COMBINED AXIAL AND BENDING LOAD TESTS OF FULLY-SHEATHED COLD-FORMED STEEL WALL ASSEMBLIES

Final Report

Prepared for

The U.S. Department of Housing and Urban Development
Office of Policy, Development and Research
Washington D.C.

The American Iron and Steel Institute
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NAHB Research Center, Inc.
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The U.S. Department of Housing and Urban Development, Office of Policy, Development and Research
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INTRODUCTION

The purpose of this test program was to investigate the structural capacity and performance of fully-sheathed load bearing walls of cold-formed steel framing. The configuration of the walls tested was limited to 4 foot by 8 foot wall panels sheathed with ½-inch gypsum wallboard (GWB) and 7/16-inch oriented strandboard (OSB) panels assembled in accordance with the *Prescriptive Method for Residential Cold-Formed Steel Framing* (Prescriptive Method) [1]. Currently, the allowable capacities of wall assemblies are calculated in accordance with the *Specification for the Design of Cold-Formed Steel Structural Members* (AISI Design Specification) based on the simplified beam-column approach [2]. Each wall stud member is designed as an independent element, neglecting potential composite action and load sharing that occurs between the sheathing and the studs. This simplified design method underestimates the bending and compression capacities of the actual sheathed wall assembly resulting in a less than optimum design.

The goal of this research was to identify the degree of load carrying increase provided by OSB and gypsum panel sheathed wall assemblies relative to predicted capacities using the AISI Design Specifications. With significant strength increase, the additional cost of the exterior sheathing will be offset by the savings of using thinner more economical light-gauge steel studs for wall framing. Other benefits resulting from a fully sheathed wall assembly are:

- OSB sheathing provides a small thermal break;
- OSB sheathing provides large shear wall capacities while preventing the track from being overloaded as a shear collector;
- foam insulation, siding and other finishes can be directly nailed to the structural sheathing using less costly fasteners and tools;
- studs are fully braced against lateral and torsional buckling.

LITERATURE REVIEW

Previous research on similar wood wall systems demonstrated increases in wall strength of 1.56 to 4 times that predicted by a simplified beam/column design approach [3]. Similarly, the *Southern Building Code* utilizes system factors for fully-sheathed wood-framed wall assemblies which are constructed in a similar manner to those tested under this program. This type of research has helped to optimize and maintain the competitiveness of wood-frame construction [4].

Paul Schurter, Reinhold Schuster and Andrew Zakrzewski performed nine tests on steel-framed wall panels subjected to combined compression and lateral loads to simulate their use in external load bearing walls [5]. The panels were framed with conventional C-shaped studs and proprietary shaped "thermal studs" which had large web cut-outs to reduce heat flow. The investigation compared the experimental results with AISI calculated results. The test specimens used a four stud approach, framed 16 inches-on-center. The wall specimens varied sheathing applications as follows: ½-inch gypsum board on one side; ½-inch gypsum board on both sides; and ½-inch gypsum board on one side and ½-inch plywood on the other. All sheathing was attached with screws 6 inches on center. The lateral loads were applied in both directions with a magnitude of 25 psf. Loads were applied with either concrete blocks or a vacuum system. Compression (axial) loads were applied to each stud in a wall specimen using hydraulic jacks.

The end studs received either full compression load or half compression load. The wall assembly with gypsum on one side showed a ratio of tested to calculated results of 1.35. For walls with sheathing on one side the failure mode was primarily torsional-flexural buckling of the studs. For walls with sheathing on both sides the failure mode was typically local end buckling of the studs.

EXPERIMENTAL APPROACH

The wall test specimens represent common construction practices. All steel used in the test had a minimum specified tensile strength of 33 ksi, which was verified by tensile tests in accordance with ASTM A370-92 [6]. Base steel thicknesses were also determined using ASTM 90-93 [7]. Mechanical properties were based from coupons cut from the center of the web. All steel used in the tests conformed to the Prescriptive Method requirements. A total of 20, 4-foot wide by 8-foot high wall panels were tested in accordance with Table 1. The construction method followed a "two stud" approach. The "two stud" approach, uses two load bearing studs spaced 24 inches on center relative to each other and 12 inches from each edge of the 4x8 sheathing panels. The edges of the panels are connected with short spacers which are short pieces of stud which cannot carry any axial loads but help to provide support to maintain the spacing of the gypsum board and OSB sheathing as would be expected in actual construction. The primary advantage to the "two stud" approach is that both studs receive the same lateral and axial load when loaded simultaneously under bending and compression. The studs were connected to a top and bottom track through the flanges with #8 screws as required in the Prescriptive Method. The interior side of the wall was cladded with ½-inch GWB fastened with #6 screws at 12 inches on center. The exterior side of the wall was cladded with 7/16 inch OSB (APA rated 24/16) using #8 screws at 6 inches on center on the top and bottom track and 12 inches on center on the two studs, as shown in Figure 1.

TABLE 1
Wall Test Specimens

WALL STUD AND TRACK SIZE	LATERAL PRESSURE (PSF)	LATERAL LOAD APPLICATION[1]	NUMBER OF TESTS
2x4x33	0	n/a	2
2x4x33	25	OSB	2
2x4x33	25	GWB	2
2x4x33	50	OSB	2
2x4x33	50	GWB	2
2x4x54	0	n/a	2
2x4x54	25	OSB	2
2x4x54	25	GWB	2
2x4x54	50	OSB	2
2x4x54	50	GWB	2

1. The lateral load was applied to either the GWB or OSB side of the wall using concrete blocks.

The wall specimens were mounted horizontally between a reaction frame and a hydraulic actuator with a calibrated load cell as shown in Figures 2 and 3. A heavy steel I-beam distributed the actuator applied loads and reactions to the wall specimens through 1.5 inch-wide steel bearing plates placed at the ends of the studs. The bearing plates were intended to represent point loads as expected in repetitive, in-line framing situations. The bottom beam had a 4'x3-1/2"x½" OSB spacer representing the wall sitting on a OSB sub-floor. The width was purposely set to 3.5" to ensure that no sheathing made direct contact with the reaction beam or concentrated load plate. Lateral loads of 25 and 50 psf were applied to both sides of the walls (i.e. representing outward or inward acting wind pressures) by evenly distributing pre-weighed concrete blocks over the wall specimens. While maintaining a constant lateral load, the axial load was applied until the specimen failed. Actual deflections of the walls were recorded at mid-span using LVDTs. Drawings of the test set-up apparatus can be found in Appendix A.

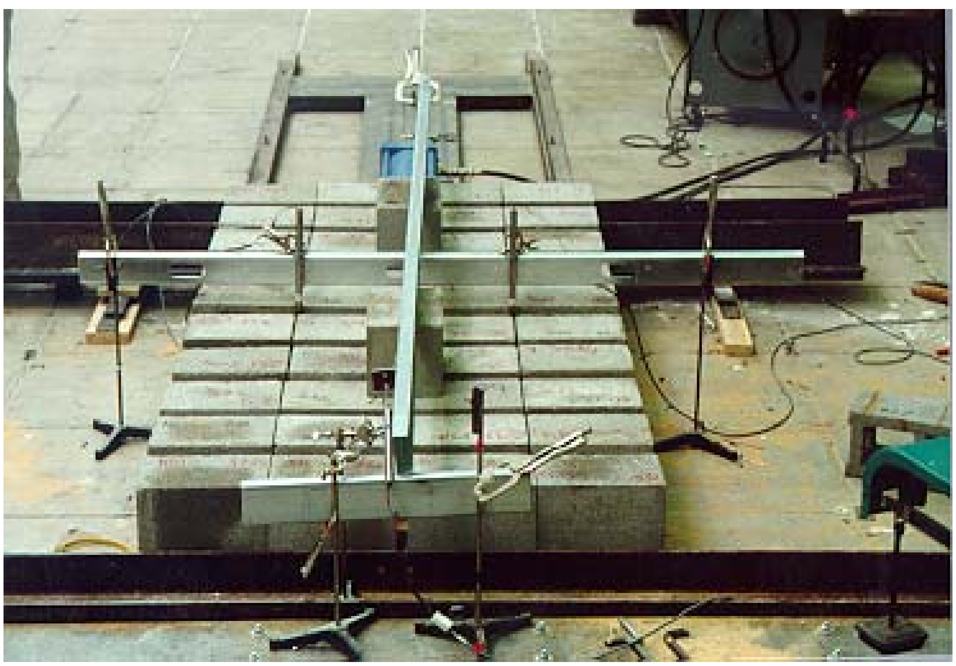

FIGURE 2
Test specimen with 50 psf lateral load.

FIGURE 3
Test specimen with a 25 psf lateral load.

RESULTS

Table 2 summarizes the results of the combined axial and out-of-plane lateral load test as well as compares the results to AISI calculated allowable values. AISI-calculated values were computed using the AISI WIN software [8].

TABLE 2
Tested vs. Calculated Results

WALL STUD AND TRACK SIZE[1]	LATERAL LOAD AND DIRECTION (PSF)[2]	STATIC DEFLECION (INCH)[3]	CALCULATED ALLOWABLE AXIAL LOAD WITH CONTINUOUS BRACING[4] (LB)	AVERAGE TESTED ULTIMATE[5] (LB)	ESTIMATE AXIAL LOAD SAFETY FACTOR
2x4x33	0	0	2,939	6,647	2.3
2x4x33	25_{OSB}	.281	726	5,944	8.2
2x4x33	25_{GYP}	.290	726	4,798	6.6
2x4x33	50_{OSB}	.590	0	2,975	∞
2x4x33	50_{GYP}	.641	0	3,250	∞
2x4x54	0	0	5,451	11,560	2.1
2x4x54	25_{OSB}	.192	3,005	13,208	4.4
2x4x54	25_{GYP}	.228	3,005	12,174	4.05
2x4x54	50_{OSB}	.389	1,305	11,472	8.8
2x4x54	50_{GYP}	.397	1,305	9,757	7.5

Notes:

1. Actual lip size was ½ inch; actual flange size was 1 5/8 inch; actual web size was 3½ inch.
2. 'OSB' signifies that the lateral load is applied to the OSB sheathing side of the wall and 'GWB' signifies that the lateral load is applied to the GWB side of the wall.
3. Static deflection of the wall is measured at mid-span after application of the lateral load and prior to application of any axial load.
4. Calculated values are based on actual average yield stress from a sample of three studs tested per ASTM 370-92 [2x4x33 = 49.5 ksi (COV = .0126) 2x4x54 = 60.0 ksi (COV = .007)] and actual average thickness from a sample of three studs measured per ASTM A90-93 [2x4x33 = .0325 inch (COV = .010) 2x4x54 = .0534 inch (COV = .007)]. The provisions of the AISI Design Specification are applied following the procedures for walls braced with gypsum wall board on both sides with studs spaced at 24 inches on center.
5. Using a sample of three studs per ASTM 370-92, the stress. The following mechanical properties were also verified: [2x4x33 = 57.5 ksi] [2x4x54 = 74.3 ksi].
6. Values are based on an average of two tests per configuration.

The data show that the AISI Design Specification is slightly conservative for cases involving zero lateral load and assuming that the wall is continuously braced (with GWB on both sides). For this condition, the safety factor was 2.3 for the 2x4x33 mil walls and about 2.1 for 2x4x54mil walls. The actual factor of safety used in the AISI Axial Load Design is Log 2. However, for conditions with combined lateral and axial loads, the calculated allowable axial load capacities are very conservative in comparison to the tested axial load capacities for 25 psf and 50 psf lateral loads. In this situation, the AISI Design Specification results in an axial load safety factor of 4.1 and higher. The disparity in actual axial load capacity to allowable axial load capacity increases as the lateral load increases. This trend is most evident for the 2x4x33 mil wall specimens with a 50 psf lateral load where the AISI Design Specification allows no axial load and "fails" the member in bending alone. The test results show that this wall should be capable of resisting axial loads in the range of 3,000 pounds.

The failure mode of the walls specimens followed expectations. For all tests with lateral loads, the failure mode was local buckling of the compression flange at the location of a web punchout nearest to the region of maximum moment (see Figures 4 and 5). For all tests with no lateral load, the failure mode was crippling at the end of the stud where the load was applied through a 1.5 inch-wide bearing plate (see Figures 6 and 7). A notable observation in these tests and in a number of pilot tests of various wall assemblies (see Appendix B), was that the track and end of the stud was able to deform to more evenly distribute the end loads into the stud without an apparent detrimental effect on ultimate capacity. This may suggest that end cut tolerances (i.e., non-square cuts) and gaps between the end of the stud and the track may not be as critical as originally believed. Some additional testing on the sensitivity to eccentricities and tolerance would be necessary to confirm this observation. Also, the failure modes in the assemblies tested indicate that the critical design consideration is local buckling either at a web punch-out (bending initiated) or at the ends of the studs (axial load initiated). **It appears that for the wall assemblies tested, the yield strength of the steel plays a minimal role in comparison to steel thickness and local stability (i.e. at the compression flange adjacent to web openings or at the end of the stud).**

Due to the different properties and fastening of the OSB and GWB sheathing materials, it was necessary to test lateral loads applied to both sides of the wall (see Table 1). The results showed that the walls with lateral loads applied to the OSB side resisted greater axial load in all cases except for the 2x4x33 wall specimens with a 50 psf lateral load.

FIGURE 4
Failure of a 2x4x33 mil wall stud due to local buckling of the compression flange at a web punch-out with a 25 psf or 50 psf lateral load (sheathing has been removed).

FIGURE 5
Failure of a 2x4x54 mil wall stud due to local buckling of the compression flange at a web punch-out with a 25 psf or 50 psf lateral load (sheathing has been removed).

FIGURE 6
Failure of a 2x4x33 mil wall stud by crippling at the end of the stud with 0 psf lateral load (sheathing has been removed).

FIGURE 7
Failure of a 2x4x54 mil wall stud by crippling at the end of the stud with 0 psf lateral load (sheathing has been removed).

The static deflection reading shown in Table 2 is the amount the wall specimen deflected, out-of-plane, after the lateral load was applied with no axial load. Two measurements were taken per test–one at the mid-point of each stud. The value in Table 2 is the average value for each stud and both tests of each respective wall specimen. All deflections were less than a L/120 (0.8”) deflection limit. Similarly, all deflections except for the 50 psf laterally loaded 2x4x33 wall specimens were less than a L/240 (0.4”) deflection limit.

DISCUSSION

While the results follow general expectations in terms of ultimate capacities, static bending deflections, and failure modes, some conditions during testing should be noted regarding the 2x4x54mil wall specimens. Because the 2x4x54 mil walls were capable of carrying much higher axial loads, deflection in the test apparatus at high axial loads resulted in rotation of the top and bottom load beams. This condition introduced non-uniform bearing loads into the top and bottom of the studs which caused the 2x4x54mil walls to deflect upward, even when the 25 psf and 50 psf lateral loads were applied. This condition is believed to have decreased the tested ultimate capacity of the walls by creating an eccentric loading initiating end crippling of the stud. However, a certain number of tests should be repeated with the appropriate modifications to the test apparatus to confirm this belief. Future tests are planned for this purpose.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are based on the findings of this study:

1. The AISI Design Specification is reasonably consistent for conditions of axial load only on light-gauge steel wall studs.

2. The actual capacity of light-gauge steel walls sheathed with OSB on one side and GWB on the other far exceeds the capacities predicted by the AISI Design Specification for combined axial and bending loads.

3. The failure modes of light-gauge steel walls with OSB and GWB sheathing are primarily related to local buckling effects**, and yield strength appears to have a minimal effect on actual capacity for the application conditions considered in this study.**

The following recommendations are given:

1. The data produced in this study should be subject to further analysis to develop a design methodology for inclusion in the AISI Design Specification.

2. Additional tests should be performed on the 2x4x54 mil walls specimens using an improved test apparatus to confirm the results. These tests are expected to be conducted in the future.

3. Additional testing should be performed to investigate the following issues:

    - the degree of load sharing and composite action provided by the OSB and GWB sheathing in comparison to the effects of continuous lateral support;
    - the effects of eccentric end loads (i.e. offset to the side of the stud);
    - the effects of uneven end load either from rotation of the bearing member on the stud (i.e. a floor joist) or unsquare end cuts on the stud;
    - the maximum bending moments possible with similar wall assemblies with no axial loads applied; and,
    - the effects of alternate sheathing materials and assembly methods (i.e., stucco and GWB, pneumatic pins instead of screws, etc.).

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APPENDIX A

Drawings of the Test Apparatus

CURRENTLY NOT AVAILABLE

APPENDIX B

Pilot Axial Load Tests of Cold-Formed Steel Wall Assemblies with Various Sheathing Materials

OVERVIEW

The purpose of this experiment was to gather preliminary data on the system effects that OSB, plywood, and GWB sheathing have on the axial load carrying capacities of 33 mil steel C-section studs. The potential effect of eccentric loads was also investigated experimentally. Nine tests were performed based on the ASTM E72 standard for a compressive load test. All walls were 4 feet by 8 feet in dimension with three 33mil (20g) studs spaced at 24 inches on center. All tests with the exception of two were loaded eccentrically at the 1/3 point from the interior face of the wall. Two of the walls were loaded concentrically. The testing apparatus was a Universal Testing Machine located at the NAHB Research Center.

RESULTS

The configurations and ultimate axial load capacities of the nine test specimens can be found in Table B-1. All tests except 7 and 9 were performed eccentrically with the axial load being applied at 1/3 of the total width from the interior edge of the wall specimen. This is in contrast to the AISI calculated ultimate values because the AISI Design method considers all loads to be concentrically applied. The system effects of the wood sheathing and GWB have on the load carrying capacities of the wall system appears very advantageous. For instance, when comparing test 5 (mechanical bracing on both sides) to test 2 (7/16 inch OSB on exterior and ½ inch GWB on interior), there is a 7,040 lb gain in axial load capacity for the wall system. All other conditions are the same including the eccentricity. Likewise, when comparing test 7 (15/32 inch plywood and ½ inch GWB) to the AISI calculated value, there is a 10,036 lb or a 72 percent gain in axial load carrying capacity for the 4 foot wall system. In this comparison, both methods reflect a concentrically loaded wall.

Table B-1
Test Specimens and Ultimate Loads

Test Number	Interior Bracing	Exterior Bracing	Applied Load	Calculated* Ultimate	Test Ultimate	Percentage Increase
1	none	none	Eccentric	5,120	7,700	50%
2	with a 12/12 schedule	7/16” OSB screwed with a 6/12 schedule	Eccentric	14,014	18,300	31%
3	mechanical bracing at 48 inches	7/16” OSB screwed with a 6/12 schedule	Eccentric	12,430	12,620	2%
4	½” GWB screwed with a 12/12 schedule	mechanical bracing at 48 inches	Eccentric	12,430	19,820	59%
5	mechanical bracing at 48 inches	mechanical bracing at 48 inches	Eccentric	12,430	11,260	-9%
6	½” GWB glued and screwed with a 24/24 schedule	7/16” OSB screwed with a 6/12 schedule	Eccentric	14,014	17,800	27%
7	½” GWB screwed with a 12/12 schedule	15/32” Plywood screwed with a 6/12 schedule	Concentric	14,014	24,050	72%
8	½” GWB screwed with a 12/12 schedule	½” GWB screwed with a 12/12/ schedule	Eccentric	14,014	18,680	33%
9	mechanical bracing at 48 inches	7/16” OSB screwed with a 6/12 schedule	Concentric	12,430	14,640	18%

Note:
1. All calculated ultimates were based on concentric axial load capacities based on the AISI Design Specification, 1986 edition with 1989 Addendum.
2. Eccentricities were applied at 1/3 of the total wall width from the inside edge of the wall.
3. Studs were installed 24 inches on centers with two studs located at either end of the specimen and one at the center (three studs total).
4. All studs were 33 mils (20 gauge). Actual yield strength and thickness of the studs was not measured.

Specimens with wood sheathing, such as 7/16 inch OSB and ½ inch GWB sheathing were much stiffer on the wood sheathed side of the wall than the GWB side. This difference in stiffness caused GWB side of the wall to yield at a faster rate which tended to exaggerate the eccentricity applied to the wall. This theory may explain why test 4 (mechanical bracing at 48 inches on the exterior and GWB on the interior) out-performed test 3 (OSB on the exterior and mechanical bracing on the interior) by 6,660 pounds or 53 percent.

Finally, these pilot tests indicate that when the wall specimens were loaded with a 1/3 eccentricity towards the interior of the wall surface, which would be the worst case, the results were consistently higher than the calculated results. From these findings, it is apparent that conservatism in the AISI Design Specification is adequate to offset realistic eccentricities found in day-to-day construction.

A summary of each individual test can be found in the following 10 pages.

CONCLUSIONS

This preliminary test resulted in a good indication that significant "system effects" exist when Plywood, OSB, or GWB sheathing are applied to 2x4x33mil C-section wall assemblies. The sheathing provides the following benefits to the wall assembly:

- provides weak axis lateral support to the studs;
- provides torsional support to the studs;
- provides some additional axial load carrying capacity.

Future testing should expand to examine 2x6 walls as well as 2x4 walls in various stud thicknesses. Furthermore, future test should concentrate on concentric loading so the results can be directly compared to calculated values. Also, variability in steel yield strength and base metal thickness should be adequately documented in all future tests.

APPENDIX C

Metric Conversions

1 inch = 1000 mils = 25.40 mm

1 kip = 1000 lbs = 4.448 kN