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# Experimental response of cold-formed steel walls with bridging and sheathing

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**Abstract**
The objective of this paper is to describe experiments conducted on cold-formed steel walls under axial loading with a variety of different discrete bracing and sheathing conditions. Cold-formed steel wall systems are commonly braced using small bridging channels that run through the web of the studs (discrete bracing) as well as by sheathing that is attached directly to the stud flanges. Previous research has shown that sheathing, on its own, can be a highly effective means of bracing studs; however, sheathing is not always present during construction and in some cases, e.g., a sprinkler system saturating a gypsum board panel, may not provide adequate restraint. As a result, discrete (all-steel) bracing systems are sometimes favored. All-steel bracing systems under ultimate applied loads can be costly – particularly if brace force accumulation, and commensurate loss of stiffness, is properly accounted for in the design. To better understand the flow of forces in cold-formed steel walls with combinations of discrete and sheathing bracing, a set of pilot experiments have been conducted. The experiments consider (a) whether or not the discrete bracing is properly resolved at its end, (b) whether or not gypsum sheathing is in place, in addition to the discrete bracing, and (c) sequence of loading, i.e., when the gypsum sheathing is installed. Forces in the discrete bracing are directly measured, as is sidesway and twist displacement of the studs under load. The resulting tests indicate that bridging only plays a secondary role in bracing steel studs once sheathing is installed. It is intended to use these results to develop improved engineering guidance on the use of combined steel bridging plus sheathing, bracing conditions for walls.

## 1. Introduction
Cold-formed steel gravity, load bearing, walls consist of vertical lipped channel studs capped with horizontal plain channel track – typically fastened together by self-drilling screws (see Figure 1). The open cross-section lipped channel studs have relatively weak torsional stiffness and are oriented such that minor axis bending is in the plane of the wall. Without bracing of the studs, the wall capacity would be severely limited.

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The most common form of wall bracing is small channels, known as bridging, that are installed through holes (knockouts) in the stud web (see the 150U50-54 in Figure 1). These bridging channels provide minor-axis flexural bracing, and depending on their stiffness and installation details can also restrict torsion of the stud. The typical stiffness of these systems was explored in Green et al. (2006). Of course, an isolated bridging channel must be resolved to a stiff member so that the bracing forces can be carried out of the wall – these may be achieved in a variety of ways such as using kickers (direct axial members that go from the bridging to the floors) or strongback studs (members with high bending rigidity that can have the bracing force transmitted directly). However, predictions of the accumulated brace force and stiffness requirements for an entire wall can be significant and result in design requirements that are not aligned with long-standing practice and, as a result, have been a topic of some study. (Blum et al. 2015, Sputo and Beery 2008, Ziemian and Ziemian 2017).

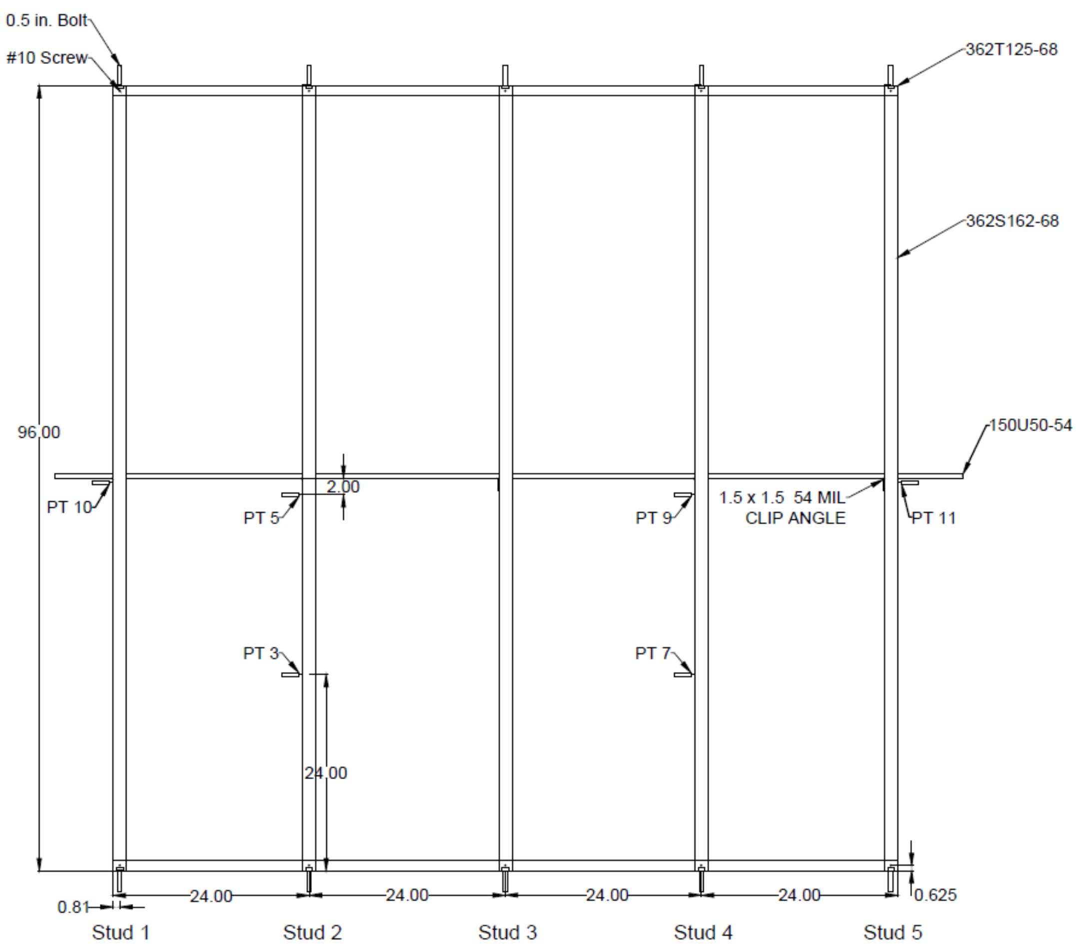


Figure 1: Elevation of typical CFS frame, nomenclature, and sensors (PTs) dimensions in inch.

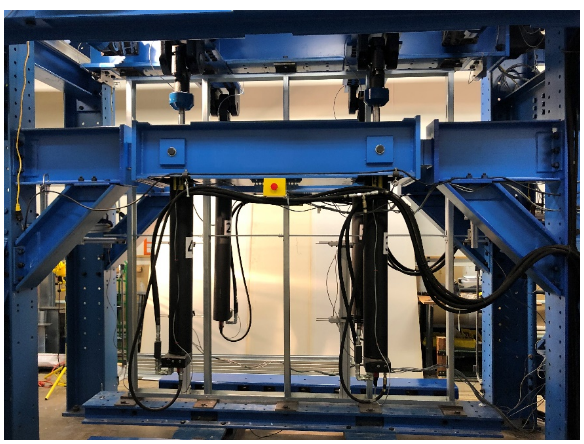
From a practical standpoint, all CFS walls will have finishing applied to both sides of the wall. This finishing typically includes sheathing, which is directly applied to the stud flanges. Gypsum board sheathing is the most common form of finishing. Once installed, the gypsum board can also serve to brace the studs – particularly if installed on both sides, such sheathing can be an effective restraint against both minor-axis and torsional deformations of the stud. A comprehensive series of research on the role of sheathing in bracing cold-formed steel walls, summarized in Schafer

(2013) and supported by the efforts in Vieira (2011), Vieira and Schafer (2013), Peterman (2012), and Peterman and Schafer (2014) unequivocally demonstrated that sheathing bracing could effectively stabilize cold-formed steel stud walls, and developed a supporting design method. However, since many finish systems are non-structural, concerns persist as to whether such systems will be available during an overload or other critical loading conditions (e.g., fire).

In practice, both steel discrete bridging and wall sheathing exist in a cold-formed steel stud wall. It is desired to know how these two systems work when under load and acting as bracing. What is the impact of not fully resolving (anchoring) the bridging? What is the impact of the construction sequence on the relative bracing forces between the bridging and the sheathing? When both bridging and sheathing are present, which system actually carries the bracing demands? A focused series of tests was developed to explore these questions and are introduced in this paper and fully detailed in the Qian and Schafer (2020) testing report.

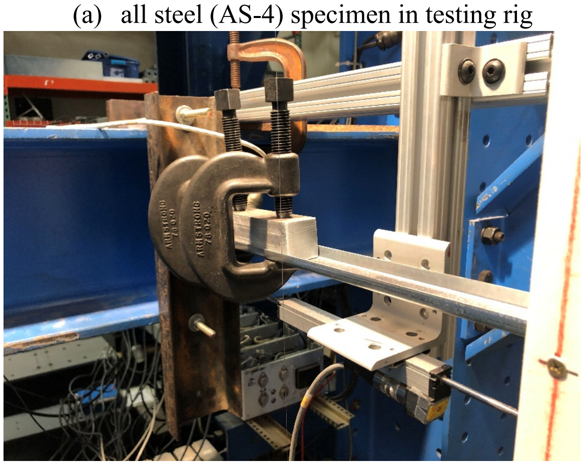
**2. Experiments**

This section introduces the basic test setup, the matrix of tests performed, and the fundamental results from compression testing of the walls. A detailed discussion of the testing and its implications are provided in the subsequent section.

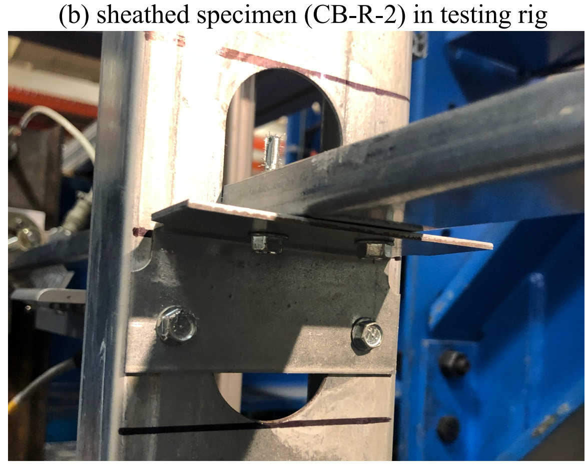


(a) all steel (AS-4) specimen in testing rig

(b) sheathed specimen (CB-R-2) in testing rig



(c) anchoring bridging to load cell and fixed support by machined block and clamps



(d) detail of clip and bridging channel through knockout of the stud at mid-height

Figure 2. Typical test specimens

*2.1 Setup*

Compression testing was performed on 8 ft × 8 ft. CFS-framed walls. All testing was conducted in the multi-axis testing rig in the Thin-walled Structures Laboratory at Johns Hopkins University. Typical tests in the rig are provided in Figure 2. The basic test setup is similar to Vieira and Schafer (2013). The top of the rig is a sizeable built-up steel cross-head that is actuated for control in compression, bending, and shear. The cross-head has regularly spaced holes for connecting specimens. The bottom of the rig is a built-up steel section with a similar hole pattern for specimen connection. Steel plates, ¾ in. thick, are placed at each stud end and then bolted through the track to the distribution members at the top and bottom of the testing rig. The plates are no wider than the track width, ensuring that the sheathing, when present, cannot contribute in the direct bearing under the compression load. Bearing is supplied to the track, and then subsequently to the stud ends. For specimens with bridging, the clip angle and bridging details are provided in Figure 2d. When the bridging is anchored, this is accomplished by connecting a steel block to the web of the bridging channel at one end, as shown in Figure 2c. The steel block is itself connected to a load cell, which is supported by a steel cross-beam.

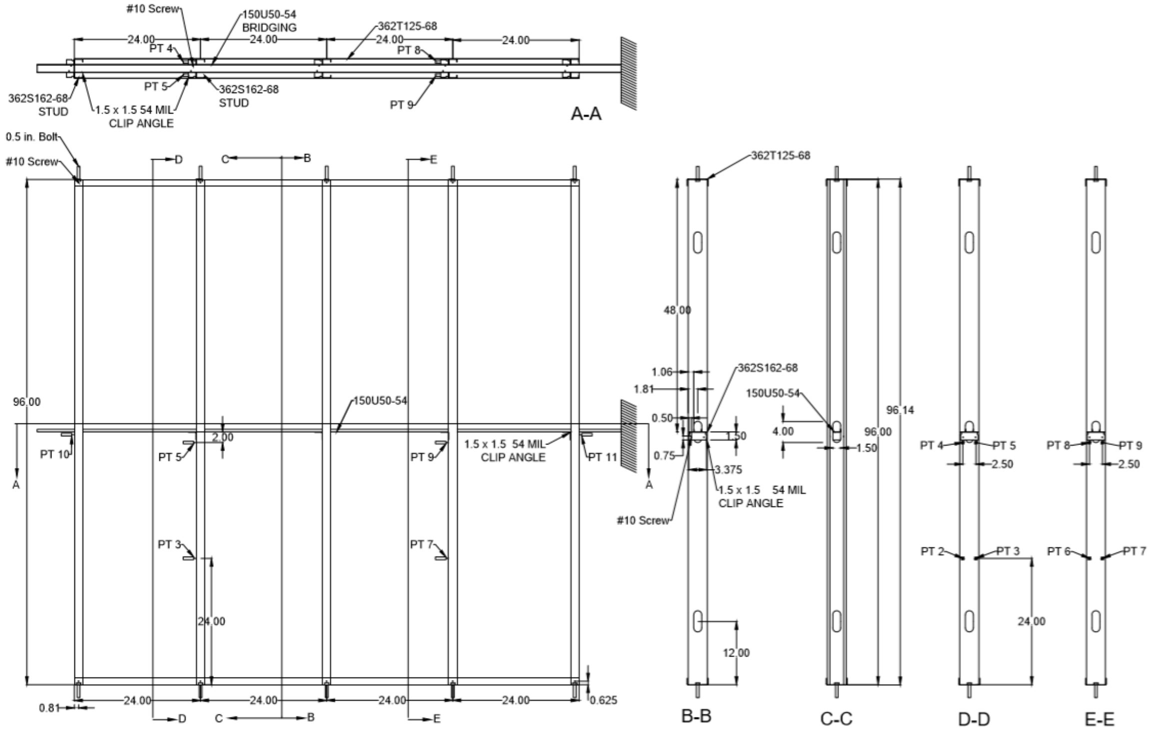
*2.2 Test Matrix*

The configuration of tested walls is summarized in Table 1. The basic geometry is motivated by past testing from Vieria and Schafer (2013) and consists of an 8 ft × 8 ft CFS frame employing 362S162-68 [50] studs and 362T125-68 [50] track. The first test series consists of only steel support or “all steel” design and is designated as AS-1 through AS-4, see Table 1 and Figure 3a for details. The AS series considers how the response of an all-steel wall is modified by the installation of a bridging channel and anchoring (resolution) of the bridging channel to one end. In addition, the AS series provides the baseline response: stiffness, strength, ductility, and limit states for the all-steel wall prior to the application of sheathing.

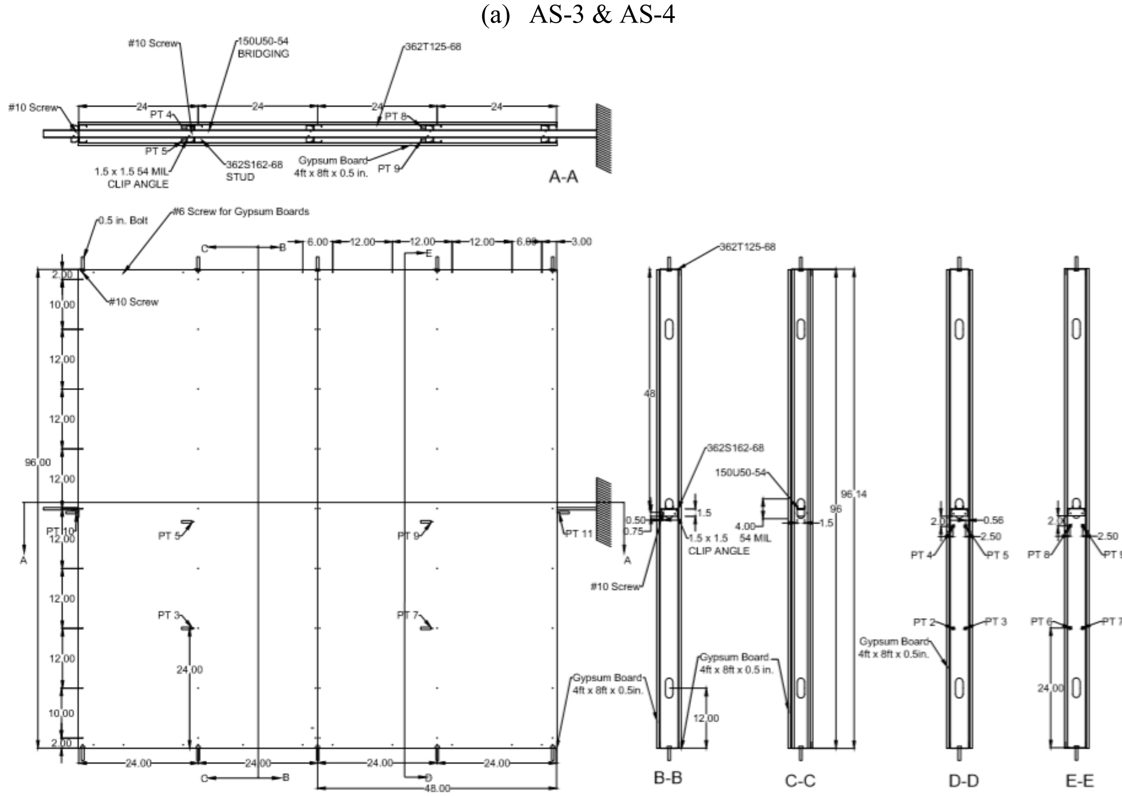
Table 1: Test Matrix

| Type | Nomenclature | Load | Bridging | Resolution | Sheathing |
|---|---|---|---|---|---|
| All Steel | AS-1 | ~25 kips | None | None | None |
| | AS-2 | " | 150U50-54 [50] | None | None |
| | AS-3 | " | " | Fixed Point | None |
| | AS-4 | To Failure | " | " | None |
| Combined Bracing Resolved | CB-R-1 | ~25 kips | " | Fixed Point | 1/2 in. Gyp (both sides) |
| | CB-R-2 | To Failure | " | " | " |
| Combined Bracing Unresolved | CB-U-1 | ~25 kips | " | None | 1/2 in. Gyp (both sides) |
| | CB-U-2 | To Failure | " | None | " |
| Combined Bracing Construction Seq. | CB-C-1 | ~25 kips | " | Fixed Point | None |
| | CB-C-2 | DL+Hold | " | " | " |
| | CB-C-3 | DL+To Failure | " | " | 1/2 in. Gyp (both sides) |
| Combined Bracing Unresolved | CB-G1U-1 | ~25 kips | " | None | 1/2 in. Gyp (one side) |
| | CB-G1U-2 | To Failure | " | None | " |

Notes: AS = All Steel, CB = Combined Bracing, R = Bridging resolved/fixed at one end, U = Unresolved bridging, C = Construction Seq., G1=Gyp one side only; Stud: 362S162-68 [50], Track: 362T125-68 [50]
Bridging clip detail: 1-1/2 × 1-1/2 x 3-3/8 54 mil, i.e., CD Easy Clip U-series U683, connected with #10 steel-to-steel
Stud-to-track detail: single #10 steel-to-steel self-drilling fasteners from track-to-stud
Studs should be fully seated, i.e., stud flanges in direct contact with corner radius or web of the track during assembly
Gypsum Board: 1/2 in., 4 ft. × 8 ft. sheets (e.g. USG Lightrock) installed vertical, #6 @ 12 in. o.c. perimeter and field
Punchout: 1 1/2 in. × 4 in. rounded, standard SFIA layout




(a) AS-3 & AS-4




(b) CB-R-1 & CB-R-2

Figure 3: Complete schematics for selected tests

The second series of tests includes ½ in. gypsum board sheathing fastened 12 in. o.c. on both sides of the wall (CB-R, CB-U, and CB-C), see Table 1 and Figure 3b. All of these "combined bracing" test series include bridging and sheathing. In the CB-R series, the bridging channel is resolved/anchored at the far end. In the CB-U series, the bridging channel is installed in the wall but unresolved/unanchored at its end. In the CB-C series, the construction sequence is considered. The all-steel wall is tested under dead load and held (the bridging is installed and resolved in this condition). While under dead load, the gypsum sheathing is installed, and then the test continued to failure. This test series mimics the field stick construction. The final test series (CB-G1U) is similar to the CB-U testing, but with the gypsum board sheathing installed on only one side.

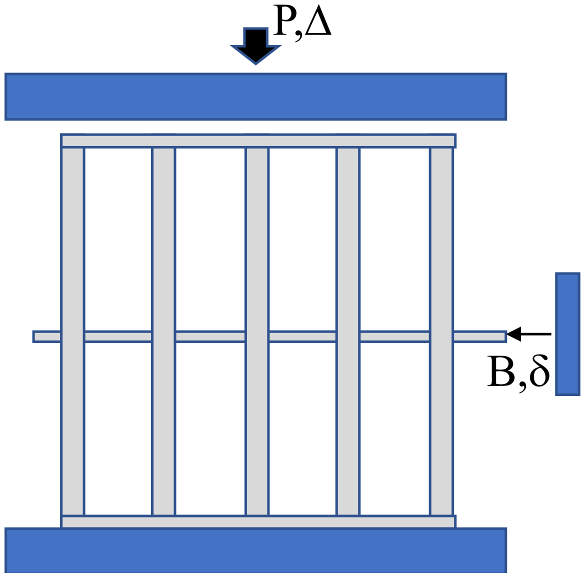
Table 2: Summary of Measured Tensile Properties

| Part | ID | $F_y$ mean (ksi) | $F_y$ std. dev. (ksi) | $F_u$ Mean (ksi) | $F_u$ std. dev. (ksi) |
|---|---|---|---|---|---|
| Stud | 362S162-68 [50] | 52.0 | 0.38 | 74.2 | 0.38 |
| Track | 362T125-68 [50] | 52.6 | 0.26 | 73.6 | 0.15 |
| Bridging | 150U50-54 [50] | 53.6 | 0.10 | 64.1 | 0.12 |

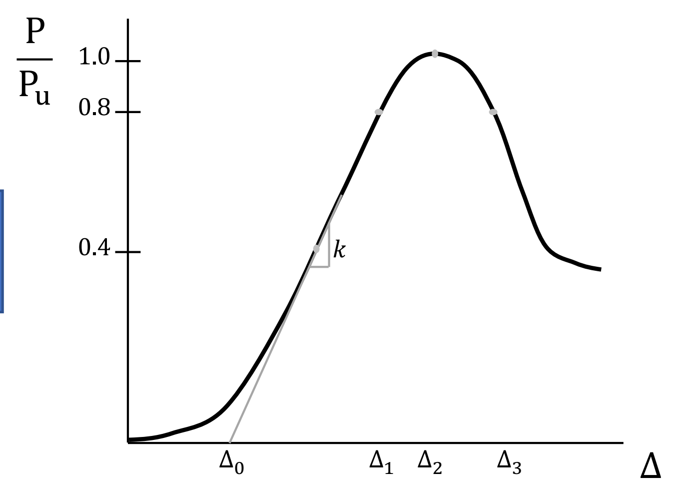
Average material properties for the steel framing are provided in Table 2. Individual material tests and stress-strain curves are provided in a test report (Qian and Schafer 2020). Measured dimensions for the specimen parts, identification labels from fasteners and sheathing, schematic drawings of every test, and all additional test setup details are also provided in the test report.

*2.3 Results*

For each test compression load, P is applied, and the axial displacement, Δ, and sideway displacement, δ, is measured. When bridging is present and resolved/anchored to the end, then the bracing force in the bridging, B, is also measured – as depicted in Figure 4a. Axial and sidesway displacement of the specimens tested to failure are provided in Figure 5.

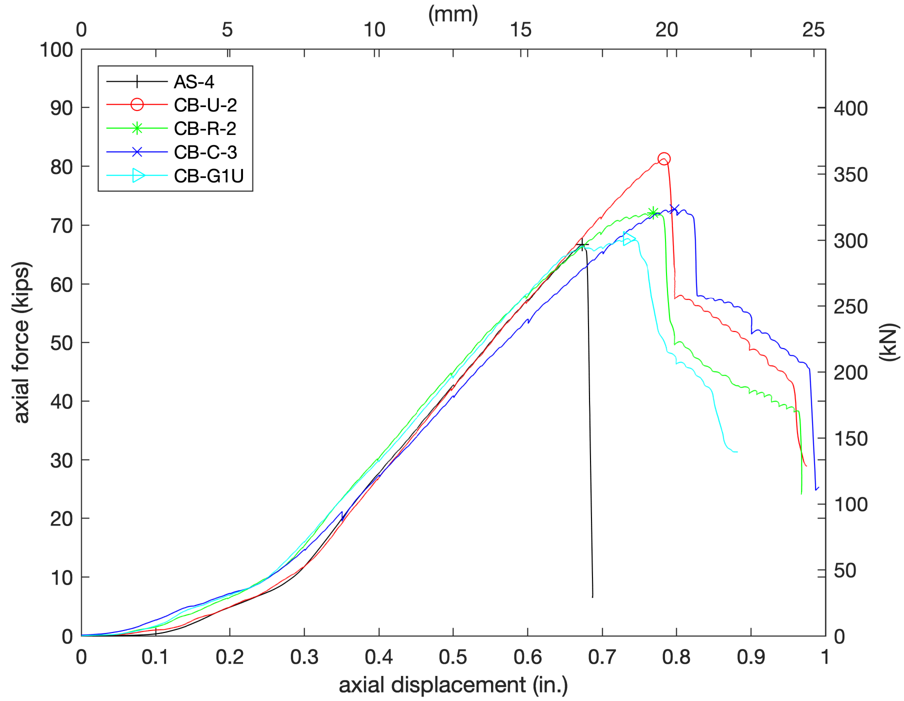


(a) setup and nomenclature

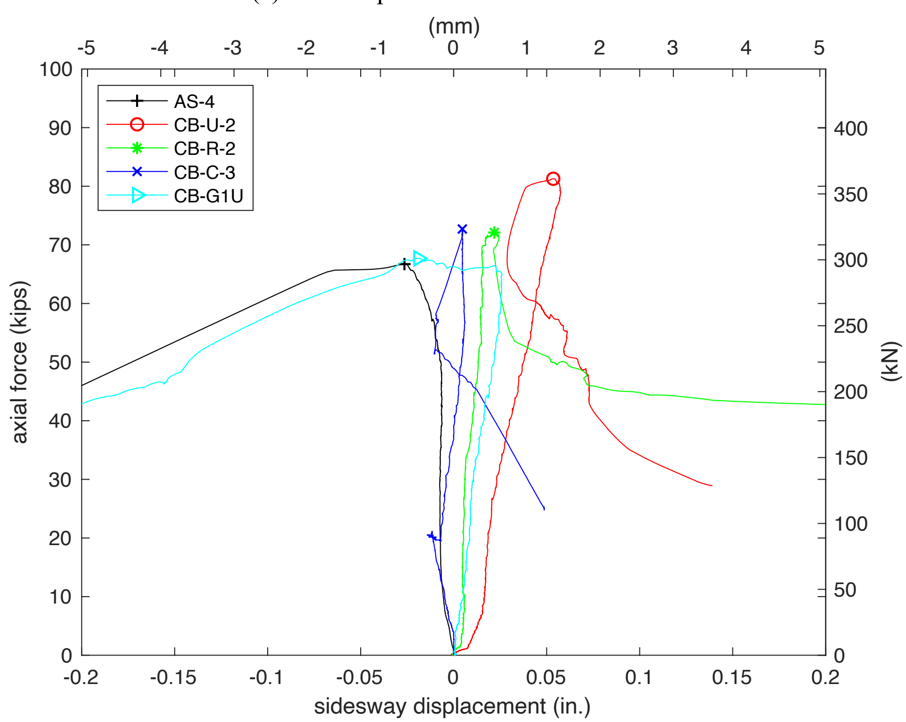


(b) typical output response processing

Figure 4: Essential response characteristics for compression testing and bracing




(a) axial displacement of the walls




(b) sidesway displacement of the walls

Figure 5: Summary force vs. displacement for specimens tested to failure

For each test conducted to failure, the peak load as well as the tangent stiffness at 40% pre-peak load, deflection at 80% pre-peak, peak, and 80% post-peak may all be determined as depicted in Figure 4b. These basic response statistics combined with the bracing force are provided for the specimens tested to failure in Table 3. Observed primary and secondary limit states are indicated in the table and are also shown in Figure 6.

Table 3: Summary Results from Specimens Tested to Failure

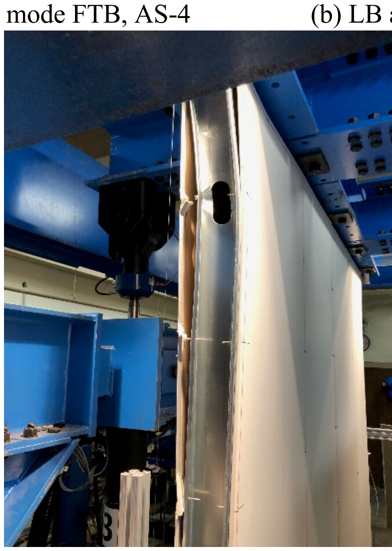
| **id** | **$P_{max}$** (kip) | **Limit State** | **$k_{40\%}$** (kip/in.) | **$\Delta_0$** (in.) | **$\Delta_1$** (in.) | **$\Delta_2$** (in.) | **$\Delta_3$** (in.) | **$B(P_{max})$** (lbf) | **max(\|B\|)** (lbf) | **B/P** (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| AS-4 | 66.7 | FTB2 | 150.8 | 0.22 | 0.57 | 0.67 | 0.68 | 604 | 677 | 1.0% |
| CB-U-2 | 81.3 | LB@Hole (FB/TB) | 149.1 | 0.22 | 0.65 | 0.78 | 0.80 | 0 | 0 | 0.0% |
| CB-R-2 | 72.1 | LB@Hole (TB/FB) | 137.9 | 0.18 | 0.60 | 0.77 | 0.79 | -130 | 276 | 0.4% |
| CB-C-3 | 72.7 | LB@Hole (TB/FB) | 131.8 | 0.19 | 0.64 | 0.80 | 0.83 | 79 | 490 | 0.7% |
| CB-G1U-2 | 67.7 | TB2 | 138.0 | 0.18 | 0.57 | 0.73 | 0.77 | 0 | 0 | 0.0% |

Notes: LS = limit state, P = axial force, B = bridging force, FTB = Flexural-torsional buckling, LB = Local buckling, FB = minor-axis flexural buckling, TB = torsional buckling, trailing 2 in LS indicates $2^{nd}$ mode, () indicates secondary mode

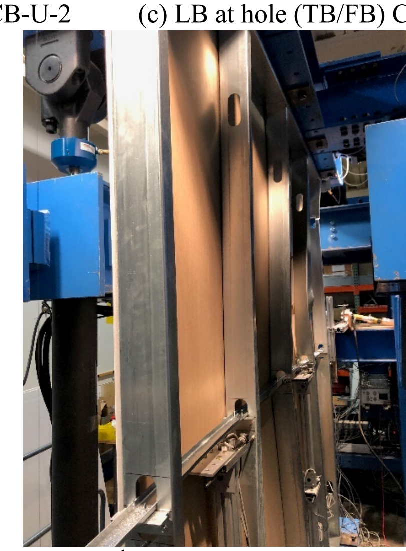
(a) $2^{nd}$ mode FTB, AS-4

(b) LB at hole (FB/TB) CB-U-2

(c) LB at hole (TB/FB) CB-R-2



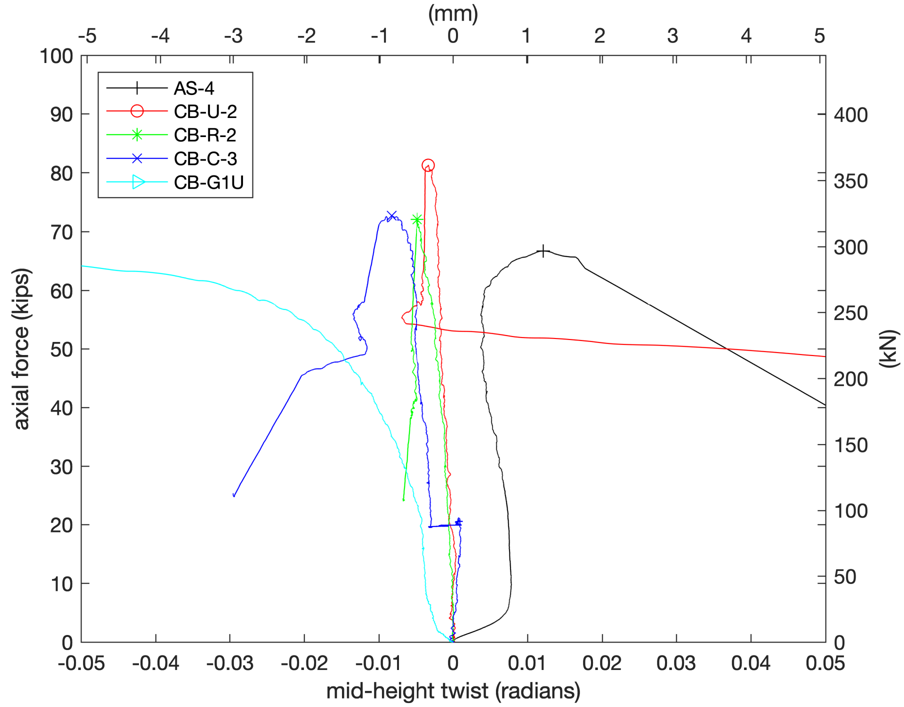
(d) LB at hole (TB/FB) CB-C-3



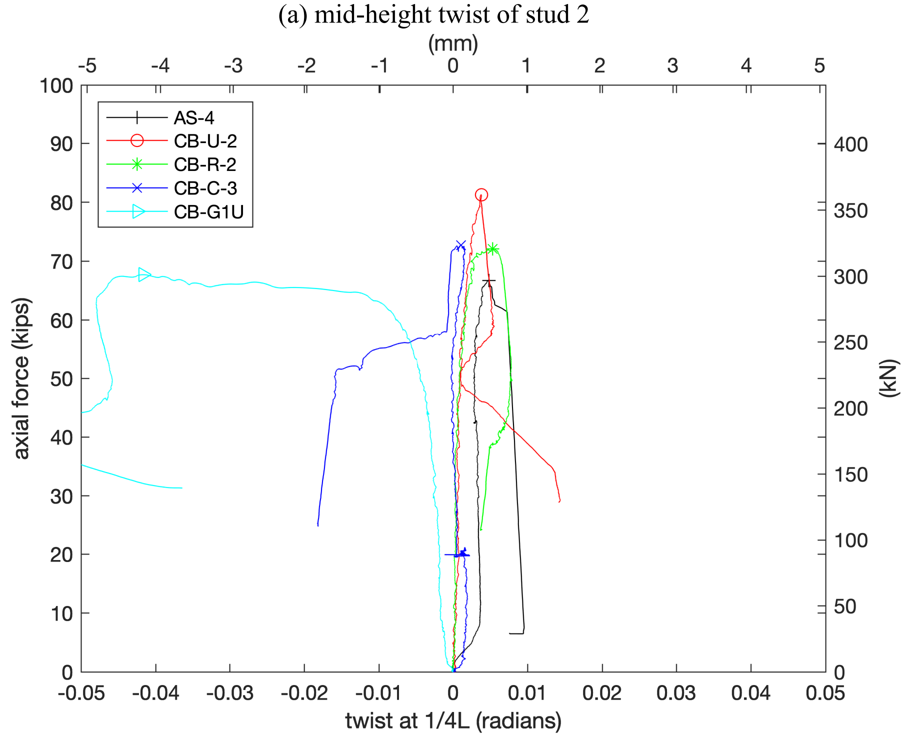
(e) $2^{nd}$ mode TB CB-G1U-2

Figure 6: Limit states of tested specimens

As detailed in Figure 3, pairs of position transducers are placed at the mid-height and quarter-height of studs 2 and 4. These pairs, placed transversally across the web at the web/flange juncture, allow the twist of the studs to be monitored during the testing. The mid-height and quarter-point stud twist for the specimens tested to failure is provided in Figure 7.




(a) mid-height twist of stud 2




(b) quarter point twist of stud 2

Figure 7: Summary force vs. twist for specimens tested to failure

Specimen AS-4, CB-R-2, and CB-C-3 were tested to failure and included bridging that was fully resolved. For these specimens, the peak and typical bridging force, B, is provided in Table 3 and also provided as a percentage of the axial load P during the testing in Figure 8. The high values of %P at low absolute magnitudes of P are not important since the steady-state values and values at peak load (indicted by markers in the traces of Figure 8) provide reliable indications of the brace force demands in the bridging.

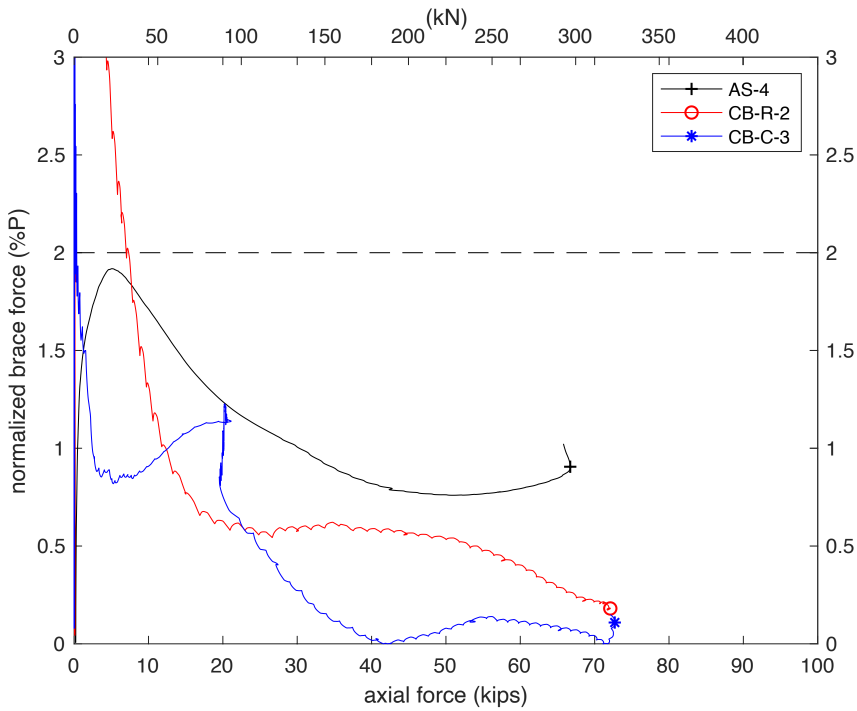
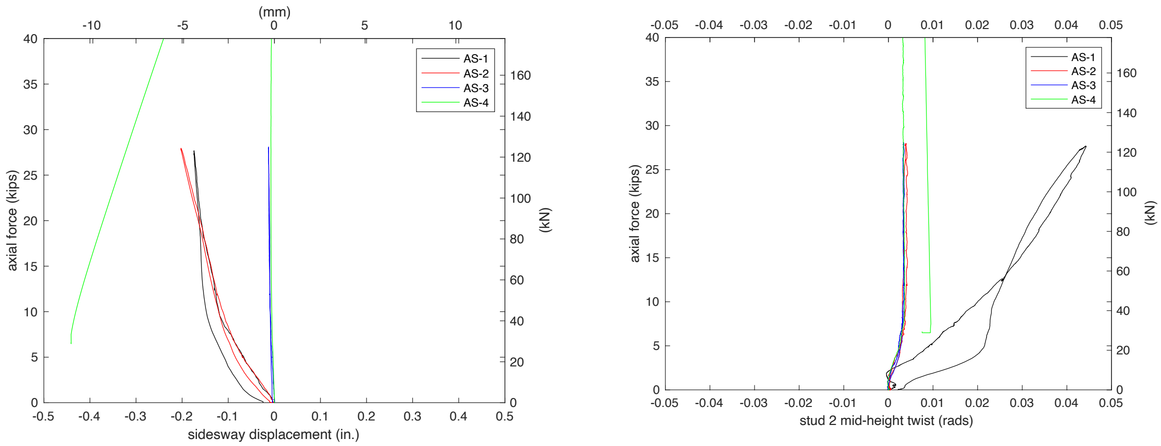



Figure 8: Normalized brace force in specimens where bridging is fixed at its end and wall tested to failure

Complete results for every specimen, including those not tested to failure (e.g., AS-1,2,3), are provided in Qian and Schafer (2020). Results include force-deformation plots, plots of all sensors, and pictures of observed deformations during the testing.

## 3. Discussion

The all-steel test specimen (AS-1,2,3,4) has no sheathing in place and had the lowest observed axial capacity (Table 3). However, these specimens unequivocally demonstrate the role of bridging in an all-steel wall system. Once the bridging is installed (AS-2), even when not resolved (to the support), the twist of the studs is significantly reduced (compare AS-1 to AS-2,3,4 in Figure 9b). However, unresolved bridging still allows large minor-axis flexure in the studs (compare unresolved AS-1,2 to resolved AS-3,4 in Figure 9a). When the bridging is resolved to the support, the stud twist is further reduced, but the lateral deformation is nearly removed at the brace points. For the resolved bridging, the axial force in the bridging is directly measured, and at peak load is 1.0% of the axial load (Figure 8, Table 3). At failure of AS-4, the all-steel specimen with fully resolved mid-height bridging, the final primary limit state is $2^{nd}$ mode flexural-torsional buckling. The bridging restrains flexure and torsion at the mid-height but not in the 1/2 spans above and below the bracing. It should be noted that the flexural-torsional buckling is sudden and results in a significant load drop in the all-steel specimen.




(a) mid-height sidesway (stud 2) (b) mid-height twist (stud 2)

Figure 9: Force displacement response of all steel (steel only) wall specimens

When two-sided gypsum sheathing is applied to the walls (CB-U, CB-R, and CB-C series), the strength of the wall is increased substantially, and the primary failure mode switches to local buckling in the stud holes located 12 in. from the ends. The failure is more gradual in the local bucking limit state with the sheathing applied than in the all-steel specimens without sheathing. In the sheathed specimens, the importance of the bridging is dramatically reduced. Bracing force in the bridging is less than 0.5%P. In fact, the specimen with unresolved bridging (CB-U) had a higher ultimate capacity than the specimens with resolved/anchored bridging (CB-R, CB-C) though the limit state was essentially the same. In the conducted tests, if sheathing, even ½ in. gypsum board only fastened at 12 in. o.c., on both sides of the stud, the bridging plays little to no role in the ultimate strength of the specimen.

A practical scenario of interest that is explored in the CB-C test series is what happens if the dead load is applied to an all-steel wall, and only at this point is the sheathing added to the walls. This would be consistent with on-site stick construction of the wall, or even panelized construction where the finish is applied in the field. The tests show that under the dead load, the wall behaves like the typical all-steel system, and the bridging supplies lateral bracing and develops a small (<1.0%P) bracing force. However, once the sheathing is applied (note the large drop in bracing force at approximately 20 kips in Figure 8) and additional gravity load is added, the bridging unloads, and all brace forces move to the sheathing connections. Only after failure, does the bridging pick up any substantial additional force. Thus, a design practice where all-steel bridging is designed for construction loads, and sheathing braced design is used for ultimate loads, seems to have merit.

Noting that for two-sided sheathing (test CB-U), the bridging did not need to be resolved, we considered in a final scenario if one-sided sheathing (CB-G1U) could adequately resolve the bridging. The test indicated that one-sided sheathing performed as well, or even better than no sheathing and a fully anchored bridging channel (AS-4). The strength in the one-sided sheathing case was slightly higher than the all-steel case (AS-4), and the failure mode, 2$^{nd}$ mode restrained-axes torsional buckling, was more benign than the all-steel 2$^{nd}$ mode flexural-torsional buckling failure. However, the one-sided sheathing did not sufficiently restrict torsion to allow the wall to develop the higher capacity associated with local buckling. The results suggest that a design practice where discrete bridging is unresolved/unanchored may be adequate for construction loads so long as at least one side of the wall is sheathed.

## 4. Supplementary Stiffness Testing

To determine the bridging system stiffness in the all-steel test, a supplementary test was performed. The dead load of the top crosshead was applied to the wall. A hydraulic hand jack was placed in-line with the load cell at the fixed support for the bridging and exercised. The test setup is depicted in Figure 10. To minimize error, the specimen is tested 3 times. Displacements are measured for the bridging channel itself at each end and for the middle two studs at mid-height and at the quarter-point. The average measured displacements at an applied force of 200 lbf are provided in Table 4.

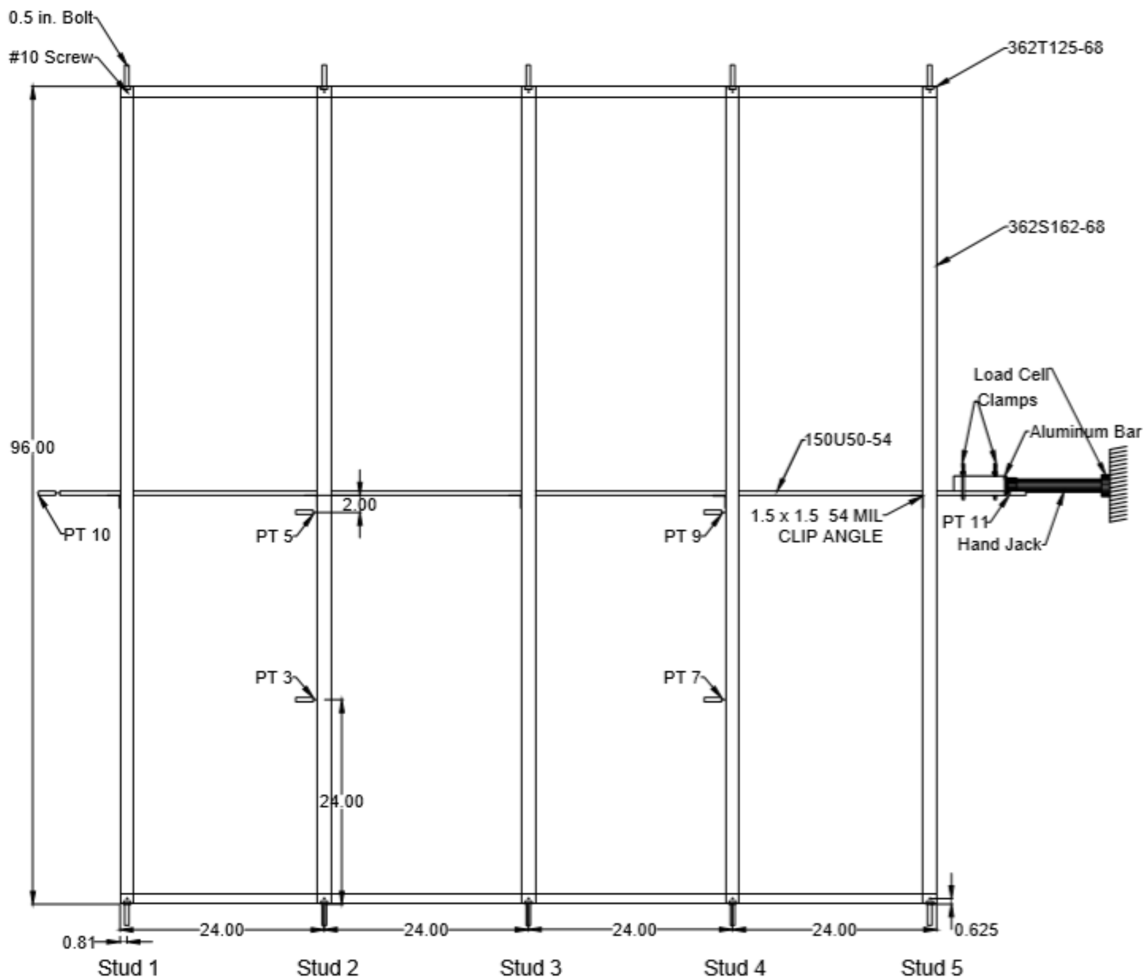



Figure 10: Elevation drawing of stiffness test

Table 4: Summary of sideway displacement when brace force is 200 lbf

| Location of Position Transducers | Lateral Displacement (avg.) (in.) |
|---|---|
| end of bridging close to stud 1 | 0.118 |
| 2 in. below mid-point of stud 2 | 0.115 |
| 2 in. below mid-point of stud 4 | 0.119 |
| end of bridging close to stud 5 | 0.122 |
| quarter-point of stud 2 | 0.0695 |
| quarter-point of stud 4 | 0.0802 |

## 5. Future Work

In addition to the testing, strength calculations for the wall system are ongoing. Based on a rational extension of the design method for sheathing braced walls from Schafer (2013), it is possible to provide proposed design predictions for all the tested walls. These calculations must include the influence of the bridging and sheathing on local, distortional, and global buckling for stud sections with holes. The stiffness of the sheathing and of the bridging are critical inputs to the design. Existing methods exist for establishing these stiffness quantities, and the stiffness testing of Section 4 provides additional data on the bridging stiffness. A spring in series model should be adequate for estimating the relative stiffness of the bridging to stud connection, and this additional analysis is ongoing. The provided tests are a limited study of only a single wall stud section. Different stud sections place varying degrees of demand on the bridging and sheathing. Different bridging locations and connection details and different sheathing types and fastener schedules provide varying degrees of relative restraint – while developed design methods provide an overall approach, focused additional testing could be beneficial. In the future, a design method whereby engineers can, when desired, account for the benefits of combined bracing, both sheathing and discrete, across all typical configurations is needed.

## 6. Conclusions

Cold-formed steel stud walls benefit significantly from bracing. Conventional design favors all-steel solutions using discrete bridging channels for the bracing. The resolution of the accumulated bracing forces at the ends of walls is costly, and design practice is not always aligned with analytical models used by design specifications to determine accumulated brace forces and minimum brace stiffness. Sheathing, such as gypsum board, is commonly applied to both sides of walls to provide necessary structural (e.g., fire protection) and non-structural (e.g., thermal and acoustic) performance. Previous testing has shown that the sheathing can serve as the bracing for the wall. Tests reported on herein show that if sheathing is present that bridging need not necessarily be resolved at the wall ends. Further, the tests indicate that sheathing, even ½ in. gypsum board with fasteners at 12 in. o.c. more effectively provides bracing to a stud than traditional through the knockout bridging channel connected by clip angles. Gypsum sheathing on both sides of the wall leads to higher strength and a more favorable failure mode and post-peak response than fully resolved discrete bridging. The tests also show that accumulated brace forces are low, less than 1% of the axial force applied to a 5 stud wall with steel only, and less than ½% of the axial force if the wall has sheathing. Further, with respect to the ultimate response, it is shown that the sheathing can be applied after dead load without changing the bracing condition. Finally, we also show that one-sided sheathing can provide bracing, at least as effective as a fully anchored all-steel bracing system; however, to achieve the most desirable limit state, strength, and post-peak response two-sided sheathing is favored. Comparisons to proposed design calculations are ongoing, and additional testing, including different parameters such as fastener spacing and other sheathing (e.g., OSB), is recommended.

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