

Development of Cost-Effective, Energy Efficient Steel Framing: Structural Performance of Slit-Web Steel Wall Studs

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PREFACE

This report presents the results of structural tests that were performed at the NAHB Research Center on a prototype slit web stud. Based on this work, and that of the companion report on Thermal Performance of Slit-Web Steel Wall Studs, it is hoped that manufacturers may have interest in commercializing the thermal stud. The reader is cautioned that the Research Team had the following specific questions and concerns related to the report:

- From the photos it appears that the flexural tests failed in a combination of bending and web crippling. No reinforcement was added to the webs to preclude a web crippling failure at the load application. This may explain the failure mode being reported as “local buckling under the point load”. Comparisons should have been made between the tests of the solid web stud and the AISI Specification calculations. There is insufficient information in the report to determine the test failure moment and the mode of failure for the solid web studs.
- There are no photos of the solid web stud tests and it is unclear whether they had standard perforations. This would affect the calculated capacities.
- A portion of the difference in strength is attributed to the higher yield and ultimate strength values of 27% and 30%. Per Table A1, the difference in yield is only 13%.
- The bracing of the two members in the axial tests precluded anything but local buckling. The results of the stub-column tests, essentially the same as the axial tests, confirm this.
- Table 7 gives the shear test results, but is not clear whether these are the test loads or the failure shear values.
- The results of the axial tests of the solid web studs should be compared with the AISI Specification. Since these were essentially stub column tests, the results should be able to be calculated.
- The shear test set-up seems to be unnecessarily complex. Most shear tests are carried out on short specimens reinforced to prevent a flexural or web crippling failure. The report concluded that failure was localized buckling of the flanges under the point load. This does not sound like a shear failure, but may be combined shear and bending.
- The shear wall tests are not relevant to the investigation of the strength of the member by itself. Also, the shear walls tested experienced premature failures (first due to the hold-down tearing out of the web and then due to an inadequate number of chord studs). This precluded any meaningful conclusions to be reached regarding their performance.
- Web crippling tests were not conducted. The report implies that web crippling would not need to be investigated for fully sheathed walls; however, this statement is not necessarily correct. Industry experts advise that web crippling would need to be tested even for sheathed walls, but definitely for unsheathed walls.
- The report concludes that the slit web stud “performed similar to or better than a solid-web stud”. While this is true for the tests carried out, there is some question whether the desired failure mode was achieved. It should be recommended that addition tests be carried out to isolate the specific failure modes (shear, web crippling, distortional buckling, overall buckling) to verify the behavior.

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Development of Cost-Effective, Energy -Efficient Steel Framing

Structural Performance of Slit-Web Steel Wall Studs

Prepared for

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Washington, DC

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EXECUTIVE SUMMARY

Steel members in wall construction form a thermal bridge that interrupts the insulation layer of a wall. This causes higher rate of heat transfer by conduction through the wall framing than through other parts of the wall. The objectives of this project are to analyze and design components and systems for the construction of homes using cold-formed steel whose thermal performance meets energy code requirements in a cost-effective manner, and to document system performance through thermal testing.

A thermally efficient slit-web stud was developed in this program to mitigate the conductivity of steel. The prototype slit-web steel stud has been shown to be:

- Thermally efficient
- Economically viable
- Structurally sound
- Easily manufactured
- Usable in a range of residential installations (“Buildable”)

The behavior of 3-1/2 inch (89 mm) slit-web stud (perforated web) was evaluated and test results showed that the prototype slit web stud performed similar to or better than a solid-web stud in bending, axial, and shear tests. The shearwall test results indicated the importance of using multiple chord studs and the need to address the connection to the tension chord end stud where heavy connections are made and locally high compressive and tension forces must be transferred through connections or bearing of end studs. Tests also showed that the slit-web stud is very sensitive to the distortional buckling mode. The 350S162-33 slit-web stud tested in this report was shown to be better than or essentially equivalent to a 350S162-33 solid-web stud in most structural performance characteristics investigated. Web crippling was not investigated for the slit-web stud, as it is not considered a failure mode for wall studs that are fully sheathed with structural sheathing. Web crippling strength should be investigated when slit-web studs are used in non-sheathed wall applications.



ABSTRACT

The behavior of 3-1/2 inch (89 mm) slit-web stud (perforated web) was evaluated by performing axial, bending, shear, shearwall, and stub column tests. Test results indicated that the prototype slit web studs performed similar to or better than solid-web studs in bending, axial, and shear tests. The shearwall test results indicated the importance of using multiple chord studs and the need to address the connection to the tension chord end stud where heavy connections are made and locally high compressive and tension forces must be transferred through connections or bearing of end studs. Tests showed that slit-web studs are very sensitive to the distortional buckling mode. The 350S162-33 slit-web studs tested in this report were shown to be better than or essentially equivalent to 350S162-33 solid-web studs in most structural performance characteristics investigated. Web crippling was not investigated for the slit-web stud in this report. Web crippling strength should be investigated when slit-web studs are used in non-sheathed wall applications.



INTRODUCTION

Cold-formed steel framing has seen some market growth in the housing market most probably due to its similarity to wood stick framing. However, due to concerns about the thermal performance of steel, the use of steel framing in the residential market is still relatively low.

The American Iron and Steel Institute (AISI) initiated a multi-year program with funding from the U.S. Department of Energy (DOE) through the Technology Roadmapping Program (TRP) to investigate the thermal conductivity of cold-formed steel framed walls in residential construction and develop a thermally efficient stud. Prior to this program, the only nonproprietary commercially available thermal break for steel-framed walls was the use of rigid foam on the exterior of a steel-framed wall as specified in the *Thermal Design Guide* [1]. Other available products and construction methods and materials are mostly proprietary products, not widely available, or too costly. Even the exterior rigid foam insulation requirements specified in the *Thermal Design Guide* can be costly and inefficient in colder climates as the foam thickness can be up to 2 inches (51 mm) to achieve a required (effective) R-value.

The *Thermal Performance of Slit-Web Steel Wall Studs* report [2] investigated available options that mitigate the thermal conductivity of steel framing and developed and tested a slit-web stud that is thermally efficient. The newly developed stud can provide a solution to users once its structural characteristics are proved to be equivalent to that of a solid-web stud.

PURPOSE

The objective of this report is to document the structural performance of the slit-web stud (SWS) as developed in the thermal report [2]. The testing includes axial, bending and web crippling. This report also compares the test results of the SWS to those of a solid web stud.

LITERATURE REVIEW

Numerous papers have been written about the structural behavior of slit-web studs. The most comprehensive study was done by Bethlehem Steel Corporation in 1974 [3]. The Bethlehem Steel study investigated slit-web stud wall systems (4 ft. x 8 ft.) (1219 mm x 2438 mm) under concentric compression, eccentric compression, transverse load, and racking load. The primary components of the wall systems were cold-formed channel C-shaped 3-1/2" x 1-1/2" x 0.36" (20 gauge) (89 x 38 x 9 mm) studs which snap-lock into a top and bottom steel track (see Figure 1). The studs were spaced at 24 inch on center. The studs had slits in the webs and 3/4" (19 mm) diameter utility holes. Wall assembly sheathing arrangement is described in Table 1.

Table 1 – Wall Assembly Sheathing Arrangement

Test No.	1/2" Drywall/ 1/2" Gyplab	1/2" Drywall/ 1/2" Drywall	Gyplab One Side	No Sheathing	1/2" Plywood/ 1/2" Drywall
1,2,3,5	√				
4,6,7,10		√			
8				√	
9			√		
12,13	√				
11,14,15					√

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The study concluded that the design of the thermal slits in the studs, particularly when they extend to the ends of the studs, significantly reduce the strength of the wall panels. Summary of test results is shown in Figures 2 through 4. The stud pullout test results shown in Figure 4 were based on single studs.

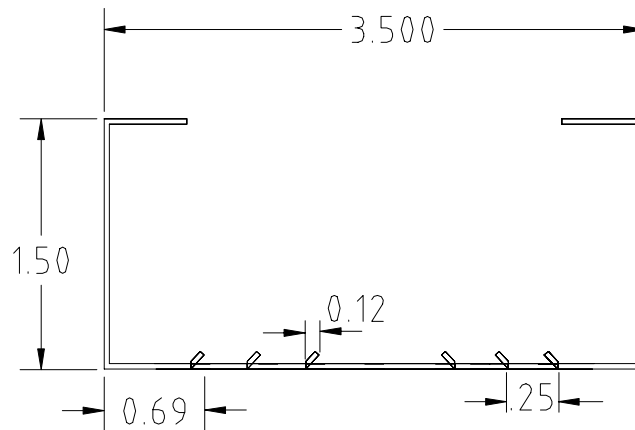


**Figure 1 – Bethlehem Steel Slit-Web Stud
(Dimensions in inches)**

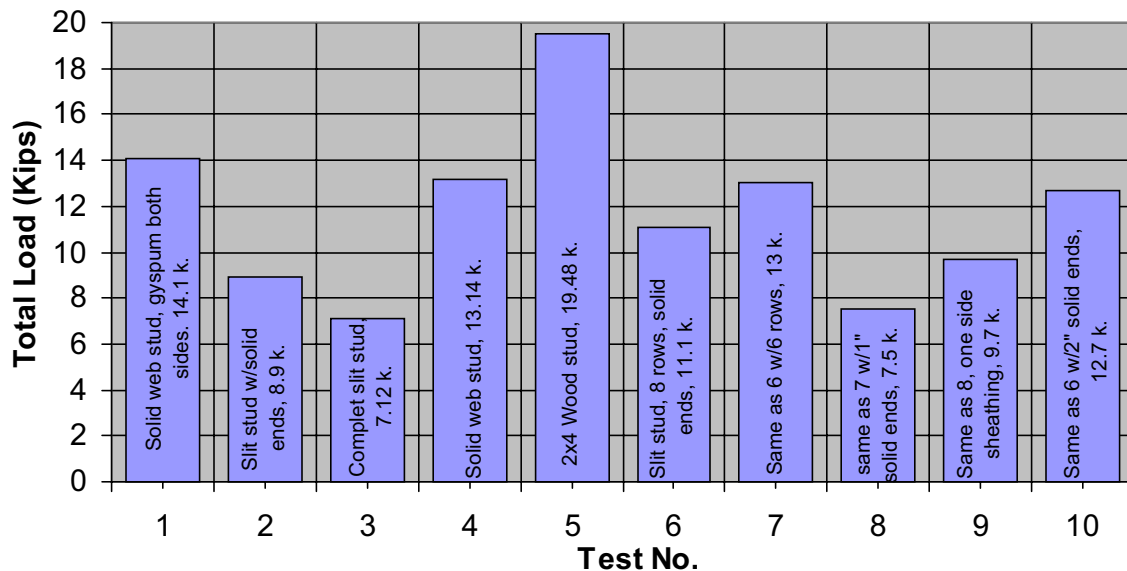


Figure 2 – Concentric Compression Tests

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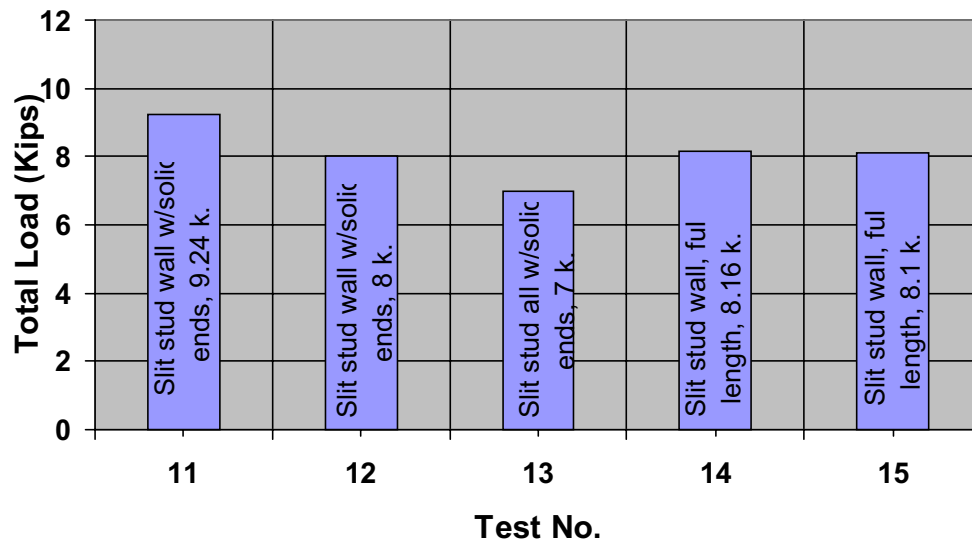


Figure 3 – Eccentric Compression Tests

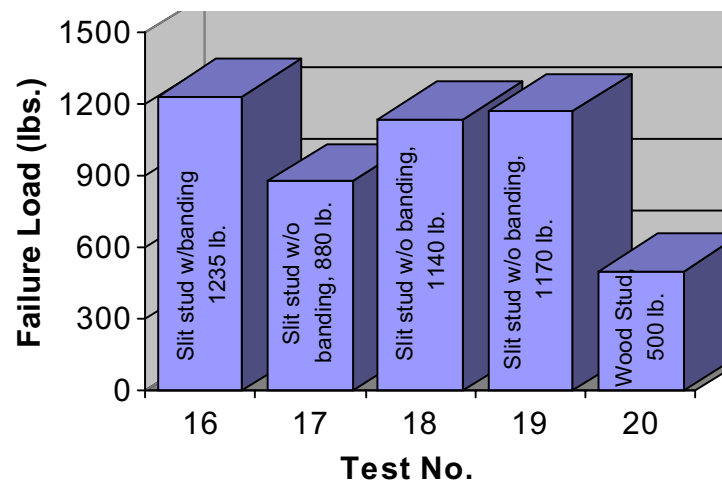


Figure 4 – Stud Pullout Test Results

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Ratliff and Roeder conducted full-scale structural tests on steel wall panels constructed of slit-web studs [4]. Test results showed that the full scale compression-load tests of 4-foot (1219 mm) wide wall panels made with slit studs supported 12.8 kips (56.93 kN) compared with 12.2 kips (54.27 kN) for 4-foot (1219 mm) wide panels made with standard unslit studs. The results of the full-scale wind load tests showed that 4-foot (1219 mm) wide wall panels made with slit web studs supported a uniform load of 150 psf. The results of the short-column compression tests indicated that the compression load capacity of light-gauge steel stiffened channel section with slit webs was about 17 percent less than that of similar sections with un-slit webs.

Kesti investigated the structural capacity of web-perforated steel wall studs (see Figure 5) at Helsinki University [5]. Kesti concluded that the perforation changes the behavior of the stud under compressive and lateral loading, reduces the shear stiffness and shear strength of the stud, and also decreases the bending stiffness of the web causing decreased distortional buckling strength. Kesti investigated structures consisting of studs with perforated cold-formed sigma-profiles and gypsum wallboards attached to the stud flanges. The aim was to determine compression and bending moment capacities by full scale testing. The wall stud assemblies were subjected to combined axial and lateral loading. Kesti reported that the test specimens failed by distortional buckling of the upper (tension) flange while fasteners pulled through the sheathing boards. Stub column tests were conducted to evaluate the local and distortional buckling behavior of the stud sections.



Figure 5 – Web Perforated Steel Stud Tested by Kesti

A slotted light-gauge steel stud was developed in Sweden for load-bearing external walls in single-family homes and infill walls in blocks of flats (see Figure 6). The slots are about 2.75 inches in length, and the distance between them in the longitudinal direction is 0.8-1 inch (20.3 – 25.4 mm) and in the transverse direction 1/4 - 3/8 inch (6.4 – 9.5 mm). The edges of the slots are folded inward and form edge stiffeners, which increase the buckling strength. In order to increase the strength further, the web is sometimes folded or given a longitudinal groove in the center. In most cases, the web has two panels with five rows of slots between them, while in smaller sections there are fewer rows of slots.

The Swedish Institute of Steel Construction [6][7] reported that several failure modes have been observed in tests of steel wall panels constructed with slotted steel studs, such as:

1. Flexural buckling in the plane of the web.
2. Lateral buckling of flanges in compression.
3. Shear failure of the slotted web.
4. Failure due to support reaction.
5. Failure under concentrated force.

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6. Buckling of the edges of the flanges in the span (axial force and bending moment).
7. Buckling of the edges of the flanges at the supports (axial force).

In all cases, the capacity of the wall panel is affected by shear deformation of the slotted web and by the reduced transverse bending stiffness of the web.

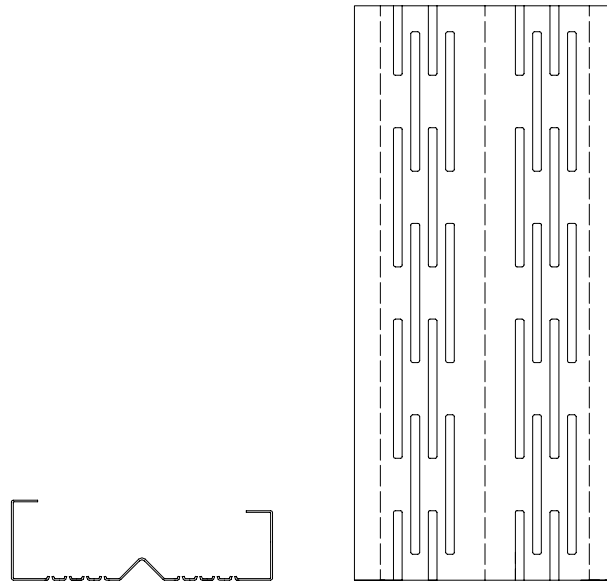


Figure 6 – Swedish Slit-Web Stud Profile

A Finnesteel Programme developed a thermoprofile stud in which the perforations were located in the middle part of the stud web in order to increase the bending stiffness (see Figure 7). In addition, longitudinal stiffeners stiffened the web to increase the overall buckling resistance of the profile [8]. Design guidance and design charts were developed for the thermoprofile stud.

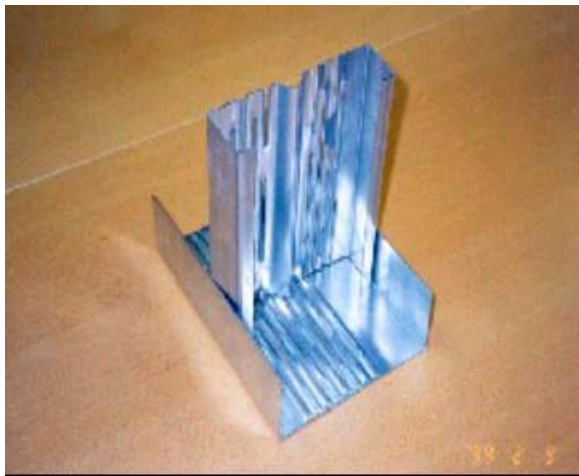


Figure 7 – Thermoprofile Stud