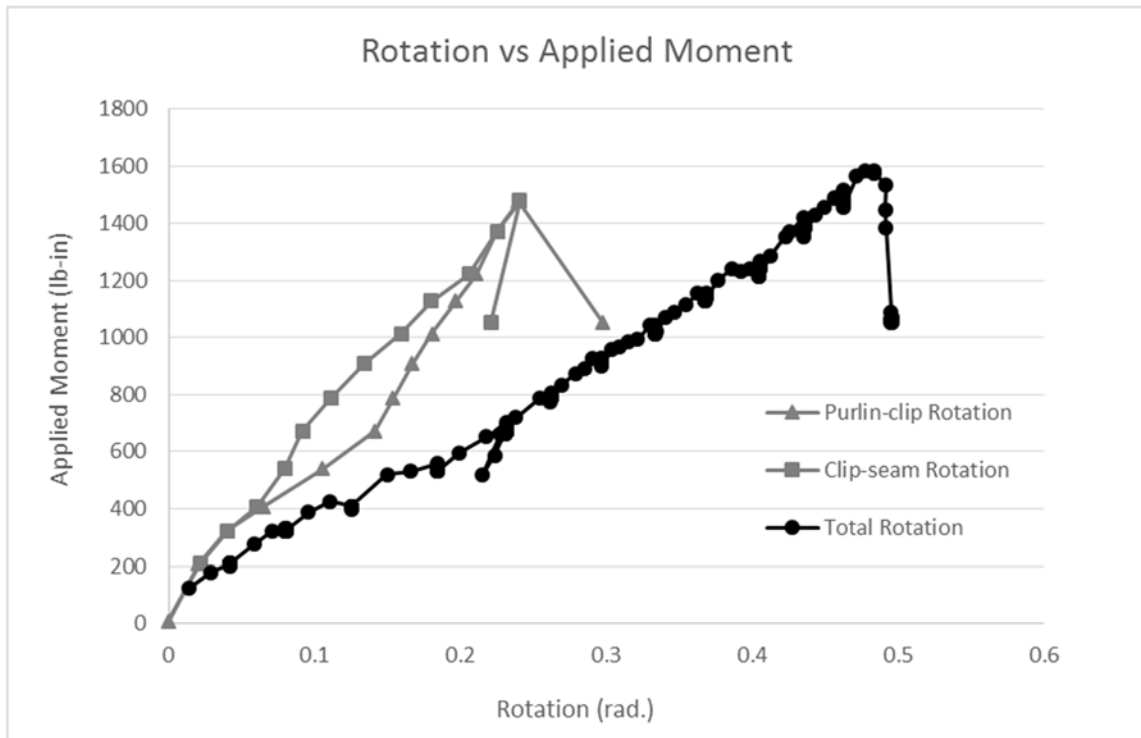
Summary - Test 1: T-LF-0

Test Parameters

Test Number	1
Test ID	T-LF-0
Panel	Trapezoidal
Clip Type	Low Fixed
Clip base to seam CL	3.00 in.
Insulation	0 in.
Purlin	8ZS2.5x105x24"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	4.0 in.
Load height from seam CL	11.375 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.263
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.239
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.126
Effective Standoff (in.)	1.44
Effective Standoff Ratio	0.48
Peak Linear Moment (lb-in.)	1582



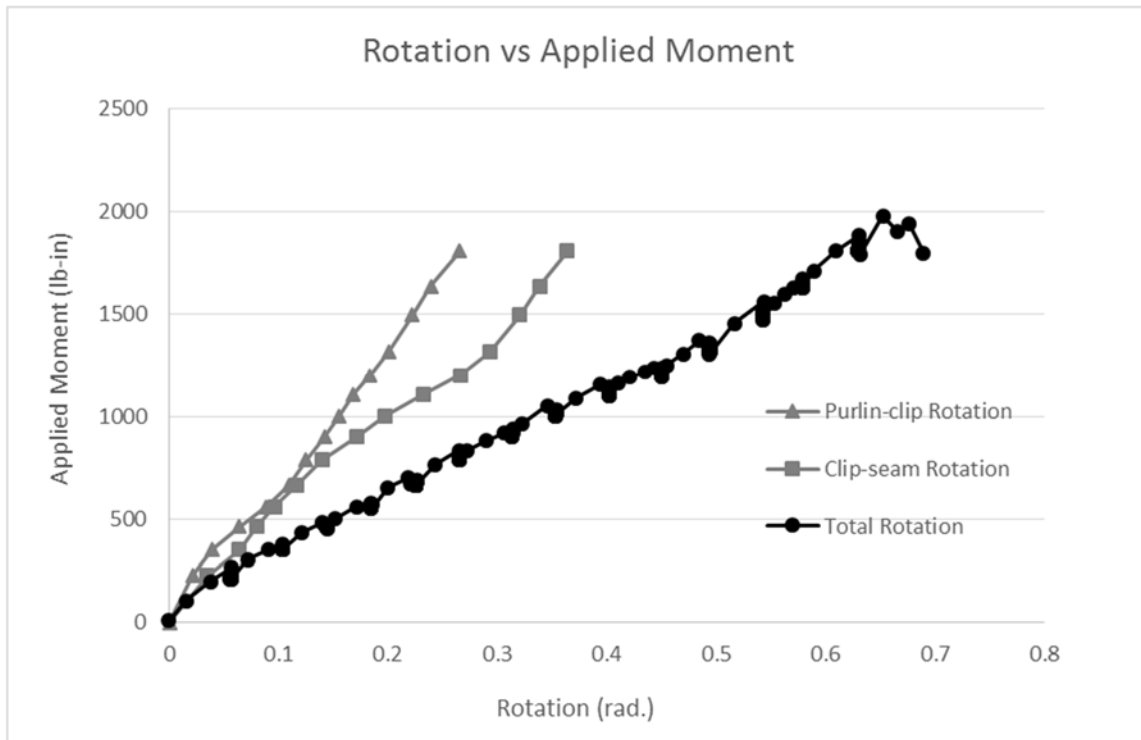
Summary - Test 2: T-LF-4

Test Parameters

Test Number	2
Test ID	T-LF-4
Panel	Trapezoidal
Clip Type	Low Fixed
Clip base to seam CL	3.09 in.
Insulation	4 in.
Purlin	8ZS2.5x105x24"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	3.75 in.
Load height from seam CL	11.375 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.202
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.277
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.117
Effective Standoff (in.)	1.79
Effective Standoff Ratio	0.58
Peak Linear Moment (lb-in.)	1979



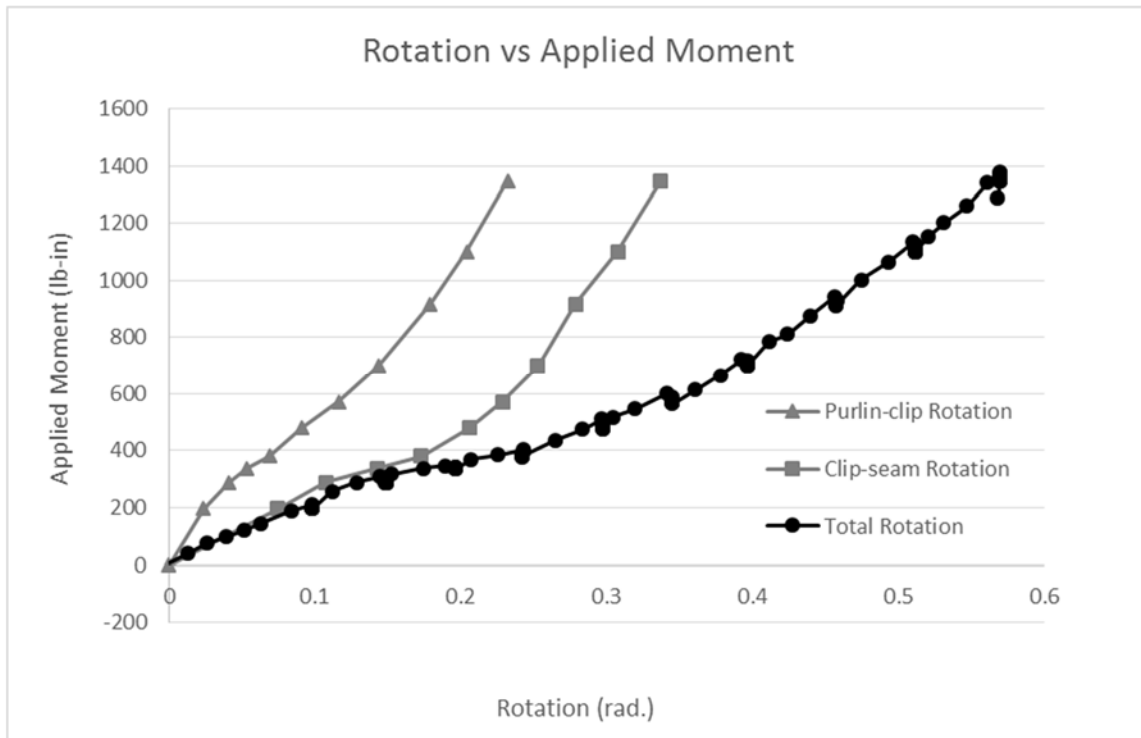
Summary - Test 2u: T-LF-4u

Test Parameters

Test Number	2u
Test ID	T-LF-4u
Panel	Trapezoidal
Clip Type	Low Fixed
Clip base to seam CL	3.09 in.
Insulation	4 in.
Purlin	8ZS2.5x105x24"
Crimped/Un-crimped	Un-crimped
Clip Sensor Spacing	3.325 in.
Load height from seam CL	11.375 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.098
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.240
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.070
Effective Standoff (in.)	2.20
Effective Standoff Ratio	0.71
Peak Linear Moment (lb-in.)	478



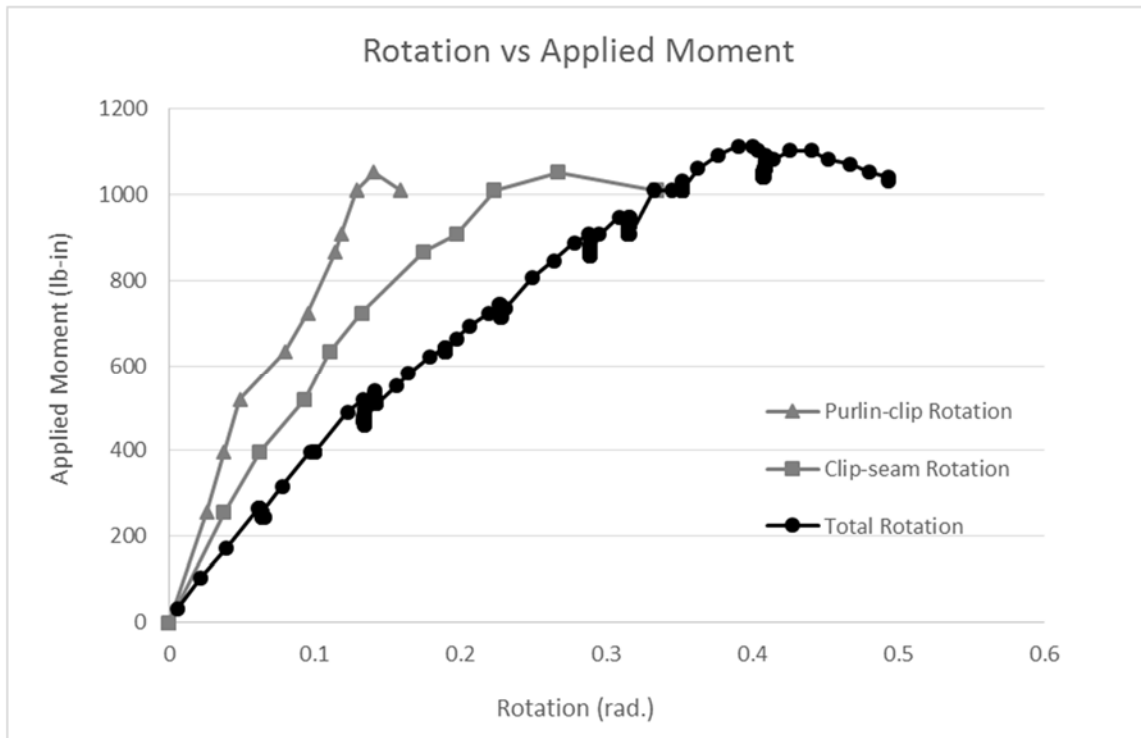
Summary - Test 3: T-HF-4

Test Parameters

Test Number	3
Test ID	T-HF-4
Panel	Trapezoidal
Clip Type	High Fixed
Clip base to seam CL	4.09 in.
Insulation	4 in.
Purlin	8ZS2.5x105x24"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	3.5 in.
Load height from seam CL	12.25 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.206
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.330
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.127
Effective Standoff (in.)	2.53
Effective Standoff Ratio	0.61
Peak Linear Moment (lb-in.)	1050



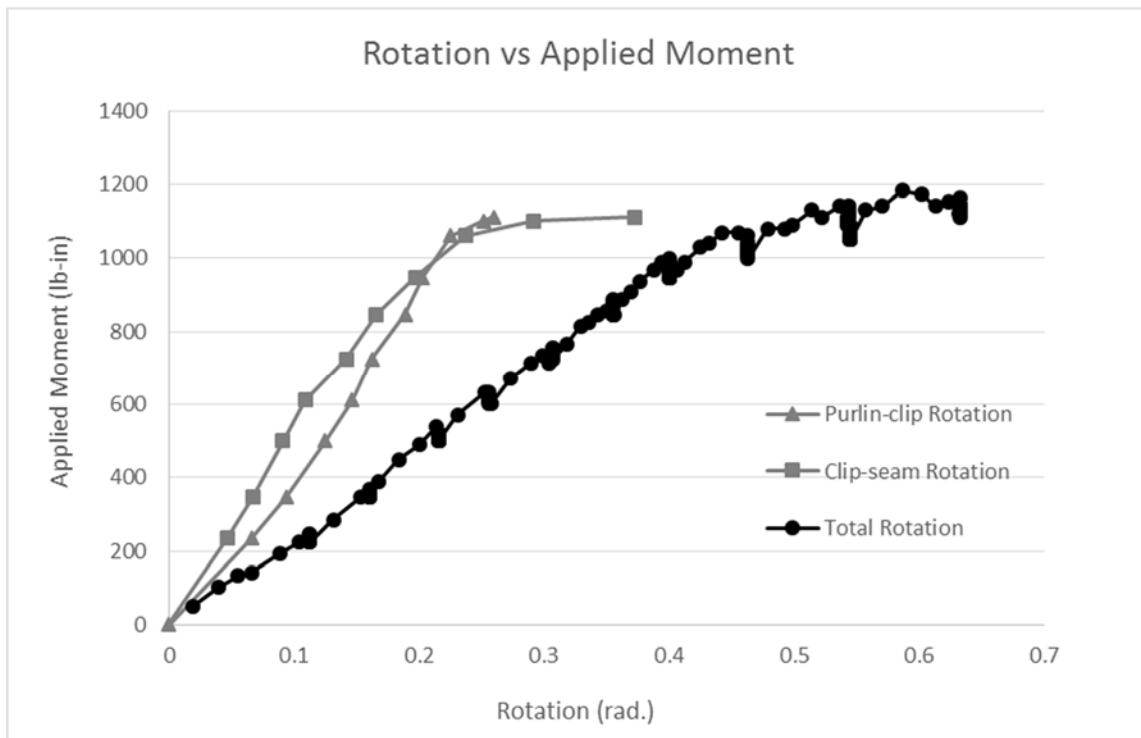
Summary - Test 4: T-HF-6

Test Parameters

Test Number	4
Test ID	T-HF-6
Panel	Trapezoidal
Clip Type	High Fixed
Clip base to seam CL	4.13 in.
Insulation	6 in.
Purlin	8ZS2.5x105x24"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	3.75 in.
Load height from seam CL	12.25 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.204
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.186
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.097
Effective Standoff (in.)	1.98
Effective Standoff Ratio	0.48
Peak Linear Moment (lb-in.)	1060



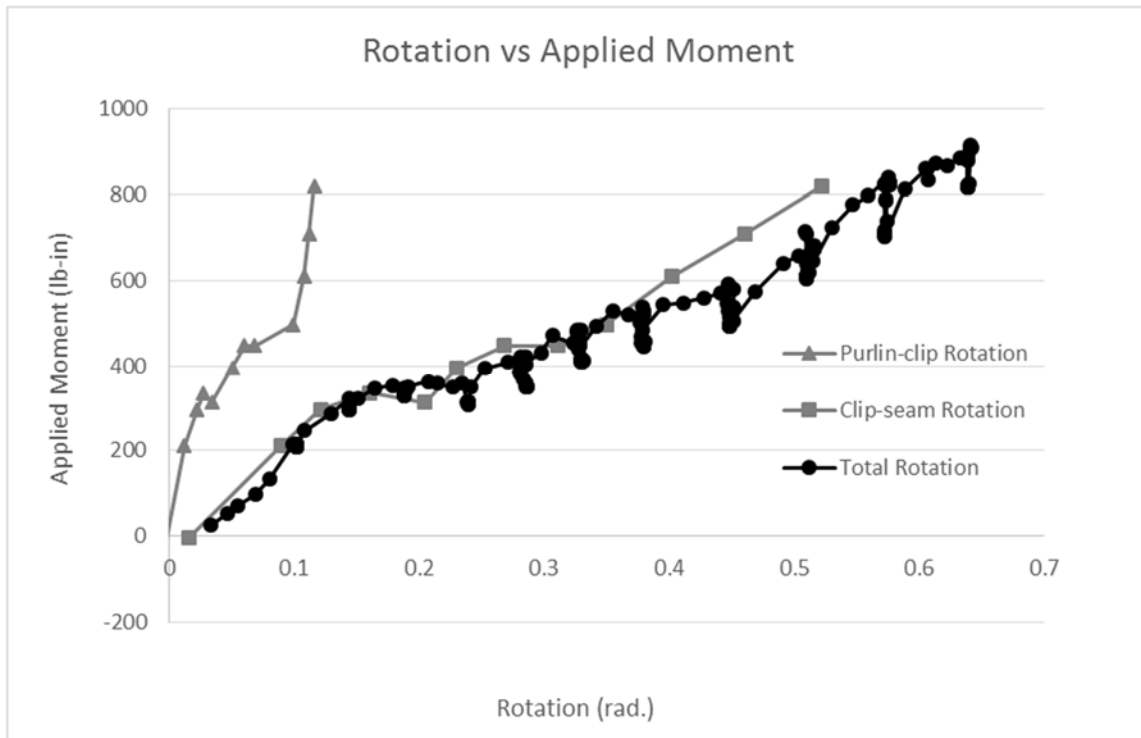
Summary - Test 3u: T-HF-4u

Test Parameters

Test Number	3u
Test ID	T-HF-4u
Panel	Trapezoidal
Clip Type	High Fixed
Clip base to seam CL	4.09 in.
Insulation	4 in.
Purlin	8ZS2.5x105x24"
Crimped/Un-crimped	Un-crimped
Clip Sensor Spacing	3.25 in.
Load height from seam CL	12.125 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.100
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.589
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.086
Effective Standoff (in.)	3.53
Effective Standoff Ratio	0.86
Peak Linear Moment (lb-in.)	298



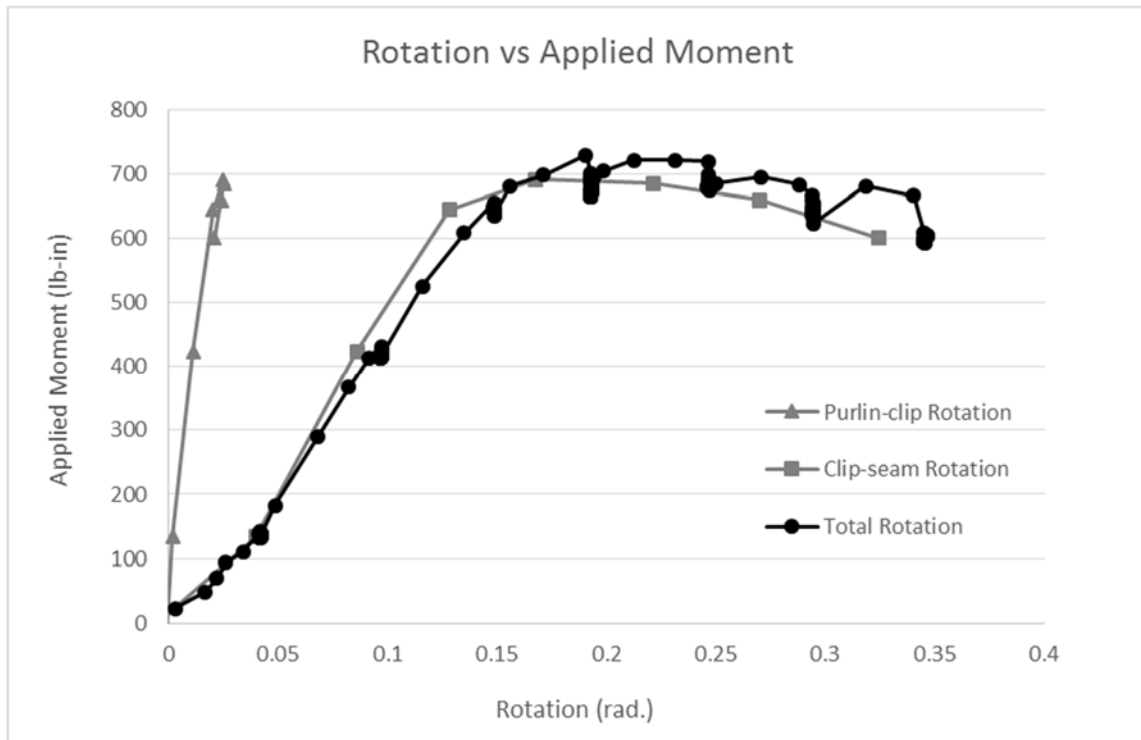
Summary - Test 5: T-LS-0

Test Parameters

Test Number	5
Test ID	T-LS-0
Panel	Trapezoidal
Clip Type	Low Sliding
Clip base to seam CL	2.85 in.
Insulation	0 in.
Purlin	8ZS2.5x105x24"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	3.75 in.
Load height from seam CL	11.5 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.204
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	1.396
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.178
Effective Standoff (in.)	2.50
Effective Standoff Ratio	0.88
Peak Linear Moment (lb-in.)	645



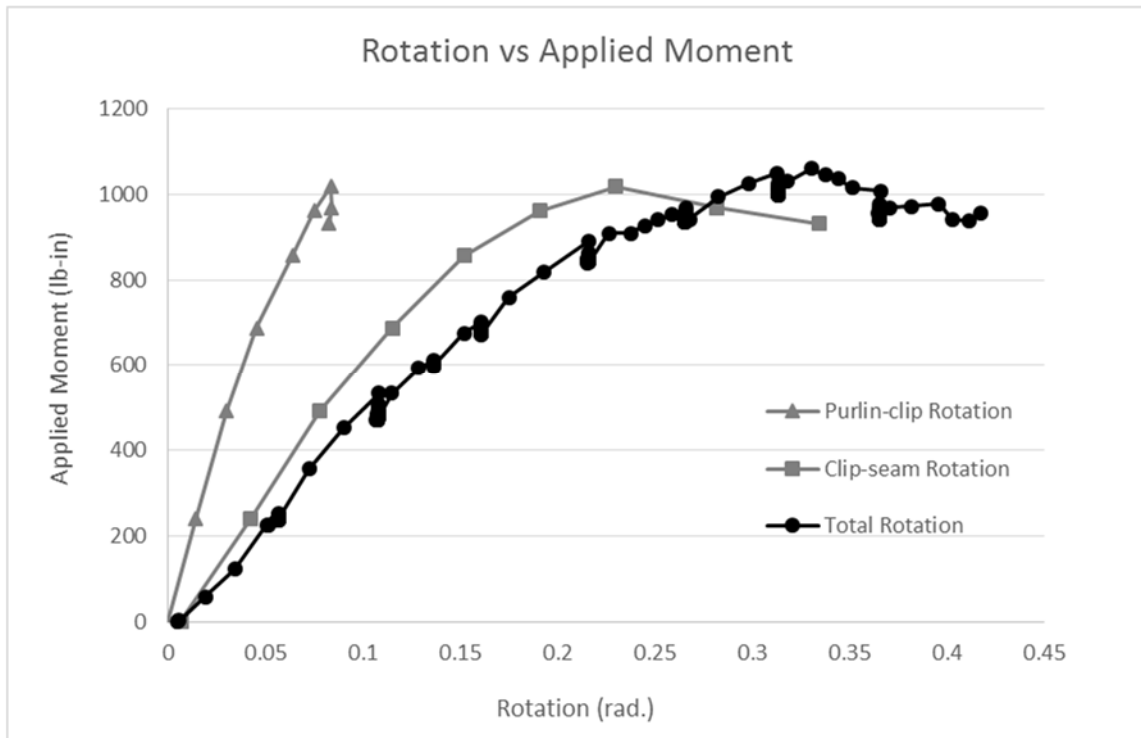
Summary - Test 6: T-LS-4

Test Parameters

Test Number	6
Test ID	T-LS-4
Panel	Trapezoidal
Clip Type	Low Sliding
Clip base to seam CL	2.94 in.
Insulation	4 in.
Purlin	8ZS2.5x105x24"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	4.25 in.
Load height from seam CL	11.375 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.228
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.571
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.163
Effective Standoff (in.)	2.10
Effective Standoff Ratio	0.72
Peak Linear Moment (lb-in.)	891



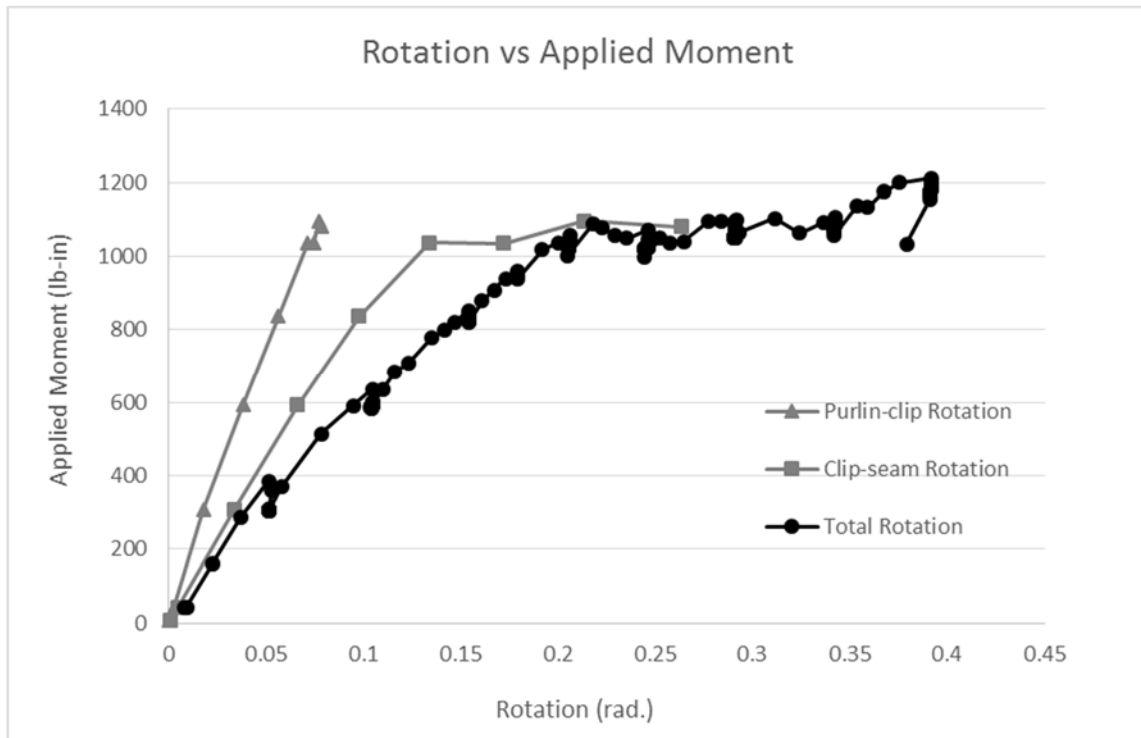
Summary - Test 7: T-HS-4

Test Parameters

Test Number	7
Test ID	T-HS-4
Panel	Trapezoidal
Clip Type	High Sliding
Clip base to seam CL	3.94 in.
Insulation	4 in.
Purlin	8ZS2.5x105x24"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	4.25 in.
Load height from seam CL	12.375 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.341
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.618
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.220
Effective Standoff (in.)	2.54
Effective Standoff Ratio	0.64
Peak Linear Moment (lb-in.)	1056



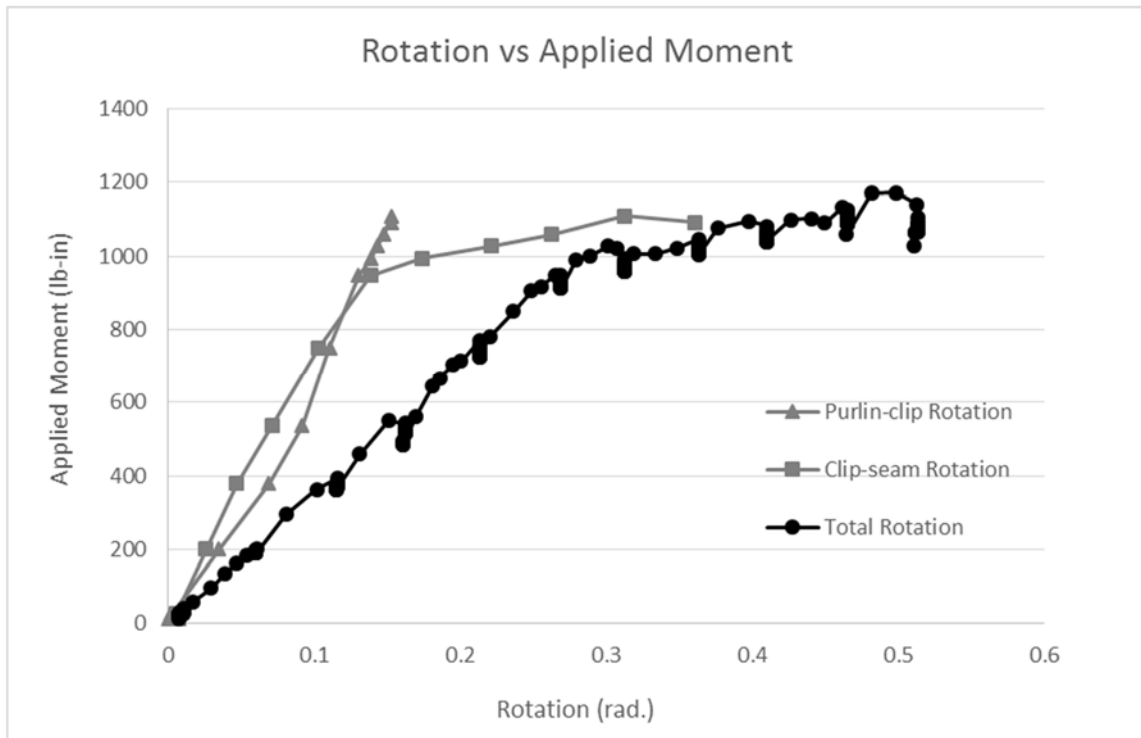
Summary - Test 8: T-HS-6

Test Parameters

Test Number	8
Test ID	T-HS-6
Panel	Trapezoidal
Clip Type	High Sliding
Clip base to seam CL	3.98 in.
Insulation	6 in.
Purlin	8ZS2.5x105x24"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	4.5 in.
Load height from seam CL	12.375 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.297
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.277
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.144
Effective Standoff (in.)	1.93
Effective Standoff Ratio	0.49
Peak Linear Moment (lb-in.)	946



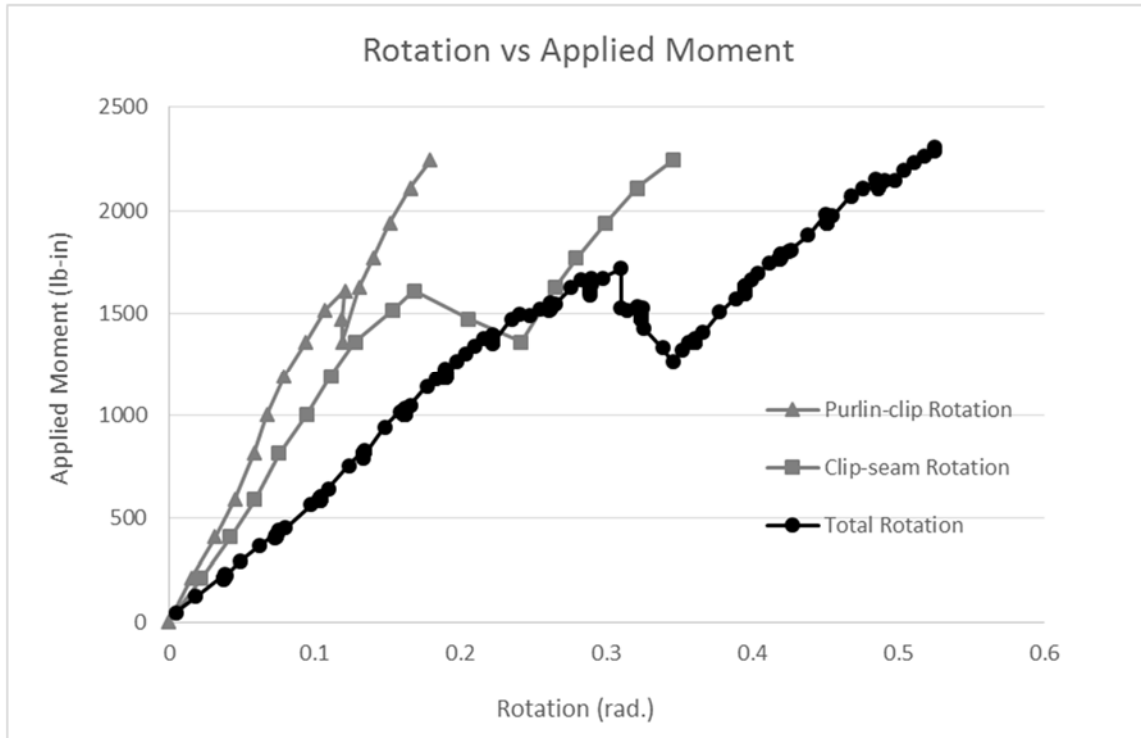
Summary - Test 9: T-LFo-0

Test Parameters

Test Number	9
Test ID	T-LFo-0
Panel	Trapezoidal
Clip Type	Low Floating
Clip base to seam CL	3.0 in.
Insulation	0 in.
Purlin	8ZS2.5x105x24"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	3.875 in.
Load height from seam CL	11.75 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.427
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.587
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.246
Effective Standoff (in.)	1.74
Effective Standoff Ratio	0.58
Peak Linear Moment (lb-in.)	1671



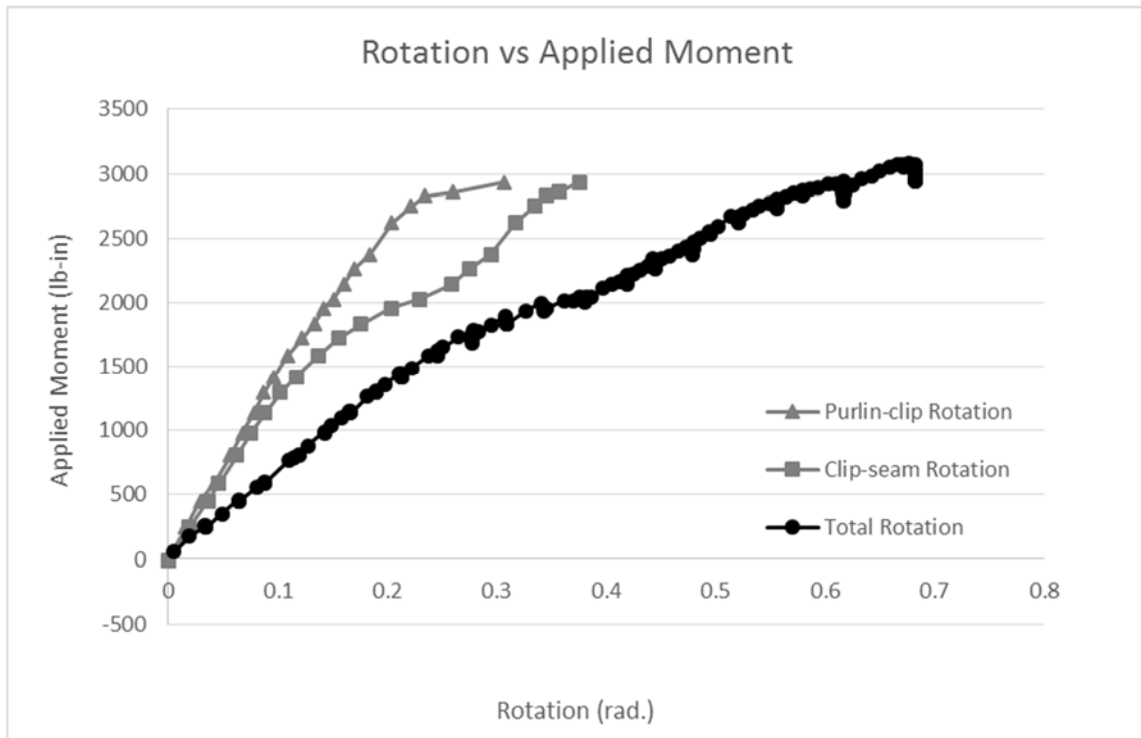
Summary - Test 10: T-LFo-4

Test Parameters

Test Number	10
Test ID	T-LFo-4
Panel	Trapezoidal
Clip Type	Low Floating
Clip base to seam CL	3.09 in.
Insulation	4 in.
Purlin	8ZS2.5x105x24"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	3.75 in.
Load height from seam CL	11.75 in.

Test Results

Clip-Seam, $k_{\phi_{clip-seam}}$ (kip-in./rad/in.)	0.499
Purlin-Clip, $k_{\phi_{purlin-clip}}$ (kip-in./rad/in.)	0.603
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.273
Effective Standoff (in.)	1.69
Effective Standoff Ratio	0.55
Peak Linear Moment (lb-in.)	1897



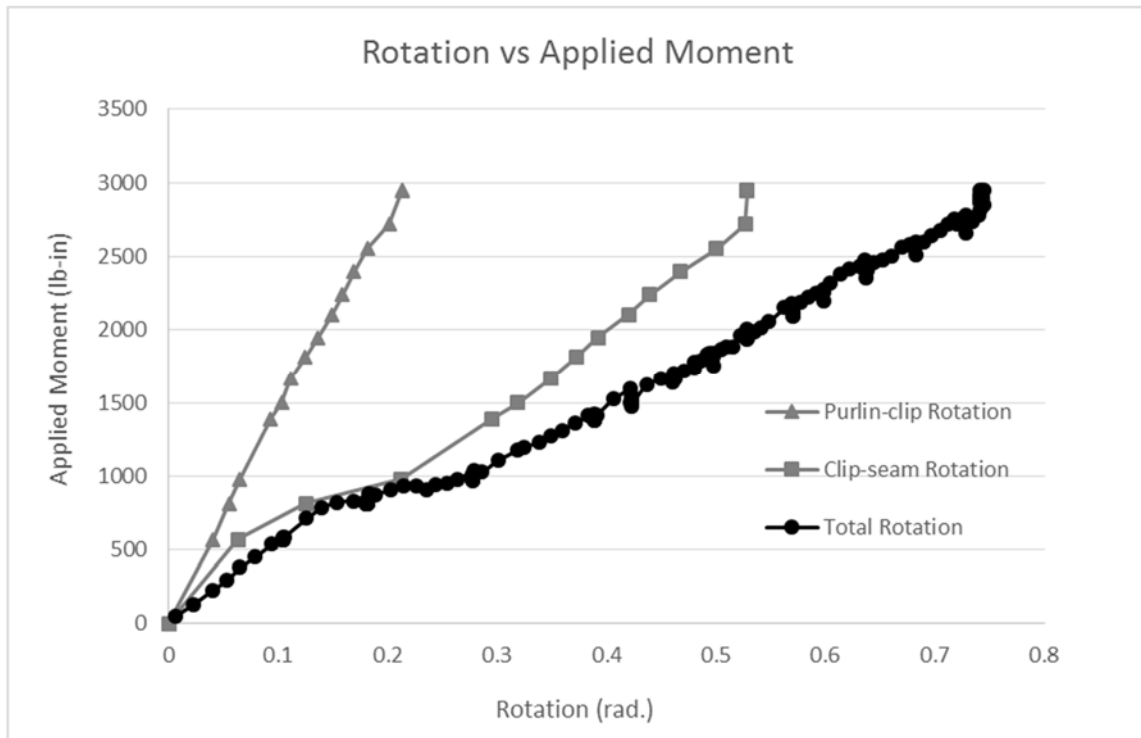
Summary - Test 10u: T-LFo-4u

Test Parameters

Test Number	10u
Test ID	T-LFo-4u
Panel	Trapezoidal
Clip Type	Low Floating
Clip base to seam CL	3.09 in.
Insulation	4 in.
Purlin	8ZS2.5x105x24"
Crimped/Un-crimped	Un-crimped
Clip Sensor Spacing	3.75 in.
Load height from seam CL	11.75 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.209
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.590
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.154
Effective Standoff (in.)	2.10
Effective Standoff Ratio	0.68
Peak Linear Moment (lb-in.)	821



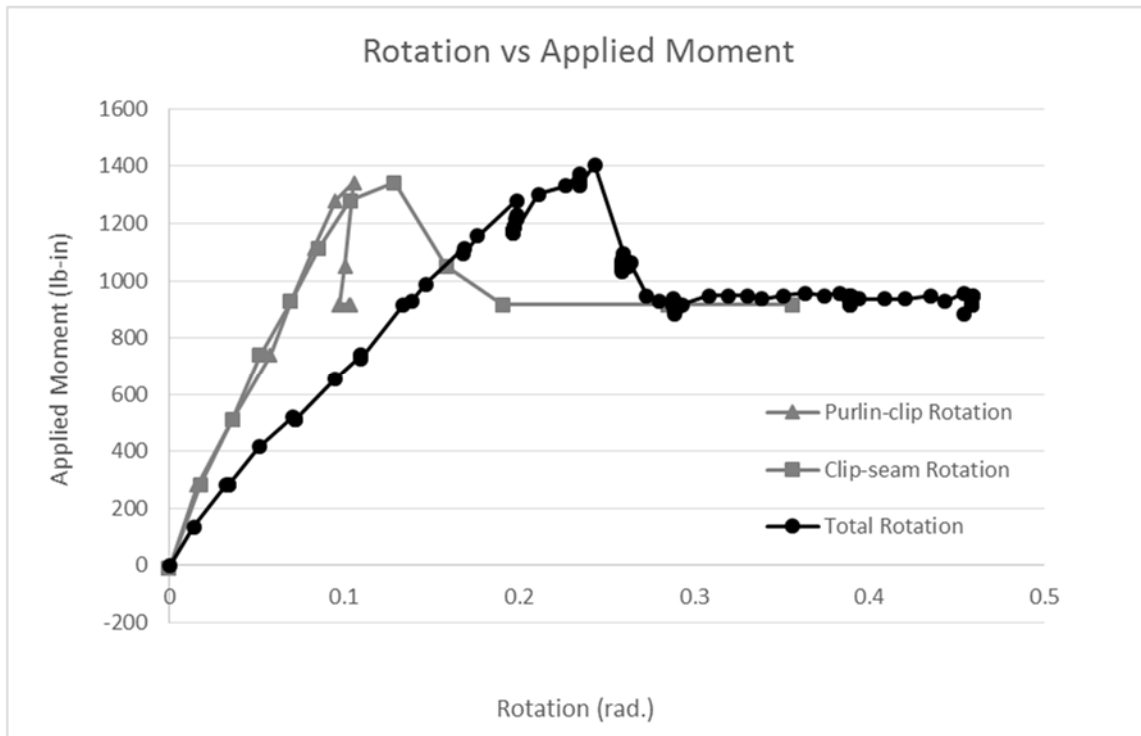
Summary - Test 11: T-HFo-4

Test Parameters

Test Number	11
Test ID	T-HFo-4
Panel	Trapezoidal
Clip Type	High Floating
Clip base to seam CL	4.09 in.
Insulation	4 in.
Purlin	8ZS2.5x105x24"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	3.75 in.
Load height from seam CL	12.5 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.543
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.560
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.276
Effective Standoff (in.)	2.08
Effective Standoff Ratio	0.51
Peak Linear Moment (lb-in.)	1280



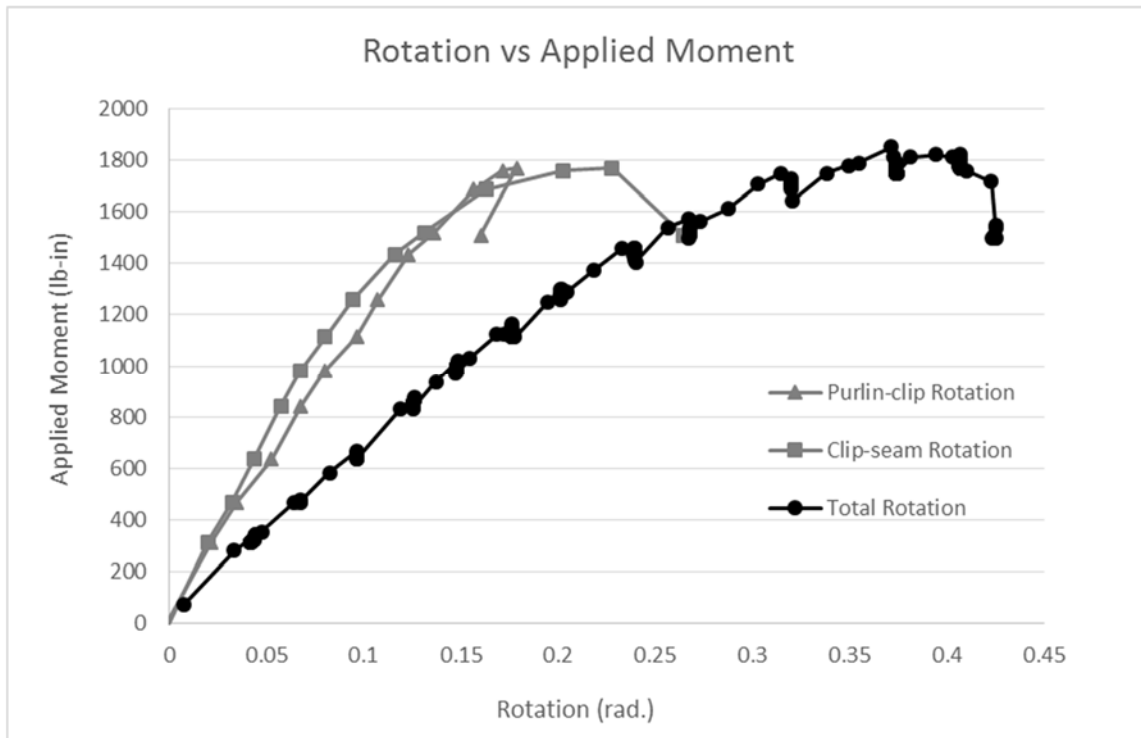
Summary - Test 12: T-HFo-6

Test Parameters

Test Number	12
Test ID	T-HFo-6
Panel	Trapezoidal
Clip Type	High Floating
Clip base to seam CL	4.13 in.
Insulation	6 in.
Purlin	8ZS2.5x105x24"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	3.75 in.
Load height from seam CL	12.5 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.537
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.487
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.256
Effective Standoff (in.)	1.96
Effective Standoff Ratio	0.48
Peak Linear Moment (lb-in.)	1519



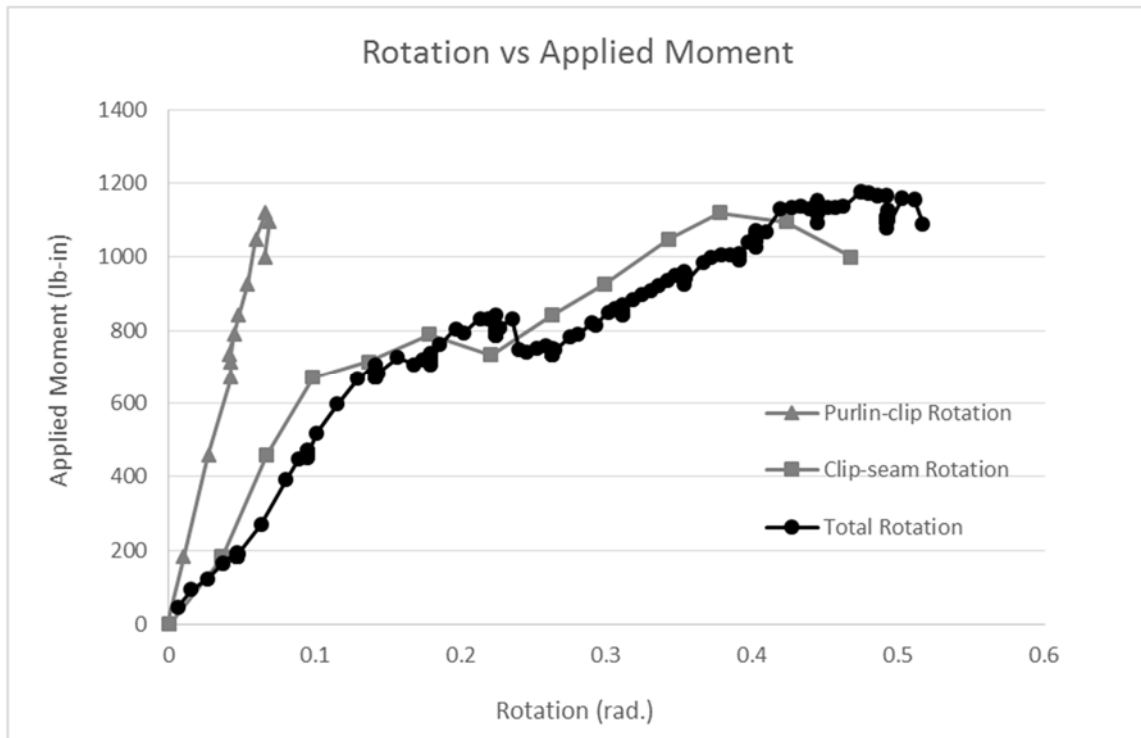
Summary - Test 11u: T-HFo-4u

Test Parameters

Test Number	11u
Test ID	T-HFo-4u
Panel	Trapezoidal
Clip Type	High Floating
Clip base to seam CL	4.09 in.
Insulation	4 in.
Purlin	8ZS2.5x105x24"
Crimped/Un-crimped	Un-crimped
Clip Sensor Spacing	3.325 in.
Load height from seam CL	12.5 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.276
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.669
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.196
Effective Standoff (in.)	2.90
Effective Standoff Ratio	0.71
Peak Linear Moment (lb-in.)	671



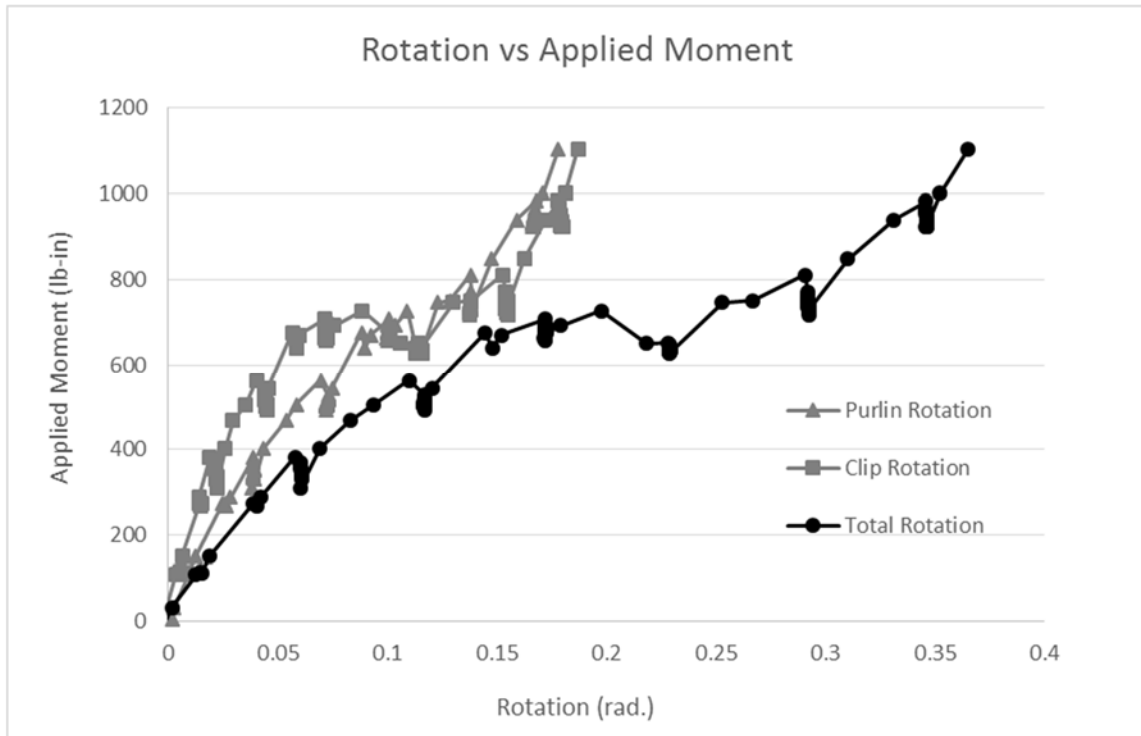
Summary - Test 13: V-LF-0

Test Parameters

Test Number	13
Test ID	V-LF-0
Panel	Vertical Rib
Panel Width	16 in.
Clip Type	Low Fixed
Clip base to seam CL	2.00 in.
Insulation	0 in.
Purlin	8ZS2.5x105x16"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	3.25 in.
Load height from seam CL	10.875 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.873
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.524
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.328
Effective Standoff (in.)	0.75
Effective Standoff Ratio	0.38
Peak Linear Moment (lb-in.)	676



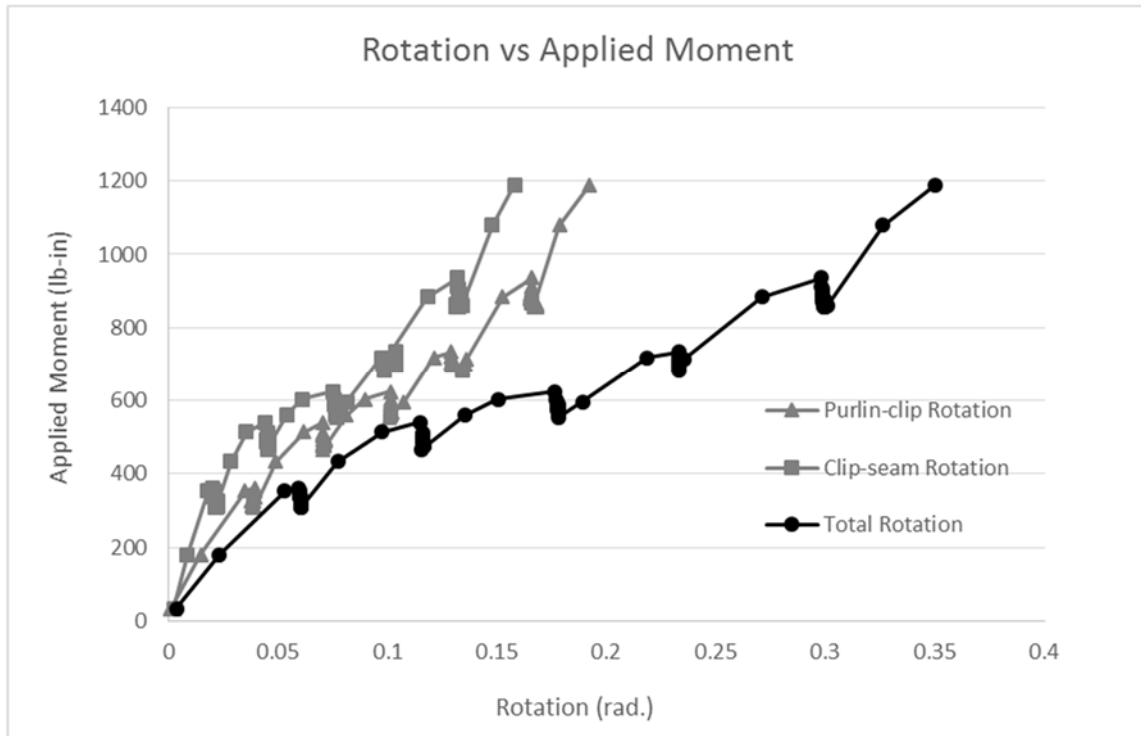
Summary - Test 14: V-LF-4

Test Parameters

Test Number	14
Test ID	V-LF-4
Panel	Vertical Rib
Panel Width	16 in.
Clip Type	Low Fixed
Clip base to seam CL	2.09 in.
Insulation	4 in.
Purlin	8ZS2.5x105x16"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	3.25 in.
Load height from seam CL	10.875 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.745
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.477
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.291
Effective Standoff (in.)	0.82
Effective Standoff Ratio	0.39
Peak Linear Moment (lb-in.)	604



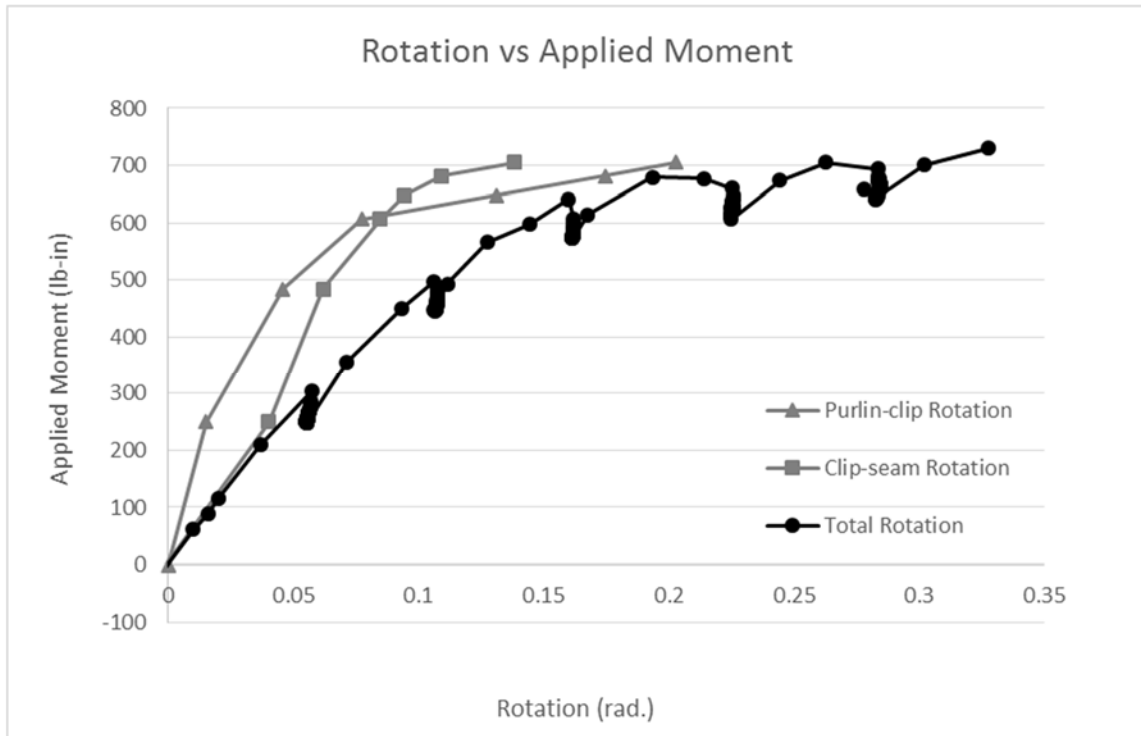
Summary - Test 15: V-HF-4

Test Parameters

Test Number	15
Test ID	V-HF-4
Panel	Vertical Rib
Panel Width	16 in.
Clip Type	High Fixed
Clip base to seam CL	2.72 in.
Insulation	4 in.
Purlin	8ZS2.5x105x16"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	3.5 in.
Load height from seam CL	11.375 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.452
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.549
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.251
Effective Standoff (in.)	1.51
Effective Standoff Ratio	0.56
Peak Linear Moment (lb-in.)	648



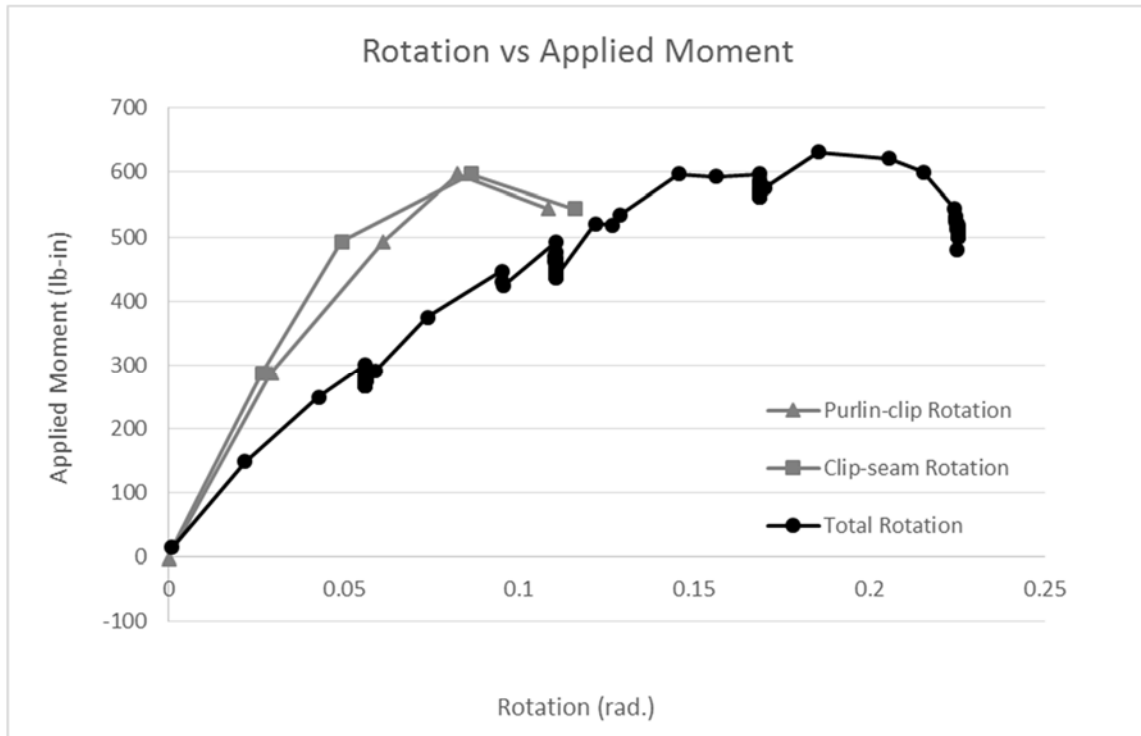
Summary - Test 16: V-HF-6

Test Parameters

Test Number	16
Test ID	V-HF-6
Panel	Vertical Rib
Panel Width	16 in.
Clip Type	High Fixed
Clip base to seam CL	2.75 in.
Insulation	6 in.
Purlin	8ZS2.5x105x16"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	3.75 in.
Load height from seam CL	11.375 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.493
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.481
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.244
Effective Standoff (in.)	1.36
Effective Standoff Ratio	0.50
Peak Linear Moment (lb-in.)	597



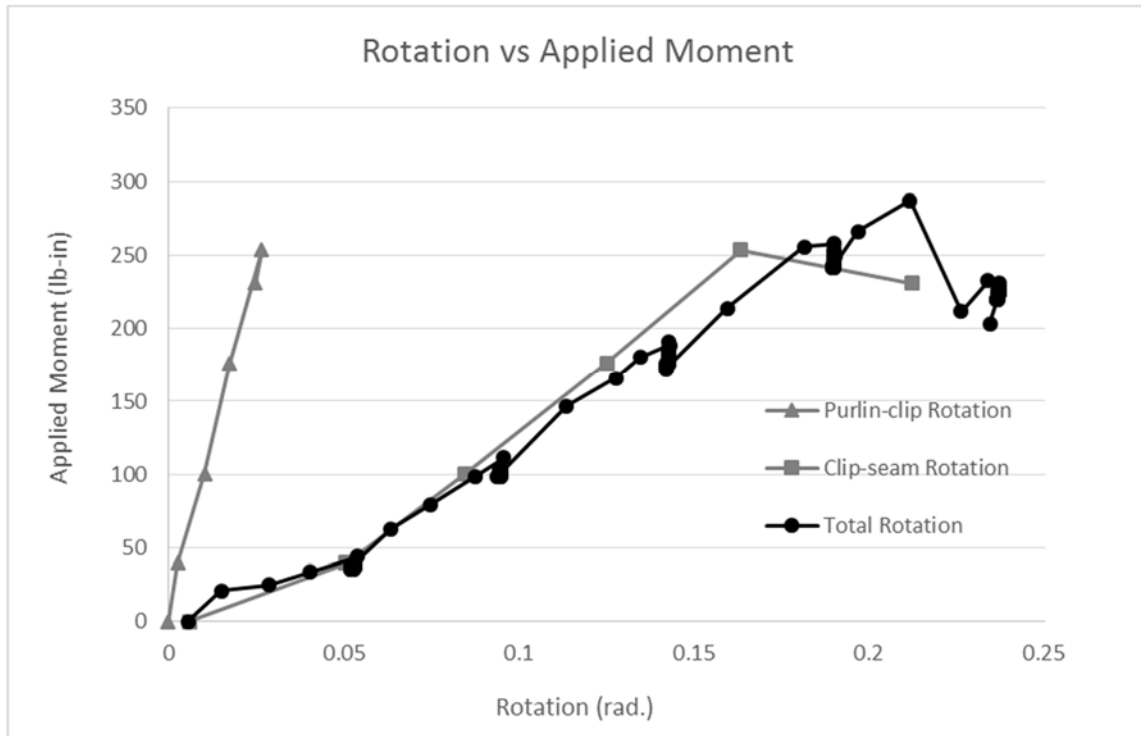
Summary - Test 15u: V-HF-4u

Test Parameters

Test Number	15u
Test ID	V-HF-4u
Panel	Vertical Rib
Panel Width	16 in.
Clip Type	High Fixed
Clip base to seam CL	2.72 in.
Insulation	6 in.
Purlin	8ZS2.5x105x16"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	3.875 in.
Load height from seam CL	11.375 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.089
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.608
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.078
Effective Standoff (in.)	2.38
Effective Standoff Ratio	0.88
Peak Linear Moment (lb-in.)	254



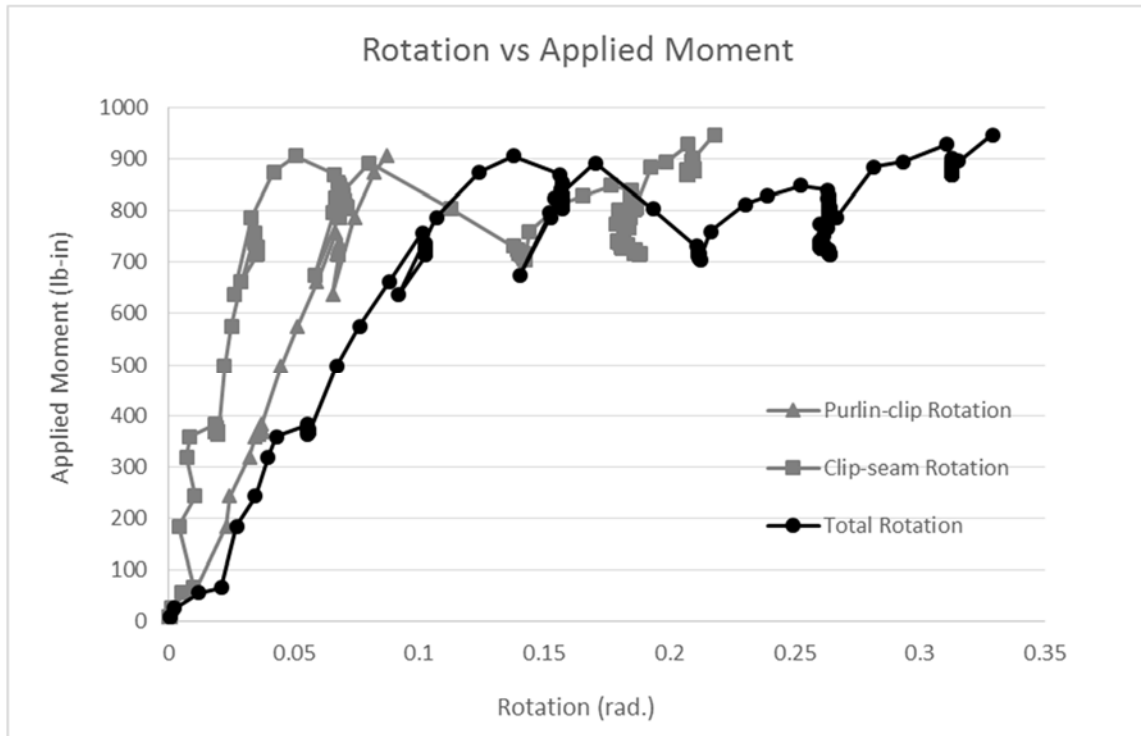
Summary - Test 17: V-LFo-0

Test Parameters

Test Number	17
Test ID	V-LFo-0
Panel	Vertical Rib
Panel Width	16 in.
Clip Type	Low Floating
Clip base to seam CL	2.125 in.
Insulation	0 in.
Purlin	8ZS2.5x105x16"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	3.25 in.
Load height from seam CL	10.875 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	1.288
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.659
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.437
Effective Standoff (in.)	0.72
Effective Standoff Ratio	0.34
Peak Linear Moment (lb-in.)	906



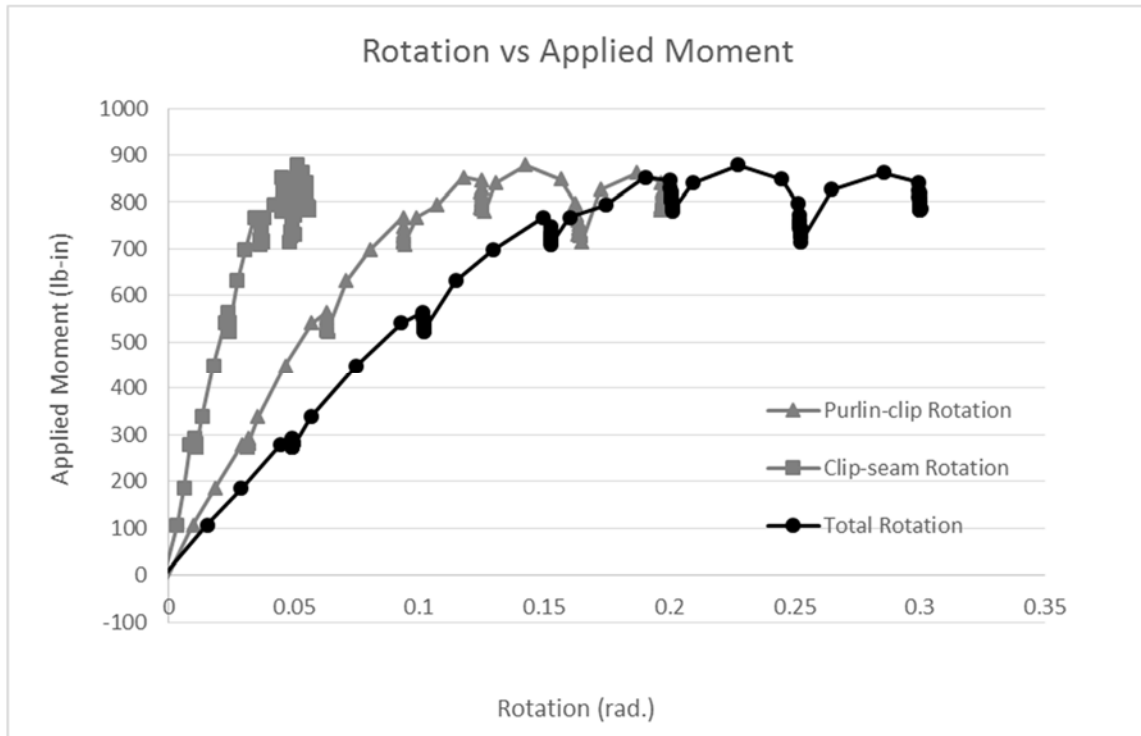
Summary - Test 18: V-LFo-4

Test Parameters

Test Number	18
Test ID	V-LFo-4
Panel	Vertical Rib
Panel Width	16 in.
Clip Type	Low Floating
Clip base to seam CL	2.22 in.
Insulation	4 in.
Purlin	8ZS2.5x105x16"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	3.25 in.
Load height from seam CL	10.875 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	1.49
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.449
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.345
Effective Standoff (in.)	0.52
Effective Standoff Ratio	0.23
Peak Linear Moment (lb-in.)	768



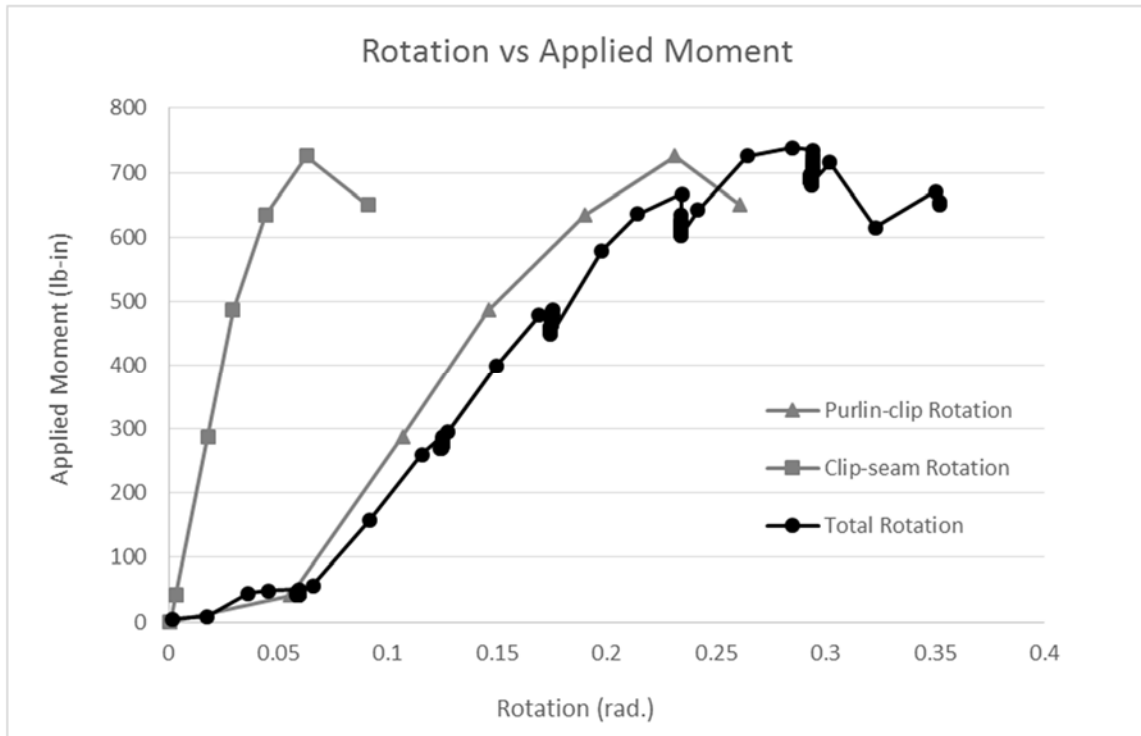
Summary - Test 19: V-HFo-4

Test Parameters

Test Number	19
Test ID	V-HFo-4
Panel	Vertical Rib
Panel Width	16 in.
Clip Type	High Floating
Clip base to seam CL	2.72 in.
Insulation	4 in.
Purlin	8ZS2.5x105x16"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	4.25 in.
Load height from seam CL	11.375 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	0.943
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.195
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.162
Effective Standoff (in.)	0.47
Effective Standoff Ratio	0.17
Peak Linear Moment (lb-in.)	633



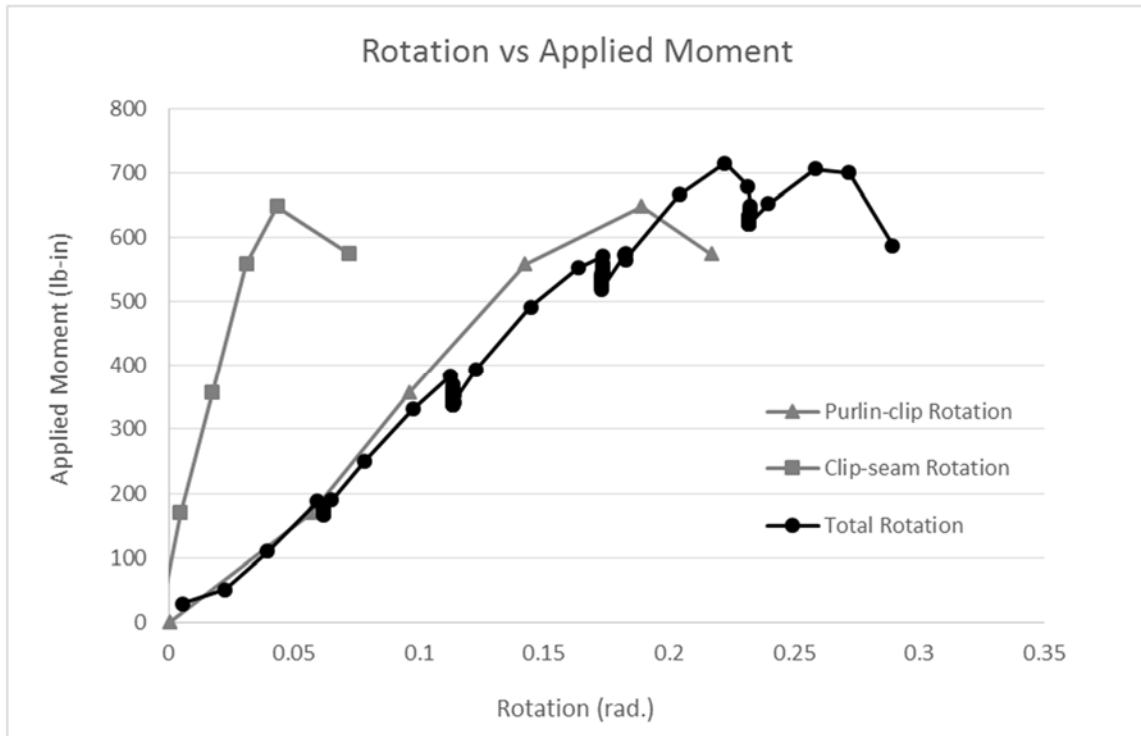
Summary - Test 20: V-HFo-6

Test Parameters

Test Number	20
Test ID	V-HFo-6
Panel	Vertical Rib
Panel Width	16 in.
Clip Type	High Floating
Clip base to seam CL	2.75 in.
Insulation	4 in.
Purlin	8ZS2.5x105x16"
Crimped/Un-crimped	Crimped
Clip Sensor Spacing	4.25 in.
Load height from seam CL	11.375 in.

Test Results

Clip-Seam, $k_{\phi\text{clip-seam}}$ (kip-in./rad/in.)	1.166
Purlin-Clip, $k_{\phi\text{purlin-clip}}$ (kip-in./rad/in.)	0.195
Net Stiffness, k_{ϕ} (kip-in./rad/in.)	0.198
Effective Standoff (in.)	0.47
Effective Standoff Ratio	0.17
Peak Linear Moment (lb-in.)	559





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