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Shear Resistance of Steel-stud Wall Panels

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SHEAR RESISTANCE OF STEEL-STUD WALL PANELS

by Thomas S. Tarpy, Jr.[1] and Joseph D. Girard[2]

Introduction

Previous research by the writer has shown that steel stud framed wall panels sheathed with gypsum wallboard can effectively be used as shear walls to resist lateral in-plane loads (3, 7, 8 and 9). The magnitude of the shear resistance to in-plane loading is a function of the manner of the attachment of the sheathing material to the steel stud frame assembly and the type and manner of anchorage used to attach the wall panel to the floor or roof assembly. The study reported herein was in response to a need within the industry to develop design criteria for steel stud framed shear wall panels with different sheathing materials for inclusion in the various design codes. This study was directed specifically at determining maximum height/length ratios, allowable shear strength values per lineal foot and allowable deflections for a wide range of different types of wall construction commonly encountered in practice.

The available information on shear values for plywood sheathed wood stud shear wall panels is fairly extensive (4, 10). The allowable shear value is essentially a function of the stud spacing, nail spacing and orientation of the plywood which may be applied directly to the framing studs. The allowable in-plane deflection for wood framed shear walls is not accurately defined and is controlled by maximum height/length limitations. Typical hold-down construction details to resist wall panel uplift or overturning forces produced by in-plane forces parallel to the shear wall are required by the codes.

Allowable shear values for vertical steel stud shear walls with various types of sheathing are not currently included in the various design codes for resisting horizontal in-plane forces (5, 6, 10). It should be pointed out, however, that steel stud framed shear walls are permitted in certain types of construction provided some form of lateral bracing is used within the wall panel (5). This bracing usually consists of 0.125 inch by one-inch steel straps used as diagonal bracing with a maximum angle of 60 degrees to the horizontal. The maximum allowable horizontal load which can be resisted is 1,000 pounds for each brace. The steel studs within the assembly are also further specified to be a minimum of 16 gage (base metal thickness of 0.0598 inches) and located at a maximum stud spacing of 16 inches on center.

This paper presents the more recent results of an experimental test program for determining the shear resistance of framed steel-stud wall panels with different construction details and sheathing materials without the use of the diagonal X-bracing. The overall objective of the test program was: (1) to determine the effect of different construction techniques and anchorage details on the in-plane shear resistance of steel-stud shear walls with different types of

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sheathing and, (2) to determine the thresholds for damage of the walls due to lateral in-plane displacement.

Test Program

The test program reported herein consisted of testing seven different types of wall panel construction and anchorage techniques using static uni-directional loading procedures. The number of actual tests included in each wall type was a function of the requirements of ASTM E 564 - 76 (1). ASTM E 564 - 76 is a static test method for determining the shear resistance of framed walls for buildings. Basically, this method requires that if the results of two different tests for a given wall type construction differ by more than 10%, a third test is run and the shear resistance of the wall type is the mean of the lower two values obtained from the three test results. The typical wall assembly is shown in Figure 1a.

The actual wall construction and anchorage details for each wall type, as well as the type of loading condition, are shown in Table 1. The parameters considered in this study are:

a) The effect of using light gage clip angles and powder-actuated fasteners in place of bolts and washers to anchor the base of the wall panel--Wall Types A, B, E, G & K.
b) The effect of anchoring the wall panel through transverse floor joists--Wall Types L, P and Q.
c) The effect of plywood or gypsum exterior sheathing in place of gypsum wallboard as a diaphragm material--Wall Types L, M, and N.
d) The effect of using fillet welds instead of self drilling screws to attach the studs to the runner tracks--Wall Types A and L.
e) The effect of using a 16-inch rather than a 24-inch stud spacing--Wall Types A and R.

These conditions were considered to have significant influence on the wall performance based on the previous research results (3, 8). The wall panel elevation and construction details are shown in Figures 2 thru 12 for those wall types being considered herein.

The individual wall panels were constructed using 3-½ inch web by 1-½ inch flange by ½ inch lip painted structural steel "C" studs with a base metal thickness of 0.0359 inches (nominal 20 gage). The steel-studs were attached to 3-5/8 inch web by 1-½ inch flange painted structural steel-runner track with a base metal thickness of 0.0359 inches (nominal 20 gage). Unpunched steel floor joists with a base metal thickness of 0.0598 inches (nominal 16 gage) measuring 7-¼ inch web by 1-5/8 inch flange by 9/16 inch lip were used to distribute the load along the top of each wall panel. The measured yield strength of the studs for three coupons cut longitudinally from the web ranged from 29.5 ksi to 30.6 ksi with a mean value of 30 ksi.

The diaphragm material was attached to both sides of the stud frame as noted in Table 1 by wall type. The gypsum wallboard seams were caulked and taped to complete the construction of the wall panel. The panel caulking was allowed to cure at least 24 hours before the wall panel was moved. The gypsum sheathing and plywood seams were left open. The special anchorage details for Wall Types P and Q to evaluate load transfer through floor joists are shown in Figures 10 and 11 respectively.

Test Set-up

A load bearing block and structural steel joist member was attached along the top of the wall panels in the plane of loading to uniformly distribute the load along the wall to prevent localized failure of the panel at the point of loading. This detail is shown in Figure 13. It was felt that by attaching the steel joist to the wall panels in this manner the laboratory conditions would represent as closely as possible actual field installation and loading conditions.

Prior to starting a test, displacement indicating devices were mounted on the test frame at locations shown in Figure 1b. The total deflection at the top of the wall panel was measured at Locations 1 and 2. This deflection included shear and bending deflection, rotation and slippage of the wall panel, and load frame deformation. Wall panel rotation was measured at Locations 3 and 5, and slippage of the wall panel was measured at Location 4. Deformation of the load frame was measured at Locations 6 and 7.

Test Procedure

The loading sequence consisted of applying an initial load to the top of the wall panel of approximately 10% of the estimated ultimate load carrying capacity of the wall panel using a hydraulic jack/load cell/digital strain indicator combination. This load was held for two minutes to set the wall panel connections and was then removed. The wall panel was allowed to fully recover and the dial gages set to zero to begin the test at this zero load-deflection condition. The load was then applied incrementally to the wall panel, and displacement measurements recorded at each interval following a two-minute hold period. At load levels of approximately one-third and two-thirds of the estimated ultimate load carrying capacity of the wall panel, the load was fully removed, and the wall panel recovery was recorded after a five-minute hold period. The load was then re-applied to the next higher increment above the back-off load. Loading continued in this manner until the wall panel was no longer capable of holding addditional load. The last load, held for two minutes with displacement measurements recorded, was defined as the ultimate load.

Analysis of Test Results

The information obtained from the test data is load deflection curves, ultimate shear strength, shear stiffness and damage threshold load level. The load-deflection curves are plots of the applied load versus the measured total panel deflection.

The total panel deflection, Δ_T is defined as:

$$T = \Delta_1 - \Delta_4 \qquad (1)$$

where Δ_1 and Δ_4 are measured deflections (in) at gage locations 1 and 4 respectively.

The ultimate shear strength, S_u, of the wall panel is defined as:

$$S_u = P_u/b \qquad (2)$$

where P_u is the ultimate load carrying capacity of the wall panel (lb) (i.e. the largest load held for two minutes and gage measurements recorded) and b is the length of the wall panel (ft.).

The total shear stiffness, G'_T, is determined from the load-deflection curve at a value less than the proportional limit. A suggested reference load level by ASTM is 0.33 P_u. If the selected load level is beyond the proportional limit, a reduced value is chosen. The total shear stiffness is defined as:

$$G'_T = \frac{a}{b}\left(\frac{P}{\Delta_T}\right) \qquad (3)$$

where P is the load (lb); and Δ_T is the corresponding total deflection (in) at one-third P_u, a is the height of the wall panel (ft), and b is the wall panel length (ft).

The damage threshold load level, P', is a visual observation and is defined as the load level at which damage to the diaphragm or sheathing material occurred. As such, the values are based on the general observations of several individuals involved in the testing.

Discussion of Results

The experimental results for Wall Types A, B, E, G, K thru N and P thru R are summarized in Table 2. Average gypsum damage thresholds are shown in the table as initial damage. For a detailed discussion of the individual test results, refer to Reference 2.

All wall types tested experienced the same basic type of failure. The initial sign of distress was the wall base runner tracks deforming around the anchorage device (either clip angle, powder actuated fastener, or washers) at the tension or uplift corner of the wall identified by Location 5 in Figure 1b. As the load was increased, cracking of the gypsum wallboard occurred at the same locations from the corner fasteners to the edge of the wallboard. This process continued with increased track deformation and increased tearing of the wallboard until the wall panel was no longer able to carry additional load.

Wall Type A is used as the base reference in the following discussion of the effect of various parameters on the shear resistance of the wall panel where possible. This reference is due to the extensive amount of data on Wall Type A with variable aspect ratios (3).

a) Effect of Wall Panel Anchorage

The wall panel anchorage effect on the shear strength is seen by comparing Wall Types A, B, E, G and K. The elimination of the clip angles at the interior locations (Type B) had little effect on the shear strength or stiffness. This was due to the stiffening effect the corner angles furnish to the runner track and end vertical stud against local bending and shear deformations. A 24% decrease in shear strength resulted with the substitution of bolt and washers (Type E) in place of the corner angles. The use of powder actuated fasteners (Type G) had a similar restraining effect as the angle for Types A and B because of the spread of the fasteners to as close to the edge of the wall as possible, thus, eliminating the track bending around the anchoring devices. This restraining effect existed as long as the fastener embedment was sufficient against pullout. The type of interior anchorage had little effect on the shear resistance. Wall Type K with the light gage clip angles experienced earlier pullout of the powder-actuated fasteners than Wall Type G without the clip angles, thus, resulting in a significant decrease (32%) in shear strength.

The shear stiffness appears to be highly dependent upon the corner anchorage of the wall. The use of corner angles for Wall Types A and B resulted in essentially the same value for shear stiffness. The elimination of the angles resulted in a 58% decrease for Type E and a 52% decrease for Type G. This was because of the larger wall panel rotation that occurred when the corner angles are removed.

The influence of corner anchorage is also apparent in the damage threshold load level. The bolt and washer anchorage resulted in a 17% decrease in load level. The use of powder actuated fasteners or corner clip angles resulted in a negligible increase in load level. A 134% increase in shear stiffners was noted for Wall Type K over Wall Type G due to the addition of the corner light gage clip angle.

b) Effect of Anchoring Through Floor Joists

The effects of wall panel base anchorage through floor joists is seen by comparing Wall Types L, P and Q. The only variation between these wall types was in the method of wall panel anchorage. Failure of the welds in the floor joist system of Wall Types P and Q, and the subsequent deformations of the joists and track sections, exaggerated the rotation and total deflection of these wall panels. This large panel rotation caused weakening of the wall panel and early failure

The total ultimate shear strength of Wall Type L is 17% greater than wall Type P and 42% greater than Wall Type Q. This is to be expected since Wall Type L is more rigidly attached without being anchorage through floor joists. Additionally, Wall Type L resulted in a greater shear stiffness than either wall Types P or Q but with approximately the same damage threshold load level.

c) Effect of Diaphragm Material

As shown in Table 1, Wall Types L, M and N were constructed and anchored identically, except for the diaphragm material used on one side of the wall panel. Wall Type M, covered with exterior gypsum sheathing on one side and gypsum wallboard on the other side resulted in an ultimate shear strength of only 63% of that of Wall Type L which was covered with gypsum wallboard on both sides. Wall Type N, constructed with construction grade plywood on one face and gypsum wallboard on the other face resulted in a 26% increase in ultimate shear strength.

The total shear stiffness of Wall Type M was essentially the same as that of Wall Type L while that of Wall Type N was 10% less. A reduction of 24% in initial damage threshold was obtained using gypsum sheathing in place of gypsum wallboard.

d) Effect of Stud Attachment

The effect of welding the stud to be the runner track instead of using self drilling screws is seen by comparing Wall Types A and L. Wall Type L was identical to Wall Type A in all other aspects of construction and anchorage.

The ultimate shear strength of Wall Types A and L were essentially the same while the gypsum damage threshold of Wall Type A was 14 percent greater than that of Wall Type L. The shear stiffness for Wall Type A was 26% greater than Wall Type L due to the stiffening effect at lower load levels. A comparison of the load-deflection curves indicates that the earlier stiffening effect is reduced to essentially the same for both wall types at loads near ultimate.

e) Effect of Stud Spacing

The effect of stud spacing is seen by comparing Wall Types A and R. Wall panels constructed with the studs at 16 inches on centers instead of 24 inches on centers, but with the same wallboard fastener spacing, provide more points for the transfer of the load between the diaphragm material and the wall panel steel stud frame. This resulted in a 9% increase in ultimate wall panel shear strength due to the closer stud spacing but resulted in an 8% decrease in damage threshold load level.

The total shear stiffness of Wall Type A was 29 percent greater than Wall Type R, by virtue of its smaller total deflection at the lower load levels.

Conclusions

The results obtained from this investigation indicate that any of the wall panels, framed with "C" shaped steel studs and constructed and anchored as reported herein are a feasible way of resisting lateral in-plane shear loads when used as vertical shear wall diaphragms in buildings. However, it is the professional opinion of the writer that certain design and construction recommendations should be followed. These recommendations are:

1. A rigid attachment should be designed to connect the wall panel to the floor or roof framing systems if a resultant uplift force exists (i.e. the design dead load is not sufficient to prohibit overturning of the wall). This attachment could be with the corner clip angle detail used herein or by some equivalent means.

2. A solid transfer through floor joists is necessary to prevent local failure. This could be accomplished with solid wood blocking or steel plates.

3. Welding the studs to the track is as effective as using self-drilling screws and results in essentially the same shear resistance.

4. The wall panel diaphragm or web material should possess at least the shear modulus of the gypsum-paper/wallboard material used in Wall Type A.

5. The use of plywood sheathing drastically increases the shear resistance of the wall panel over that with gypsum wallboard.

6. Decreasing the stud spacing slightly increases the shear strength.

7. Finally, for design purposes, a minimum factor of safety of 2.0 is recommended to determine the design shear strength from the ultimate shear strength for steel-stud framed wall panels constructed

as reported herein. This minimum value results in a design load level below the damage threshold load level. The designer must also consider deflection or serviceability requirements for a particular application.

Acknowledgement

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Appendix. -- Notation

A = Aspect Ratio (length/height)

a = Height of the wall panel (ft)

b = Length of the wall panel (ft)

G'_T = Shear stiffness based on total deflection (lb, in)

P_u = Ultimate Load (lb)

P' = Damage threshold load level at initial cracking (lb)

S_u = Ultimate shear strength (lb/ft)

Δ_i = Deflection at gage i (in)

Δ_T = Total deflection (in)

Appendix. -- References

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9. Tarpy, T.S., "Pseudo-Dynamic Response of Steel-Stud Framed Wall Panels," Proceedings of the ASCE/EMD Specialty Conference on Dynamic Response of Structures: Experimentation, Observation, Prediction and Control, held at Atlanta, Georgia, January 15-16, 1981, pp. 631-648.

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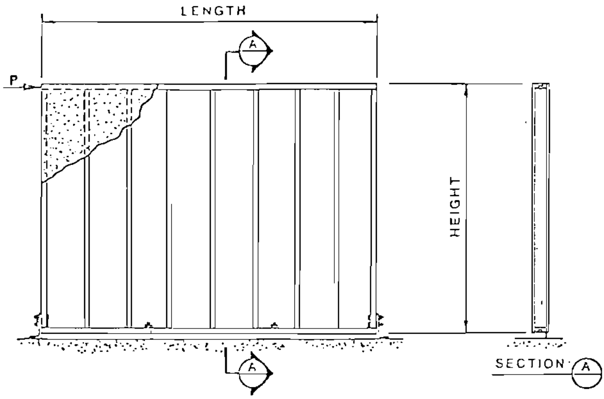
TABLE 1

Wall Type	Loading Condition	Wall Height	Wall Length	Type & Thickness of Diaphragm Material	Wall Construction	Diaphragm Attachment	Stud Spacing	Stud Attachment	Wall Anchorage
A	Static	8'-0	8'-0	1/2" Gypsum Wallboard	Single-Ply Each Face	#6x1" Bugle Head Screws @ 12" o.c. Studs & Track	20 gage C-stud @ 24" o.c.	#10x1/2" Low Profile Head Screws Each Side Top and Bottom	L3x3x3/8x3-1/4" LG @ 48" o.c. with 3/8" Hex Head Bolts
B	Static	8'-0	12'-0	1/2" Gypsum Wallboard	Single-Ply Each Face	#6x1" Bugle Head Screws @ 12" o.c. Studs and Track	20 gage C-stud @ 24" o.c.	#10x1/2" Low Profile Head Screws Each Side Top and Bottom	L3x3x3/8x3-1/4" LG @ Ends with 3/8 Hex Head Bolts 3/8" Hex Head Bolt with 1" O.D. Washer @ Mid-point
E	Static	8'-0	8'-0	1/2" Gypsum Wallboard	Single-Ply Each Face	#6x1"Bugle Head Screws @ 12" o.c. Studs and Track	20 gage C-stud @ 24" o.c.	#10x1/2" Low Profile Head Screws Each Side Top and Bottom	3/8" Hex Head Bolts with 1" Washer @ 48" o.c.
G	Static	8'-0	8'-0	1/2" Gypsum Wallboard	Single-Ply Each Face	#6x1" Bugle Head Screws @ 12" o.c. Studs and Track	20 gage C-stud @ 24" o.c.	#10x1/2" Low profile Head Screws Each Side Top and Bottom	9/64" x 1-1/4" Powder Actuated Fasteners @ 6" o.c.
K	Static	8'-0	8'-0	1/2" Gypsum Wallboard	Single-Ply Each Face	#6x1" Bugle Head Screws @ 12" o.c. Studs & Track	20 gage C-stud @ 24" o.c.	#10x1/2" Low Profile Head Screws Each Side Top and Bottom	16 gage clip angle @24" o.c. with 9/64" Ø x 1 1/4" LG Powder Actuated Fasteners @ 6" o.c.
L	Static	8'-0	8'-0	1/2" Gypsum Wallboard	Single-Ply Each Face	#6x1" Bugle Head Screws @ 12" o.c. Studs and Track	20 gage C-stud @ 24" o.c.	1/8" X 1" Fillet Weld Each Side	L3x3x3/8x3-1/4" LG @ 48" o.c. with 3/8" Ø Hex Head Bolts
M	Static	8'-0	8'-0	1/2" Exterior Gypsum Sheathing and 1/2" Gypsum	Single-Ply Opposite Face	#6x1" Bugle Head Screws @ 12" o.c. Studs and Track	20 gage C-stud @ 24" o.c.	1/8" X 1" Fillet Weld Each Side	L3x3x3/8x3-1/4 LG @ 48" o.c. with 3/8" Ø Hex Head Bolts
N	Static	8'-0	8'-0	1/2" Construction Grade Plywood and 1/2" Gypsum	Single-Ply Opposite Face	#6x1" Bugle Head Screws @ 12" o.c. Studs and Track	20 gage C-stud @ 24" o.c.	1/8" X 1" Fillet Weld Each Side	L3x3x3/8x3-1/4" LG @ 48" o.c. with 3/8" Ø Hex Head Bolts
P	Static	8'-0	8'-0	1/2" Gypsum Wallboard	Single-Ply Each Face	#6x1" Bugle Head Screws @ 12" o.c. Studs and Track	20 gage C-stud @ 24" o.c.	1/8" X 1" Fillet Weld Each Side	Welded Track to Floor Joists per Details and Bolted to Load Frame
Q	Static	8'-0	8'-0	1/2" Gypsum Wallboard	Single-Ply Each Face	#6x1" Bugle Head Screws @ 12" o.c. Studs and Track	20 gage C-stud @ 24" o.c.	1/8" X 1" Fillet Weld Each Side	Track Fastened to Floor Joists per Details and Bolted to Load Frame
R	Static	8'-0	8'-0	1/2" Gypsum Wallboard	Single-Ply Each Face	#6x1" Bugle Head Screws @ 12" o.c. Studs and Track	20 gage C-stud @ 16" o.c.	#10x1/2" Low Profile Head Screws Each Side Top and Bottom	L3x3x3/8x3-1/4" LG @48" o.c. with 3/8" Ø Hex Head Bolts

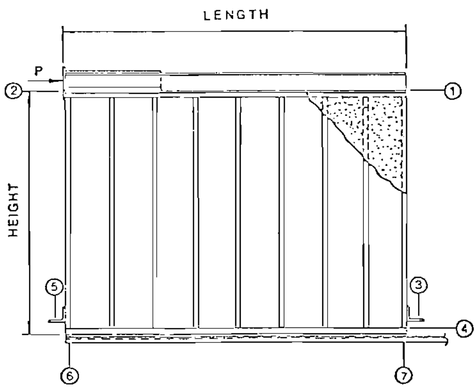
TABLE 2

SUMMARY OF TEST RESULTS

Wall Type	Loading Condition	Wall Height (ft)	Wall Length (ft)	Ultimate Load (lb)	Ult. Shear Strength (lb/ft)	Max. Total Deflection (in)	Total Shear Stiffness (lb/in)	Initial Cracking Load Level (lb)	Initial Cracking Shear Strength (lb/ft)	Initial Cracking Total Deflection (in)
A	Static	8'-0	8'-0	3300	413	0.98	9700	2400	300	0.40
B	Static	8'-0	12'-0	4500	375	0.58	12700	3800	317	0.40
E	Static	8'-0	8'-0	2500	313	1.20	4100	2000	250	0.70
G	Static	8'-0	8'-0	3100	388	1.48	4700	2500	313	0.94
K	Static	8'-0	8'-0	2100	262	1.04	11000	1400	175	0.26
L	Static	8'-0	8'-0	3400	425	0.93	7500	2100	262	0.42
M	Static	8'-0	8'-0	2150	269	1.13	7700	1600	200	0.35
N	Static	8'-0	8'-0	4300	538	1.54	6700	2300	288	0.50
P	Static	8'-0	8'-0	2900	362	2.83	1800	2400	300	2.15
Q	Static	8'-0	8'-0	2400	300	2.68	2100	2100	262	2.19
R	Static	8'-0	8'-0	3800	475	1.35	4200	2200	275	0.55



a. Wall Assembly



b. Dial Gage Locations

Figure 1. ASTM E564 Racking Load Assembly

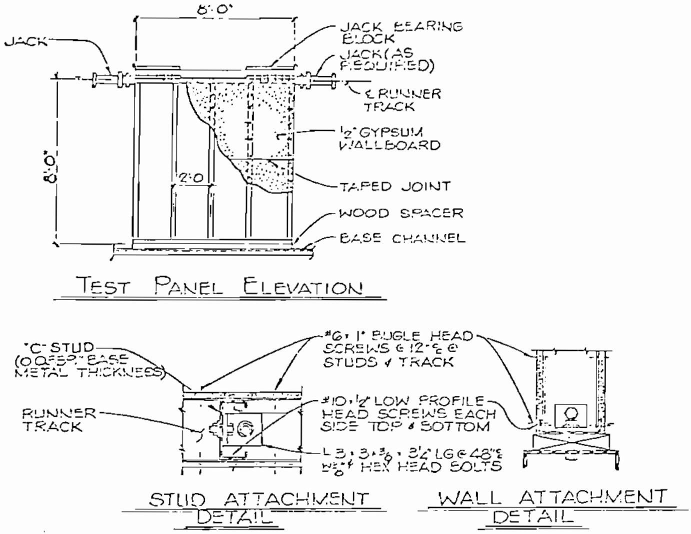


Figure 2. Test Assembly Plan & Details - Wall Type A

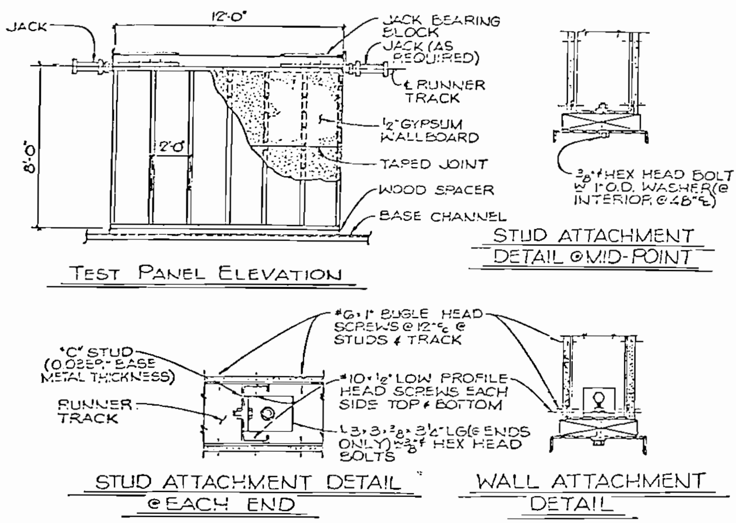


Figure 3. Test Assembly Plan & Details - Wall Type B

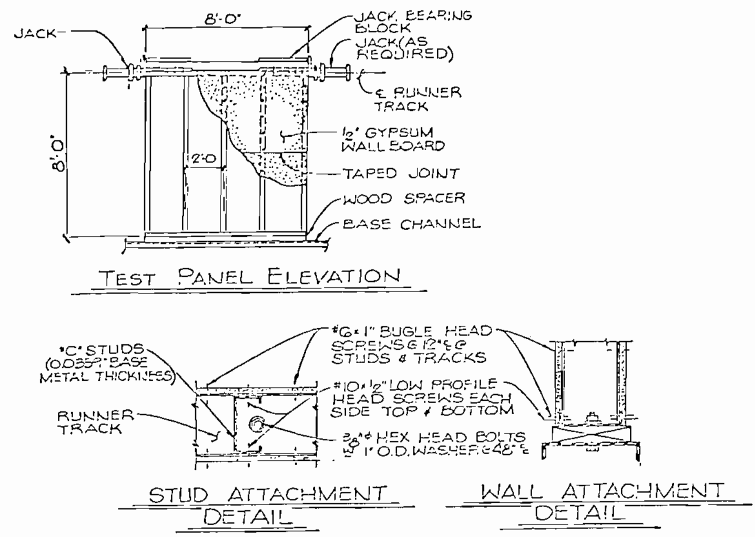


Figure 4. Test Assembly Plan & Details - Wall Type E

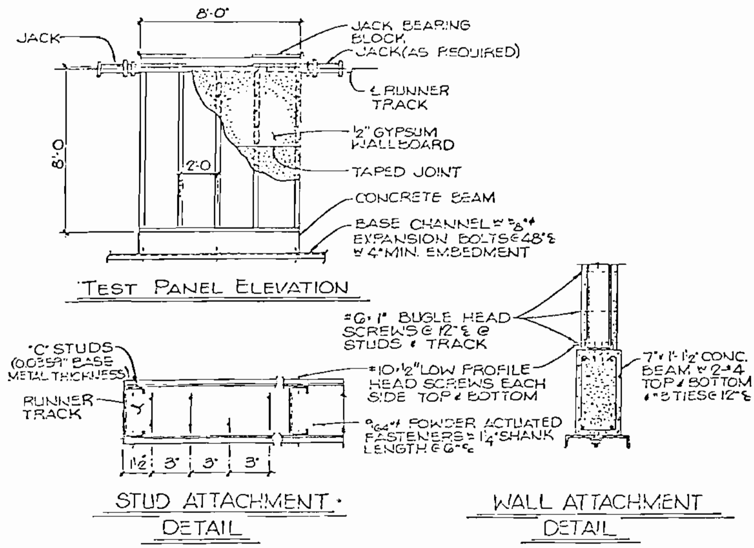


Figure 5. Test Assembly Plan & Details - Wall Type G

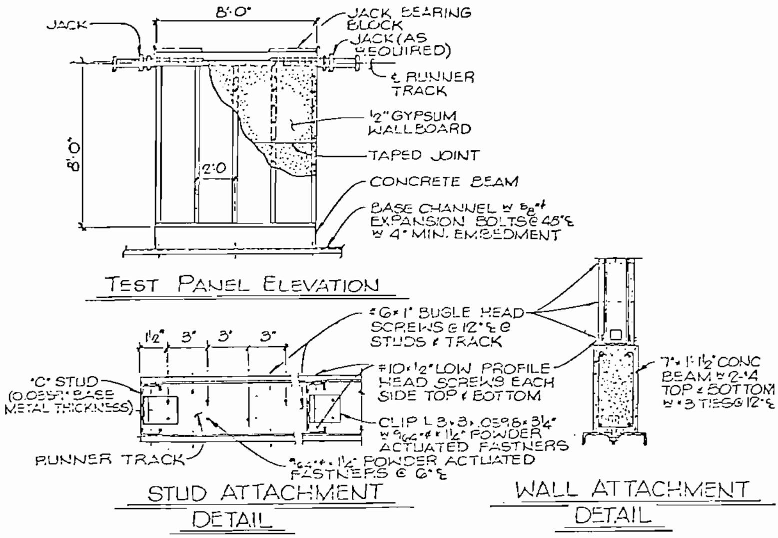


Figure 6. Test Assembly Plan & Details - Wall Type K

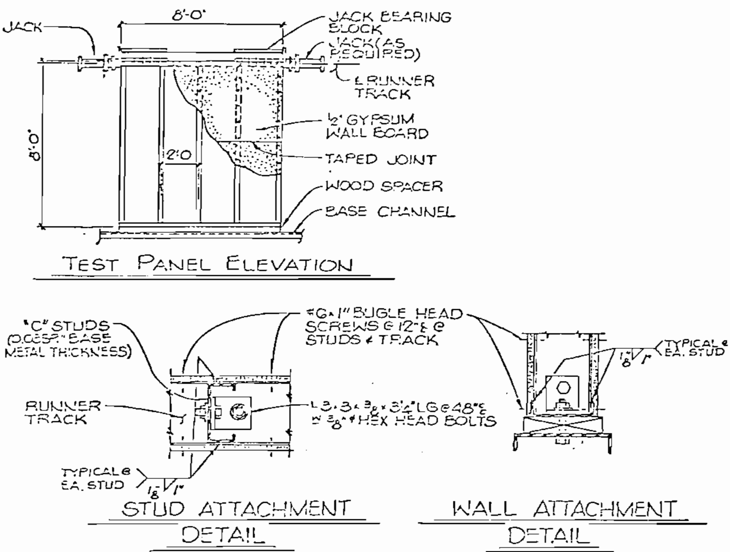


Figure 7. Test Assembly Plan & Details - Wall Type L

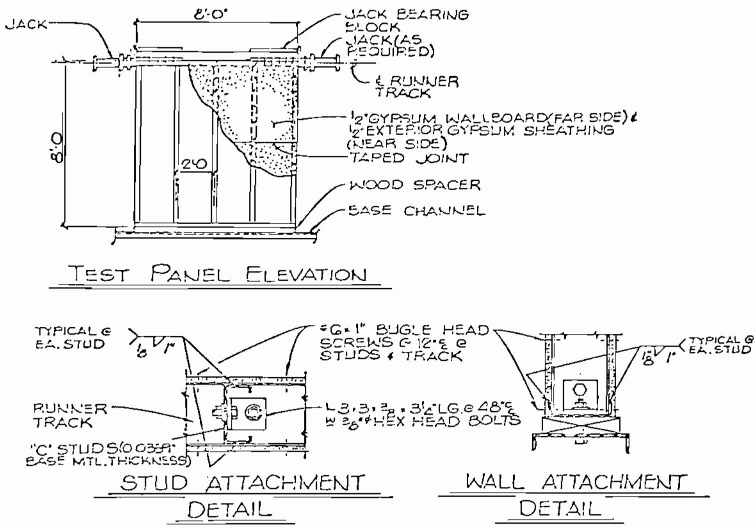


Figure 8. Test Assembly Plan & Details - Wall Type M

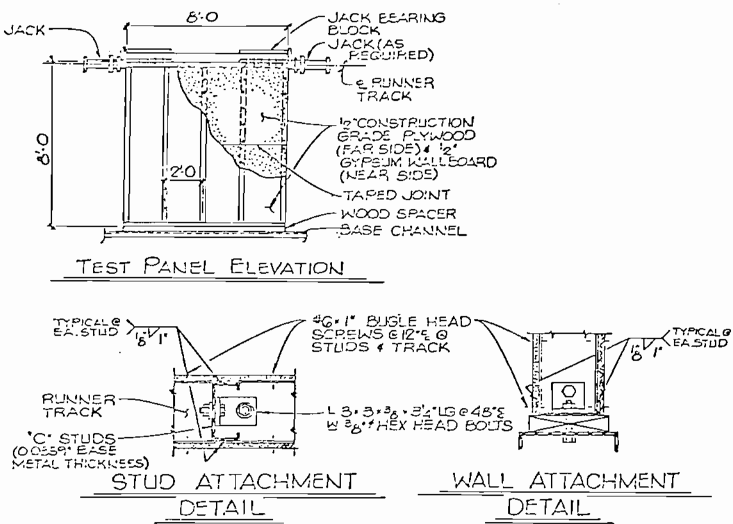


Figure 9. Test Assembly Plan & Details - Wall Type N

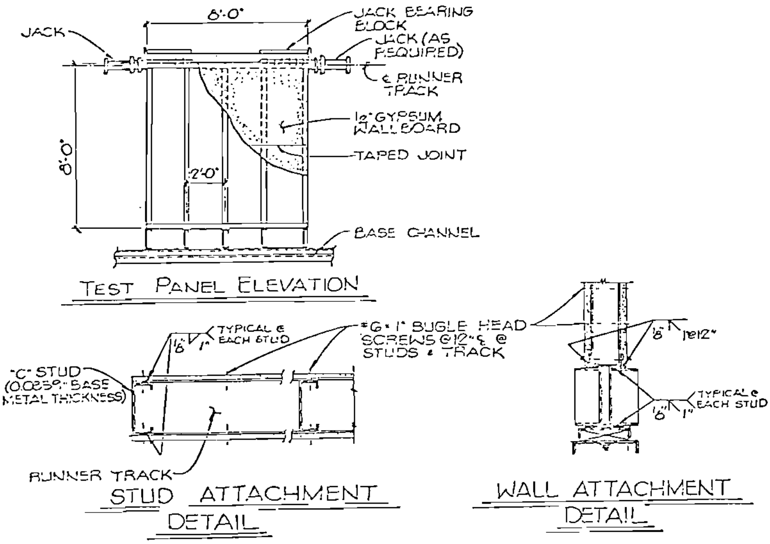


Figure 10. Test Assembly Plan & Details - Wall Type P

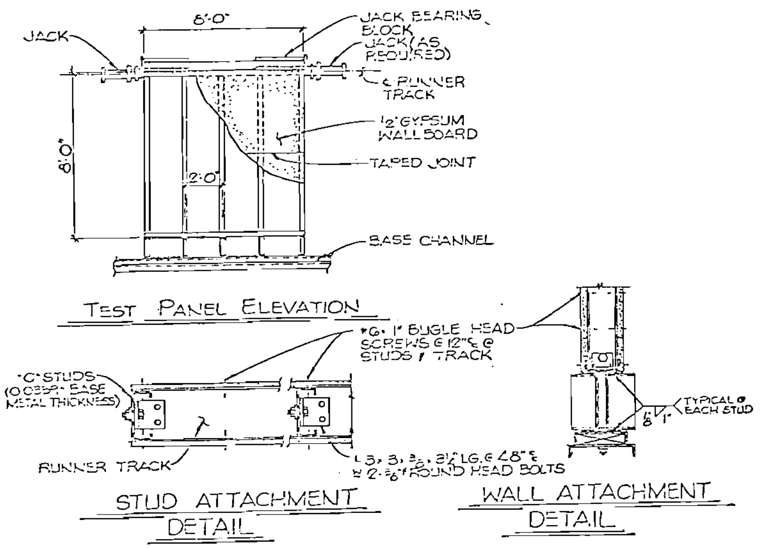


Figure 11. Test Assembly Plan & Details - Wall Type Q

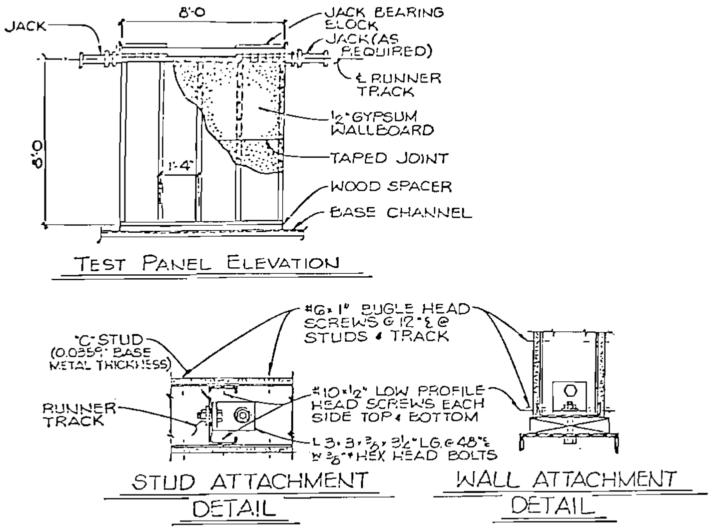


Figure 12. Test Assembly Plan & Details - Wall Type R

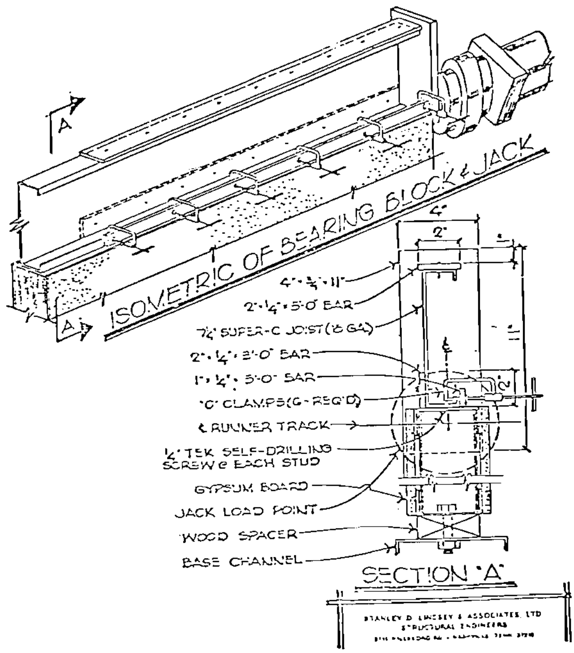


Figure 13. Load Distribution Bearing Block Detail