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John L. Lutfallah

Frederick A. Thulin Jr.

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COLD-FORMED STEEL FRAMING WITH GYPSUM FACING

By

Frederick A. Thulin, Jr.* and John L. Lutfallah**

INTRODUCTION

Cold-formed steel wall stud framing laterally supported by gypsum panels on both faces is subject to calculative analysis when subjected to axial and combined axial and bending loads in accordance with current procedures outlined by the American Iron and Steel Institute (A.I.S.I.). However, the AISI in their Specifications for the Design of Cold-Formed Steel Structural Members 1968 Edition,[2] Supplementary Information,[3] Commentary,[5] and Charts and Tables[4] provide no clear method for computing the allowable axial load, and combined axial and bending loads on cold-formed steel wall studs laterally braced on one side with gypsum facing. On the other hand, the American Society for Testing Materials (ASTM) in their Standard[6] E-72 provide test methods for ascertaining the racking resistance for cold-formed steel wall framing laterally braced on one or both faces with gypsum facing materials.

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* Corporate Member American Institute of Architects, Registered Architect, Registered Professional Engineer, Senior Research Staff Member, United States Gypsum Company, 1000 East Northwest Highway, Des Plaines, IL 60016

** Registered Structural Engineer, Senior Research Staff Member, United States Gypsum Company, Research Department, 1000 East Northwest Highway, Des Plaines, IL 60016

With steel framing laterally supported on both faces with gypsum materials or without any lateral support, laboratory load tests indicate that AISI calculative methods are safe but conservative. These tests and calculations are described in Wiss, Janney, Elstner and Associates Report on Cold-Formed Steel Framing System for Low-Rise Construction[9] dated June 15, 1972.

The laboratory tests and calculated results were fully supported by tests on a full-size experimental building (see Fig. 1) simulating actual combined wind, snow and floor loading. The cold-formed steel framing members were stiffened C-shapes as manufactured by United States Gypsum Company. This experimental building consists of a two-story four-room rectangular structure measuring 17 feet in depth and 52 feet in length. Figures 2, 3 and 4 show the building framework. Wiss, Janney, Elstner and Associates report entitled Structural Performance Test of a Building Incorporating USG Cold-Formed Steel Framing System[8] dated June 23, 1972 gives complete details of this full-scale test.

During the erection process this experimental building was subjected to natural snow, wind and construction live loads with the load-bearing studs laterally supported on one side only with screw attached gypsum sheathing. No quantitative load measurements were made; however, no structural failures or noticeable deformation occurred during this phase of construction. Because the question of safety was raised and no accurate calculative method available, tests were conducted per ASTM-E72[6] (see Fig. 5

and 6) to investigate the gypsum facing-one-side case. The tests showed favorable but inconclusive results.

The experience of the test building program indicates that a simplified empirical method for calculating the structural performance of cold-formed steel framing laterally supported by a wall material on one face is needed to achieve complete computative design. This is required not only for axial but combined axial and bending loads. The problem is also encountered for pure bending loads.

OBJECTIVES

The purposes of this technical paper are as follows:

(1) To demonstrate that a cold-formed steel framing system using channel studs laterally braced one side is structurally adequate to meet AISI Spec.[2] 5.1 if

  (a) the steel studs are within a given range of slenderness (KL/r) and web flat width (h/t) ratios and

  (b) the gypsum sheathing has an adequate modulus of elastic support (k_w) and fastener strength (F) per AISI Suppl.[3] 4.2.

(2) To present an empirical method for calculating allowable axial and lateral loads where

  (a) KL/r and/or h/t are not within the range of 1(a) and/or

  (b) k_w and/or F do not meet AISI Suppl.[3] 4.2

THEORY

Bleich, Buckling Strength of Metal Structures[1] presents the basic Euler column buckling formula for the critical stress f_{cr} is in the general form

(Eq 1)

$$f_{cr} = \frac{\pi^2 E\ T_E}{12(1-n_p^2)} \left(\frac{t}{w}\right)^2 k$$

or in the elastic range since

$T_E = 1$

(Eq 2)

$$f_{cr} = \frac{\pi^2 E}{12(1-n_p^2)} \left(\frac{t}{w}\right)^2 k$$

where

f_{cr} = critical buckling stress, psi

E = Modulus of elasticity, psi

T_E = tangent modulus of elasticity divided by E

n_p = Poisson's ratio

t = thickness of material in.

w = full unreduced width of element, in.

k = coefficient depending on the aspect ratio, support conditions and the value of T_E

For the case of a channel stud attached to a facing one flange may be approximated as a combination tee and an angle with one lip. The latter may be considered as a channel or a combination of two angles. This is illustrated in Figure 7. The flange of the tee is related to the transformed area of the sheathing. For the tee the equations are

(Eq 3)

$$z = \frac{t_w{}^3}{t_f{}^3} \; \frac{1}{1 - 0.106 \, \frac{t_w{}^2 w_f{}^2}{t_f{}^2 h_w{}^2}}$$

which is valid for

$$0.106 \; \frac{t_w{}^2 w_f{}^2}{t_f{}^2 h_w{}^2} \leq 1 \; ;$$

(Eq 4) $\sqrt{k} = 0.65 + \frac{2}{3z + 4}$

(Eq 5) $h_w/t \leq C_{1r}\sqrt{k}$

Where

z = coefficient of restraint

t_f = thickness of flange, in.

t_w = thickness of web, in.

w_f = full width of flange, in.

h_w = height of web, in.

$$C_{1r} = \frac{0.303}{\sqrt[4]{T_E}} \, \frac{1}{r}$$

For the channel, assuming uniform thickness, the equations are

(Eq 6) $z = 2 \left[\frac{0.16 + 0.0056 \; (h_w/b_f)^2}{1 - 9.4 \; (b_f/h_w)^2} \right]$

(Eq 7) $k = 2 + \frac{2}{10z + 3}$

(Eq 8) $b_f/t \leq C_{1r}\sqrt{k}$

and for the angle

(Eq 9) $h_w/t \leq 0.652 \; C_{1r}$

(Eq 10) $h_1/t = h_e/t_{actual}$

b_f = reduced width of flange per AISI, in.

h_1 = depth of angle leg, in.

h_w = depth of web, in.

After solving for z, the k can be determined, then the effective thickness calculated. The Engresser Formula (see Ref. 1) provides a simplified solution to obtain the spring constant. A tentative solution is also provided in AISI Supplementary Information[3] Section 3. Evidence of this behavior occurring is shown if deformation takes to form multiples of half sine (or cosine) waves.

The case of a channel with sheet facing on one flange may also be evaluated from test determined coefficients applied using the following general form equations:

(Eq 11) $F_{al\ adj} = C_{t1} F_{al}$

(Eq 12) $F'_e\ adj = C_{t2} F'_e$

(Eq 13) $F_b\ adj = C_{t3} F_b$

Where

F_{al} = allowable concentric stress under concentric loading, ksi

KL/r = effective slenderness ratio

h/t = web depth to thickness ratio

adj = subscript meaning adjusted

F'_e = $\dfrac{12\ \pi^2 E}{23(Kl_b/r_b)^2}$, ksi

C_{tn} = test determined coefficient

n = integer subscript defining constant C_{tn}

PROCEDURE

Six panels 4 ft wide by 8 ft high were subjected to axial and bending loads in vertical position per ASTM E-72 test procedure using the vacuum chamber method. Figure 8 shows the test setup. The studs used were USG 35ST10 (3½", 20 ga, channels) spaced 16 in. on centers. Figure 9 shows the stud cross-section. USG Gypsum Sheathing was attached with screws 12 in. o.c. one face. Three samples were tested with load applied on the facing side; and three, on the unsupported flange side.

These tests were repeated on six more samples with the panel in a horizontal position and a lead weight bending load. The test setup was as shown in Figure 13 except for 16 in. o.c. stud spacing. The results were compared to determine whether the different test procedures produced substantially the same results. The mean test results using this procedure were then averaged with the vacuum chamber tests. These initial tests both using vacuum chamber and lead weights are given the designation "0" with suffix "1" indicating load on facing side and "2" with load on unsupported flange side. The following table clarifies these initial test series

Test Series No.	Stud @ 16" O.C.	Span, L, in.	Loading Type	½" Gypsum Sheathing Facing Position
0-1	35ST10	96	Combined	Toward Load
0-2	35ST10	96	Combined	Away from Load

A further test series using the horizontal setup is shown in Figures 13, 13A, 17 and 18. Panels were constructed as shown in Figures 11, 12, 19 and 20. Components are illustrated in Figures 9, 10 and 21. Axial loads only and combined axial and bending loads were applied. A complete schedule of this second series of tests is as follows:

Test No.	Stud @ 24" O.C.	Span, L, in.	Loading type	½" Gypsum Sheathing Facing Position
A-1	35ST8	192	Axial	Up (Toward Load)
A-2	35ST8	192	Axial	Down (Away From Load)
A-3	35ST8	192	Combined	Up
B-1	35ST10	192	Axial	Up
B-2	35ST10	192	Combined	Down
B-3	35ST10	192	Combined	Up
C-1	75FJ10	192	Axial	Up
C-2	75FJ10	192	Combined	Down
D-1	55FJ10	120	Axial	Up
D-2	55FJ10	120	Combined	Up
D-3	55FJ10	120	Combined	Down
E-1	55FJ10	120	Combined	Up
F-1	35ST8	96	Combined	Up
F-2	35ST8	96	Combined	Down
F-3	35ST8	96	Axial	Up
G-1	35ST10	96	Combined	Down
G-2	35ST10	96	Combined	Up
G-3	35ST10	96	Axial	Up
H-1	55FJ10	96	Axial	Up
H-2	55FJ10	96	Combined	Up
I-1*	38ST10	96	Axial	Up

* Note: On this test screw spacing securing facing is spaced 8 in. o.c. All other tests have 12 in. o.c. screw spacing.

The third phase of the procedure involved tests for determining modulus of elastic support, k_w, and attachment strength, F, per AISI Supplementary Information[3] 4.2. using gypsum facing one face.

After completion of the testing the allowable loads were calculated per AISI Spec[2] and compared with test determined safe loads. Also, calculated required and test determined actual k_w and F were compared.

To aid in making an analysis of performance the following were graphed:

(1) P_{test}/P_{calc}, versus slenderness ratio, KL/r, with constant depth thickness ratio (h/t).

(2) P_{test}/P_{calc}, versus h/t with KL/r constant. (These graphs (1) and (2) were prepared for Case 1 axial, Case 2 axial and bending, and Case 3 both Case 1 and Case 2 combined.)

After this the allowable axial loads were spot-checked using Equations 3 through 13.

Then in cases where allowable loads cannot be calculated in accordance with theoretical procedures, the values of the coefficients in Equations 11, 12 and 13 were determined to give $F_{al\ adj}$, $F'_{e\ adj}$ and $F_{b\ adj}$ that correspond to tests.

TEST DATA

Data obtained from load tests are as follows:

Test or Test Series No.	Axial Load at Failure, P_{ult}, Kips/stud	Beam Load at Failure, W_{ult}, Kips/in./stud	Failure Mode* and/or Remarks
0-1	5.6	0.00250	TFB
0-2	5.0	0.00250	TFB
A-1	4.5	None	TFB
A-2	5.0	None	TFB Full sine wave deformation on one stud, half sine wave on other
A-3	1.35	0.00205	CB
B-1	5.35	None	TFB
B-2	1.0	0.00198	TFB one stud + ETFB other stud
B-3	1.25	0.00253	CB
C-1	3.2	None	CB
C-2	2.05	0.00253	ETFB 1.5 in. rotation of stud before failure; screws pulled out; sheathing cracked
D-1	6.0	None	TFB on one stud C on other stud
D-2	5.25	0.00375	TFB on one stud C on other stud
D-3	4.5	0.00375	TFB
E-1	5.9	0.00375	TFB on one stud C on other stud
F-1	2.9	0.00375	CB
F-2	1.8	0.00375	TFB
F-3	4.5	None	TFB
G-1	3.5	0.00375	TFB

Test or Test Series No.	Axial Load at Failure, P_{ult}, Kips/stud	Beam Load at Failure, W_{ult}, Kips/in./stud	Failure Mode* and/or Remarks
G-2	4.35	0.00375	TFB
G-3	5.75	None	SPO + TFB
H-1	5.9	None	SPO + TFB
H-2	5.4	0.00375	SPO + TFB
I-1	6.05	None	C (near end)

The k_w tests produced the following data:

Stud	Stud Spacing, In.	Screw Spacing, In.	k_w Kip/In.	F, Kips/half fastener
35ST10	16	12	0.096	0.061
35ST8	24	12	0.078	0.051
35ST10	24	12	0.094	0.061
75FJ10	24	12	0.043	0.028
55FJ10	24	12	0.059	0.095
35ST10	24	8	0.062	0.061

Figure 22 shows a typical test, G-2, with the *facing* up just prior to failure; Figure 23, test G-1, the facing down case. Note the half-sine wave pattern the compressive flanges take. Figures 24 and 25 show the same tests, G-2 and G-1, respectively, just

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* Failure mode symbols

TFB = Torsional flexural buckling
ETFB = Elastic torsional flexural buckling
CB = Compressive buckling of the compressive *flange*
C = Straight compressive failure
SPO = Screw pullout

after failure.

Figures 26, 27, 28 and 29 illustrate TFB with facing down, TFB with facing up, CB and C failure modes, respectively.

CALCULATIONS

Safe loads were determined from test failure loads per AISI Spec 6.2(b). The axial load, P, was assumed to be 60% live and 40% dead load. Bending in the case of combined loads was presumed to result from wind.

Allowable design axial loads, P, were calculated per AISI Spec 2.3, 3.6 and 3.7, assuming as if adequately laterally supported. The safe beam load was assumed to be the same as the test determined value and to result from wind.

The required k_w and P_{min} (min fastener strength) were calculated per AISI Spec 5.1(c) and (d).

The test derived and calculated values are compared as follows:

Test No.	Safe Wind Load, w, Kips/in./Stud	Safe Axial Load, P, Test Derived	Kips/Stud Calculated
0-1	0.00166	4.2	2.9
0-2	0.00166	3.7	2.9
A-1	None	2.5	1.7
A-2	None	2.8	1.7
A-3	0.00136	1.0	0.20
B-1	None	3.0	2.0
B-2	0.00132	0.74	0.45
B-3	0.00168	0.93	0.20
C-1	None	1.8	3.8

Test No.	Safe Wind Load, w, Kips/in./Stud	Safe Axial Load, P, Kips/Stud	
		Test Derived	Calculated
C-2	0.00168	1.5	3.1
D-1	None	3.3	3.8
D-2	0.00250	3.9	3.4
D-3	0.00250	3.3	3.7
E-1	0.00250	4.4	3.4
F-1	0.00250	2.2	1.7
F-2	0.00250	1.3	1.7
F-3	None	2.5	2.6
G-1	0.00250	2.6	2.4
G-2	0.00250	3.2	2.4
G-3	None	3.2	3.2
H-1	None	3.3	3.8
H-2	0.00250	4.0	3.4
I-1	None	3.4	3.2

The following table shows a comparison of the calculated required and actual modulus of elastic support, k_w; and connection strength, P_{min} and F :

Test No.	k_w Req'd, Kip/In.	P_{min} Req'd, Kips/Half Fastener	k_w Actual Kip/In.	F, Kips/Half Fastener	Result
A-1	0.044	0.013	0.078	0.051	ok
A-2	0.044	0.013	0.078	0.051	ok
A-3	0.044	0.00118	0.078	0.051	ok
B-1	0.053	0.016	0.094	0.061	ok
B-2	0.053	0.0027	0.094	0.061	ok
B-3	0.053	0.0012	0.094	0.061	ok

Test No.	k_w Req'd, Kip/In.	P_{min} Req'd, Kips/Half Fastener	k_w Actual Kip/In.	F, Kips/Half Fastener	Result
C-1	0.101	0.040	0.043	0.028	ng
C-2	0.101	0.030	0.043	0.028	ng
D-1	0.074	0.025	0.059	0.095	marg
D-2	0.074	0.021	0.059	0.095	ok
D-3	0.074	0.021	0.059	0.095	marg
E-1	0.074	0.021	0.059	0.095	ok
F-1	0.044	0.0071	0.078	0.051	ok
F-2	0.044	0.0071	0.078	0.051	marg
F-3	0.044	0.013	0.078	0.051	marg
G-1	0.053	0.0026	0.094	0.061	ok
G-2	0.053	0.0026	0.094	0.061	ok
G-3	0.053	0.016	0.094	0.061	ok
H-1	0.074	0.025	0.059	0.095	marg
H-2	0.074	0.021	0.059	0.095	ok
I-1	0.035	0.0109	0.062	0.061	ok
O-1	0.053	0.014	0.096	0.061	ok
O-2	0.053	0.014	0.096	0.061	ok

Figures 14, 15 and 16 show the following tests and curves extrapolated therefrom:

Test No.	Y, $P_{test}/P_{calc} \times 100$	Load Type*	Facing Position*	X, Kl/r	Z, h/t
0-1	145	C	U	69	94
0-2	128	C	D	69	94
A-1	148	A	U	137	113
A-2	165	A	D	137	113

Test No.	Y, P_{test}/P_{calc} x100	Load Type*	Facing Position*	X, Kl/r	Z, h/t
A-3	505	C	U	137	113
B-1	150	A	U	138	94
B-2	167	C	D	138	94
B-3	185	C	U	138	94
C-1	47.4	A	U	69	205
C-2	47.9	C	D	69	205
D-1	87	A	U	57	149
D-2	133	C	U	57	149
D-3	97	C	D	57	149
E-1	129	C	U	57	149
F-1	106	C	U	69	113
F-2	76.5	C	D	69	113
F-3	96	A	U	69	113
G-1	108	C	D	69	94
G-2	133	C	U	69	94
G-3	100	A	U	69	94
H-1	87	A	U	57	149
H-2	118	C	U	57	149
I-1	106	A	U	69	94

* A = Axial load only
C = Combined axial and bending
D = Facing down or away from load
U = Facing up or on load side

The following calculations show a sample problem calculated using Equation 3 to 10, inclusive.

Problem:

Computation of the critical load "P_{cr}" of 7½ 20 gage stud (75FJ10) 16'-0" span

Assumption:

Consider stud as "Tee" plus equal flange channel (the Tee section to be used for stiffness consideration only).

Studs 24" o.c. with gypsum facing

Modular ratio $= \frac{\text{E steel}}{\text{E gypsum}} = 120$

Transformed area of gypsum A_{gt}

$$A_{gt} = \tfrac{1}{2} \times 24 \times \frac{1}{120} = 0.1 \text{ in.}^2$$

Equivalent 20 gage flange width $= \frac{0.1}{0.036} = 2.8$ in.

Total flange width = 1.6 + 2.8 = 4.4 in.

Equivalent half flange = 2.2 in.

Consider "Tee" section

Projected web width $h_w = 7$ in. approximately

Stud radius of gyration $r_x = 2.767$

$$\frac{Kl}{r_x} = \frac{192}{2.767} = 20$$

For $F_y = 45$ ksi

$C_{1r} = 3.17 \frac{l}{r} - 2.4 = 24$ simplified for $F_y = 45$ ksi (Bleich)[1]

From Equation 5

$$\sqrt{k} = \frac{h_w}{24t}$$

Equating this value of k to that given in equation 4

(Eq 4A)

$$\frac{h_w}{24t} = 0.65 + \frac{2}{3z+4}$$

z can be calculated from Eq. 3 thus

$$z = \frac{1}{1}\,\frac{1}{1-0.106\,\frac{(2.2)^2}{h_w^2}}$$

$$z = \frac{1}{1-\frac{0.51}{h_w^2}} = \frac{h_w^2}{h_w^2 - 0.51}$$

Limiting conditions

$$1 - \frac{0.51}{h_w^2} \geq 0$$

$$\frac{h_w^2 - 0.51}{h_w^2} \geq 0$$

h_w^2 always positive

Therefore $h_w^2 - 0.51 \geq 0$

or $(h_w - 0.704)\ (h_w + 0.704) \geq 0$

$h_w < -0.704$ neglect

$h_w > 0.704$ which is the limiting condition

Therefore replacing this value of z in Eq. 4A

$$\frac{h_w}{24t} = 0.65 + \frac{2}{3\,\frac{h_w^2}{h_w^2 - 0.51} + 4}$$

for 20 gage t = 0.036

$$1.16\ h_w = \frac{6.55\ h_w^2 + 2.35}{7\ h_w^2 + 2.04}$$

$$8.1\ h_w^3 - 6.55\ h_w^2 + 2.37\ h_w - 2.35 = 0$$

Solving this equation yields

$h_w = 0.86$ in. > 0.704 ok

For the bottom flange, divide the channel into two equal angles.

Check formula 9. See Fig. (30)

$$\frac{h_w}{t} = 0.652\ C_{1r} \quad \text{(for 1:1 ratio)}$$

$$= 0.652 \times 24 = 15.6$$

$$t = 0.036$$

$$h_w = 15.6 \times 0.036 = 0.56$$

Check ratio 1:1 assumed

$$\text{ratio} = \frac{0.56}{0.5} = 1.12 \quad \text{say ok}$$

Effective area = 5.0 x 0.036 = 0.18 sq. in.

$$F_{cr} = \frac{\pi^2 E \quad (1)}{12(1-n_p{}^2)} \left(\frac{t}{w}\right)^2 \ k$$

For $n_p = 0.3$

$$\frac{\pi^2 E}{12(1-n_p{}^2)} = 26.7 \times 10^3$$

$$\left(\frac{t}{b}\right)^2 = \left(\frac{0.036}{0.86}\right)^2 = 1.75 \times 10^{-3}$$

Coefficient of restraint $z = \frac{h_w{}^2}{h_w{}^2 - 0.51} = \frac{0.74}{0.74-0.51} = 3.2$

$$\sqrt{k} = 0.65 + \frac{2}{3 \times 3.2+4}$$

$$\sqrt{k} = 0.797$$

$$k = 0.635$$

$F_{cr} = 26.7 \times 10^3 \times 1.75 \times 10^{-3} \times 0.635 = 29.7$ ksi

$P_{cr} = 29.7 \times 0.18 = 5.34$ kips

The safe load considering a safety factor of 1.92 will be

$P_{safe} = \frac{5.34}{1.92} = 2.78$ kips say 2.8 kips

Derivation of Adjustment Coefficients

The families of curves shown in Figs. 14, 15 and 16 can be expressed as surfaces in the polynomial form

$$y\ (x) = C_1\ x^n + C_2\ x^{n-1} \ldots\ldots\ C_{n-1}x + C_n$$

$$y\ (Z) = k_1\ Z^n + k_2\ Z^{n-1} \ldots\ldots\ k_{n-1}Z + k_n$$

or combining

$$y = C_1\ x^n + k_1\ Z^n + C_2\ x^{n-1} + k_2\ Z^{n-1} \ldots\ldots$$

$$\ldots\ldots\ C_{n-1}\ x + k_{n-1}\ Z + C_n + k_n$$

Where k and C are constants

Using USG computer program POLRG, a curve fitting program, the following equations result:

(Eq 14)

$$y_a = 0.00272\ x^2 - 0.00164\ Z^2$$
$$+0.0131\ x + 0.0311\ Z + 100$$

For combined face up

(Eq 15)

$$y_{cw} = 0.000000395\ x^4 - 0.000169\ x^2$$
$$+0.0208\ x^2 - 0.00131\ Z^2$$
$$-0.00352\ x + 0.0742\ Z + 100$$

For combined face down

(Eq 16)

$$y_{cl} = 0.00428\ x^2 - 0.00205\ Z^2$$
$$-\ 0.0463\ x + 0.066\ Z + 100$$

Where

$y = P_{test}/P_{calc} \times 100$

$x = Kl/r$

$Z = h/t$

subscript w means bending load applied on facing side

subscript 1 means bending load applied on unsupported flange side

Using the relationship

(Eq 17)

$$y_b = \left(\frac{P_{calc}/QA}{M_{calc}/S_{reduced}} + 1 \right) y_c - \left(\frac{P_{calc}/QA}{M_{calc}/S_{reduced}} \right) y_a$$

The conditions for bending alone are determined from Equations 14, 15 and 16 to be as follows:

For facing toward load (indicated by subscript w)

(Eq 18)

$$y_{bw} = 0.00000101\ x^4 - 0.000433\ x^3 + 0.0490\ x^2 - 0.000790\ z^2 - 0.0294\ x + 0.142\ z + 100$$

For facing away from load (indicated by subscript 1)

(Eq 19)

$$y_{b1} = 0.00676\ x^2 - 0.00269\ z^2 - 0.139\ x + 0.121\ z + 100$$

Where subscript b means pertaining to bending; a, axial

P = Axial load
Q = Column factor
A = Area
M = Moment
S = Section modulus

DISCUSSION

Now F_{a1}, F'_e and F_b may be adjusted in accordance with Equations 11, 12 and 13 using the following values for the coefficients:

(Eq 20)

$$C_{t1} = y_a/100$$

(Eq 21)

$$C_{t2} = y_a/100$$

(Eq 22)

$$C_{t3} = y_{bw}/100 \text{ or } y_{bl}/100$$

since F_{al} and F'_e are directly related to the calculated axial load and F_b is directly related to the calculated bending load. The k_w factor appears to be directly related to h/t and F/P_{min} inversely related to KL/r. Spot checking for some of the test conditions shows the following comparison between test and calculated adjusted axial loads using $F_{al\ adj}$, $F'_{e\ adj}$ and $F_{a\ adj}$:

Test No.	Loading Type	P_{test}, Kips	$P_{calc\ adjusted}$ Kips	% Error
C-1	Axial	1.8	1.95	+8
D-1	Axial	3.3	2.96	-10
F-2	Combined Face-down	1.3	1.7	+30
G-1	Combined Face-down	2.6	2.46	-5
F-1	Combined Face-up	2.2	2.4	+9
G-2	Combined Face-up	3.2	3.1	-3

The method for calculating axial loads appears to be quite accurate. This methodology for combined loading, although sufficiently accurate for most practical problems, merits further refinement.

RESULTS

The tests and mathematical analysis show that, where fasteners provide adequate fastener strength, the safe axial loads on the panels evaluated are related to KL/r and w/t ratios as expressed graphically in Figures 14, 15 and 16.

Equations developed for adjustment coefficients for Case A, F_a and F'_e and Case B, F_b are, respectively, as follows:

Case A: Equation 14

Case B: Equations 18 and 19

CONCLUSIONS

(1) A cold-formed steel framing system using channel studs laterally braced one side is structurally adequate to meet AISI Spec 5.1 and may be designed as if laterally braced on both faces if the following conditions are met:

(a) KL/r and w/t are in a range such that y_a in axial load case and y_a, y_{bw} and y_{bl} in the combined load case are greater than or equal to 100, and

(b) laterally supported with gypsum sheathing having an adequate modulus of elastic support (k_w) and fastener strength (F) per AISI Suppl. 4.2.

The following equations giving the values of y_a, y_{bw} and y_{bl} are restated as follows:

For axial load

(Eq 14)

$$y_a = 0.00272\ x^2 - 0.00164\ z^2 \\ + 0.131\ x + 0.0311\ z + 100$$

For facing toward bending load

(Eq 18)

$$y_{bw} = 0.00000101\ x^4 = 0.000433\ x^3 \\ + 0.0490\ x^2 - 0.000790\ z^2 \\ - 0.0294\ x + 0.142\ z + 100$$

For facing away from bending load

(Eq 19)

$$y_{bl} = 0.00676\ x^2 - 0.00269\ Z^2$$
$$- 0.139\ x + 0.121\ Z + 100$$

Where

$y = P_{test}/P_{calc} \times 100$

$x = Kl/r$

$Z = h/t$

a = subscript indicating axial

b = subscript indicating bending

w = subscript indicating load applied on facing side

l = subscript indicating load applied on unsupported flange side

(2A) To determine structural adequacy of a cold-formed steel framing system laterally braced one side, where k_w and F are adequate to meet AISI Spec[2] 5.1 but KL/r and/or h/t are such that the acceptable criterion in (1) are not met, use the following procedure:

Case 1 - Axial Loads Only:

Step 1: Calculate y_a

Step 2: Calculate $F_{a\ adj}$ per following formula:

(Eq 23)

$$F_{a\ adj} = y_a\ F_a/100$$

Step 3: Complete analysis per AISI Spec[2] using $F_{a\ adj}$ for F_a as if laterally supported both faces.

Case 2 - Combined Axial and Bending Loads:

Step 1: Calculate y_a and y_{bw} or y_{bl} depending on lateral load direction

Step 2: Calculate F_a , F'_e and F_b in accordance with the following formulae:

(Eq 24)

$$F_{a\ adj} = y_a\ F_a/100$$

(Eq 25)

$$F'_{e\ adj} = y_a\ F'_e/100$$

(Eq 26)

$$F_{b\ adj} = y_{bw}\ F_b/100 \text{ (for facing toward load)}$$

(Eq 27)

$$F_{b\ adj} = y_{bl}\ F_b/100 \text{ (for facing away from load)}$$

Step 3: Complete analysis per <u>AISI Spec</u>[2] as if laterally supported both faces using $F_{a\ adj}$, $F'_{e\ adj}$ and $F_{b\ adj}$ in place of F_a, F'_e and F_b, respectively. If it is not obvious by inspection that the adjusted values will produce lower results, calculate using F_a, F'_e and F_b and use the more conservative values.

(2B) If k_w and/or F are deficient solve in accordance with (2A) with modified x and Z values as follows:

$$x_{modified} = x\ P_{min}/F$$

$$Z_{modified} = Z\ k_{w\ test}/k_{w\ req'd}$$

Check results when using (2B) in accordance with Equation 3 thru 10. Use lowest value.

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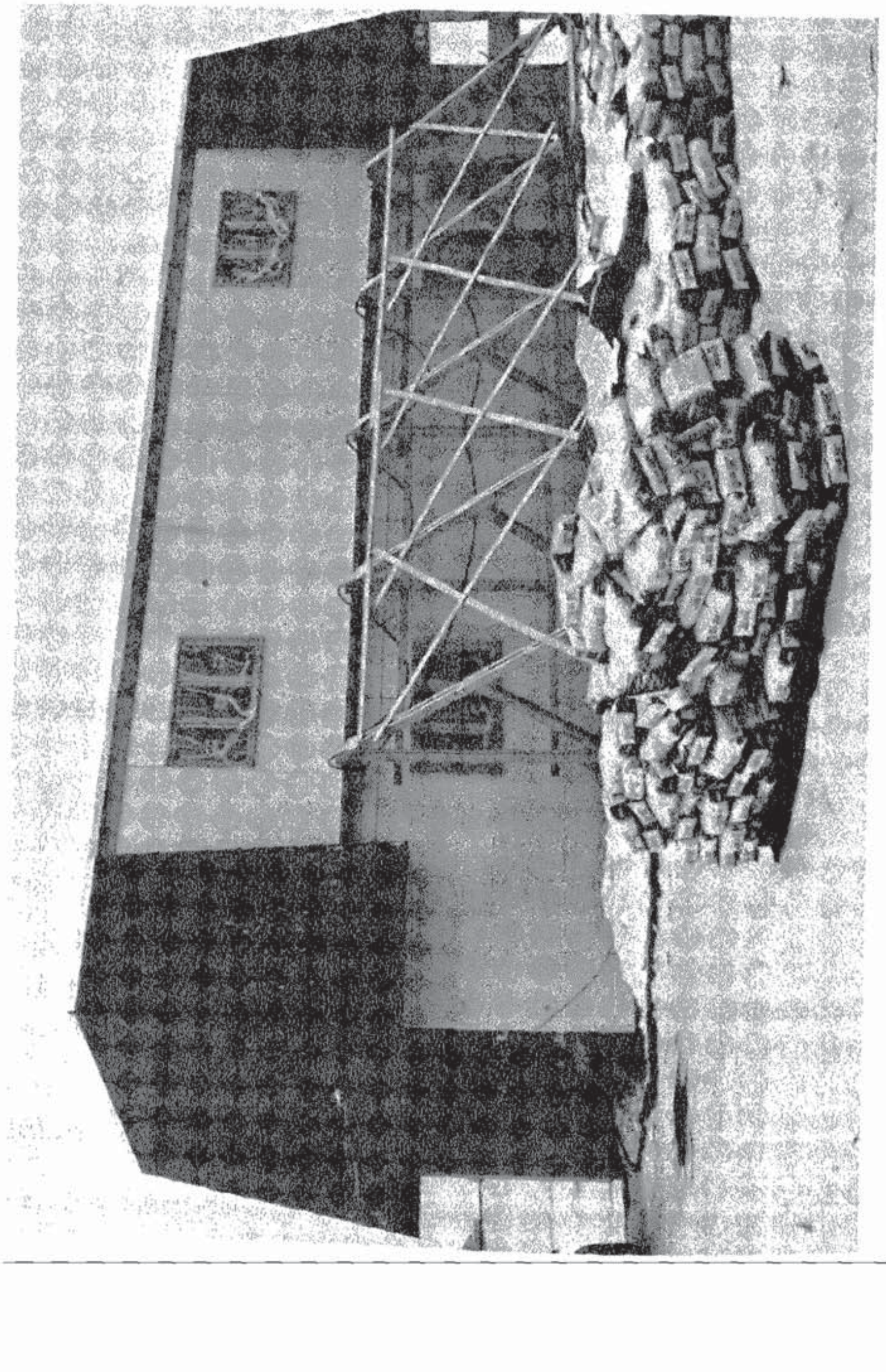


Fig. 1 Experimental Building Completed

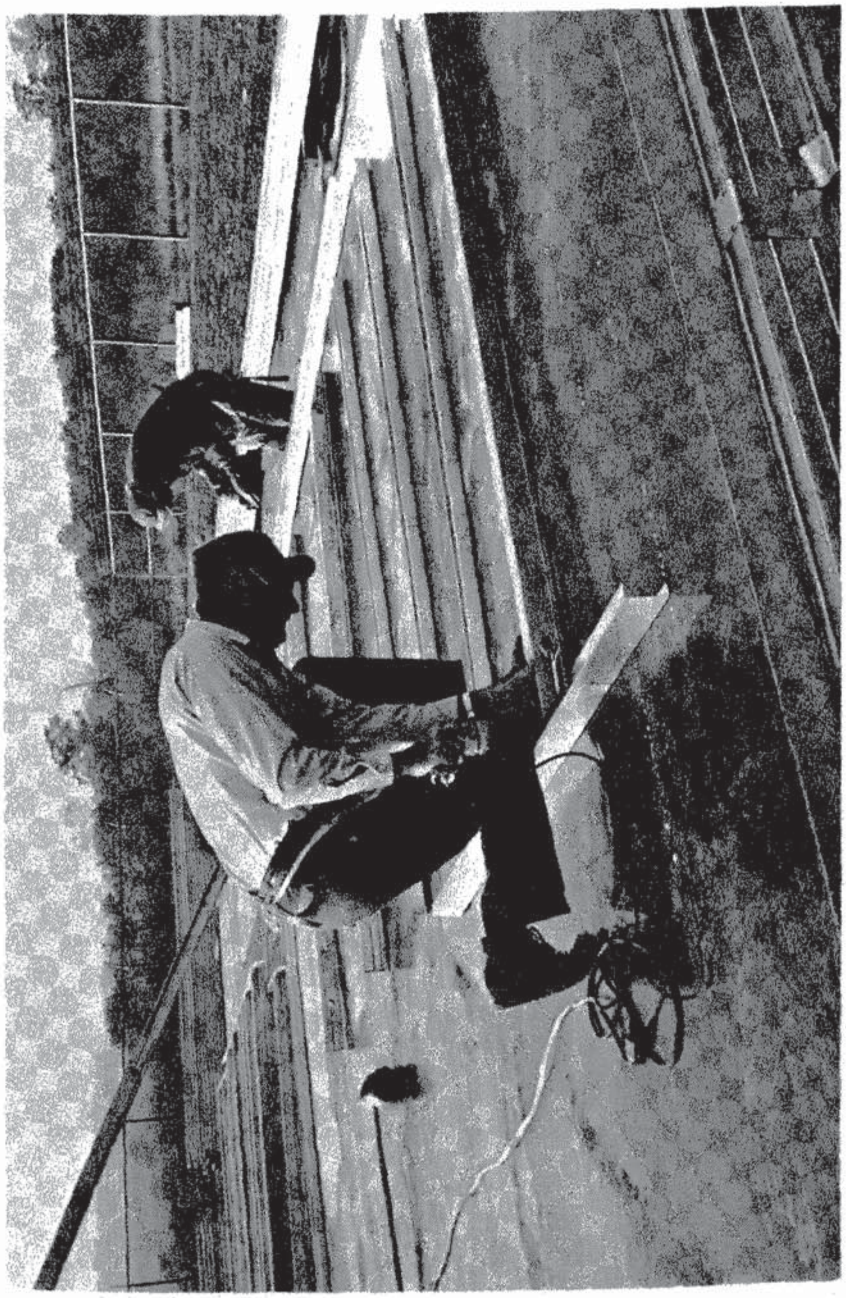


Fig. 2 Assembling Experimental Building Framework

Fig. 3 Experimental Building During Construction

Fig. 4 Experimental Building During Construction
Another View

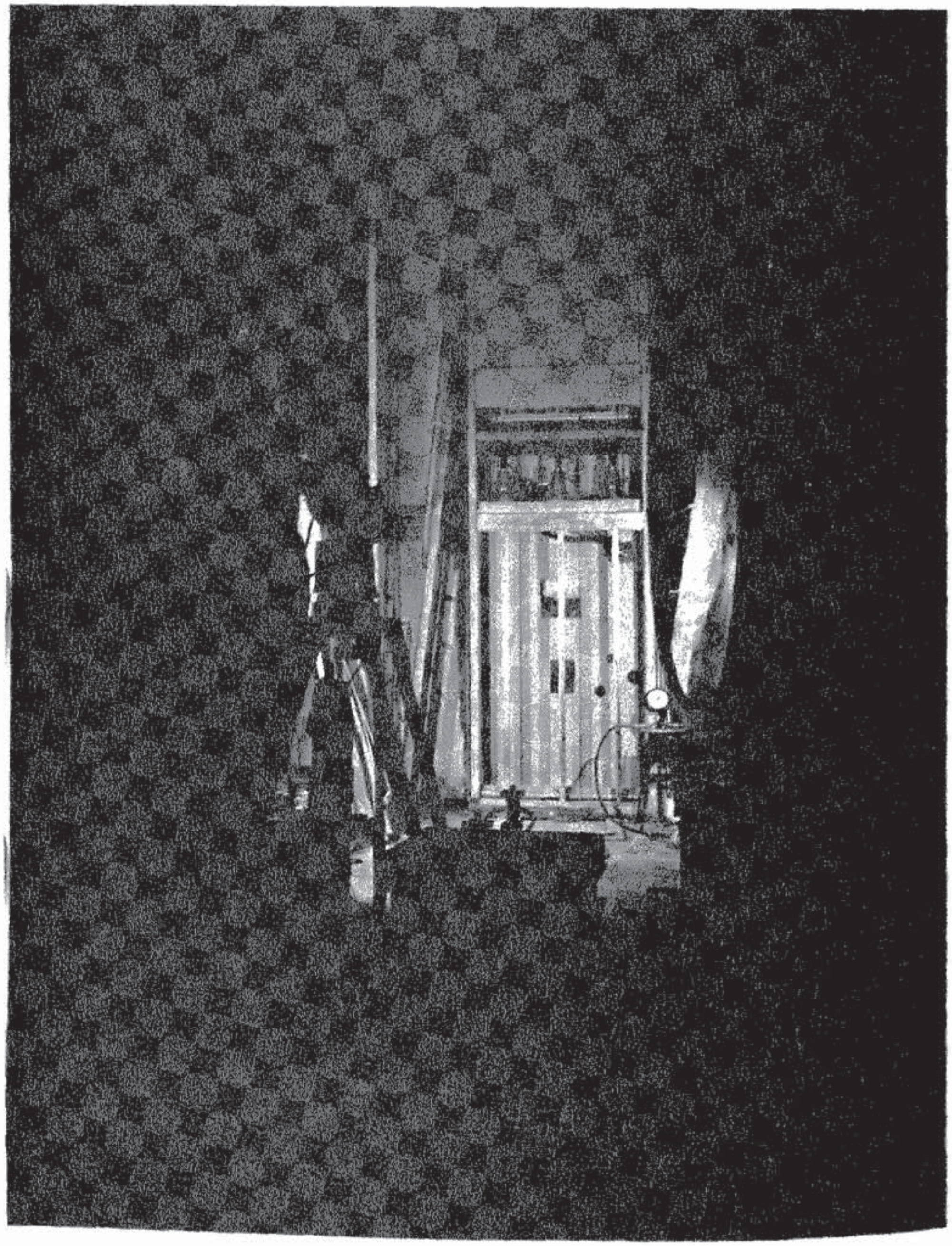


Fig. 5 Load Test Set-Up with Panel Vertical

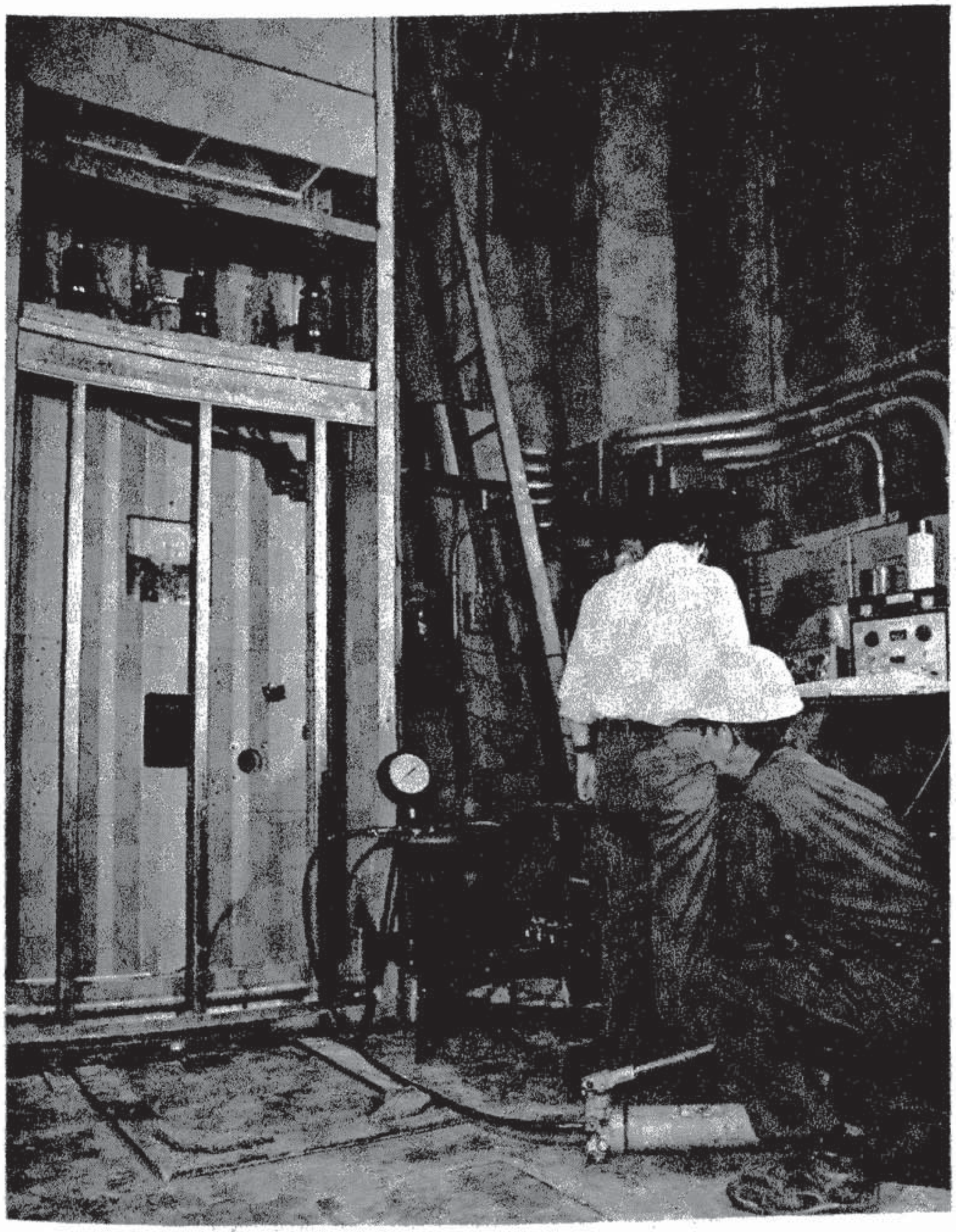
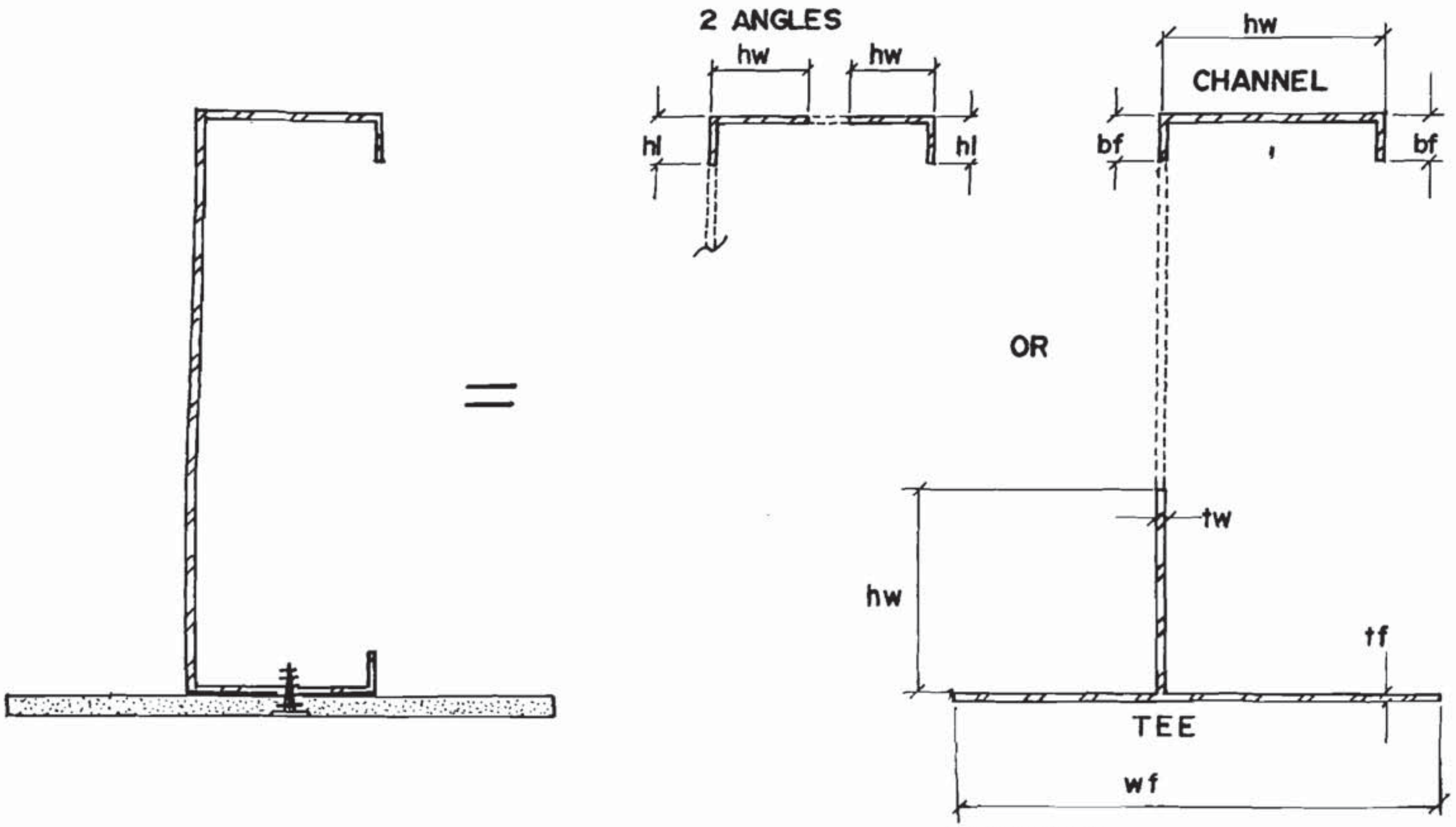


Fig. 6 Load Test Set-Up with Panel Vertical
Close Up View



TRANSFORMED AREA = AREA(GYPSUM) X $\frac{E(GYPSUM)}{E(STEEL)}$

FIG. 7 MODEL OF STUD SHEATHED ON ONE SIDE

Fig. 8 Test Series 01 and 02

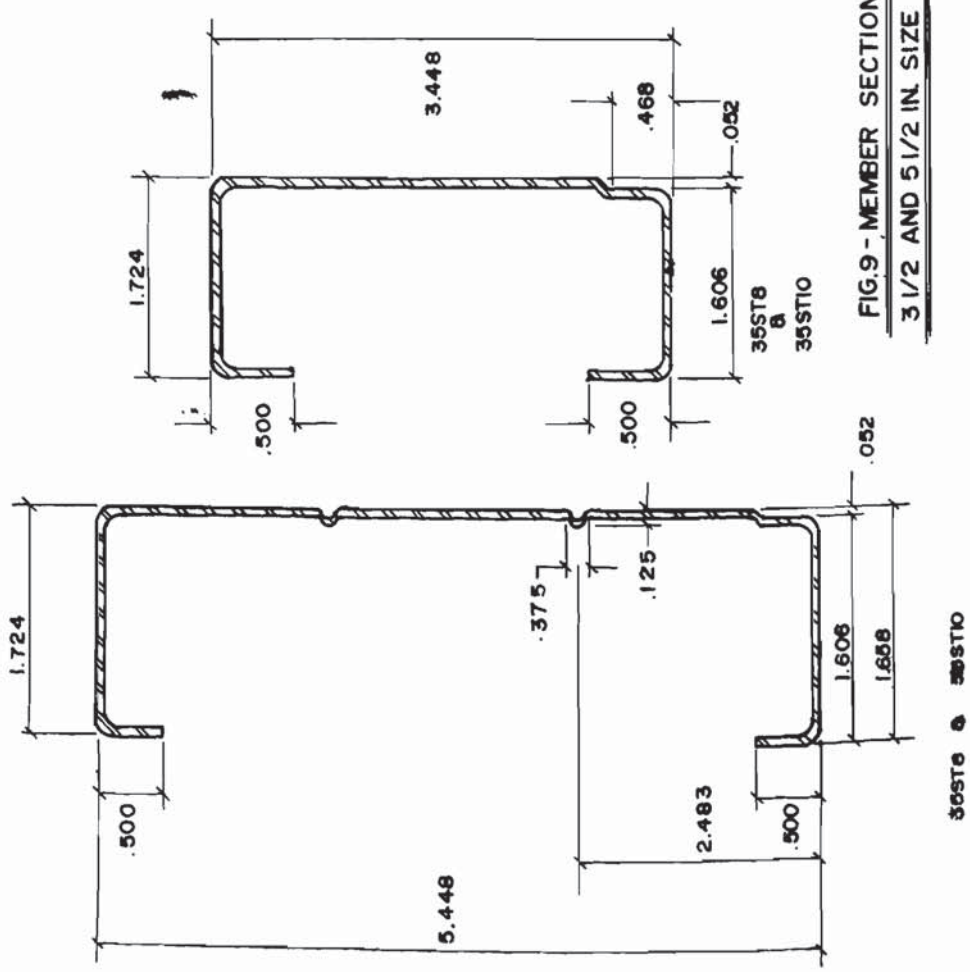


FIG.9 - MEMBER SECTIONS 3 1/2 AND 5 1/2 IN. SIZE

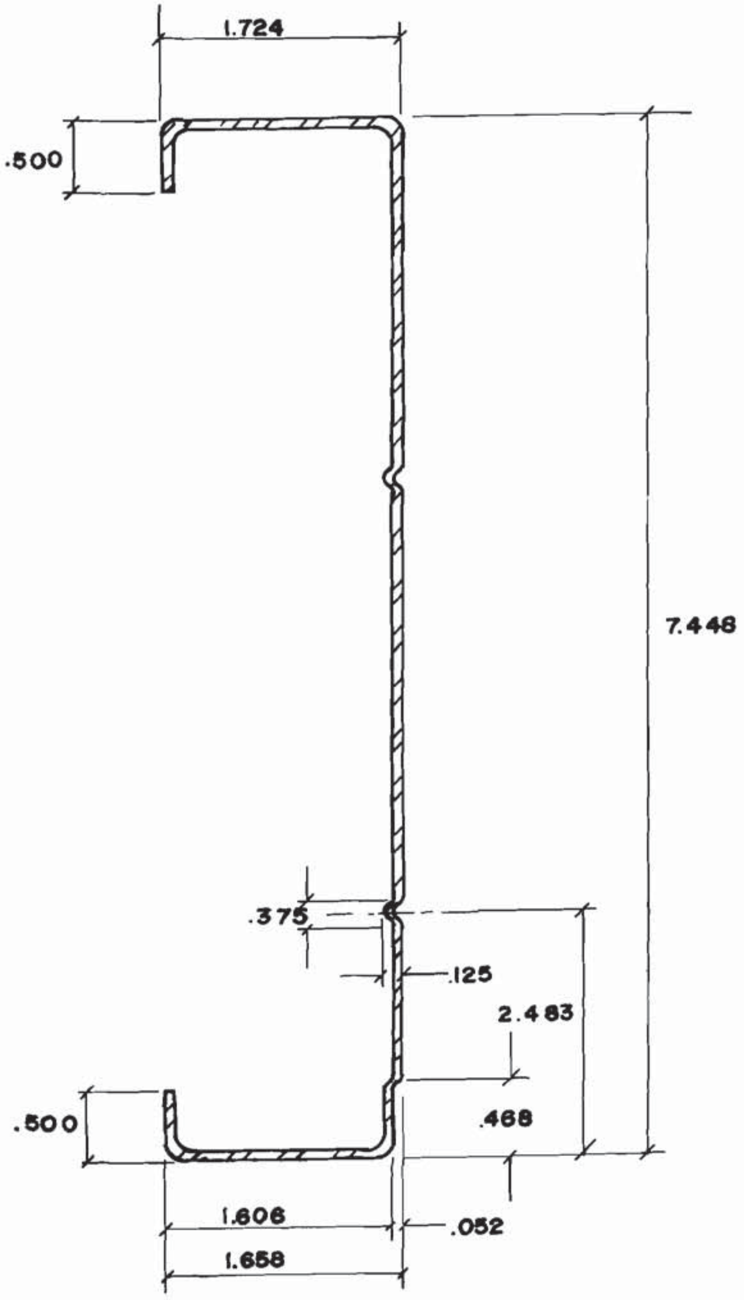


FIG. 10— MEMBER SECTION 7 1/2 IN. SIZE

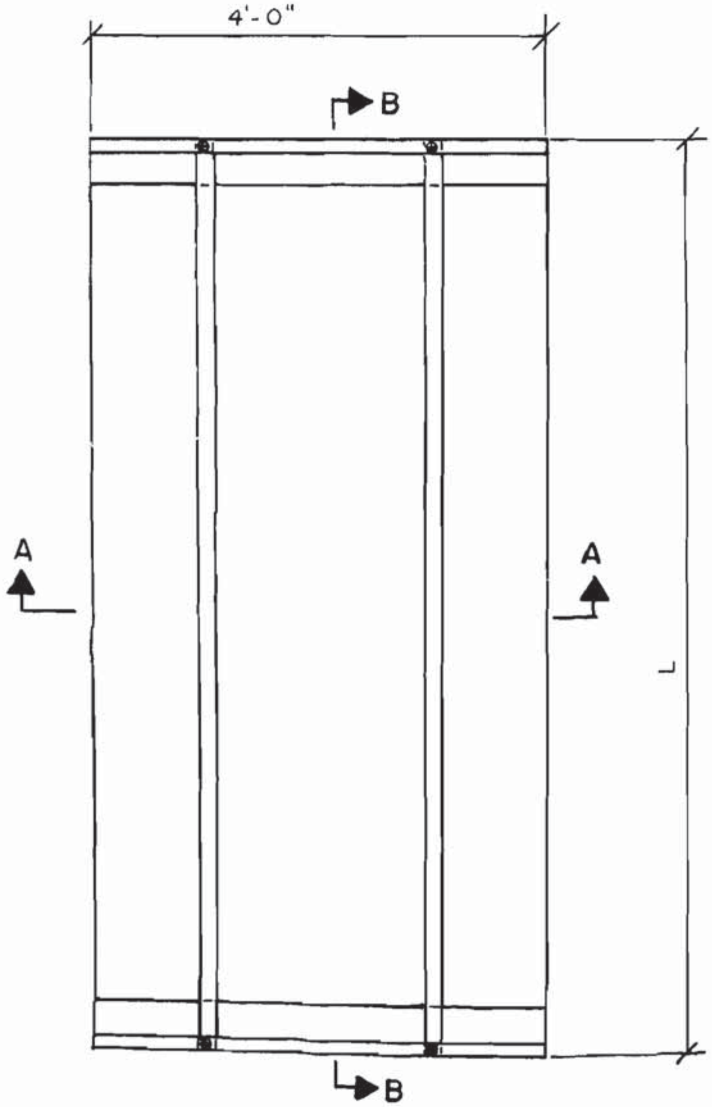


FIG. 11- TEST PANEL

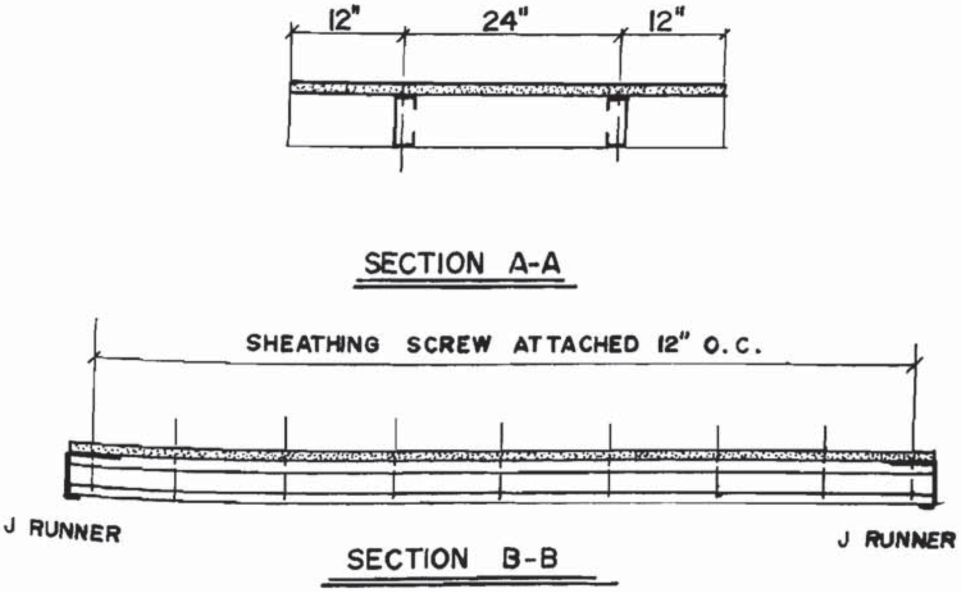
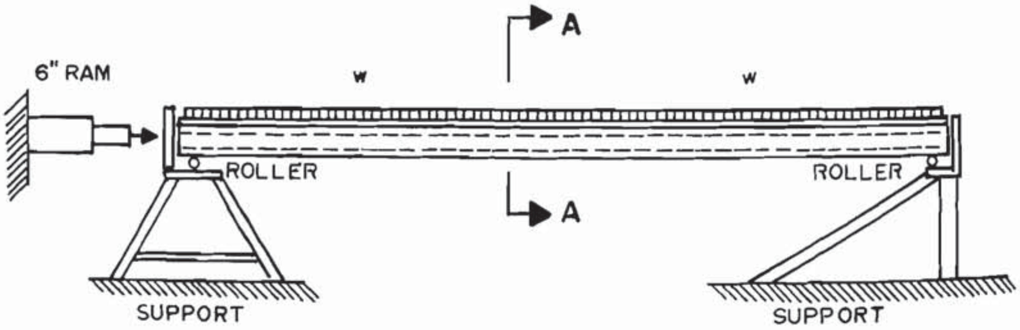
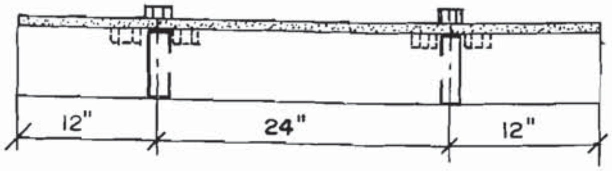


FIG.12 - TEST

PANEL SECTIONS



SECTION A-A



TEST EXECUTED WITH BOARD EITHER UP OR DOWN.

FIG. 13 - TEST SET-UP WITH PANEL HORIZONTAL

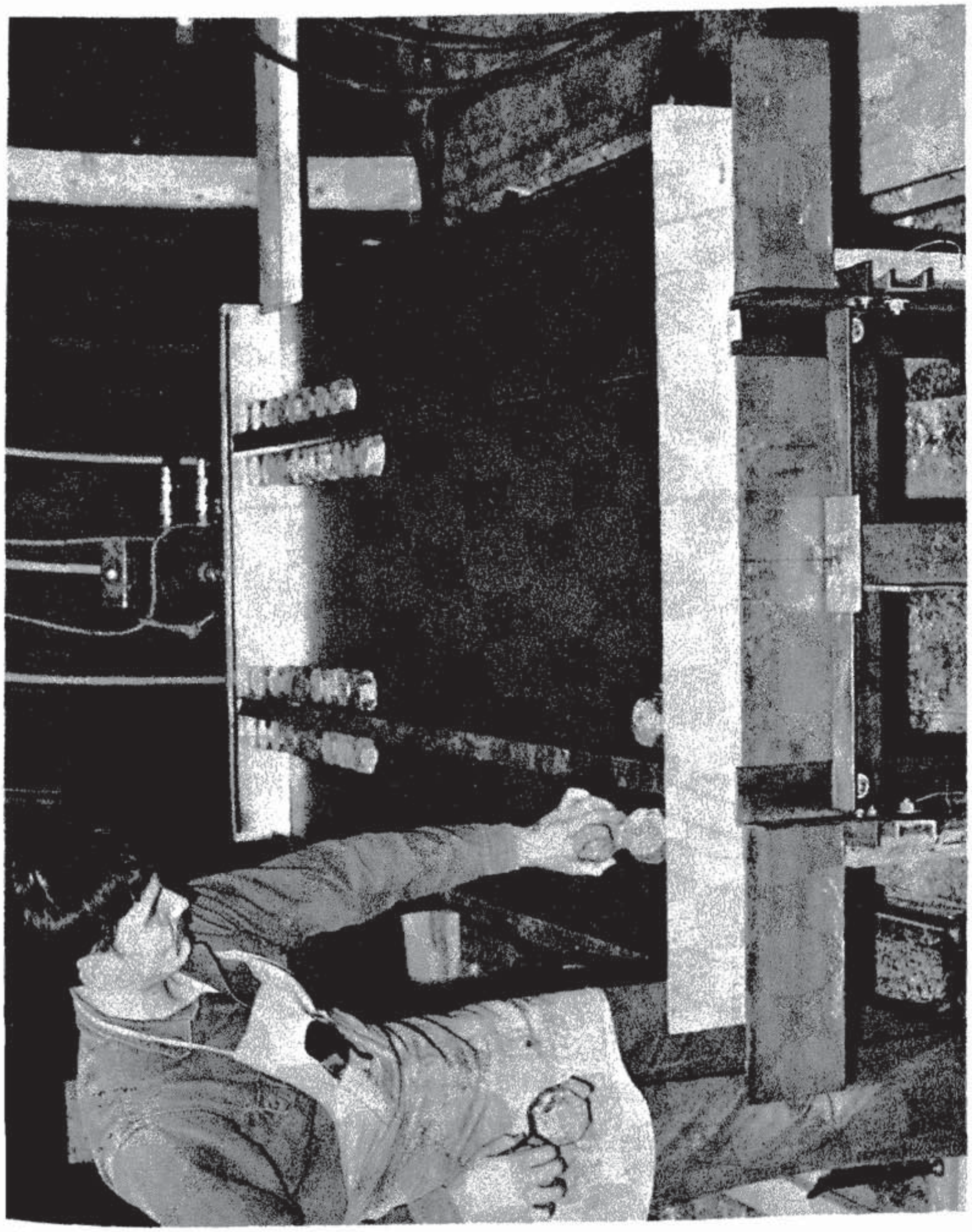
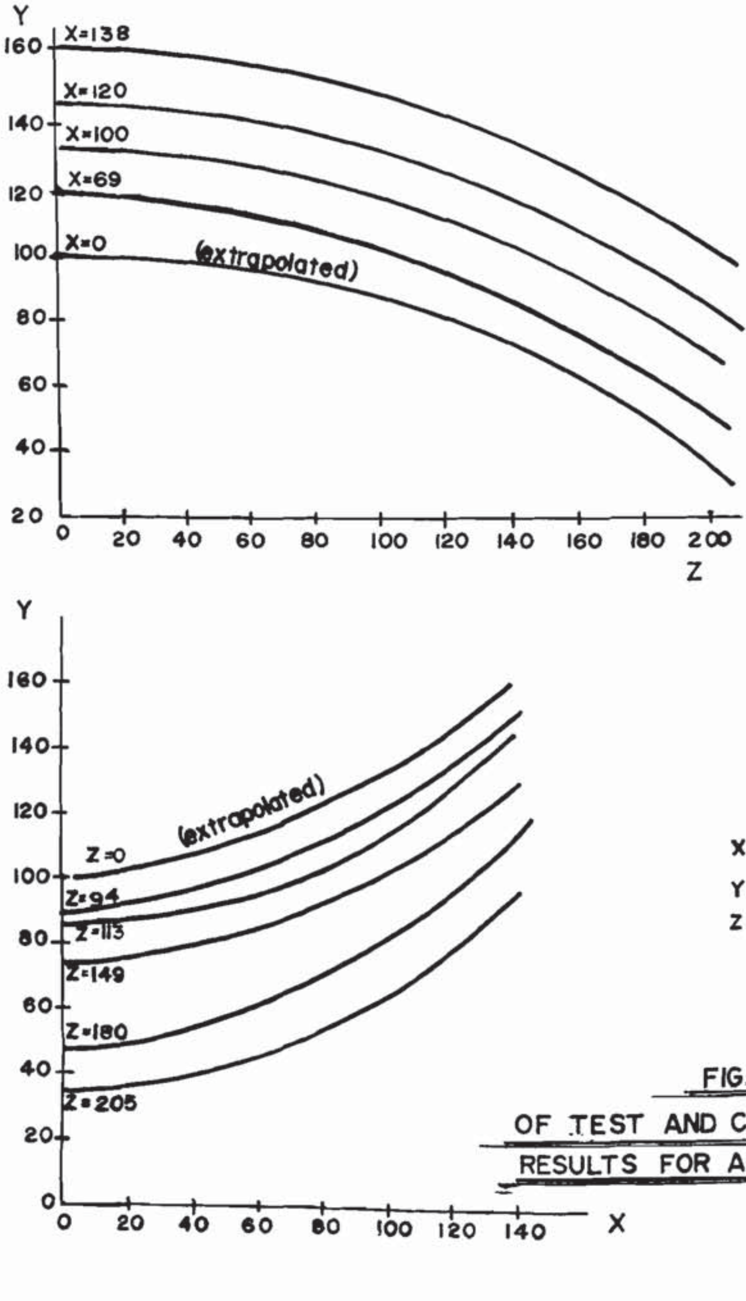


Fig. 13A Horizontal Test Set-Up



X = Kl/r

Y =(P test/ Pcalc) X100

Z = h/t

FIG. 14 - COMPARISON OF TEST AND CALCULATED RESULTS FOR AXIAL LOADING

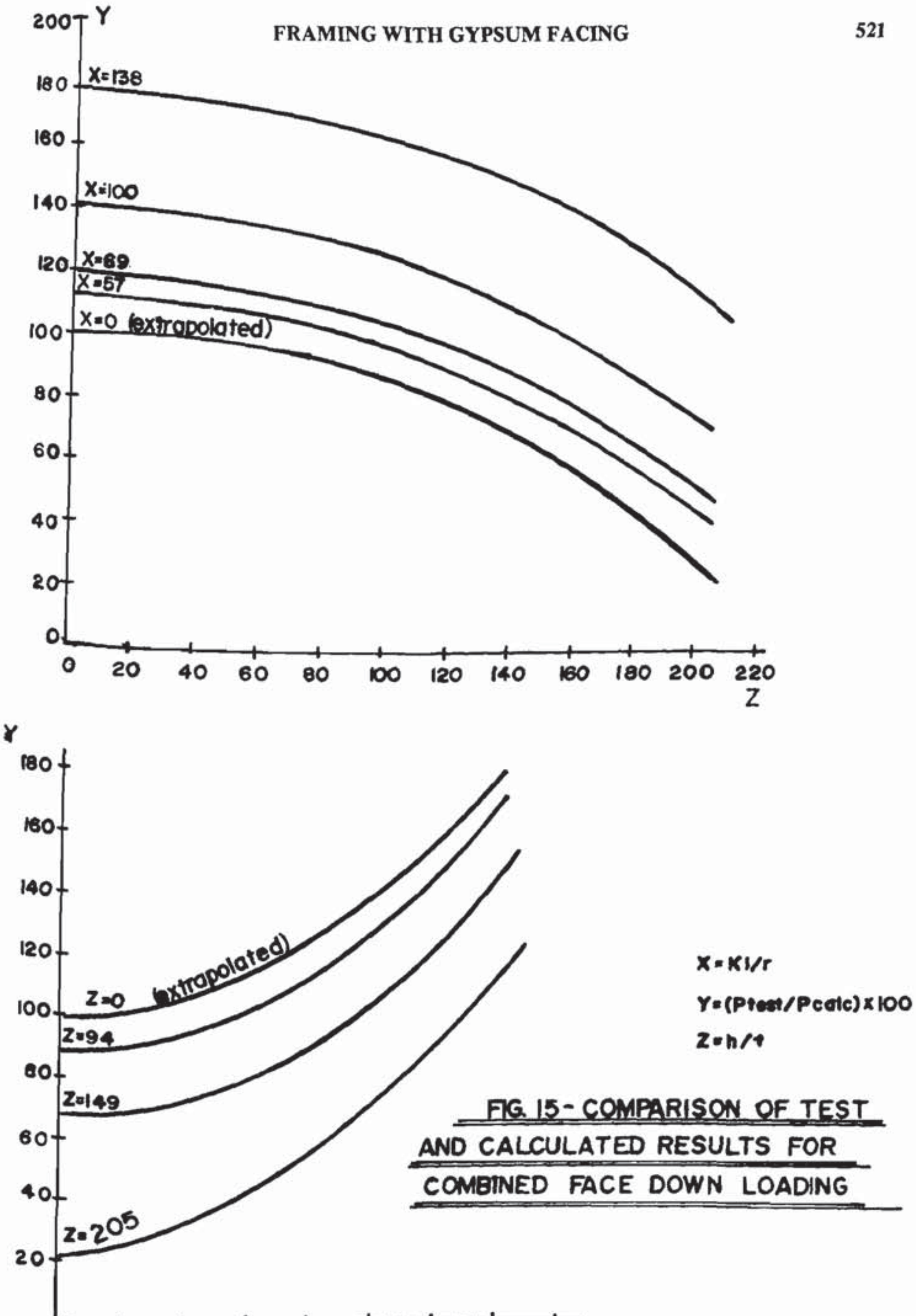
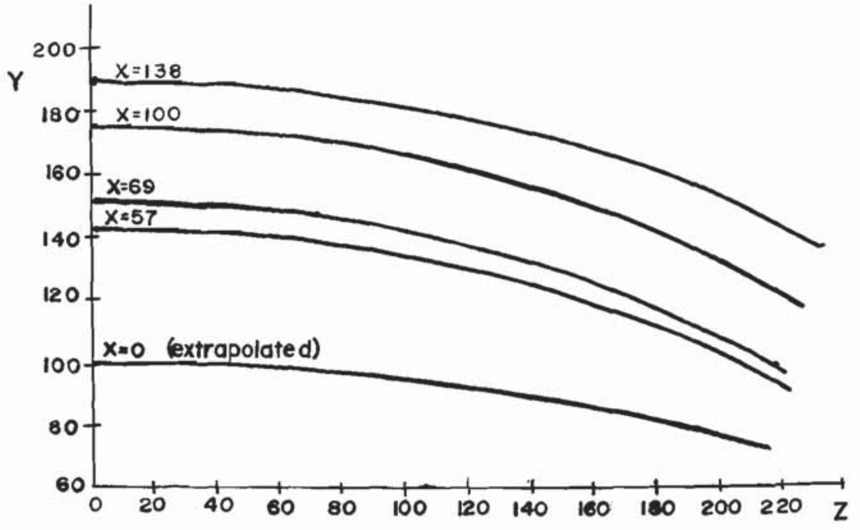


FIG. 15 - COMPARISON OF TEST AND CALCULATED RESULTS FOR COMBINED FACE DOWN LOADING



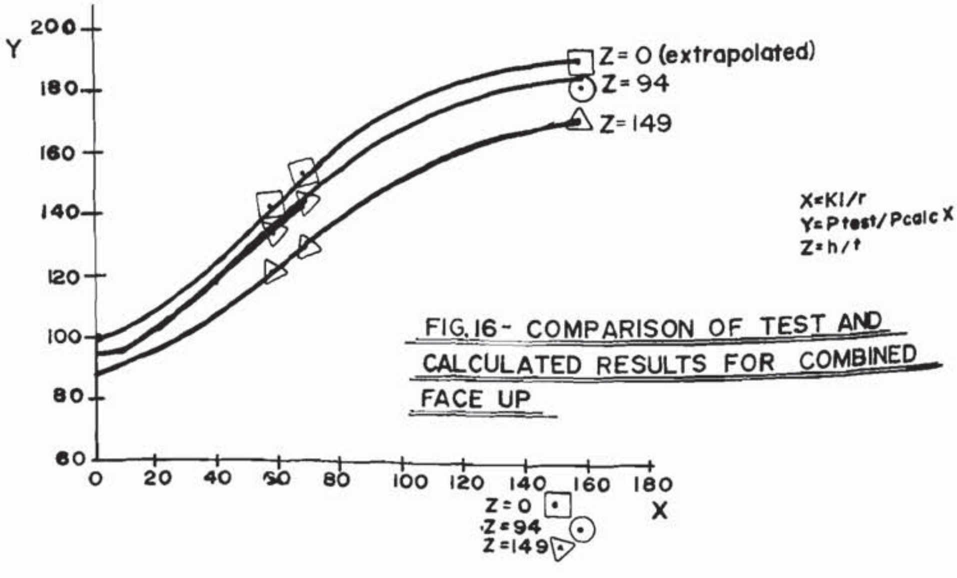


FIG. 16 - COMPARISON OF TEST AND CALCULATED RESULTS FOR COMBINED FACE UP

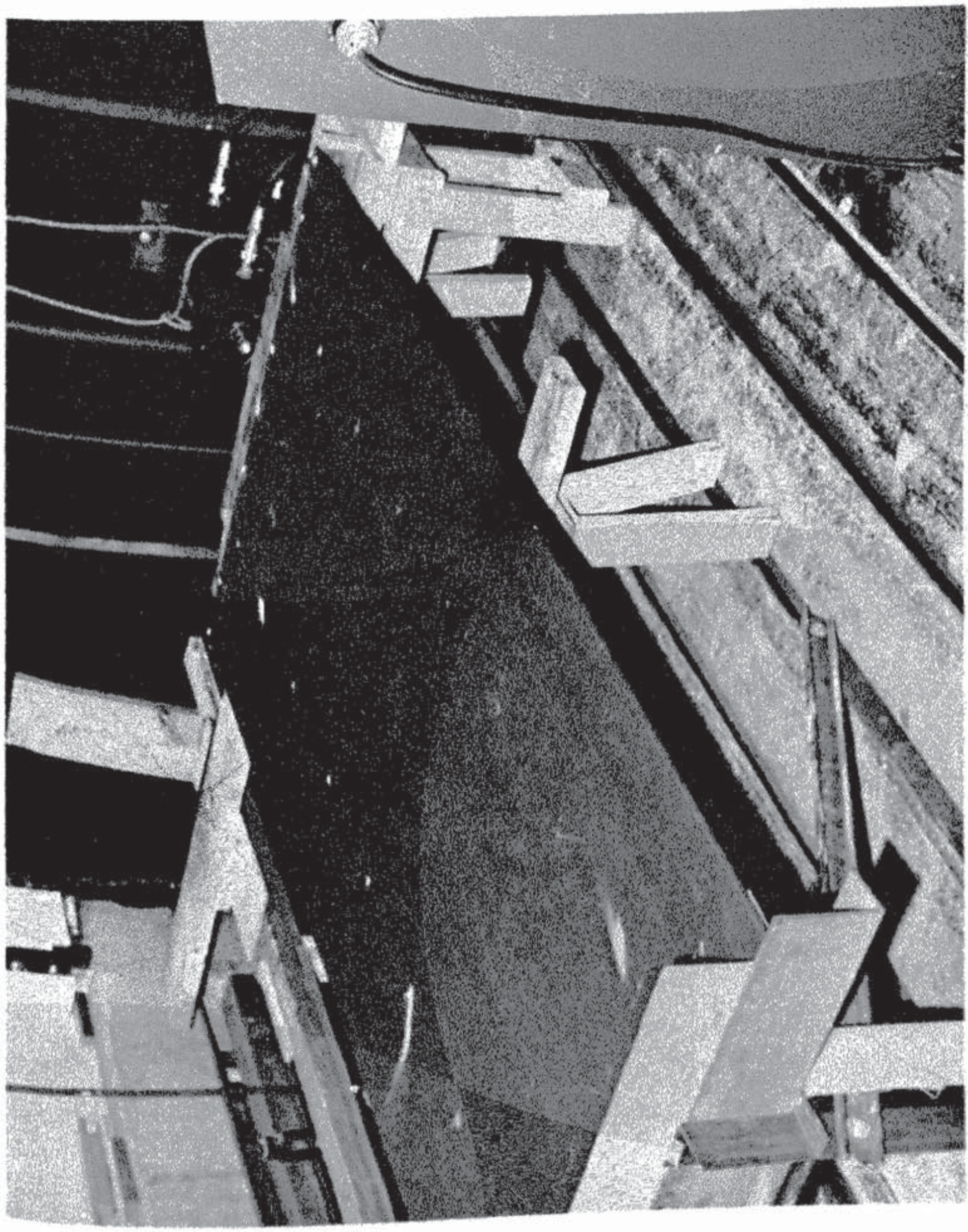


Fig. 17 Horizontal Test Set-Up

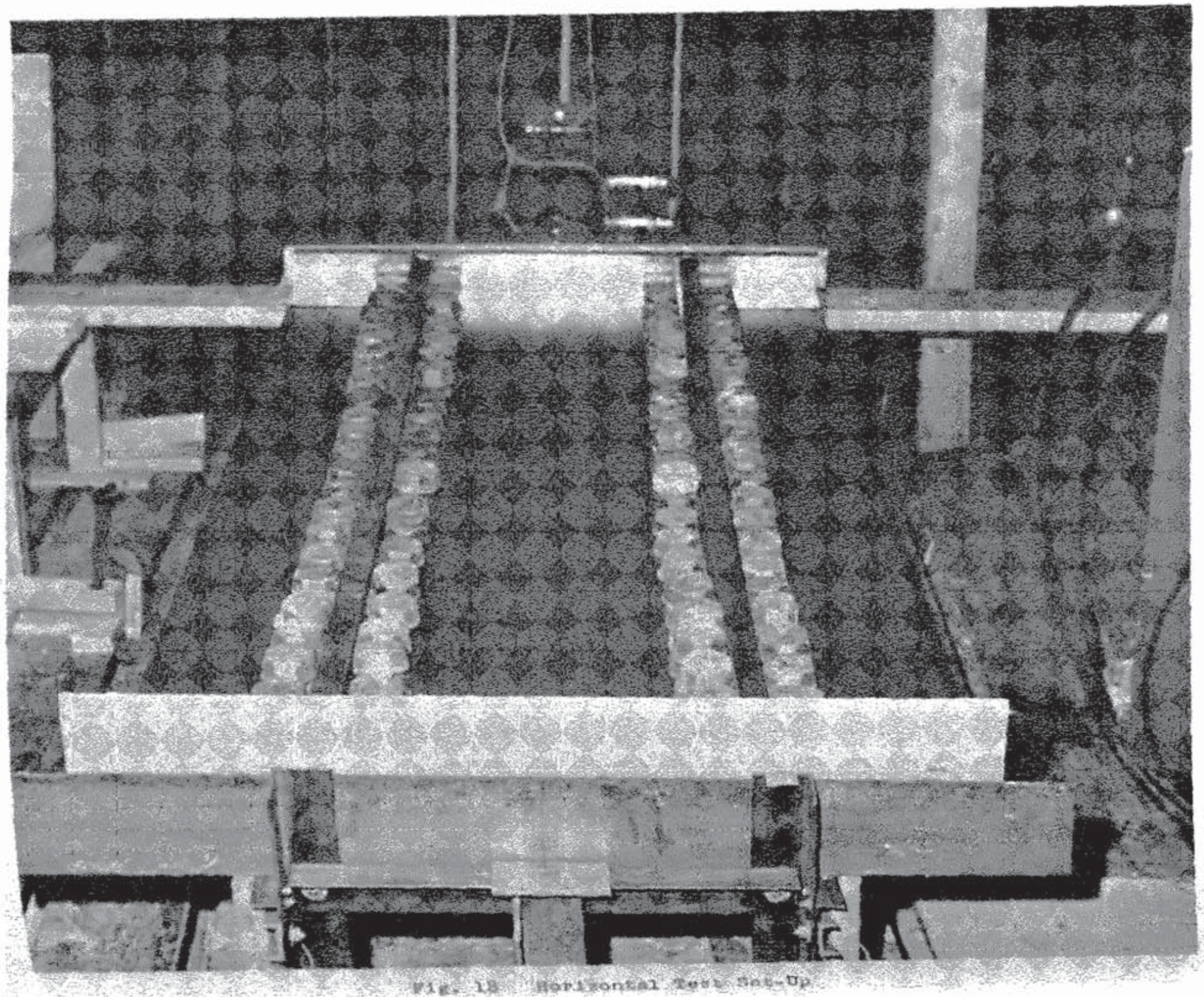


Fig. 18 Horizontal Test Set-Up

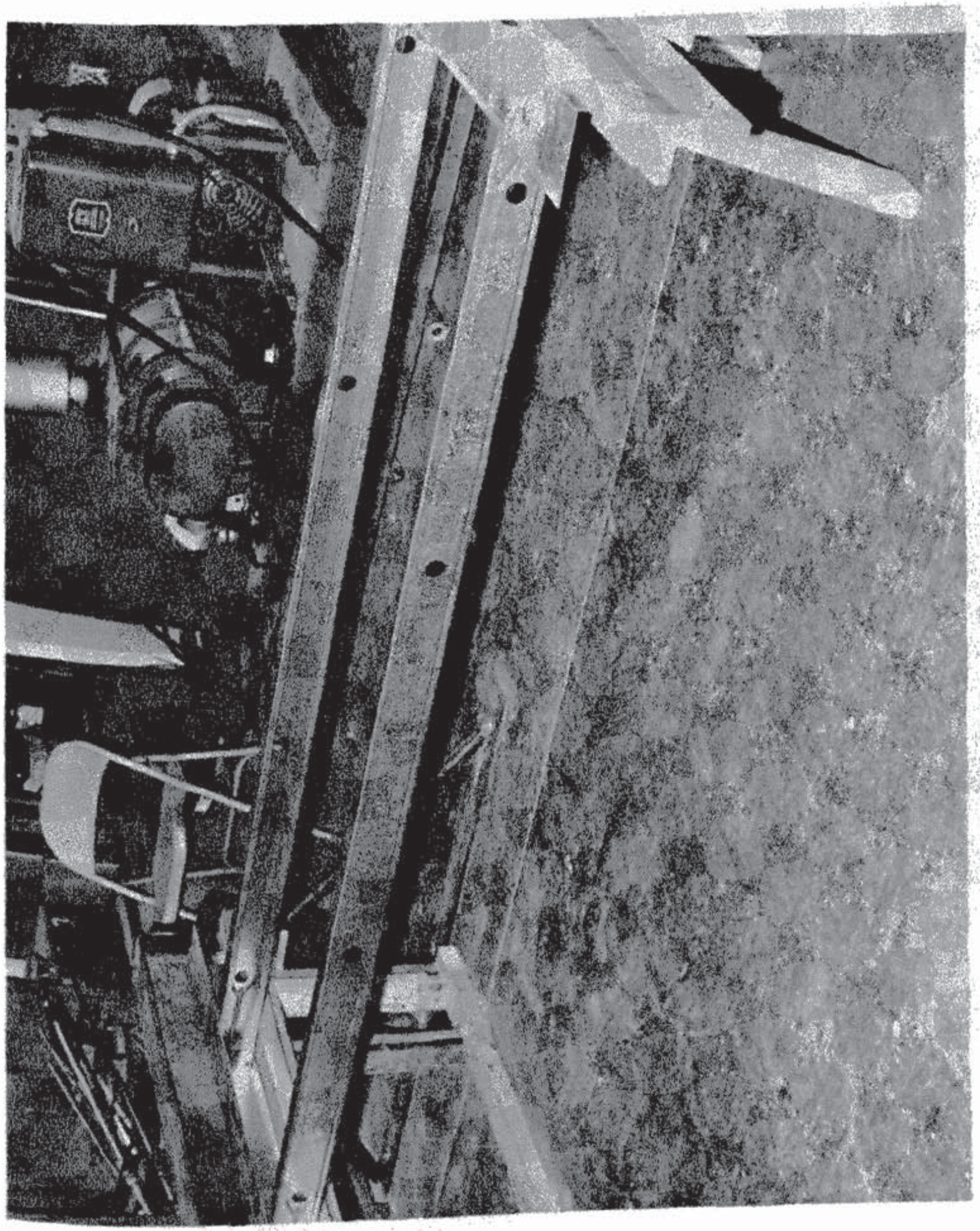


Fig. 19 Test Panel Construction

Fig. 20 Test Panel Construction

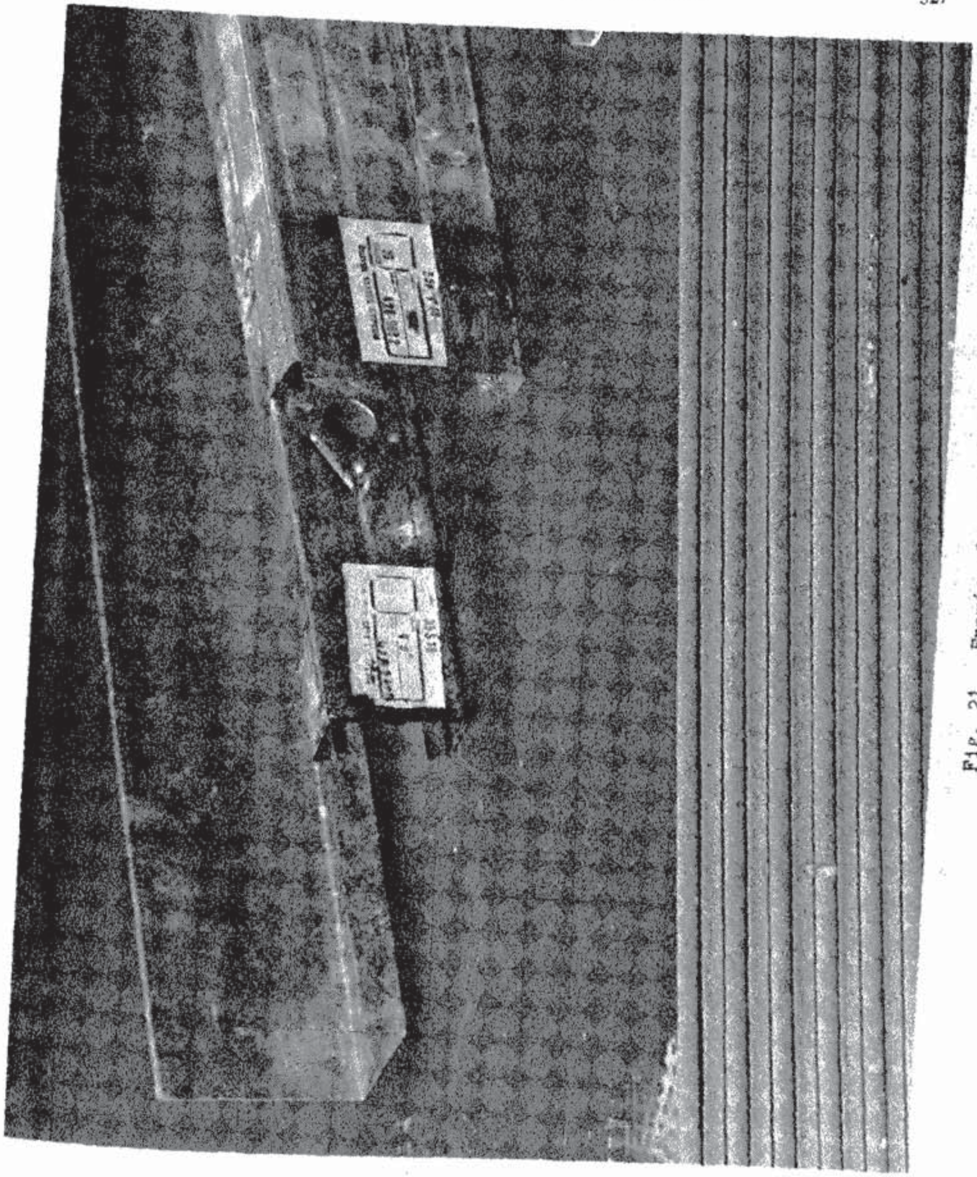


Fig. 21 Framing Components

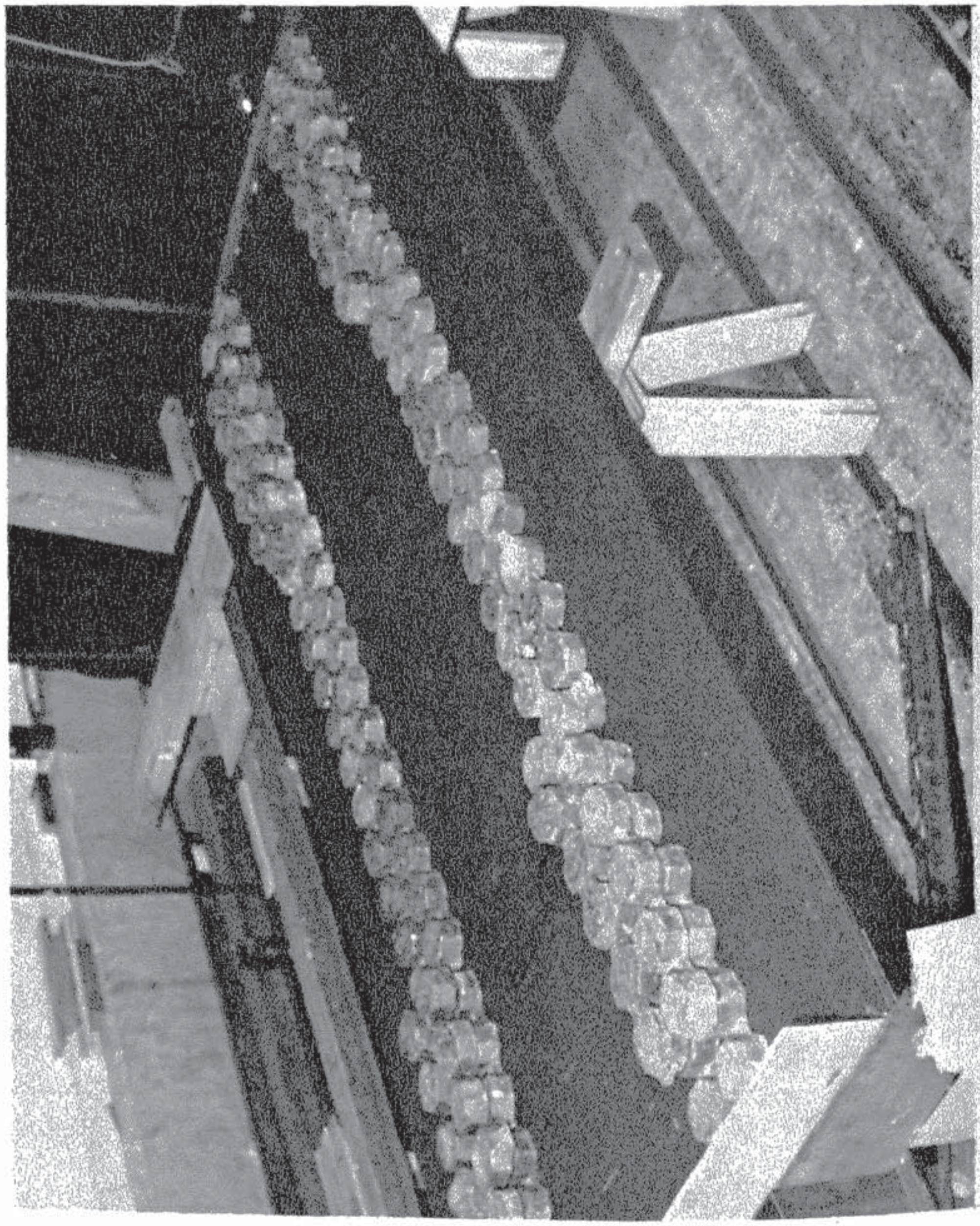


Fig. 22 Test G-2

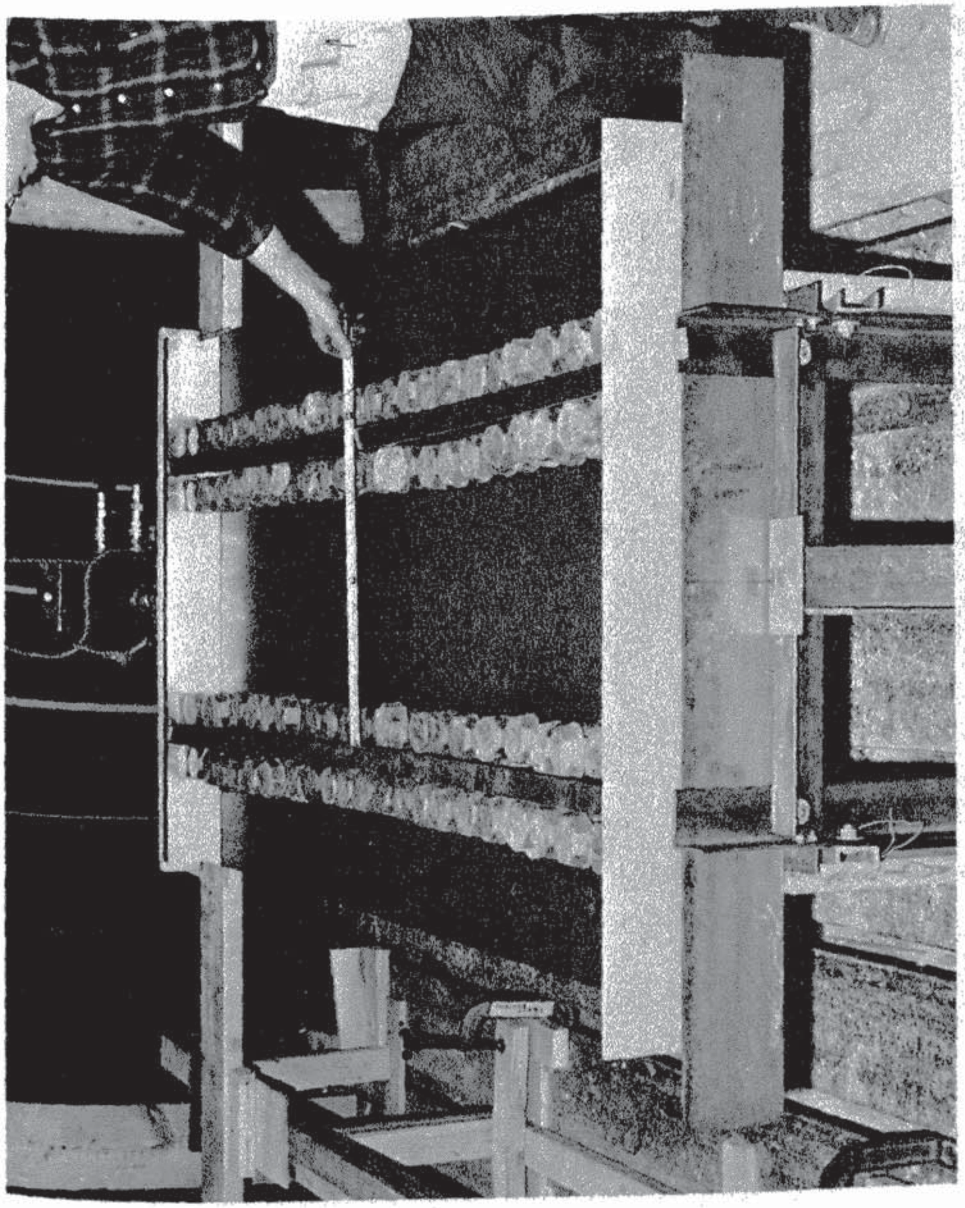


Fig. 23 Test G-1

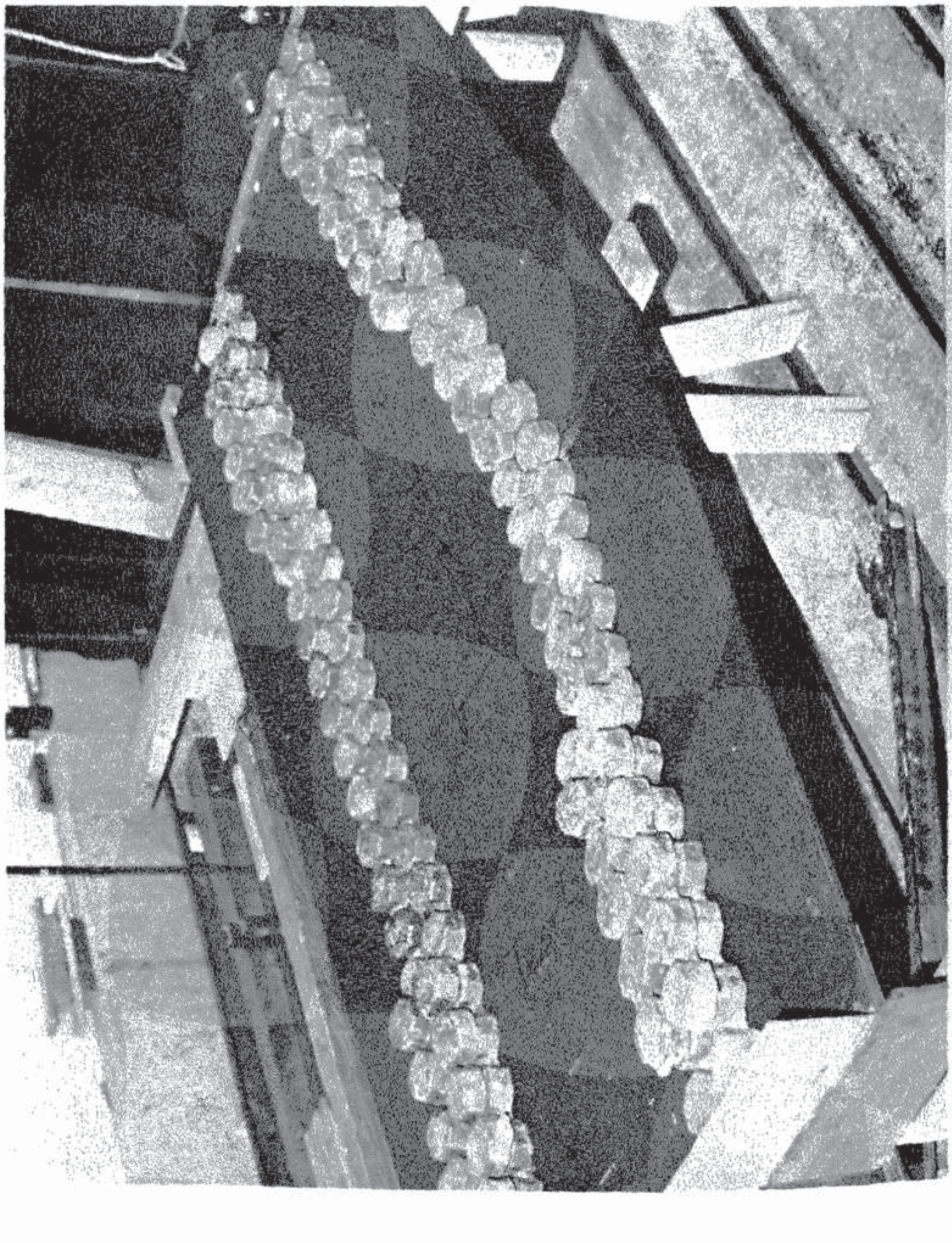


Fig. 24 Test G-2 After Failure

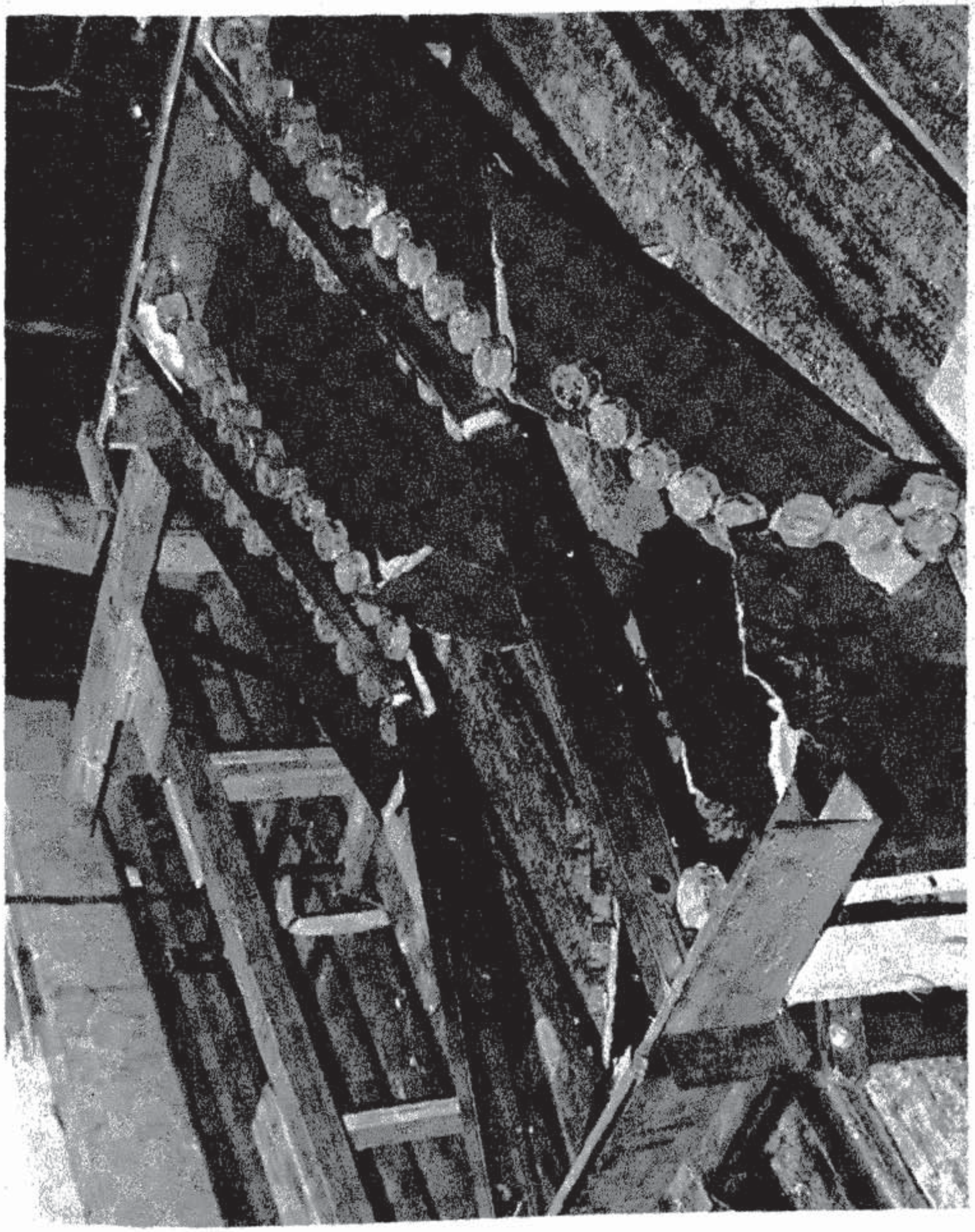


Fig. 25 Test G-1 After Failure

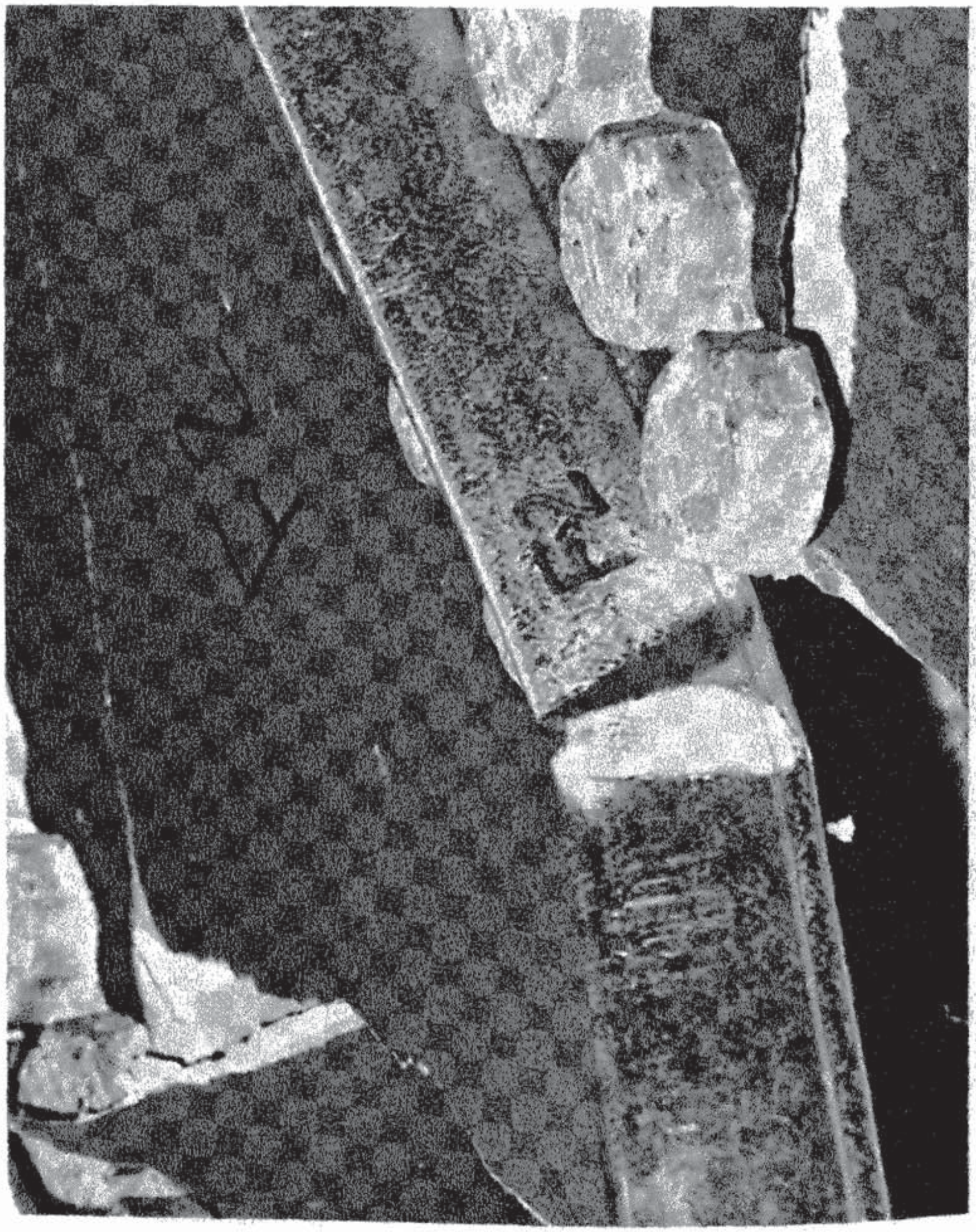


Fig. 26 Torsional Flexural Buckling
With Facing Down

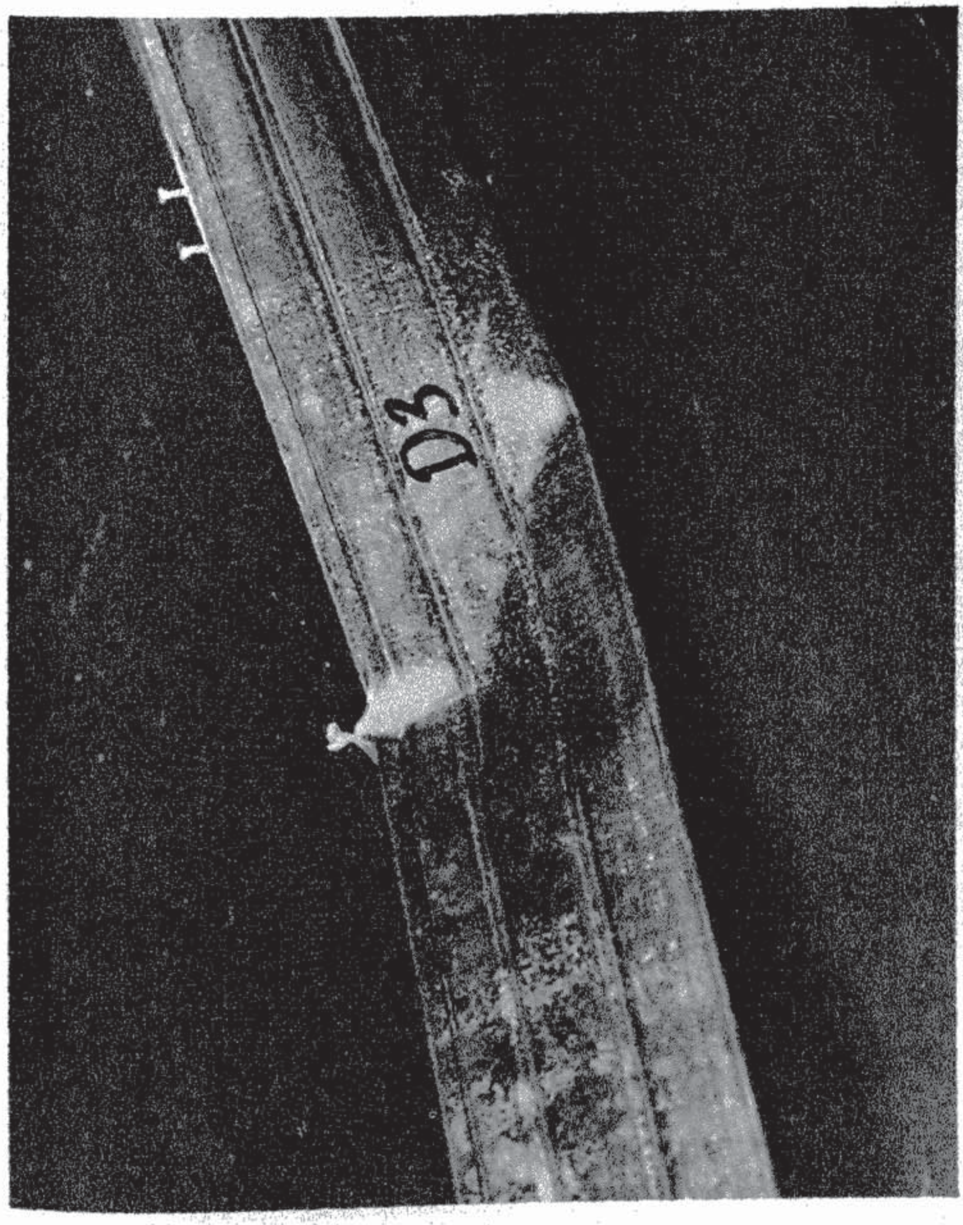


Fig. 27 Torsional Flexural Buckling With Facing Up

Fig. 28 Buckling of Unsupported Compression Flange

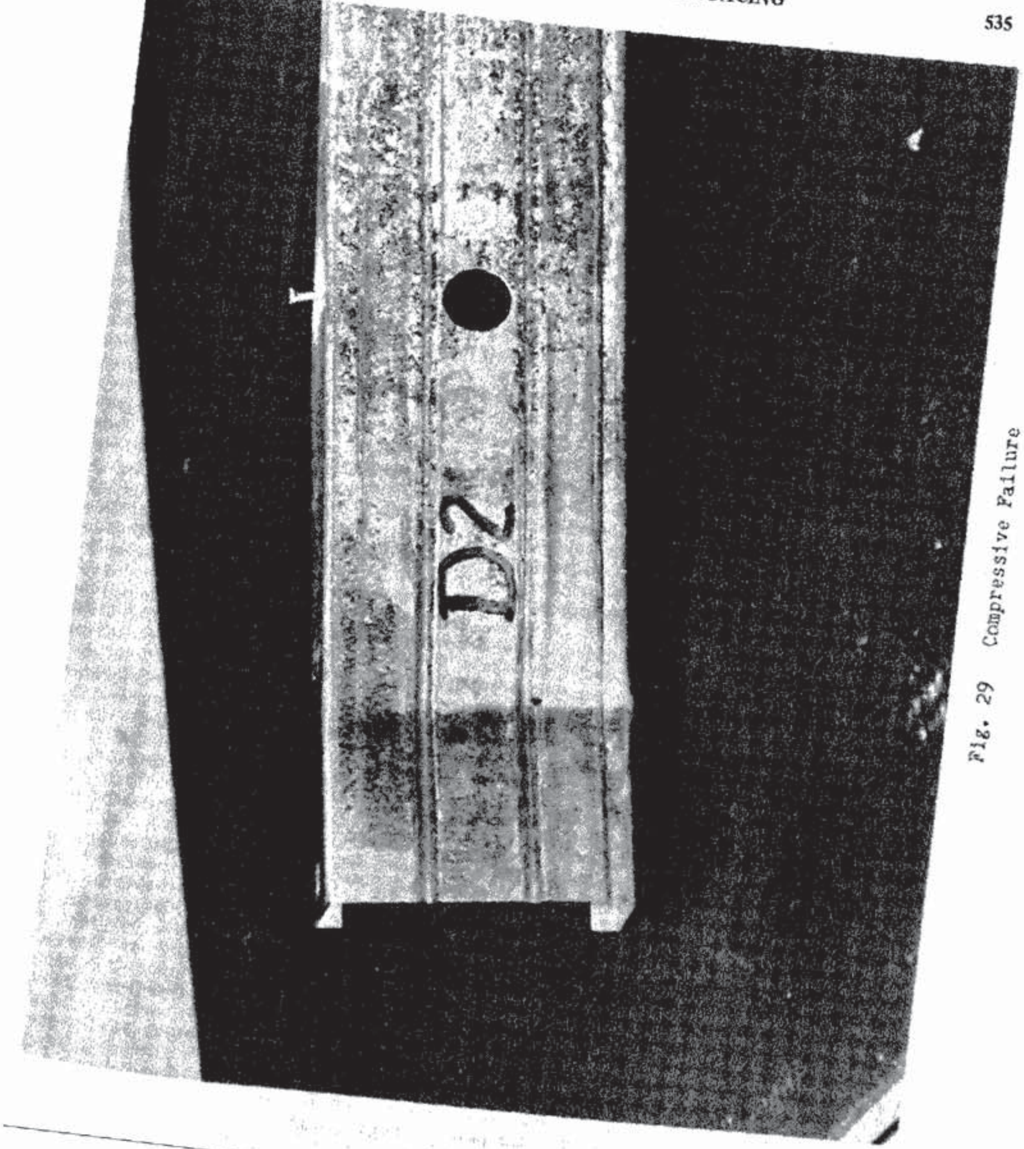


Fig. 29 Compressive Failure

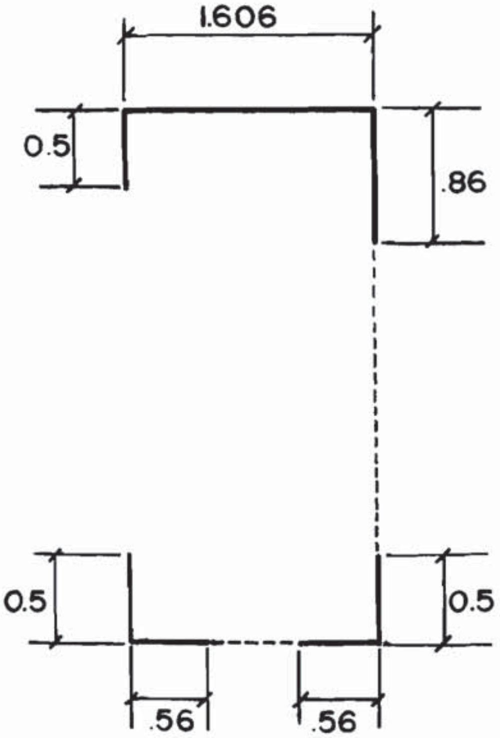


FIG. 30 - MATHEMATICAL MODEL FOR SAMPLE PROBLEM