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COMBINED COMPRESSION AND LATERAL LOADS ON LOAD BEARING STEEL STUD WALLS

by

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SUMMARY

Steel framed wall panels were tested under combined compression and lateral loads to simulate their use in external load bearing walls. The panels were framed with conventional C-shaped studs and newly developed "thermal" studs with large web cut-outs to reduce heat flow. Experimental and calculated results are compared and discussed.

INTRODUCTION

Load bearing steel studs have been used for some time in building construction, mainly in interior walls, where they are subjected to compression loads only. Their use in external walls, which are subjected to the combined action of compression and lateral (wind) loads, has been less frequent to date.

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Steel framed walls usually consist of studs attached to upper and lower channels by means of screws or welding, sheathing and sometimes diagonal and horizontal bracing members. The sheathing is usually connected to one or both sides of the steel frame by means of self-drilling screws.

The sheathing not only serves as the enclosure material but most importantly acts as the structural bracing system for the studs. This bracing action of the sheathing (diaphragm action) is the result of its shear rigidity which tends to restrain the displacement of the studs in the plane of the wall and it also offers twisting resistance to the studs at the connector locations. From a structural viewpoint, steel studs have a high strength-to-weight ratio, leading to an economical and efficient wall system. The studs are commonly roll formed and precut and in some cases also prepunched to permit the passage of electrical conduits.

One disadvantage of using steel framing in external walls is the well known fact that it creates thermal bridges. As energy costs grow, the amount of wall insulation increases and the losses created by thermal bridges become unacceptable. One way of reducing these losses is to provide large openings in stud webs in order to increase their resistance to heat flow. Such studs are commonly referred to as "thermal" studs.

Large openings also facilitate the installation of plumbing and wiring.

OBJECTIVE

The objective of the work reported herein was to experimentally and analytically determine the load carrying capacity of wall assemblies framed with three different cold formed steel stud sections. Wall assemblies were subjected to compression loads only and combined compression and lateral loads. Plain C-shaped (non-thermal) studs and two newly developed thermal studs (delta and stepped delta) with large openings in the web were used in the investigation. Dimensions of all three types of studs are shown in Figure 1.

SCOPE

The tests consisted of:

(1) Stub column tests.

(2) Full scale, steel framed wall tests.

Analytical computations were carried out in accordance with the latest (1980) edition of the American Iron and Steel Institute (AISI) Specification for the Design of Cold Formed Steel Structural Members (1). The analytical results were compared with the test results and commented on.

EXPERIMENTAL TESTING

Dimensions of all three types of studs are shown in Figure 1. Table 1 summarizes the computed section properties for each stud. The mechanical properties determined from coupon tests are shown in Table 2.

(1) Stub Column Tests

Because of the large openings in the webs of the thermal studs, stub column tests were conducted to determine the effect of local buckling, as defined by the Q_{test} values. This was carried out in accordance with Technical Memorandum No. 3 of reference (3).

Table 3 summarizes the stub column test results; Figure 2 shows a photograph of a typical failed specimen of each of the sections tested. Three of each type were tested.

(2) Full Scale Steel Framed Walls

All wall panel tests were carried out in a horizontal test frame, as shown in Figure 3. A typical test panel is shown in Figure 4.

Concrete blocks were used to simulate the lateral (wind) load in tests 1 through 6. The blocks were sufficiently separated to avoid any bridging effect. Support details are shown in Figure 5(a). The lateral load was applied so that the two inner studs received twice as much load as the two outer studs (see Figure 6). The axial compression load was applied with jacks, such that the inner studs received twice as much load as the outer studs.

Vacuum suction was used to simulate the lateral (wind) load in tests 7 and 8 (see Figure 5(b) for support details). It was not known until after these tests how the suction load would be distributed over the four studs. The applied vacuum load was increased above the design wind load in order to ensure that the inner studs received at least the design wind load. This was necessary because the wall panel was three stud spaces wide, but contained four studs. The actual lateral load per stud is presented in the Discussion of Test Results below. The compression load was applied with jacks (one per stud).

Test 9 was conducted with a compression load only (see Figure 5(a) for support details).

The panel tests are summarized in Table 4.

The following compression and lateral design load combinations were established as typical cases in practice:

(a) Design compression load based on studs spaced 16" (406 mm) on center and supporting a total load (dead plus live) of 50 psf (2.40 kN/m^2) over a 14' (4270 mm) portion of roof = 933 lb. (4.15 kN) per stud.

(b) Design wind load based on 25 psf (1.20 kN/m^2).

The following sequence of loading was followed with all panels:

(i) Apply compression load in three stages up to design load.

(ii) Maintain design compression load and apply lateral load in two stages up to design wind load.

(iii) Maintain design wind load and increase compression load in stages until failure.

DISCUSSION OF TEST RESULTS

The average results for the inner studs are listed in Table 4. As expected, the outer studs deflected less than the inner studs.

(1) Sheathing On One Side Only (Positive Wind Pressure) - See Figures 5(a) and 6(a)

Figure 7 shows the load-deflection behaviour of wall panels framed with the plain, delta and stepped delta studs, respectively. While the deflection due to lateral (wind) load was greatest for the stepped delta panel, it carried the largest ultimate compression load and experienced a less severe mode of failure than the plain stud panel. The plain stud panel failed in overall torsional-flexural buckling of the stud section.

By shifting part of the web towards the center of gravity in the stepped delta section, the torsional-flexural buckling capacity was greatly improved relative to the plain and delta studs. The deflection and failure load of the delta stud panel was similar to that of the plain stud. However, both the delta and stepped delta panels failed in local buckling near the ends of the studs. This was the result of the end support detail which concentrated the reaction due to wind on only one flange of each stud.

(2) Sheathing On One Side Only (Negative Wind Pressure) - See Figures 5(a) and 6(c)

Initially, two stepped delta stud panels were tested. The compression loads were applied in the first panel (test 5) about 1/8" (3 mm) below the stud center line (i.e. on the sheathing side of the center line). The load-deflection behaviour is shown in Figure 8. In the second panel (test 6), the compression load was applied 15/16" (24 mm) above the stud center line. The failure occurred not on the studs, but was the result of the screws pulling through the gypsum sheathing. This is attributed to the deliberate eccentricity in the application of the compression load and to the sheathing material being gypsum.

Because of this failure, two more tests were conducted (7 and 8), this time applying a vacuum load to simulate the wind suction more realistically and using plywood as a sheathing material to eliminate failure due to pull-through of the screws. The compression load was applied at a point one-third of the wall thickness from the inside face of the panel, i.e. approximately 7/16" (11 mm) above the stud center line, as specified in reference 8.

In addition, the end support details were changed as shown in Figure 5(b). One screw per stud space was used to fasten the bottom channel into a 2 x 6 wood support. It was felt that this would better represent the actual connection of a framed wall to the floor deck. The top channel was also fastened with three screws to a 2 x 2 wood support attached to a plywood base, which provided some restraint against rotation.

The deflection ratio from outer to inner studs due to vacuum load only was 1:1.63. The suction load on the total panel was 31.25 psf (1.50 kN/m^2). Therefore, based on the relative deflections, the inner studs experienced an actual suction load of 29 psf (1.39 kN/m^2) while the outer studs were subjected to a suction load of 18 psf (0.85 kN/m^2).

It is interesting to note that the deflection due to lateral load (with design compression load maintained) was about 29% greater for the plain delta panel than the stepped delta panel (see Figure 8). The failure mode in both cases was overall torsional-flexural buckling of the stud sections. There was no evidence of local end buckling, which was the failure mode in the previous tests with different end conditions. Therefore the bottom channel was effective in transferring the lateral load reaction to both flanges of the stud.

(3) Sheathing On Both Sides

Two panels were tested; in test 4 a stepped delta panel under combined loads, and in test 9 a plain delta panel under pure compression load.

The failure mode in test 4 was consistent with tests 2 and 3 which had similar end supports (see Table 4). In test 9, only one of the four studs failed. The test was halted by local end buckling of the stud at the compression jack.

After all tests were completed, an attempt was made to explain the apparent upward bowing of the panels when the compression load was applied. The application of the compression load was expected to cause a downward bowing of the panel, particularly after the lateral load was applied. It was found that the jacks moved upward in the test frame, thus raising the top channel end of the panel. Since the deflection at each end of the studs was not measured during the tests, the midspan deflection alone cannot be used to determine the actual curvature in the wall panel under load. However, the load measurements are correct and therefore the failure loads specified are valid.

ANALYTICAL COMPUTATIONS

The latest (1980) AISI Specification for the Design of Cold Formed Steel Structural Members(1) presents design criteria for wall studs with sheathing attached to both faces of the studs.

The "STUD" computer program issued by AISI(6) can also be used for steel stud framed walls sheathed on one side only.

Limit states stress values were used in the AISI interaction expressions for combined loads. These equations were used to predict the failure compression load when applied simultaneously with a known lateral load.

COMPARISON OF TEST AND ANALYTICAL RESULTS

Table 5 summarizes both the test results and the analytical results for various loads, sheathing applications and types of studs.

It can be observed that in the case of a wall panel sheathed on both sides and framed with stepped delta studs, the analytical and test results were practically identical.

The computed values of Table 5 for sheathing on one side only consistently underestimate the failure loads. This is because the rotational restraint, F, of the sheathing material, which should be included in the one sided sheathing computations, was estimated. No values are presented in the AISI Specification(1) and the determination of such values is beyond the scope of this work. Prescribed small scale tests must be carried out in order to determine the rotational restraint values. This parameter is not as important with sheathing on both sides and is set equal to zero by the AISI Specification(1).

CONCLUSIONS AND RECOMMENDATIONS

(1) The stepped delta stub wall assembly with sheathing on one side only was able to carry approximately 35% more concentric load in addition to a 25 psf (1.20 kN/m^2) lateral wind load (either pressure or suction) than did both the plain and the delta stud wall assemblies. This is the result of its improved torsional-flexural buckling capacity.

(2) A good correlation between the tested and computed ultimate loads of the doubly sheathed stepped delta wall assembly was obtained.

(3) The computed ultimate loads for wall stud assemblies with sheathing on one side only underestimated the test failure load in every case. In the case of wall assemblies with sheathing on one side only, additional tests are needed. Also, small scale tests should be carried out to determine the rotational resistance of the sheathing. The AISI computer program(6) for one sided wall assemblies can be used with the understanding that the results are rather conservative. This can be corrected with additional testing and proper analysis.

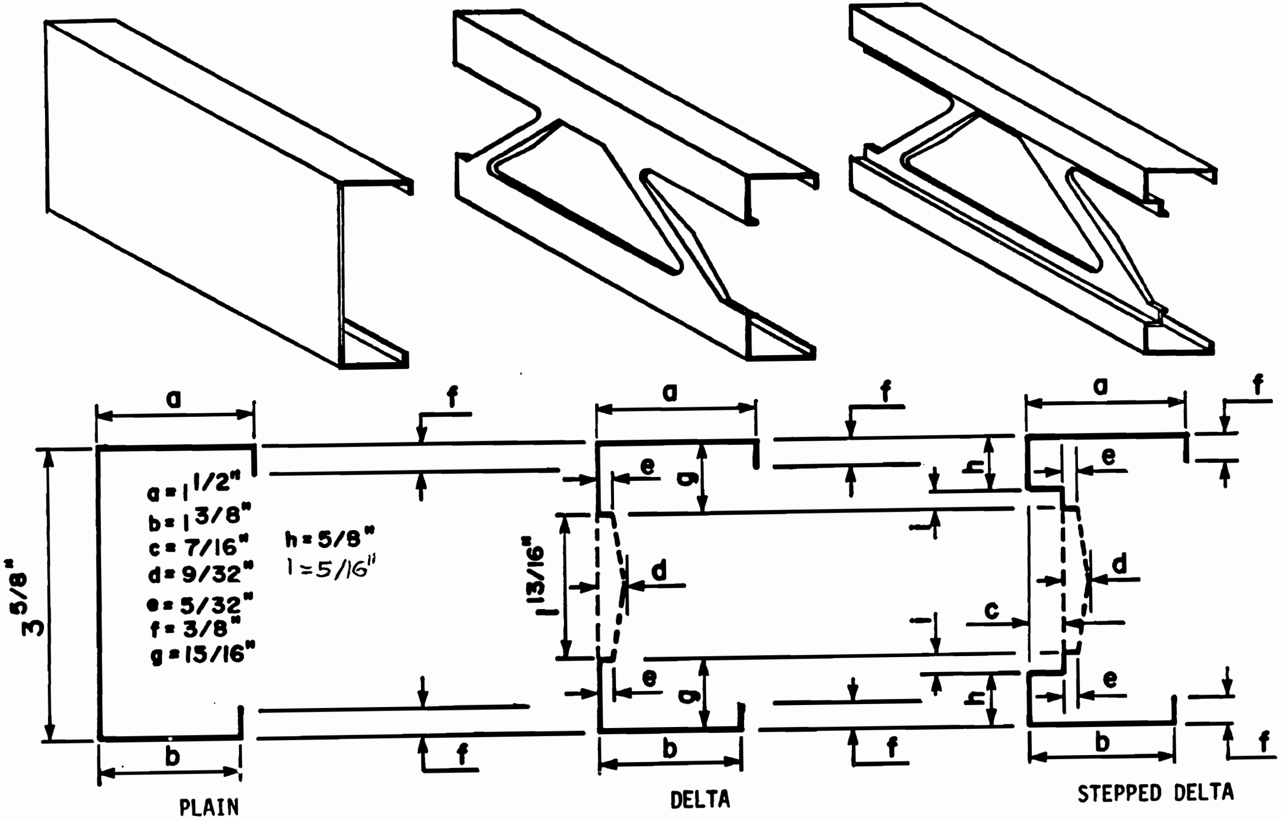


FIGURE 1 - PROTOTYPE COLD FORMED STEEL STUDS INVESTIGATED (NOMINAL DIMENSIONS - ALL INSIDE RADII BETWEEN 1 AND 2t)

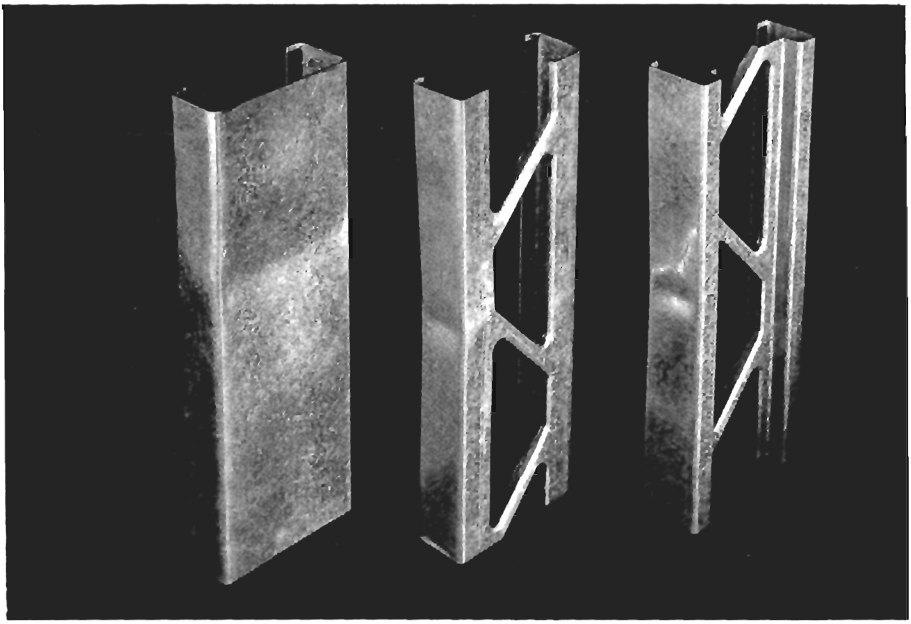


FIGURE 2 - PHOTOGRAPH OF TYPICAL FAILED STUB COLUMN SPECIMENS

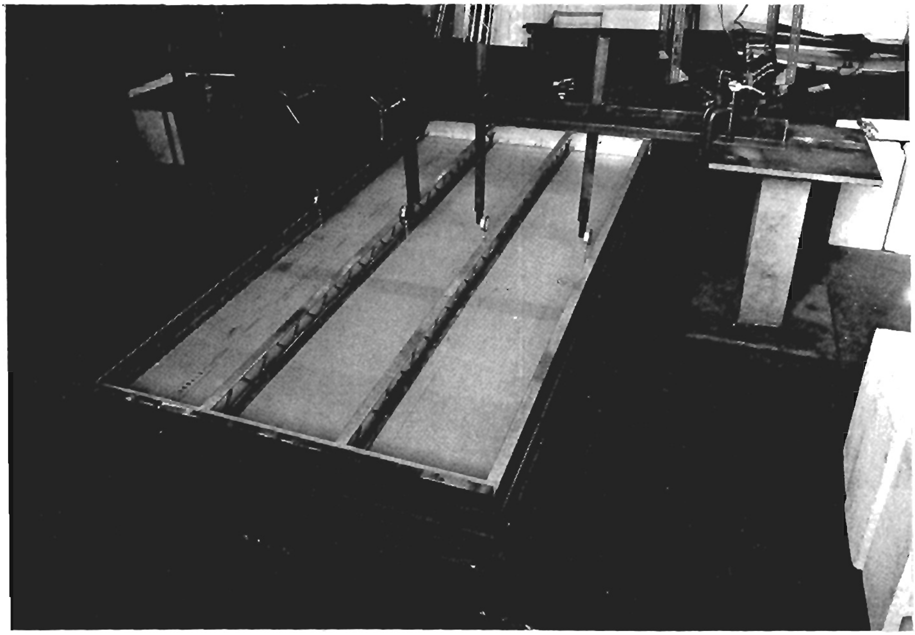


FIGURE 3 - PHOTOGRAPH SHOWING TYPICAL FULL SCALE WALL STUD PANEL TEST SET-UP

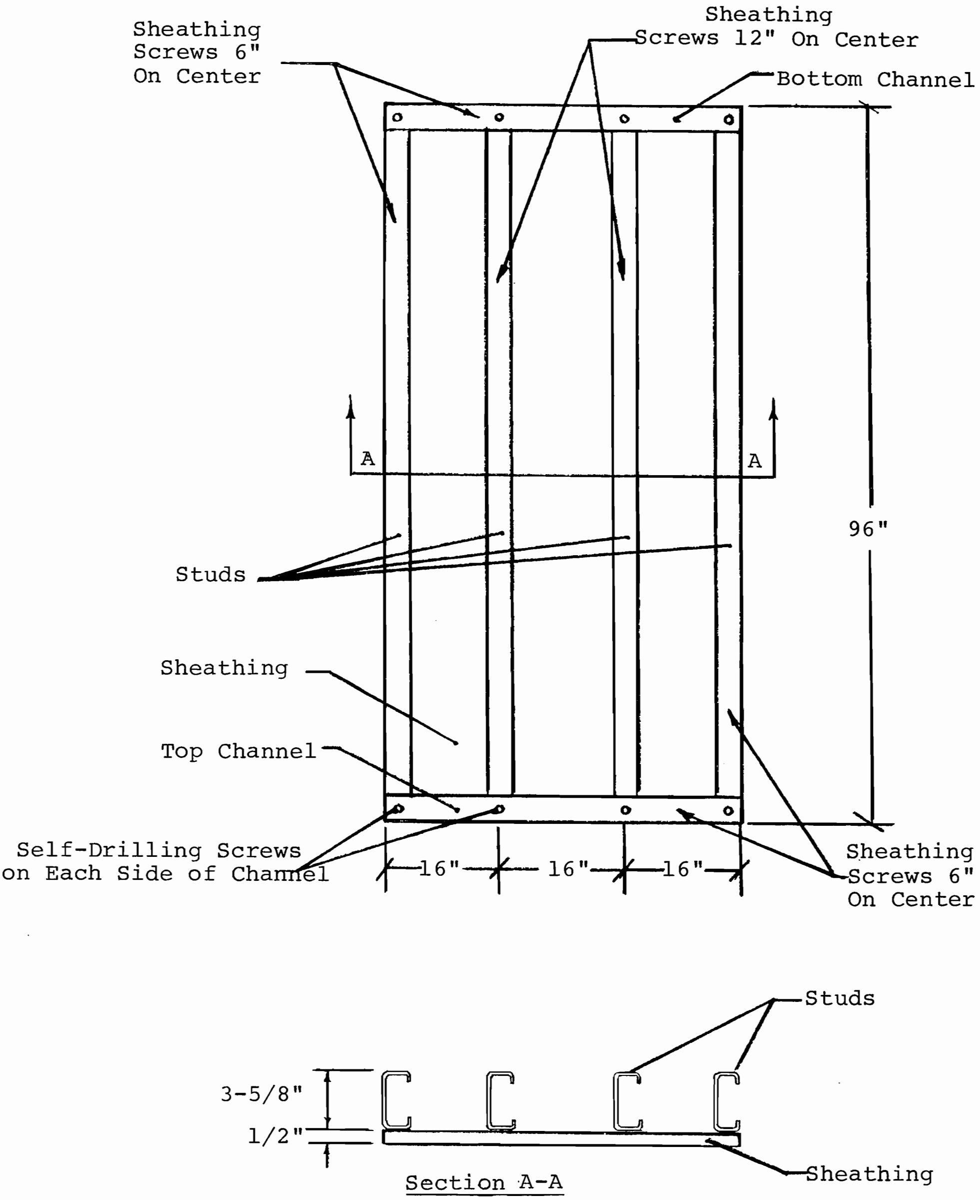


FIGURE 4 - TYPICAL TEST PANEL

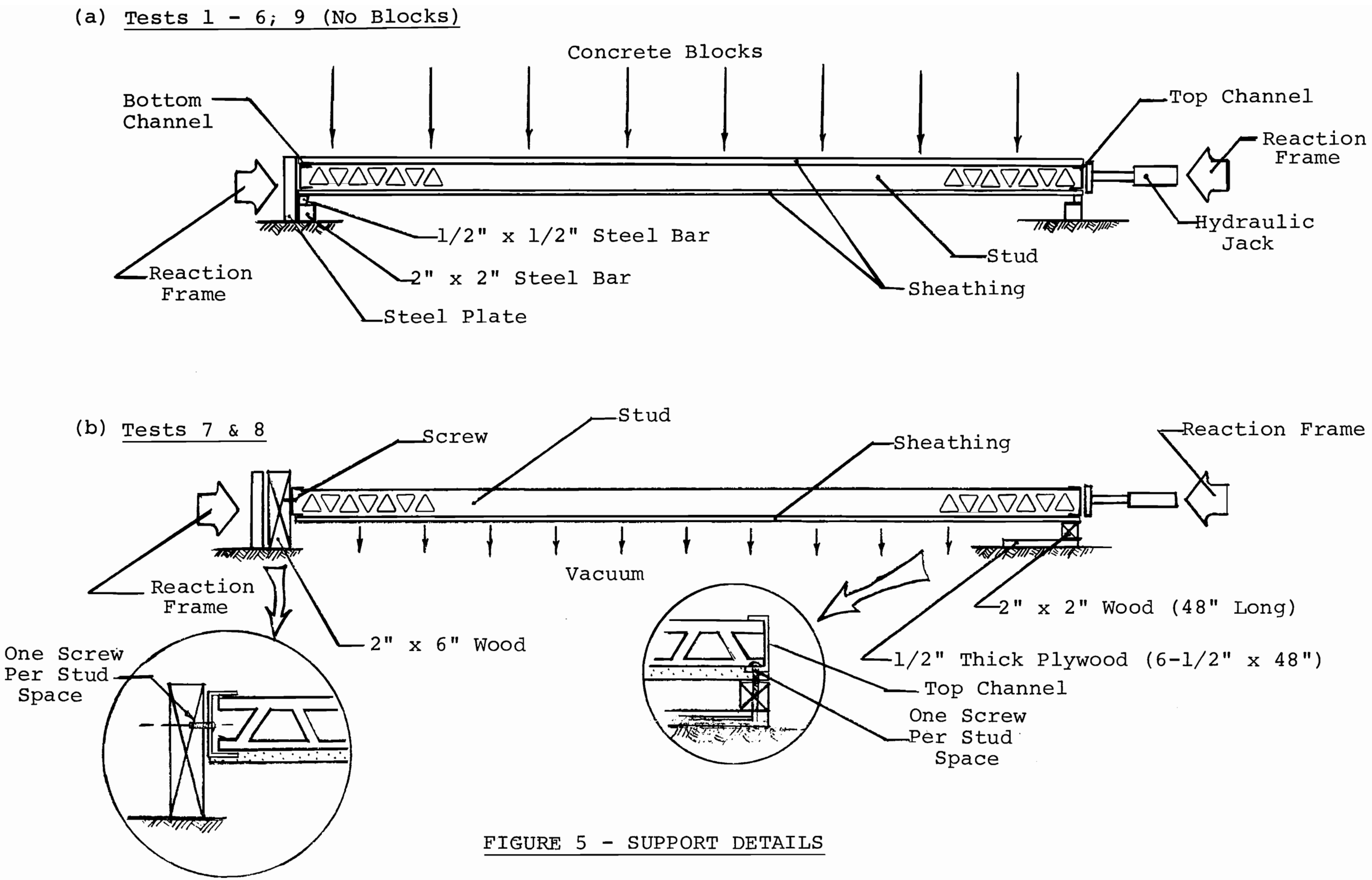
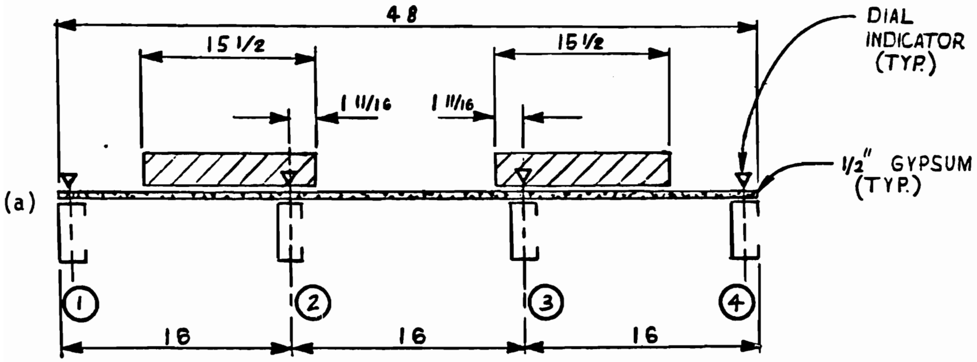
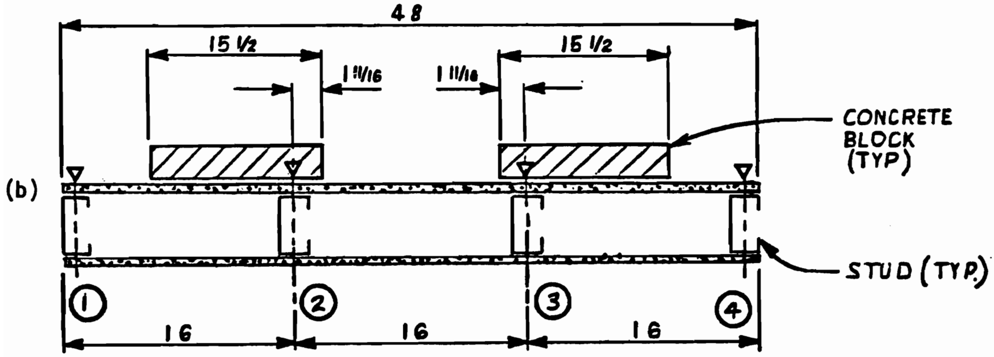


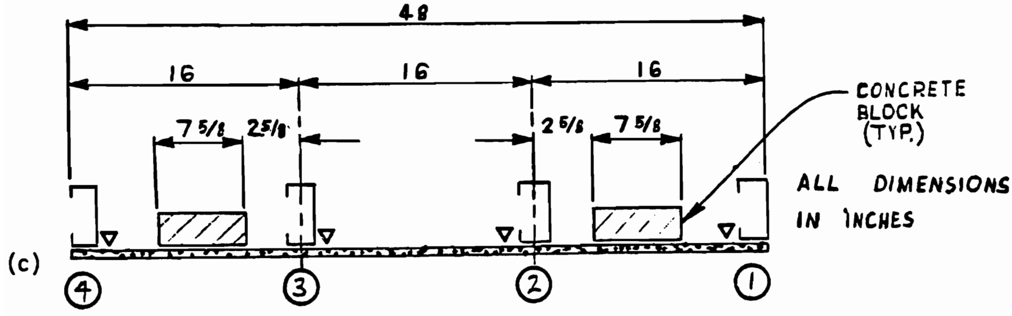
FIGURE 5 - SUPPORT DETAILS



Tests 1 to 3 - Positive Wind Load (Pressure)



Test 4 - Positive Wind Load (Pressure)



Tests 5 and 6 - Negative Wind Load (Suction)

FIGURE 6 - TYPICAL LATERAL LOAD APPLICATIONS

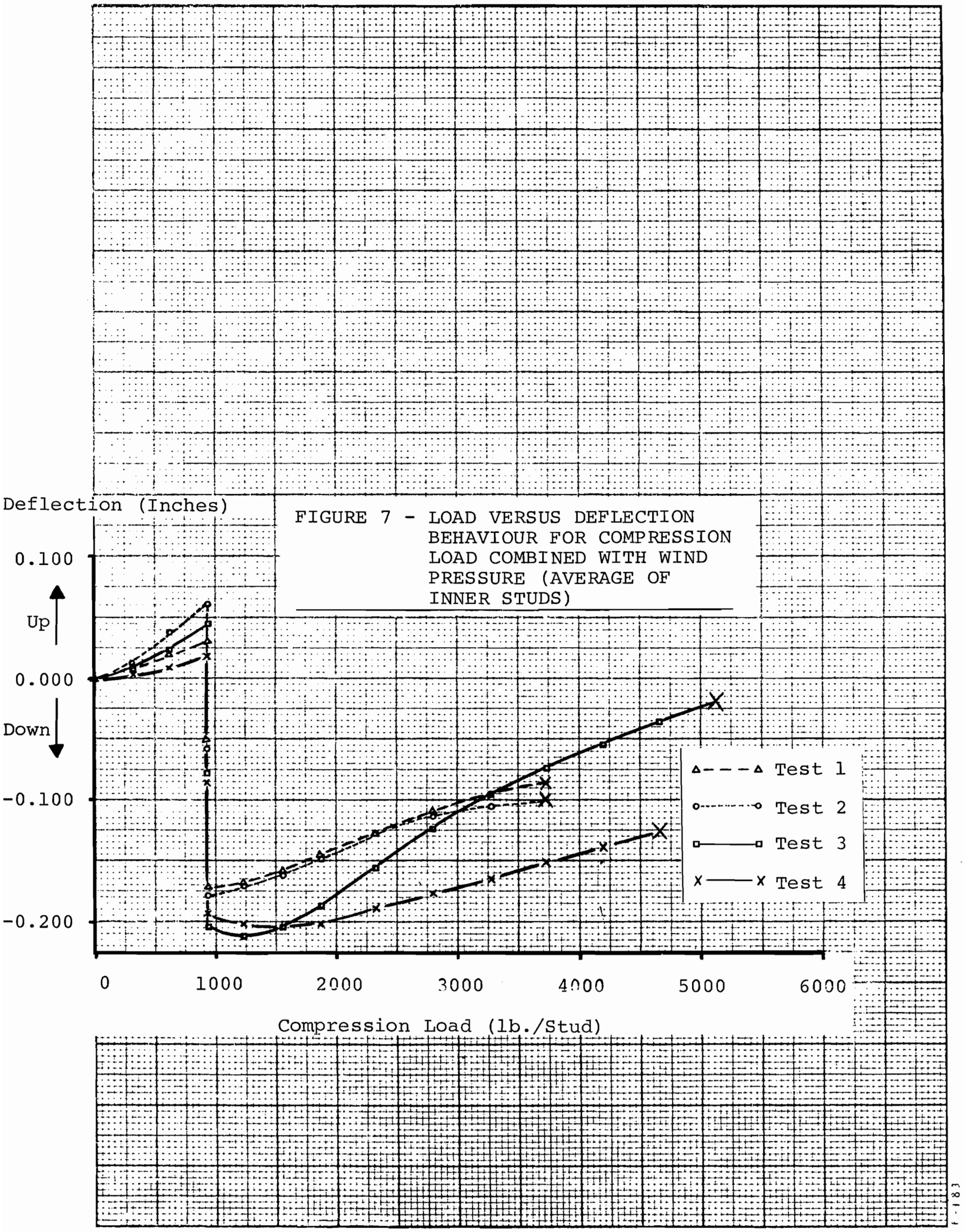


FIGURE 7 - LOAD VERSUS DEFLECTION BEHAVIOUR FOR COMPRESSION LOAD COMBINED WITH WIND PRESSURE (AVERAGE OF INNER STUDS)

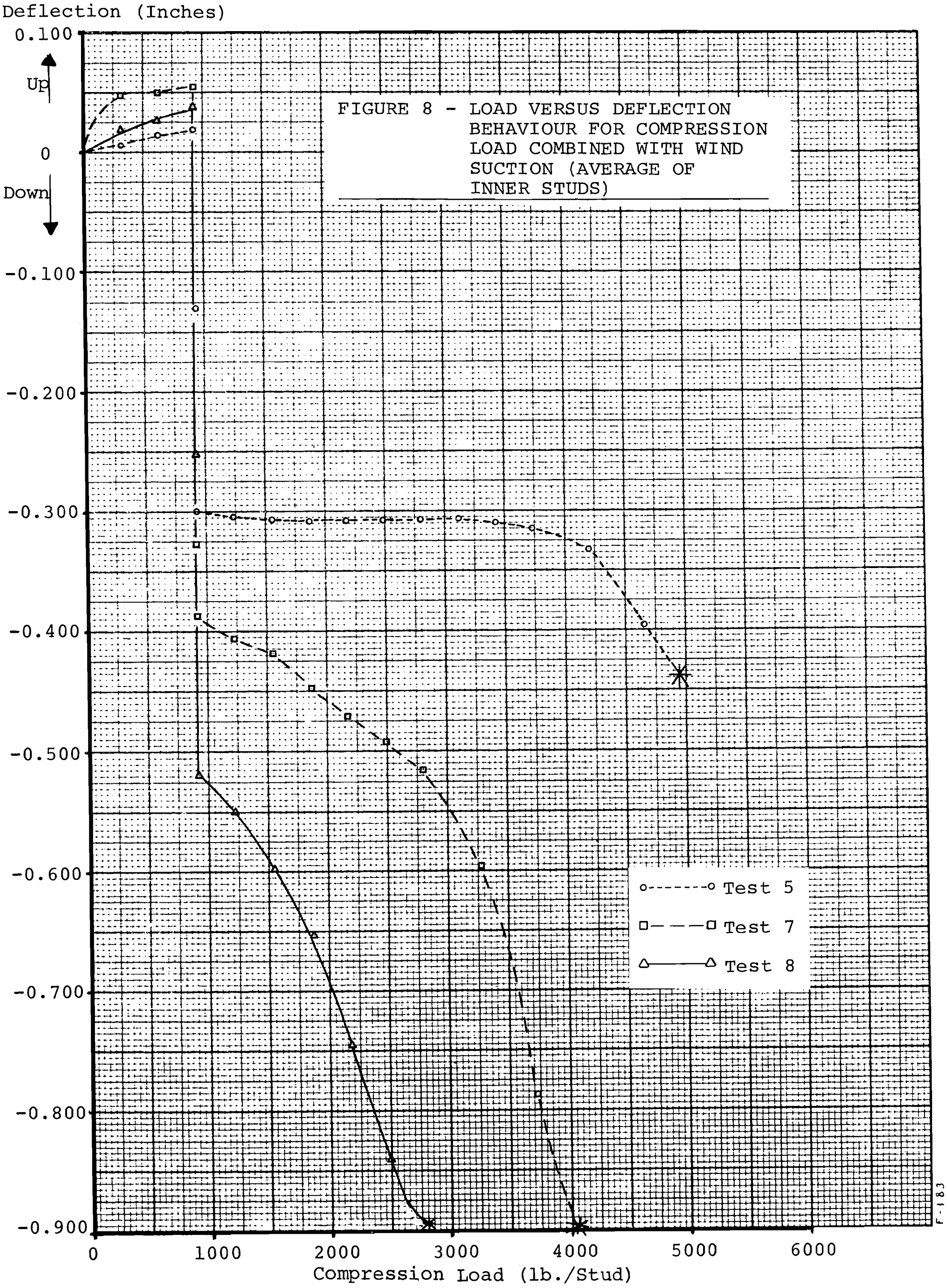


FIGURE 8 - LOAD VERSUS DEFLECTION BEHAVIOUR FOR COMPRESSION LOAD COMBINED WITH WIND SUCTION (AVERAGE OF INNER STUDS)

TABLE 1 - COMPUTED SECTION PROPERTIES OF STUD SECTIONS

STUD TYPE	t (in.)	A (in.^{2})	I_x (in.^{4})	r_x (in.)	I_y (in.^{4})	r_y (in.)	X_o (in.)	r_o^2 (in.^{2})	J (in.^{4})	C_w (in.^{6})
Plain	0.036	0.256	0.524	1.439	0.0682	0.519	1.027	3.395	0.000111	0.163
Delta	0.036	0.198	0.535	1.644	0.0565	0.534	1.167	4.350	0.0000855	0.163*
Stepped Delta	0.036	0.226	0.577	1.597	0.0526	0.482	0.802	3.425	0.0000976	0.163*

* Was conservatively taken as 0.163, based on the plain stud section.

Note: Whenever applicable, section properties were computed in accordance with CSA S136-1974 (reference 2).

TABLE 2 - MECHANICAL STEEL PROPERTIES OBTAINED FROM COUPON TESTS

MECHANICAL PROPERTIES	PLAIN AND DELTA STUDS $t = 0.036$ in.	STEPPED DELTA STUD $t = 0.036$ in.
Yield Strength (ksi)	43.30	41.39
Ultimate Strength (ksi)	55.87	56.15
Modulus of Elasticity (ksi) (times 10^3)	30.70	30.18
Percent Elongation in 2 in. Gauge Length	32.10	30.50

Note: Values in table are averages of four coupon tests for each stud type.

TABLE 3 - STUB COLUMN TEST RESULTS (AVERAGE OF THREE TESTS EACH)

STUD TYPE	F_y (ksi)	A (in.^{2})	AVERAGE P_u (lb.)	AVERAGE Q_{test}	FAILURE
Plain	43.30	0.256	6860	0.619 0.699*	Local Web Buckling
Delta	43.30	0.198	7015	0.818	Local Flange Buckling
Stepped Delta	41.39	0.226	8178	0.874	Local Flange Buckling

* Computed based on Clause 4.9 of reference 2.

Note: All stub columns were 10.0 in. long

TABLE 4 - SUMMARY OF PANEL TESTS

TEST NO.	STUD TYPE	SHEATHING	LATERAL LOAD		COMPRESSION LOAD		END CONDITION	COMPRESSION FAILURE LOAD (lb/STUD)	FAILURE MODE*
			METHOD	DIRECTION	LOCATION	OUTER STUDS			
1	Plain	1/2" Gypsum One Side	Blocks	Pressure	Concentric	Half Load	Simple Supports	3734	T-F Buckling of Studs
2	Delta	1/2" Gypsum One Side	Blocks	Pressure	Concentric	Half Load	Simple Supports	3734	Local End Buckling of Studs
3	Stepped Delta	1/2" Gypsum One Side	Blocks	Pressure	Concentric	Half Load	Simple Supports	5134	Local End Buckling of Studs
4	Stepped Delta	1/2" Gypsum Both Sides	Blocks	Pressure	Concentric	Half Load	Simple Supports	4666	Local End Buckling of Studs
5	Stepped Delta	1/2" Gypsum One Side	Blocks	Suction	Concentric	Half Load	Simple Supports	4960	T-F Buckling of Studs
6	Stepped Delta	1/2" Gypsum One Side	Blocks	Suction	Eccentric 1/4 Point	Half Load	Simple Supports	1866	Gypsum-Pull Through of Connectors
7	Stepped Delta	1/2" Plywood One Side	Vacuum	Suction	Eccentric 1/3 Point	Full Load	Semi-Fixed	4060	T-F Buckling of Studs
8	Delta	1/2" Plywood One Side	Vacuum	Suction	Eccentric 1/3 Point	Full Load	Semi-Fixed	2799	T-F Buckling of Studs
9	Delta	1/2" Gypsum Both Sides	None	None	Concentric	Full Load	Simple Supports	6998	Local End Buckling of Studs

*T-F means Torsional-Flexural Buckling

TABLE 5 - COMPUTED ULTIMATE CONCENTRIC LOADS (lb/STUD)

STUD TYPE	SHEATHING ONE SIDE ONLY		SHEATHING BOTH SIDES	
	AXIAL LOAD ONLY*	AXIAL LOAD PLUS 25 PSF WIND	AXIAL LOAD ONLY*	AXIAL LOAD PLUS 25 PSF WIND
Plain	4727	2758 (3734)	5960	3871
Delta	4375	2831 (3734)	6083 (6998)	4059
Stepped Delta	4599	2825 (5134) (4960)	7121	4588 (4666)

* AISI computer program was used.

Note: Values in brackets are test values. However, the results of the eccentric load tests (6, 7 and 8) are not shown.

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