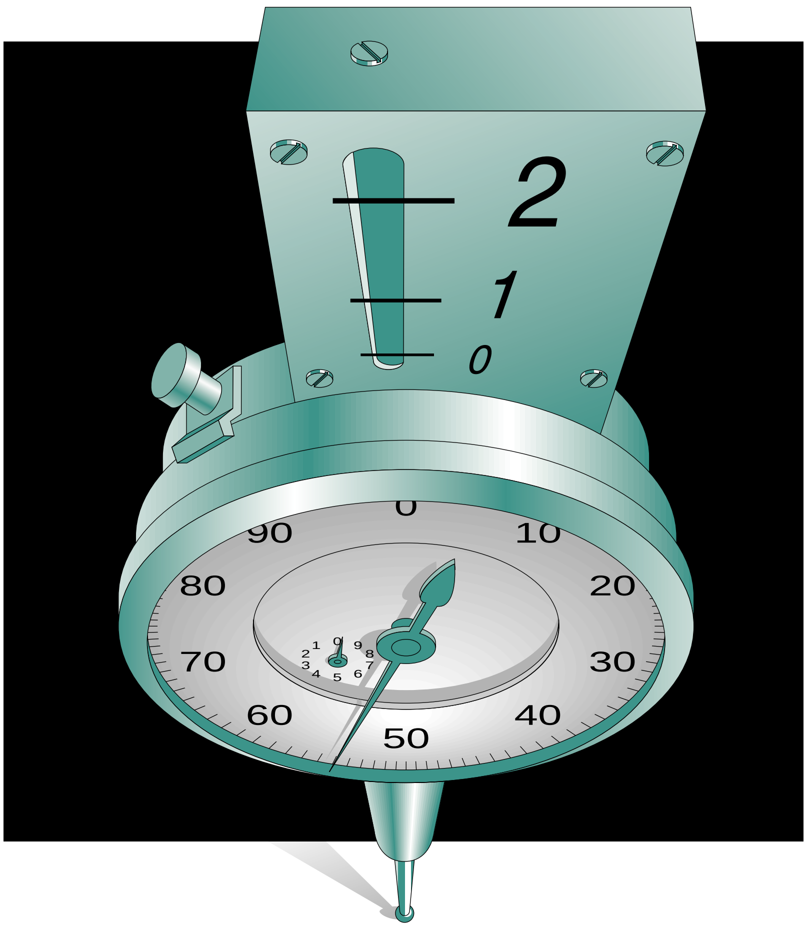
Report 154

Wood Structural Panel Shear Walls

by John R. Tissell, P.E. • *Revised May 1993*
Technical Services Division



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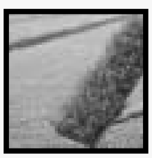
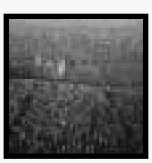
- ***We're not running out of trees.*** One-third of the United States land base – 731 million acres – is covered by forests. About two-thirds of that 731 million acres is suitable for repeated planting and harvesting of timber. But only about half of the land suitable for growing timber is open to logging. Most of that harvestable acreage also is open to other uses, such as camping, hiking, and hunting. Forests fully cover one-half of Canada's land mass. Of this forestland, nearly half is considered productive, or capable of producing timber on a sustained yield basis. Canada has the highest per capita accumulation of protected natural areas in the world – areas including national and provincial parks.



- ***We're growing more wood every day.*** American landowners plant more than two billion trees every year. In addition, millions of trees seed naturally. The forest products industry, which comprises about 15 percent of forestland ownership, is responsible for 41 percent of replanted forest acreage. That works out to more than one billion trees a year, or about three million trees planted every day. This high rate of replanting accounts for the fact that each year, 27 percent more timber is grown than is harvested. Canada's replanting record shows a fourfold increase in the number of trees planted between 1975 and 1990.

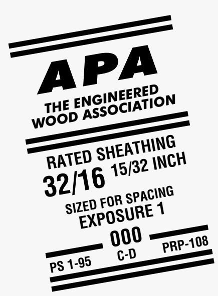
- ***Manufacturing wood is energy efficient.*** Wood products made up 47 percent of all industrial raw materials manufactured in the United States, yet consumed only 4 percent of the energy needed to manufacture all industrial raw materials, according to a 1987 study.

Material	Percent of Production	Percent of Energy Use
Wood	47	4
Steel	23	48
Aluminum	2	8



- ***Good news for a healthy planet.*** For every ton of wood grown, a young forest produces 1.07 tons of oxygen and absorbs 1.47 tons of carbon dioxide.

Wood, the miracle material for the environment, for design, and for strong, lasting construction.



NOTICE:
The recommendations in this guide apply only to panels that bear the APA trademark. Only panels bearing the APA trademark are subject to the Association's quality auditing program.

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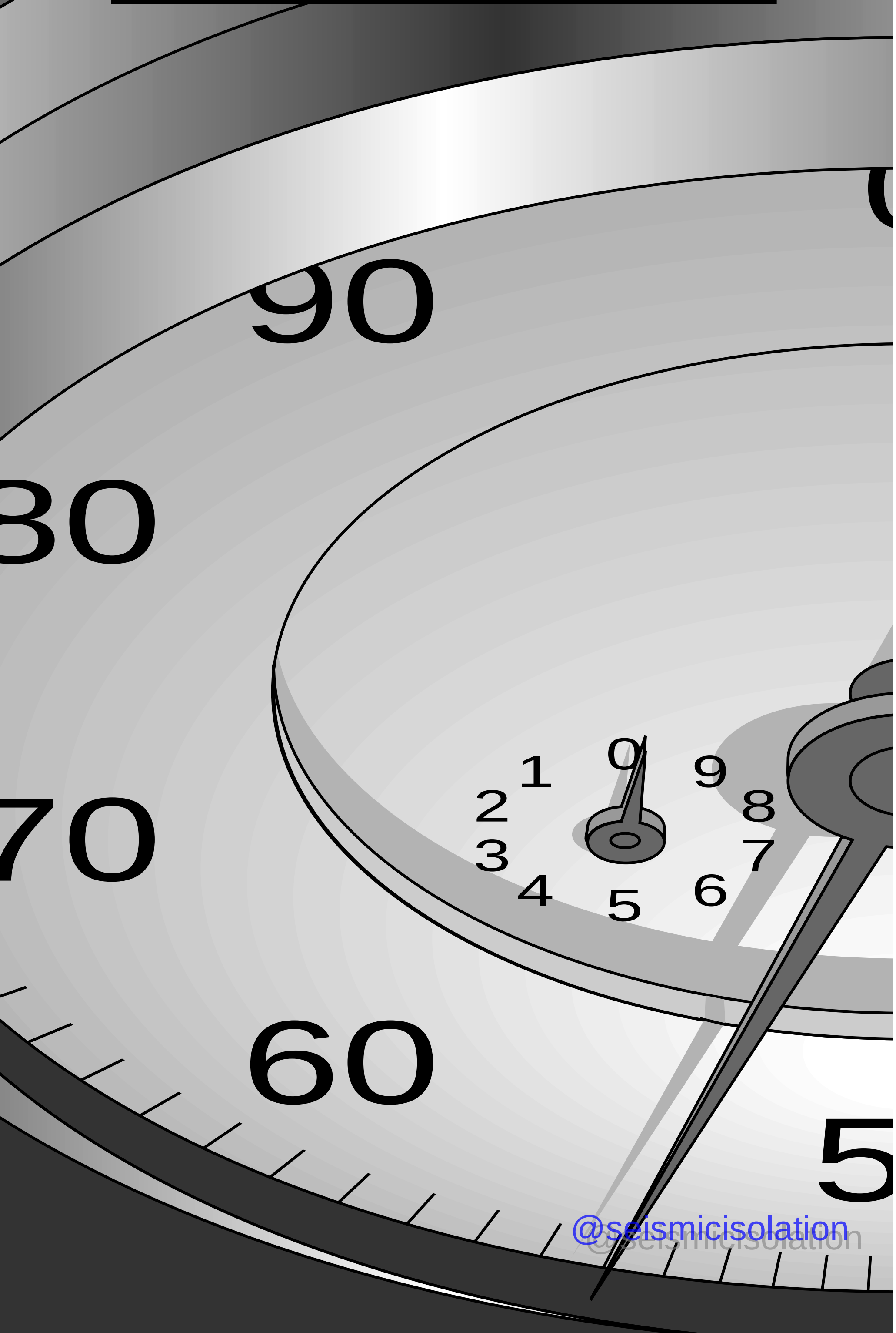
Abstract

A large number of shear walls have been tested since Laboratory Report 105, Plywood Shear Walls, was published by *APA – The Engineered Wood Association* in 1965. This report summarizes those tests, and also includes unblocked and double-sided shear walls, and panels over gypsum sheathing. Shear walls fabricated with staples as fasteners, walls with metal framing and the effect of stud spacing and stud width are also investigated.



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Wood Structural Panel Shear Walls

by John R. Tissell, P.E.

Recommended Shears

Table 1 presents recommended design values for structural-use panel shear walls which have been derived from test results given in the body of this report, with suitable reference to previous tests of shear walls. Tabulated shears are for short-term wind or seismic loading. For “normal” load duration (10 years), the design shears should be reduced by 25 percent. The recommended values assume that all framing, splices, ties, hold-downs and other connections are adequately designed and detailed for the applied shear.

Introduction

In order for a building to resist the lateral forces caused by wind or earthquake, it is necessary that the building include a lateral force resisting system. When the walls, roofs and floors are designed and constructed in such a way as to serve as the lateral force resisting system, they are commonly referred to as diaphragms. Vertical diaphragms which act to transfer lateral loads from horizontal diaphragms down into the foundation are usually termed shear walls.

Proper detailing of the framing and fasteners attaching the panel sheathing will allow the engineer to utilize the sheathing to develop the necessary lateral load capacity required in the building.

TABLE 1.

RECOMMENDED SHEAR (POUNDS PER FOOT) FOR APA PANEL SHEAR WALLS WITH FRAMING OF DOUGLAS-FIR, LARCH, OR SOUTHERN PINE[a] FOR WIND OR SEISMIC LOADING[b]

			Panels Applied Direct to Framing					Panels Applied Over 1/2" or 5/8" Gypsum Sheathing				
Panel Grade	Minimum Nominal Panel Thickness (in.)	Minimum Nail Penetration in Framing (in.)	Nail Size (common or galvanized box)	Nail Spacing at Panel Edges (in.) 6	4	3	2[e]	Nail Size (common or galvanized box)	Nail Spacing at Panel Edges (in.) 6	4	3	2[e]
APA STRUCTURAL I grades	5/16	1-1/4	6d	200	300	390	510	8d	200	300	390	510
	3/8	1-1/2	8d	230[d]	360[d]	460[d]	610[d]	10d[f]	280	430	550	730
	7/16			255[d]	395[d]	505[d]	670[d]		—	—	—	—
	15/32			280	430	550	730		—	—	—	—
	15/32	1-5/8	10d	340	510	665[f]	870	—	—	—	—	—
APA RATED SHEATHING; APA RATED SIDING[g] and other APA grades except species Group 5	5/16 or 1/4[c]	1-1/4	6d	180	270	350	450	8d	180	270	350	450
	3/8			200	300	390	510		200	300	390	510
	3/8	1-1/2	8d	220[d]	320[d]	410[d]	530[d]	10d[f]	260	380	490	640
	7/16			240[d]	350[d]	450[d]	585[d]		—	—	—	—
	15/32			260	380	490	640		—	—	—	—
	15/32	1-5/8	10d	310	460	600[f]	770	—	—	—	—	—
	19/32			340	510	665[f]	870	—	—	—	—	—
			Nail Size (galvanized casing)					Nail Size (galvanized casing)				
APA RATED SIDING[g] and other APA grades except species Group 5	5/16[c]	1-1/4	6d	140	210	275	360	8d	140	210	275	360
	3/8	1-1/2	8d	160	240	310	410	10d[f]	160	240	310	410

(a) For framing of other species with a specific gravity of 0.49 or less: (1) Determine the specific gravity for the lumber species used from the AFPA National Design Spec. (2) (a) For common or galvanized box nails, find shear value from table above for nail size for STRUCTURAL I panels (regardless of actual grade). (b) For galvanized casing nails, take shear value directly from table above. (3) Multiply this value by 0.82 for species with specific gravity of 0.42 to 0.49, and 0.65 for species with a specific gravity of less than 0.42.

(b) All panel edges backed with 2-inch nominal or wider framing. Install panels either horizontally or vertically. Space nails 6 inches o.c., along intermediate framing members for 3/8-inch and 7/16-inch panels installed on studs spaced 24 inches o.c. For other conditions and panel thicknesses, space nails 12 inches o.c. on intermediate supports.

(c) 3/8-inch or APA RATED SIDING - 16 oc is minimum recommended when applied direct to framing as exterior siding.

(d) Shears may be increased to values shown for 15/32-inch sheathing with same nailing provided (1) studs are spaced a maximum of 16 inches o.c., or (2) panels are applied with long dimension across studs.

(e) Framing at adjoining panel edges shall be 3-inch nominal or wider, and nails shall be staggered where nails are spaced 2 inches o.c.

(f) Framing at adjoining panel edges shall be 3-inch nominal or wider, and nails shall be staggered where 10d nails having penetration into framing of more than 1-5/8 inches are spaced 3 inches o.c.

(g) Values apply to all-veneer plywood APA RATED SIDING panels only. APA RATED SIDING - 16 oc plywood may be 11/32-inch, 3/8-inch or thicker. Thickness at point of nailing on panel edges governs shear values.

Shear wall design values have been in the Uniform Building Code beginning with the 1955 edition. In 1958, design shears for unblocked construction were added. However, in 1967, when vertical diaphragms (shear walls) were moved to a separate table, the unblocked values were dropped.

In addition to reestablishing test data for unblocked shear walls, this research report includes test information on panel sheathing over metal framing.

Objective

The purpose of the testing reported herein was to develop design information for constructions not currently listed in tables of recommended design shears, and to present supporting data for changes recently incorporated into Table 1. Six test series are reported:

1. Unblocked shear walls
2. Stapled shear walls
3. Sheathing over metal framing
4. Double-sided walls
5. Panels over gypsum sheathing
6. Effect of stud spacing and width

Results of past testing, both previously published and unpublished, are summarized in Appendix A.

Materials

Framing

All lumber wall frames were constructed from kiln dried (KD) Douglas-fir obtained from local building material dealers. The majority of the framing was 2 x 4, however 2 x 6 framing was used occasionally and 3 x 4's were used when required for closely spaced nails.

*Italicized numbers in parentheses refer to literature cited.

The steel members for the metal-framed walls were obtained from local suppliers. The 14-ga studs were 2-1/2-in. deep, and the 16-ga studs were 3-5/8-in. deep. All studs had 1-5/8-in.-wide flanges. The tracks (top and bottom plates) were of the same gage as the studs for each wall.

Panel Sheathing

Structural panels used in the wall tests were manufactured in accordance with the requirements of either U.S. Product Standard PS 1 *(1)** or APA PRP-108 *(2)*. The tests described in this report also apply to wood structural panels meeting the requirements of U.S. Product Standard PS 2 *(17)*, which is based on APA PRP-108.

Fasteners

The nails, staples and screws used in the shear walls were American-made, purchased from building material suppliers.

Test Set-up and Procedure

The wall racking frames were built in accordance with the provisions of ASTM E72 *(3)*. Details of the shear wall test, as recommended in ASTM E72, are shown in Figure 1. The 4 x 8-foot sheets of structural panel sheathing were oriented with their 8-foot dimension vertical to the frame. Modifications to the wall frame were made only when application recommendations specifically detailed these changes. For example, the center vertical framing member for some tests was increased to a nominal 3 x 4. In this case the shear values presented in Table 1 are footnoted to specify the wider framing member to carry the higher load by offsetting potential splitting caused by closely spaced nails.

Stud spacings greater than the 16 inches on center specified in ASTM E72 were also evaluated. For example, studs were spaced 24 inches on center for the metal-framed walls. Additional details for the metal stud shear walls included the use of single end studs and the use of two self-drilling, self-tapping screws at each stud-to-track joint.

The racking loads were applied horizontally to the specimen by a hydraulic cylinder having a capacity of 50,000 pounds. To measure load, a compression load cell was placed between the ram and the test specimen.

The walls were tested according to the procedure outlined in ASTM E72 except for use of higher test loads and referencing the deflection measurements to the base of the wall.

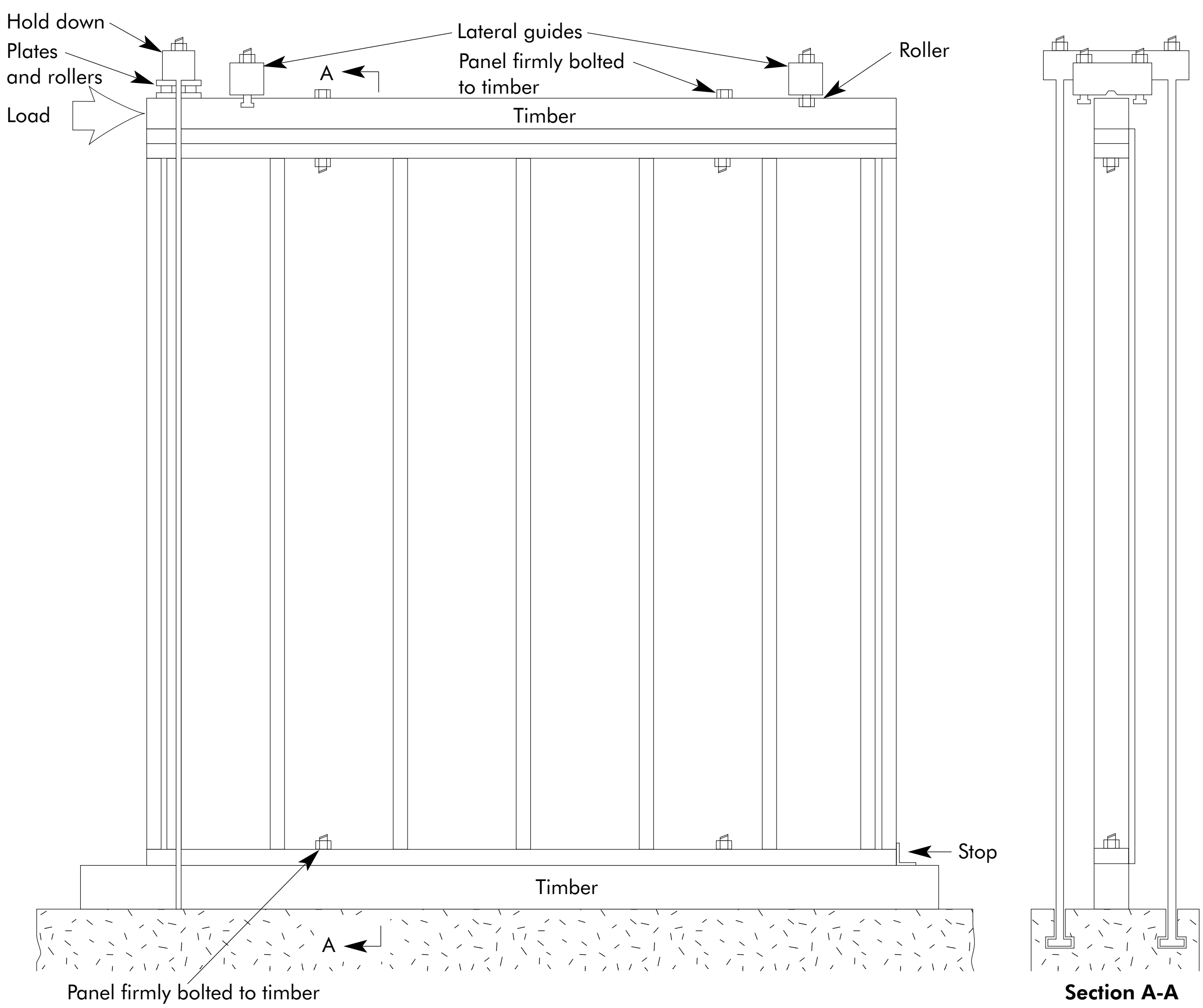
The loading sequence recommended in ASTM E72 applies load in 4 cycles. The first is to a load of 790 lb (99 plf), the second to 1,570 lb (196 plf), the third to 2,360 lb (295 plf) and the fourth is continued until the wall fails. Except for the unblocked specimens, walls tested specifically for this report had design shears ranging from 350 to 665 plf. Using the E72 recommended loading, these walls would not be stressed to design load until the fourth cycle of loading. In order to subject the wall to full design forces, the load applied to the wall during the first loading cycle was equal to the established or target design shear for the wall. The load was increased to produce twice the target design shear for the second cycle. After each of the first two cycles, the applied load was removed and the wall was allowed to recover for five minutes before residual deflection (set) was measured. The third load application to each wall specimen was continued until failure, which is indicated by a decrease in the load resisted by the wall accompanied by greatly increased deflection.

Section 14.3.5 of ASTM E72 states: "The dial at the lower left, which is attached to the stud, measures any rotation of the panel,…" Referencing net deflection to the end stud instead of to the bottom plate of the shear wall results in a significant decrease in the net deflection of the wall. This is because uplift measured relative to the end stud includes any separation between the bottom of the end stud and the plate. This separation is internal to the wall and should not be deducted when calculating net deflection. To eliminate the effect of movement between framing members, deflection of the test walls was measured with a dial gage bearing against the end of the top plate opposite the end of load application. This dial gage was supported by a triangular metal frame resting on steel supports attached to the bottom of the bottom plate at each end of the wall. Wall deflections measured relative to the bottom plate include deflection in the panels, fastener slip and any internal movement between framing members of the wall.

The frame used to hold the deflection gage is shown in Figure 2. The frame is supported by two metal supports attached to the bottom of the bottom plate at each end of the wall. The supports transmit any settlement or uplift of the wall specimen directly to the metal frame. This eliminates any uplift or settlement of the wall relative to the test fixture from the deflection measured by the single dial gage. The frame is securely clamped to the metal support at the unloaded end of the wall. This connection causes the frame to move with the specimen and eliminates any slip of the wall relative to the test fixture from the deflection reading. At the end of the wall where the test load is applied, the frame rests on the support but is not fastened

FIGURE 1.

RACKING LOAD ASSEMBLY



to it. Allowing the frame to slip at this end prevents any compression shortening of the bottom plate from affecting the deflection shown on the dial gage. Substituting this frame with its support at the bottom of the wall plate allows direct reading of the wall deflection with use of only one dial gage.

Deflection readings were recorded at increments of one-quarter the target load. Readings were made during the entire first and second load cycles and until 2-1/2 times the target load was reached during the third cycle.

Test Results

Test results are divided into six series, each is discussed in the following sections of this report. Test results described in each section may include specimens from previously reported tests.

Unblocked Shear Walls

Purpose

Unblocked shear walls were fabricated with either nails or staples to provide test data for the development of design shear recommendations.

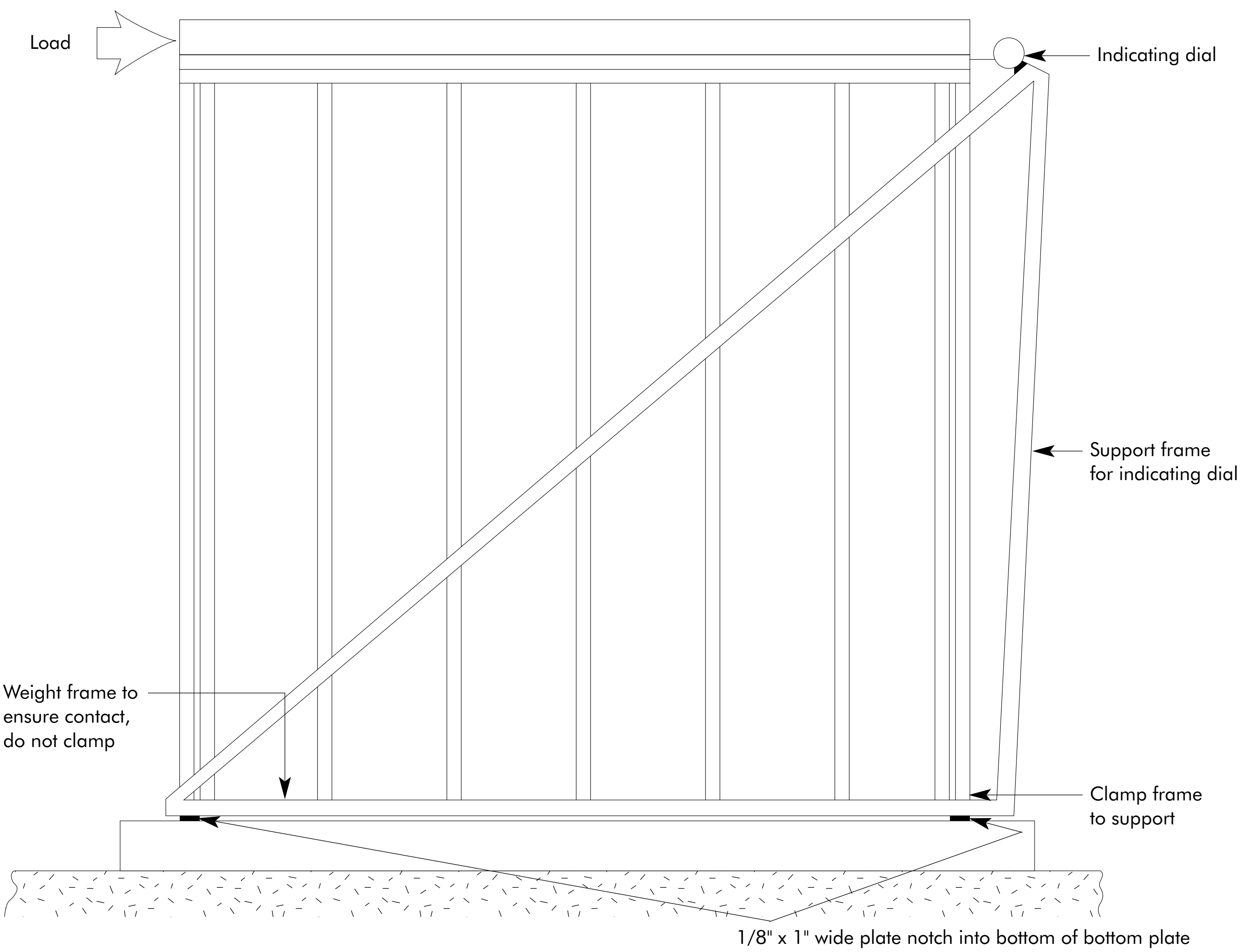
The 4 x 8-ft sheets of panel sheathing were applied with the 8-ft dimension horizontal for this series of tests only. The resulting 8-ft horizontal joint between panels at mid-height of the specimen was not blocked.

Test Results and Discussion

Tests of twelve unblocked 8 x 8-ft shear walls are summarized in Table 2. Since the strength of unblocked shear walls is a function of the framing spacing, the testing included both 16 and 24-in.-o.c. stud spacings. Typical failures of the unblocked walls were along the unblocked horizontal joint where the fasteners either withdrew from the framing members or pulled through the panel.

FIGURE 2.

DEFLECTION MEASUREMENT



The target design shear for an unblocked wall is correlated to the design shear for a blocked wall of the same panel grade and thickness with fasteners 4 in. o.c. along all panel edges. When the framing perpendicular to the unblocked edge is 16 in. o.c., the reduction is 50%. For framing 24 in. o.c., one-third of the blocked wall shear for 4-in.-o.c. fasteners is used. These values are applied to unblocked shear walls fastened 6 in. o.c. along supported panel edges. The target design shears for stapled walls shown in Table 2 were calculated using the same method, but based on values for staples in blocked walls published in NER-272 *(4)*. This calculation of design shears for unblocked shear walls is consistent with the method used for unblocked diaphragms and with the values included in the 1958 through 1964 editions of the Uniform Building Code.

Omission of blocking at the horizontal joint between sheathing panels results in the shear at this joint being transferred through the nails immediately adjacent to the horizontal joint into the vertical framing members. Performance of the wall is therefore sensitive to fastener spacing in the framing members and to the number of framing members. A typical 8 x 8-ft test wall with studs 16 in. o.c. has seven framing members perpendicular to the unblocked joint to transfer shear. The same length wall specimen with studs 24 in. o.c. has only five framing members.

The target design shears for unblocked shear walls assume fastener spacing of 6 in. o.c. along the edges of the panels supported by framing and 12 in. o.c. at intermediate framing members. Decreasing the fastener spacing can increase the shear capacity of an unblocked shear wall *(5)*. Several test walls had closer fastener spacing. The ultimate loads and load factors shown in Table 2 indicate a significant increase in ultimate load for walls with additional fasteners. Double-nailing immediately adjacent to the unblocked edge is another method of increasing the shear capacity of an unblocked wall *(6)*.

Stapled Shear Walls

Purpose

Staples provide a method for developing high design shears while still using 2-inch nominal framing. The small diameter of the staple legs is not as apt to cause splitting of the framing as are closely spaced large diameter nails. The use of staples as fasteners in shear walls is particularly useful to avoid any tendency to split the framing lumber in rehabilitation work where the lumber may be dry and existing fasteners may already be placed at minimum allowable spacing.

Shear walls tested in this group consisted of panel sheathing fastened to lumber framing members with pneumatically driven staples. Design shears for these walls were obtained from the recommended values in NER-272.

Test Results and Discussion

Tests on twenty-five blocked shear walls with the sheathing fastened to the framing with staples are summarized in Table 3.

TABLE 2.

UNBLOCKED SHEAR WALLS

Fastener			Panel			Ultimate Loads (plf)					
Size	Spacing[a] (in.)	Length (in.)	Type	Thickness (in.)	No. of Tests	Min.	Max.	Avg.	Stud Spacing (in.)	Target Design Shear (plf)	Load Factor[b]
STRUCTURAL I											
8d Nail[c]	6, 12	2-1/2	Ply	1/2	1			593	16	215	2.8
	6, 6	2-1/2	Ply	1/2	1			955	16	215	4.4
RATED SHEATHING											
6d Nail[e]	6, 12	2	Ply	5/16	2	550	588[d]	569	16	135	4.2
	6, 6	2	Ply	5/16	2	650	750	700	16	135	5.2
	6, 12	2	Ply	3/8	1			300	24	100	3.0
	6, 6	2	Ply	3/8	1			375	24	100	3.8
16 ga Staple	6, 12	1-1/2	Ply	15/32	1			346	16	130	2.7
	6, 12	2	Ply	15/32	1			381	16	130	2.9
	6, 12	1-3/4	OSB	3/8	1			335	16	105	3.2
15 ga Staple	6, 12	1-1/2	Ply	15/32	1			294	24	105	2.8

(a) The first number is the spacing at supported panel edges, the second is the spacing at intermediate framing members. Single nail at each stud along the unblocked panel edge except as noted.

(b) The load factor is determined by dividing the average ultimate load by the target design shear.

(c) Stainless steel common nail.

(d) At the unblocked edge an additional nail was placed along each panel edge and 3/4" away from the regular nailing.

(e) Common nail.

The primary failure mode for stapled shear walls was fastener withdrawal from the lumber members. Failure in both tests of double-sided walls was triggered by crushing of the lumber plates by the end studs followed by staples pulling through the panels. The large number of staples that pulled through the panels may indicate that 3/8-inch panels are too thin to fully develop the strength of a 14-ga staple.

Both walls fabricated with 5/16-inch Rated Sheathing used panels manufactured entirely of cedar veneers. Failures in these tests were caused by the staple crowns pulling through the panels.

Metal-Framed Shear Walls

Purpose

The shear walls tested were panel sheathing attached to metal framing with screws or pneumatically driven steel pins. These tests provided information on the influence of fastener size and spacing, and gage of framing metal in order to develop data for sheathing over metal framing.

Test Results and Discussion

The construction details and results of tests on shear walls with metal framing are summarized in Table 4.

There is currently very limited published information on the shear capabilities of structural panel sheathing applied to metal framing. It was therefore necessary for test purposes to select target design shears based on assumptions. It was assumed that Number 10 fasteners in 14-ga studs fully develop recognized wood framed shear wall values for 10d nails. Similarly, it was assumed that Number 10 fasteners in 16-ga studs fully develop recognized wood framed shear wall values for 8d nails, and that Number 8 fasteners in 18-ga studs fully develop values for 6d nails. Therefore, target design values were selected which correspond to these nail sizes in Table 1 for the tested panel thickness. The use of these values provided results which would be conservative in a properly designed and constructed shear wall.

TABLE 3.

STAPLED SHEAR WALLS

Staple			Panel			Ultimate Loads (plf)				
Size	Spacing[a] (in.)	Length (in.)	Type	Thickness (in.)	No. of Tests	Min.	Max.	Avg.	Target Design Shear (plf)[b]	Load Factor[c]
STRUCTURAL I										
16 ga	4, 12	1-1/2	Ply	1/2	1			698	280	2.5
	4, 8	1-1/2	Ply	1/2	2	783	888	835	280	3.0
	4, 6	1-1/2	Ply	1/2	1			824	280	2.9
	2, 12	1-1/2	Ply	1/2	1			1290	480	2.7
14 ga	2-5/8, 8	1-1/4	Ply	3/8	1			1345	435	3.1
	1-1/2, 6	2-3/4	Ply	3/8	2	3561	3771	3666	1625[d]	2.3
RATED SHEATHING										
16 ga	4, 8	1-3/8	Ply	5/16	1			606	220	2.8
		1-1/2	Ply	1/2	1			718	255	2.8
	3, 6	1-3/8	Ply	5/16	1			775	285	2.7
		1-1/2	Ply	9/16	1			876	330	2.7
	3, 6	1-3/8	OSB	3/8	2	954	1066	1010	270	3.7
		1-1/2	OSB	3/8	1			854	270	3.2
		2	OSB	3/8	1			903	270	3.3
		1-1/2	OSB	15/32	1			906	330	2.7
		2	OSB	15/32	1			885	330	2.7
		2	OSB	19/32	2	978	1083	1030	365[e]	2.8
15 ga	3, 6	1-1/2	OSB	3/8	1			1128	335	3.4
		1-1/2	OSB	1/2	1			1308	405	3.3
		2	OSB	19/32	1			1423	445[e]	3.2

(a) The first number is the spacing at supported panel edges, the second is the spacing at intermediate framing members.

(b) Refer to the latest edition of National Evaluation Service, Inc. Report NER-272 *(4)* for current code-recognized allowable shear loads for shear walls with wood structural panel sheathing fastened with staples.

(c) The load factor is determined by dividing the average ultimate load by the target design shear.

(d) Double-sided wall.

(e) Design shear is for 15/32" Structural I since values for 19/32" are not included in NER-272.

Target design shears for the steel pins were determined using the principles of mechanics based on the factors shown in the Appendix of this report. Previous testing (7) established lateral fastener values for the pins. These tests determined that the pins are equivalent to 8d common nails when used with a minimum of a 3/8-inch-thick Structural I panel and equivalent to 10d nails when used with 15/32-inch-thick or thicker Structural I panels. The basic design lateral loads for these nail sizes are then increased 25% for the metal side plate (framing member), 30% for nails used in diaphragm construction and 33% for short-term load. An 11% reduction is also applied for use of 2-in. nominal framing.

Most of the walls tested failed prematurely when the end studs buckled or the bottom plate buckled at the buttress of the test fixture due to tearing of the bottom track at the anchor bolts. The tests did not provide a true indicator of the capacity of sheathing panels fastened to framing due to the weakness of the metal framing. Shear walls using metal framing require careful design of the end studs as highly loaded columns, and sufficient anchor bolts to provide for shear transfer from the bottom plate into the foundation or to the diaphragm supporting the wall.

Further tests will be necessary to refine the method of determining design shear.

Double-Sided Shear Walls

Purpose

Occasionally the required design shear cannot be obtained by a conventional single-sided shear wall. Often the most feasible alternative is to apply structural panels to both sides of the wall. The walls tested in this series were sheathed on both sides. These tests provided verification of the current design shear provisions for double-sided shear walls.

Test Results and Discussion

Table 5 summarizes the construction details and results of tests of double-sided walls.

Results from the tests confirm that the present design shear code provisions for double-sided walls are appropriate. All of the double-sided shear walls, except the two walls noted by footnote (d), were fabricated with full 4 x 8-ft panels on both sides. Since the walls were 8 x 8 ft, this means that the panel edge joints on both sides of the wall occurred on the same stud. Good design and construction practice would be to offset the plywood edge joints on one side of the wall from those on the other. The tests, therefore, represent wall construction that is more critical than would normally occur in practice. It should also be emphasized that the walls used 2-in. nominal framing except for the one wall that used 8d nails 2 in. o.c. This one wall used a 3 x 4 for the center stud.

Typical failure of these walls was in compression of the lumber framing where the end studs bore against the bottom and top plates. Double-sided shear walls are capable of developing extremely high loads. The designer should carefully consider column buckling of the end framing members and bearing on the bottom plate in order to transmit these forces in compression to the foundation and in tension to hold-downs. In some cases it may be desirable to stop the plate short of the end studs and allow the end studs to bear directly upon the foundation.

TABLE 4.

SHEAR WALLS WITH STEEL STUDS

Stud Size (ga.)	Fastener Size	Fastener Spacing[a] (in.)	Panel Type	Panel Thickness (in.)	Ultimate Load (plf)	Target Design Shear (plf)	Load Factor[b]	Mode of Failure
STRUCTURAL I								
14	10-24	4, 12	Ply	3/8	1666	360[c]	4.6	Screw pull-through
16	10-24	4, 12	Ply	3/8	1093	360	3.0	Studs buckled
16	10-24	4, 12	OSB	7/16	1248	395	3.2	Studs buckled
18	8-18	6, 12	Ply	3/8	748	200	3.7	
18	8-18	4, 12	Ply	3/8	960	300	3.2	Studs buckled
18	8-18	3, 12	OSB	7/16	1095	390	2.8	Studs buckled
RATED SHEATHING								
14	St. Pin[d]	6, 12	OSB	19/32	1088	365	3.0	Pins overturned
14	St. Pin[d]	4, 12	Ply	5/8	1865	545	3.4	Pins overturned

(a) The first number is the spacing at supported panel edges, the second is the spacing at intermediate framing members.

(b) The load factor is determined by dividing the ultimate load by the target design shear.

(c) Design shear limited by 3/8" panel thickness.

(d) 0.144" dia. x 1-1/4" long pneumatically driven tempered steel pin.

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Compression was particularly severe in the two stapled walls due to the high design shear. Panel movement, allowed by the crushing of the lumber plates, led to localized overloading of the fasteners and premature failure. Failures were ultimately due to the staples pulling through the panels. The staple pull-through may indicate that 3/8-in. plywood is too thin to fully develop the lateral load capacity of a 14-ga staple.

Panels Over Gypsum Sheathing

Purpose

Tests in this series were conducted to verify that accepted design shears for panel sheathing or siding over 1/2-in. gypsum sheathing are applicable to panels applied over 5/8-in. gypsum sheathing. The 5/8-in. thickness is commonly used when walls must be one-hour fire-resistance rated from the outside.

Gypsum wallboard was attached to the framing with minimum fasteners (one at each corner of the 4 x 8-ft panel) to hold it in place while the plywood sheathing was placed. In normal wall construction, the additional nails placed to fasten the gypsum sheathing would add to the strength and stiffness of the wall.

Test Results and Discussion

Recent tests of panel sheathing over 5/8-in. gypsum wallboard, together with previous tests over 1/2-in. gypsum are summarized in Table 6.

Test results confirm that the presently recommended design shears for walls with panels applied over 1/2-in. gypsum sheathing also provide adequate load factors for 5/8-in. gypsum sheathing. These recommendations require the use of nails one size larger for panel sheathing over gypsum sheathing than for sheathing applied directly to the framing.

Effect of Stud Spacing and Stud Width

Purpose

The shear walls tested in this series were to evaluate the effects of stud spacing and stud width on the performance of the shear wall. These tests were included to provide confirmation for recommendations concerning closely spaced nails and for studs 24 in. o.c. in currently published shear wall tables.

Test Results and Discussion

The potential for thin panels buckling under lateral load when used over framing 24 in. o.c. is recognized in the design shears shown in Table 1 for 3/8-in. and 7/16-in.-thick panels. Table 1 allows an increase in the shear values for these thicknesses when the framing is 16 in. o.c., or when panels are applied with their strength axis perpendicular to framing.

Tests comparing identical walls, except for stud spacing, are summarized in Table 7. All shear wall specimens included in the tables were fabricated with the 8-ft panel length parallel to the studs. The panel thicknesses listed are the minimum required for the design shear. Walls fabricated with thicker panels, but with the same nailing and design shear, are included with specimens using the minimum thickness panels.

Accepted design shears for 3/8-in. and 7/16-in.-thick panels are lower for walls fabricated with studs 24 in. o.c. than for identically sheathed walls with studs spaced 16 in. o.c. The similar load factors for tests of walls with the two stud spacings indicate that the reduction in design shears for these thinner panels on widely spaced studs realistically correlates with their test performance.

TABLE 5

DOUBLE-SIDED SHEAR WALLS

Fastener Size	Fastener Type	Fastener Spacing (in.)	Fastener Length (in.)	Panel Thickness (in.)	No. of Tests	Ultimate Loads (plf) Min.	Ultimate Loads (plf) Max.	Ultimate Loads (plf) Avg.	Target Design Shear[b] (plf)	Load Factor[a]
STRUCTURAL I										
6d	Common	6	2	5/16	1			1600	400	4.0
6d	Common	2-1/2	2	5/16	1			2500[c]	900	2.8
8d	Common	3	2-1/2	3/8	1			3010	1100	2.7
8d	Common	2	2-1/2	3/8	1			4250	1460	2.9
14 ga	Staple	1-1/2	2-3/4	3/8	2	3561	3771	3666	1625	2.3
RATED SHEATHING										
8d	Common	3	2-1/2	3/8	2	2418	2471[d]	2445	820	3.0
8d	Common	3	2-1/2	15/32	2	2834	2881[d]	2858	980	2.9

(a) The load factor is determined by dividing the average ultimate load by the target design shear.
(b) Target design shears shown are twice those for single-sided walls of the same construction.
(c) Maximum for test fixture used for wall testing at the time of test, not ultimate for wall.
(d) Edge joints between panels on the two sides offset to different studs.

No reduction in design shear is required for walls sheathed with 15/32-in. and thicker panels. The similar load factors reached in most examples by specimens identical except for stud spacing indicates that the reduction applied due to the thinner panels to compensate for their tendency to buckle between studs is not necessary for panels 15/32 in. and thicker.

Currently recommended design shears require 3-in. nominal lumber at the adjoining panel edges for all nails spaced 2 in. o.c. and for 10d nails spaced 3 in. o.c. when their penetration into the framing lumber exceeds 1-5/8 in. Performance of shear walls in current and past tests was reviewed to verify that this restriction on stud width is necessary. The tests summarizing the effect of stud width and closely spaced nails are presented in Table 8. As in Table 7, the data includes shear walls sheathed with panels greater in thickness than the minimum necessary to develop the design shear.

Test frames using 3-in. nominal center studs used standard 2-in. nominal lumber for top and bottom plates and for both end studs. Observations during the tests indicate that no strength reduction is caused by 2-in. nominal lumber when the entire 2-in. nominal surface is available for attaching the edge of the sheathing panel. Problems with the lumber splitting occur only when two panels are joined over a 2-in. nominal member, and the fasteners are spaced 2 in. o.c. or when full-length 10d nails are spaced 3 in. o.c.

The low load factors for 8d and 10d nails 2 in. o.c. and, in most cases, full-length 10d nails 3 in. o.c. into 2-in. nominal lumber, indicate that this construction should not be recommended. The 3.2 load factor shown in Table 8 for five tests of 10d "short" (2-1/8 or 2-1/4 in. long) nails driven into 2-in. nominal lumber shows that 3-in. o.c. spacing of short nails does not cause strength-reducing splits in the lumber to develop.

TABLE 6

RATED SHEATHING OVER GYPSUM WALLBOARD

Fastener			Panel	GWB		Ultimate Loads (plf)			Target	
Size	Type	Spacing (in.)	Thickness (in.)	Thickness (in.)	No. of Tests	Min.	Max.	Avg.	Design Shear (plf)	Load Factor[(a)]
STRUCTURAL I										
10d	Common	4	3/8	1/2	1			1863	430	4.3
10d	Common	3	3/8	5/8	2	1568	1634	1601	550	2.9
RATED SHEATHING										
8d	Galvanized box	6	3/8	1/2	1			956	200	4.8
8d	Casing	4	3/8	1/2	2	963	1047	1005	210	4.8
8d	Common	3	3/8	5/8	2	1508	1559	1533	390	3.9

(a) The load factor is determined by dividing the average ultimate load by the target design shear.

TABLE 7

EFFECT OF STUD SPACING ON SHEAR WALLS

Stud	Fastener		Panel		Ultimate Loads (plf)			Target	
Spacing (in.)	Size	Spacing (in.)	Thickness[(a)] (in.)	No. of Tests	Min.	Max.	Avg.	Design Shear (plf)	Load Factor[(b)]
STRUCTURAL I									
16	8d	3	3/8	1			1844	550	3.4
24	8d	3	3/8	7	1136	1513	1362	460	3.0
16	10d	3	15/32	1			2222	665	3.3
24	10d	3	15/32	29	1496	2280	1954	665	2.9
RATED SHEATHING									
16	8d	3	3/8	14	1328	1675	1465	490	3.0
24	8d	3	3/8	17	1156	1680	1392	410	3.4
16	10d	3	15/32	1			1901	600	3.2
24	10d	3	15/32	30	1344	1964	1643	600	2.7
16	10d	3	19/32	2	1679	1926	1802	665	2.7
24	10d	3	19/32	16	1396	2165	1865	665	2.8

(a) Minimum panel thickness for design shear, some walls sheathed with thicker panels.
(b) The load factor is determined by dividing the ultimate load by the target design shear.

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Several tests using 2 x 6 studs indicated no significant improvement in split resistance over the use of 2 x 4's. While not tested, two 2 x 4's could be substituted for the 3x or 4x member required for closely spaced nails. This substitution would require that the two members be adequately fastened together to transfer shear forces.

Conclusions

1. Design shears for unblocked shear walls can be determined by applying adjustment factors to the design shear for a similarly constructed blocked shear wall with fasteners 4 in. o.c. at panel edges. When fasteners are spaced 6 in. o.c. along supported panel edges, an adjustment factor of 1/2 for studs 16 in. o.c. and 1/3 for studs 24 in. o.c. provide adequate load factors.

2. Reasonable load factors are obtained when ultimate loads for stapled shear walls are divided by the recommended design shears as published in NER-272.

3. Panel sheathing fastened to metal framing members develops shear wall strength which may be limited by the buckling strength of the metal end studs. Additional testing is necessary before a complete table of shear wall design recommendations can be developed.

4. A shear wall identically sheathed on both sides develops twice the design shear capacity of a wall sheathed on one side.

5. The recommended design shears for panel sheathing or siding over 1/2-in. gypsum sheathing are applicable to panels over 5/8-in. gypsum sheathing.

6. The currently recommended design shear values for thin panels on framing 24 in. o.c., as well as the stud width restrictions for closely spaced nails, are reasonable and should be continued.

TABLE 8

EFFECT OF STUD WIDTH ON SHEAR WALLS

Center Stud Width	Fastener Size	Fastener Type	Fastener Spacing (in.)	Panel Thickness[a] (in.)	No. of Tests	Ultimate Loads (plf) Min.	Ultimate Loads (plf) Max.	Ultimate Loads (plf) Avg.	Target Design Shear (plf)	Load Factor[b]
STRUCTURAL I										
2x[c]	10d	Common	3	15/32	6	1496	2222	1831	665	2.8
3x	10d	Common	3	15/32	24	1685	2280	1996	665	3.0
RATED SHEATHING										
2x[c]	8d	Common	2	3/8	4	938	1363	1156	530	2.2
2x[c]	8d	Common	2	3/8	3	1328	1688	1524	640	2.4
2x	8d	Common	3	3/8	20	1296	1718	1485	490	3.0
2x[c]	10d	Common	2	15/32	1			1586	770	2.1
2x	10d	Short	3	15/32	5	1875	1920	1897	600	3.2
2x[c]	10d	Common	3	15/32	11	1200	1901	1481	600	2.5
3x	10d	Common	3	15/32	5	1598	1964	1823	600	3.0
2x[c]	10d	Common	3	19/32	4	1679	2050	1923	665	2.9
3x	10d	Common	3	19/32	1			1805	665	2.7

(a) Minimum panel thickness for design shear, some walls sheathed with thicker panels.

(b) The load factor is determined by dividing the average ultimate load by the target design shear.

(c) This combination of nail size and/or spacing and lumber width is no longer allowed.

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Note: In 1964, the Douglas Fir Plywood Association was renamed to American Plywood Association. In 1994, the name was changed to *APA – The Engineered Wood Association.*

Appendix A
Summary Of Previous Shear Wall Tests

The tables in this appendix provide a historical record of shear wall tests conducted by *APA – The Engineered Wood Association*. Results are not reported for wall tests where there was a failure of the test fixture, or failures did not involve the sheathing or its fastening to the framing.

A large portion of the walls included in this appendix were tested per FHA Circular 12 *(8)*. Tests to this standard only load the wall to 150 plf on the first load cycle and to 300 plf on the second, prior to the third cycle to ultimate load. This low level of loading can potentially result in higher ultimate loads than are reached when the wall is tested to full design load on the first cycle, and to twice design load on the second cycle. (Standard loads for ASTM E72 *(3)* are also low: 790 lb (99 plf), 1,570 lb (196 plf) and 2,360 lb (295 plf) for the first, second and third cycles of testing.) Most of the walls were tested using the test fixture with vertical hold-down rods as outlined in ASTM E72. Several walls tested per ASTM E564 *(9)* are also included. In this method, the vertical hold-down rods specified in ASTM E72 are replaced with a framing anchor on the doubled end studs.

Table Al presents a summary of tests, combining into a single entry all tests meeting the minimum thickness and grade requirements for a design shear. Table A2 lists the tests by nominal panel thickness and separately lists plywood and nonveneer panels.

TABLE A1

SUMMARY OF APA SHEAR WALL TESTS, NAILS (Common, Short, Duplex or Galvanized Box)

Fastener		Panel	No. of	Ultimate Loads (plf)			Target	Load
Size	Spacing (in.)	Thickness[a] (in.)	Tests	Min.	Max.	Avg.	Design Shear (plf)	Factor[b]
STRUCTURAL I								
6d	6	5/16	9	635	1168	821	200	4.1
8d	6	15/32	2	973	981	977	280	3.5
	4	15/32	1			1539	430	3.6
	3	3/8	7	1136	1513	1362	460	3.0
		7/16	7	1409	1645	1497	505	3.1
		3/8	1			1844	550[c]	3.4
	2	3/8	1			1727	610	2.8
		3/8	2	1650	2109	1880	730[c]	2.6
10d	6	15/32	1			1256	340	3.7
	4	15/32	1			1701	510	3.3
	3	15/32	30	1496	2280	1963	665	3.0
RATED SHEATHING								
6d	6	1/4	18	511	850	695	180	3.9
		3/8	5	535	1076	737	200	3.7
	4	1/4	2	771	790	781	270	2.9
		3/8	2	701	828	764	300	2.5
	3	1/4	12	955	1276	1034	350	3.0
		3/8	7	816	1390	1143	390	2.9
8d	6	3/8	2	600	764	682	220	3.1
		15/32	7	689	1033	913	260	3.5
	4	3/8	1			964	320	3.0
		15/32	2	1155	1155	1155	380	3.0
	3	3/8	17	1156	1680	1392	410	3.4
		7/16	17	1295	1860	1507	450	3.3
		3/8	25	1296	1850	1520	490[c]	3.1
	2	3/8	4	938	1363	1156	530	2.2
		3/8	3	1328	1688	1524	640[c]	2.4
10d	6	15/32	3	780	1048	929	310	3.0
		19/32	1			1134	340	3.3
	4	15/32	3	1277	1881	1526	460	3.3
	3	15/32	31	1200	1964	1651	600	2.8
		19/32	18	1396	2165	1858	665	2.8
		15/32	1			1586	770	2.1

(a) Minimum panel thickness for design shear, some walls sheathed with thicker panels.
(b) The load factor is determined by dividing the average ultimate load by the target design shear.
(c) Design shear increased for "over-thick" panel, studs 16" o.c. or panel placed with length perpendicular to framing.

TABLE A2

DETAILED SUMMARY OF APA SHEAR WALL TESTS, NAILS (Common, Duplex and Galvanized Box)

Fastener		Panel			Ultimate Loads (plf)			Target	
Size	Spacing (in.)	Type	Thickness (in.)	No. of Tests	Min.	Max.	Avg.	Design Shear (plf)	Load Factor[a]
STRUCTURAL I									
6d	6	Plywood	5/16	6	650	950	784	200	3.9
			3/8	1			1168	200	5.8
			7/16	2	635	885	760	200	3.8
8d	6	Plywood	1/2	2	973	981	977	280	3.5
	4		1/2	1			1539	430	3.6
	3		3/8	1			1503	460	3.3
			3/8	1			1844	550[b]	3.4
	2		3/8	1			1727	610	2.8
			3/8	1			2109	730[b]	2.9
			1/2	1			1650	730[b]	2.3
8d	3	Nonveneer	3/8	6	1136	1513	1338	460	2.9
			7/16	7	1409	1645	1497	505	3.0
10d	6	Plywood	1/2	1			1256	340	3.7
	4		1/2	1			1701	510	3.3
	3		15/32	1			2026	665	3.0
			1/2	5	1496	2222	1758	665	2.6
			5/8	1			1929	665	2.9
			23/32	1			1976	665	3.0
	2-1/2		1/2	1			2500	770	3.2
10d	3	Nonveneer	15/32	4	1871	2200	2084	665	3.1
			1/2	5	1685	1921	1829	665	2.8
			5/8	3	1696	2176	1979	665	3.0
			3/4	10	1889	2280	2076	665	3.1
RATED SHEATHING									
6d	6	Plywood	5/16	15	578	850	727	180	4.0
			3/8	5	535	1076	737	200	3.7
	4		3/8	1			828	300	2.8
6d	6	Nonveneer	1/4	3	511	576	536	180	3.0
	4		1/4	2	771	790	781	270	2.9
			3/8	1			701	300	2.3
	3		1/4	2	778	798	788	350	2.3
			5/16	8	955	1199	1041	350	3.0
			11/32	2	1235	1276	1256	350	3.6
			3/8	6	816	1390	1143	390	2.9
			7/16	1			1140	390	2.9
8d	6	Plywood	3/8	2	600	764	682	220	3.1
			19/32	3	950	1033	992	260[b]	3.8
			5/8	4	689	1000	854	260[b]	3.3
	4		3/8	1			964	320	3.0
			1/2	1			1155	380[b]	3.0
	3		7/16	1			1860	450	4.1
			15/32	3	1340	1850	1637	490[b]	3.3
			1/2	4	1424	1718	1575	490[b]	3.2
			19/32	5	1383	1675	1509	490[b]	3.1
	2-1/2		3/8	1			1401	470	3.0
	2		3/8	4	938	1363	1156	530	2.2
				1			1556	640[b]	2.4

(Continued)

TABLE A2

DETAILED SUMMARY OF APA SHEAR WALL TESTS, NAILS (Common, Duplex and Galvanized Box) *(Continued)*

Fastener		Panel			Ultimate Loads (plf)				
Size	Spacing (in.)	Type	Thickness (in.)	No. of Tests	Min.	Max.	Avg.	Target Design Shear (plf)	Load Factor[a]
RATED SHEATHING (cont.)									
8d	4	Nonveneer	1/2	1			1155	380[b]	3.0
	3		3/8	17	1156	1680	1392	410	3.4
			7/16	16	1295	1740	1486	450	3.3
			3/8	1			1346	490[b]	2.7
			7/16	6	1328	1593	1450	490[b]	3.0
			1/2	3	1370	1785	1592	490[b]	3.2
			1/2	2[c]	1484	1546	1515	490[b]	3.1
			5/8	3	1296	1620	1480	490[b]	3.0
	2		3/8	2	1328	1688	1508	640[b]	2.4
10d	6	Plywood	1/2	3	780	1048	929	310	3.0
			5/8	1			1134	340	3.3
	4		1/2	3	1277	1881	1526	460	3.3
	3		15/32	3	1475	1740	1650	600	2.8
			15/32	1[c]			1475	600	2.5
			1/2	8	1375	1913	1657	600	2.8
			19/32	4	1679	2155	1964	665	3.0
	2		1/2	2	1924	2276	2100	770	2.7
10d	3	Nonveneer	15/32	2	1930	1964	1947	600	3.2
			1/2	16	1200	1935	1624	600	2.7
			1/2	1[c]			1629	600	2.7
			19/32	2	2036	2050	2043	665	3.1
			5/8	9	1710	2165	1886	665	2.8
			21/32	2	1515	1628	1572	665	2.4
			3/4	1			1396	665	2.1
			1/2	1			1586	770	2.1

PANEL SIDING

Fastener			Panel			Ultimate Loads (plf)				
Size	Type	Spacing (in.)	Type	Thickness (in.)	No. of Tests	Min.	Max.	Avg.	Target Design Shear (plf)	Load Factor[a]
Double row of nails at panel edge										
6d	Casing	6	Plywood	5/16	1			484	140	3.5
				3/8	1			650	140	4.6
		4		3/8	1			553	210	2.6
				1/2	1			730	210	3.5
				9/16	1			664	210	3.2
		3		3/8	1			659	275	2.4
8d	Casing	6	Plywood	19/32	1			617	160	3.9
Single row of nails at shiplap edge										
6d	Casing	6	Plywood	5/8	1			360	140	2.6
8d	Casing	6	Plywood	5/8	3	400	637	512	140	3.7
		4		5/8	7	627	819	728	210	3.4
6d	Box	6	Nonveneer	7/16	11	585	785	656	150	4.4

(a) The load factor is determined by dividing the average ultimate load by the recommended design shear.

(b) Design shear increased for "over-thick" panel, studs 16" o.c. or panel placed with 8' length perpendicular to framing.

(c) All nails overdriven 1/8".

Appendix B
Calculation Of Design Shears

The building codes allow calculation of diaphragm and shear wall values using the principles of mechanics. Such a calculation involves several factors not shown in the building codes, such as influence of framing lumber width and panel thickness versus nail size. This appendix lists these factors and details the steps required to calculate design shears.

The currently accepted shear wall design values were based on applying a load factor to ultimate loads from tests of actual shear walls. The relationship between the design shears for different nail sizes is based on the relative lateral design values for the nails in the Uniform Building Code at the time the basic shear wall research was conducted. Lateral nail values and their relationships were changed in the 1964 Code; however, the original tabulated values based on tests were never adjusted to accommodate these changes or to make them correlate with the new individual nail design values. As a result, computation of shear wall design loads using currently accepted nail values and the design factors listed in this appendix will give conservative results.

Shear Wall Design Factors

Previous tests of fasteners *(10)*, shear walls *(5)(6)(11)* and diaphragms *(12)(13)(14)(15)* have established the following factors to be used in the calculation of design shears.

1. Plywood containing Species Group 2, 3 or 4 veneer.

a. Design shears are 90 percent of those for Structural I (all-Group 1) panels of the same thickness, for the same nail size and spacing.

b. Design shears are 100 percent of those for Structural I (all-Group 1) panels one size thinner, for the same nail size and spacing, if minimum nail penetration into framing is maintained.

2. Design shears are reduced 11 percent when 2-in. nominal lumber is used.

Framing at adjoining panel edges shall be 3-in. nominal or wider, and nails shall be staggered where nails are spaced 2 or 2-1/2 in. o.c., or where 10d nails having penetration into framing of more than 1-5/8 in. are spaced 3 in. o.c.

Nailing 4 in. o.c. at panel edges of blocked shear walls is used as the "basic" shear to derive the following values for unblocked shear walls.

a. For studs 16 in. o.c., use 50 percent.

b. For studs 24 in. o.c., use 33 percent.

4. Design shears for 3/8-in. panels placed parallel to framing 24 in. o.c., must be reduced 17% to account for panel buckling (8.5% for 7/16-in. panels).

Nail examples

Example No. 1

8d common 3" o.c., 3/8" APA Rated Sheathing, parallel to 2x Douglas fir-larch framing 24" o.c.

71 x 1.1 x 1.6 x 0.89 x 0.90 x 4 x 0.83 = 332 plf

17% reduction for framing 24" o.c.
nails per foot
reduction for non-Structural I Rated Sheathing
11% reduction for 2x lumber
60% increase for wind and seismic, Para. 7.3 & 2.3.2 *(16)*
10% increase for nails used in diaphragm construction, Para. 12.3.6 *(16)*
design lateral load for 8d common nail, Para. 12.3.1 (Mode III_s, controls) *(16)*

Use 330 plf (Recommended shear value in Table 1 is 410 plf)

Example No. 2

10d common 3" o.c., 15/32" APA Rated Sheathing, 3" Douglas fir-larch framing 24" o.c.

88 x 1.1 x 1.6 x 0.90 x 4 = 558 plf

Use 560 plf (Recommended shear value in Table 1 is 600 plf)

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APA – The Engineered Wood Association's 37,000-square-foot Research Center in Tacoma, Washington is the most sophisticated facility for basic panel research and testing in the world. The center is staffed with an experienced corps of engineers, wood scientists, and wood product technicians. Their research and development assignments directly or indirectly benefit all specifiers and users of engineered wood products.

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