REFERENCES

1. Khan, F.R., and Amin, N.R. "Analysis and Design of Framed Tube Structure for Tall Concrete Buildings." Response of Multistory Concrete Structures to Lateral Forces, Publication SP - 36. Detroit: American Concrete Institute, 1973, pp. 39 - 60

2. Coull, A., and Subedi, N.K. "Framed-Tube Structure for High-rise Buildings." Journal of the Structural Division, Proceedings of the American Society of Civil Engineering, ST 8, August 1971, pp.2097-2105

3. Rutenberg, A. "Analysis of Tube Structures Using Plane Frame Programs." Proceeding of the Regional Conference on Tall Building, Bangkok: Asian Institute of Technology, 1974, pp. 397 - 413

4. Naka, T.; Kato, B.; and Nakao, M. "Analysis of Box Type Rigid Frame." Proceeding of the Symposium in Thin Walled Structures and Spaced Structures, Tokyo: Japan Society of Civil Engineering and Architectural Institute of Japan, 1969, pp. 39 - 49

5. Schwaighofer, J. and Ast, P.A. "Tables for the Analysis of Framed-Tube Buildings." Publication 72-01. Canada: University of Toronto, Department of Civil Engineering, 1972

6. Coull, A., and Bose, B. "Simplified Analysis of Frame-Tube Structures." Journal of the Structural Division, Proceedings of the American Society of Civil Engineering ST 11, November 1975, pp. 2222 - 2240

7. Chan, P.C.K.; Heidebrecht, A.C.; and Tso, W.K. "Approximate Analysis of Multistory Multibay Frames." Journal of the Structural Division, Proceedings of the American Society of Civil Engineering, ST 5, May 1975, pp. 1021 - 1035

8. Moffatt, K.R., and Dowling, P. J. "Shear Lag in Steel Box Girder Bridges." Journal of the Structural Engineer, Proceedings of the Institution of Structural Engineer, February 1975, pp. 439 - 448

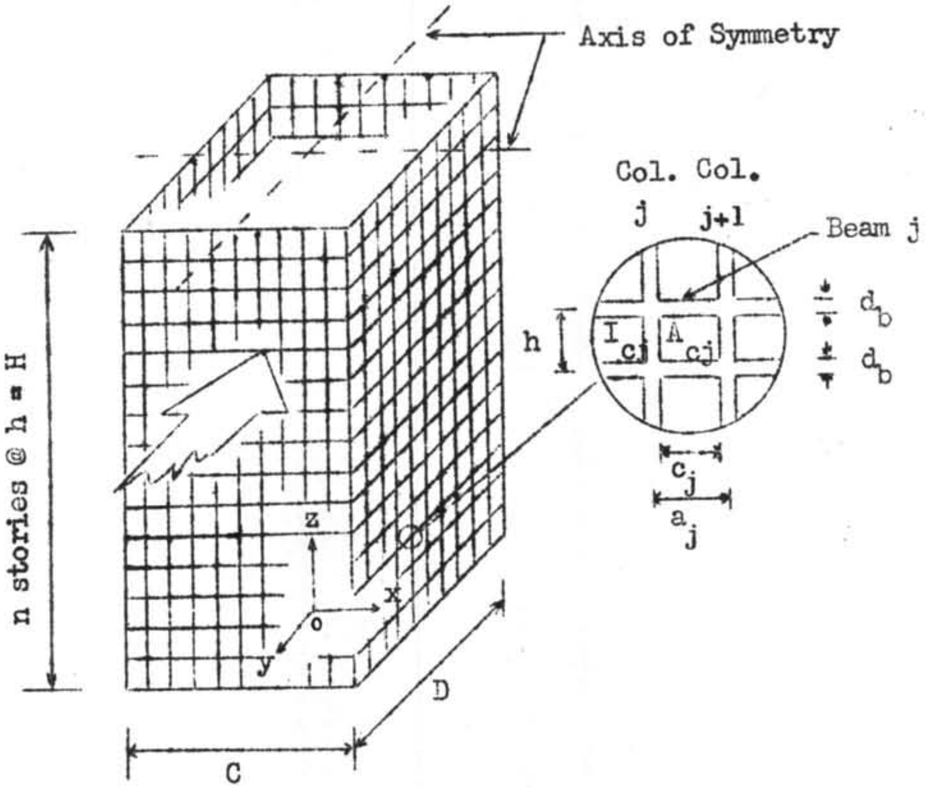


Fig. 1. - Typical Frame - Tube Structure

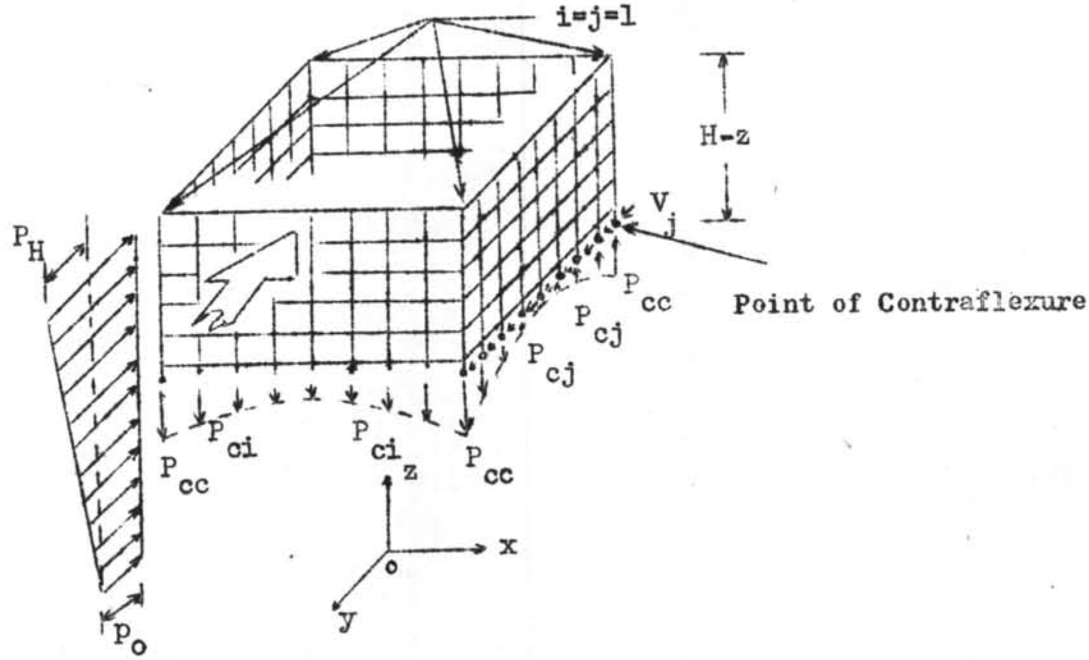


Fig. 2. - Column Forces at Points of Contraflexure

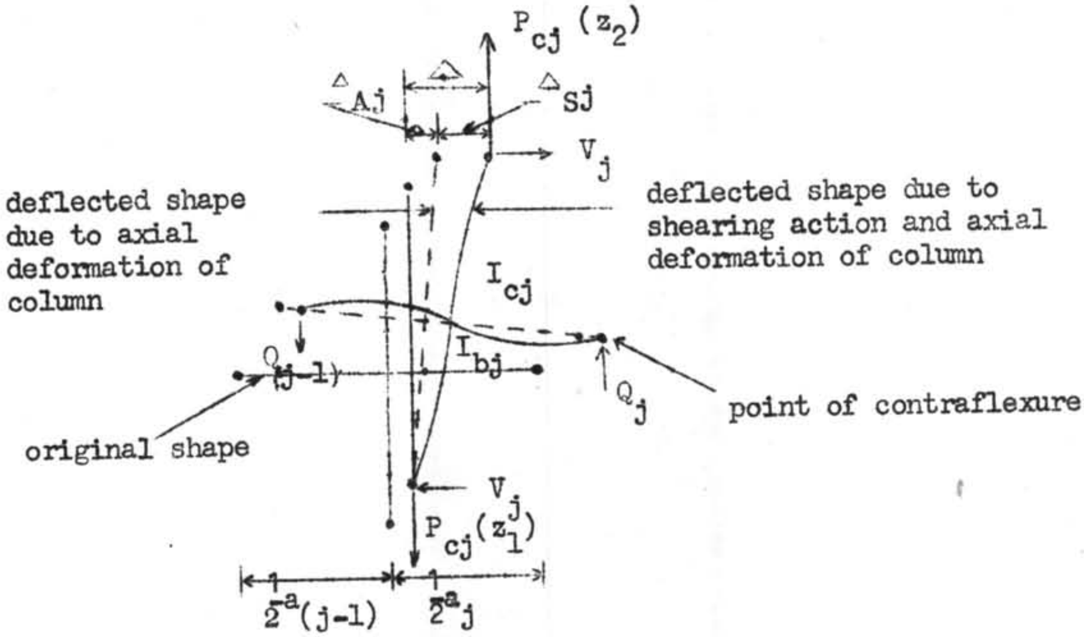


Fig. 3. - Deflected Shape of a Typical Unit

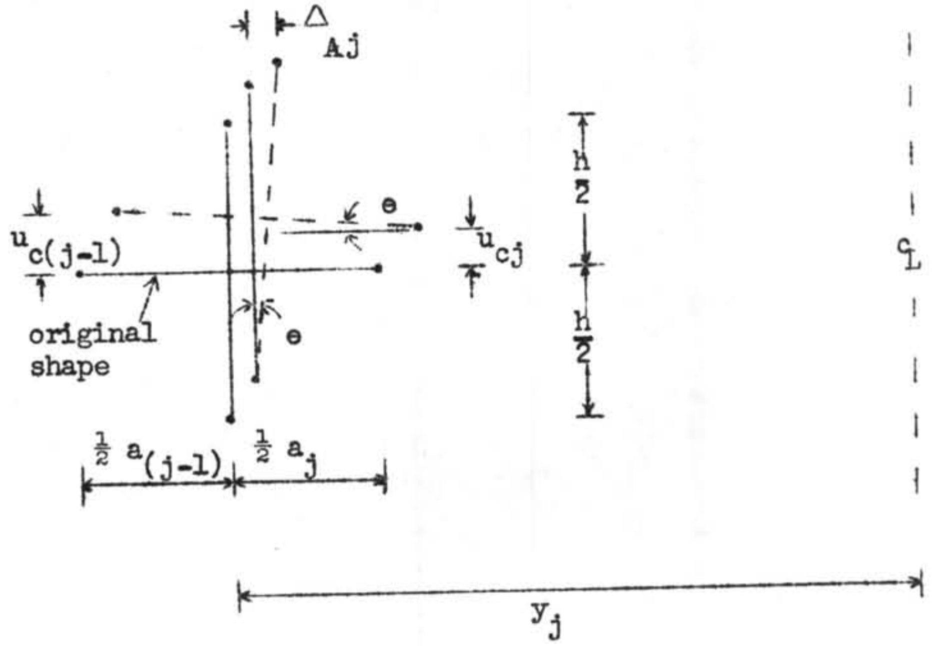


Fig. 4. - Axial Deformation of a Typical Unit

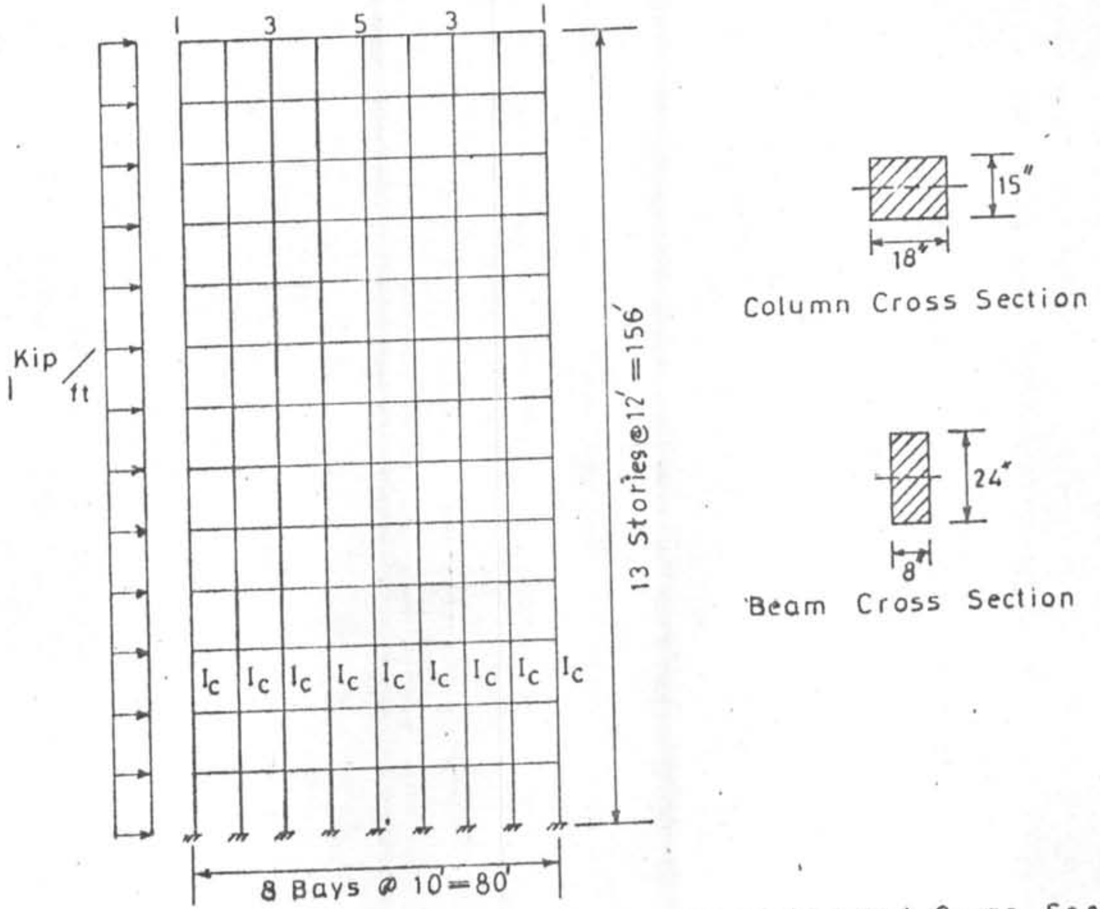


Fig. 5.—Multistory Multibay Plane Frame; Dimensions and Cross Sections

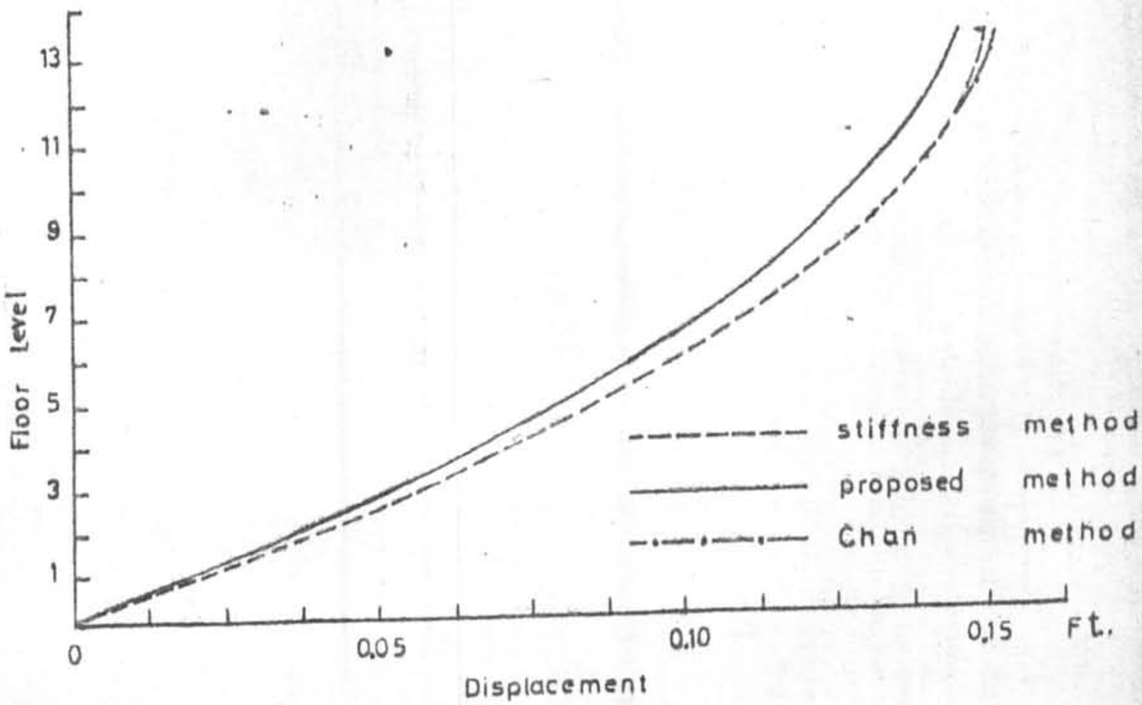


Fig. 6.—Lateral Displacement of Frame in Fig. 5

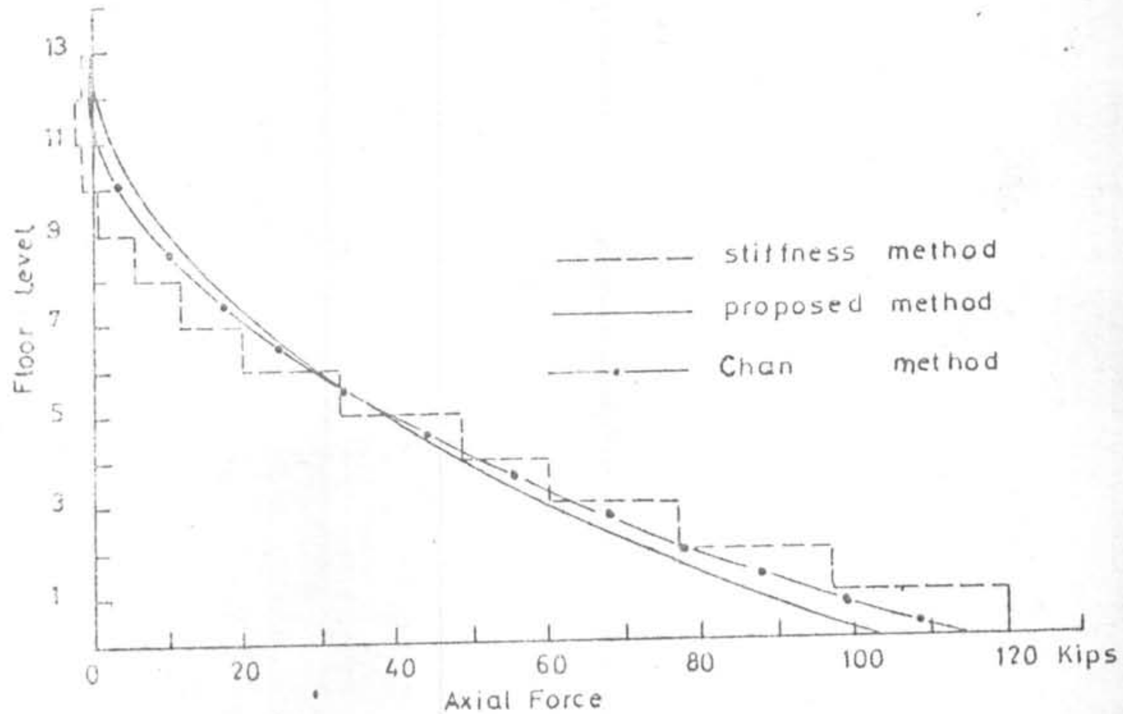


Fig. 7.—Variation of Axial Force of Exterior Column of Frame in Fig.5

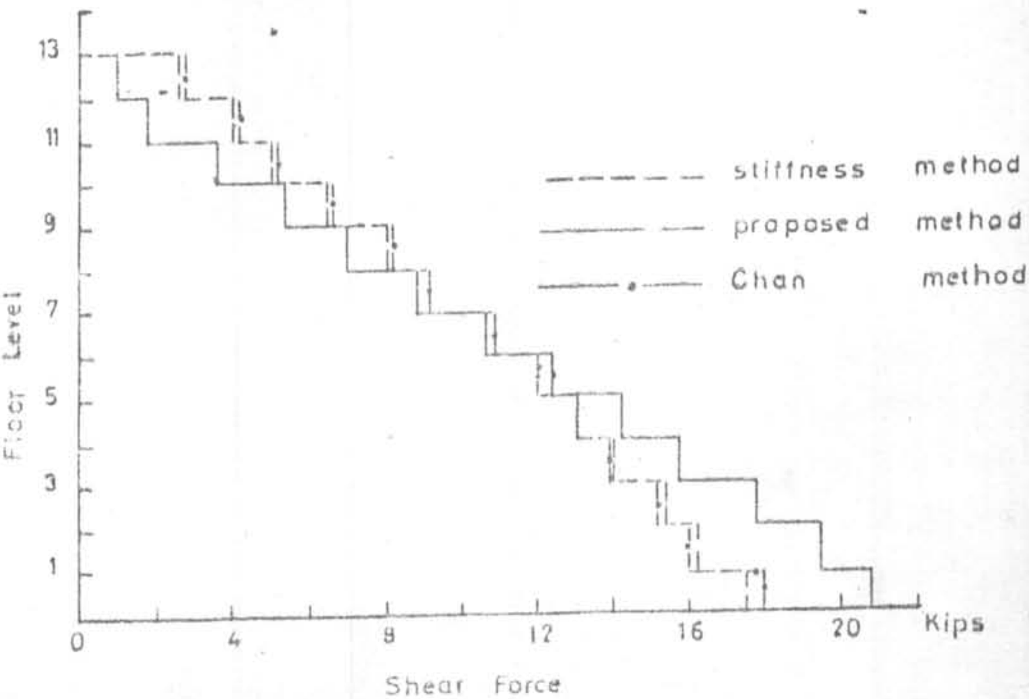


Fig. 8.—Variation of Shear Force in Column 5 of Frame in Fig. 5

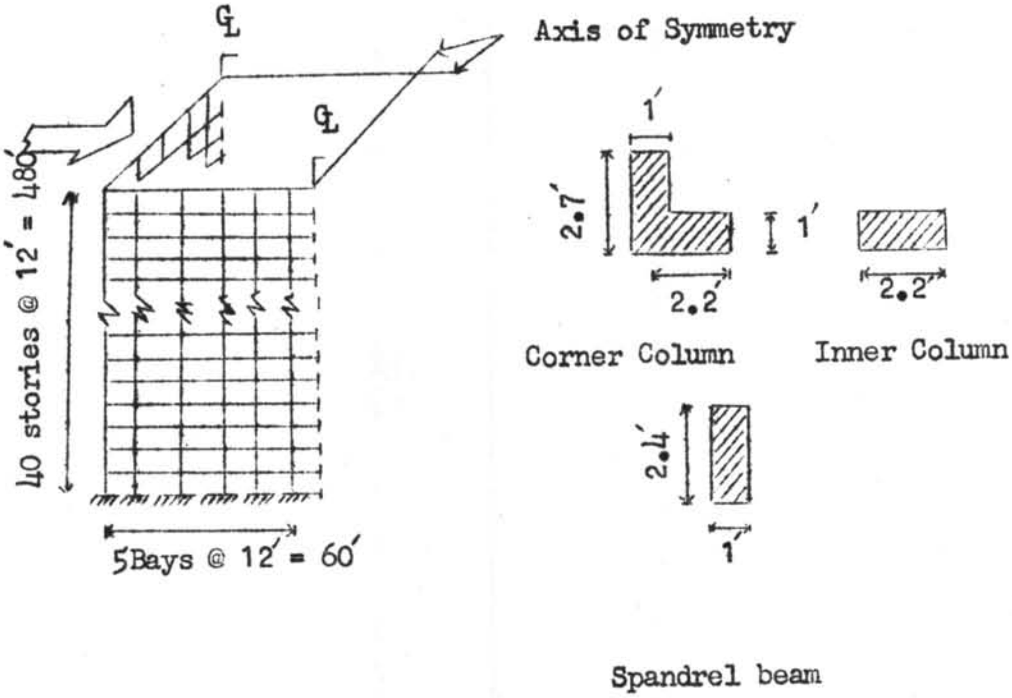
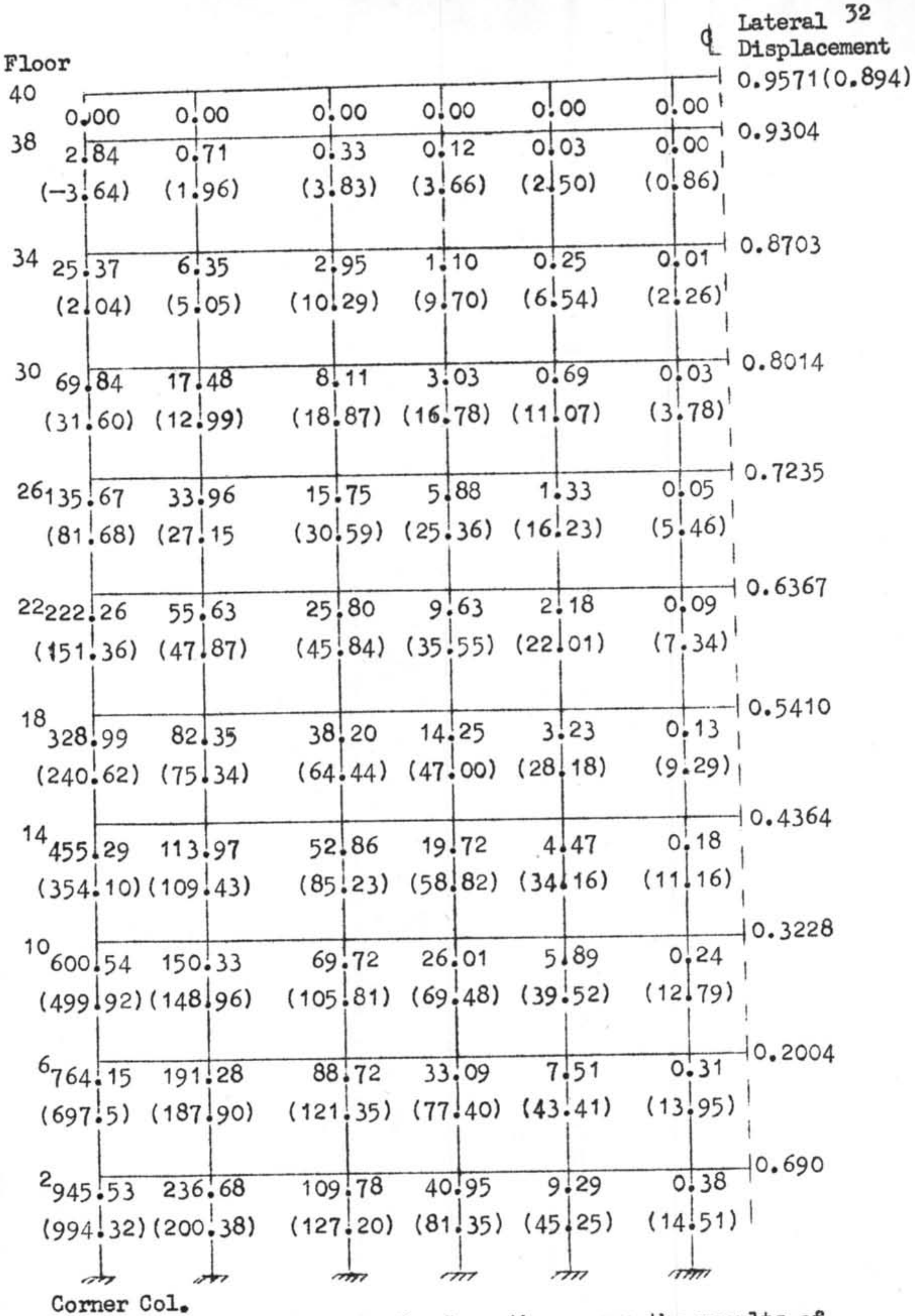


Fig. 9. - Dimensions and Member Cross Sections



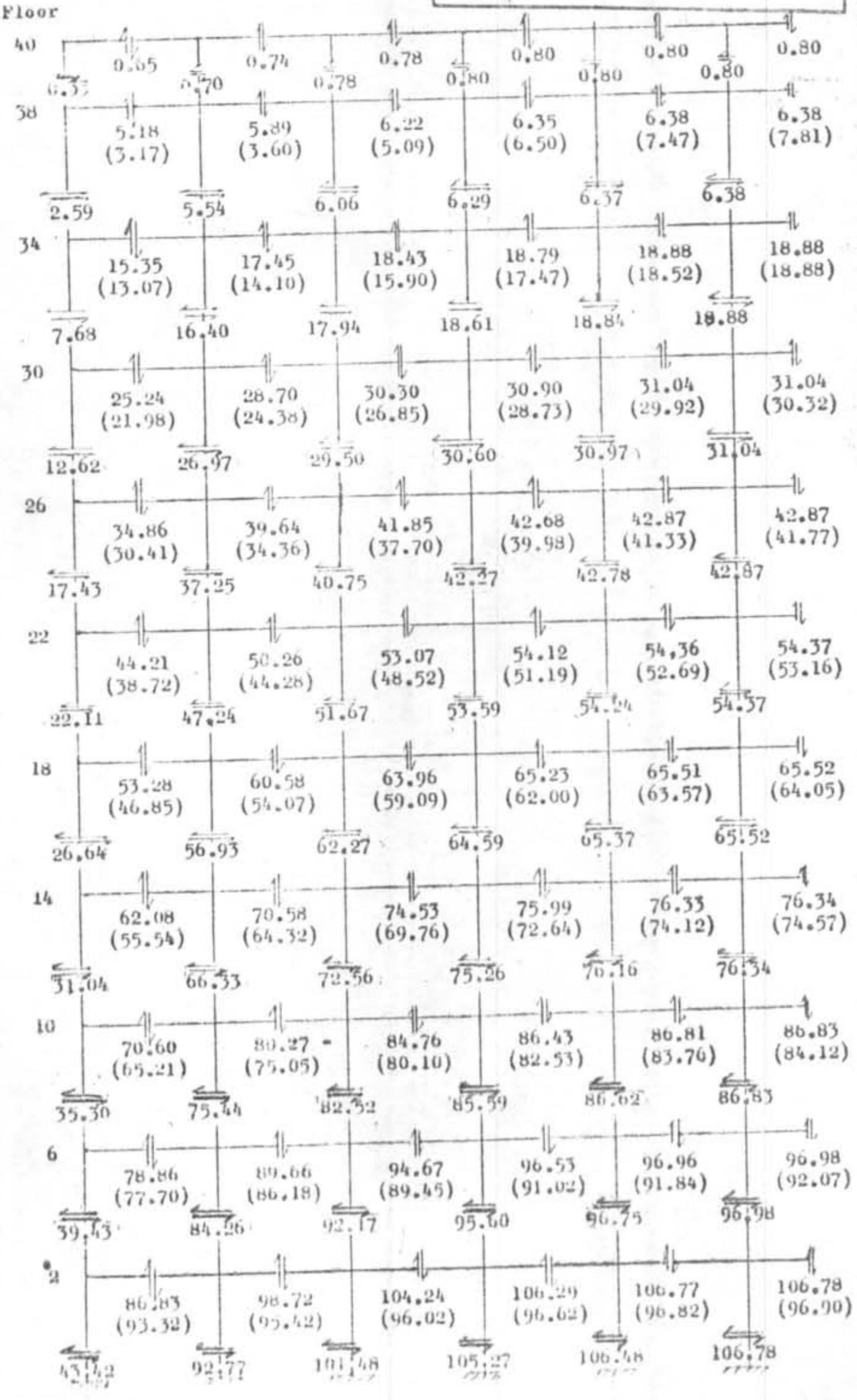
Note :- The Values in the Parentheses are the results of SCHWAIGHOFER and AST (5)

Fig. 10. - Column Axial Forces in Side Panel (Kips) and Lateral Displacement (Ft.) for Frame-Tube in Fig. 9

Floor						℄
40	0.00	0.00	0.00	0.00	0.00	0.00
38	2.84	0.95	0.61	0.37	0.24	0.18
34	25.37	8.51	5.42	3.33	2.11	1.63
30	69.84	23.43	14.93	9.16	5.81	4.47
26	135.67	45.52	29.00	17.79	11.28	8.69
22	222.26	74.57	47.51	29.14	18.48	14.24
18	328.99	110.38	70.32	43.13	27.36	21.38
14	455.29	152.75	97.32	59.69	37.86	29.17
10	600.54	201.49	128.37	78.73	49.94	38.47
6	764.15	256.38	163.34	100.18	63.54	48.95
2	945.53	317.23	202.11	123.95	78.62	60.57

Corner Col.

Fig. 11. - Column Axial Forces in Normal Panel (Kips) for Frame - Tube in Fig. 9



Note : The Values in the Parentheses are the results of SCHWAIGHOFER and AST (5)

Fig. 12. - Shear Forces in Columns and Spandrel Beams in Side Panel (kips) for Framed Tube in Fig. 9.

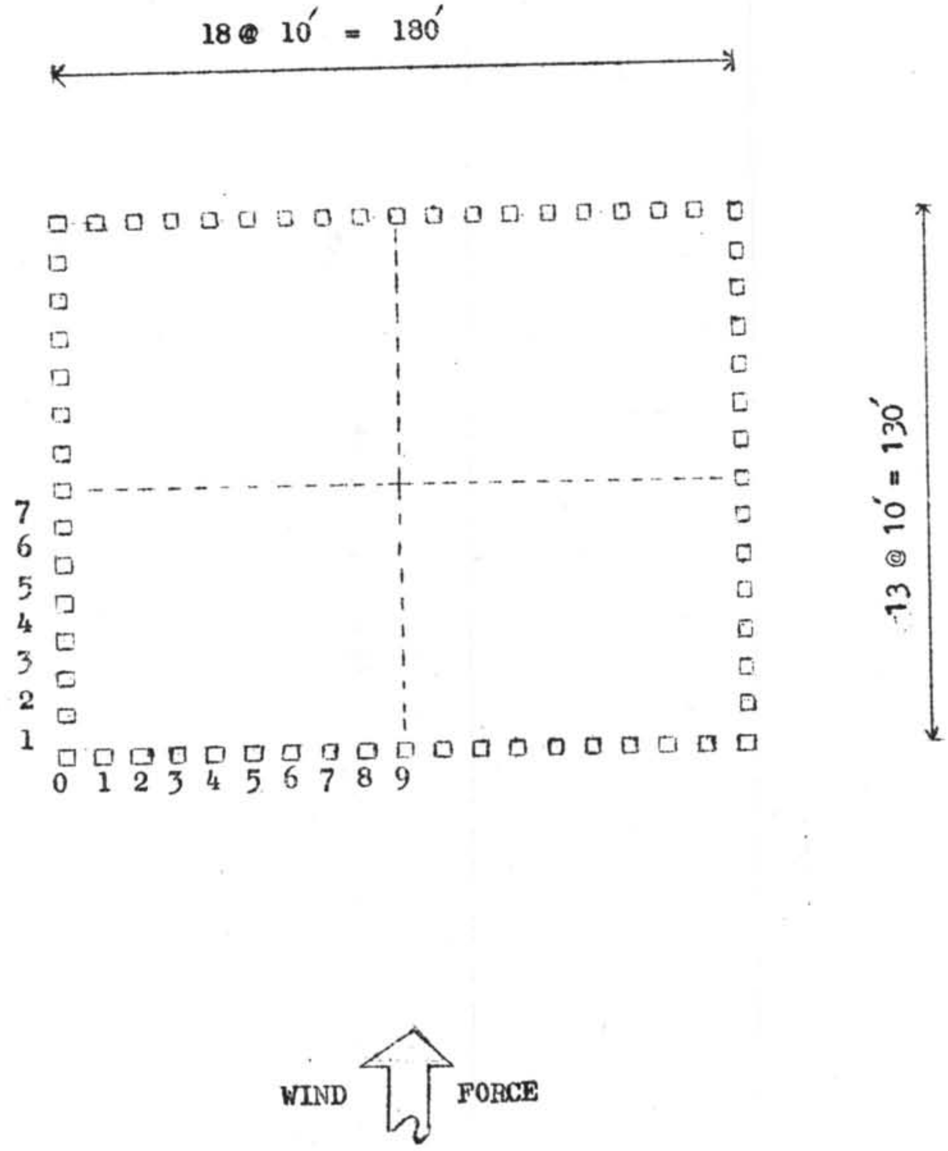


Fig. 13.- Plan View of Frame - Tube Investigated by Khan and Amin (1)

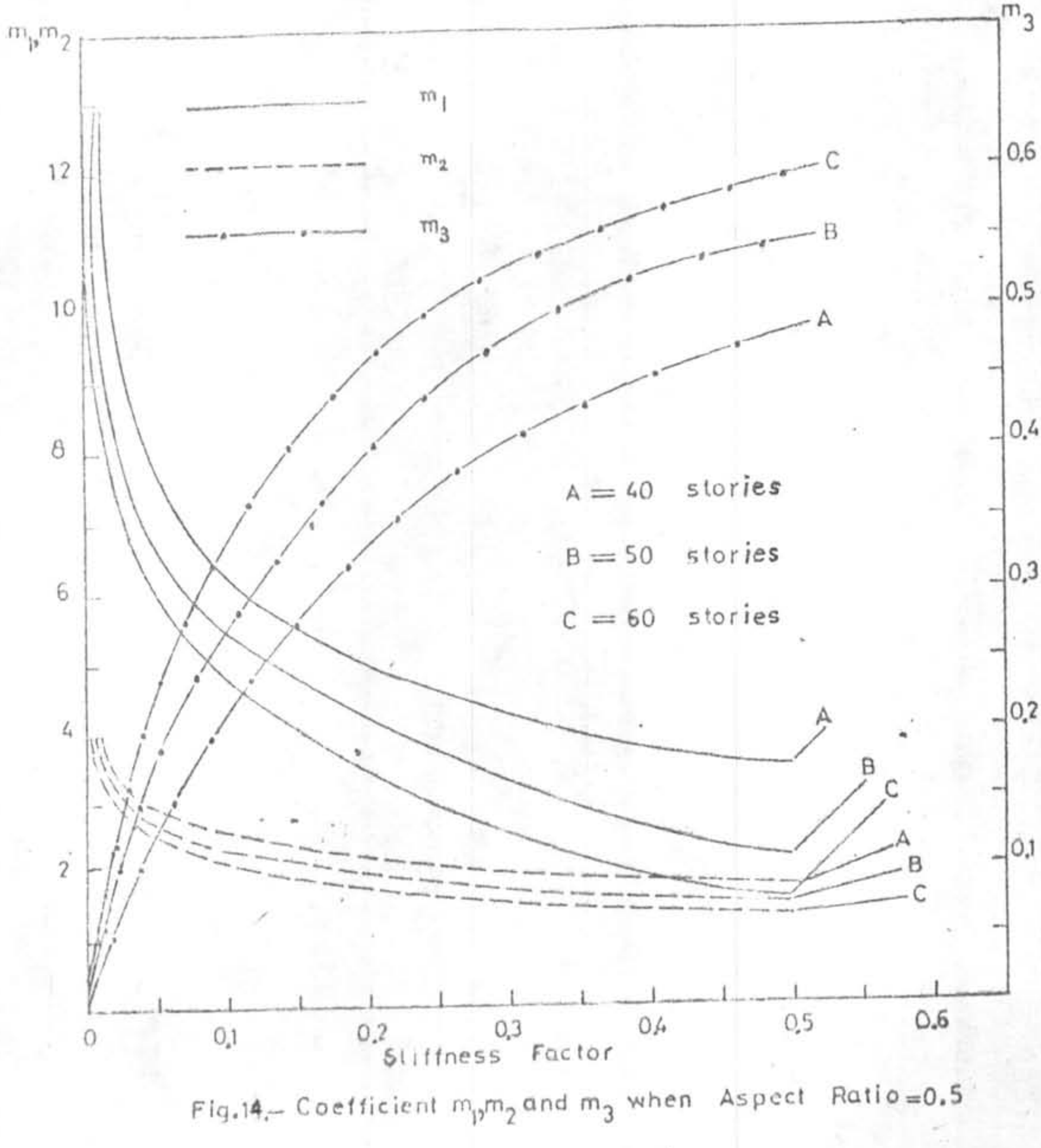


Fig.14.– Coefficient m_1, m_2 and m_3 when Aspect Ratio = 0.5

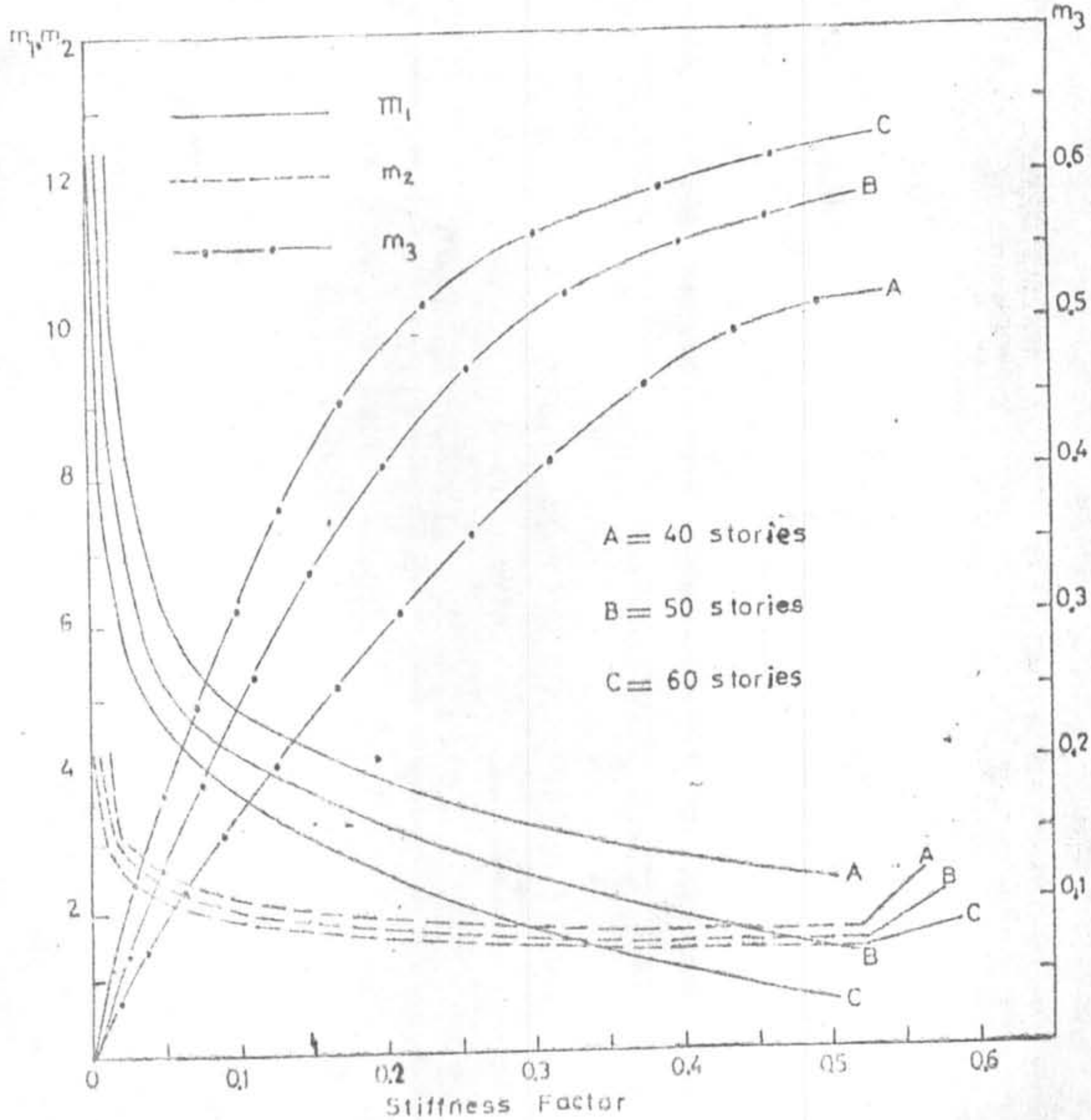


Fig.15.–Coefficient m_1, m_2 and m_3 when Aspect Ratio=0.666

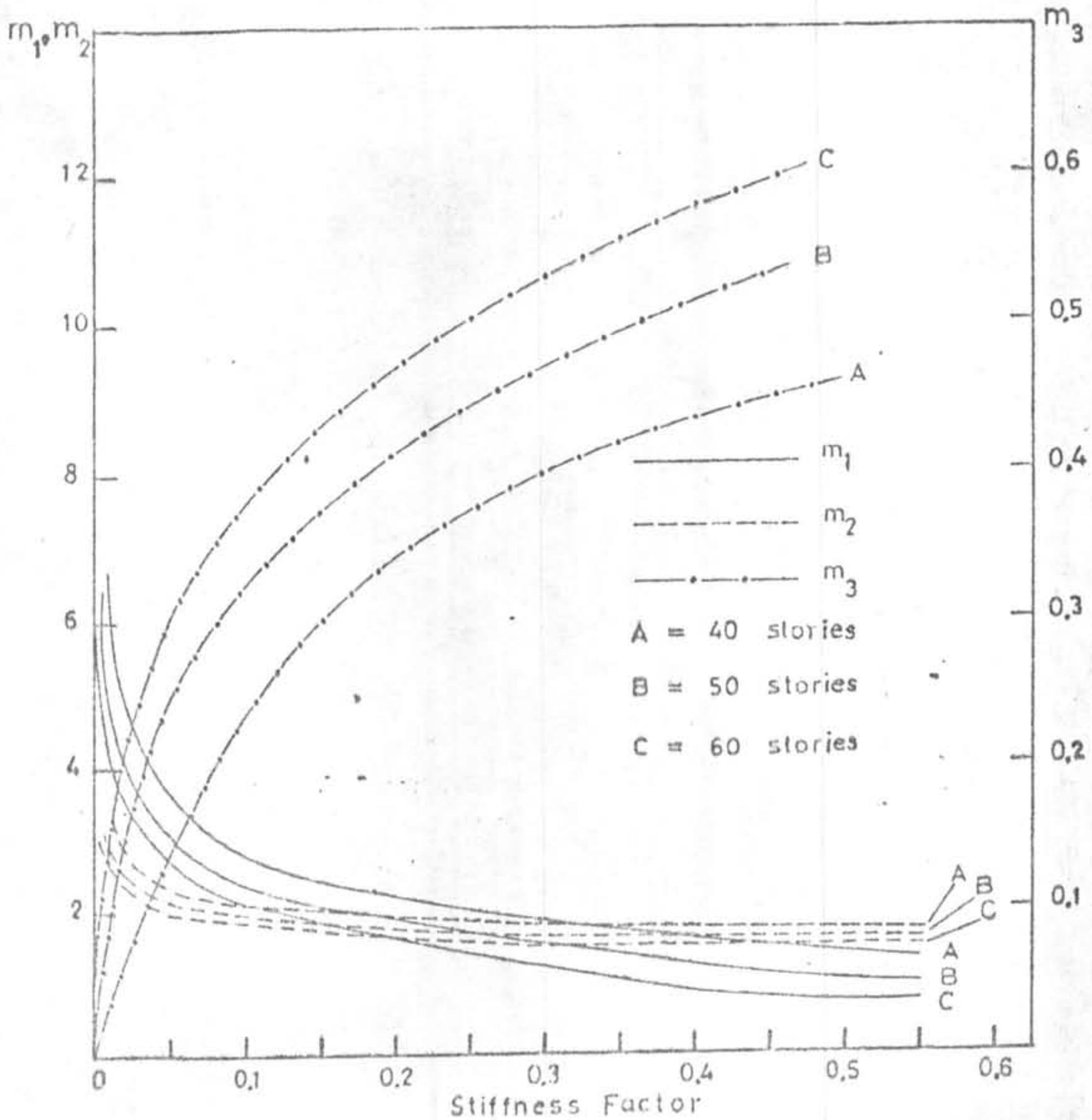


Fig. 16-Coefficient m_1, m_2 and m_3 when Aspect Ratio = 1.0

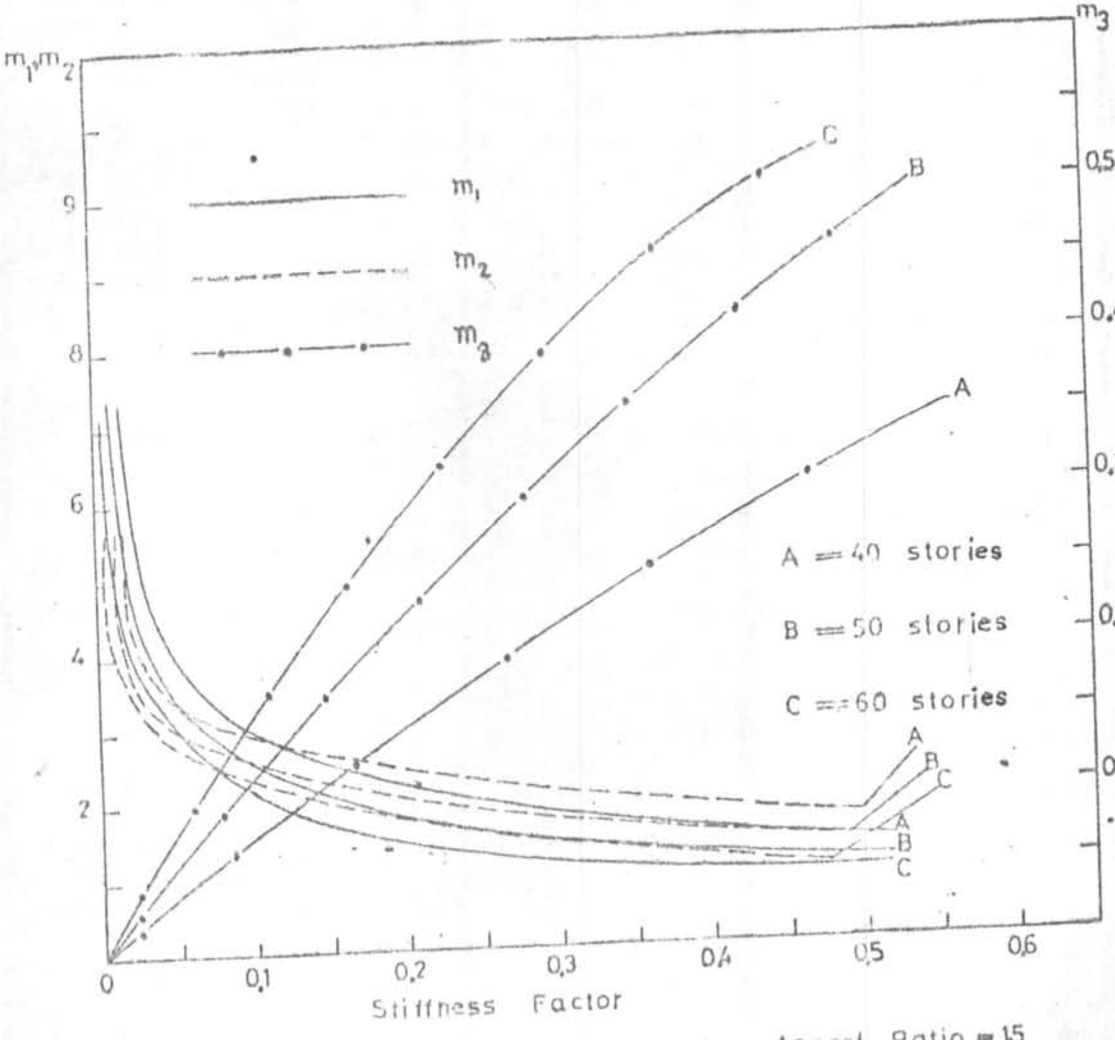


Fig. 17.— Coefficient m_1, m_2 and m_3 when Aspect Ratio = 1.5

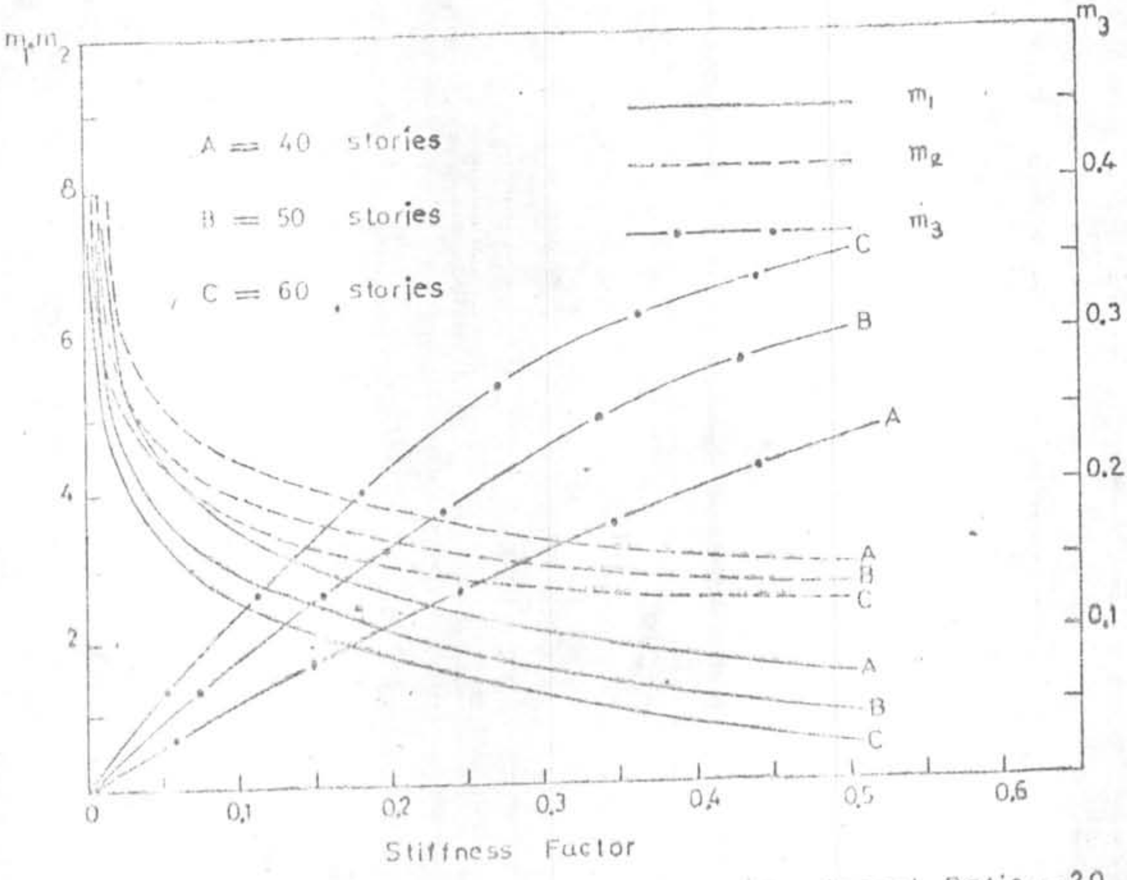


Fig. 18.--Coefficient m_1, m_2 and m_3 when Aspect Ratio = 2.0

Table. 1. - Distribution of Axial Strain in Side Panel Columns from the Results of SCHWAIGHOFER and AST (bay width = story height) and the Average Value of m_1

40 STORIES

S.F. (1)	A (2)	B (3)	C (4)	D (5)	E (6)	F (7)	m_1 (8)
	Distribution of Axial strain						
0.349	1	0.48	0.32	0.21	0.12	0.04	
0.210	1	0.54	0.38	0.26	0.15	0.05	
0.155	1	0.57	0.41	0.28	0.16	0.05	
0.147	1	0.45	0.29	0.19	0.11	0.04	
0.089	1	0.52	0.35	0.23	0.13	0.04	
0.065	1	0.54	0.38	0.26	0.15	0.05	
0.044	1	0.40	0.26	0.16	0.09	0.03	
0.026	1	0.47	0.31	0.20	0.11	0.04	
0.019	1	0.50	0.34	0.22	0.12	0.04	
Mean	1	0.50	0.34	0.22	0.13	0.04	2.9

50 STORIES

S.F. (1)	A (9)	B (10)	C (11)	D (12)	E (13)	F (14)	m_1 (15)
	Distribution of Axial strain						
0.349	1	0.69	0.46	0.31	0.18	0.06	
0.210	1	0.77	0.55	0.38	0.22	0.07	
0.155	1	0.81	0.59	0.41	0.24	0.08	
0.147	1	0.63	0.42	0.28	0.16	0.05	
0.089	1	0.72	0.50	0.34	0.20	0.06	
0.065	1	0.76	0.55	0.37	0.22	0.07	
0.044	1	0.55	0.36	0.25	0.13	0.04	
0.026	1	0.64	0.43	0.28	0.16	0.05	
0.019	1	0.68	0.46	0.31	0.18	0.06	
Mean	1	0.70	0.48	0.33	0.19	0.06	1.4

60 STORIES

S.F. (1)	A (16)	B (17)	C (18)	D (19)	E (20)	F (21)	m_1 (22)
	Distribution of Axial strain						
0.349	1	0.70	0.49	0.33	0.21	0.05	
0.210	1	0.78	0.56	0.39	0.23	0.07	
0.155	1	0.81	0.60	0.41	0.24	0.08	
0.147	1	0.65	0.44	0.30	0.17	0.06	
0.089	1	0.73	0.52	0.35	0.21	0.07	
0.065	1	0.77	0.56	0.38	0.22	0.07	
0.044	1	0.58	0.39	0.26	0.15	0.05	
0.026	1	0.66	0.45	0.30	0.17	0.06	
0.019	1	0.70	0.48	0.32	0.19	0.06	
Mean	1	0.71	0.50	0.34	0.20	0.06	1.1

Note. - Letters A,...., F denote the column location from corner to center.

Table.2. - Comparison between Results of SCHWAIGHOFER and AST and the Proposed Method when Bay width= Story height

S.F.[a]	PERCENTAGE ERROR																	
	H = 480 ft						H = 600 ft						H = 720 ft					
	ΔH[b]			P_{cc}[c]	ΣV[d]	Q[e]	ΔH			P_{cc}	ΣV	Q	ΔH			P_{cc}	ΣV	Q
(1)	(2)[f]	(3)[g]	(4)[h]	(5)	(6)	(7)	(8)[f]	(9)[g]	(10)[h]	(11)	(12)	(13)	(14)[f]	(15)[g]	(16)[h]	(17)	(18)	(19)
0.019	+19	+24	+30	+14	-1	+4	+11	+16	+21	+30	-4	+13	+8	+13	+19	+32	0	+19
0.044	+1	+7	+10	-5	-1	+10	+3	+7	+10	+16	-4	+23	+10	+14	+18	+24	0	+34
0.089	+21	+26	+33	-4	-1	0	+8	+14	+20	+21	-4	+9	+7	+13	+20	+23	0	+14
0.147	+4	+8	+13	-15	-1	+6	+3	+7	+12	+13	-4	+18	+6	+12	+18	+18	0	+26
0.349	+18	+23	+30	-19	-1	+4	+8	+14	+20	+9	-4	+13	+10	+17	+24	+13	0	+21

[a] The stiffness factor.

[b] Lateral displacement at top of structure.

[c] Axial forces in corner column at floor No. 2.

[d] Total internal shear forces in columns 18 ft. above the base.

[e] Shear forces in the central spandrel beam at floor No. 2.

[f,g,h] Designate the cases when β is taken as 0.5,0.55 and 0.6, respestively.

Table. 3. - Comparison between Results of SCHWAIGHOFER and AST and the Proposed Method when Bay width/Story height = 0.8

S.F.[a]	PERCENTAGE ERROR											
	H = 480 ft						H = 600 ft					
	$\triangle H$[b]						$\triangle H$					
	f	g	h	P_{cc}[c]	ΣV[d]	Q[e]	f	g	h	P_{cc}	ΣV	Q
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
0.047	+29	+35	+43	+ 9	-1	0	+13	+20	+26	+33	0	+10
0.107	+15	+19	+23	-10	-1	+10	+12	+17	+21	+19	0	+24
0.218	+30	+35	+40	- 8	-1	0	+27	+35	+40	+25	0	+ 9
0.360	+31	+38	+44	-18	-1	+ 7	+22	+28	+34	+14	0	+19

Table.4. - Comparison between Results of SCHWAIGHOFER and AST and the Proposed Method when Bay width/ Story height = 1.2

S.F.[a]	PERCENTAGE ERROR																	
	H = 480 ft						H = 600 ft						H = 720 ft					
	ΔH[b]			P_{cc}[c]	ΣV[d]	Q[e]	ΔH			P_{cc}	ΣV	Q	ΔH			P_{cc}	ΣV	Q
(1)	(2)[f]	(3)[g]	(4)[h]	(5)	(6)	(7)	(8)[f]	(9)[g]	(10)[h]	(11)	(12)	(13)	(14)[f]	(15)[g]	(16)[h]	(17)	(18)	(19)
0.009	+ 12	+ 16	+ 19	0	0	+ 9	+7	+ 11	+ 15	+ 12	- 1	+ 19	+ 7	+ 11	+ 15	+ 10	0	+ 24
0.021	- 3	0	+ 1	+ 5	0	+ 9	- 2	0	+ 3	+ 11	- 1	+ 21	+ 1	+ 4	+ 7	+ 15	0	+ 29
0.043	+ 8	+ 12	+ 17	+ 6	0	0	- 2	+ 3	+ 7	+ 26	- 1	+ 9	- 3	+ 2	+ 7	+ 26	0	+ 12
0.071	- 3	0	+ 4	- 11	0	+ 6	- 7	- 3	0	+ 10	- 1	+ 16	- 4	0	+ 5	+ 14	0	+ 23
0.168	0	+ 5	+ 10	- 13	0	+ 3	- 6	- 1	+ 4	+ 13	- 1	+ 12	- 4	+ 1	+ 7	+ 13	0	+ 18

Table. 5. - Distribution of Percentage Error of Tables 2,3 and 4

PERCENTAGE ERROR	FREQUENCY OF OCCURENCE, %					
	Δ H			P_{cc}	$\sum V$	Q
(1)	(2)	(3)	(4)	(5)	(6)	(7)
% Error > 30	3	10	16	5	0	3
30 ≥ % Error > 20	13	10	18	18	0	21
20 ≥ % Error > 10	18	40	32	47	0	29
10 ≥ % Error ≥ 0	66	40	34	30	100	47

(2), (3), (4) designate the cases when β is taken as 0.5, 0.55 and 0.6 respectively.

Table . 6 . - Column and Spandrel Beam Sectional Properties for Frame - Tube in Fig. 13

Floor	Column		Spandrel Beam		S.F.
	Area in^2	M.of I. in^4	Area in^2	M.of I. in^4	
(1)	(2)	(3)	(4)	(5)	(6)
1 - 5	972	462000	1455	452000	0.530
6 - 10	810	447000	1200	372000	0.525
11 - 15	810	447000	1200	372000	0.525
15 - 20	810	447000	1200	372000	0.525
21 - 25	717	400000	1058	330000	0.525
26 - 30	615	363000	940	282000	0.520
31 - 35	615	363000	940	282000	0.520
36 - 40	510	307000	754	234000	0.520
41 - 45	510	307000	754	234000	0.520
46 - 50	510	307000	754	234000	0.520

No.of stories=50

Story height = 13 ft.

Wind Load = 1 Kip /ft/ column

Table. 7. - Comparison between Results of KHAN and AMIN and the Proposed Method with the 'Actual' Solution

Column Axial Forces (Kips) in Normal Panel in the Lowest Story				Proposed Method / Actual
Col. location (1)	KHAN (2)	Actual (3)	Proposed (4)	(5)
0	1660	1583	1657	1.047
1	1530	1426	1524	1.069
2	1280	1237	1398	1.130
3	1150	1100	1281	1.165
4	1020	1001	1169	1.168
5	900	929	1067	1.149
6	830	877	974	1.111
7	830	841	893	1.062
8	830	818	827	1.011
9	795	806	787	0.976

Table. 7. - (Continue)

Sum of Shear Forces in Spandrel beam (Kips) in the First 5 Stories				Proposed Method / Actual
Beam Location (1)	KHAN (2)	Actual (3)	Proposed (4)	(5)
1	2340	1954	2313	1.184
2	2620	2257	2570	1.139
3	2750	2450	2768	1.129
4	2810	2565	2914	1.136
5	2850	2640	3013	1.141
6	2850	2690	3048	1.133
7	2850	2700	3065	1.135

Lateral Displacement at Top (inch)					Proposed Method		
KHAN	Actual	Proposed			Actual		
(1)	(2)	$(3)^a$	$(4)^b$	$(5)^c$	$(6)^a$	$(7)^b$	$(8)^c$
12.49	11.51	9.16	9.81	10.83	0.80	0.86	0.94

a,b,c

Designate the cases when β is taken as 0.5, 0.55 and 0.6, respectively

Note : The actual solutions are obtained from the computer analysis (1).

Appendix

Minimization of the Total Potential Energy by means of the Ritz method

$$\text{Assume} \qquad \Delta(z) = Az^2 + Bz \tag{33a}$$

$$\frac{d\Delta}{dz} = 2Az + B \tag{33b}$$

Substituting Eq. (33b) into the total strain energy equation, Eq. (24), leads to

$$U_s = \tfrac{1}{2}\, 2 \sum_{j=1}^{M} K_{sj} \int_0^H \Big\{ (2Az + B)^2 - 4\beta k_{cj} \frac{(N-1)}{D\phi} P_o \left(H^2 z - Hz^2 + \frac{z^3}{3}\right)$$

$$- \frac{8}{3}\beta k_{cj} \frac{(N-1)}{D\phi} P_H \left(H^2 z - Hz^2 + \frac{z^3}{3}\right)$$

$$- \frac{4}{3}\beta k_{cj} \frac{(N-1)}{D\phi} P_H \left(\frac{Hz^2}{2} - \frac{2}{3} z^3 + \frac{z^4}{4H}\right)$$

$$+ \text{ terms which are not functions of A and B} \Big\} dz \tag{34a}$$

$$= \tfrac{1}{2} K_s \left(\frac{4}{3} A^2 H^3 + 2ABH^2 + B^2 H\right) - 2\beta \frac{(N-1)}{D\phi} K_s^* P_o \left(\frac{3}{10} AH^5 + \frac{BH^4}{4}\right)$$

$$- \frac{4}{3}\beta \frac{(N-1)}{D\phi} K_s^* P_H \left(\frac{3}{10} AH^5 + \frac{BH^4}{4}\right) - \frac{2}{3}\beta \frac{(N-1)}{D\phi} K_s^* P_H \left(\frac{AH^5}{15} + \frac{BH^4}{20}\right) \tag{34b}$$

The total potential energy of the external load is

$$U_L = -(N-1) \int_0^H \left(P_o + \frac{2}{3} P_H + \frac{z}{3H} P_H\right)(Az^2 + Bz)\, dz \tag{35a}$$

$$= -\frac{1}{3} A (N-1) P_o H^3 - \frac{1}{2} B (N-1) P_o H^2 - \frac{2}{9} A (N-1) P_H H^3$$

$$- \frac{1}{3} B (N-1) P_H H^2 - \frac{1}{12} A \frac{(N-1)}{H} P_H H^4 - \frac{1}{9} B \frac{(N-1)}{H} P_H H^3 \tag{35b}$$

The undetermined weights A and B are determined from the conditions

$\frac{\partial \Pi}{\partial A} = 0$ and $\frac{\partial \Pi}{\partial B} = 0$: Thus

$$\frac{4}{3} K_s A H^3 + K_s B H^2 - \frac{3}{5} \beta \frac{(N-1)}{D \phi} K_s^* P_o H^5 - \frac{4}{9} \beta \frac{(N-1)}{D \phi} K_s^* P_H H^5$$

$$- \frac{(N-1)}{3} P_o H^3 - \frac{11}{36} (N-1) P_H H^3 = 0 \qquad (36a)$$

$$K_s A H^2 + K_s B H - \beta \frac{(N-1)}{2D \phi} K_s^* P_o H^4 - \frac{11}{30} \beta \frac{(N-1)}{D \phi} K_s^* P_H H^4$$

$$- \frac{(N-1)}{2} P_o H^2 - \frac{4}{9} (N-1) P_H H^2 = 0 \qquad (36b)$$

from which we obtain the solutions for A and B as given in Eqs. (28a) and (28b).

VITA

Mr. Suthum Watanavong acquired Bachelor's Degree in Engineering from Chiengmai University in 1975.