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Racking Performance of Light-Frame Walls Sheathed on Two Sides

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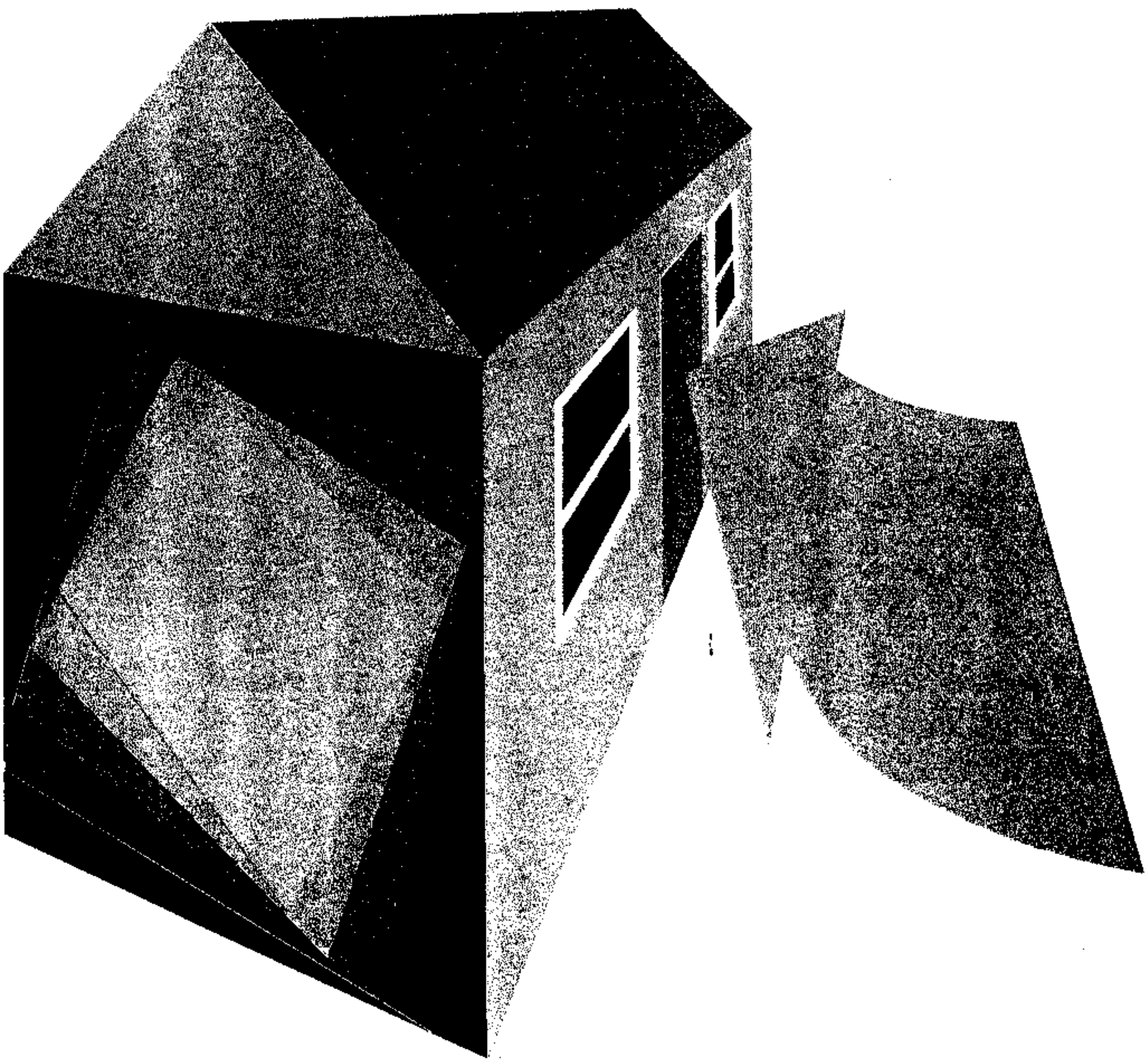

Abstract

Walls in light-frame construction resist in-plane shear forces, known as racking forces, by the interaction of the sheathing diaphragm and wood frame through the fasteners. Wall performance tests provide racking strength for a particular sheathing, fastener and wood frame configuration. Small-scale shear wall tests were conducted to investigate: (1) effect of wall length (aspect ratio) on racking resistance, (2) additive nature of single-sided walls to determine racking resistance of double-sided walls, and (3) relative racking resistance of interior- and exterior-type wall construction. Results to an aspect ratio of 3 indicate strength and stiffness values relate linearly to wall length. Double-sided wall behavior can be predicted by summing single-sided wall values. On the basis of small-scale static tests, interior wall construction (gypsum sheathing) does provide significant racking resistance relative to racking resistance of exterior wall construction (plywood sheathing). This information will be helpful to building designers and code officials to determine racking resistance of shear walls.

Keywords: Walls, light-frame construction, timber construction, shear, fasteners, plywood, gypsum, wall racking.

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Racking Performance of Light-Frame Walls Sheathed on Two Sides

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Introduction

Wood frame buildings are subject to many different types of forces. The resistance to earthquake, wind or other lateral forces acting on light-frame buildings is provided by walls parallel to the load; namely, shear walls. Since these forces tend to distort shear walls, they are often referred to as racking forces.

Shear walls in light-frame timber construction are currently designed based principally on ultimate racking loads measured during performance tests of 8- by 8-foot walls (American Society for Testing and Materials 1976, 1977; Federal Housing Administration 1949; U.S. Department of Housing and Urban Development (HUD) 1973). Racking strength is obtained from these tests for a single layer of sheathing attached to a wood stud frame. Occasionally, shear walls in light-frame structures are longer than 8 feet and are sheathed on both sides. These walls may consist of both plywood and gypsum sheathing (e.g. exterior walls) or gypsum wallboard on both sides of the frame (e.g. interior walls). Only limited data are available on racking strength of wood frame walls longer than 8 feet (Easley et al. 1982; Kamiya et al. 1981; Wolfe 1983), or walls with sheathing on both sides (lizuka 1975; Tuomi and McCutcheon 1975). Additionally, the racking resistance of interior gypsum-sheathed walls is often neglected in design because the combined behavior of sheathings with different stiffnesses is unknown.

This study investigates length effects (aspect ratio) and additive nature of one-sided walls (sheathings and wood frame) to predict behavior of double-sided shear walls. A comparison is made between racking resistance of exterior-type wall panels, e.g. plywood and gypsum sheathing, and interior wall panels, e.g. gypsum both sides.

Wall panels used in racking tests ideally represent behavior of shear walls in a structure. In this paper the terms “wall panel” and “wall” refer to wall test panels evaluated in wall racking tests, and “shear wall” refers to the walls in a structure which resist lateral loads.

Plywood and gypsum sheathing were chosen for this study as typical shear wall components in light-frame timber structures. Four aspect ratios and five wall configurations were tested in a small-scale racking test frame. No attempt was made to correlate small-scale test results to the 8- by 8-foot standard wall racking test (ASTM 1977; FHA 1949). However, several researchers (Price and Gromala 1980; Tuomi and McCutcheon 1975; Tuomi and Gromala 1977) have used a similar small-scale test.

Results include comparisons of racking strength and stiffness obtained from tests on wall panels with aspect ratio between 1 and 3. Furthermore, double-sided shear wall panel behavior is predicted by the sum of two single-sided walls. For comparison, the interior gypsum wall panel is presented as a percentage of the racking resistance of exterior plywood wall panels.

These results should be helpful to building designers and code officials to determine racking resistance of shear walls.

Background

Wall racking research has centered on predicting the behavior of the standard 8- by 8-foot wall panel (ASTM 1976, 1977; FHA 1949; HUD 1973) either by empirical models (Neisel and Guerrera 1956; Neisel 1958; Welsch 1963) or analytical models (Burgess 1976; Easley et al. 1982; Hirashima 1981; lizuka 1975; Kamiya 1981; 1951; Suzuki et al. 1978; Tuomi and McCutcheon 1978; Walker 1979) relating fastener behavior to wall racking behavior. The 8- by 8-foot wall panel behavior is then extended to the design of one- and two-sided shear walls of various lengths in light-frame structures.

Kamiya et al. (1981) examined effects of test methods and wall length on racking resistance. They concluded racking load was proportional to wall length at deformation levels below failure, and load per unit wall length increased with wall length at ultimate load. Plywood-sheathed (one-side) wall panels with aspect ratios between 113 and 2 were included in their study. Wolfe (1983) tested wall panels with one-side gypsum sheathing having a range of aspect ratios between 1 and 3. He noted an increase in racking load per foot of wall length for longer walls at deformation levels below ultimate. However, racking load was proportional to wall length at ultimate load. Wolfe used the model developed by Tuomi and McCutcheon (1978) to predict the racking strength of various length walls with continuous gypsum sheathing. The model predicted an increase in racking strength per foot of wall length for longer walls with continuous sheathing.

The Uniform Building Code (International Conference of Building Officials 1982) provides racking load values per foot of wall length for shear walls with either plywood or gypsum sheathing, implying racking resistance varies linearly with wall length.

When gypsum and plywood sheathing are used together in a shear wall, the racking resistance of the gypsum is often ignored. However, tests by Tuomi and McCutcheon (1975) indicate additional individual layers in a wall panel increase the stiffness of the wall compared to the stiffness of a single layer of plywood sheathing. lizuka (1975) compared double-sided wall panels to the strength and stiffness of singlesided walls with various sheathing types. He concluded the strength and stiffness of a double-sided wall panel is less than the sum of two single-sided wall panels.

Additional verification is needed to examine the application of current wall racking knowledge to longer walls, and to walls with sheathing on both sides.

Materials and Methods

Smaller test wall panels, 22 inches high, were used in this study because of the expense and time involved in full-scale testing. Walls 2, 4, 6, and 8 feet in length resulted in aspect ratios of approximately 1, 2, 3, and 4.

No attempt was made to scale framing, sheathing materials, or connectors. Therefore, the test wall panels were expected to be stiffer than configurations in which all quantities were scaled down. However, only relative stiffness and strength of each wall was needed to compare one-sided to two-sided sheathed walls, and to study the influence of wall length on racking resistance. Small wall panels provided adequate data for these comparisons.

Wall Construction

Test walls represent materials typically found in light-frame structures. C-D exterior (C-D EXT), 1/2-inch plywood, 1/2-inch gypsum wallboard and Douglas-fir lumber were used (table 1).

Five test wall configurations and four lengths (2-, 4-, 6-, and 8-foot) of each were included in this study for a total of 20 wall types. Ten repetitions of each wall type and length provided a measure of statistical variability. Wall types were: plywood one side; plywood two sides; gypsum one side; gypsum two sides; and mixed wall with plywood one side, gypsum one side.

All test walls were assembled and stored indoors 1 month before testing. Wall frames were constructed of nominal 2- by 4- inch top and bottom plates with studs at 12-inch spacing using 10d common wire nails.

Each 4- by 8-foot plywood panel was cut into 12- by 22-inch panels and attached to the wall frame with 8d common wire nails leaving a 1/8-inch gap between each panel. Thus, panels could rotate independently (i.e. without bearing or sliding against adjacent panels) during racking deformation of the wall.

Fastener spacing was 5-1/4 inches vertically, and ranged between 5-1/2 to 6 inches horizontally, for connectors in both plywood and gypsum walls. Typical wall construction is shown in figure 1.

Past research (Wolfe 1983) suggests the taping and spackling treatment of joints between adjacent gypsum panels provides the structural equivalent of a continuous gypsum diaphragm under racking load (fig. 2). Therefore, a single sheet of gypsum sheathing was attached to the wood frame as a continuous panel running the entire length of the wall. Connections between gypsum sheathing and wall frame were 1-1/4-inch drywall screws.

Table 1.--Sheathing and framing materials for wall racking study

Framing	Standard and better Douglas-fir - used in plywood one side, plywood two sides, and gypsum-plywood walls
	Standard and better Douglas-fir-Larch - used to construct some of the gypsum one-side and gypsum two-side walls
	20 samples of lumber had an average moisture content of 9.4 percent and average specific gravity of 0.45
Sheathing	
Plywood	1/2-inch 4-ply Douglas-fir plywood-grade C-D exterior (C-D EXT), face grain of plywood was horizontal on test walls (22- by 12-in. panels)
Gypsum	1/2-inch gypsum wallboard manufactured to conform to ASTM C36
Fasteners	
Plywood	8d common wire nails
Gypsum	1-1/4-inch drywall screws
Framing	10d common wire nails

Gypsum sheathing is manufactured with two edges confined by the cover paper and two edges unconfined. Additionally, the cover paper is stronger in the long direction of the panel than in the cross direction. The gypsum panels used in this study were cut from larger gypsum sheets such that all four edges were unconfined by the paper covering. The strong direction of the paper covering was oriented with the long dimension of the test walls. This would correspond to gypsum sheathing placed horizontally in full-size walls.

Wall Racking Test Frame

Figure 3 illustrates the test frame which applied essentially a "pure shear" load on the wall. The steel racking test frame was similar to the one Price and Gromala (1980) used. Pins at the ends of the frame members allowed the bottom frame member to move freely in the horizontal direction. Some vertical displacement occurred due to the circular motion of the test frame corners, but the bottom of the test specimen remained essentially parallel to the fixed top-frame member. Thus, the wall framing was forced to deform as a parallelogram. The overturning problems (i.e. vertical studs pulling away from the sole plate) encountered in full-size ASTM racking test procedures did not occur. Shortening of the distance between the top and bottom members was insignificant considering the small horizontal displacements taking place.

The center of gravity of the nonsymmetric one-sided wall or a two-sided wall with dissimilar materials was not at the geometric center of the wall thickness. Because all walls were loaded at the geometric center of the wood frame's bottom plate, the point of load did not coincide with the center of gravity of the nonsymmetric walls. Walls were held in the steel test frame by steel pins through the wood frame's top and bottom plates, to prevent out of plane motion resulting from the slightly eccentric load. This method of restraint also allowed sheathing to rotate (fig. 2) without bearing against the steel test frame.

Instrumentation and Conduct of Test

Horizontal wall displacement was measured using a diagonally mounted continuous linear variable differential transformer (LVDT) with an accuracy of 0.01 inch. Horizontal deformation can be related to either shortening of the compression diagonal, or lengthening of the tension diagonal. Shortening of the compression diagonal was measured on the 8-foot walls with a single layer of plywood or gypsum. Lengthening of the tension diagonal was measured on the remainder of the walls.

Racking tests were conducted at a constant horizontal displacement rate of 0.2 inch per minute. Load cell capacities were 2,500, 5,000, 10,000, or 20,000 pounds corresponding to the different sheathing types and wall lengths. Load cells provided an accuracy of ± 1 percent of the full range.

An X-Y plotter recorded racking load versus diagonal displacement of walls. Walls were loaded to failure load (maximum load) or 2 inches diagonal displacement, whichever occurred first. Only three walls reached the displacement limit.

Lateral Nail Tests

Lateral load tests were conducted on the fasteners and sheathings according to ASTM D 1761-74 (ASTM 1974) using samples cut from the walls after testing. All fastener tests loaded the wood frame member parallel to the wood grain. A 314-inch sheathing edge distance corresponded with the diagonal corner distance of connectors in the wall tests (fig. 1). Plywood lateral nail test specimens were the standard 2-inch width, but gypsum specimens were 4-112 to 5 inches wide forcing failure to occur at the screw rather than a gross section failure. Load rate was the standard 0.1 inch per minute. Both digital and X-Y load-slip data were recorded.

Lateral load resistance of fasteners in gypsum wallboard is increased by cover paper confining the loaded edge of the panel (Wolfe 1983). The edge of the gypsum fastener test specimen was similar to edges of gypsum test wall panels and was not confined by cover paper. Face grain of the plywood could be placed either parallel or perpendicular to the load. Plywood tests were conducted for both cases.

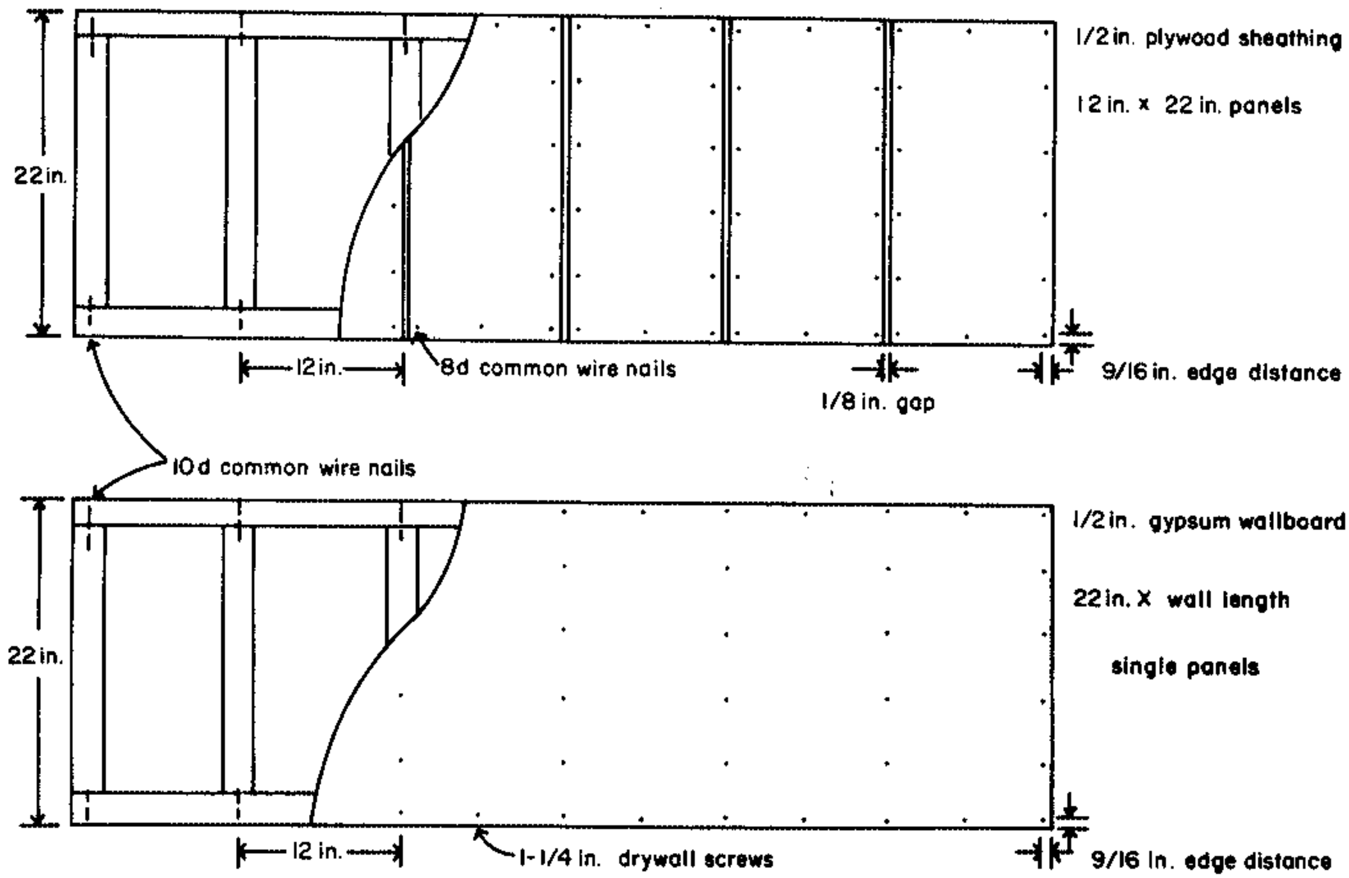

Figure 1.--Typical wall construction used in wall racking test (6-foot wall used for illustration). (ML84 5245)

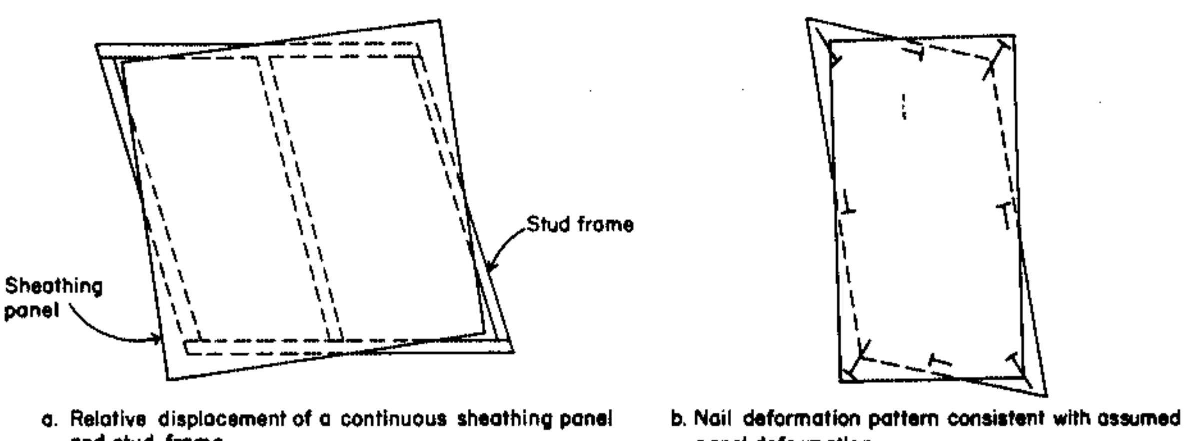

Figure 2.--Nail deformation pattern during wall racking tests. (ML84 5246)

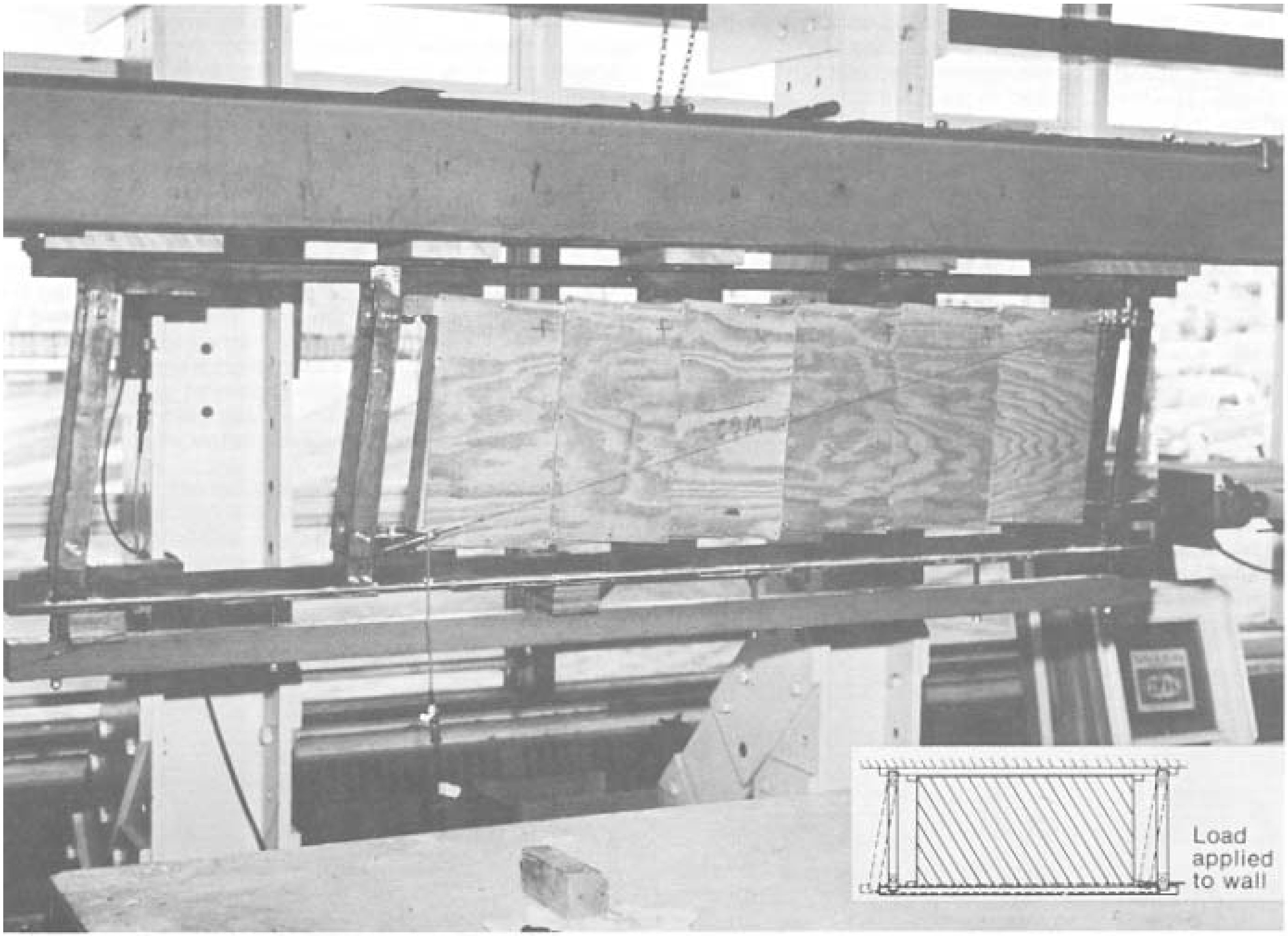

Figure 3.--Test apparatus for wall racking tests. Test panel is 2 feet high by 6 feet long. Racking load is applied at lower right corner of frame. (M153003-11)

Data Analysis

The load-displacement relationships obtained for the one-sided 8-foot-long gypsum and one-sided 8-foot-long plywood sheathed walls were not included in this study. The method used to measure displacements on these two data sets was different, and determined to be less dependable than the procedure used on the other 18 data sets. For consistency, only tension diagonal measurements were compared below failure for the 18 remaining data sets. However, failure load was not a function of displacement measurements, and all 20 data sets were evaluated at failure load.

To evaluate relative stiffness of the various sets of test walls, a curve was statistically fit to data from the 10 walls in each series. The curve fit was terminated at the start of a failure load plateau. A fourth-order polynomial was fit using a least squares fit in "Y" load. R-squared values for these polynomials ranged from 0.89 to 0.99.

Polynomial expressions for each wall type and length were integrated to determine energy versus displacement relationships which are contained in Appendix A. This information is important for earthquake-resistant design of light-frame structures.

Results and Discussion

Comparisons of results between all wall types and lengths are made using points from the polynomials representing each set of 10 walls. Average values of ultimate load and ultimate load per foot of wall length for all test-wall types and lengths are listed in table 2. Test values ranged from a low of approximately 300 lb/ft for single-sided gypsum walls, to a high of approximately 1,500 lb/ft for double-sided plywood walls. Coefficients of variation on ultimate load were 3 to 5 percent.

Load versus horizontal deformation data are plotted for the 10 walls tested with plywood sheathing attached to one side of a 4-foot-long wood frame (fig. 4). Similar plots for other wall types and lengths appear in a separate data report (Patton-Mallory et al. 1983). Figure 4 exhibits the nonlinear load-deformation behavior and variability representative of all data sets.

Figure 5 is a representative data set with the polynomial plotted over the data shown in figure 4. Similar plots for other wall types and lengths are reported in the data report (Patton-Mallory et al. 1983).

Fastener load-slip behaviors for the gypsum sheathing, plywood sheathing, and fasteners used in this study are contained in Appendix B.

Table 2.--Ultlmate racking resistance for five wall types and four lengths

Wall configuration	2 feet[1]		4 feet[1]		6 feet[1]		8 feet[1]	
	Ultimate load	Ultimate load per foot of length	Ultimate load	Ultimate load per foot of length	Ultimate load	Ultimate load per foot of length	Ultimate load	Ultimate load per foot of length
	Lb	*Lb/ft*	*Lb*	*Lb/ft*	*Lb*	*Lb/ft*	*Lb*	*Lb/ft*
Plywood one side	1,580 (75)[2]	790	2,900 (150)	725	4,200 (170)	700	5,500 (260)	690
Plywood two sides	3,000 (160)	1,500	5,600 (240)	1,400	8,400 (250)	1,400	10,600 (300)	1,325
Gypsum one side	600 (30)	300	1,325 (60)	330	1,975 (80)	330	2,250 (110)	280
Gypsum two sides	1,150 (60)	575	2,700 (90)	675	3,900 (90)	650	4,700 (200)	590
Plywood/gypsum	2,025 (90)	1,010	4,050 (190)	1,010	5,800 (165)	970	7,600 (350)	950

[1]Wall length.

[2]Standard deviation of ultimate load in parentheses.

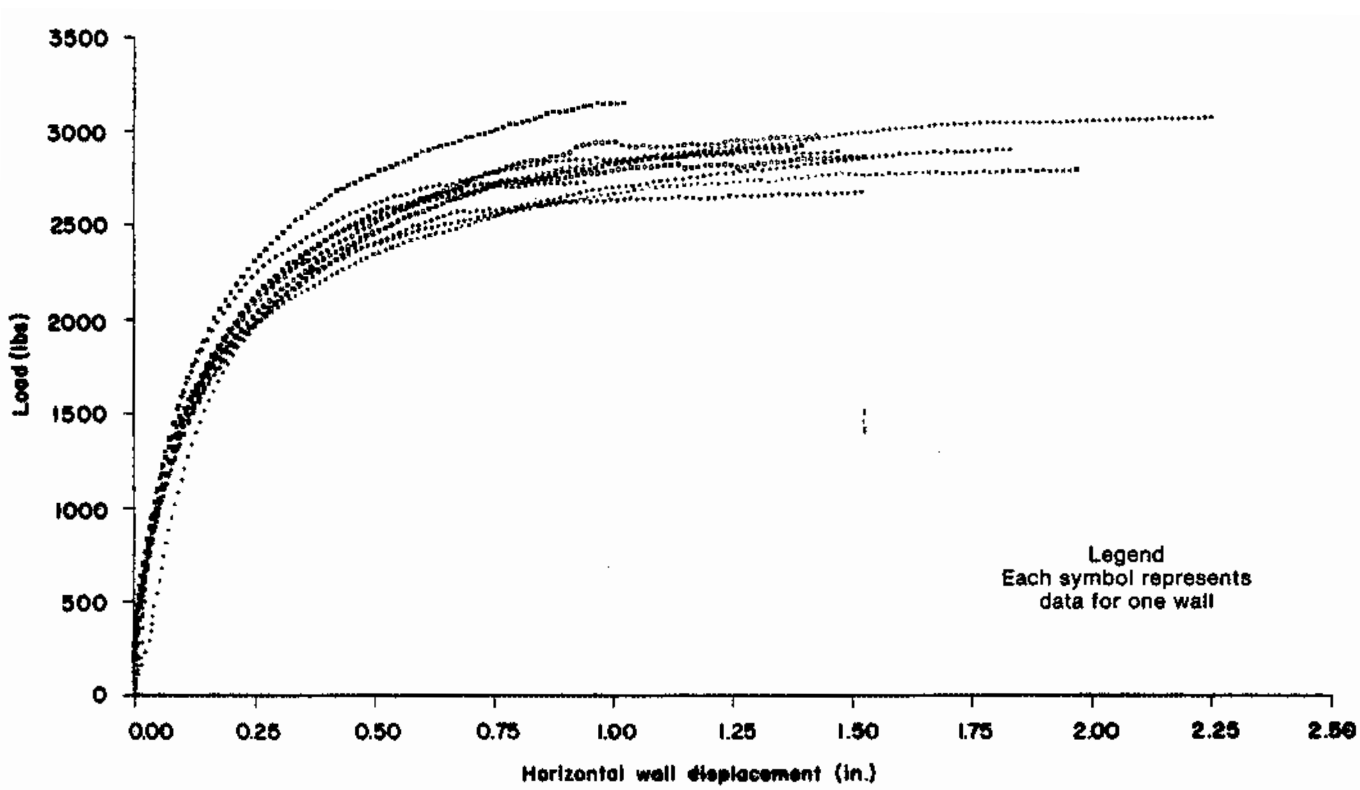

Figure 4.--Load versus horizontal wall displacement for 10 plywood one-sided walls 4 feet in length. (ML84 5247)

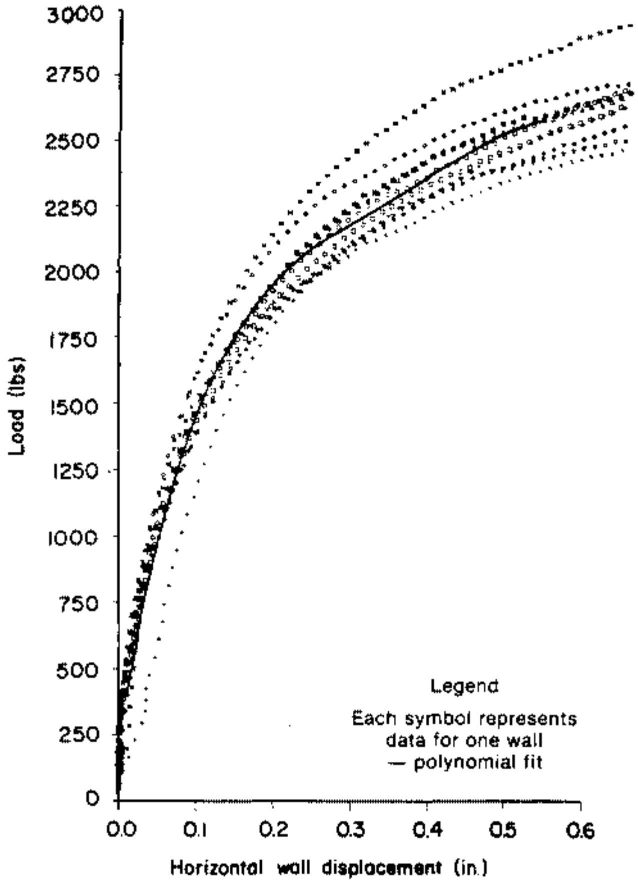

Figure 5.--Loadversus horizontal wall displacement for 10 plywood one-sided walls 4 feet in length with polynomial fit. Points from polynomials are used to compare wall types and lengths. (ML84 5248)

Wall Length

One objective of this study was to investigate the effect of wall length on racking resistance. (Published wall racking values are based on the ASTM test wall which has an aspect ratio of 1.)

Racking load versus wall length is plotted in figures 6 through 10. Ultimate load, 0.25-inch deformation, and 0.10-inch deformation are compared for all five wall types.

Plywood-sheathed wall data (figs. 6 and 7) were fit with a straight line relationship between racking load and wall length. Two-foot-long wall data from tables 3 and 4 predicted average 4-, 6-, and 8-foot-long wall racking load to within 18 percent error. Eight-foot wall data predicted 2-, 4-, and 6-foot-long wall racking loads with errors less than 23 percent.

Gypsum-sheathed wall data (figs. 8 and 9) could not easily be fit with a straight line relationship. The relationship between wall length and racking load was nonlinear. However, 2-foot-long wall data predicted average 4-, 6-, and 8-foot-long wall racking loads with errors less than 15 percent. Eight-foot wall data predicted 2-, 4-, and 6-foot racking loads with errors less than 15 percent.

Double-sided plywood-gypsum wall data (fig. 10) were fit with a straight line relationship between racking load and wall length. Two-foot-long wall data predicted average 4-, 6-, and 8-foot-long wall racking loads with errors less than 9 percent. Eight-foot wall data predicted 2-, 4-, and 6-foot-long wall racking loads with errors less than 13 percent.

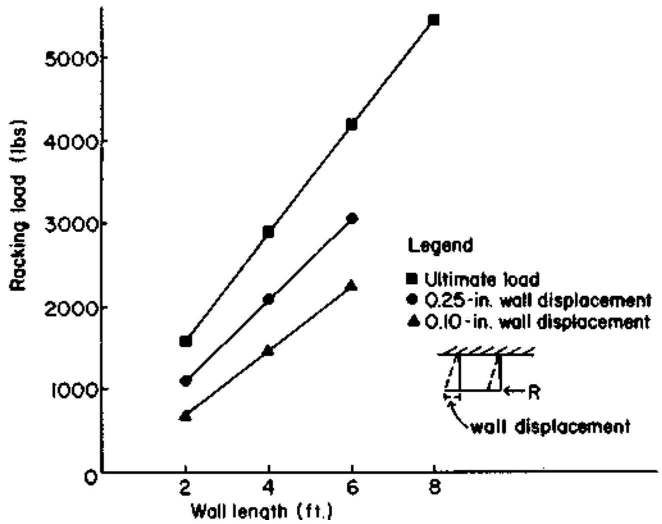

Figure 6.--Racking load versus wall length for single-sided plywood-sheathed walls at 0.10-, 0.25-inch horizontal wall displacements and at ultimate load. (ML84 5249)

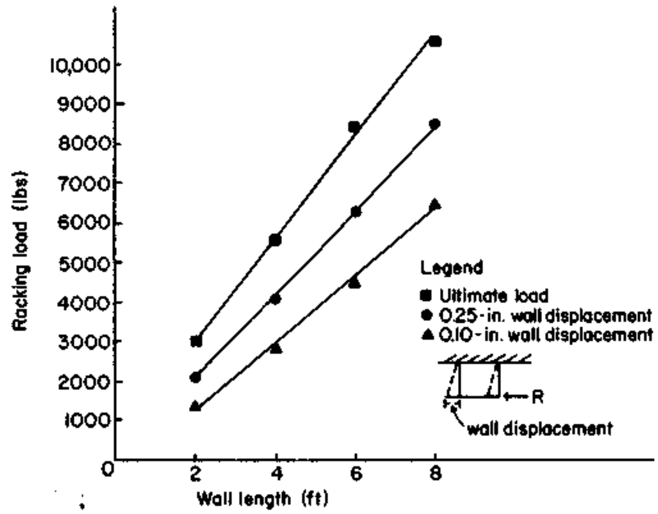

Figure 7.--Racking load versus wall length for double-sided plywood-sheathed walls at 0.10-, 0.25-inch horizontal wall displacements and at ultimate load. (ML84 5250)

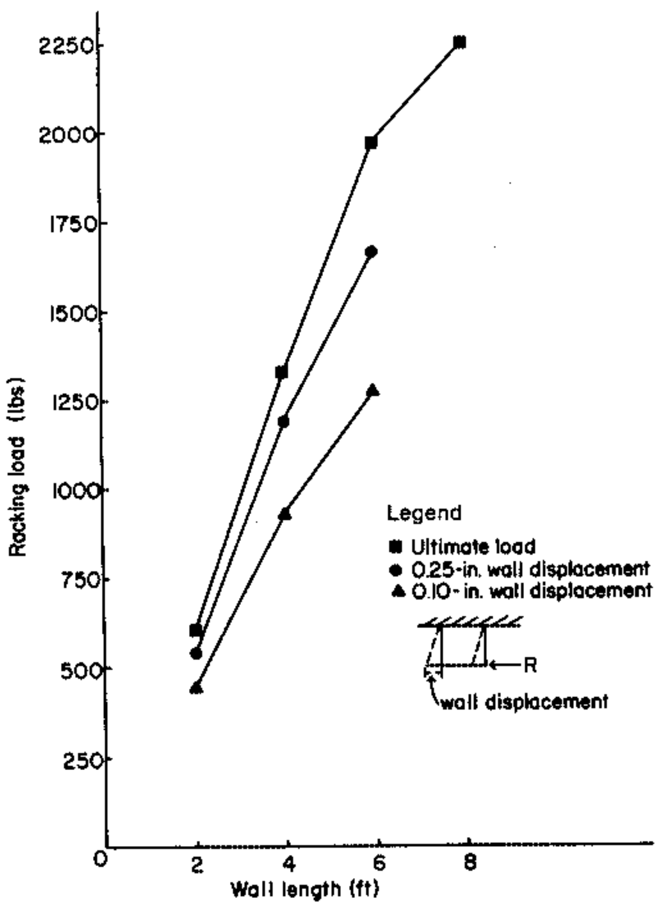

Figure 8.--Racking load versus wall length for singlesided gypsum-sheathed walls at 0. 10-, 0.25-inch horizontal wall displacements and at ultimate load. (ML84 5251)

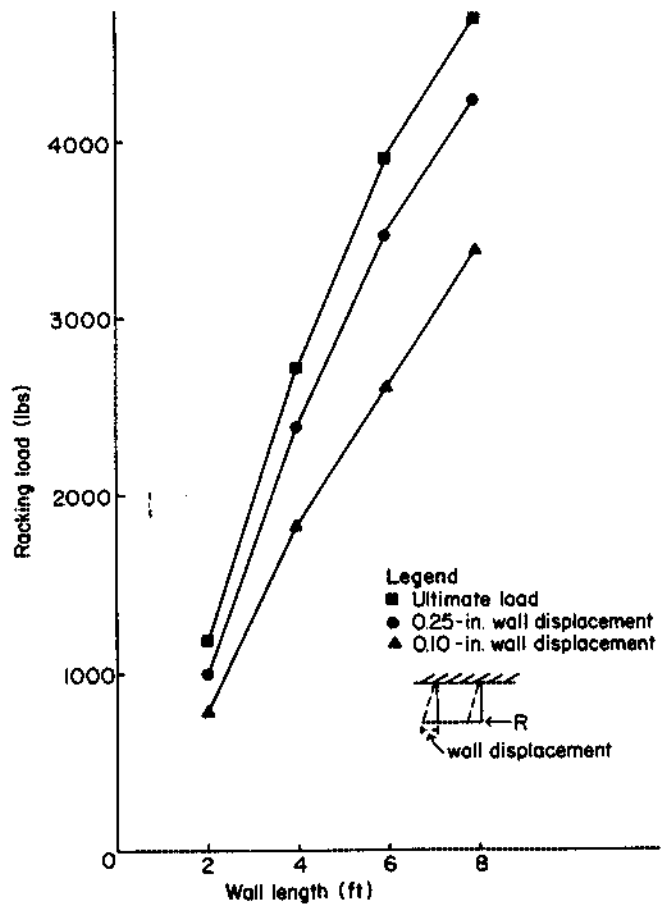

Figure 9.--Racking load versus wall length for double-sided gypsum-sheathed walls at 0.10-, 0.25-inch horizontal wall displacements and at ultimate load. (ML84 5252)

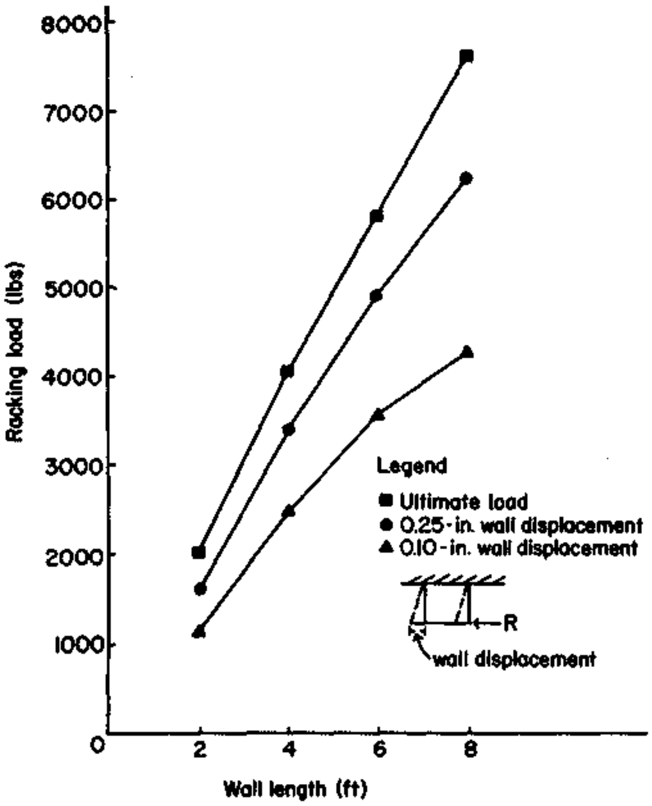

Figure 10.--Racking load versus wall length for double sided plywood-gypsum walls at 0.10-, 0.25-inch horizontal wall displacements and at ultimate load. (ML84 5253)

Two-Sided Walls

A second objective of this study was to determine if the performance of a wall with sheathing on two sides is simply the sum of the strengths and stiffnesses of individual single-sided walls tested separately. Additionally, differences between results obtained in single- and double-sided wall tests were studied in an attempt to better define the racking resistance contributed by the wood frame.

Tables 3 and 4 compare the racking loads resisted by double-sided walls to the sum of loads resisted by the two single-sided walls tested individually. The ratios of double- to single-sided wall racking resistance at various displacement levels and at failure are contained In the last column for each sheathing type. The ratio being nearly equal to 1.0 indicates stiffness and strength of single-sided walls and appears to be directly additive for predicting behavior of double-sided walls. This simple addition neglects racking contribution of the wood frame.

Table 3.--Predictingthe load resisted by two-sided walls from one-sided wall data: plywood and gypsum sheathing

Sheathing type	Length	Displace ment	Wall 1, 1-sided	Wall 2, 2-sided	Wall 21 (wall 1) X2	Sheathing type	Length	Displace. ment	Wall 1, 1-sided	Wall 2, 2-sided	Wall 2/ (wall 1) X2
	Ft	*In.*	*Lb*	*Lb*			*Ft*	*In.*	*Lb*	*Lb*	
Plywood	2	0.05	450	860	0.95	Gypsum	2	0.05	330	550	.83
		.10	690	1,310	.95			.10	440	770	.88
		.25	1,070	2,080	.97			.25	540	990	.92
		failure	1,580	3,000	.95			failure	600	1,150	.96
Plywood	4	.05	950	1,790	.94	Gypsum	4	.05	680	1,350	.99
		.10	1,440	2,770	.96			.10	930	1,810	.97
		.25	2,080	4,060	.98			.25	1,190	2,380	1.00
		failure	2,900	5,600	.97			failure	1,325	2,700	1.02
Plywood	6	.05	1,550	2,950	.95	Gypsum	6	.05	870	1,840	1.06
		.10	2,260	4,490	.99			.10	1,240	2,610	1.05
		.25	3,040	6,250	1.03			.25	1,660	3,460	1.04
		failure	4,220	8,400	1.00			failure	1,975	3,900	.99
Plywood	8	failure	5,500	10,600	.96	Gypsum	8	failure	2,250	4,700	1.04

Table 4.--Predicting the load resisted by two-sided walls from one-sided wall data: plywood-gypsum sheathing

Sheathing type	Length	Dis- place- ment	One Skin		Wall 1 plus wall 2	Wall 3, plywood- gypsum	Wall31 wall1 plus wall 2
			Wall 1 plywood	Wall 2 gypsum			
	Ft	In.	Lb	Lb	Lb	Lb	
Plywood-gypsum	2	0.05	450	330	780	760	0.97
		.10	690	440	1,130	1,130	1.00
		.25	1,070	540	1,610	1,590	.99
		failure	1,580	600	2,180	2,025	.93
Plywood-gypsum	4	.05	950	680	1,630	1,730	1.06
		.10	1,440	930	2,370	2,470	1.04
		.25	2,080	1,190	3,270	3,400	1.04
		failure	2,900	1,325	4,225	4,050	.96
Plywood-gypsum	6	.05	1,550	860	2,410	2,560	1.06
		.10	2,260	1,240	3,500	3,560	1.02
		.25	3,040	1,660	4,700	4,900	1.04
		failure	4,220	1,975	6,195	5,800	.94
Plywood-gypsum	8	failure	5,500	2,250	7,750	7,600	.98

Interior Walls (Gypsum Sheathing) Versus Exterior Walls (Plywood Sheathing)

A comparison of racking resistance of interior and exterior wall panels is given in table 5. Interior wall panels with a single- or double-sided sheathing of gypsum are proportioned as a percentage of the racking resistance provided by an exterior wall panel consisting of either a single layer of plywood or mixed (plywood and sheathing gypsum) in a double-sided wall. Also, the increase in an exterior wall panel's racking resistance due to including gypsum sheathing is compared to a single-sided plywood sheathing.

An interior wall panel with a single side of gypsum sheathing resists 38 to 64 percent of the racking resistance provided by single-sided plywood exterior wall panels, and 30 to 39 percent of the racking resistance provided by double-sided plywood-gypsum exterior wall panels (table 5). Interior wall panels with gypsum on two sides resist 57 to 67 percent of the racking resistance provided by doublesided plywood-gypsum exterior wall panels.

Table 5.--Comparing racking resistance of interior type versus exterior type wall panels. Interior wall panels are proportioned as a percentage of the racking resistance provided by exterior wall panels. Gypsum sheathing's contribution to exterior type wall panels is also included

Wall type	Dis-place-ment	Wall length (ft) 2	4	6	8
	In.	(Percent strength of exterior walls)			
Exterior wall: plywood-gypsum Interior wall: gypsum one side	0.10	39	38	35	
	.25	34	35	34	
	failure	30	33	34	30
Exterior wall: plywood-gypsum Interior wall:' gypsum-two sides	.10	68	73	73	
	.25	62	70	71	
	failure	57	66	67	62
Exterior wall: single side plywood Interior wall: gypsum one side	.10	64	65	55	
	.25	50	57	55	
	failure	38	45	47	41
Exterior wall: plywood-gypsum Interior wall: gypsum two sides	.10	112	126	115	
	.25	93	114	114	
	failure	74	92	92	85
Exterior wall: single side plywood versus Exterior wall: plywood-gypsum	.10	164	172	158	
	.25	149	163	161	
	failure	129	139	137	137

Including the racking resistance of gypsum sheathing in exterior plywood-gypsum wall panels results in 29 to 72 percent increase in racking resistance compared to single-sheathed plywood exterior wall panels.

Wall Deformation Patterns

Qualitatively, nail deformation patterns of plywood-sheathed walls at failure were consistent with the assumed behavior shown in figure 2. The nail pattern is essentially identical in each of a series of 2-foot panels. The nearly linear load versus wall length relationship (figs. 6 and 7) suggests the racking load is equally distributed along the length of the wall; i.e., each panel resists nearly the same shear force. The racking resistance predicted from walls with an aspect ratio of 1 gave a good estimate of performance of longer walls.

Walls with gypsum sheathing exhibit some nonlinearities comparing load versus wall length, as expected. Gypsum sheathing was attached as one continuous panel, therefore the nail deformation pattern changes with wall length. Directions of nail forces (or deformations) were not measured, although visual observations were made. The 2- and 4-foot-long gypsum walls followed the symmetric fastener deformation patterns illustrated in figure 2, while the 6-and 8-foot-long gypsum walls exhibited a nonsymmetric fastener deformation pattern.

Typical failure observed in 6- and 8-foot-long gypsum walls was a shearing of all fasteners along the top or bottom edge of the panel. The fasteners on the opposite edge exhibited less deformation than occurred in the failed fasteners. The deformation pattern at failure was not symmetric about the geometric center of the sheathing panel. These two sources of geometric changes in the fastener deformation pattern, as aspect ratio of the wall increases, may be the reason for nonlinear racking resistance versus wall length relationships for wall panels containing gypsum sheathing. However, the racking values predicted from the gypsum walls with an aspect ratio of 1 gave a reasonable approximation of longer wall performance.

Conclusions

Small-scale wall racking tests were used to study aspect ratio (length effects), additive nature of individual sheathings in double-sided shear walls, and the contribution of gypsum sheathing to shear wall behavior. Results of racking tests indicate:

(1) Strength and stiffness per foot of wall length obtained on walls with an aspect ratio of 1 gave reasonable predictions of wall behavior to an aspect ratio of 3. Racking resistance of plywood-sheathed walls appeared to be directly proportional to wall length; racking resistance of gypsum-sheathed walls was not directly proportional to wall length but could be estimated by a linear relationship.

(2) Double-sided shear wall behavior was predicted by the sum of individual single-sided wall racking behavior. Both ultimate load and deformation levels below ultimate load were considered. No racking resistance of the wood frame could be isolated from test data.

(3) Single-gypsum sheathing provides at least 38 percent of the racking resistance of single plywood sheathing in small-scale tests. Double-gypsum sheathing (representing interior walls) provides at least 57 percent of the racking resistance of double-sided plywood-gypsum walls (representing exterior walls).

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Appendix A

Energy absorption of shear walls is important for earthquake-resistant design. Energy absorption is determined by the area under load versus deformation curves. Although outside the scope of this study, these data are included for the test walls in future studies.

Plywood wall load versus displacement curves were integrated up to 0.40-inch wall displacement. The gypsum and plywood-gypsum data were integrated up to 0.25-inch displacement.

Double-sided wall energy absorption is predicted from the sum of single-sided walls in tables A-1 and A-2.

Energy absorption (tables A-1 and A-2) versus wall length can be plotted at particular horizontal displacements similar to figures 6 through 10 (Patton-Mallory et al. 1983). The resulting plots indicate energy absorption is proportional to wall length for all small-scale wall configurations included in this study.

Table **A-1.--Comparing energy of one-sided versus two-sided walls at displacements below failure: plywood sheathing and gypsum sheathing**

Sheathing type/length	Dis- place ment	Wall 1, 1-sided	Wall 2, 2-sided	Wall 2/ (wall 1) X2	Sheathing type/length	Dis- place ment	Wall 1, 1-sided	Wall 2, 2-sided	Wall 21 (wall 1)X2
	In.	*Lb-in.*	*Lb-in.*			*In.*	*Lb-in.*	*Lb-in.*	
Plywood	0.05	15	28	0.93	Gypsum	.05	11	17	.77
2-foot	.10	44	83	.94	2-foot	.10	30	51	.85
	.15	83	158	.95		.15	54	92	.85
	.20	129	247	.96		.20	78	138	.88
	.25	181	347	.96		.25	104	186	.89
Plywood	.05	30	55	.92	Gypsum	.05	21	43	1.02
4-foot	.10	90	171	.95	4-foot	.10	63	124	.98
	.15	171	326	.95		.15	112	220	.98
	.20	263	507	.96		.20	166	325	.98
	.25	365	704	.96		.25	224	439	.98
Plywood	.05	50	90	.90	Gypsum	.05	26	57	1.10
6-foot	.10	146	280	.96	6-foot	.10	80	170	1.06
	.15	271	529	.98		.15	147	311	1.06
	.20	410	813	.99		.20	221	468	1.06
	.25	560	1,117	1.00		.25	302	637	1.05

Table A-2.--Comparing energy of one-sided versus two-sided walls at displacements below failure: plywood-gypsum sheathing

Sheathing type/length	Displacement	Wall 1	Wall 2	Wall 3	Wall 4	Wall 4/ Wall 3
		Plywood-1 sided	gypsum 1-sided	Wall 1 plus wall-2	Measured plywood-gypsum	
	In.	*Lb-in.*	*Lb-in.*	*Lb-in.*	*Lb-in.*	
Plywood-gypsum	0.05	15	11	26	24	0.92
2-foot	.10	44	30	74	72	.97
	.15	83	54	137	135	.99
	.20	129	78	207	206	1.00
	.25	181	104	285	283	.99
Plywood-gypsum	.05	30	21	51	53	1.04
4-foot	.10	90	63	153	160	1.05
	.15	171	112	283	295	1.04
	.20	263	166	429	446	1.04
	.25	365	224	589	610	1.04
Plywood-gypsum	.05	50	26	76	83	1.09
6-foot	.10	146	80	226	239	1.06
	.15	271	147	418	433	1.04
	.20	410	221	631	651	1.03
	.25	560	302	862	889	1.03

Appendix B

Racking resistance of walls has been related empirically and analytically to lateral resistance of the fastener connecting the sheathing to the framing. Although these comparisons are outside the scope of this study, fastener lateral load resistance data are included for future studies.

Results are given for 8d common wire nails (fig. B-1) and 1-1/4-inch drywall screws (fig. B-2). The fasteners were tested in 1/2-inch plywood and 1/2-inch gypsum wallboard, respectively. Table B-1 lists average ultimate fastener loads.

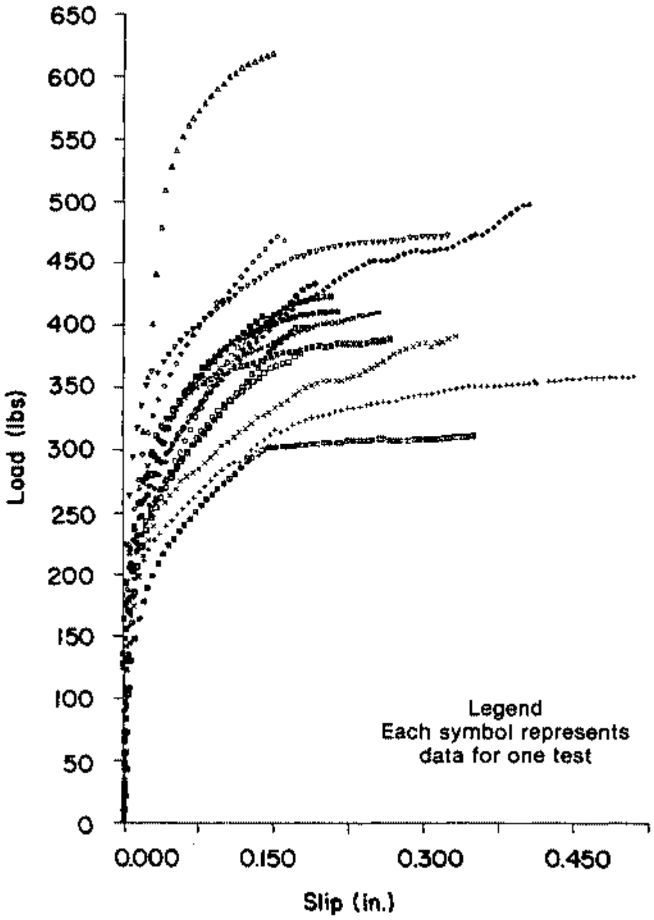

Figure B-1.--Load versus slip for 8d common wire nails and 1/2-inch plywood. (ML84 5254)

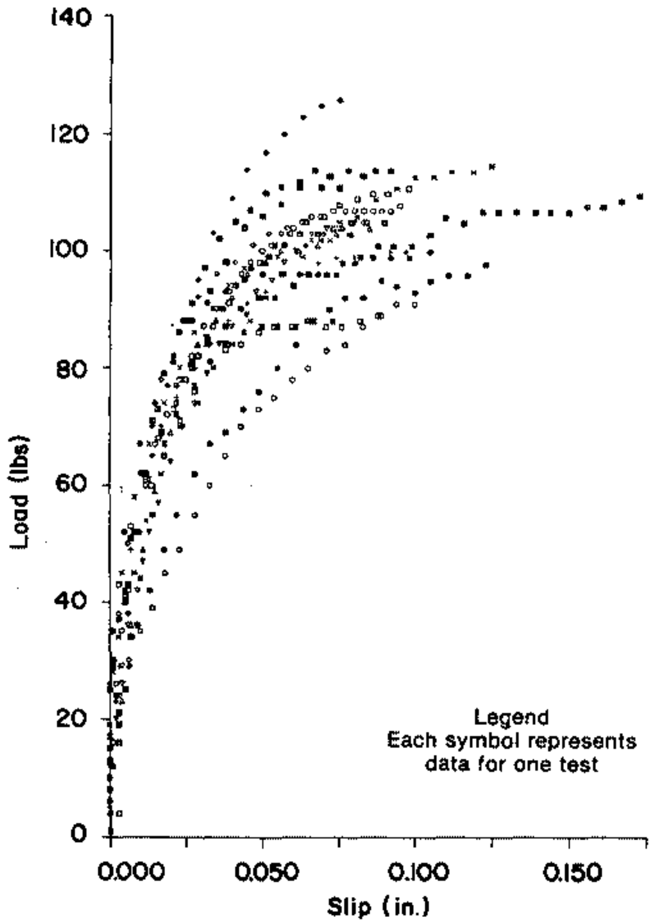

Figure B-2.--Load versus slip for 1-1/4-inch drywall screws and 1/2-inch gypsum. (ML84 5255)

Table B-1.--Average ultimate lateral loads on 8d common wire nails and 1-1/4-inch drywall screws with plywood and gypsum sheathing, respectively

	Ultimate strength	Standard deviation
	———— *Lb* ————	
Plywood with load parallel to face grain, average ultimate load (10 samples)	411	52.8
Plywood with load perpendicular to face grain, average ultimate load (9 samples)	416	36.3
Gypsum with load parallel and perpendicular to 8-foot length of 4- by 8-foot panel edges unconfined by paper, average ultimate load (20 samples)	105	10.0

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