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An exploratory study on the behavior of cold-formed steel wall studs

Yaochun Zhang

Teoman Peköz

Department of Structural Engineering
School of Civil and Environmental Engineering
Cornell University

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- Draft -

AN EXPLORATORY STUDY ON THE BEHAVIOR OF COLD-FORMED STEEL WALL STUDS

by
Yaochun Zhang
and
Teoman Peköz, Project Director

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1. GENERAL

Cold-formed steel wall studs are widely used in the U. S. and Canada. The 1980 A. I. S. I. Specification (Ref. 1) contains provisions for the design of such wall studs based primarily on the research conducted at Cornell University (Refs. 2 and 3). This research involved theoretical and experimental studies on wall studs subjected axial loads only. The Specification provisions on the case of combined axial and lateral loading were derived intuitively and were made intentionally conservative.

The excessive conservatism in the provisions for the combined loading case prevents using wall studs as economically as possible. The primary objective of the tests reported herein was to provide experimental evidence to assess the degree of conservatism in the present approach and to formulate a program for future studies. This study was not intended to result in conclusive design recommendations. The secondary objective of the study was to explore the behavior of 16 foot long wall studs that are 6 inches deep. Such applications are more common now than when the original research was conducted. The previous work was on 4 inch deep and 8 foot long wall studs.

2. TEST PROGRAM

All the tests involved lipped channel wall studs 6.07 inches deep with 1.7 inch wide flanges and .077 inch in thickness. The measured average dimensions are given in Fig. 1. Nine tensile coupons were tested and the average .2 percent offset yield stress was found to be 50.16 ksi. The average ultimate stress was 70.28 ksi. The wall board used was 1/2 inch thick gypsum. Cantilever shear tests were conducted and the results are discussed below.

2.1 WALL ASSEMBLY TESTS

Altogether 8 tests were conducted on three types of wall assemblies. The wall assembly types are shown in Fig. 2. Assembly types shown in Figs. 2a and 2b were tried first. However due to the uncertainties in the influence of the configuration on the behavior in these types of assemblies, the remaining tests were conducted on assemblies as shown in Fig. 2c. To explore the effect of the loading on the behavior, different arrangements as shown in Fig. 3 were tried.

The test results are summarized in Table 1. The deflections and rotations observed during the tests are plotted in Figs.5 through 12. In these plots u is the deflection in the

the first three tests when the axial load was applied to the studs the flanges of the end channels were wedged open. This caused a tensile force combined with a shear force in the screw on connecting the end channels and the wall studs. In general at failure these screws broke off. This might have resulted in premature failure of the entire assembly. In the subsequent tests, other channels that permitted the resting of the studs entirely on the web were used.

The axial loads were applied by hydraulic jacks. In Test 4, the lateral load was first applied by vacuum. However the wall board could not sustain the vacuum pressures that the wall stud could carry (see the footnote in Table 1). Therefore the arrangement described in Table 1 was tried. In Tests 6 and 8 first an axial load equal to the ultimate load in tests 5 and 7,respectively, divided by 1.92 was applied. Then the lateral load was applied by means of iron bricks each weighing about 26 lbs. The bricks were 12"x4" in size. Pads of homosote 1"x1" were placed at each corner of the bricks between the bricks and the wall board. This was done to reduce the effect of friction between the bricks and the wall board.

Since the assemblies were tested in a horizontal position, the dead load in all cases were present as a lateral load. The dead loads were 7.55, 6.47, 6.51 and 6.84 psf for the assemblies shown in Figs. 2a,2b,2c & 2d for 16 ft span and 2e for 8 ft span, respectively.

The ends of the stud assemblies were free to rotate about the symmetry axes of the studs due to the knife edges provided. However the rotation was restrained about the principal axes perpendicular to the symmetry axes due to the end channels and the wall board. The axial loads were aligned with the centroidal axes geometrically at the ends.

In general, the initial failure mode was not clear. Almost all the specimens had a significant amount of bending, twisting and local buckling. However, this does not give a clear indication as to how the failure was initiated. In the first three tests it is likely that the failure of the screws connecting the end channels, wall board and the studs might have initiated the failure as discussed above. Then a significant amount of bending, twisting and local buckling followed. The local buckles in each case were between the end and the quarter point in the span. In each case the failure was quite sudden and caused the specimen to jump out of the test fixture.

The failure in Test 4 is described in part in Table 1. The failure in this case was rather gradual involving large deflections.

Rather sudden failures were also observed in Tests 5 through 8. Again in each case local buckles were observed after the failure at the quarter point in the span. In Test 5 the screws were seen to bite into the wall board material several steps before failure. In general, the studs had about .5 inch sweep in 16' feet before they were connected to the wall boards. In the assemblies of Tests 1, 5, and 6, the sweep after the wall boards were attached was 1/2, 3/4 and 5/8 inches, respectively.

2.2 CANTILEVER SHEAR TESTS

The cantilever shear tests were conducted on two types of specimens as illustrated in Figs. 13 and 14. The specimen in Fig.13 is intended to simulate the conditions in the first four wall assembly tests. The specimen shown in Fig. 14 is intended to simulate conditions in the last four tests. The results are plotted and evaluated in Figs. 15 through 17. In these figures it is seen that the results are sensitive to the type of screw used. The deflections for the ultimate loads were extrapolated in each case from the last two readings before failure. In general it is not possible to measure deflections at failure.

For No. 6 screws at 12 inches with gypsum board the A. I. S. I. Specification gives values of G' and gamma as 2.0 k/in and .008 in/in, respectively. The corresponding values observed in the tests were 2.642 k/in and .011 in/in, respectively.

It is desirable to carry out several duplicate tests and additional tests for panels with No. 8 screws. The values of the wall board parameters as stipulated in the Specification and as determined in the tests will be used below in the correlation of the test results with the calculated results.

2.3 STUB COLUMN TESTS

Three stub column tests were conducted according to the A. I. S. I. Specification (Ref. 1) and Q values of .736, .720 and 693 were determined. The average of these values is .72.

3. CORRELATION OF THE TEST RESULTS WITH THOSE PREDICTED BY THE A. I. S. I. SPECIFICATION

The test results are compared with results calculated using the A. I. S. I. Specification and several variations of it in Tables 2 through 12. In Tables 2 through 4 the predicted values were obtained ignoring the dead load that was acting as a lateral load in all cases. In Tables 5 through 12 the effect of dead load as a lateral load is included in the calculations.

The variations of the Specification include using a 33%

increase in allowable stresses even though this is not applicable for the purposes of this investigation and ignoring the requirement that Fbx shall not exceed 1.7 times Fa3. This requirement is referred to in the Tables as the Fbx3 requirement. In all cases, though the Specification is not very clear on this point, the length was taken as twice the screw spacing in applying Section 3.3.

The most literal application of the Specification is used in Table 9. It is not possible to assess the accuracy of the specification for the case of axial loading only because in all cases lateral load was present at least as a result of dead load. In all the 16 ft long cases except ~~one~~ two the Specification is seen to be very conservative. In particular for example for the 16 ft long studs with 45 psf lateral loading the Specification is unsatisfactory. FOr this case it is seen that for the given lateral loading the stud is predicted to be able to carry 4.7 kips only. However in the test each stud was able to carry 12.5 kips. The results are improved but still unsatisfactorily conservative when the Fbx3 requirement is ignored. This case is studied in Table 12. The prediction for the 16 ft assembly with lateral loading is seen to be 76% conservative. The conservatism involved can be explained in part by looking at the result of Test 4.

In Test 4 only lateral loads were applied. However the distribution of the loads between the four studs is not very clear. Thus the maximum calculated bending moment depends on the assumed distribution of the loading between the studs. It is likely that the concentrated loads which were the result of pig iron blocks placed on top of the assembly were equally shared among the studs. If the vacuum loading is assumed to be distributed according to the tributary area of each stud then the maximum moment at failure can be calculated to be 95.2 k-in. Assuming the vacuum load to be equally shared between the studs the calculated maximum bending moment becomes 80.83 k-in. The yield moment assuming full lateral restraint is 66.22 k-in. If 1.7 times Fa3 were taken as the failure stress, the calculated ultimate moment would be much lower. An ultimate moment for the section can be calculated according to Section 3.9 to be 83.6 k-in which is of the same order as that calculated maximum moment. The assumption of the yield moment as the failure moment is thus seen to be very conservative. Furthermore the composite behavior of the wall board material with the studs may add to the conservatism.

The conservatism involved in treating the bending stresses also affects the calculations in a significant way when the case of combined axial and lateral loading is considered. The test evidence developed so far is indeed very inadequate to develop a design criteria. However it confirms the suspected very excessive conservatism in the Specification for the combined loading case.

4. CONCLUSIONS AND DESIRABLE FUTURE STUDIES

Based on a few tests the study herein indicates that the present A. I. S. I. Specification provisions on wall studs subjected to combined axial and lateral loads can, depending on the application, be undesirably conservative. Since the study was exploratory in nature, design provisions cannot be reached at this time.

Further systematic theoretical and experimental studies are needed to formulate a design procedure for the case of combined loading. These studies should include repeat tests of the tests conducted in this exploratory study as well as theoretical studies and tests exploring several parameters not covered here. The following are some of the points to be considered:

- Stud sizes and wall board types need to be varied.
- The effect of perforations needs to be investigated.
- The effect of local instability $(Q<1)$ needs to be investigated.
- Screw types and spacing need to be varied.
- Loading should include eccentric axial load to simulate the effect of types of loads caused by the floor joists.
- The relative magnitudes of the axial load and the lateral load

need to be varied systematically.

- Provisions need to be developed for the case of wall board only on one side as well as the case of unmatched wall materials on each flange.

- The relevance of small scale cantilever shear tests to the predictions for full scale walls needs to be established.

- Composite action with the wall board particularly for large lateral loads need to be investigated.

REFERENCES

1. "Specification for the Design of Cold-Formed Steel Structural Members", American Iron and Steel Institute, Washington, D.C., 1980 Edition.

2. Simaan A. and Pekoz, T., "Buckling of Diaphragm-Braced Columns of Unsymmetrical Sections and Application to Wall Studs Design", Department of Structural Engineering, Cornell University, Report No. 353, August 1973.

3. Simaan, A. and Pekoz, T., "Cold Formed Steel Wall Stud Design", Proceedings, of the American Society of Civil Engineers, Vol. 102, ST1, January 1976.

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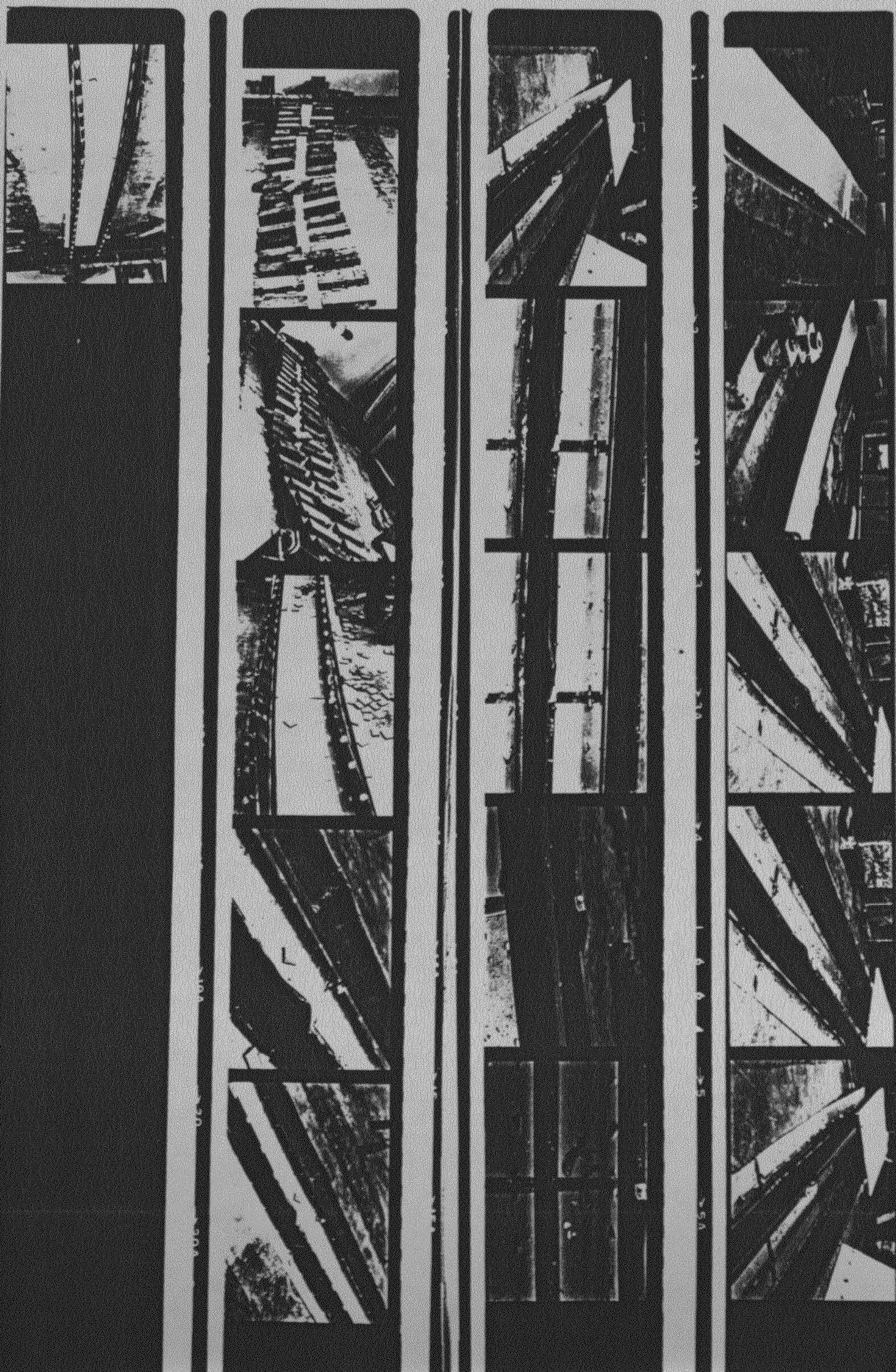


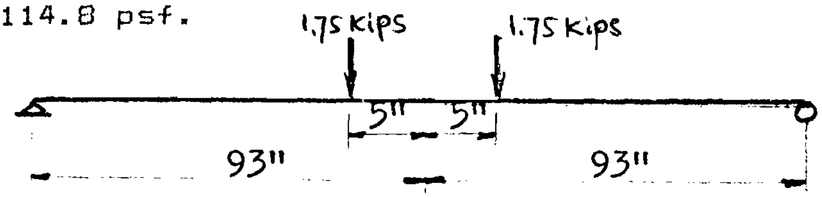
TABLE 1
WALL ASSEMBLY TEST RESULTS

TEST NO	NO OF STUDS	ASSEMBLY FIGURE	LOADING FIGURE	LENGTH (FT)	PULT (K)	LAT. LOAD
1	2	2a	3a	16	15.80	(2)
2	4	2b	3c	16	20.80	(2)
3	4	2b	3b(1)	16	11.00	(2)
4	4	2b	3d	16	0.00	(3)
5	2	2c	3a	16	16.00	(2)
6	2	2c	3a	16	12.50	(4)
7	2	2c	3a	8	23.14	(2)
8	2	2c	3a	8	25.96	(4)

(1) Interior studs were loaded to twice the axial load of the end studs

(2) Dead load of the assembly was the only lateral load

(3) Wall board failed at a vacuum of 82 psf. The wall board was replaced and a 1/2 inch layer of plywood was placed on the assembly. The concentrated loads shown in the figure below were applied. Then a vacuum was drawn. The failure ocurred at a vacuum of 114.8 psf.



(4) 45 psf lateral load in addition to the dead load

TABLE 2
EVALUATION OF TEST RESULTS

G= 2000 lb/in.

	TEST 1	TEST 5	TEST 7
PT	15.80	16.00	23.14
P1	12.20	17.40	21.60
P2	9.20	13.10	17.70
PT/P1	1.30	0.92	1.07
PT/P2	1.72	1.22	1.31

All loads in kips.
PT Test ultimate axial load
P1 Calculated using gamma= 0.014 in/in
P2 calculated using gamma= 0.008 in/in

TABLE 3
EVALUATION OF TEST RESULTS

G= 2000 lb/in.

	TEST 2	TEST 3
PET	20.28	11.00
PIT	20.28	22.00
PE1	12.20	12.20
PE2	9.20	9.20
PI1	17.00	17.00
PI2	12.80	12.80
PET/PE1	1.70	0.90
PET/PE2	2.26	1.20
PET/PI1	1.22	1.29
PIT/PI2	1.63	1.72

All loads in kips.
PET Test ultimate axial load for end studs

PIT Test ultimate load for interior studs

PE1 Calculated ultimate load for end studs using gamma= 0.014

PE2 Calculated ultimate load for end studs using gamma= 0.008

PI1 Calculated ultimate load for interior studs using gamma= 0.014

PI2 Calculated ultimate load for interior studs using gamma= 0.008

TABLE 4
EVALUATION OF TEST RESULTS

G= 2000 lb/in.

	TEST 6	TEST 8
PT	12.50	25.96
P11	8.90	25.40
P12	4.70	20.40
P21	4.30	18.20
P22	1.30	14.50
P31	12.50	26.00
P32	10.00	21.40
P41	7.50	18.80
P42	6.10	15.50
PT/P11	1.40	1.02
PT/P12	2.66	1.27
PT/P21	2.91	1.43
PT/P22	9.62	1.79
PT/P31	1.00	1.00
PT/P32	1.25	1.21
PT/P41	1.67	1.38
PT/P42	2.05	1.67

All loads in kips.
PT Test ultimate axial load
P11 Calculated with 1.33 factor and gamma=.014
P12 Calculated with 1.33 factor and gamma=.008
P21 Calculated without 1.33 factor and gamma=.014
P22 Calculated without 1.33 factor and gamma=.008
P31 P11 without the Fbx3 requirement (L=2xscrew spacing)
P32 P12 without the Fbx3 requirement (L=2xscrew spacing)
P41 P21 without the Fbx3 requirement (L=2xscrew spacing)
P42 P22 without the Fbx3 requirement (L=2xscrew spacing)

TABLE 5

EVALUATION OF TEST RESULTS

G=2000 lb/in
(without 1.33 factor)

TEST NUMBER	PT1	PT2	P11	P12	P21	P22	PT1/P11	PT1/P12	PT2/P21	PT2/P22
1	15.80		7.7	10.5			2.05	1.50		
2	20.80	20.80	7.7	10.5	9.5	13.1	2.70	1.98	2.19	1.59
3	11.00	22.00	7.7	10.5	9.5	13.1	1.43	1.05	2.32	1.68
5	16.00		10.5	14.2			1.52	1.13		
6	12.50		0.0	3.0			*	4.17		
7	23.14		17.2	21.0			1.35	1.10		
8	25.96		14.0	17.7			1.85	1.31		

* Axial tensile force required in order to have failure at the given lateral load.

All loads in kips
The dead load is taken to be 7 psf.
PT1 Test ultimate axial load of end studs.
PT2 Test ultimate axial load of interior studs.
P11 Calculated with gamma = .008 in/in for end studs.
P12 Calculated with gamma = .014 in/in for end studs.
P21 Calculated with gamma = .008 in/in for interior studs.
P22 Calculated with gamma = .014 in/in for interior studs.

TABLE 6

EVALUATION OF TEST RESULTS

G=2000 lb/in
(without Fbx3 requirement)
(with 1.33 factor)

TEST NUMBER	PT1	PT2	P11	P12	P21	P22	PT1/P11	PT1/P12	PT2/P21	PT2/P22
1	15.80		11.7	15.4			1.35	1.03		
2	20.80	20.80	11.7	15.4	15.3	19.9	1.78	1.35	1.36	1.05
3	11.00	22.00	11.7	15.4	15.3	19.9	0.94	0.71	1.44	1.11
5	16.00		16.0	20.9			1.00	0.77		
6	12.50		9.1	11.30			1.37	1.11		
7	23.14		23.2	28.3			1.00	0.82		
8	25.96		21.1	25.6			1.23	1.01		

All loads in kips
The dead load is taken to be 7 psf.
PT1 Test ultimate axial load of end studs.
PT2 Test ultimate axial load of interior studs.
P11 Calculated with gamma = .008 in/in for end studs.
P12 Calculated with gamma = .014 in/in for end studs.
P21 Calculated with gamma = .008 in/in for interior studs.
P22 Calculated with gamma = .014 in/in for interior studs.

TABLE 7

EVALUATION OF TEST RESULTS

G=2000 lb/in
(without Fbx3 requirement)
(without 1.33 factor)

TEST NUMBER	PT1	PT2	P11	P12	P21	P22	PT1/P11	PT1/P12	PT2/P21	PT2/P22
1	15.80		8.6	11.4			1.84	1.39		
2	20.80	20.80	8.6	11.4	11.1	14.3	2.42	1.82	1.87	1.45
3	11.00	22.00	8.6	11.4	11.1	14.3	1.28	0.96	1.98	1.54
5	16.00		11.7	15.2			1.37	1.05		
6	12.50		5.2	6.5			2.40	1.92		
7	23.14		17.3	21.1			1.34	1.10		
8	25.96		15.2	18.4			1.71	1.41		

All loads in kips
The dead load is taken to be 7 psf.
PT1 Test ultimate axial load of end studs.
PT2 Test ultimate axial load of interior studs.
P11 Calculated with gamma = .008 in/in for end studs.
P12 Calculated with gamma = .014 in/in for end studs.
P21 Calculated with gamma = .008 in/in for interior studs.
P22 Calculated with gamma = .014 in/in for interior studs.

TABLE 8

EVALUATION OF TEST RESULTS

G=2000 lb/in
(with 1.33 factor)

TEST NUMBER	PT1	PT2	P11	P12	P21	P22	PT1/P11	PT1/P12	PT2/P21	PT2/P22
1	15.80		10.7	14.5			1.48	1.09		
2	20.80	20.80	10.7	14.5	13.70	18.60	1.94	1.43	1.52	1.12
3	11.00	22.00	10.7	14.5	13.70	18.60	1.03	0.76	1.61	1.18
5	16.00		14.7	19.9			1.09	0.80		
6	12.50		3.2	7.3			3.91	1.71		
7	23.14		23.1	28.2			1.01	0.82		
8	25.96		19.9	24.9			1.30	1.06		

All loads in kips
The dead load is taken to be 7 psf.
PT1 Test ultimate axial load of end studs.
PT2 Test ultimate axial load of interior studs.
P11 Calculated with gamma = .008 in/in for end studs.
P12 Calculated with gamma = .014 in/in for end studs.
P21 Calculated with gamma = .008 in/in for interior studs.
P22 Calculated with gamma = .014 in/in for interior studs.

TABLE 9

EVALUATION OF TEST RESULTS

(without 1.33 factor)

TEST NUMBER	PT1	PT2	P1	P2	PT1/P1	PT2/P2
1	15.80		11.3		1.40	
2	20.80	20.80	11.3	14.5	1.84	1.43
3	11.00	22.00	11.3	14.5	0.97	1.52
5	16.00		16.4		0.98	
6	12.50		4.7		2.66	
7	23.14		25.3		0.91	
8	25.96		21.9		1.19	

All loads in kips
The dead load is taken to be 7 psf.
For test 1 and end studs of test 2,3, G = 3800 lb/in, gamma = 0.009 in/in
For interior studs of test 2,3, G=2600 lb/in, gamma = 0.011 in/in
For test 5.6.7 and 8, G=5600 lb/in, gamma = 0.007 in/in , b=11.94 in
P1 calculated for end studs
P2 calculated for interior studs

TABLE 10

EVALUATION OF TEST RESULTS

(with 1.33 factor)

TEST NUMBER	PT1	PT2	P1	P2	PT1/P1	PT2/P2
1	15.80		15.6		1.01	
2	20.80	20.80	15.6	20.5	1.33	1.01
3	11.00	22.00	15.6	20.5	0.71	1.07
5	16.00		22.9		0.70	
6	12.50		9.7		1.29	
7	23.14		33.9		0.68	
8	25.96		30.4		0.85	

All loads in kips
The dead load is taken to be 7 psf.
For test 1 and end studs of test 2,3, G = 3800 lb/in, gamma = 0.009 in/in
For interior studs of test 2,3, G=2600 lb/in, gamma = 0.011 in/in
For test 5.6.7 and 8, G=5600 lb/in, gamma = 0.007 in/in , b=11.94 in
P1 calculated for end studs
P2 calculated for interior studs

TABLE 11

EVALUATION OF TEST RESULTS

(with 1.33 factor)
(without Fbx3 requirement)

TEST NUMBER	PT1	PT2	P1	P2	PT1/P1	PT2/P2
1	15.80		16.5		0.96	
2	20.80	20.80	16.5	21.6	1.26	0.96
3	11.00	22.00	16.5	21.6	0.67	1.02
5	16.00		23.7		0.68	
6	12.50		12.5		1.00	
7	23.14		33.9		0.68	
8	25.96		30.5		0.85	

All loads in kips
The dead load is taken to be 7 psf.
For test 1 and end studs of test 2,3, G = 3800 lb/in, gamma = 0.009 in/in
For interior studs of test 2,3, G=2600 lb/in, gamma = 0.011 in/in
For test 5.6.7 and 8, G=5600 lb/in, gamma = 0.007 in/in , b=11.94 in
P1 calculated for end studs
P2 calculated for interior studs

TABLE 12

EVALUATION OF TEST RESULTS

(without 1.33 factor)
(without Fbx3 requirement)

TEST NUMBER	PT1	PT2	P1	P2	PT1/P1	PT2/P2
1	15.80		12.2		1.30	
2	20.80	20.80	12.2	15.5	1.70	1.34
3	11.00	22.00	12.2	15.5	0.90	1.42
5	16.00		17.1		0.94	
6	12.50		7.1		1.76	
7	23.14		25.3		0.91	
8	25.96		21.9		1.19	

All loads in kips
The dead load is taken to be 7 psf.
For test 1 and end studs of test 2,3, G = 3800 lb/in, gamma = 0.009 in/in
For interior studs of test 2,3, G=2600 lb/in, gamma = 0.011 in/in
For test 5.6.7 and 8, G=5600 lb/in, gamma = 0.007 in/in , b=11.94 in
P1 calculated for end studs
P2 calculated for interior studs

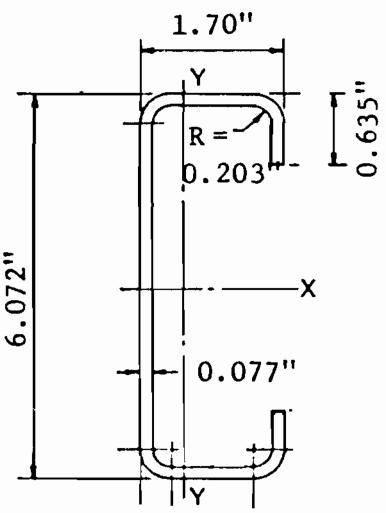


Fig. 1 Stud Section

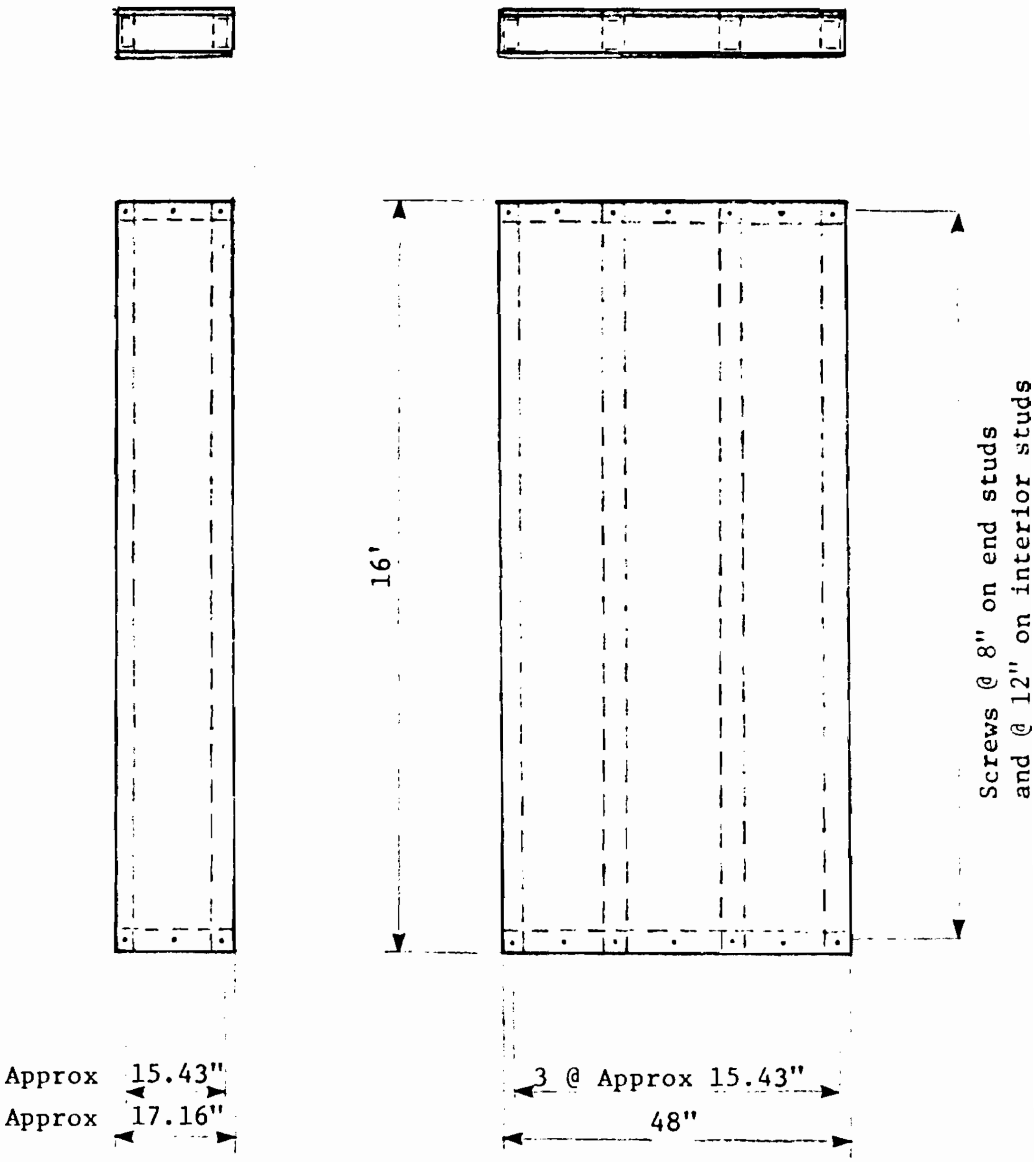
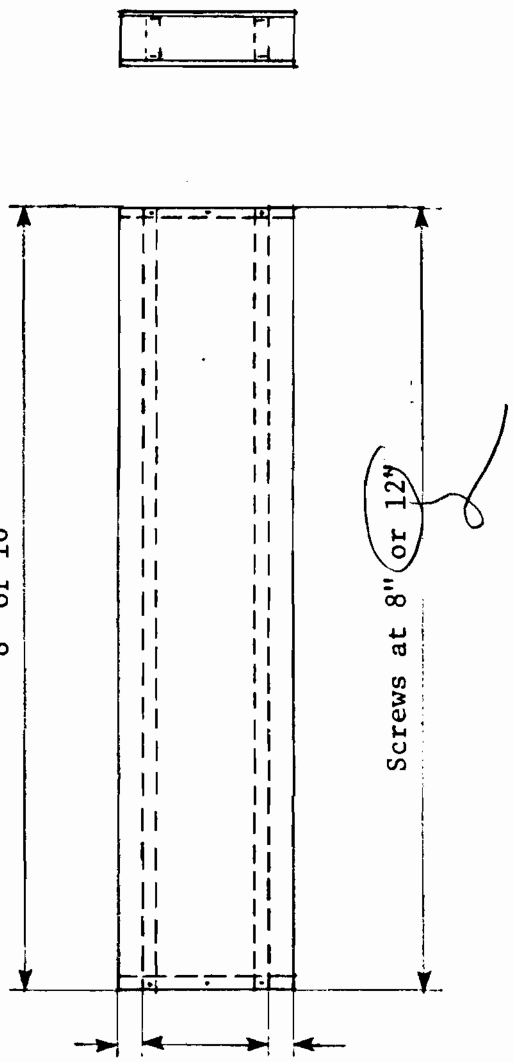


Fig. 2a

Fig. 2b

Fig. 2 Test Assemblies



Approx 4" 15.9" 4"

Fig. 2c

Fig. 2 Test Assemblies (cont.)

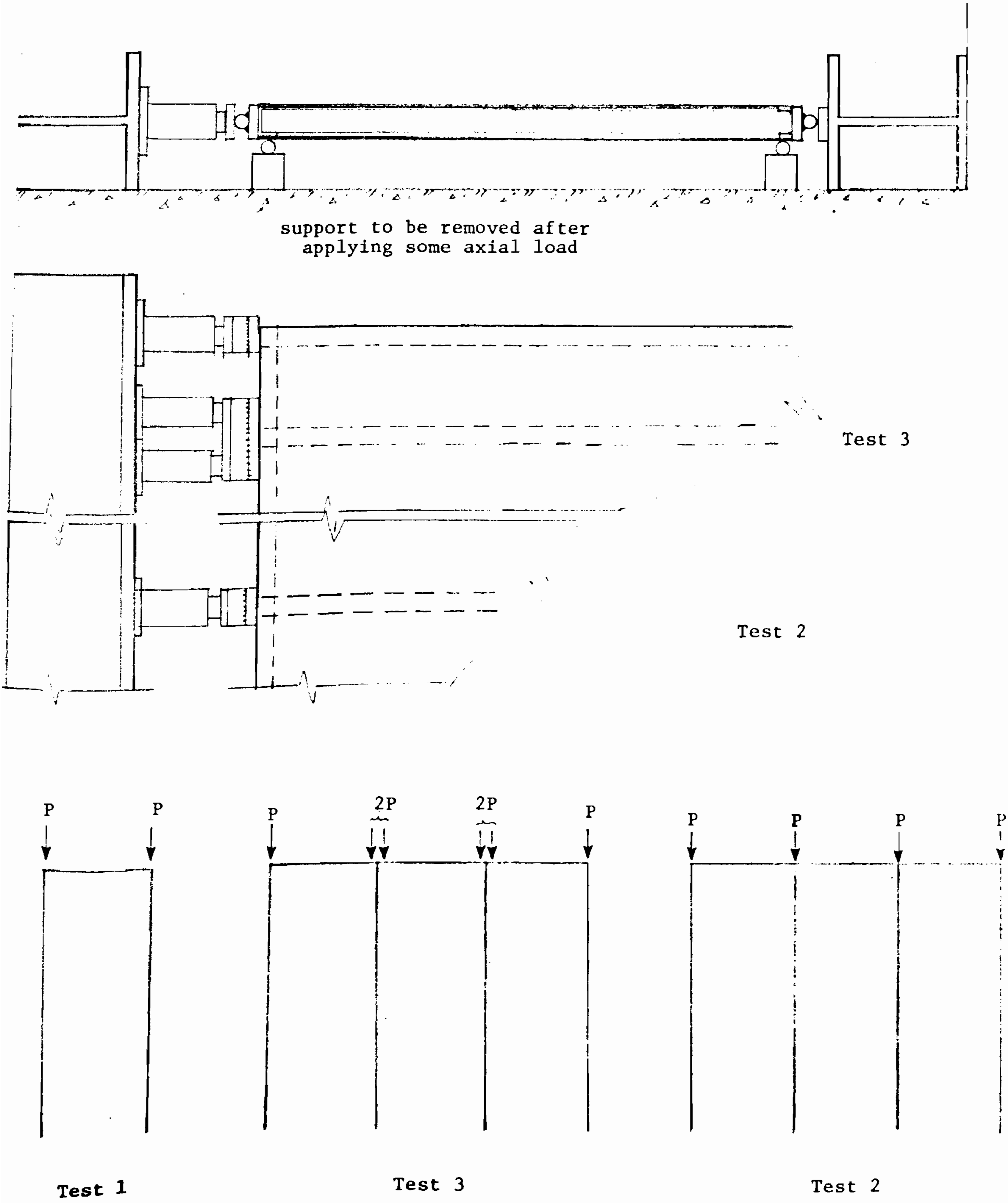


Fig. 3 Loading Schemes

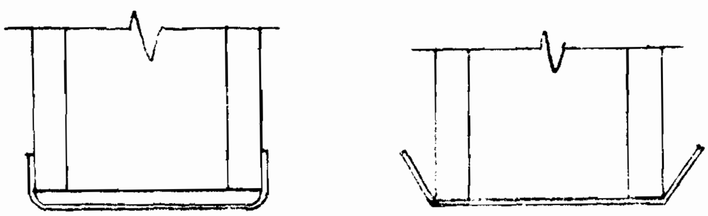


Fig. 4 End Channel

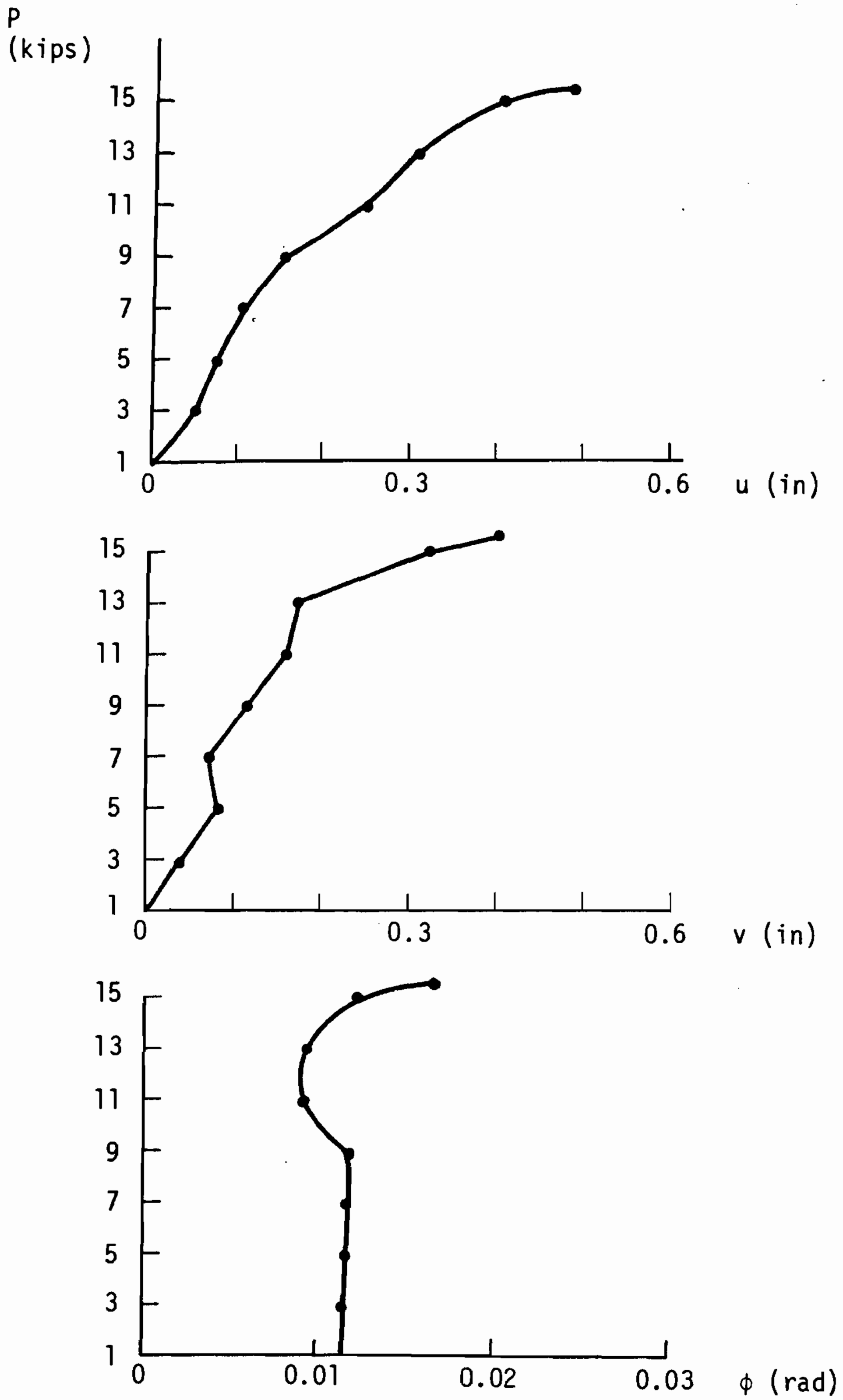


Fig. 5a Load-Deformation Curves for Test 1, Stud 1

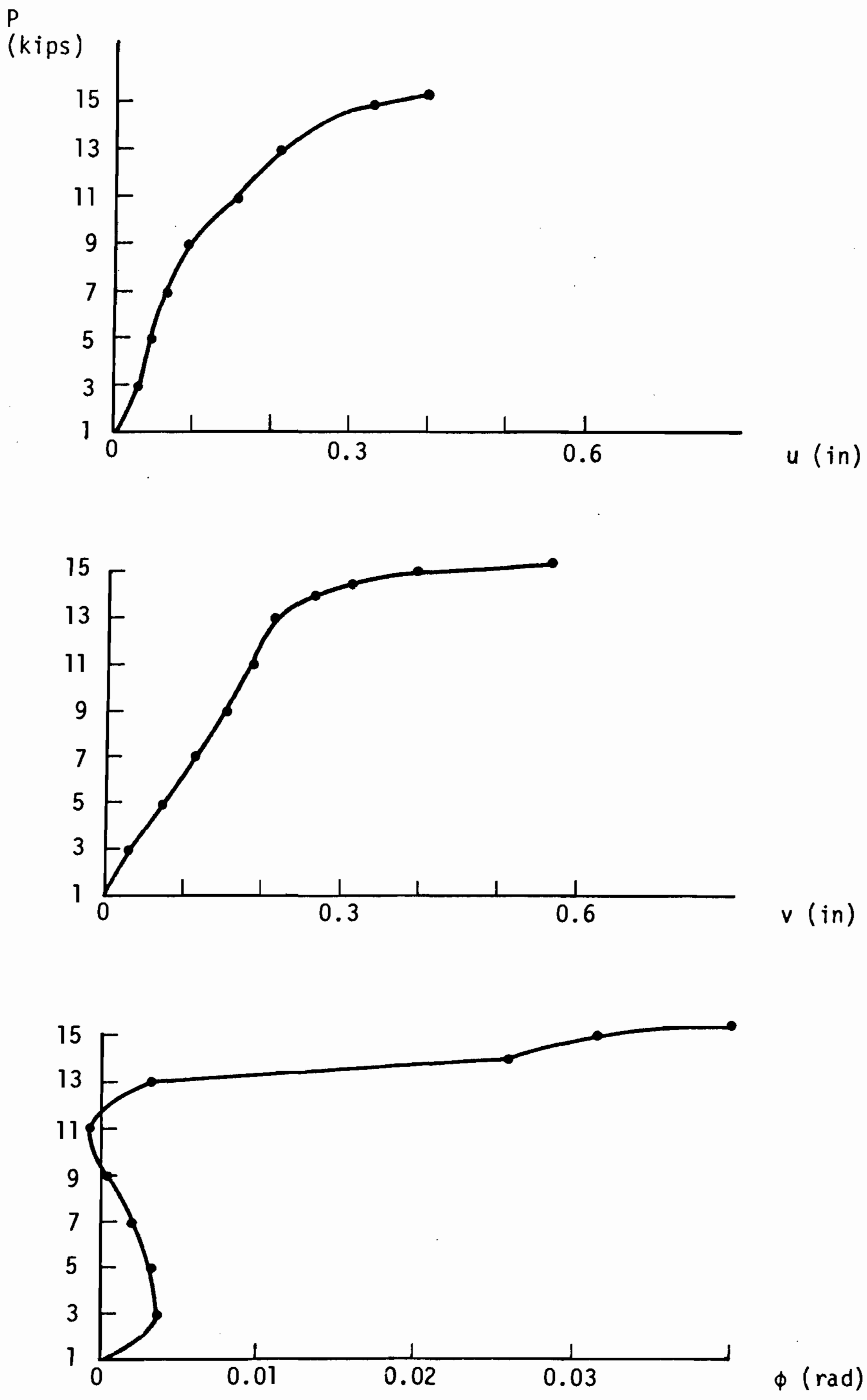


Fig. 5b Load-Deformation Curves for Test 1, Stud 2

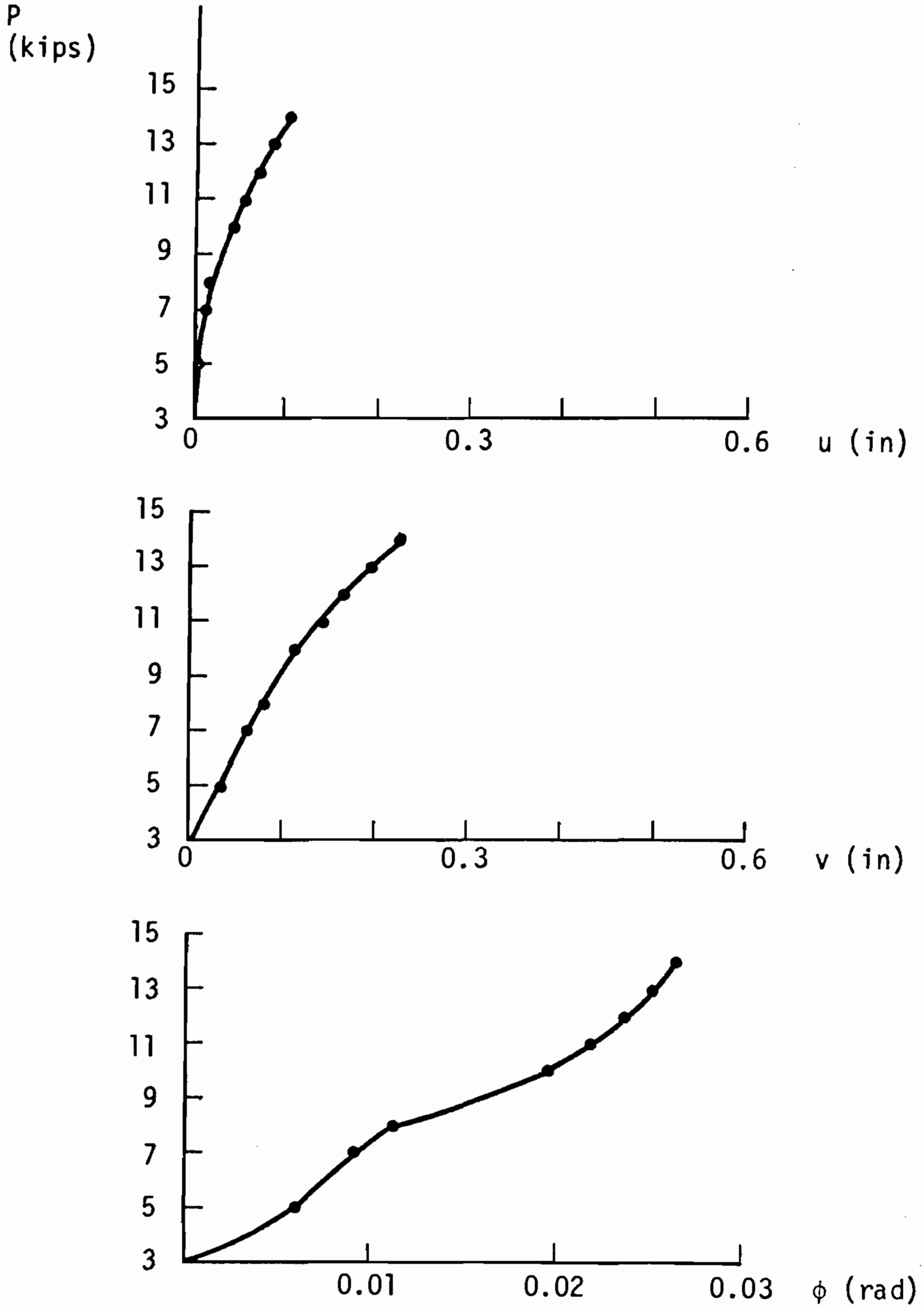


Fig. 6 Load-Deformation Curves for Test 2

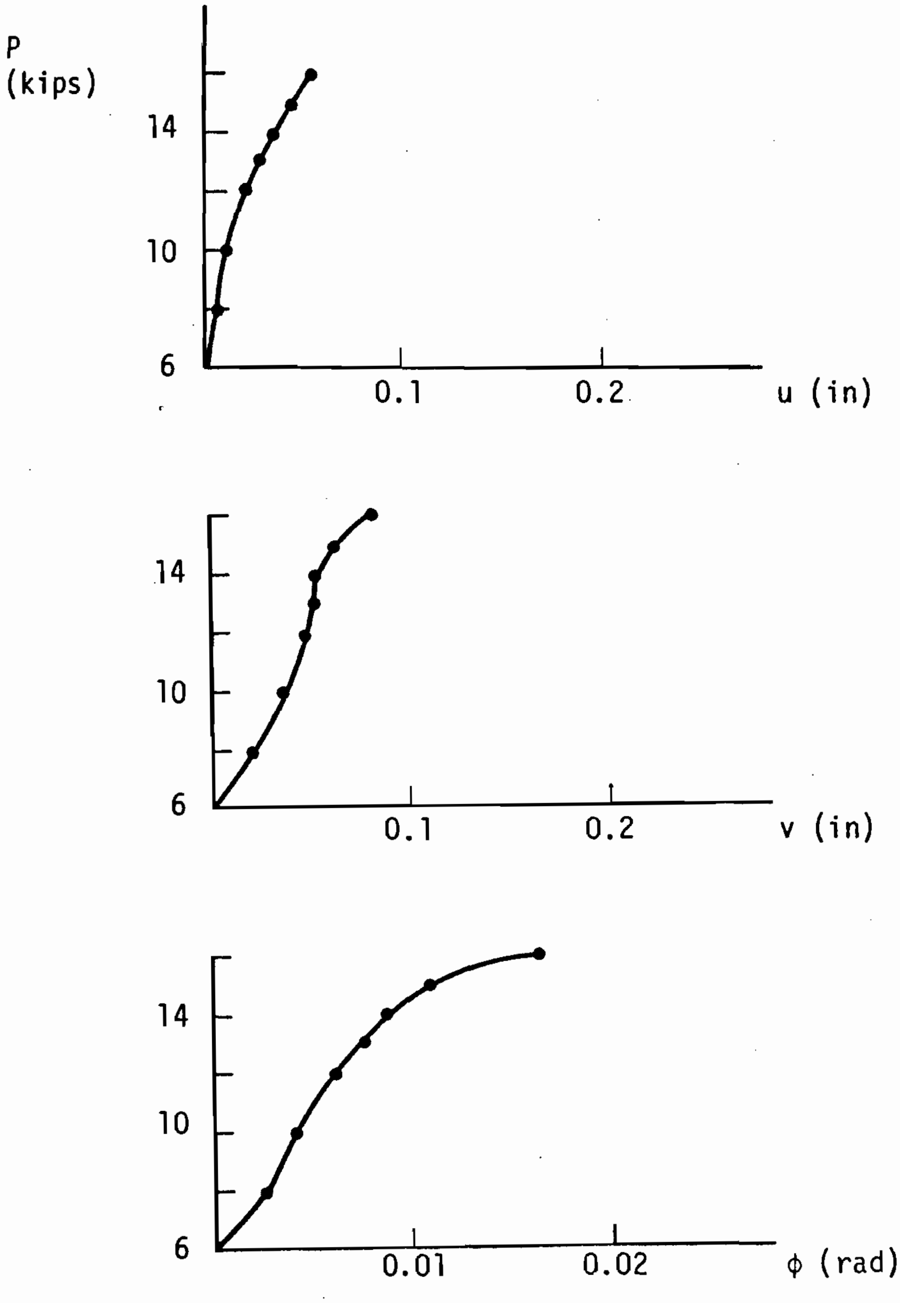


Fig. 7 Load-Deformation Curves for Test 3

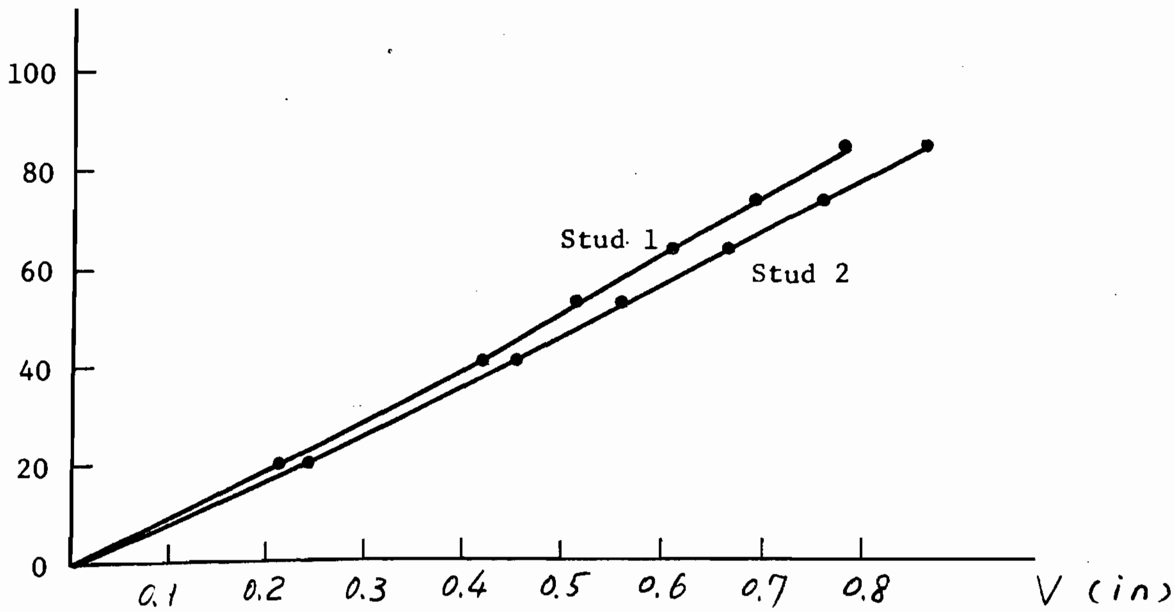


Fig. 8 Load-Deflection Curves for Test 4

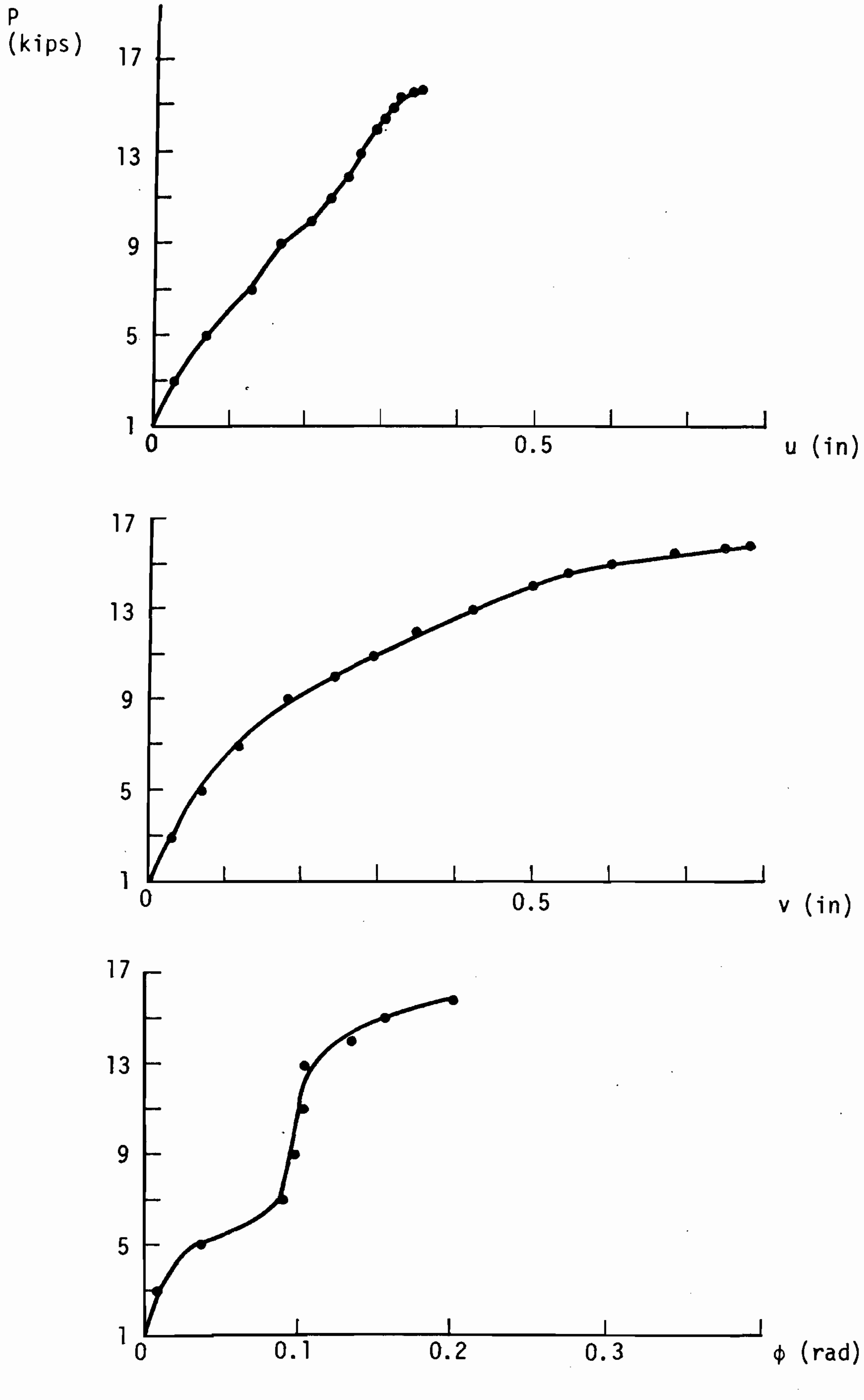


Fig. 9 Load-Deformation Curves for Test 5

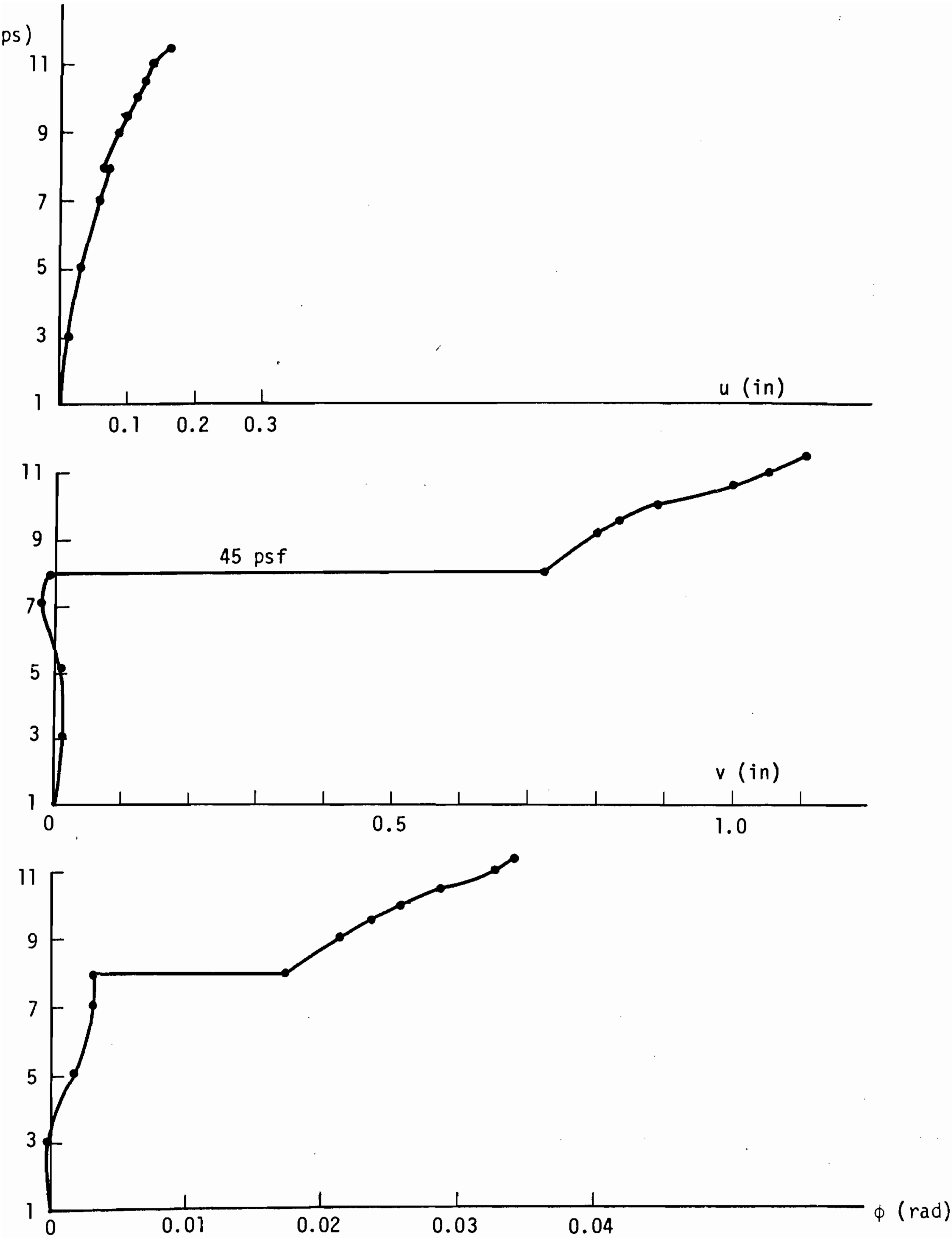


Fig. 10 Load-Deformation Curves for Test 6

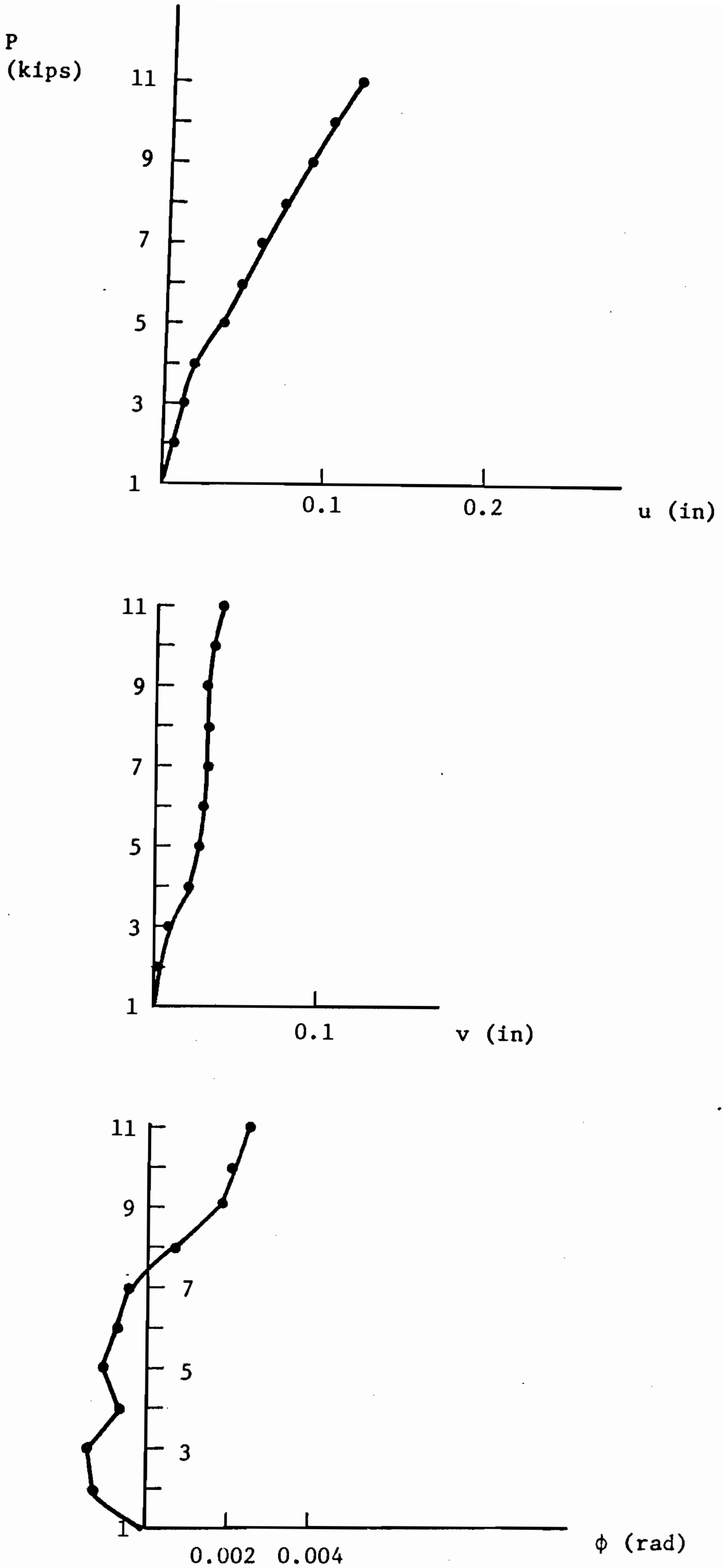


Fig. 11 Load-Deformation Curves for Test 7

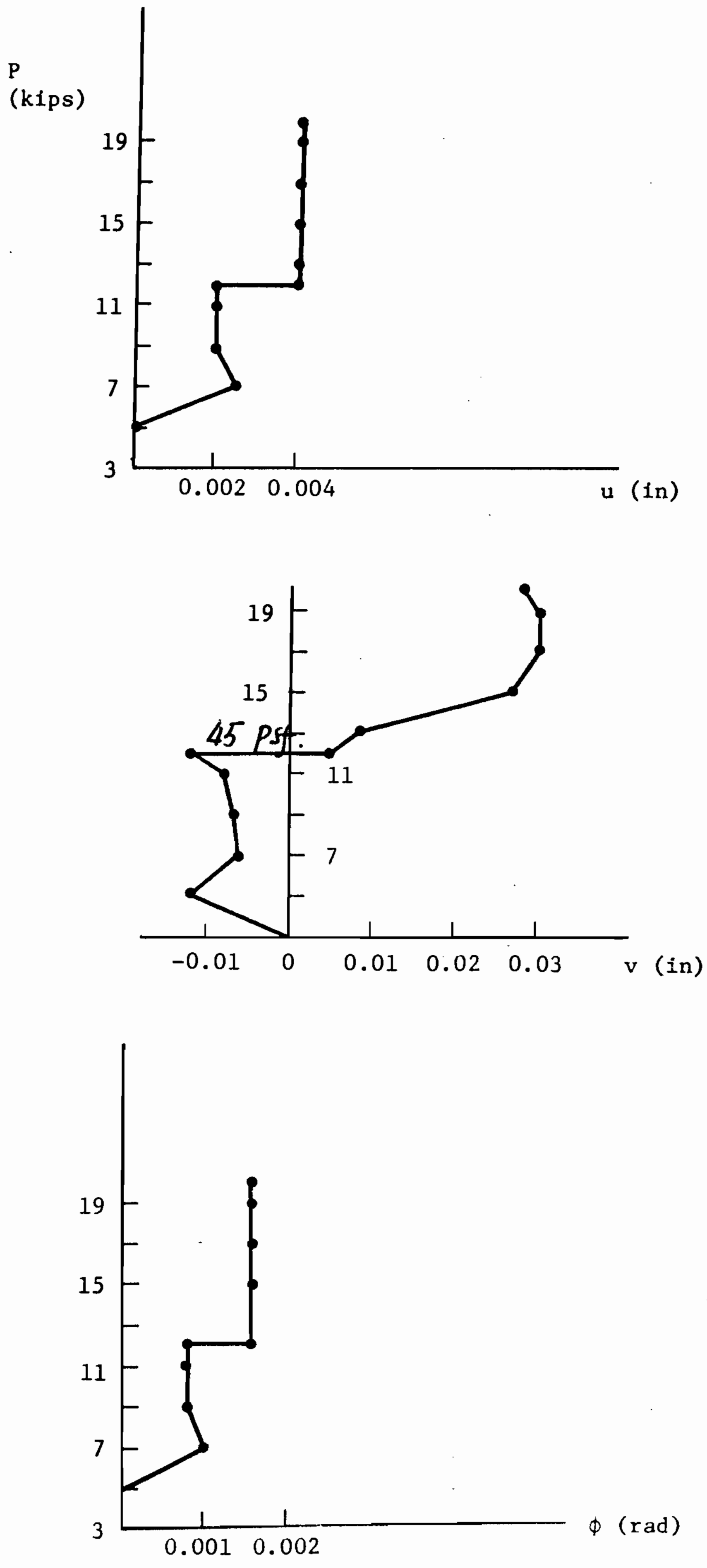


Fig. 12 Load-Deformation Curves for Test 8

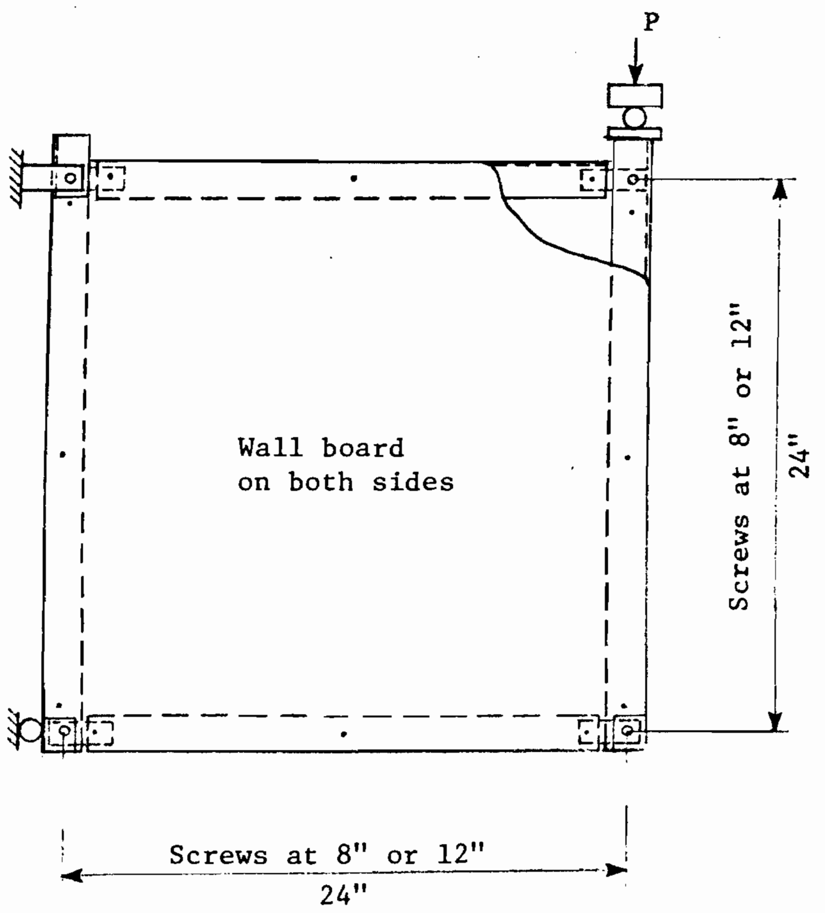


Fig. 13 Cantilever Shear Test Set-up

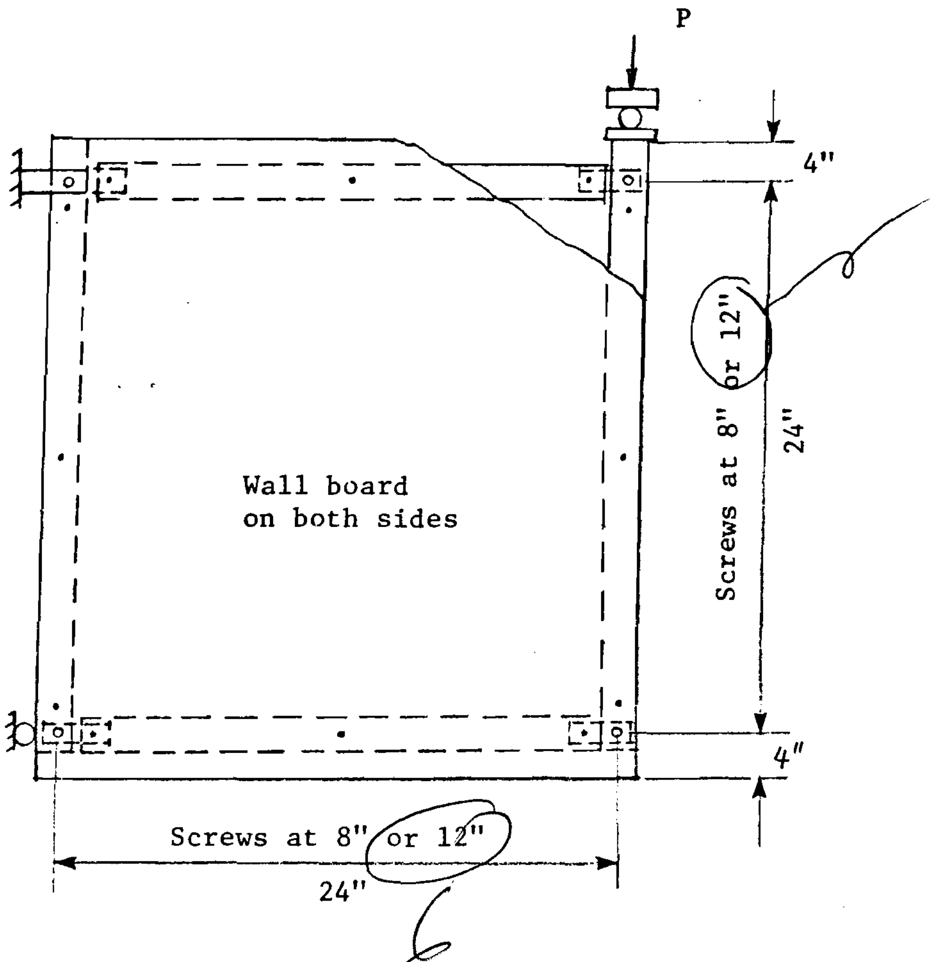


Fig. 14 Cantilever Shear Test Set-up

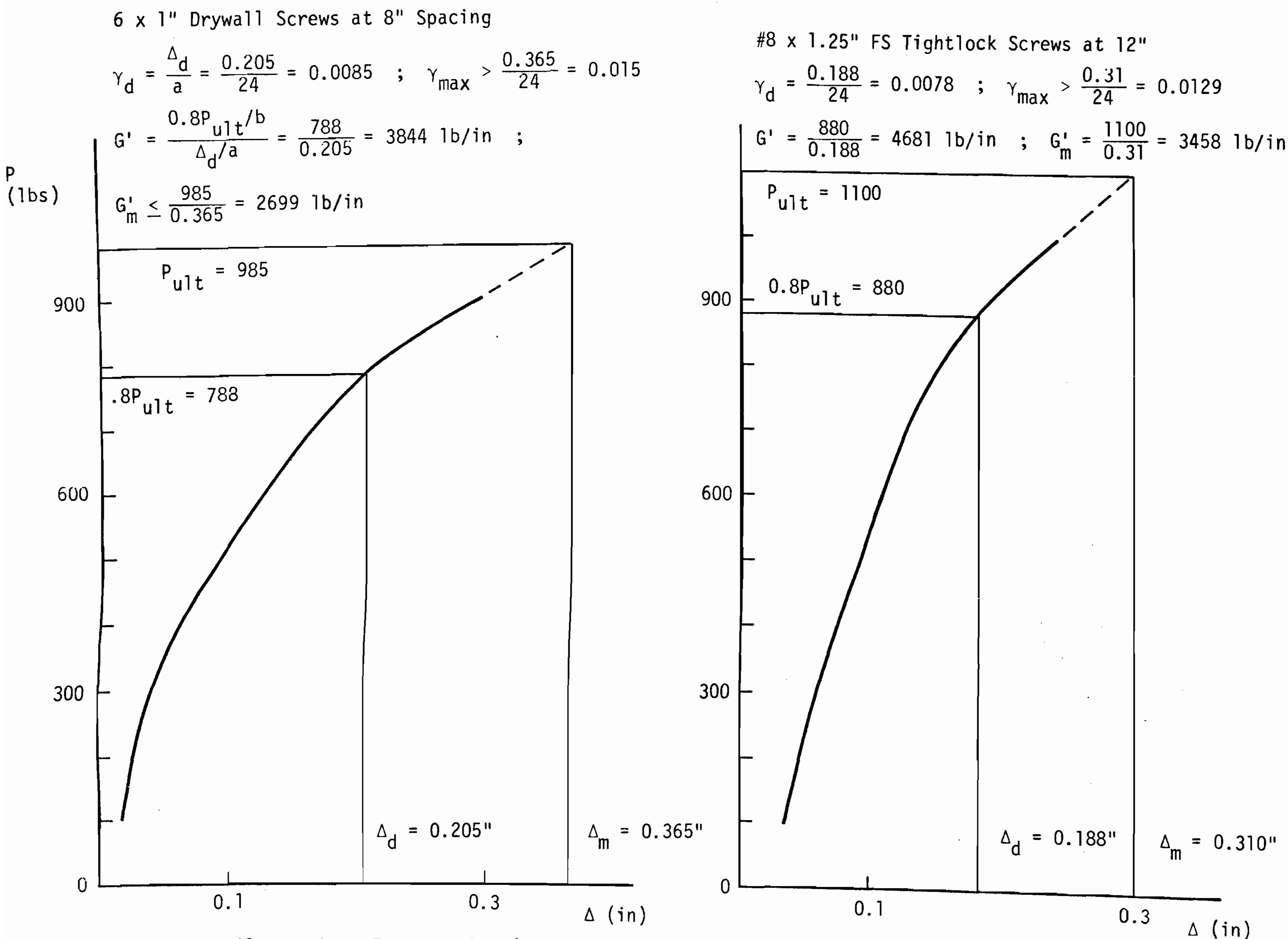


Fig. 15 Cantilever Shear Test Results (Specimen as shown in Fig. 13)

6 x 1" Drywall Screws at 12" Spacing

$$\gamma_d = \frac{\Delta_d}{a} = \frac{0.265}{24} = 0.011 \quad ; \quad \gamma_{max} > \frac{0.44}{24} = 0.018$$

$$G' = \frac{0.8P_{ult}/b}{\Delta_d/a} = \frac{700}{0.265} = 2642 \text{ lb/in}$$

$$G'_m < \frac{875}{0.44} = 1989 \text{ lb/in}$$

#8 x 1.25" FS Tightlock Screws at 8"

$$\gamma_d = \frac{0.17}{24} = 0.007 \quad ; \quad \gamma_{max} > \frac{0.26}{24} = 0.011$$

$$G' = \frac{716}{0.17} = 4212 \text{ lb/in}$$

$$G'_m < \frac{895}{0.26} = 3442 \text{ lb/in}$$

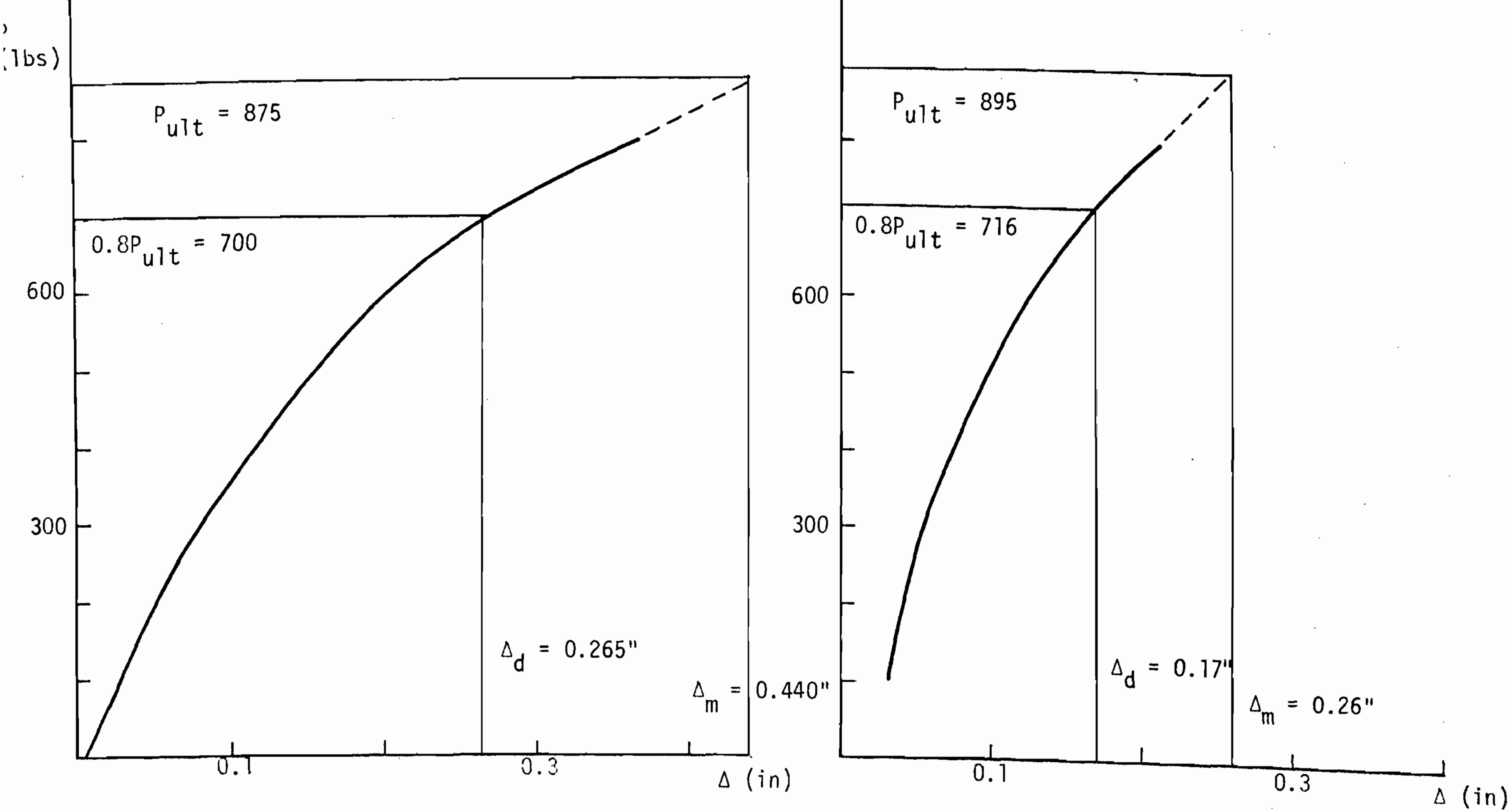


Fig. 16 Cantilever Shear Test Results (Specimen as shown in Fig. 13)

#8 x 1.25 FS Tightlock Screws at 8"

$$\gamma_d = \frac{0.165}{24} = 0.0068 \quad ; \quad \gamma_{max} > 0.0133 \text{ lb/in}$$

$$G' = \frac{916}{0.165} = 5552 \quad ; \quad G'_m < \frac{1145}{0.318} = 3601 \text{ lb/in}$$

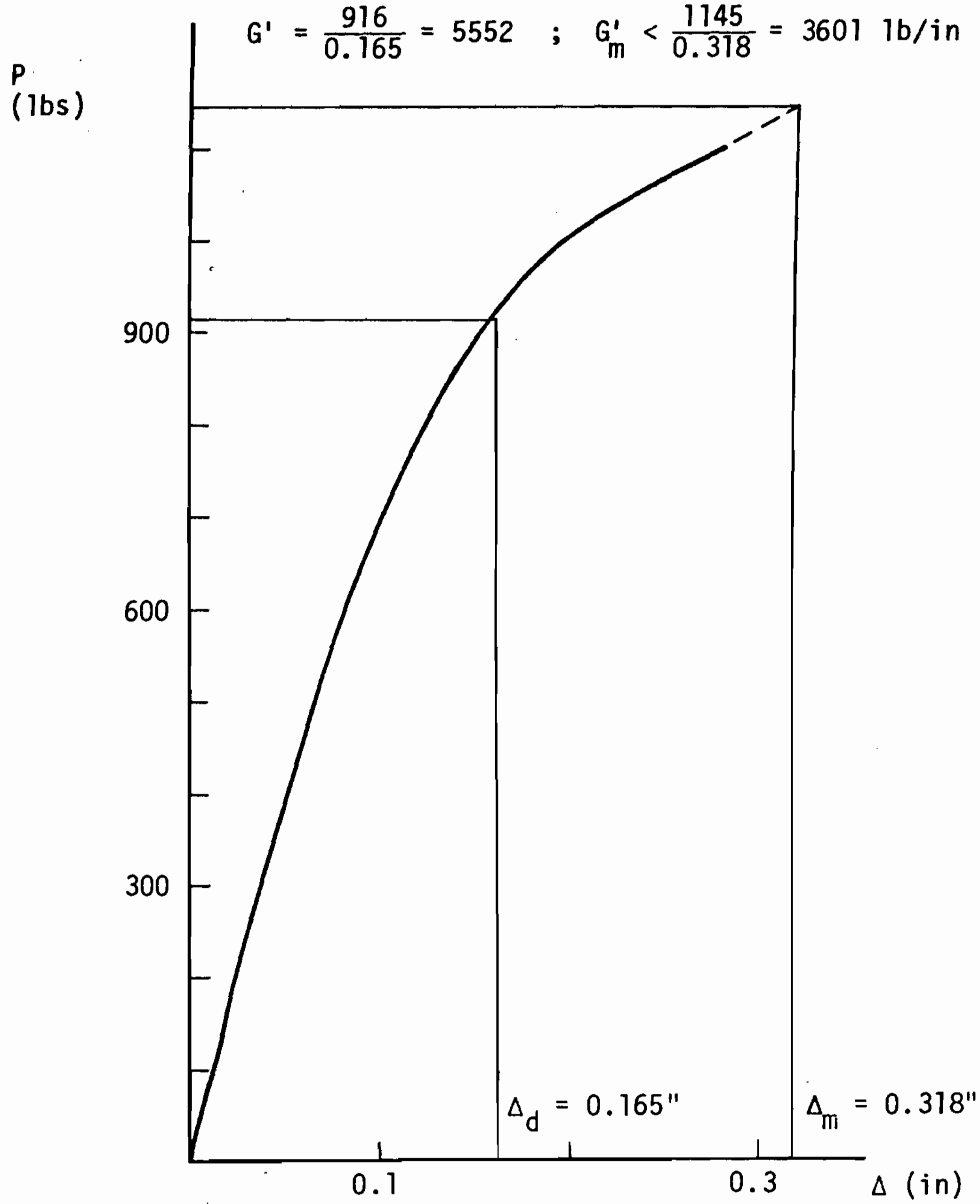


Fig. 17 Cantilever Shear Test Results
(Specimen as shown in Fig. 14)

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1982

An Exploratory Study on the Behavior
of Cold-Formed Steel Wall Studs

Draft

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Department of Structural Engineering
School of Civil and Environmental Engineering
Cornell University

Report No. 82-

- Draft -

AN EXPLORATORY STUDY ON THE BEHAVIOR OF COLD-FORMED STEEL WALL STUDS

by

Yaochun Zhang

and

Teoman Peköz, Project Director

A Research Project Sponsored by
The American Iron and Steel Institute

Ithaca, N.Y. July 1982

1. GENERAL

Cold-formed steel wall studs are widely used in the U. S. and Canada. The 1980 A. I. S. I. Specification (Ref. 1) contains provisions for the design of such wall studs based primarily on the research conducted at Cornell University (Refs. 2 and 3). This research involved theoretical and experimental studies on wall studs subjected axial loads only. The Specification provisions on the case of combined axial and lateral loading were derived intuitively and were made intentionally conservative.

The excessive conservatism in the provisions for the combined loading case prevents using wall studs as economically as possible. The primary objective of the tests reported herein was to provide experimental evidence to assess the degree of conservatism in the present approach and to formulate a program for future studies. This study was not intended to result in conclusive design recommendations. The secondary objective of the study was to explore the behavior of 16 foot long wall studs that are 6 inches deep. Such applications are more common now than when the original research was conducted. The previous work was on 4 inch deep and 8 foot long wall studs.

2. TEST PROGRAM

All the tests involved lipped channel wall studs 6.07 inches deep with 1.7 inch wide flanges and .077 inch in thickness. The measured average dimensions are given in Fig. 1. Nine tensile coupons were tested and the average .2 percent offset yield stress was found to be 50.16 ksi. The average ultimate stress was 70.28 ksi. The wall board used was 1/2 inch thick gypsum. Cantilever shear tests were conducted and the results are discussed below.

2.1 WALL ASSEMBLY TESTS

Altogether 8 tests were conducted on three types of wall assemblies. The wall assembly types are shown in Fig. 2. Assembly types shown in Figs. 2a and 2b were tried first. However due to the uncertainties in the influence of the configuration on the behavior in these types of assemblies, the remaining tests were conducted on assemblies as shown in Fig. 2c. To explore the effect of the loading on the behavior, different arrangements as shown in Fig. 3 were tried.

The test results are summarized in Table 1. The deflections and rotations observed during the tests are plotted in Figs.5 through 12. In these plots u is the deflection in the plane of the wall, v is the deflection perpendicular to the wall and phi is the rotation all measured at midspan. The tested specimens are shown in the photographs at the end of this report.

In the first four tests 6x1" Drywall Screws with Sharp S Type Point were used. In the remaining tests No. 8x1.25" FS Tightlock screws provided by the manufacturer of the studs were used. In both cases holes of smaller diameter than that of the screws were predrilled.

In the first four tests the wall board was cut at the end studs. Thus the screws were near the cut edge of the wall board. The cutting operation in general introduces cracks in the wall board, and hence, lowers the strength of the overall assembly. In the assemblies for the last four tests, the wall board was cantilevered 5 inches over the studs (see Fig. 2c). Also in the first four tests, the wall board was used in 8 feet long sections along the length of the studs. In the last four tests the wall boards were cut into 4 feet long segments along the length of the studs. This was done to simulate the case when the wall boards are placed horizontally with the 8 feet wide side parallel to the floor.

In the first four tests the end channel used was such that the flanges of the studs rested on the round corner between the web and the flange of the end channels as shown in Fig. 4. In the first three tests when the axial load was applied to the studs the flanges of the end channels were wedged open. This caused a tensile force combined with a shear force in the screw on connecting the end channels and the wall studs. In general at failure these screws broke off. This might have resulted in premature failure of the entire assembly. In the subsequent tests, other channels that permitted the resting of the studs entirely on the web were used.

The axial loads were applied by hydraulic jacks. In Test 4, the lateral load was first applied by vacuum. However the wall board could not sustain the vacuum pressures that the wall stud could carry (see the footnote in Table 1). Therefore the arrangement described in Table 1 was tried. In Tests 6 and 8 first an axial load equal to the ultimate load in tests 5 and 7,respectively, divided by 1.92 was applied. Then the lateral load was applied by means of iron bricks each weighing about 26 lbs. The bricks were 12"x4" in size. Pads of homosote 1"x1" were placed at each corner of the bricks between the bricks and the wall board. This was done to reduce the effect of friction between the bricks and the wall board.

Since the assemblies were tested in a horizontal position, the dead load in all cases were present as a lateral load. The dead loads were 7.55, 6.47, 6.51 and 6.84 psf for the assemblies shown in Figs. 2a,2b,2c for 16 ft span and 2c for 8 ft span, respectively.

The ends of the stud assemblies were free to rotate about the symmetry axes of the studs due to the knife edges provided. However the rotation was restrained about the principal axes perpendicular to the symmetry axes due to the end channels and the wall board. The axial loads were aligned with the centroidal axes geometrically at the ends.

In general, the initial failure mode was not clear. Almost all the specimens had a significant amount of bending, twisting and local buckling. However, this does not give a clear indication as to how the failure was initiated. In the first three tests it is likely that the failure of the screws connecting the end channels, wall board and the studs might have initiated the failure as discussed above. Then a significant amount of bending, twisting and local buckling followed. The local buckles in each case were between the end and the quarter point in the span. In each case the failure was quite sudden and caused the specimen to jump out of the test fixture.

The failure in Test 4 is described in part in Table 1. The failure in this case was rather gradual involving large deflections.

Rather sudden failures were also observed in Tests 5 through 8. Again in each case local buckles were observed after the failure at the quarter point in the span. In Test 5 the screws were seen to bite into the wall board material several steps before failure. In general, the studs had about .5 inch sweep in 16 feet before they were connected to the wall boards. In the assemblies of Tests 1, 5, and 6, the sweep after the wall boards were attached was 1/2, 3/4 and 5/8 inches, respectively.

2.2 CANTILEVER SHEAR TESTS

The cantilever shear tests were conducted on two types of specimens as illustrated in Figs. 13 and 14. The specimen in Fig.13 is intended to simulate the conditions in the first four wall assembly tests. The specimen shown in Fig. 14 is intended to simulate conditions in the last four tests. The results are plotted and evaluated in Figs. 15 through 17. In these figures it is seen that the results are sensitive to the type of screw used. The deflections for the ultimate loads were extrapolated in each case from the last two readings before failure. In general it is not possible to measure deflections at failure.

For No. 6 screws at 12 inches with gypsum board the A. I. S. I. Specification gives values of G' and gamma as 2.0 k/in and .008 in/in, respectively. The corresponding values observed in the tests were 2.642 k/in and .011 in/in, respectively.

It is desirable to carry out several duplicate tests and additional tests for panels with No. 8 screws. The values of the wall board parameters as stipulated in the Specification and as determined in the tests will be used below in the correlation of the test results with the calculated results.

2.3 STUB COLUMN TESTS

Three stub column tests were conducted according to the A. I. S. I. Specification (Ref. 1) and Q values of .736, .720 and 693 were determined. The average of these values is .72.

3. CORRELATION OF THE TEST RESULTS WITH THOSE PREDICTED BY THE A. I. S. I. SPECIFICATION

The test results are compared with results calculated using the A. I. S. I. Specification and several variations of it in Tables 2 through 12. In Tables 2 through 4 the predicted values were obtained ignoring the dead load that was acting as a lateral load in all cases. In Tables 5 through 12 the effect of dead load as a lateral load is included in the calculations.

The variations of the Specification include using a 33%

increase in allowable stresses even though this is not applicable for the purposes of this investigation and ignoring the requirement that Fbx shall not exceed 1.7 times Fa3. This requirement is referred to in the Tables as the Fbx3 requirement. In all cases, though the Specification is not very clear on this point, the length was taken as twice the screw spacing in applying Section 3.3.

The most literal application of the Specification is used in Table 9. It is not possible to assess the accuracy of the specification for the case of axial loading only because in all cases lateral load was present at least as a result of dead load.

In all the 16 ft long cases except ~~one~~ two the Specification is seen to be very conservative. In particular for example for the 16 ft long studs with 45 psf lateral loading the Specification is unsatisfactory. FOr this case it is seen that for the given lateral loading the stud is predicted to be able to carry 4.7 kips only.

However in the test each stud was able to carry 12.5 kips. The results are improved but still unsatisfactorily conservative when the Fbx3 requirement is ignored. This case is studied in Table 12. The prediction for the 16 ft assembly with lateral loading is seen to be 76% conservative. The conservatism involved can be explained in part by looking at the result of Test 4.

In Test 4 only lateral loads were applied. However the distribution of the loads between the four studs is not very clear. Thus the maximum calculated bending moment depends on the assumed distribution of the loading between the studs. It is likely that the concentrated loads which were the result of pig iron blocks placed on top of the assembly were equally shared among the studs. If the vacuum loading is assumed to be distributed according to the tributary area of each stud then the maximum moment at failure can be calculated to be 95.2 k-in. Assuming the vacuum load to be equally shared between the studs the calculated maximum bending moment becomes 80.83 k-in. The yield moment assuming full lateral restraint is 66.22 k-in. If 1.7 times Fa3 were taken as the failure stress, the calculated ultimate moment would be much lower. An ultimate moment for the section can be calculated according to Section 3.9 to be 83.6 k-in which is of the same order as that calculated maximum moment. The assumption of the yield moment as the failure moment is thus seen to be very conservative. Furthermore the composite behavior of the wall board material with the studs may add to the conservatism.

The conservatism involved in treating the bending stresses also affects the calculations in a significant way when the case of combined axial and lateral loading is considered. The test evidence developed so far is indeed very inadequate to develop a design criteria. However it confirms the suspected very excessive conservatism in the Specification for the combined loading case.

4. CONCLUSIONS AND DESIRABLE FUTURE STUDIES

Based on a few tests the study herein indicates that the present A. I. S. I. Specification provisions on wall studs subjected to combined axial and lateral loads can, depending on the application, be undesirably conservative. Since the study was exploratory in nature, design provisions cannot be reached at this time.

Further systematic theoretical and experimental studies are needed to formulate a design procedure for the case of combined loading. These studies should include repeat tests of the tests conducted in this exploratory study as well as theoretical studies and tests exploring several parameters not covered here. The following are some of the points to be considered:

- Stud sizes and wall board types need to be varied.
- The effect of perforations needs to be investigated.
- The effect of local instability $(Q<1)$ needs to be investigated.
- Screw types and spacing need to be varied.
- Loading should include eccentric axial load to simulate the effect of types of loads caused by the floor joists.
- The relative magnitudes of the axial load and the lateral load

need to be varied systematically.

- Provisions need to be developed for the case of wall board only on one side as well as the case of unmatched wall materials on each flange.

- The relevance of small scale cantilever shear tests to the predictions for full scale walls needs to be established.

- Composite action with the wall board particularly for large lateral loads need to be investigated.

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1. "Specification for the Design of Cold-Formed Steel Structural Members", American Iron and Steel Institute, Washington, D.C., 1980 Edition.

2. Simaan A. and Pekoz, T., "Buckling of Diaphragm-Braced Columns of Unsymmetrical Sections and Application to Wall Studs Design", Department of Structural Engineering, Cornell University, Report No. 353, August 1973.

3. Simaan, A. and Pekoz, T., "Cold Formed Steel Wall Stud Design", Proceedings, of the American Society of Civil Engineers, Vol. 102, ST1, January 1976.

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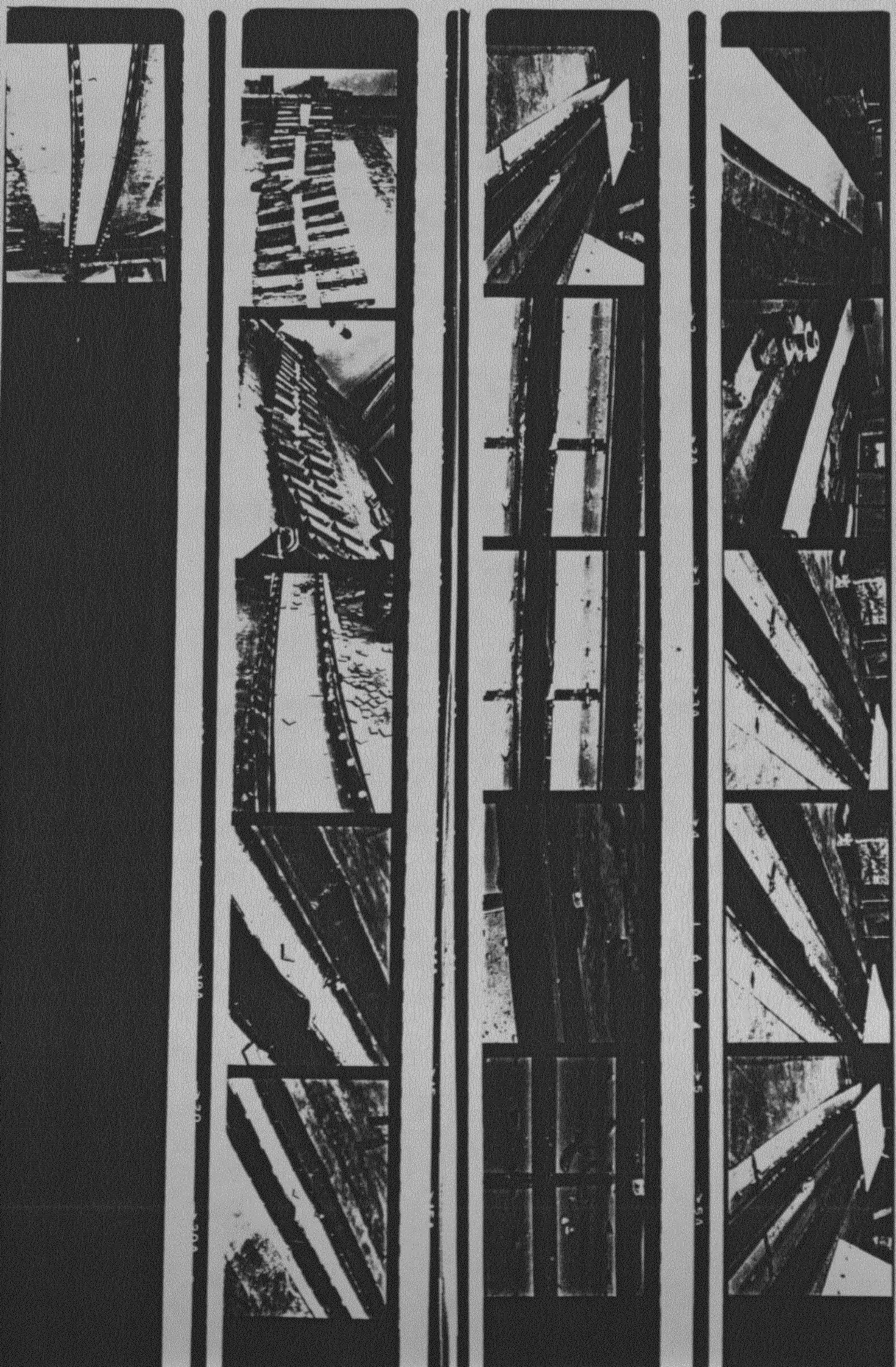


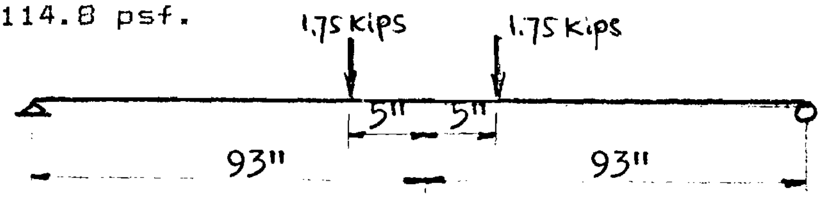
TABLE 1
WALL ASSEMBLY TEST RESULTS

TEST NO	NO OF STUDS	ASSEMBLY FIGURE	LOADING FIGURE	LENGTH (FT)	PULT (K)	LAT. LOAD
1	2	2a	3a	16	15.80	(2)
2	4	2b	3c	16	20.80	(2)
3	4	2b	3b(1)	16	11.00	(2)
4	4	2b	3d	16	0.00	(3)
5	2	2c	3a	16	16.00	(2)
6	2	2c	3a	16	12.50	(4)
7	2	2c	3a	8	23.14	(2)
8	2	2c	3a	8	25.96	(4)

(1) Interior studs were loaded to twice the axial load of the end studs

(2) Dead load of the assembly was the only lateral load

(3) Wall board failed at a vacuum of 82 psf. The wall board was replaced and a 1/2 inch layer of plywood was placed on the assembly. The concentrated loads shown in the figure below were applied. Then a vacuum was drawn. The failure ocurred at a vacuum of 114.8 psf.



(4) 45 psf lateral load in addition to the dead load

TABLE 2
EVALUATION OF TEST RESULTS

G= 2000 lb/in.

	TEST 1	TEST 5	TEST 7
PT	15.80	16.00	23.14
P1	12.20	17.40	21.60
P2	9.20	13.10	17.70
PT/P1	1.30	0.92	1.07
PT/P2	1.72	1.22	1.31

All loads in kips.
PT Test ultimate axial load
P1 Calculated using gamma= 0.014 in/in
P2 calculated using gamma= 0.008 in/in

TABLE 3
EVALUATION OF TEST RESULTS

G= 2000 lb/in.

	TEST 2	TEST 3
PET	20.28	11.00
PIT	20.28	22.00
PE1	12.20	12.20
PE2	9.20	9.20
PI1	17.00	17.00
PI2	12.80	12.80
PET/PE1	1.70	0.90
PET/PE2	2.26	1.20
PET/PI1	1.22	1.29
PIT/PI2	1.63	1.72

All loads in kips.
PET Test ultimate axial load for end studs

PIT Test ultimate load for interior studs

PE1 Calculated ultimate load for end studs using gamma= 0.014

PE2 Calculated ultimate load for end studs using gamma= 0.008

PI1 Calculated ultimate load for interior studs using gamma= 0.014

PI2 Calculated ultimate load for interior studs using gamma= 0.008

TABLE 4
EVALUATION OF TEST RESULTS

G= 2000 lb/in.

	TEST 6	TEST 8
PT	12.50	25.96
P11	8.90	25.40
P12	4.70	20.40
P21	4.30	18.20
P22	1.30	14.50
P31	12.50	26.00
P32	10.00	21.40
P41	7.50	18.80
P42	6.10	15.50
PT/P11	1.40	1.02
PT/P12	2.66	1.27
PT/P21	2.91	1.43
PT/P22	9.62	1.79
PT/P31	1.00	1.00
PT/P32	1.25	1.21
PT/P41	1.67	1.38
PT/P42	2.05	1.67

All loads in kips.
PT Test ultimate axial load
P11 Calculated with 1.33 factor and gamma=.014
P12 Calculated with 1.33 factor and gamma=.008
P21 Calculated without 1.33 factor and gamma=.014
P22 Calculated without 1.33 factor and gamma=.008
P31 P11 without the Fbx3 requirement (L=2xscrew spacing)
P32 P12 without the Fbx3 requirement (L=2xscrew spacing)
P41 P21 without the Fbx3 requirement (L=2xscrew spacing)
P42 P22 without the Fbx3 requirement (L=2xscrew spacing)

TABLE 5

EVALUATION OF TEST RESULTS

G=2000 lb/in
(without 1.33 factor)

TEST NUMBER	PT1	PT2	P11	P12	P21	P22	PT1/P11	PT1/P12	PT2/P21	PT2/P22
1	15.80		7.7	10.5			2.05	1.50		
2	20.80	20.80	7.7	10.5	9.5	13.1	2.70	1.98	2.19	1.59
3	11.00	22.00	7.7	10.5	9.5	13.1	1.43	1.05	2.32	1.68
5	16.00		10.5	14.2			1.52	1.13		
6	12.50		0.0	3.0			*	4.17		
7	23.14		17.2	21.0			1.35	1.10		
8	25.96		14.0	17.7			1.85	1.31		

* Axial tensile force required in order to have failure at the given lateral load.

All loads in kips
The dead load is taken to be 7 psf.
PT1 Test ultimate axial load of end studs.
PT2 Test ultimate axial load of interior studs.
P11 Calculated with gamma = .008 in/in for end studs.
P12 Calculated with gamma = .014 in/in for end studs.
P21 Calculated with gamma = .008 in/in for interior studs.
P22 Calculated with gamma = .014 in/in for interior studs.

TABLE 6

EVALUATION OF TEST RESULTS

G=2000 lb/in
(without Fbx3 requirement)
(with 1.33 factor)

TEST NUMBER	PT1	PT2	P11	P12	P21	P22	PT1/P11	PT1/P12	PT2/P21	PT2/P22
1	15.80		11.7	15.4			1.35	1.03		
2	20.80	20.80	11.7	15.4	15.3	19.9	1.78	1.35	1.36	1.05
3	11.00	22.00	11.7	15.4	15.3	19.9	0.94	0.71	1.44	1.11
5	16.00		16.0	20.9			1.00	0.77		
6	12.50		9.1	11.30			1.37	1.11		
7	23.14		23.2	28.3			1.00	0.82		
8	25.96		21.1	25.6			1.23	1.01		

All loads in kips
The dead load is taken to be 7 psf.
PT1 Test ultimate axial load of end studs.
PT2 Test ultimate axial load of interior studs.
P11 Calculated with gamma = .008 in/in for end studs.
P12 Calculated with gamma = .014 in/in for end studs.
P21 Calculated with gamma = .008 in/in for interior studs.
P22 Calculated with gamma = .014 in/in for interior studs.

TABLE 7

EVALUATION OF TEST RESULTS

G=2000 lb/in
(without Fbx3 requirement)
(without 1.33 factor)

TEST NUMBER	PT1	PT2	P11	P12	P21	P22	PT1/P11	PT1/P12	PT2/P21	PT2/P22
1	15.80		8.6	11.4			1.84	1.39		
2	20.80	20.80	8.6	11.4	11.1	14.3	2.42	1.82	1.87	1.45
3	11.00	22.00	8.6	11.4	11.1	14.3	1.28	0.96	1.98	1.54
5	16.00		11.7	15.2			1.37	1.05		
6	12.50		5.2	6.5			2.40	1.92		
7	23.14		17.3	21.1			1.34	1.10		
8	25.96		15.2	18.4			1.71	1.41		

All loads in kips
The dead load is taken to be 7 psf.
PT1 Test ultimate axial load of end studs.
PT2 Test ultimate axial load of interior studs.
P11 Calculated with gamma = .008 in/in for end studs.
P12 Calculated with gamma = .014 in/in for end studs.
P21 Calculated with gamma = .008 in/in for interior studs.
P22 Calculated with gamma = .014 in/in for interior studs.

TABLE 8

EVALUATION OF TEST RESULTS

G=2000 lb/in
(with 1.33 factor)

TEST NUMBER	PT1	PT2	P11	P12	P21	P22	PT1/P11	PT1/P12	PT2/P21	PT2/P22
1	15.80		10.7	14.5			1.48	1.09		
2	20.80	20.80	10.7	14.5	13.70	18.60	1.94	1.43	1.52	1.12
3	11.00	22.00	10.7	14.5	13.70	18.60	1.03	0.76	1.61	1.18
5	16.00		14.7	19.9			1.09	0.80		
6	12.50		3.2	7.3			3.91	1.71		
7	23.14		23.1	28.2			1.01	0.82		
8	25.96		19.9	24.9			1.30	1.06		

All loads in kips
The dead load is taken to be 7 psf.
PT1 Test ultimate axial load of end studs.
PT2 Test ultimate axial load of interior studs.
P11 Calculated with gamma = .008 in/in for end studs.
P12 Calculated with gamma = .014 in/in for end studs.
P21 Calculated with gamma = .008 in/in for interior studs.
P22 Calculated with gamma = .014 in/in for interior studs.

TABLE 9

EVALUATION OF TEST RESULTS

(without 1.33 factor)

TEST NUMBER	PT1	PT2	P1	P2	PT1/P1	PT2/P2
1	15.80		11.3		1.40	
2	20.80	20.80	11.3	14.5	1.84	1.43
3	11.00	22.00	11.3	14.5	0.97	1.52
5	16.00		16.4		0.98	
6	12.50		4.7		2.66	
7	23.14		25.3		0.91	
8	25.96		21.9		1.19	

All loads in kips
The dead load is taken to be 7 psf.
For test 1 and end studs of test 2,3, G = 3800 lb/in, gamma = 0.009 in/in
For interior studs of test 2,3, G=2600 lb/in, gamma = 0.011 in/in
For test 5.6.7 and 8, G=5600 lb/in, gamma = 0.007 in/in , b=11.94 in
P1 calculated for end studs
P2 calculated for interior studs

TABLE 10

EVALUATION OF TEST RESULTS

(with 1.33 factor)

TEST NUMBER	PT1	PT2	P1	P2	PT1/P1	PT2/P2
1	15.80		15.6		1.01	
2	20.80	20.80	15.6	20.5	1.33	1.01
3	11.00	22.00	15.6	20.5	0.71	1.07
5	16.00		22.9		0.70	
6	12.50		9.7		1.29	
7	23.14		33.9		0.68	
8	25.96		30.4		0.85	

All loads in kips
The dead load is taken to be 7 psf.
For test 1 and end studs of test 2,3, G = 3800 lb/in, gamma = 0.009 in/in
For interior studs of test 2,3, G=2600 lb/in, gamma = 0.011 in/in
For test 5.6.7 and 8, G=5600 lb/in, gamma = 0.007 in/in , b=11.94 in
P1 calculated for end studs
P2 calculated for interior studs

TABLE 11

EVALUATION OF TEST RESULTS

(with 1.33 factor)
(without Fbx3 requirement)

TEST NUMBER	PT1	PT2	P1	P2	PT1/P1	PT2/P2
1	15.80		16.5		0.96	
2	20.80	20.80	16.5	21.6	1.26	0.96
3	11.00	22.00	16.5	21.6	0.67	1.02
5	16.00		23.7		0.68	
6	12.50		12.5		1.00	
7	23.14		33.9		0.68	
8	25.96		30.5		0.85	

All loads in kips
The dead load is taken to be 7 psf.
For test 1 and end studs of test 2,3, G = 3800 lb/in, gamma = 0.009 in/in
For interior studs of test 2,3, G=2600 lb/in, gamma = 0.011 in/in
For test 5.6.7 and 8, G=5600 lb/in, gamma = 0.007 in/in , b=11.94 in
P1 calculated for end studs
P2 calculated for interior studs

TABLE 12

EVALUATION OF TEST RESULTS

(without 1.33 factor)
(without Fbx3 requirement)

TEST NUMBER	PT1	PT2	P1	P2	PT1/P1	PT2/P2
1	15.80		12.2		1.30	
2	20.80	20.80	12.2	15.5	1.70	1.34
3	11.00	22.00	12.2	15.5	0.90	1.42
5	16.00		17.1		0.94	
6	12.50		7.1		1.76	
7	23.14		25.3		0.91	
8	25.96		21.9		1.19	

All loads in kips
The dead load is taken to be 7 psf.
For test 1 and end studs of test 2,3, G = 3800 lb/in, gamma = 0.009 in/in
For interior studs of test 2,3, G=2600 lb/in, gamma = 0.011 in/in
For test 5.6.7 and 8, G=5600 lb/in, gamma = 0.007 in/in , b=11.94 in
P1 calculated for end studs
P2 calculated for interior studs

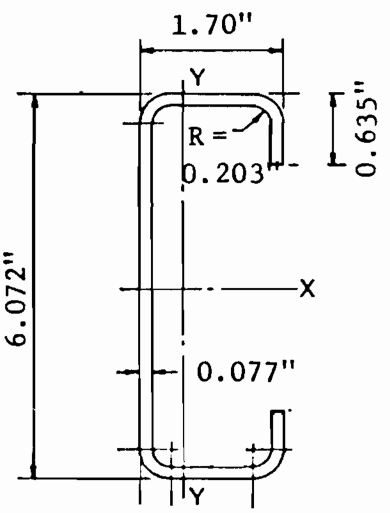


Fig. 1 Stud Section

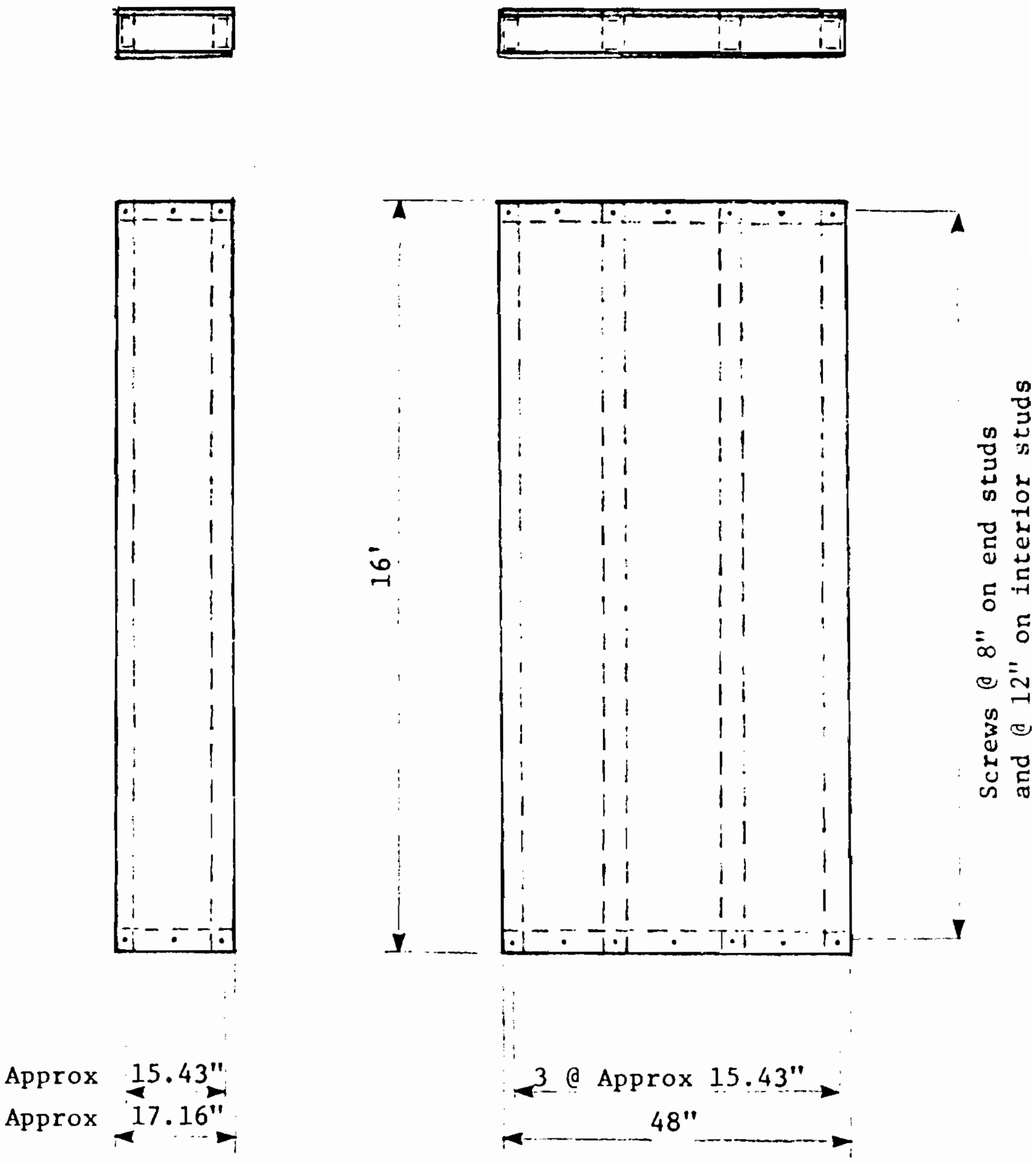
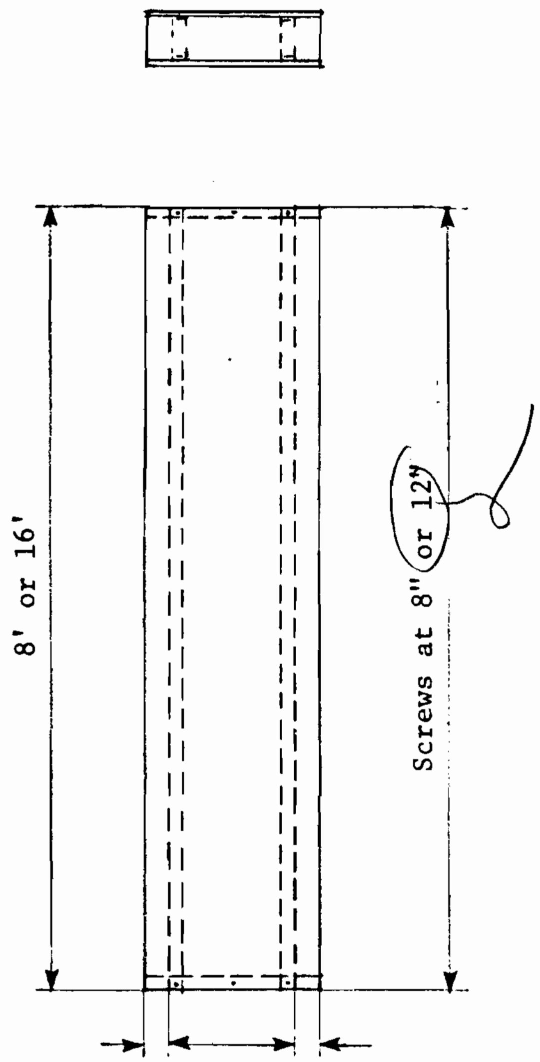


Fig. 2a

Fig. 2b

Fig. 2 Test Assemblies



Approx 4" 15.9" 4"

Fig. 2c

Fig. 2 Test Assemblies (cont.)

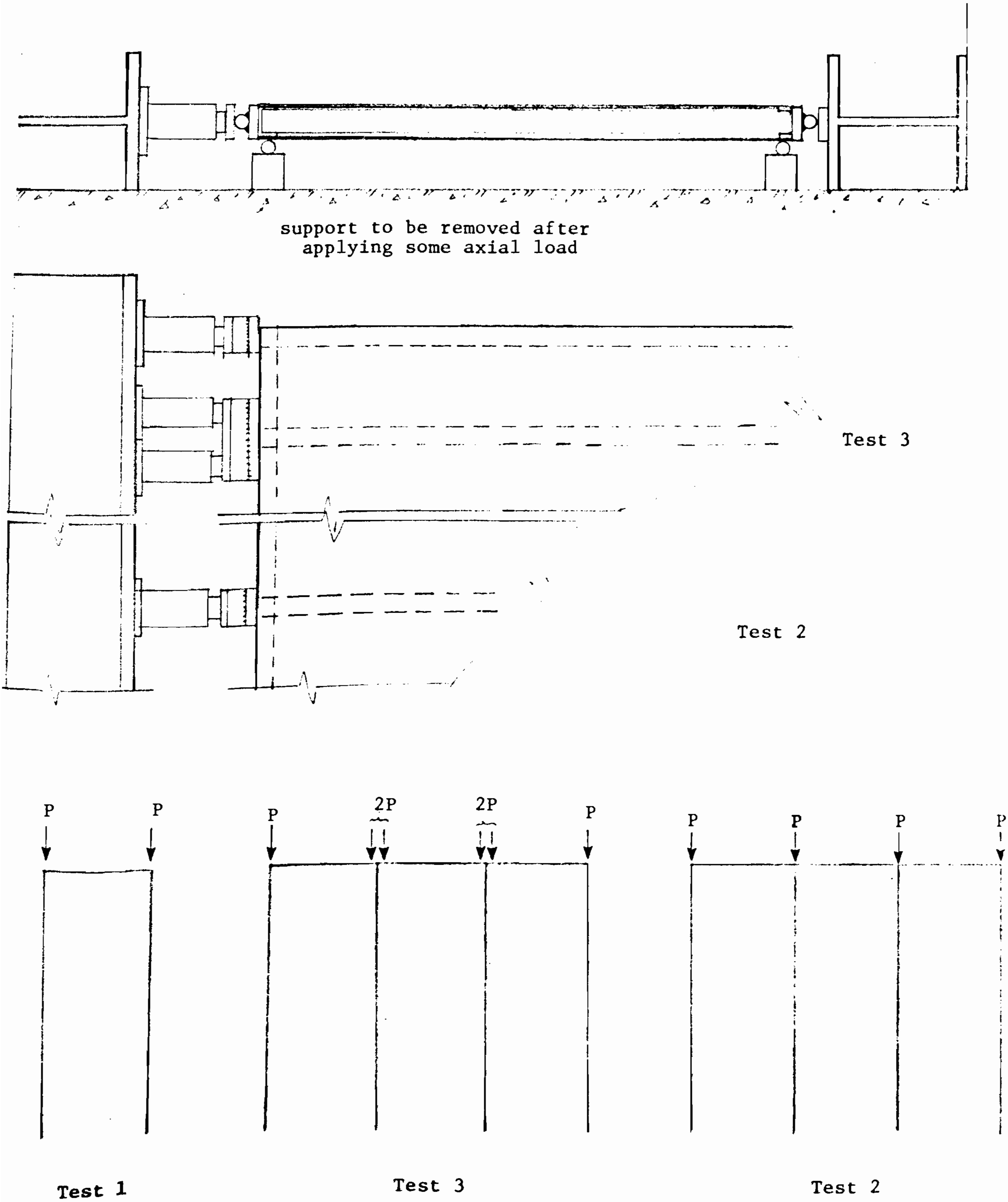


Fig. 3 Loading Schemes

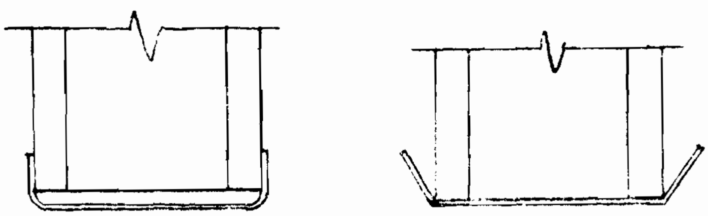


Fig. 4 End Channel

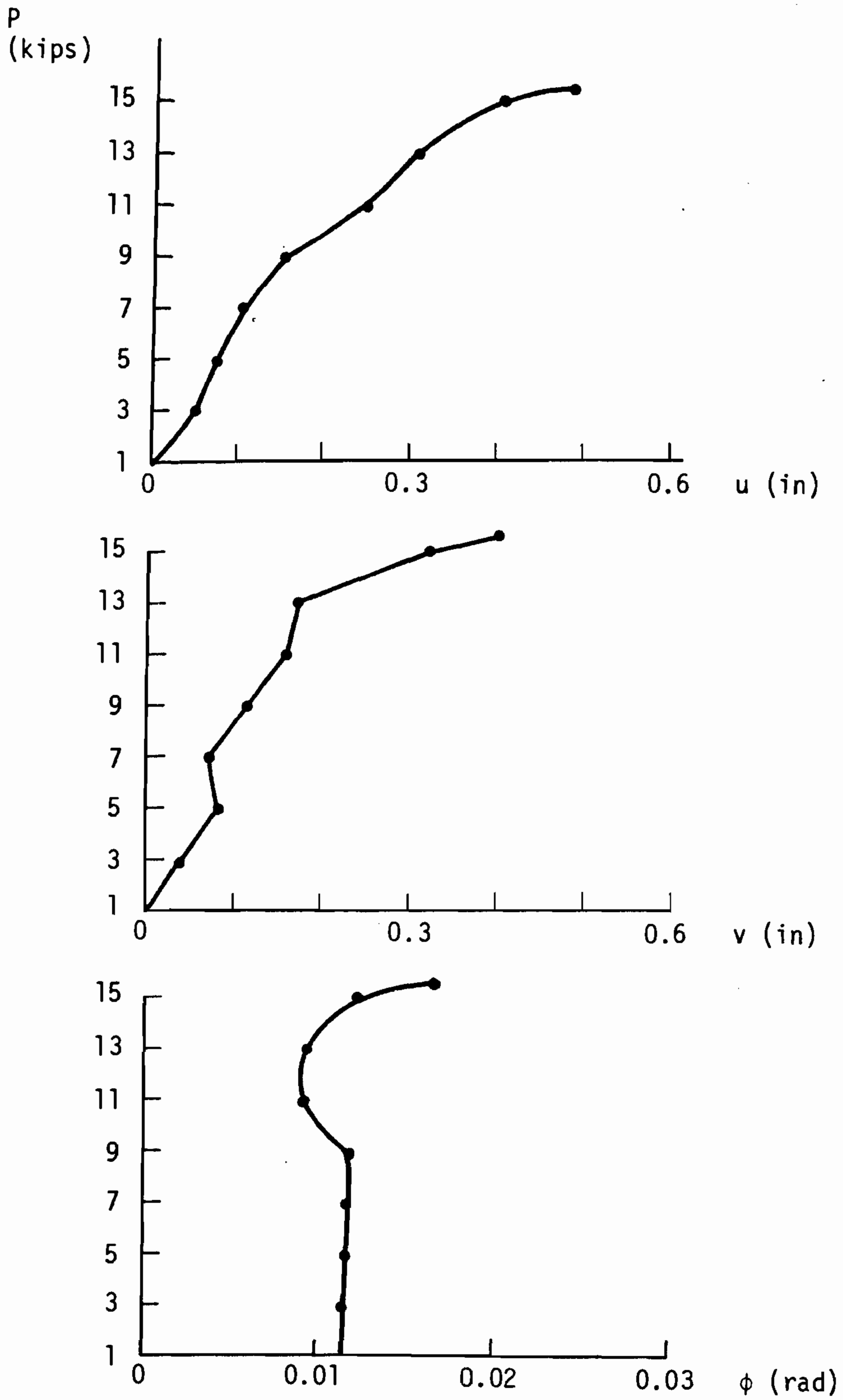


Fig. 5a Load-Deformation Curves for Test 1, Stud 1

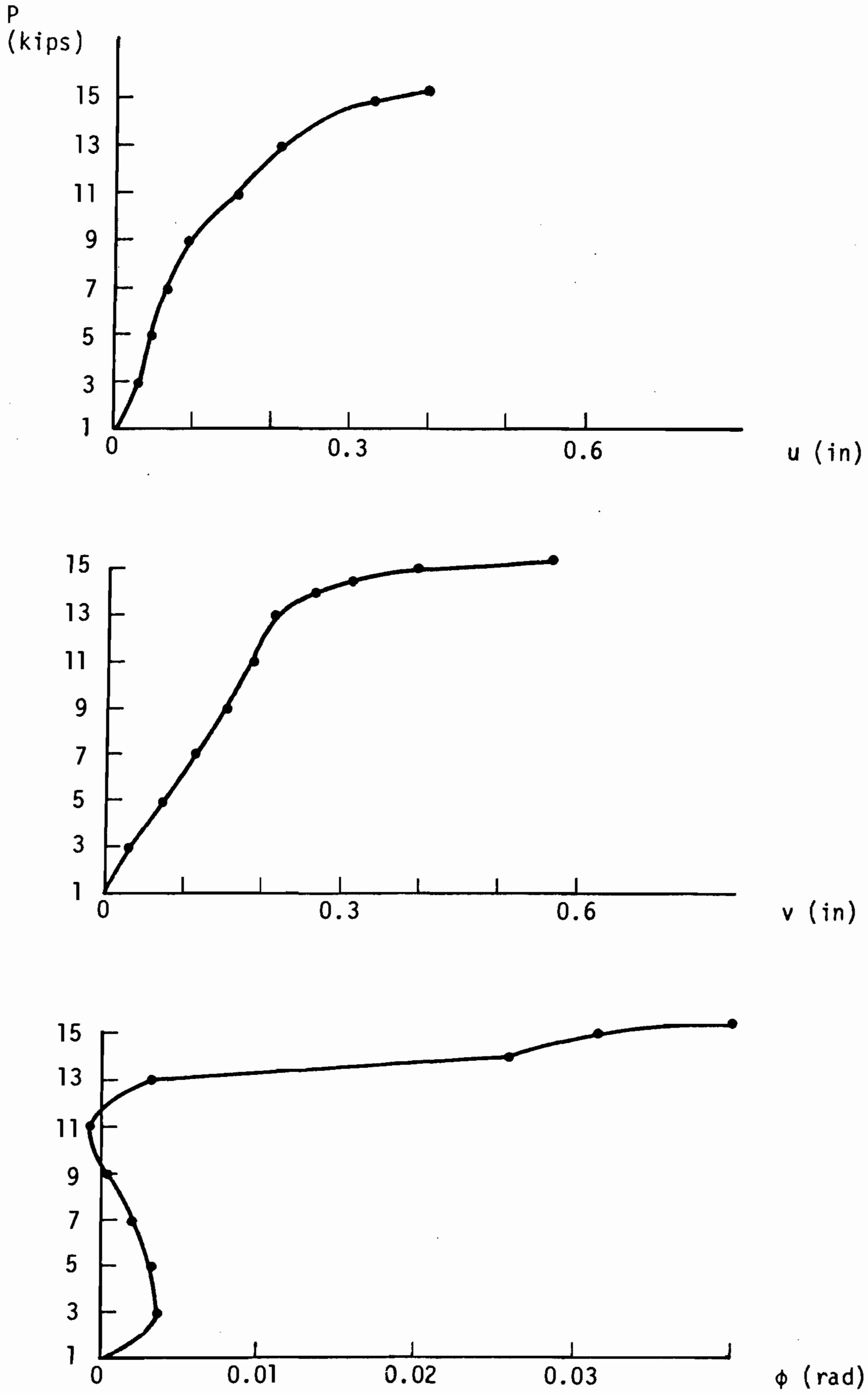


Fig. 5b Load-Deformation Curves for Test 1, Stud 2

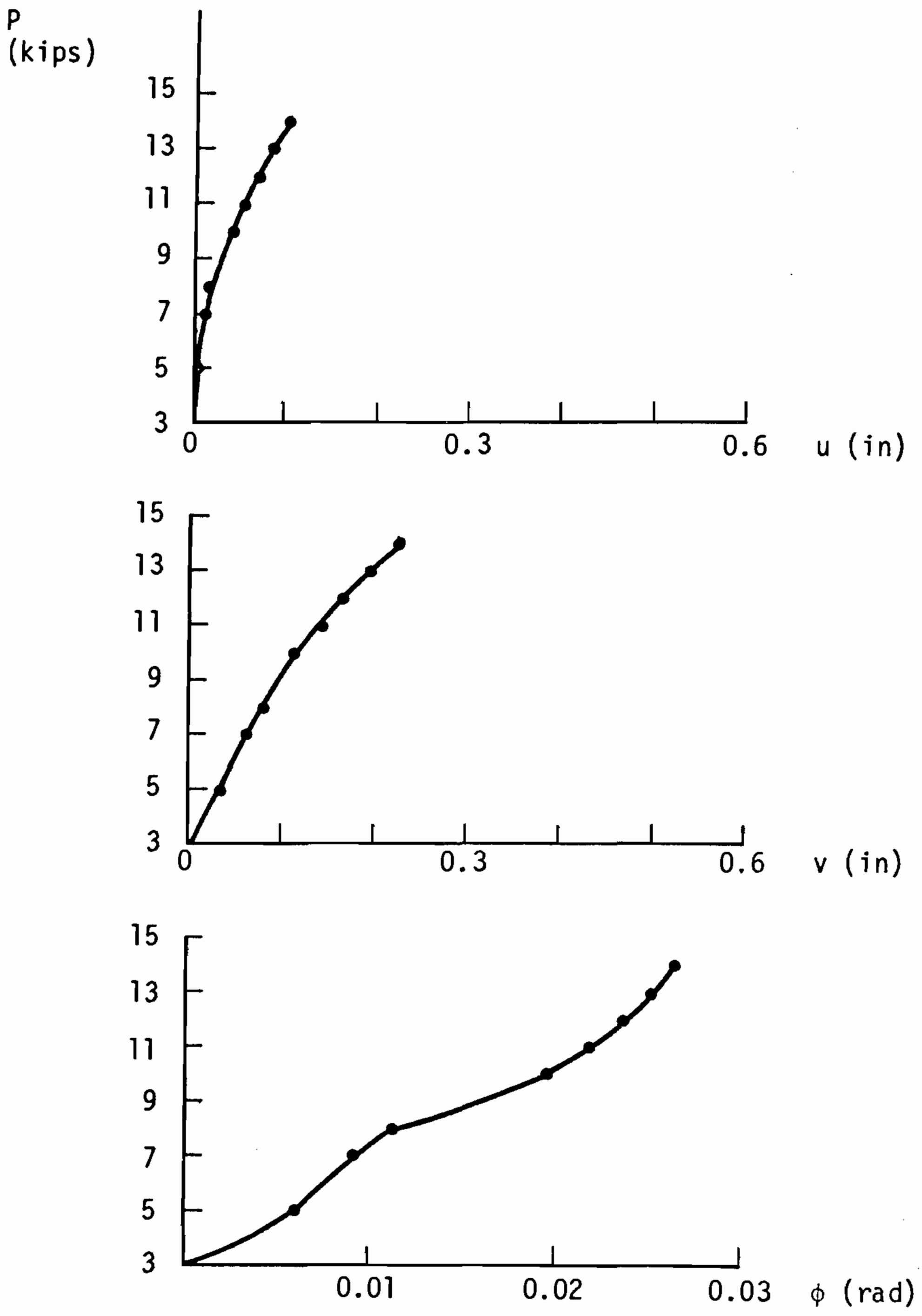


Fig. 6 Load-Deformation Curves for Test 2

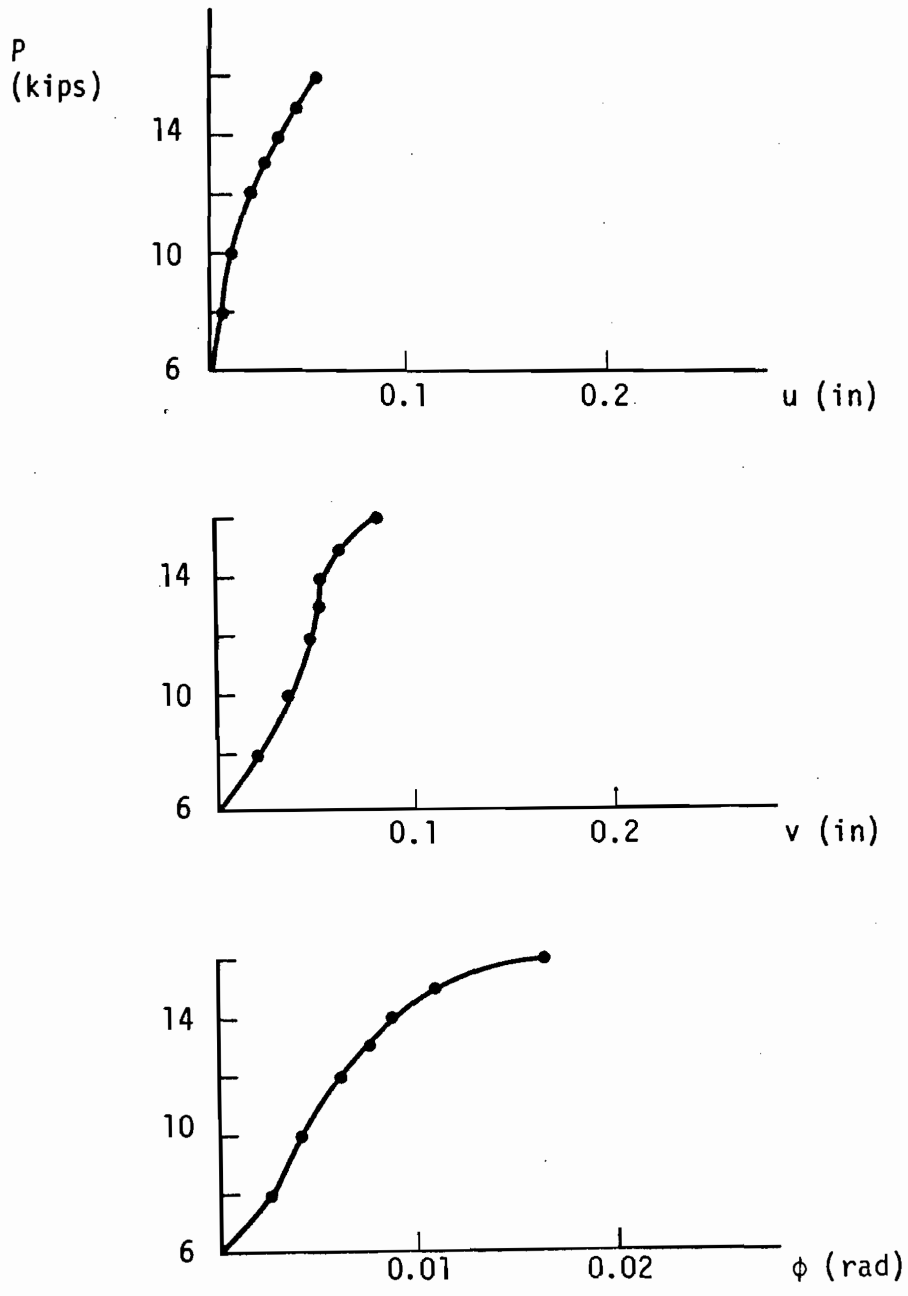


Fig. 7 Load-Deformation Curves for Test 3

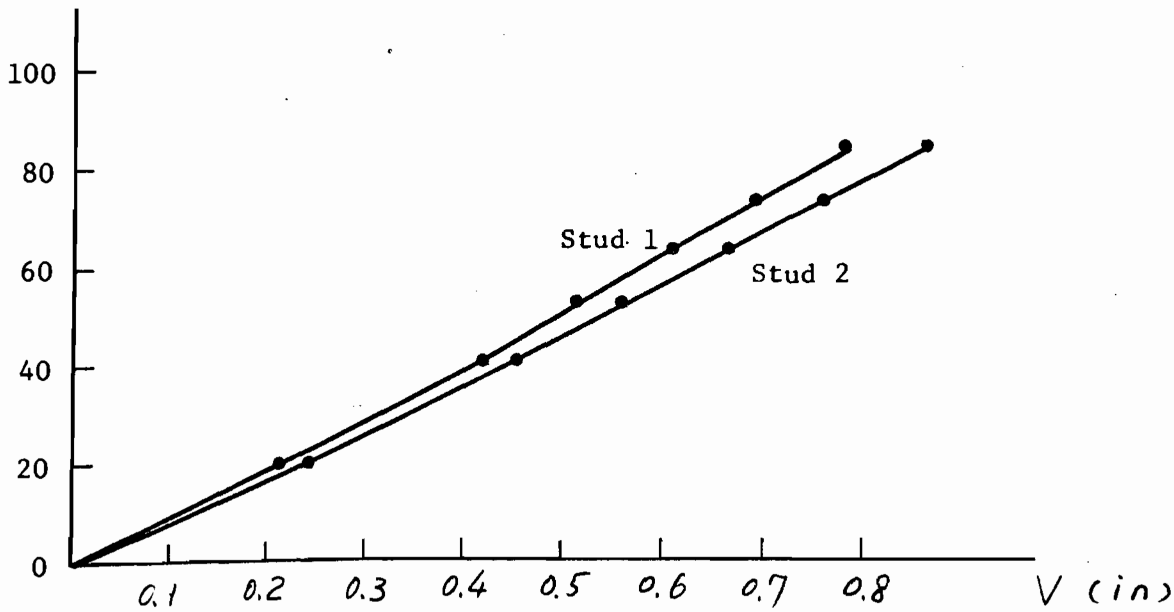


Fig. 8 Load-Deflection Curves for Test 4

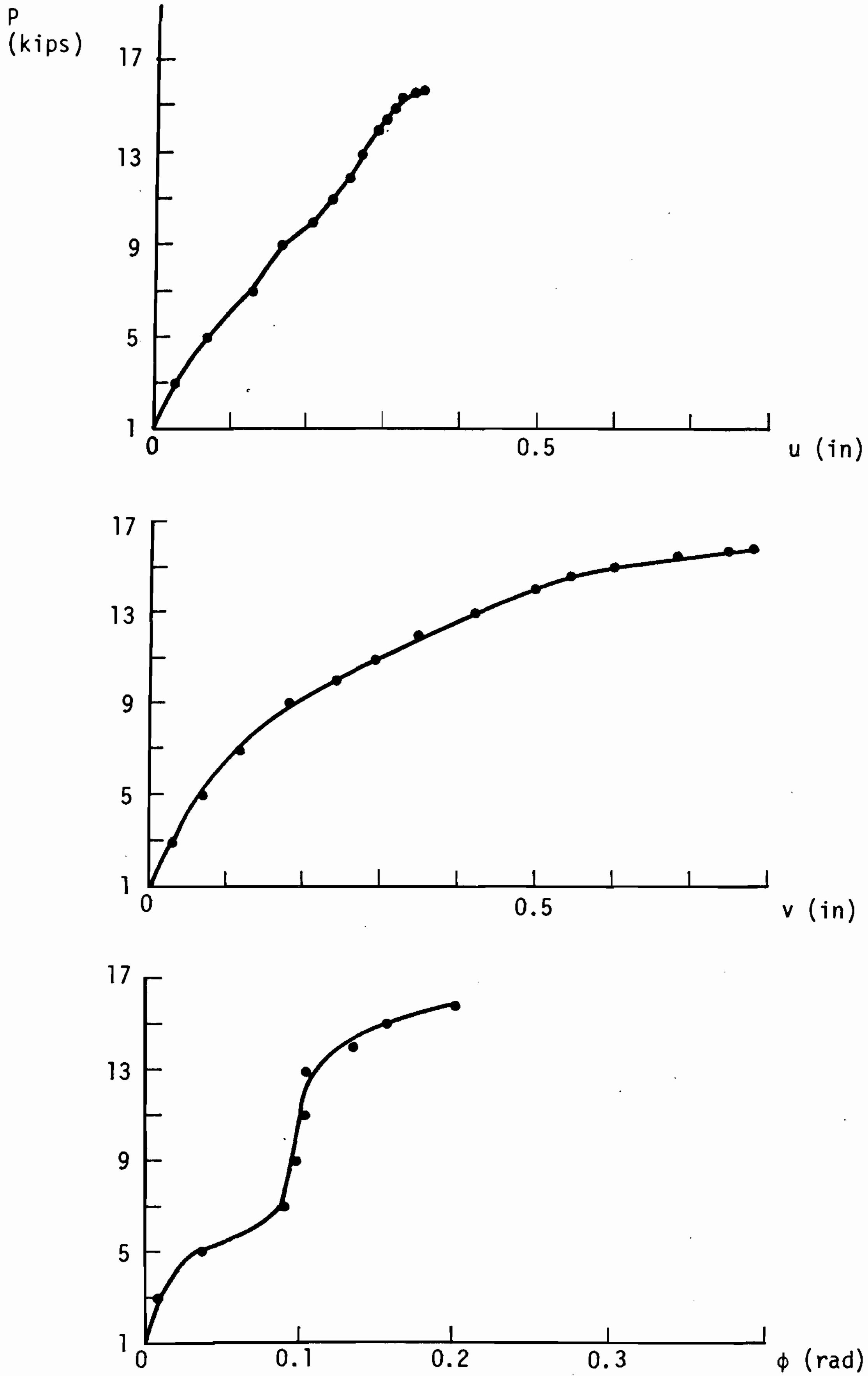


Fig. 9 Load-Deformation Curves for Test 5

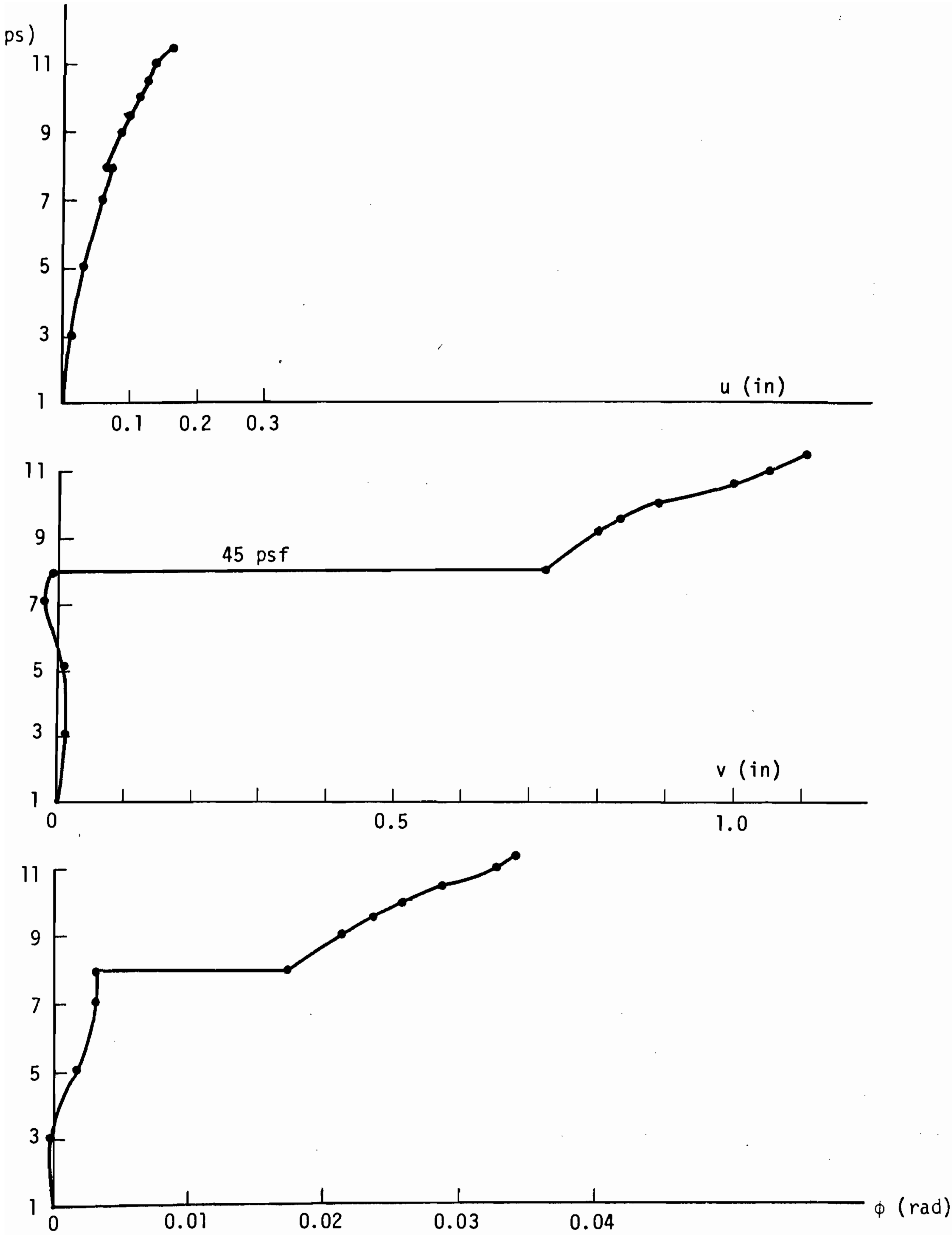


Fig. 10 Load-Deformation Curves for Test 6

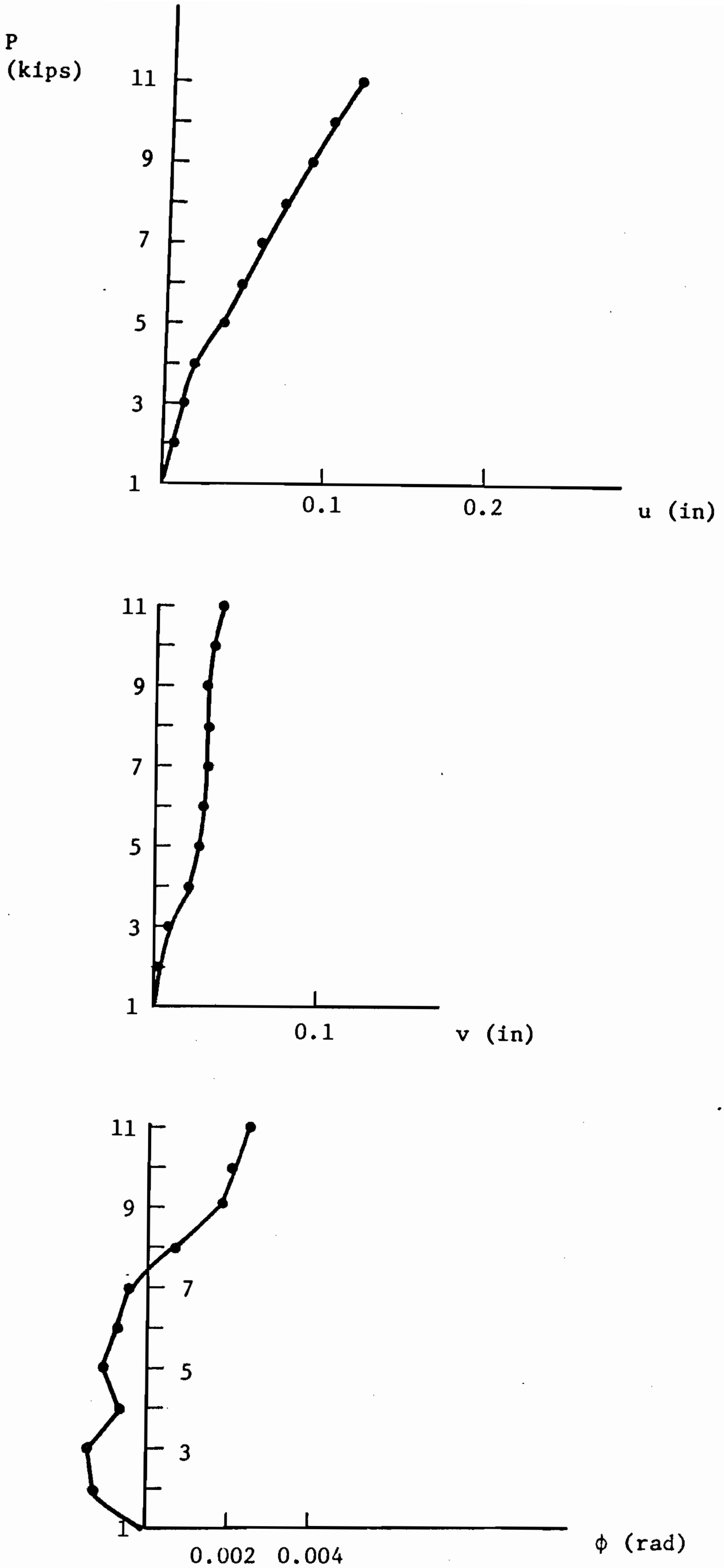


Fig. 11 Load-Deformation Curves for Test 7

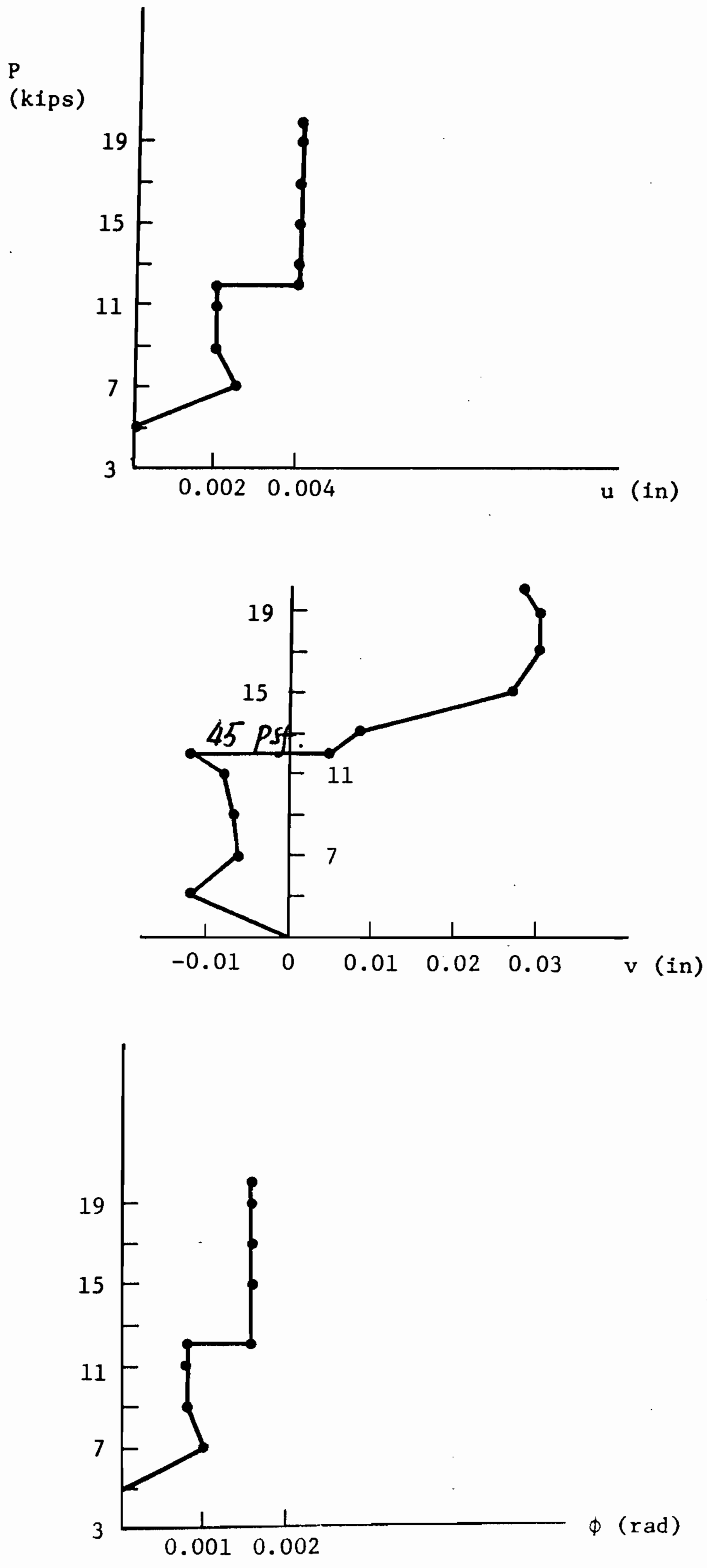


Fig. 12 Load-Deformation Curves for Test 8

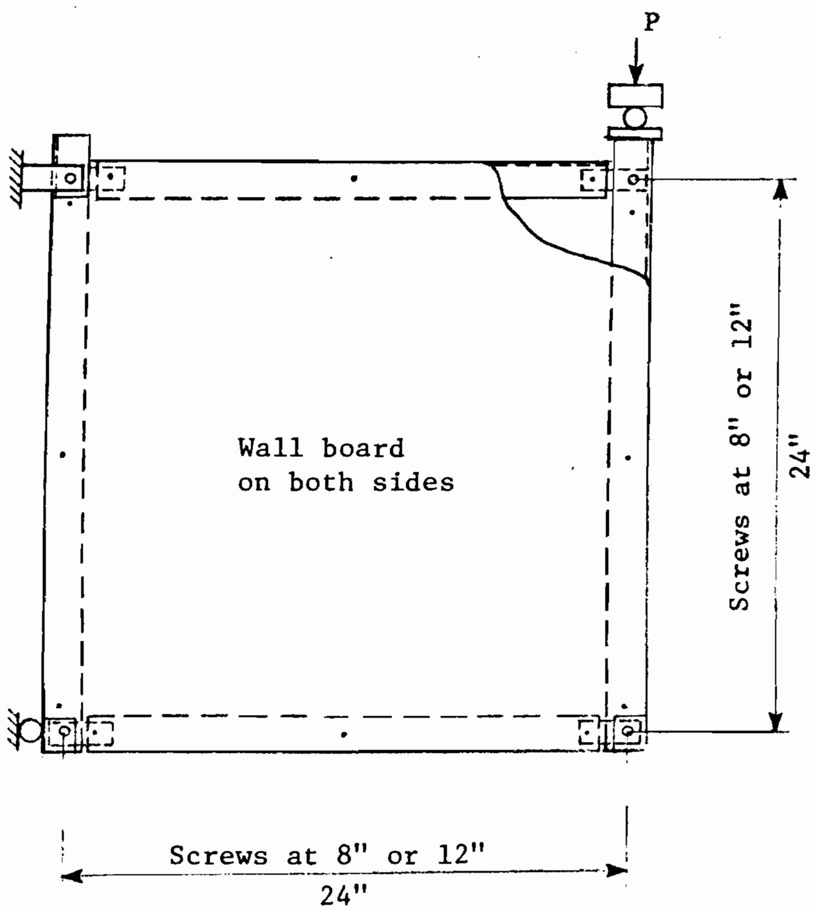


Fig. 13 Cantilever Shear Test Set-up

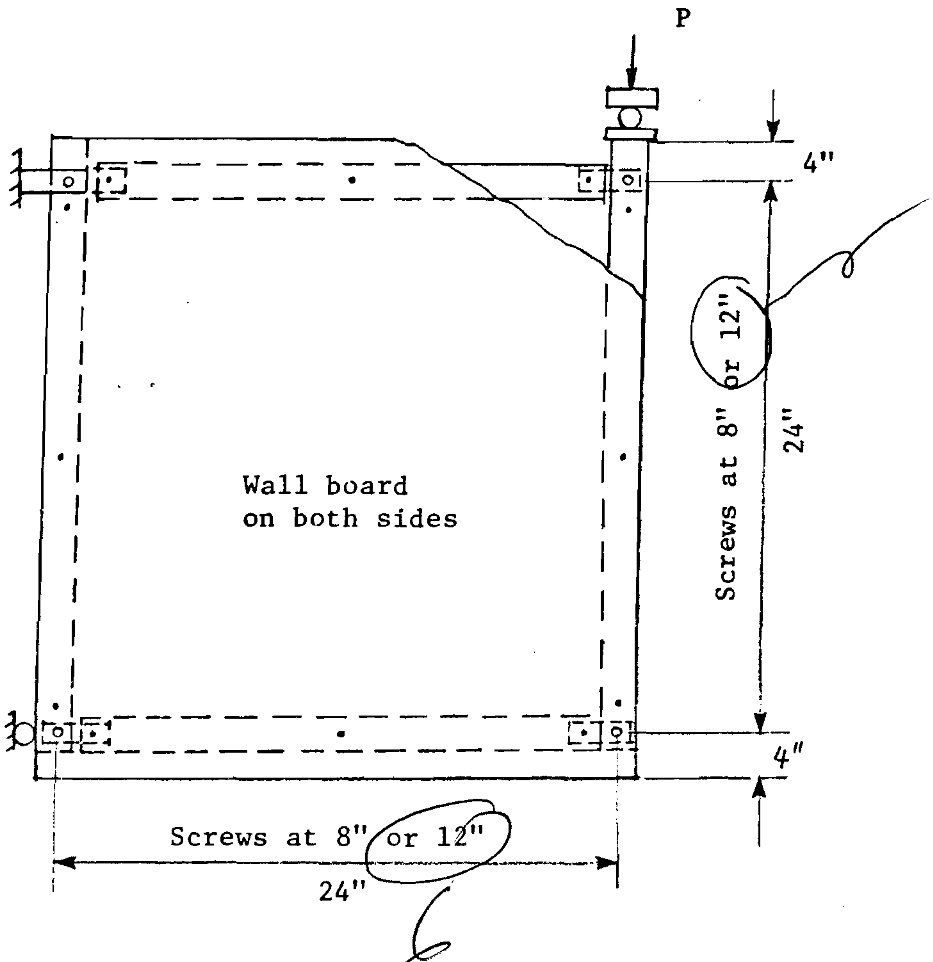


Fig. 14 Cantilever Shear Test Set-up

6 x 1" Drywall Screws at 8" Spacing

$$\gamma_d = \frac{\Delta_d}{a} = \frac{0.205}{24} = 0.0085 \quad ; \quad \gamma_{max} > \frac{0.365}{24} = 0.015$$

$$G' = \frac{0.8P_{ult}/b}{\Delta_d/a} = \frac{788}{0.205} = 3844 \text{ lb/in} \quad ;$$

$$G'_m \leq \frac{985}{0.365} = 2699 \text{ lb/in}$$

#8 x 1.25" FS Tightlock Screws at 12"

$$\gamma_d = \frac{0.188}{24} = 0.0078 \quad ; \quad \gamma_{max} > \frac{0.31}{24} = 0.0129$$

$$G' = \frac{880}{0.188} = 4681 \text{ lb/in} \quad ; \quad G'_m = \frac{1100}{0.31} = 3458 \text{ lb/in}$$

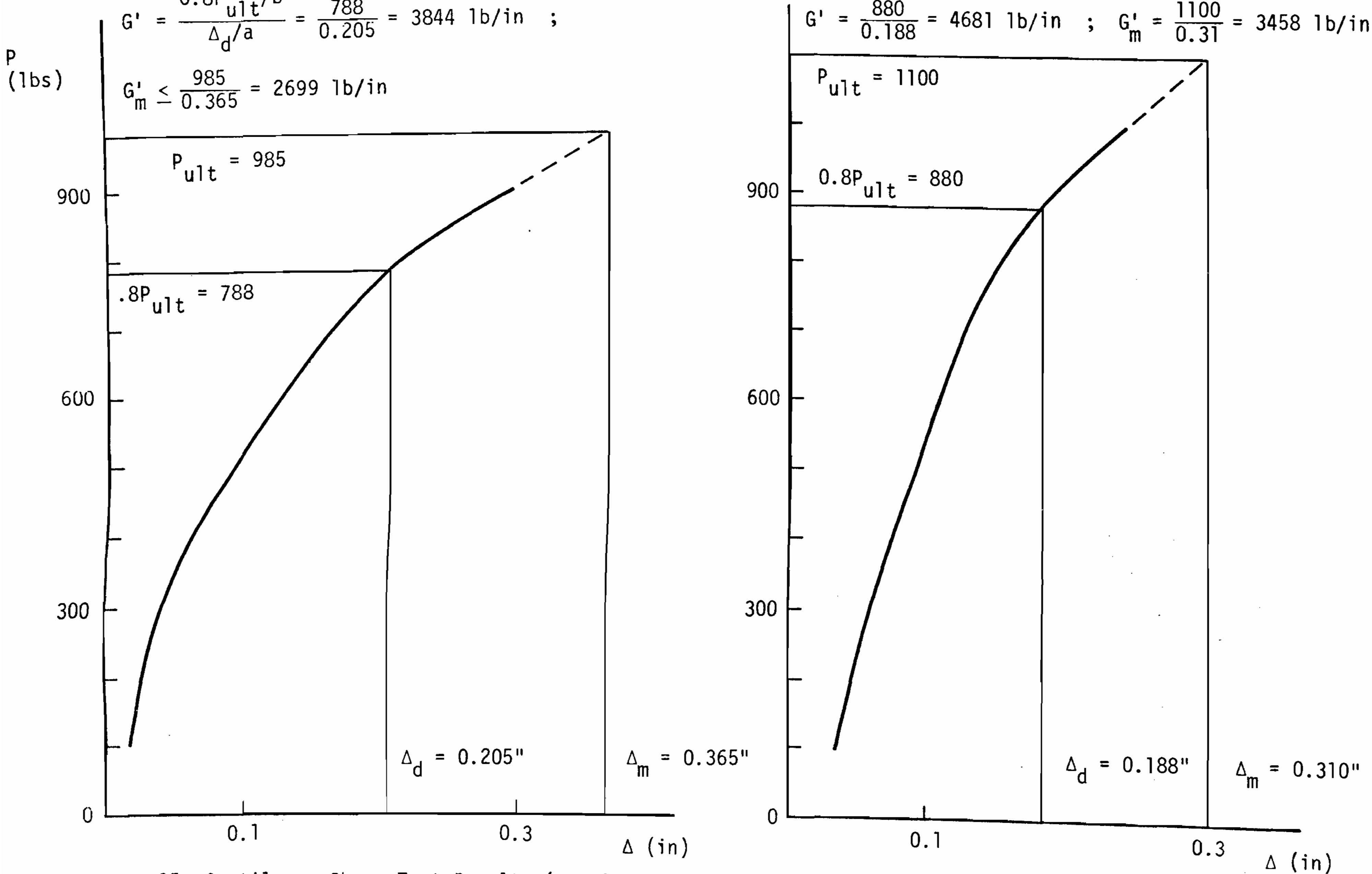


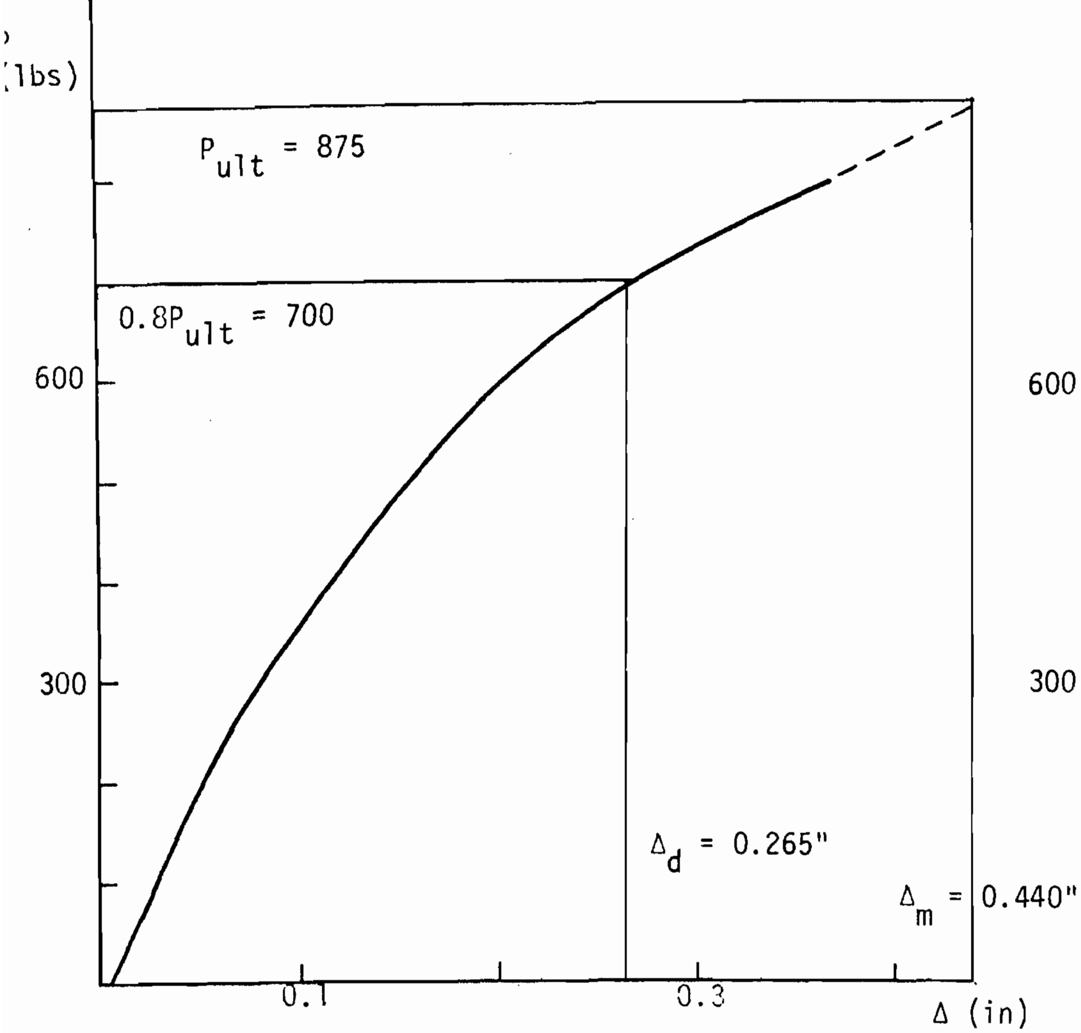
Fig. 15 Cantilever Shear Test Results (Specimen as shown in Fig. 13)

6 x 1" Drywall Screws at 12" Spacing

$$\gamma_d = \frac{\Delta_d}{a} = \frac{0.265}{24} = 0.011 \quad ; \quad \gamma_{max} > \frac{0.44}{24} = 0.018$$

$$G' = \frac{0.8P_{ult}/b}{\Delta_d/a} = \frac{700}{0.265} = 2642 \text{ lb/in}$$

$$G'_m < \frac{875}{0.44} = 1989 \text{ lb/in}$$



#8 x 1.25" FS Tightlock Screws at 8"

$$\gamma_d = \frac{0.17}{24} = 0.007 \quad ; \quad \gamma_{max} > \frac{0.26}{24} = 0.011$$

$$G' = \frac{716}{0.17} = 4212 \text{ lb/in}$$

$$G'_m < \frac{895}{0.26} = 3442 \text{ lb/in}$$

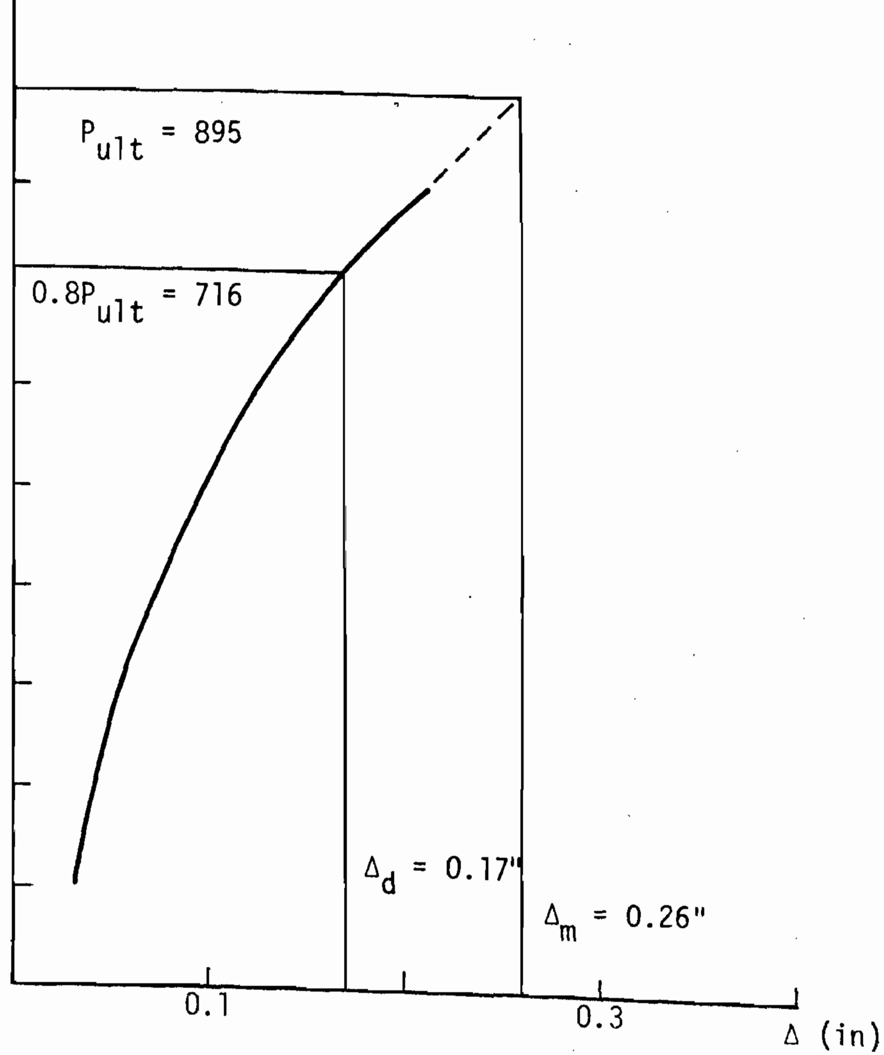


Fig. 16 Cantilever Shear Test Results (Specimen as shown in Fig. 13)

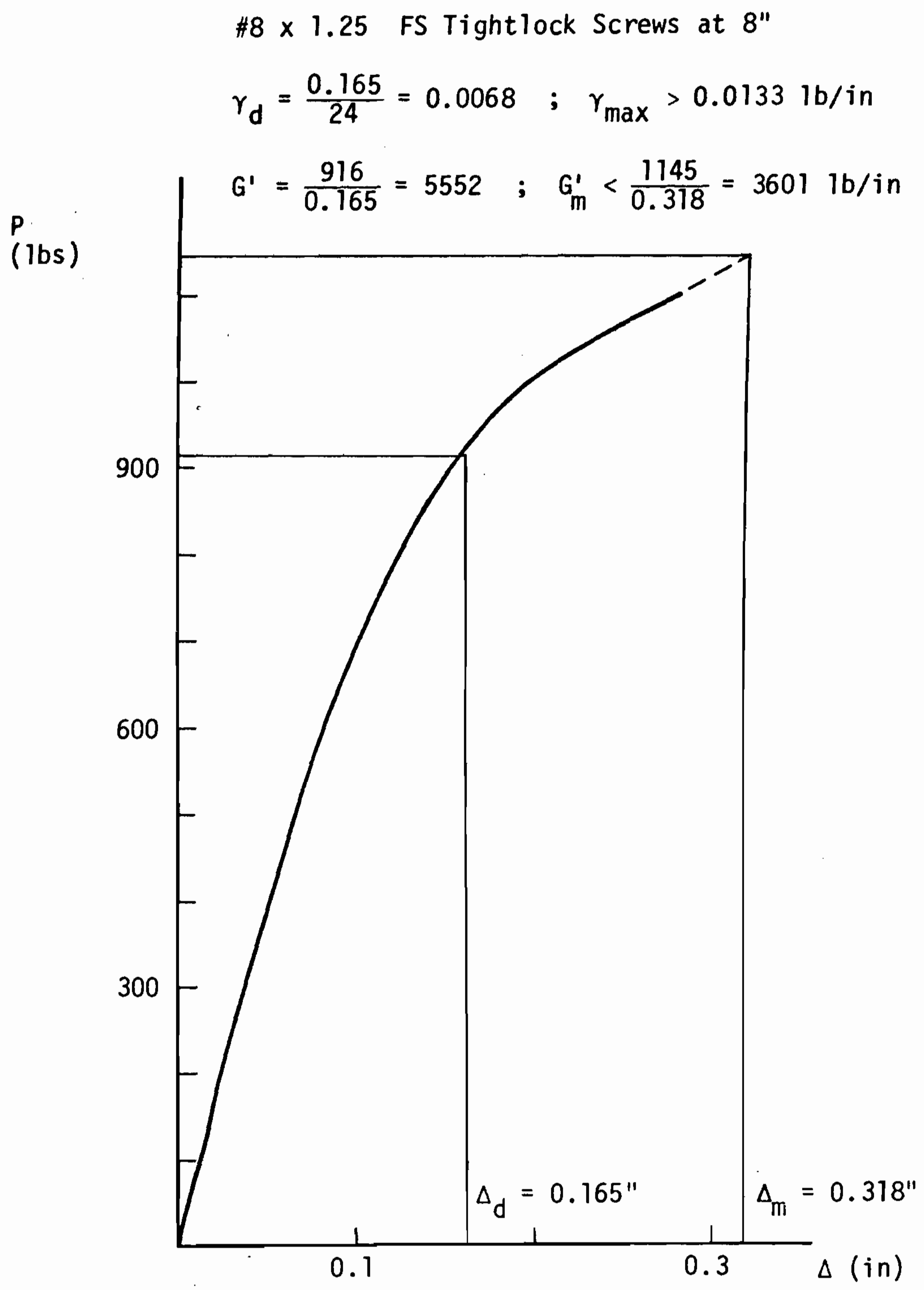


Fig. 17 Cantilever Shear Test Results
(Specimen as shown in Fig. 14)

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