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Iron and Steel
Institute

DESIGN GUIDE

2

Design of Cold-Formed Steel Shear Walls

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1. Overview

In residential construction, steel studs and track are generally covered with cladding to form a wall assembly with significant shear strength. It is common design practice to use this wall shear strength to resist lateral loads, such as those caused by wind and earthquake.

This document includes information on walls constructed with (1.) plywood and oriented strand board (OSB) on the exterior wall surface, with or without gypsum wall board (GWB) on the interior wall surface, (2.) GWB on both surfaces, (3.) steel sheathing on one side, and (4.) steel X-bracing on one side. Most of this information is based on 3-1/2 x 1-5/8 in. studs, and attachment to the studs and track with self drilling screws. Limited information is included on walls with 6 x 1-5/8 in. studs sheathed with plywood, OSB, GWB, and with steel X-bracing; and on walls with sheathing attached by pneumatically driven pins. Additional information on sheathing attached by pneumatically driven pins is available from suppliers.

The strength of a wall system depends on the interaction of many factors including the strength of the sheathing; the type, size, and spacing of the fasteners used to attach the sheathing; the panel aspect ratio (ratio of long to short dimension of shear panel); and the strength of the studs. Because of these variables, the design strength of shear walls is usually based on tests of full height specimens. Thus, this document provides a summary of the results obtained in wall tests conducted by Serrette (1997, 1996, and 1994) and Tissell (1993). Of course, to develop the shear strength values, walls must be provided with anchors designed to resist the shear and uplift forces that are developed.

It has been common practice to base shear wall design values on the results of static tests. However it is well known that earthquakes can cause severe cyclic loadings. Wind also causes repeated load applications, although usually not at peak load levels. Static test results have been used because it was not considered practical to conduct large scale cyclic testing. However, tests conducted by Serrette (1996 and 1997) involved a significant number of cyclic tests. Consequently it is now possible to more rationally address shear wall design in high seismic regions.

2. Shear Wall Design Data

Tables 1, 2, and 3 give nominal (ultimate) strengths for the design of shear walls with cold-formed steel framing. As indicated, some of the values have been approved by national codes while more recent values are proposed for inclusion. The approved values have been accepted in the following codes: SBC, 1997; UBC, 1997; BOCA, 1999; IBC, current draft. Appendix Tables A1, A2, and A3 give test references for the values in Tables 1, 2, and 3.

The values in Tables 1 through 3 must be divided by a safety factor Ω (for Allowable Stress Design) or multiplied by a reduction factor ϕ (for Load and Resistance Factor Design). See the pertinent building codes for complete requirements. In the absence of other requirements, consider the following: Seismic, $\Omega = 2.5$ or $\phi = 0.60$; Wind, $\Omega = 2.0$ or $\phi = 0.65$. These values correspond to those given by AISI for steel diaphragm construction with mechanical fasteners (see *Specification for the Design of Cold-Formed Steel Structural Members*, American Iron and Steel Institute, 1996).

Table 1 is for wind loads and Table 3 is for seismic loads. Generally, for similar wall construction, the test values used to derive the wind load table are higher than the test values used to derive the table for seismic loads (Table 3). Thus, for cases that are not covered for wind loads (Table 1) but are covered for seismic loads (Table 3), it is conservative to use Table 3 for wind loads. Table 2 is for walls sheathed with GWB on both sides and is applicable to wind loads only. Maximum aspect ratios are as indicated. It is important to note that, as the aspect ratio increases, it is essential to properly tighten hold-downs and remove slack to minimize deflections.

Table 1 includes walls sheathed with plywood or OSB on one side; the OSB values are conservative where plywood values are not shown. For the 6/12 in. spacing, the strength can be increased by 30 percent if GWB is added to the opposite side of the wall. Table 1 also includes walls sheathed with steel sheet on one side. Table 3 is for seismic loads resisted by walls sheathed with plywood, OSB, or steel sheet, as indicated, on one side only.

Tables 1 through 3 are for walls with steel studs spaced at no more than 24 in. on centers. The studs must be doubled at the shear wall ends. Except where indicated otherwise, minimum stud size is 3-1/2 x 1-5/8 x 0.033 in. and minimum track size is 3-1/2 x 1-1/4 x 0.033 in. (minimum metal base thicknesses). In Table 3, thicknesses of 0.0433 are indicated for certain cases. In all cases, for seismic design in Zones 3 and 4, the stud and track thickness should not exceed 0.0433 in.

All panel edges must be fully blocked. Horizontal steel straps used as blocking must be a minimum of 1-1/2 in. wide and of the same material and thickness as the studs and track. Boundary members and anchorage details for uplift must have adequate strength to resist the forces resulting from the load combinations imposed by the building code. Panels must be at least 12 in. wide, such as when needed to complete a wall.

No code values are proposed for steel X-bracing because, as confirmed by the most recent tests (Serrette, 1997), it can be designed directly for the imposed loads. However, the design must address two important considerations. First, because the material yield strength is typically greater than the specified minimum value, end connections must be designed to withstand a brace force greater than that corresponding to the minimum specified material yield strength. Second, flat strap bracing on one side of a wall causes an eccentric loading on tracks and chord (end)

studs; this eccentricity must be considered in design, particularly in high seismic zones.

3.0 Shear Wall Tests

3.1 Tests by Serrette (1997) on Walls with 3-1/2 x 1-5/8 in. Studs

Both static and cyclic load tests were conducted on walls with 3-1/2 x 1-5/8 studs spaced at 24 in. Double studs (back-to-back) were used at the ends of the walls. Tests included panels with APA rated sheathing (OSB or plywood, vertical), steel X-bracing, and steel sheet sheathing. The sheathing or bracing was placed on only one side of the panels. The tests were planned to answer remaining questions on OSB and plywood sheathed walls, to obtain design data for panels with high aspect ratios, and to obtain design data for walls with steel X-bracing or steel sheathing.

Static Tests

The test setup was essentially the same as that used for earlier tests as described below under 3.2 except that the loading rate was decreased to approximately 0.10 in./min. Studs were 0.033 in. thick except for one case where 0.043 in. thick studs were used as noted. The following assemblies were tested (see Table 4):

- OSB sheathing at aspect ratio of 4:1 with screw spacings along the edges of 2, 4, and 6 in. (Tests 5 - 10.)
- Steel X-bracing, 4-1/2 x 0.033 in. and 7-1/2 x 0.033 in., with aspect ratio of 2:1 (Tests 1- 4).
- Steel sheathing, 0.018 and 0.027 in. thick, with aspect ratios of 4:1 and 2:1 and screw spacings along the edges of 4 and 6 in. (Tests 11 - 16).

Table 4 lists the average value of maximum load obtained in the tests. Duplicate specimens were tested and the results of the two were within 10 percent except as noted in the table. Salient points are as follows.

OSB Sheathing with High Aspect Ratio. The displacement at maximum load was 2 in. or more for all specimens. With a 2 in. edge screw spacing, the end studs buckled just above the track. With a 6-in. screw spacing failure was initiated by buckling of the end studs at the hold-down, and with a 4-in. spacing displacements became excessive. Based on the 1996 and 1997 tests by Serrette, Figure 1 shows graphically how the static shear strength varies with the screw spacing, and how it compares with that of panels with an aspect ratio of 1 or 2. Previous tests had established that the shear strength per unit length was essentially the same for 8 x 8 ft and 8 x 4 ft panels and that results for 7/16 in. OSB could be used conservatively for 15/32 in. plywood (see 3.2). Figure 1 illustrates that, on a force per unit length

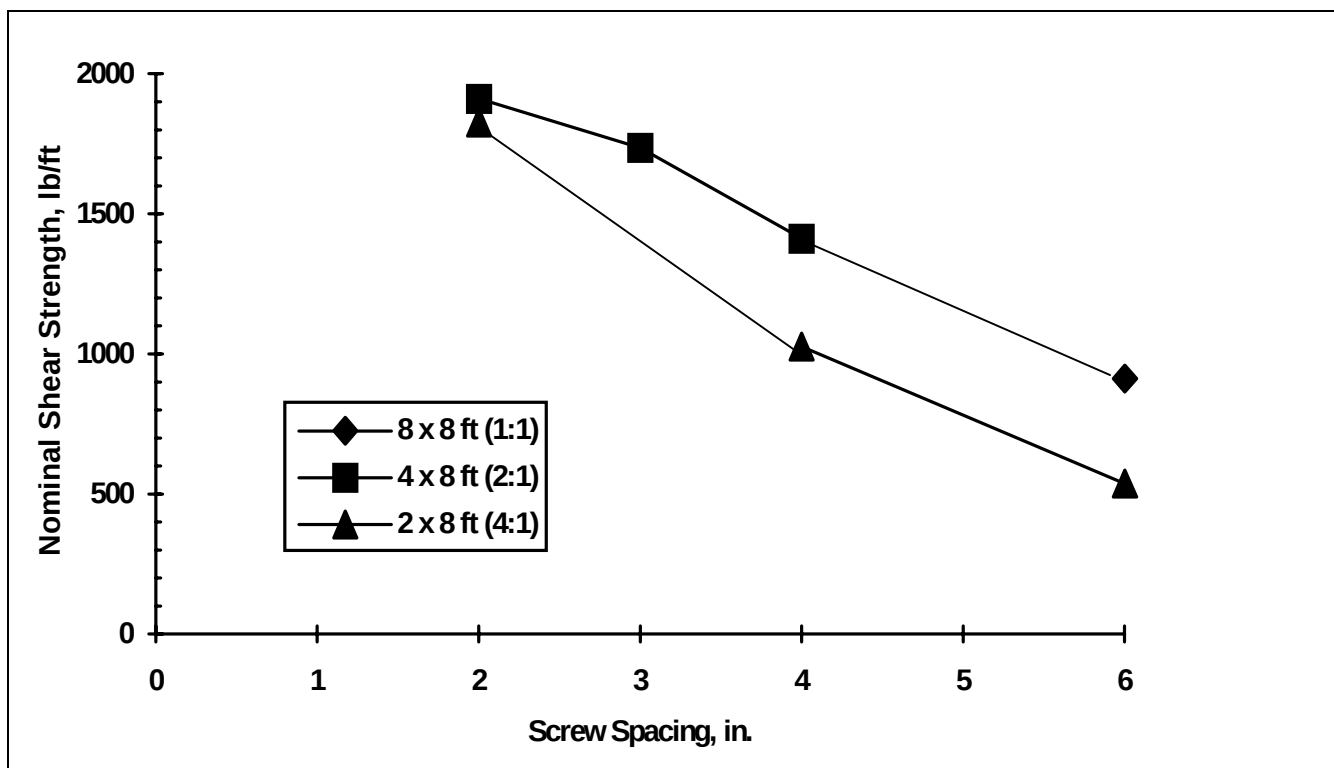


Figure 1. Nominal Static Shear Strength with OSB Sheathing as a Function of Screw Spacing and Aspect Ratio

basis, the shear strength of panels with an aspect ratio of 4:1 varies from 95 to 59 percent (depending on screw spacing) of that of panels with an aspect ratio of 2:1 or 1:1. The lower shear strength percentages occurred in those cases where the wall deflection became relatively large, long before the wall was able to develop its maximum strength.

Steel X-Bracing. With the 4-1/2 in. strap, failure resulted from local buckling of the end studs. With the 7-1/2 in. strap, failure resulted from local buckling in the top track and end stud, aggravated by bending due to the eccentricity of the strap force. Thus, although the strap area was increased by a factor of 1.67, the load increased by a factor of only 1.30. The maximum load for the wide strap, 877 lb/ft, was close to that for OSB sheathing with 6/12 in. screw spacing, 911 lb/ft. The effect of strap eccentricity should be considered when designing wall systems. Also, the force in the strap may be larger than that corresponding to the specified minimum yield strength because the actual yield strength is likely to be higher. Designers should consider that fact when calculating connection requirements. Average displacement at maximum load was 0.70 in. for the 4-1/2 in. straps and 0.82 in. for the 7-1/2 in. straps.

Steel Sheathing. Failure of these panels resulted from rupture of the steel sheet along the line of screws at the edges. Diagonal "tension field" patterns were not

observed. Decreasing the fastener spacing and increasing the steel sheathing thickness were effective in increasing the maximum load. The maximum loads for panels with an aspect ratio of 4:1 were similar (within 10 percent) to those for OSB panels with the same aspect ratio and fastener spacings. Displacement at maximum load was 2 in. or more for panels with an aspect ratio of 4:1, and averaged 1.30 in. for the panel with a ratio of 2:1.

Cyclic Tests

The test setup was essentially the same as that used for earlier tests as described below under 3.2 except that the loading rate was increased to 1 second per cycle (1.0 Hz). Studs were 0.033 in. thick except as noted. The following assemblies were tested (see Table 5):

- OSB and plywood sheathing at aspect ratio of 2:1 with screw spacings along the edges of 2 and 3 in. (Tests A1 - A8). These tests were conducted on panels with 0.033 in. thick framing but with thicker end studs (0.043 in.) because the shear strength in prior (1996) tests with these spacings had been limited by the strength of the end studs.
- Plywood sheathing at aspect ratio of 2:1 attached to thicker framing with screw spacings along the edges of 6 in. (Tests B1 - B4). These tests were conducted on panels with 0.043 in. and 0.054 in. thick framing to evaluate the behavior of fasteners in thicker studs.
- OSB sheathing at aspect ratio of 4:1 with screw spacings along the edges of 2, 4, and 6 in. (Tests E1 - E6).
- Steel X-bracing, 4-1/2 x 0.033 in. and 7-1/2 x 0.033 in., with aspect ratio of 2:1 (Tests C1 - C4).
- Steel sheathing, 0.018 and 0.027 in. thick, with aspect ratios of 2:1 and 4:1 and screw spacings along the edges of 4 and 6 in. (Tests D1 - D2, and F1 - F4).

Table 5 lists the average value of maximum load obtained in the tests. Duplicate specimens were tested and the results of the two were within 10 percent except as noted in the table. Salient points are as follows.

OSB and Plywood Sheathing at Aspect Ratio of 2. The back-to-back 0.043 in. thick studs provided increased strength so that failure was initiated by screw heads pulling through the sheathing. The plywood panels were 6 to 16 percent stronger than the OSB panels. Based on the 1996 and 1997 tests by Serrette, Figure 2 illustrates how the cyclic shear strength varies with screw spacing, aspect ratio, and thickness of end studs.