Chapter V

RESULTS

5.1 Basic properties of Takian-tong timber

The tested basic properties of small clear specimen of Takian-tong timber are tabulated. The maximum load of the joint for rings on two faces, proportional limit load and average values are presented.

Table 5.1 Static bending

SPECIMEN No.	DIMENSIONS cm. x cm. x cm.	LOAD (kg) P.L.	LOAD (kg) Max.	DEFLECTION (mm.) P.L.	DEFLECTION (mm.) Max.	MODULUS OF ELASTICITY $x10^4 kg/cm^2$	% M.C.
1	4.05 x 4.085 x 76.00	370	610	0.078	0.234	14.82	12.01
2	4.09 x 4.10 x 76.00	300	485	0.083	0.172	11.00	13.23
3	4.095x4.075 x 76.00	310	570	0.079	0.214	12.10	13.92
4	4.07 x 4.10 x 76.00	350	638	0.086	0.215	11.70	11.64
5	4.06 x 4.08 x 76.00	335	455	0.089	0.173	11.96	12.49
6	4.07 x 4.13 x 76.00	350	650	0.077	0.305	12.65	12.88

Table 5.2 Compression parallel to grain

SPECIMEN No.	DIMENSIONS cm. x cm. x cm.	LOAD (kg) P.L.	LOAD (kg) Max.	DEFORMATION (mm.) P.L.	DEFORMATION (mm.) Max.	COMPRESSIVE STRESS kg/cm^2 P.L.	COMPRESSIVE STRESS kg/cm^2 Max.	% M.C.
1	4.08 x 4.10 x 20.15	5500	9100	0.328	0.754	329	545	12.77
2	4.08 x 4.09 x 19.60	5000	8200	0.302	1.195	299	491	13.06
3	4.06 x 4.09 x 20.16	4750	8500	0.340	0.740	287	511	11.79
4	4.08 x 4.10 x 19.90	5500	9000	0.386	0.763	330	540	11.98
5	4.07 x 4.13 x 19.90	5500	7900	0.305	0.562	328	471	13.27

Table 5.3 Shear parallel to grain

SPECIMEN No.	DIMENSIONS (cm.)(as in Fig.16) a	b	c	d	e	SHEARING AREA (cm^2)	MAXIMUM LOAD (kg)	SHEAR STRESS kg/cm^2	%M.C.
1	4.085	5.140	6.350	5.190	3.095	21.0377	2030	96.493	10.79
2	4.080	5.165	6.250	5.180	3.110	21.1344	2980	141.002	12.60
3	4.120	5.140	6.350	5.200	3.110	21.424	2140	99.887	11.61
4	4.070	5.130	6.350	5.230	3.075	21.286	1940	91.139	12.48
5	4.110	5.150	6.360	5.210	3.100	21.413	3090	144.304	12.79

Table 5.4 Joint strength

SPECIMEN No.	STRENGTH OF JOINT (kg.)		SLIP OF JOINT x 0.001 (mm.)		% M.C.
	P.L.	Max.	P.L.	Max.	
1	4000	10000	135	1007.5	18.25
2	4500	8500	185	920.5	15.20
3	4500	8650	200	723.5	17.42
4	5250	8000	160	476.5	13.45
5	5250	8000	200	385.0	17.95
6	5750	11000	175	819.0	14.55

Table 5.5 The average values

Modulus of Elasticity, E	12.539×10^4	kg/cm^2
Maximum compressive stress, $\sigma_{max.}$	511.60	kg/cm^2
Comp. stress at P.L. σ	314.60	kg/cm^2
Max. shear stress (Parallel to grain), τ	114.565	kg/cm^2
Joint strength, Load P.L.	4875.0	kg.
Maximum Load	9025.0	kg.

5.2 Test results of columns

The results of the major test were tabulated in Table 5.6. Both maximum loads and proportional limit loads of each kind of columns were presented in according to their tested lengths. It was found out that the strengths of solid squared columns of 8.5 x 8.5 cm. were higher than those of spaced columns (2 - 4 x 9 cm.) of both types for the same length. This was dued to the solid squared columns had the lower slenderness ratios than those of the spaced columns.

Curves of loads and their corresponding lateral deflections at mid height of each column were plotted separately for tension side and compression side as shown in Appendix B. The comparison of load deflection curves of solid squared columns and of spaced columns of both types for the same length were shown in Fig. 23 to Fig. 27. The results showed that solid squared column having the smallest lateral deflection at mid height as compared with spaced columns of both types under the same load. Spaced column type 'a' had the largest lateral deflection at mid height under the same load. The lateral deflection under proportional limit load was less than 0.002 of column length. It was found by observation that the buckle shapes of solid squared columns were conformed with equation (5) as shown in Fig. 33, but those of spaced columns were absolutely different as shown in Fig. 34 and Fig. 35.

Table 5.6 Tested column load

LENGTH	SOLID COLUMN (kg.)		SPACED COL. TYPE 'a' (kg.)		SPACED COL. TYPE 'b' (kg.)	
(cm.)	P.L.	Max.	P.L.	Max.	P.L.	Max.
150	8500	18950	5000	12950	6000	14580
200	5000	13850	3000	6100	3500	10500
250	3750	9300	1875	3550	2500	7650
300	2250	6000	1200	2850	1750	5000
350	1750	5600	1000	2620	1100	3080

The comparison of tested spaced column loads of both types and computed Euler loads of solid rectangular columns (size 4 x 18 cm.) having the same l/d ratios were tabulated in Table 5.7. The tested spaced column loads of type 'a' and type 'b' were of 1.87 to 2.70 and 2.53 to 4.02 greater than that of solid rectangular columns respectively. This was dued to the greater of moment of inertia of spaced columns (2 - 4 x 9 cm.) than that of solid rectangular columns.

In Fig. 28 were curves of tested spaced columns loads of both types, the computed solid rectangular (size 4 x 18 cm.) column loads and the computed spaced column loads of both types. These computed spaced column loads were obtained by multiplied the factor of safety of 2.74 to equations (16) and (17) for type 'a' and type 'b' respectively. The graph showed that the strength of tested spaced columns of type 'a' were lower than the computed but the strength of tested spaced columns of type 'b' were higher than that of computed when having l/d ratio of 40.75 or greater.

The computed spaced column loads of both types by equations (16) and (17) and the proportional limit loads of spaced columns of both types obtained from tests were plotted in Fig. 29. The graph showed that the proportional limit loads obtained from tests of spaced columns type 'a' and type 'b' were slightly higher than the computed ones respectively.

Table 5.7 Ratio of test spaced column load to Euler load of solid columns of same areas and l/d

LENGTH (cm.)	l/d	EULER LOAD (kg.)	TESTED SPACED COL. LOAD(kg)		SPACED COL.LOAD/EULER LOAD	
			TYPE 'a'	TYPE 'b'	TYPE 'a'	TYPE 'b'
150	37.5	5284	12590	14580	2.38	2.76
200	50.0	2972	6100	10500	2.05	2.53
250	62.5	1902	3550	7650	1.87	4.02
300	75.0	1321	2850	5000	2.16	3.78
350	87.5	970	2620	3080	2.70	3.17

The Fourth-Power parabolic formula was derived to determine the strength of timber columns of intermediate class, i.e. slenderness ratios l/d of 11 to l_1/d_1. The graph in Fig. 30 confirmed that the Fourth-Power parabolic formula could be applied to compute the strength of solid columns only of slenderness ratios l/d of 11 to 17.395 for Takian-Tong timber.

The solid squared column loads computed by using Perry Robertson formula with different values of n were plotted in Fig. 31. It could be seen from the graph that the maximum loads obtained from tests were higher than the computed ones when using n = 0.003 l/r in the formula.

The strengths of spaced columns type 'a' and type 'b' obtained from tests were 38 to 66 per cent and 55 to 83 per cent of the strength of the tested solid squared columns respectively as shown in Table 5.8. The test results were also plotted in Fig. 32 to compare with the computed column loads by Euler and Perry Robertson formulas. The computed loads by formulas were based on the same cross-sectional areas and lengths with the tested solid squared columns. The graph showed that the strength of spaced columns type 'a' was the lowest one. The strength of solid squared columns were well expressed by Euler formula when the length of 190 cm. and higher.

Table 5.8 Ratio of test spaced column loads to Euler load and ratio of test spaced column loads to test solid column loads of same area and lengths

LENGTH (cm.)	EULER (kg)	TESTED SOLID COLUMN (kg)	TESTED SPACED COLUMN		SPACED COL./EULER		SPACED COL./TESTED SOLID	
			TYPE 'a'	TYPE 'b'	TYPE 'a'	TYPE 'b'	TYPE 'a'	TYPE 'b'
150	23945.53	18950	12590	14580	0.53	0.61	0.66	0.77
200	13469.35	13850	6100	10500	0.45	0.78	0.44	0.76
250	8620.36	9300	3550	7650	0.41	0.89	0.38	0.82
300	5986.35	6000	2850	5000	0.48	0.84	0.48	0.83
350	4398.15	5600	2620	3080	0.60	0.70	0.47	0.55

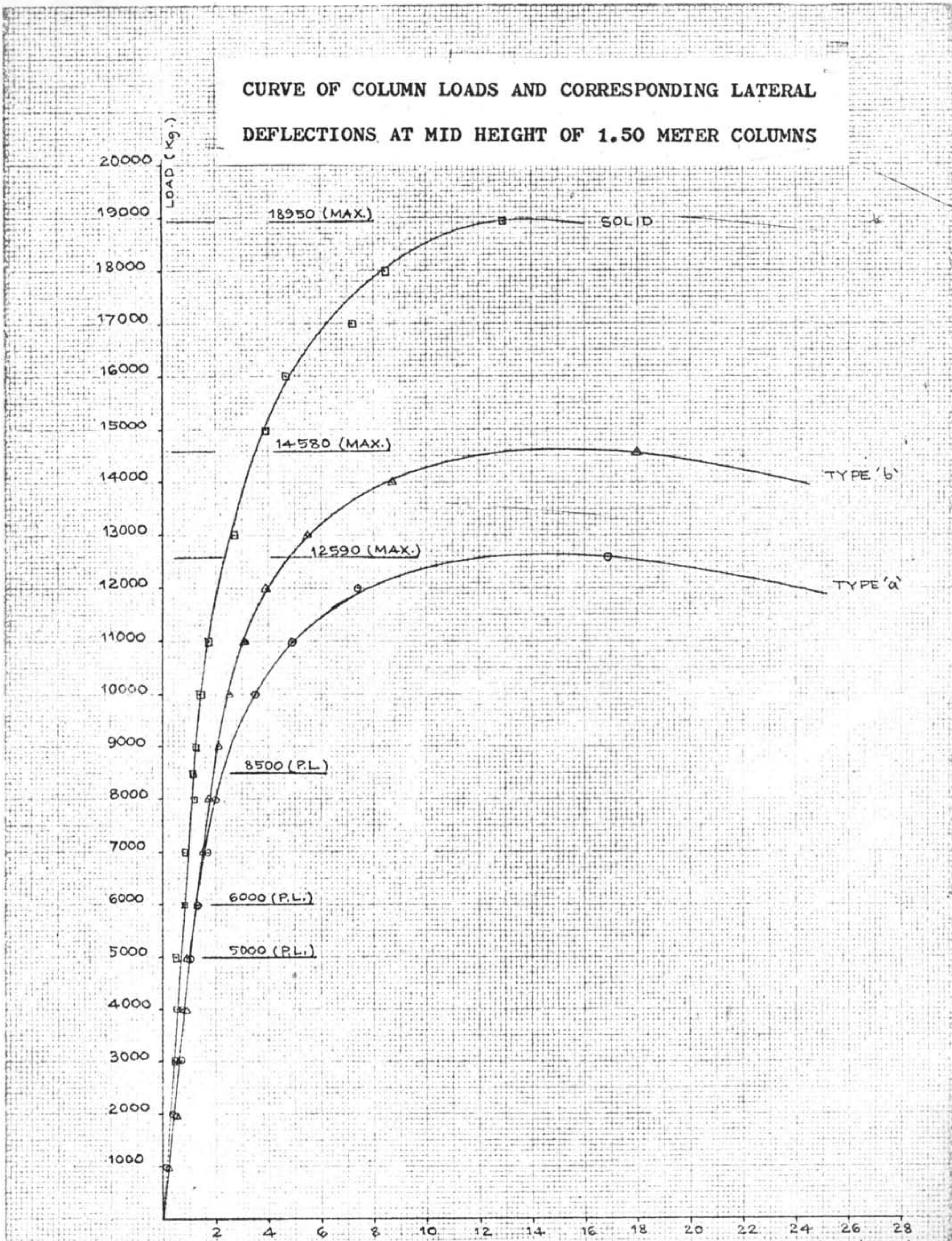

CURVE OF COLUMN LOADS AND CORRESPONDING LATERAL
DEFLECTIONS AT MID HEIGHT OF 1.50 METER COLUMNS
LOAD (Kg.)
20000
19000
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
18950 (MAX.)
SOLID
14580 (MAX.)
TYPE 'b'
12590 (MAX.)
TYPE 'a'
8500 (P.L.)
6000 (P.L.)
5000 (P.L.)
2 4 6 8 10 12 14 16 18 20 22 24 26 28
LATERAL DEFLECTION (mm.)

Fig. 23

CURVE OF COLUMN LOADS AND CORRESPONDING LATERAL DEFLECTIONS AT MID HEIGHT OF 2.00 METER COLUMNS

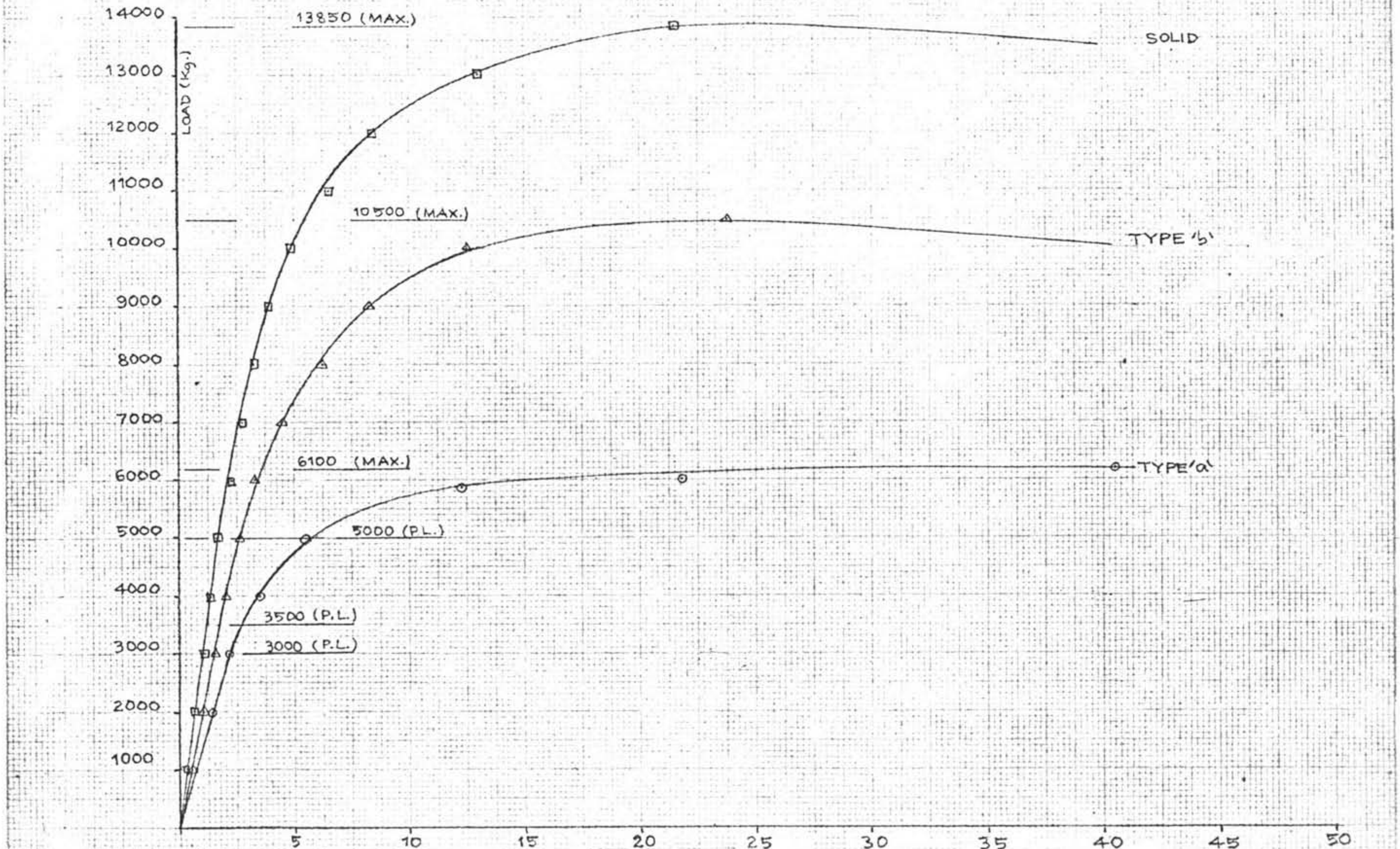
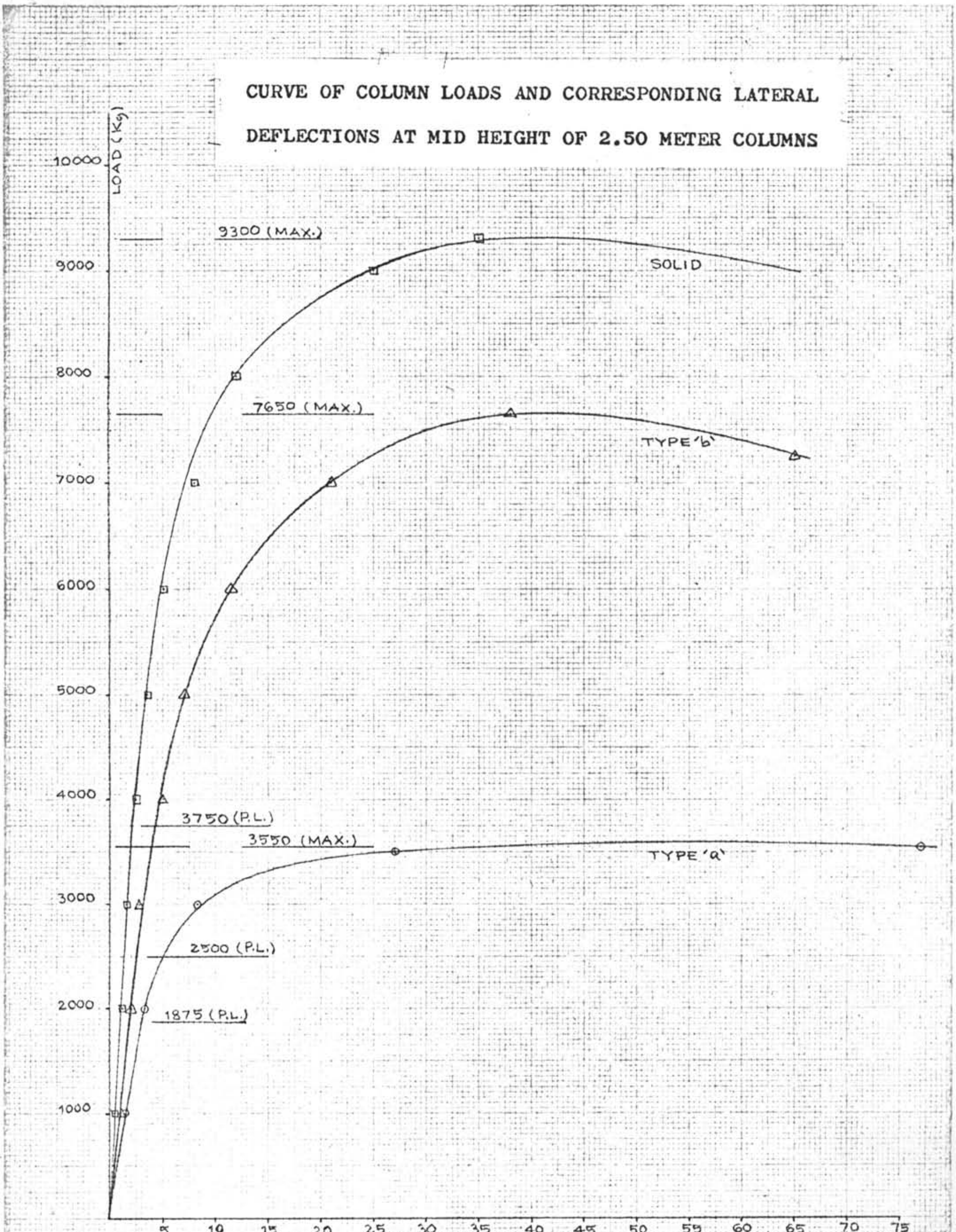


Fig. 24



CURVE OF COLUMN LOADS AND CORRESPONDING LATERAL
DEFLECTIONS AT MID HEIGHT OF 2.50 METER COLUMNS
LOAD (Kg)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
9300 (MAX.)
SOLID
7650 (MAX.)
TYPE 'b'
3750 (P.L.)
3550 (MAX.)
TYPE 'a'
2500 (P.L.)
1875 (P.L.)
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
LATERAL DEFLECTION (mm.)

Fig. 25

CURVE OF COLUMN LOADS AND CORRESPONDING LATERAL DEFLECTIONS AT MID HEIGHT OF 3.00 METER COLUMNS

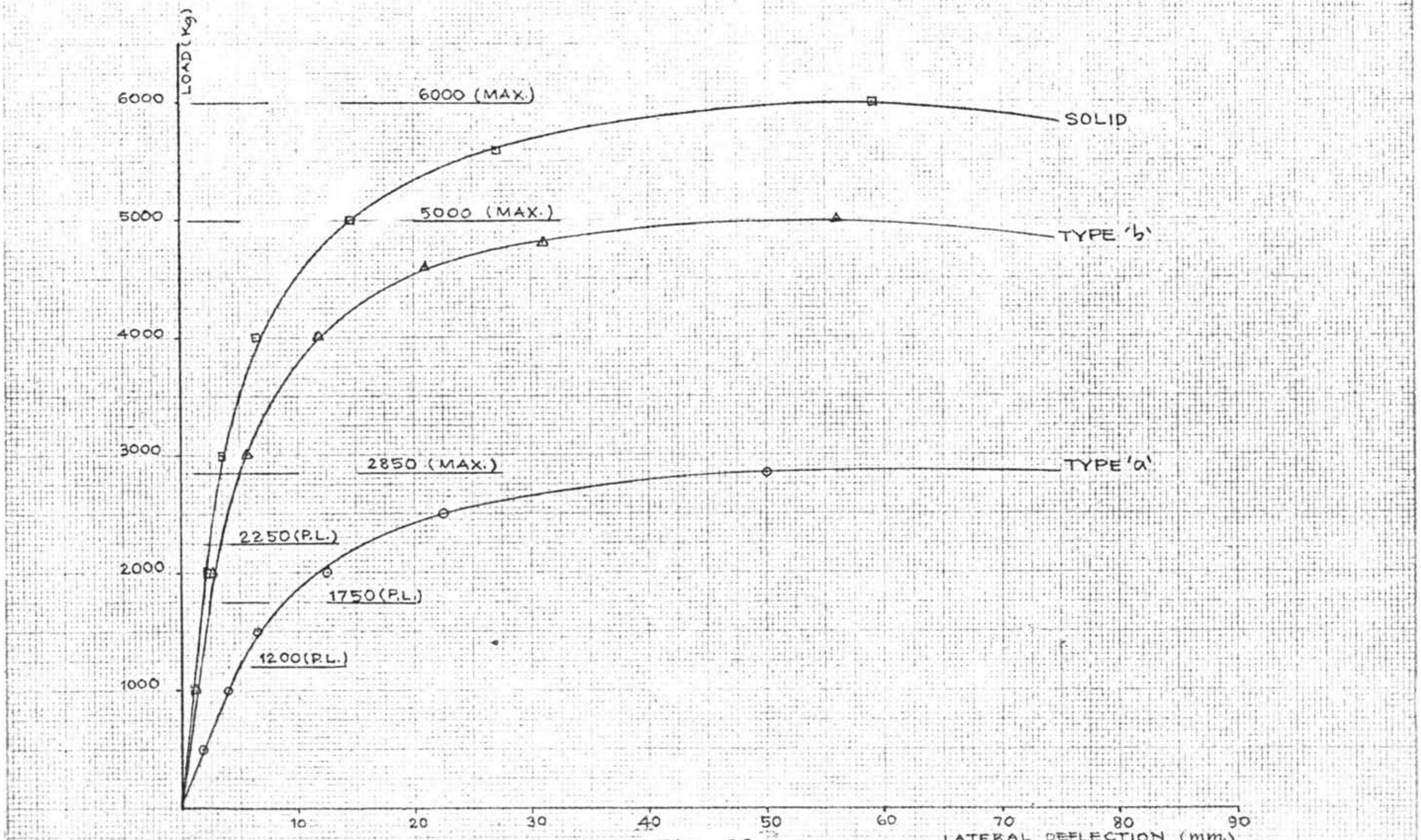
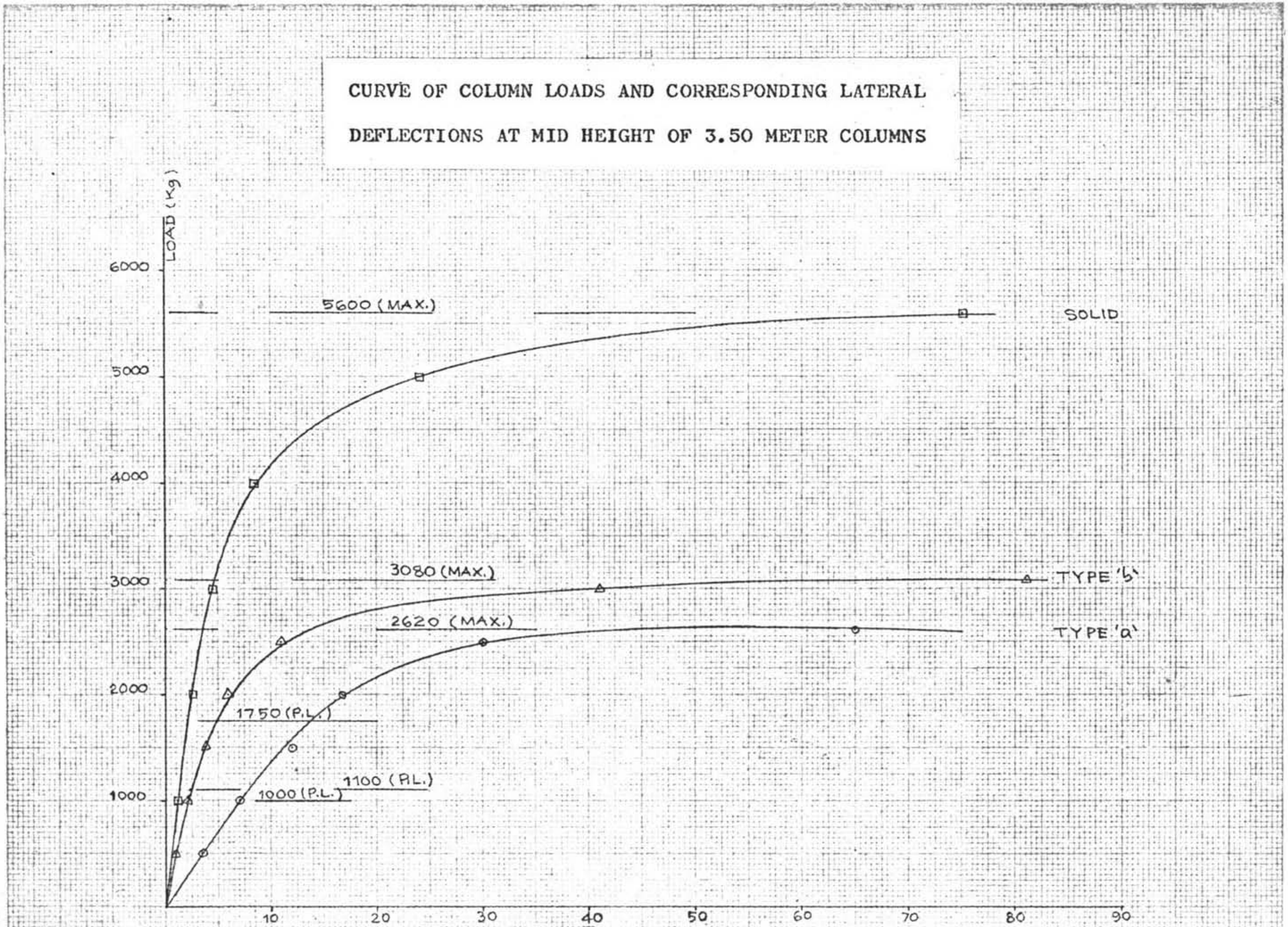


Fig. 26



CURVE OF COLUMN LOADS AND CORRESPONDING LATERAL DEFLECTIONS AT MID HEIGHT OF 3.50 METER COLUMNS
LOAD (Kg)
6000
5000
4000
3000
2000
1000
5600 (MAX.)
SOLID
3080 (MAX.)
TYPE 'b'
2620 (MAX.)
TYPE 'a'
1750 (P.L.)
1100 (P.L.)
1000 (P.L.)
10
20
30
40
50
60
70
80
90
LATERAL DEFLECTION (mm.)

Fig. 27

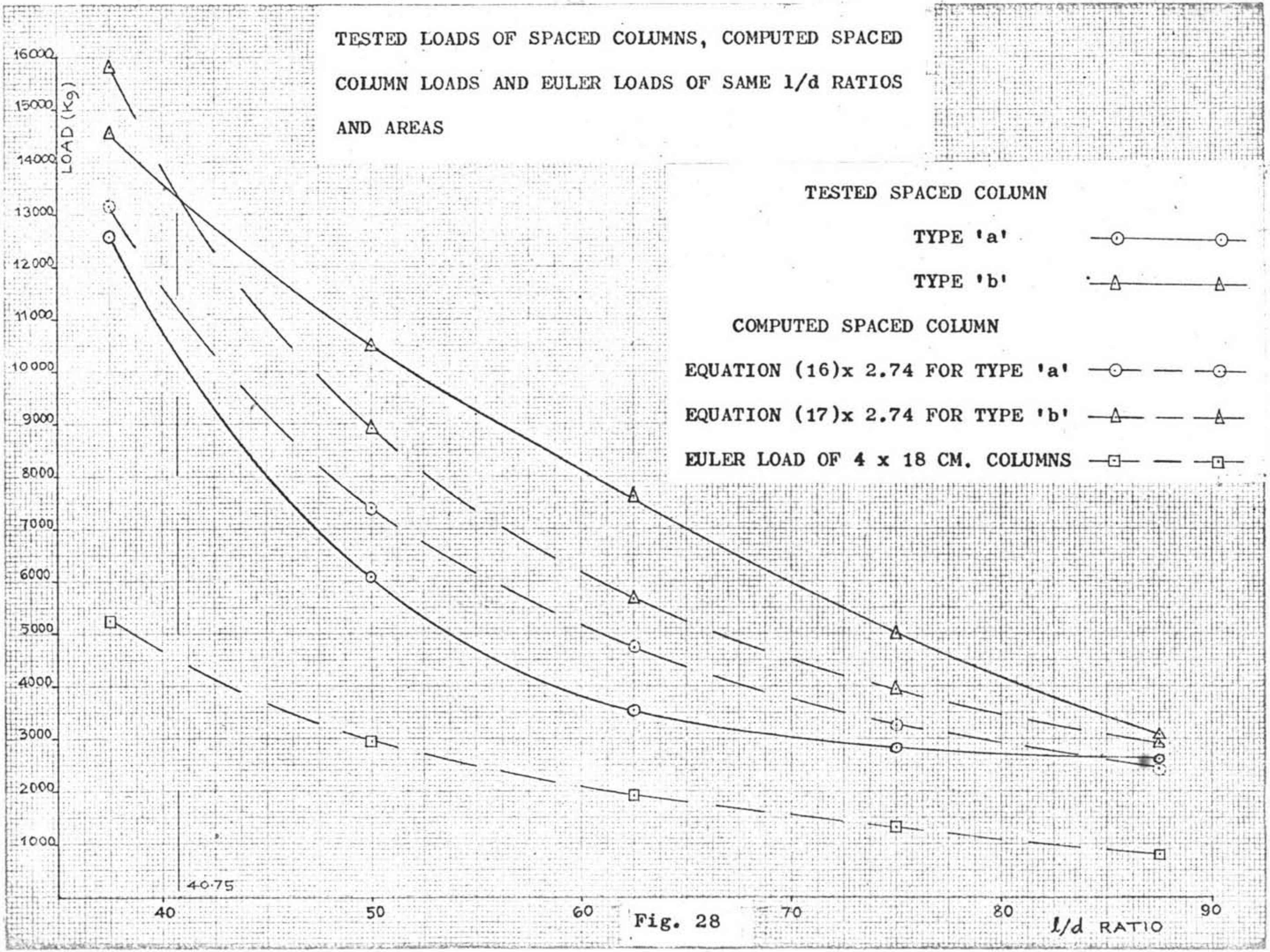

TESTED LOADS OF SPACED COLUMNS, COMPUTED SPACED COLUMN LOADS AND EULER LOADS OF SAME l/d RATIOS AND AREAS
LOAD (Kg)
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
TESTED SPACED COLUMN
TYPE 'a'
TYPE 'b'
COMPUTED SPACED COLUMN
EQUATION (16)x 2.74 FOR TYPE 'a'
EQUATION (17)x 2.74 FOR TYPE 'b'
EULER LOAD OF 4 x 18 CM. COLUMNS
40·75
40
50
60
70
80
90
l/d RATIO

Fig. 28

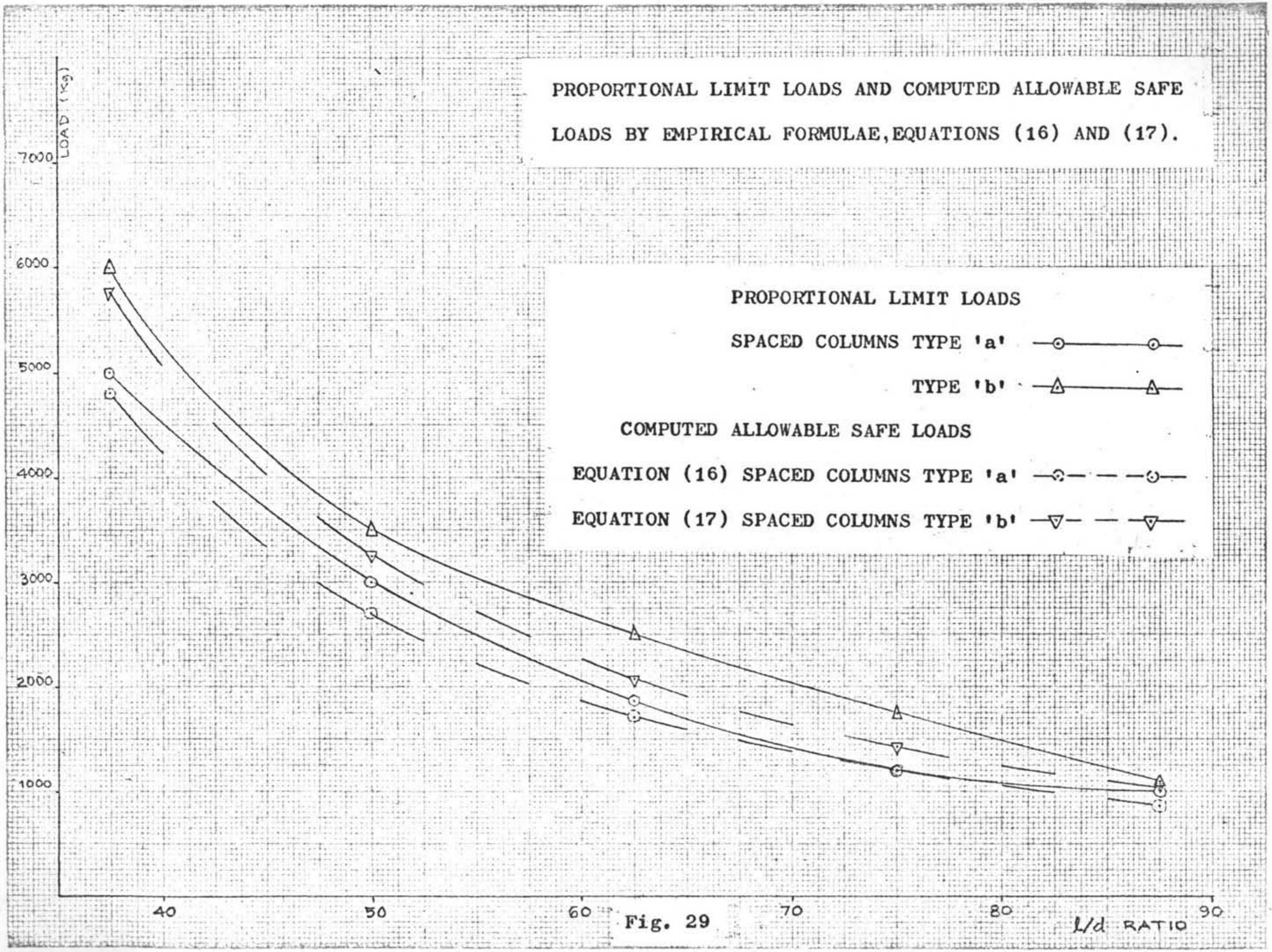
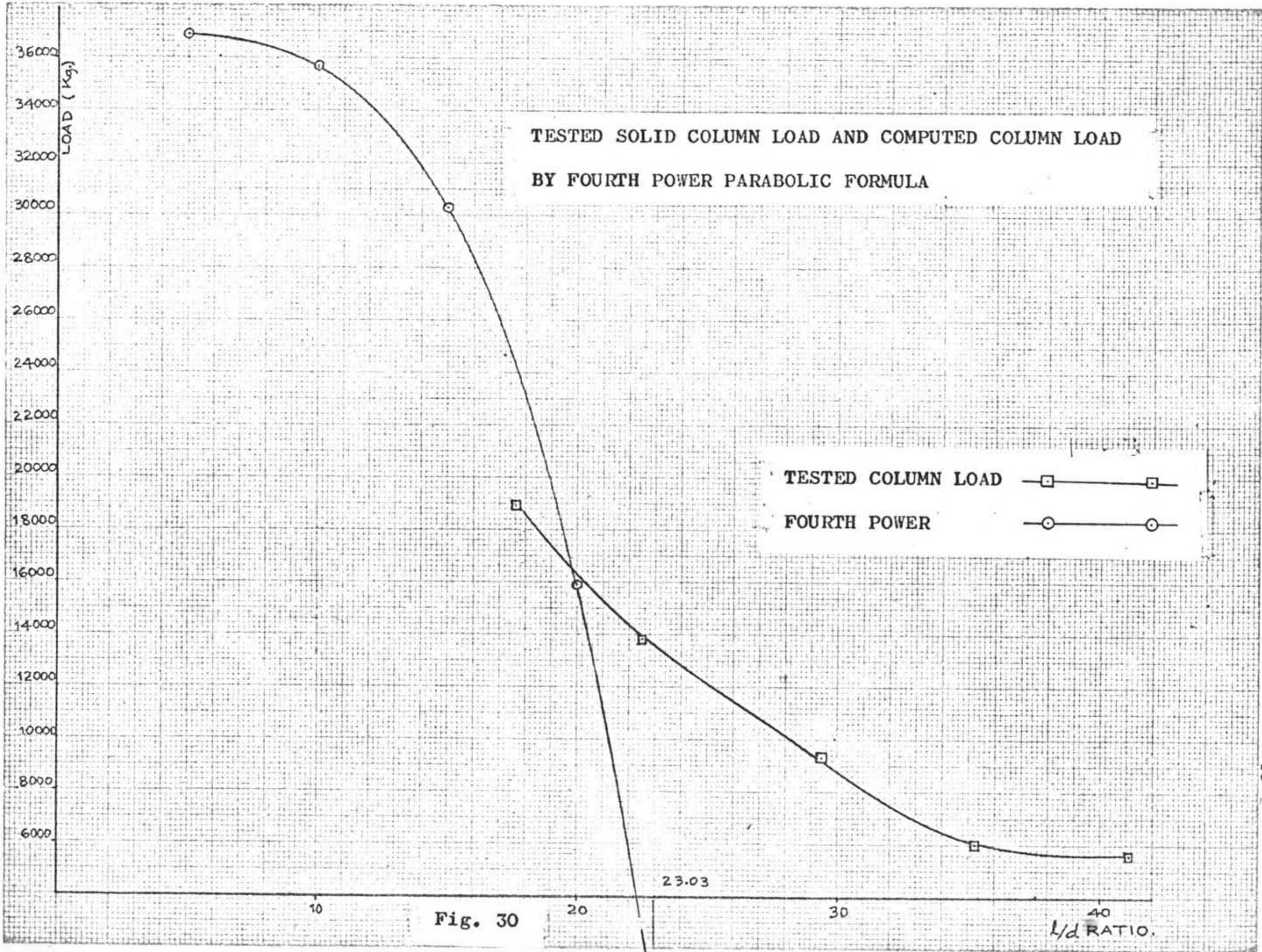

PROPORTIONAL LIMIT LOADS AND COMPUTED ALLOWABLE SAFE LOADS BY EMPIRICAL FORMULAE, EQUATIONS (16) AND (17).
PROPORTIONAL LIMIT LOADS
SPACED COLUMNS TYPE 'a'
TYPE 'b'
COMPUTED ALLOWABLE SAFE LOADS
EQUATION (16) SPACED COLUMNS TYPE 'a'
EQUATION (17) SPACED COLUMNS TYPE 'b'
LOAD (Kg)
7000
6000
5000
4000
3000
2000
1000
40
50
60
70
80
90
l/d RATIO

Fig. 29


TESTED SOLID COLUMN LOAD AND COMPUTED COLUMN LOAD
BY FOURTH POWER PARABOLIC FORMULA
LOAD (Kg.)
36000
34000
32000
30000
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
TESTED COLUMN LOAD
FOURTH POWER
23.03
10
20
30
40
l/d RATIO.
Fig. 30

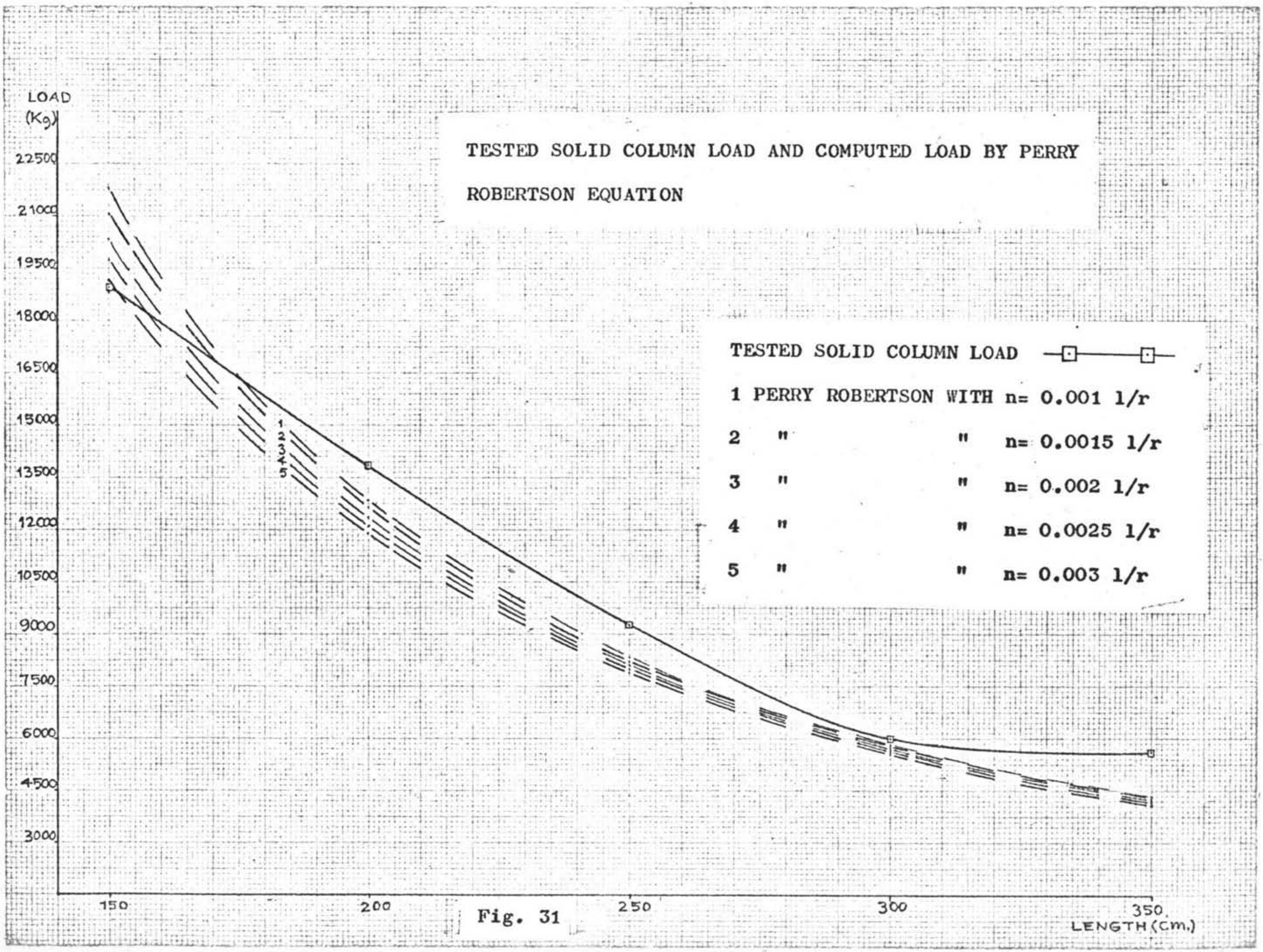
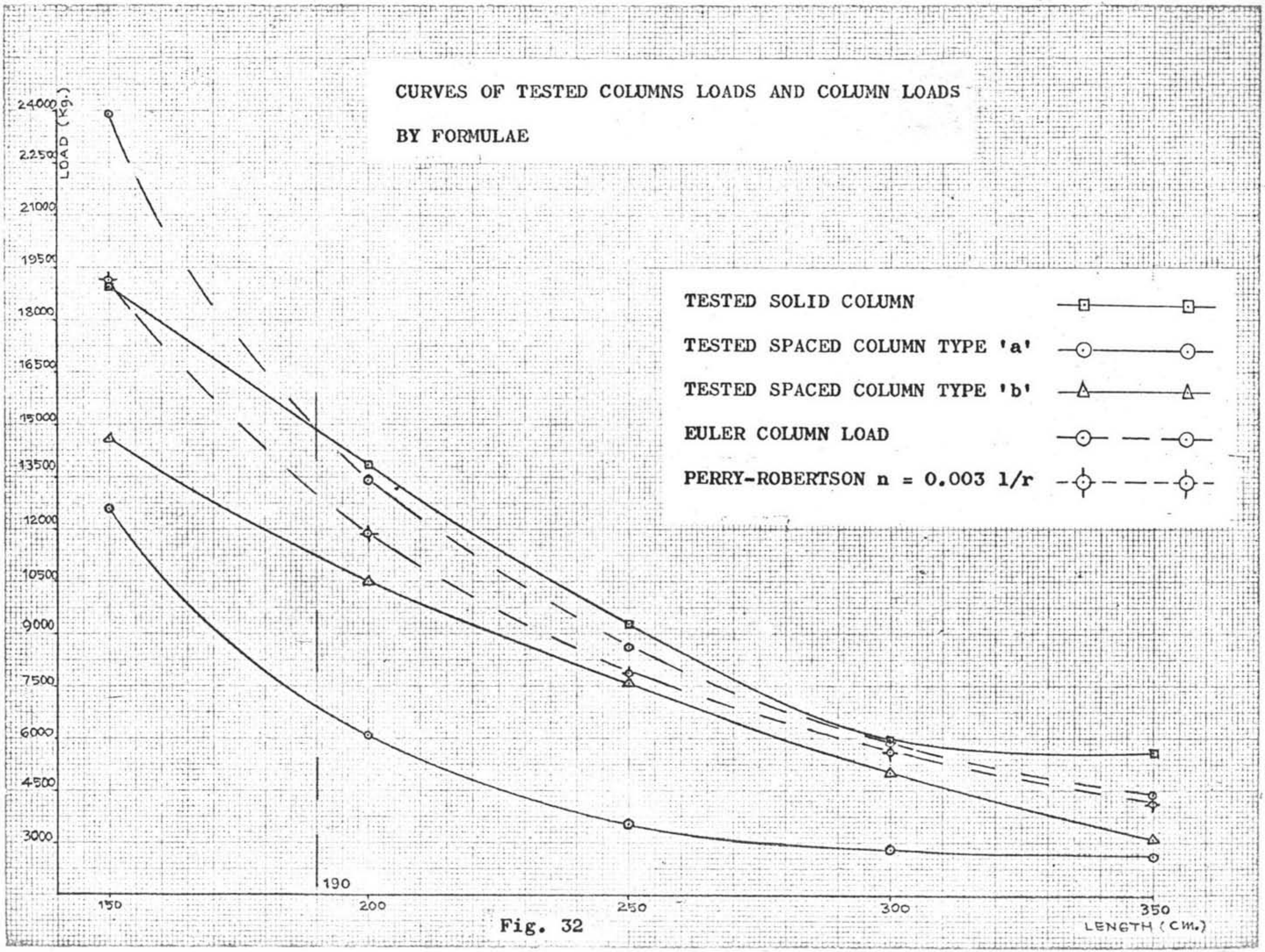

TESTED SOLID COLUMN LOAD AND COMPUTED LOAD BY PERRY ROBERTSON EQUATION
LOAD (Kg)
22500
21000
19500
18000
16500
15000
13500
12000
10500
9000
7500
6000
4500
3000
150
200
250
300
350
LENGTH (cm.)
1
2
3
4
5
TESTED SOLID COLUMN LOAD
1 PERRY ROBERTSON WITH n= 0.001 1/r
2 " " n= 0.0015 1/r
3 " " n= 0.002 1/r
4 " " n= 0.0025 1/r
5 " " n= 0.003 1/r

Fig. 31



CURVES OF TESTED COLUMNS LOADS AND COLUMN LOADS
BY FORMULAE
TESTED SOLID COLUMN
TESTED SPACED COLUMN TYPE 'a'
TESTED SPACED COLUMN TYPE 'b'
EULER COLUMN LOAD
PERRY-ROBERTSON n = 0.003 l/r
LOAD (Kg.)
24000
22500
21000
19500
18000
16500
15000
13500
12000
10500
9000
7500
6000
4500
3000
190
150
200
250
300
350
LENGTH (CM.)

Fig. 32

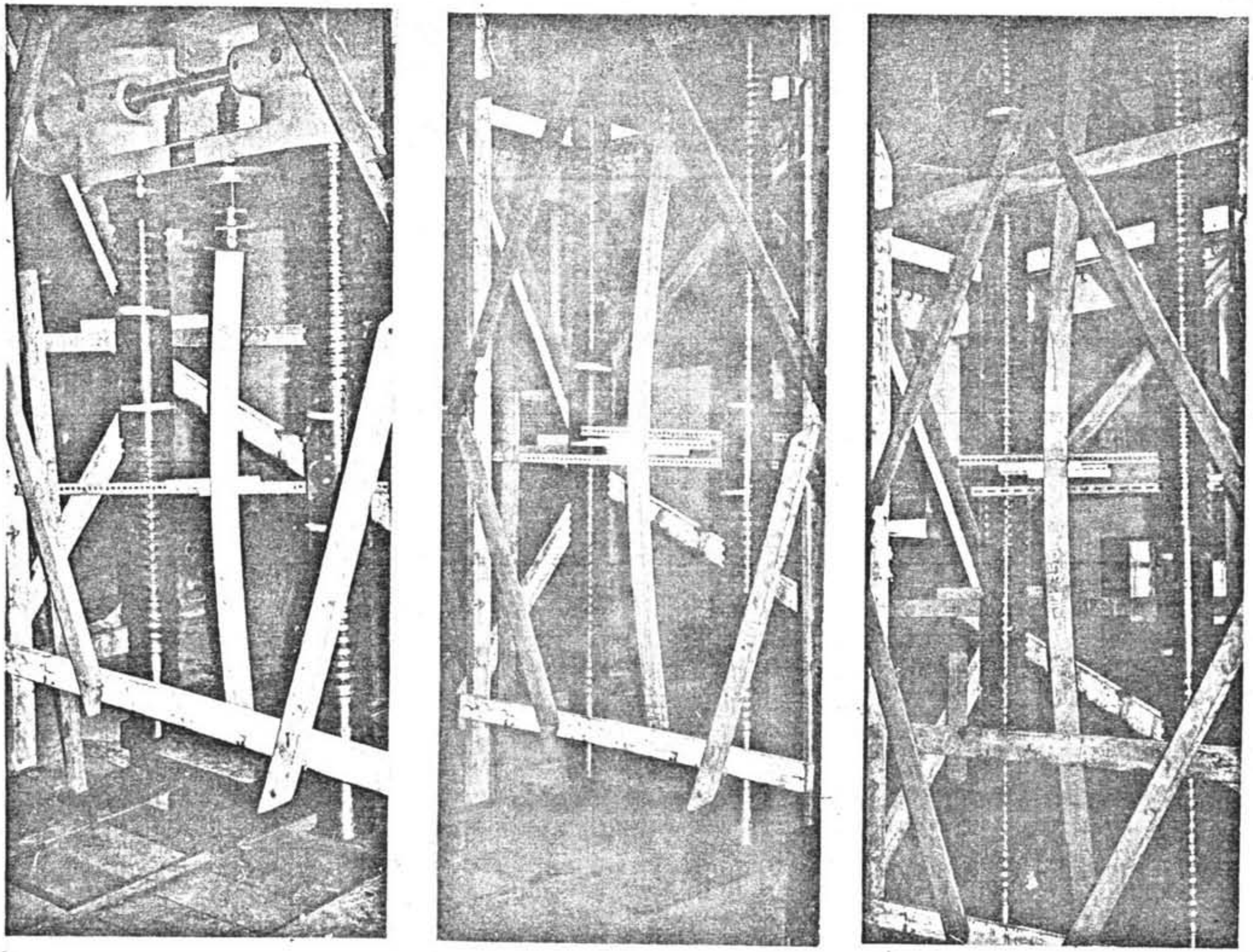


Fig. 33 Buckle shapes of solid squared columns

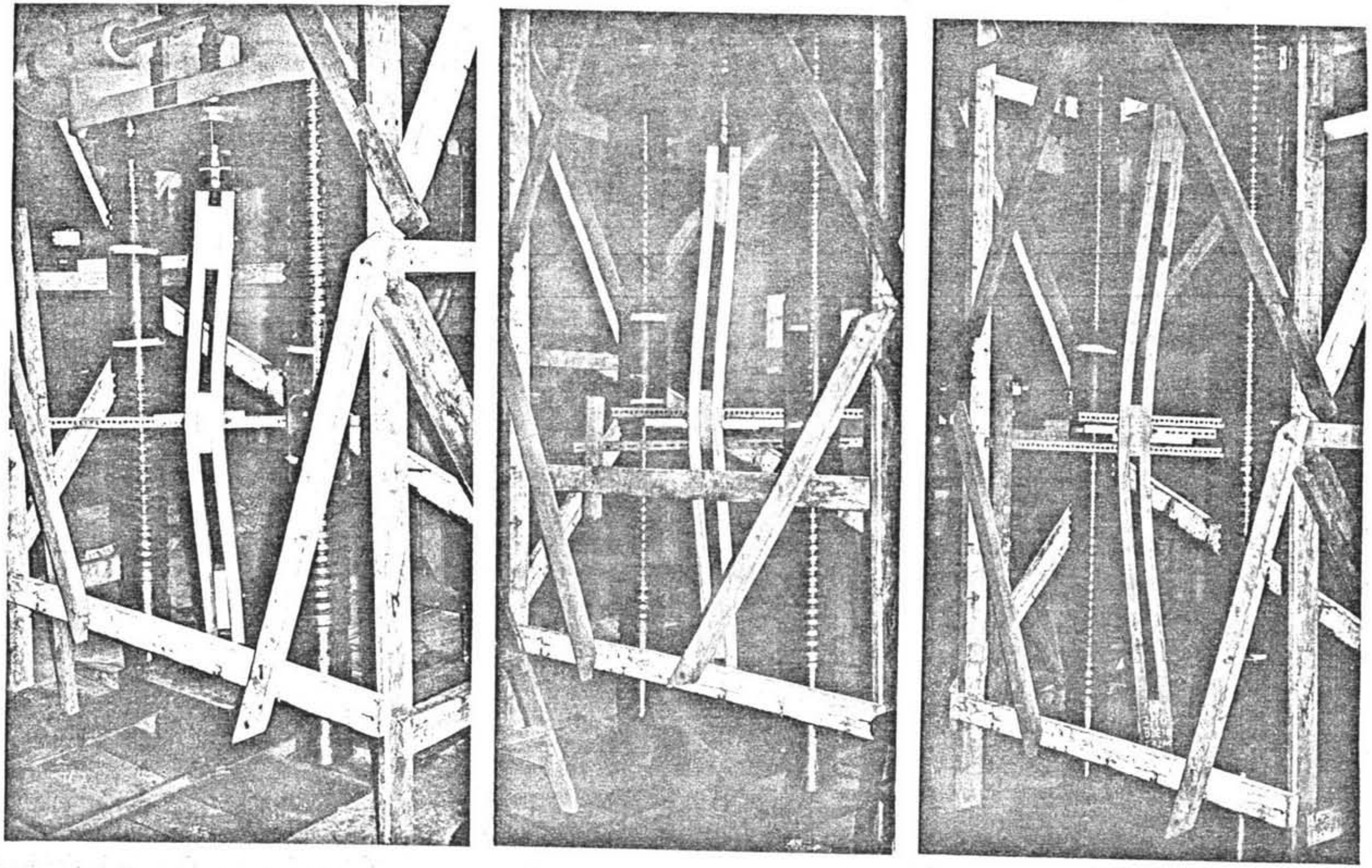


Fig. 34 Buckle shape of 1.50, 2.00 and 2.50 meter spaced columns

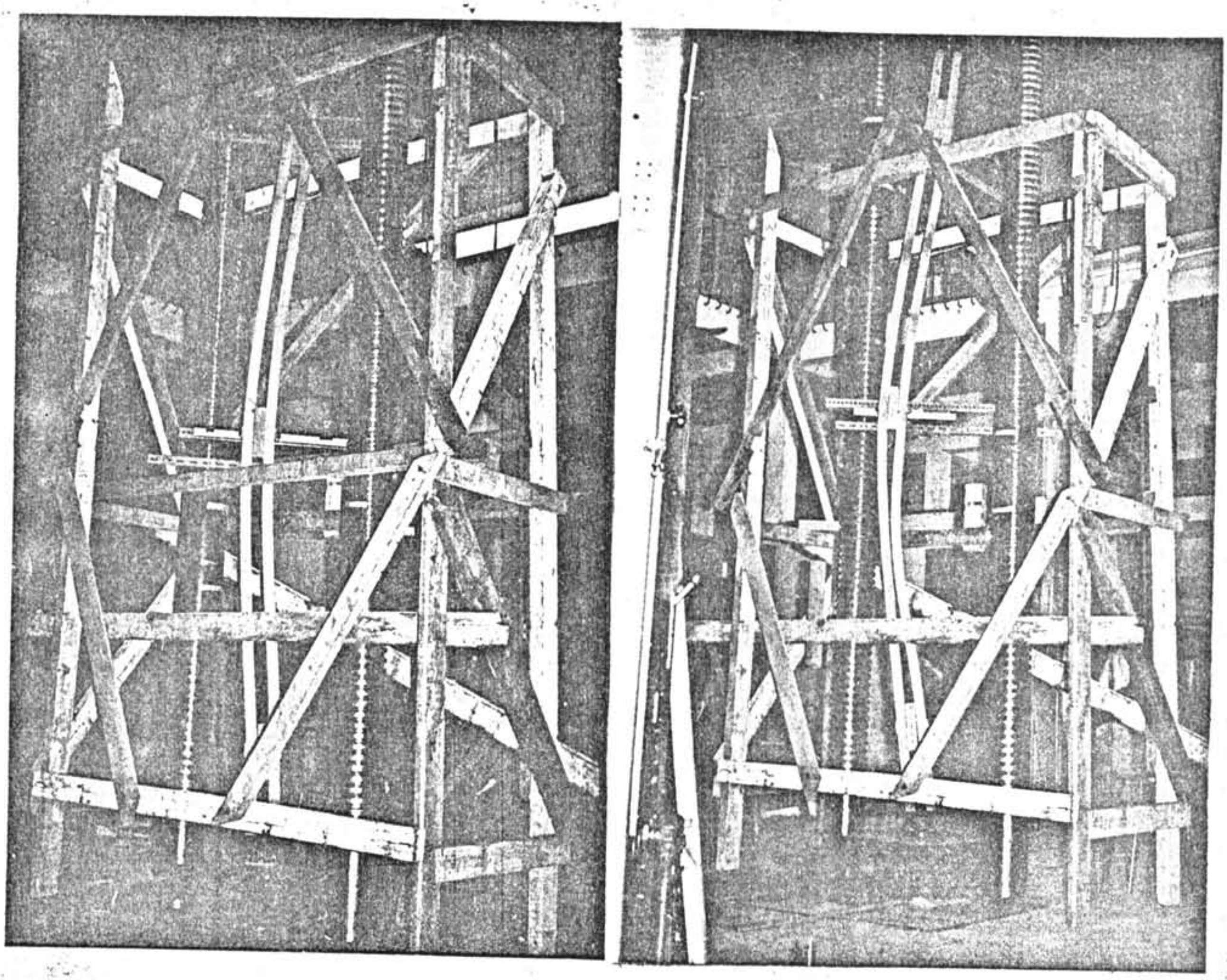


Fig. 35 Buckle shape of 3.00 (left) and 3.50 (right) meter spaced columns

Typesof failures of solid squared columns were shown in Fig. 36 and Fig. 37. The failures of 1.50 meter column were wedge split on the compression side and tension cracks on the tension side. The 3.00 meter column showed crushing failure at mid height. The types of failures of 2.00, 2.50 and 3.50 meter were classified as tension cracks failure. Columns of 2.00 and 2.50 meters were showing longitudinal tension cracks along the column length while the 3.50 meter column was showing the cross grain tension cracks at the sections close to mid height.

Spaced columns of both types showed similar failures (Fig. 38). The failures were of cross grain tension cracks of the fiber on the tension shaft and compression failure of fiber on the compression shaft. Failures occured in the vicinity of mid height. There was no failure of joint at spacer blocks of spaced columns of both types. The split ring cut from steel tube could be used satisfactory.

It was observed that all columns, solid squared columns and spaced columns of both types, showed failures after the maximum load was reached.

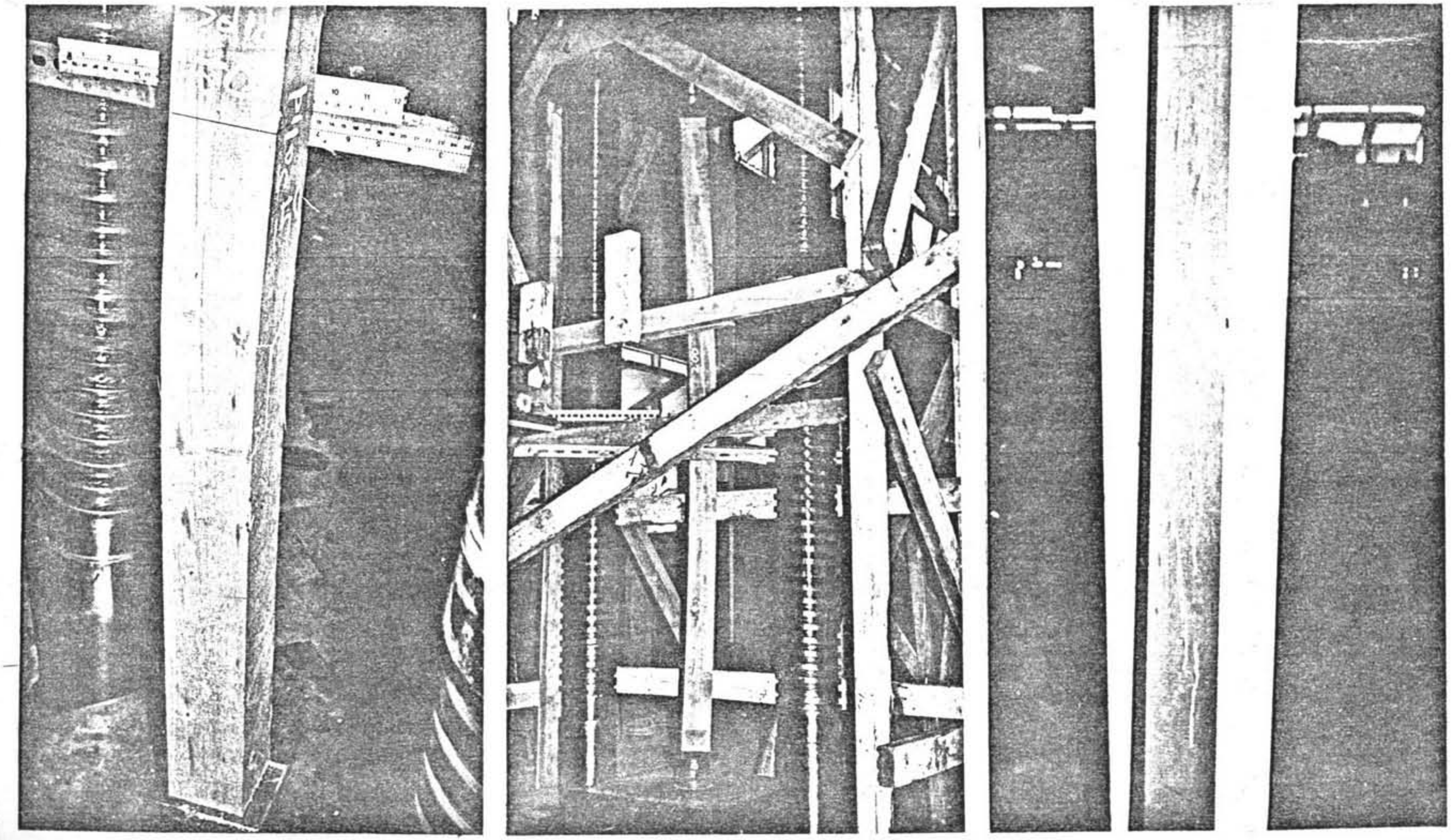


Fig. 36 Failure of 1.50, 2.00 and 2.50 meter solid columns

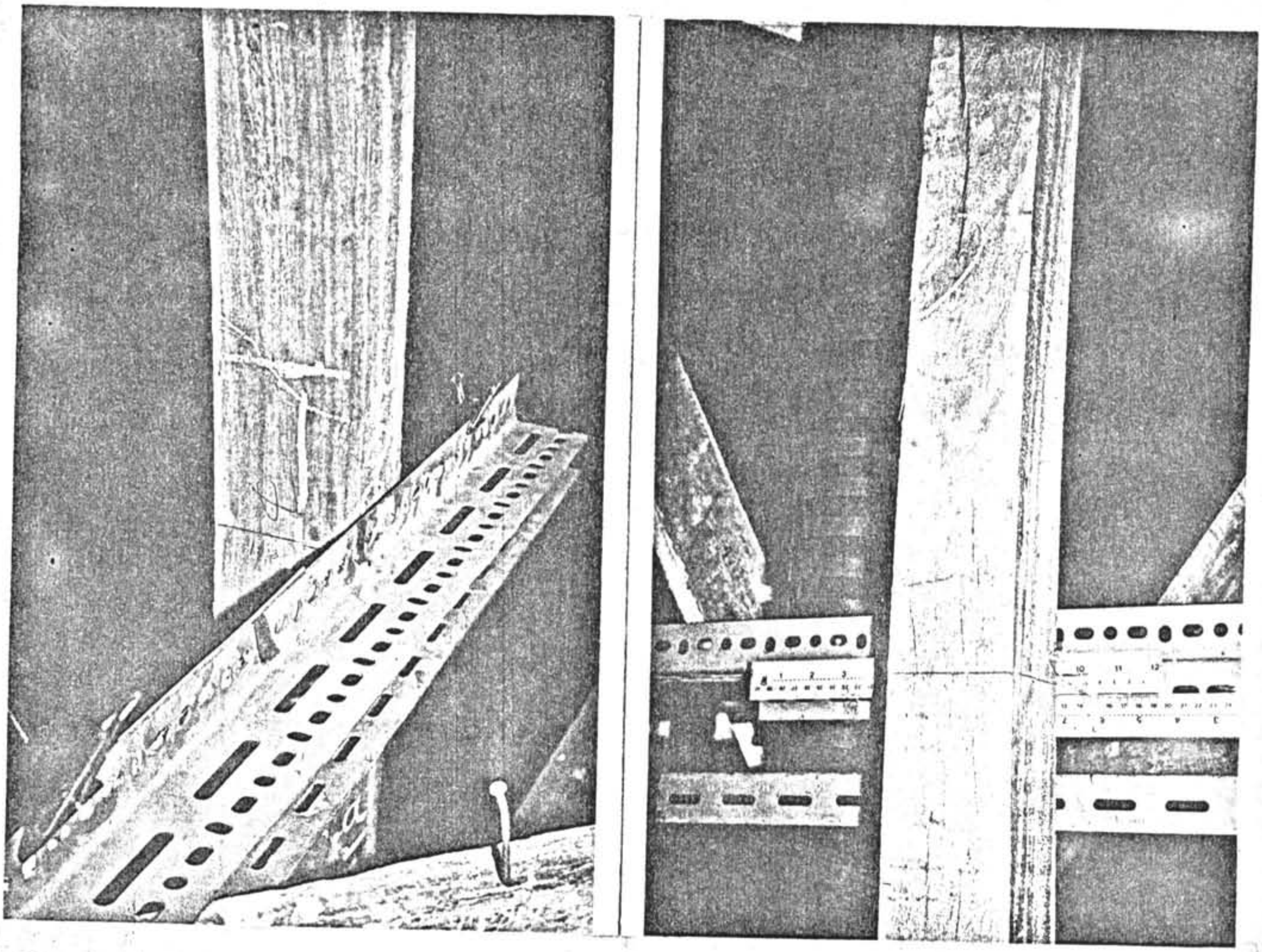


Fig. 37 Failure of 3.00 (left) and 3.50 (right) meter solid columns

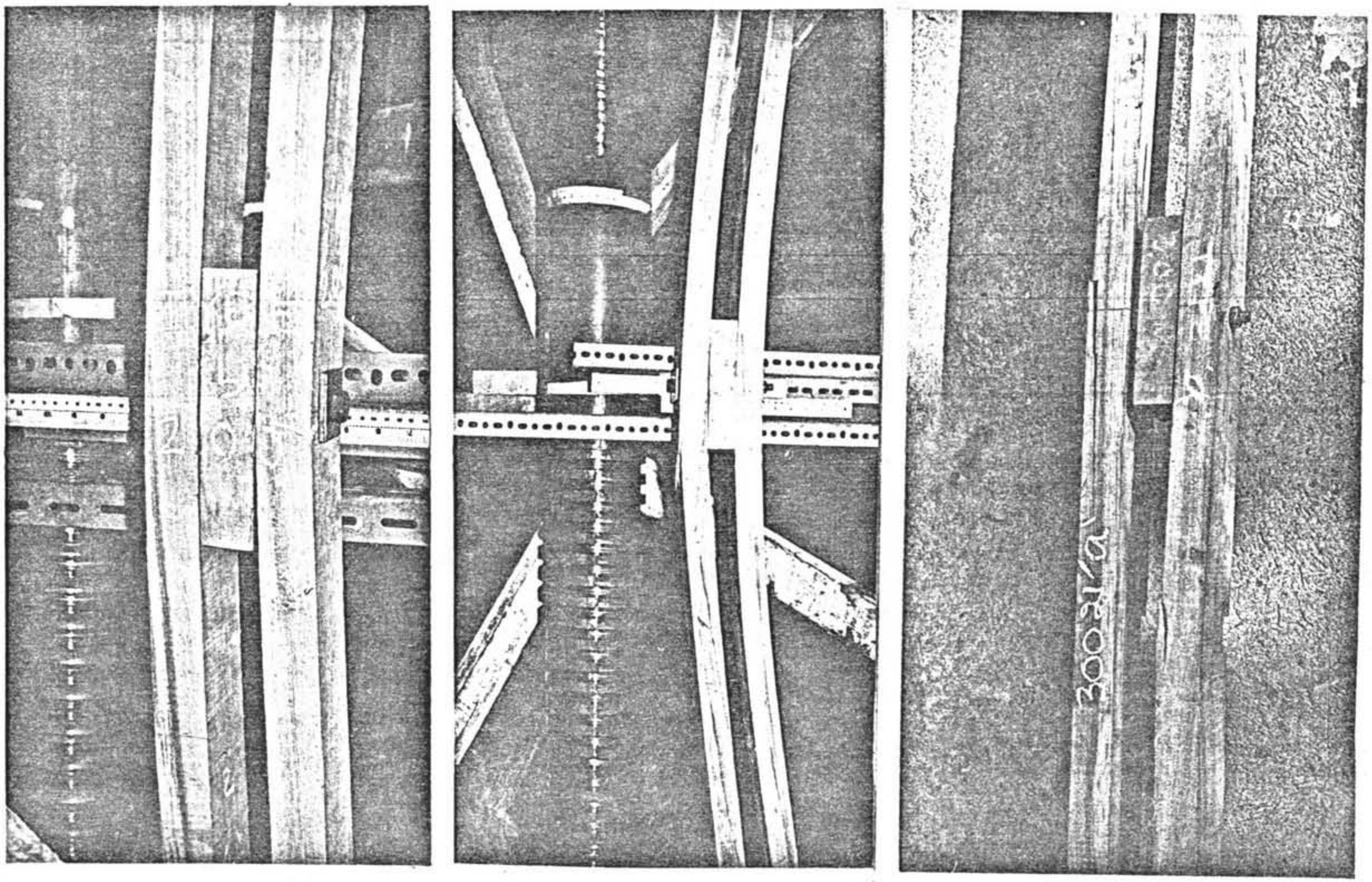


Fig. 38 Failures of spaced columns