CHAPTER III

VERIFICATION OF PROPOSED CONFINEMENT MODELS

3.1 Stress-strain Relationship for Confined Concrete

To verify the validity of the method proposed, we first examine the accuracy in predicting the axial strains in perimeter ties of the column specimens tested by Sun et al (1996). Table 3.1 lists the details of the test specimens. It is to be noted that the specimens were reinforced with high-strength steel ties. The predicted values of the axial strains normalized to the yield strain of the hoop are plotted as functions of the volumetric ratio, ρ_h, in Figure 3.1, together with the experimental results. It is seen that, for columns confined with 10-mm diameter ties, the numerical and experimental values agree reasonably well, with a discrepancy around 10-30% in general. For columns with 6-mm ties, the agreements are poor. It should be observed, however, that while the experimental method may be susceptible to error due to difficulty in measuring strains in hoops, the analytical approach can be more consistent in predicting the trend of influencing parameters. This can be seen by comparing the test results of Specimens HB6-70 and HB10-80, both having the same column sections and tie configurations. The former was confined by 6-mm diameter transverse steel at 70 mm spacing with a volumetric ratio of 1.70%, while the latter specimen was reinforced with 10-mm diameter ties at 80 mm spacing, resulting in a volumetric ratio about twice that of Specimen HB6-70. The proposed analytical method predicts strains in perimeter ties of Specimen HB10-80 higher than those of Specimen HB6-70 by 38%, consistent with previous findings that suggest a higher stress in the transverse reinforcement in a column with more confinement steel [Cusson and Paultre (1995) and Razvi and Saatcioglu (1999)]. On the other hand, the experimental results for these two specimens failed to reflect this fact (refer to Figure 3.1). Furthermore, at a given volumetric ratio, a tie configuration which results in a higher hoop stiffness, as indicated by a higher value of the ratio of the hoop diameter d_h to the unsupported length L_s, should give rise to a larger axial strain in the hoop. Again, this is nicely reflected in the analytical results shown in Figure 3.1.

The axial strains in the ties are related to the effective confinement pressure. Therefore, it is interesting to compare the effective confinement pressures predicted by Razvi and Saatcioglu (1999), $\sigma_{eff,RS}$, and the present study, $\sigma_{eff,prop}$. Tables 3.2-3.4 list the relevant details of the specimens considered for comparison, which cover both normal- and high-strength concrete and various tie configurations. Typical arrangements of the transverse steel are shown in Figure 3.2. The unconfined concrete strength and the yield strength of transverse steel ranged from 50 to 105 MPa and 400 to 1400 MPa, respectively. The values of the effective confinement pressure are plotted in Figure 3.3 together with the best fit curve which is given by

$$\sigma_{eff,prop} = 0.9853\sigma_{eff,RS} \tag{3.1}$$

with the goodness-of-fit index R^2 of 0.72.

The predicted peak confined strengths of the above specimens and the specimens tested by sheikh (1980) are compared with the experimental results in Figure 3.4. The details of the reinforced concrete columns tested by Sheikh and Uzumeri (1980) are given in Table 3.5. Good agreement is observed with maximum difference between experimental and analytical results about 15%. Finally, samples of stress-strain relationships for both normal- and high-strength concrete columns confined by normal- or high-strength transverse steel are presented in Figures 3.5-3.9. Samples of calculation for determining the peak confined compressive strength of the selected columns are given in Appendix B. It should be noted that the descending branches of the stress-strain curves can be fairly predicted by using the proposed procedure.

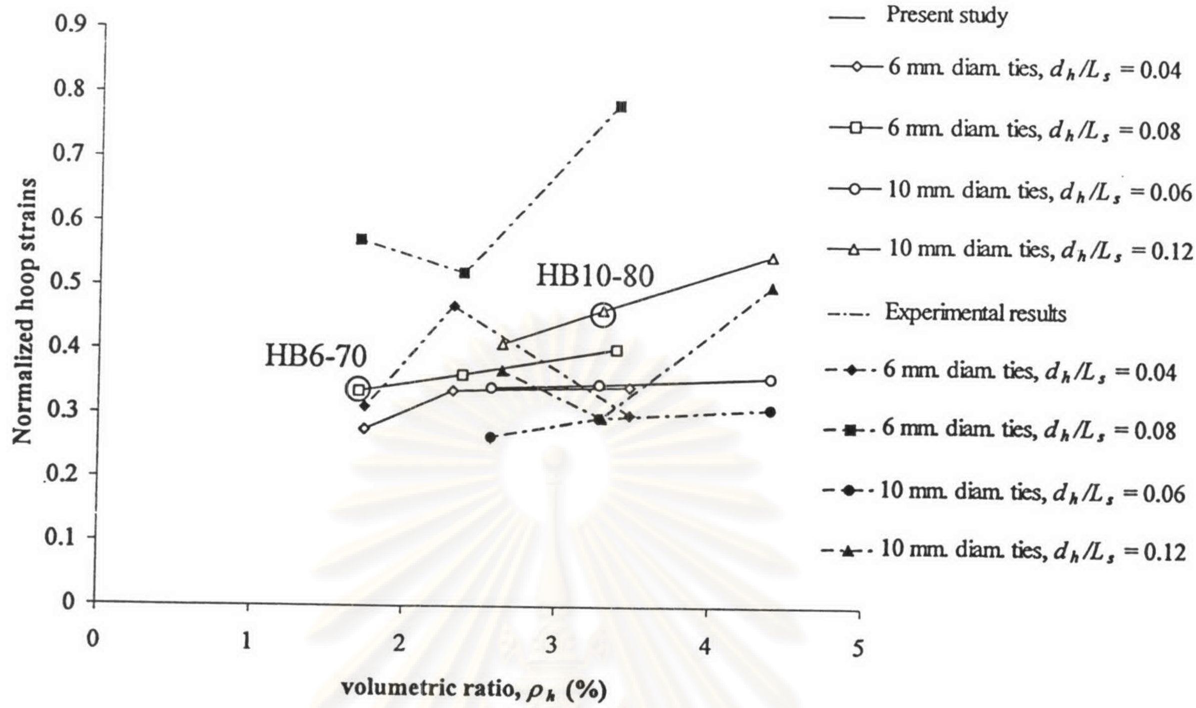
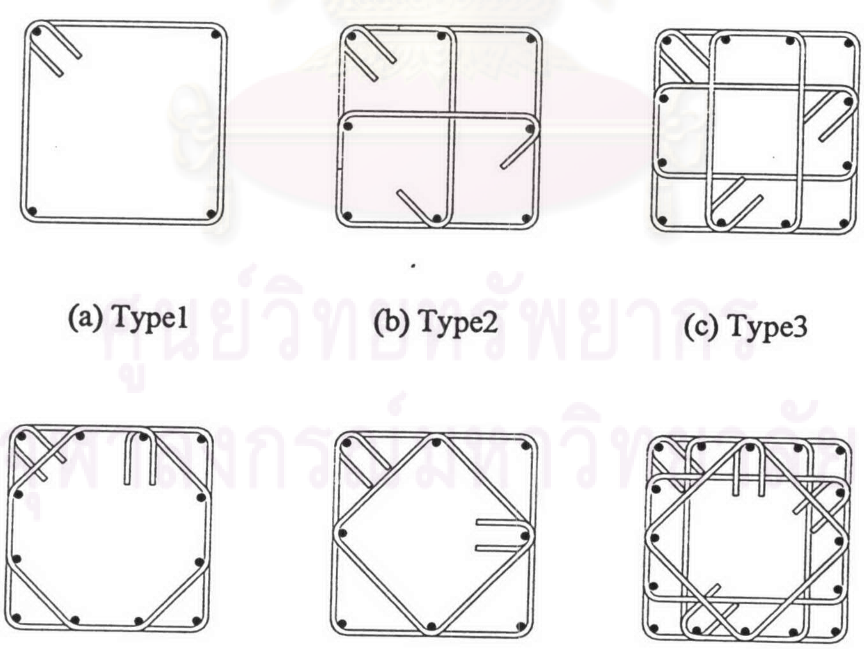


Figure 3.1 Variation of normalized hoop strains with volumetric ratios



(a) Type1 (b) Type2 (c) Type3

(d) Type4 (e) Type5 (f) Type6

Figure 3.2 Typical arrangements of transverse steel

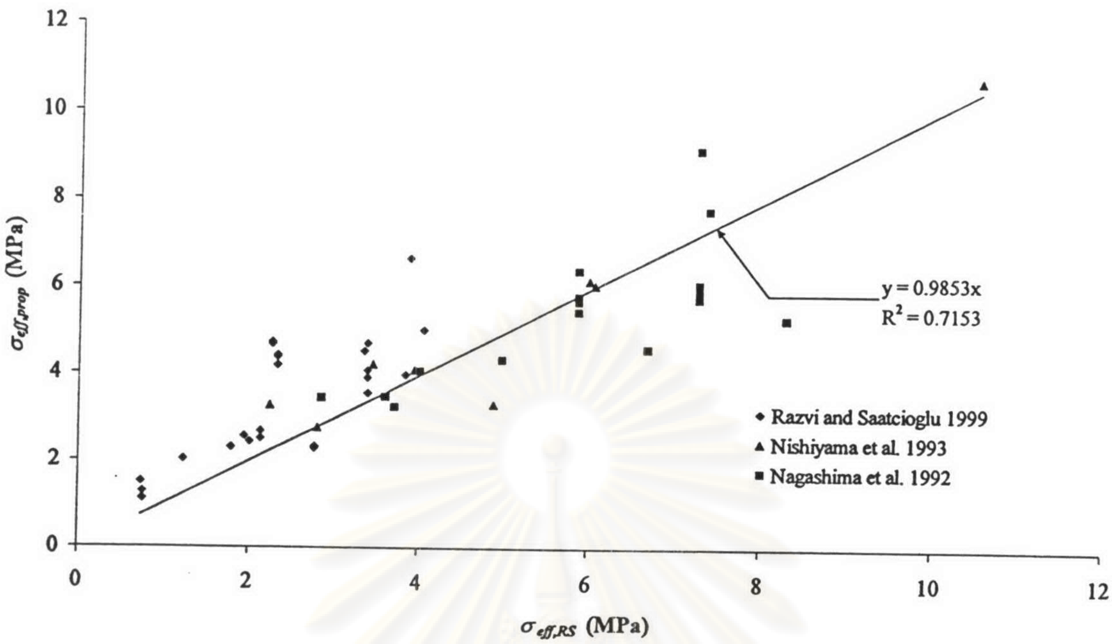


Figure 3.3 Comparison of $\sigma_{eff,prop}$ with $\sigma_{eff,RS}$

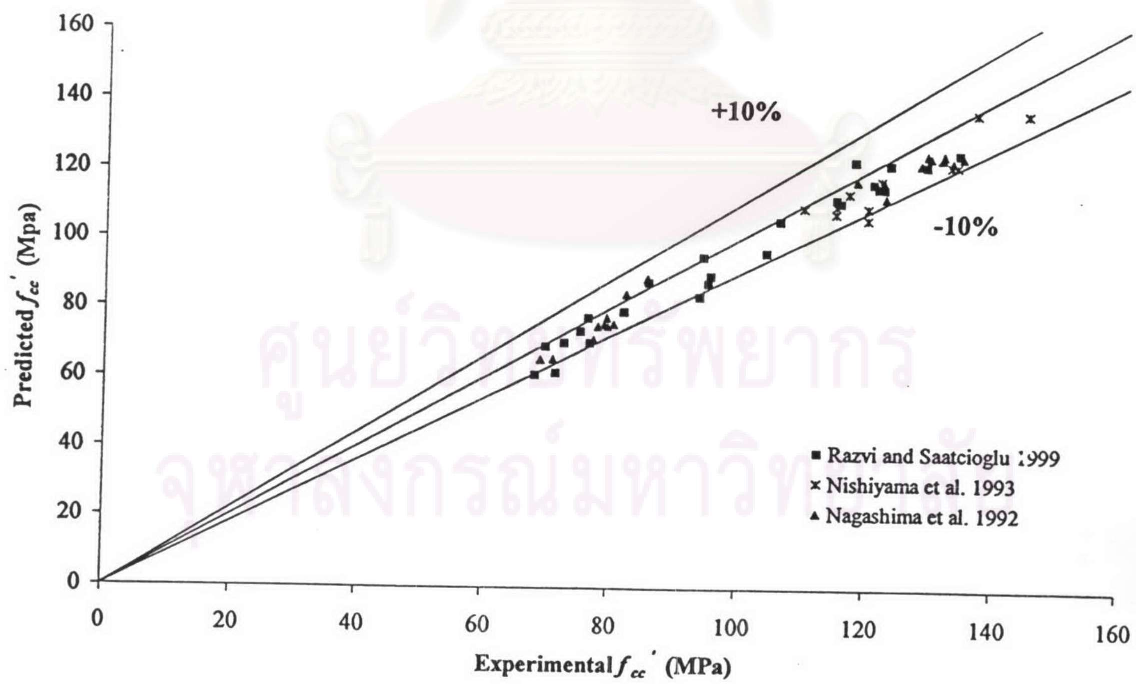


Figure 3.4 Comparison of predicted confined compressive strength with experimental results

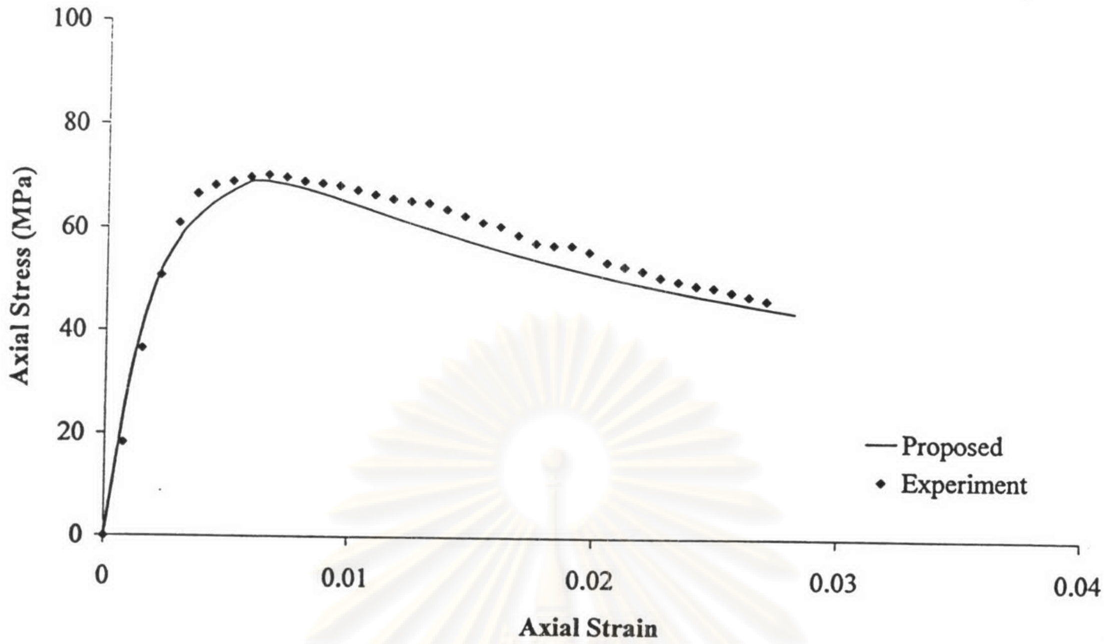


Figure 3.5 Stress-strain relationship for column CS-24 [Razvi and Saatcioglu (1999)]

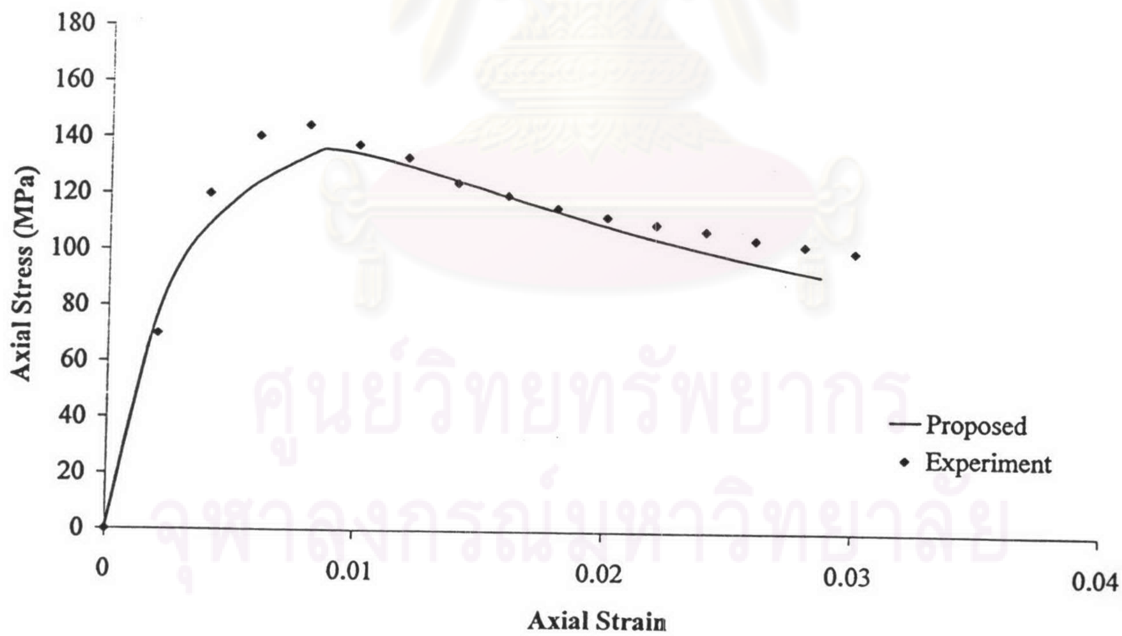


Figure 3.6 Stress-strain relationship for column Unit 3 [Nishiyama et al. (1993)]

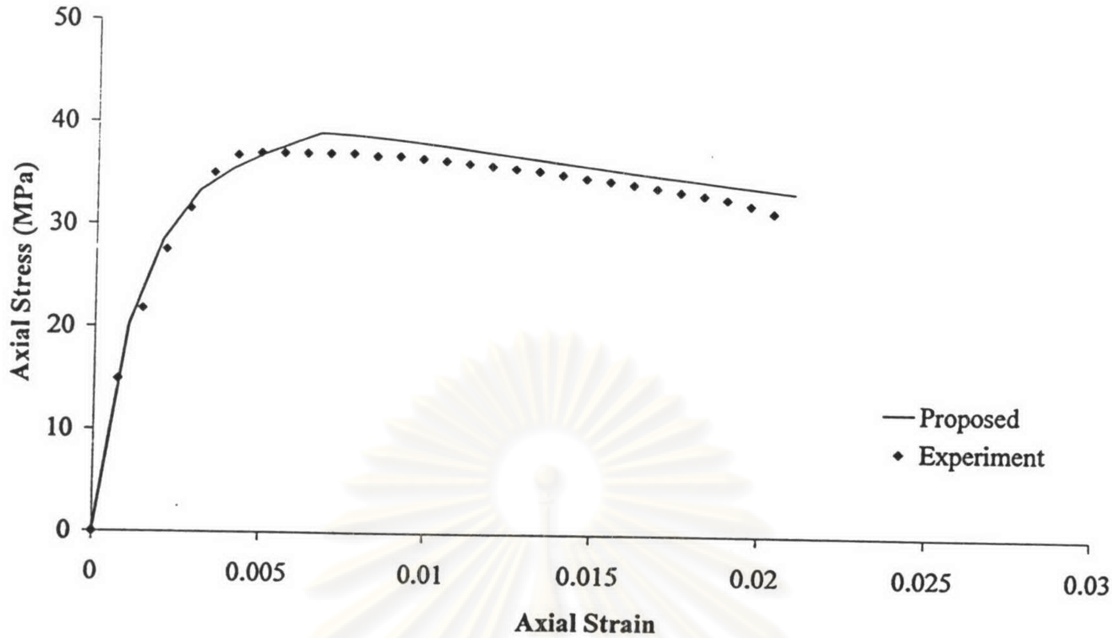


Figure 3.7 Stress-strain relationship for column 2A5-14 [Sheikh and Uzumeri (1980)]

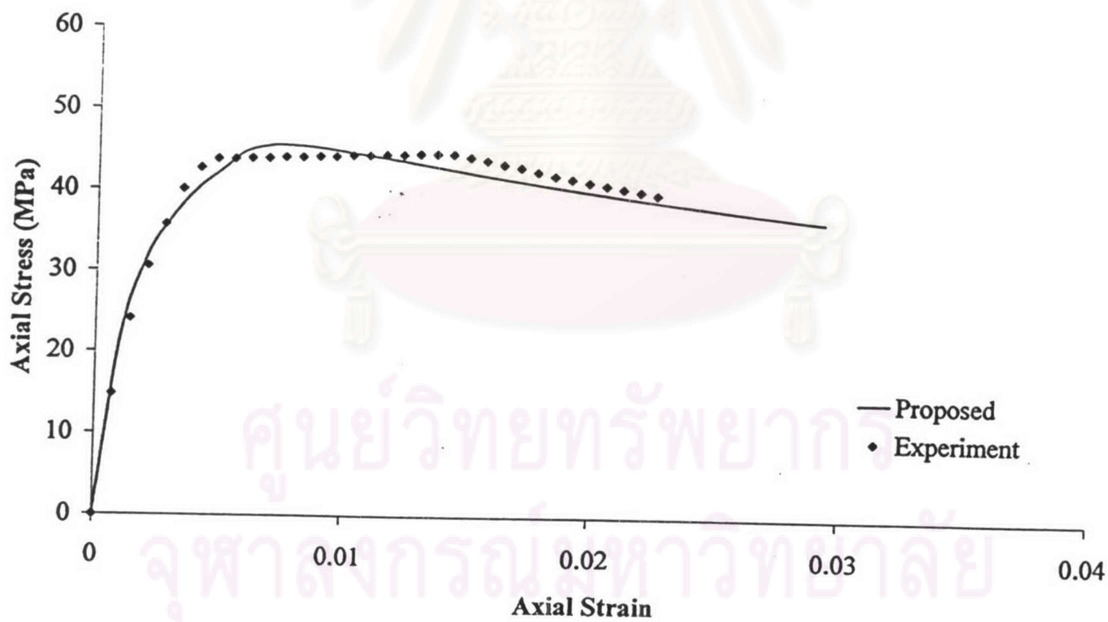


Figure 3.8 Stress-strain relationship for column 4B6-21 [Sheikh and Uzumeri (1980)]

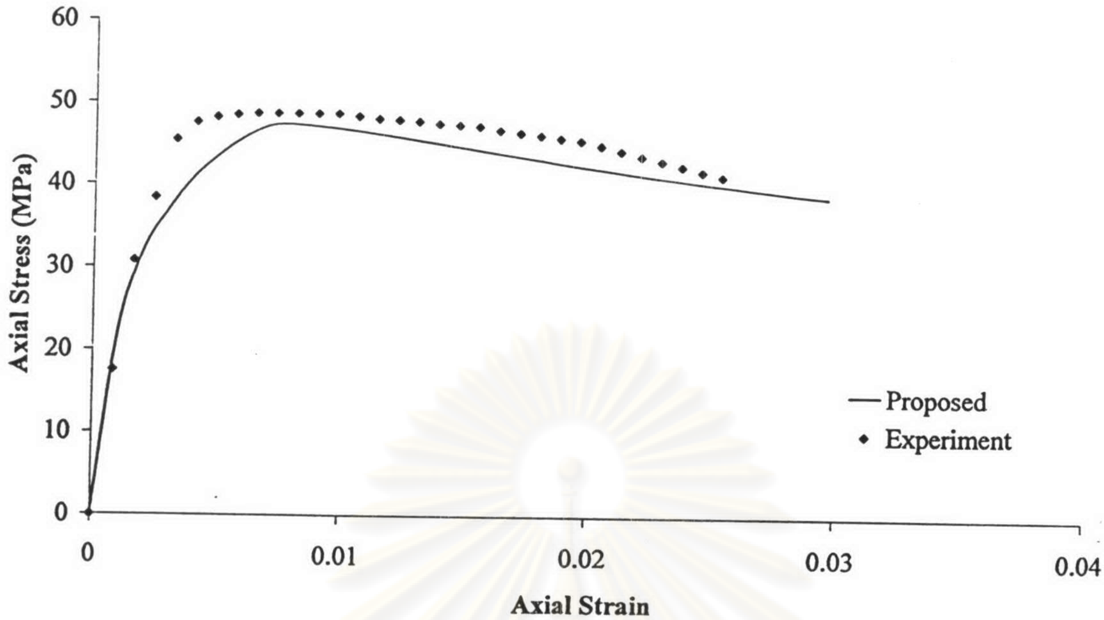


Figure 3.9 Stress-strain relationship for column 4D6-24 [Sheikh and Uzumeri (1980)]

Table 3.1 Strength enhancement in square columns tested by Sun et al. (1996)

Column label (1)	ρ_h (%) (2)	Tie configuration (3)	B_c (mm) (4)	d_h (mm) (5)	s (mm) (6)	f_{yh} (MPa) (7)	f_{co}' (MPa) (8)	f_{cc}' (MPa) Experimental (9)	f_{cc}' (MPa) Analytical (10)	Analytical/ experimental (11)
HA6-20	3.48	Type A	162	6.4	20	1025	43.8	62.7	68.7	1.10
HA6-30	2.32	Type A	162	6.4	30	1025	43.8	58.4	60.2	1.03
HA6-40	1.74	Type A	162	6.4	40	1025	43.8	55.1	53.9	0.98
HB6-35	3.39	Type B	162	6.4	35	1025	43.8	72.4	77.3	1.07
HB6-50	2.38	Type B	162	6.4	50	1025	43.8	67.9	65.0	0.96
HB6-70	1.70	Type B	162	6.4	70	1025	43.8	58.7	58.0	0.99
HA10-35	4.40	Type A	158	9.6	35	872	45.6	69.8	73.7	1.06
HA10-47	3.28	Type A	158	9.6	47	872	45.6	66.4	65.9	0.99
HA10-60	2.57	Type A	158	9.6	60	872	45.6	65.8	61.3	0.93
HB10-60	4.40	Type B	158	9.6	60	872	44.2	84.5	93.4	1.10
HB10-80	3.30	Type B	158	9.6	80	872	44.2	73.1	76.0	1.04
HB10-100	2.64	Type B	158	9.6	100	872	44.2	67.3	66.7	0.99

Note : Type A consists of perimeter ties only; Type B consists of perimeter and inner ties.

Table 3.2 Strength enhancement in square columns tested by Razvi and Saatcioglu (1999)

Column label (1)	ρ_h (%) (2)	Tie configuration (3)	B_c (mm) (4)	d_h (mm) (5)	s (mm) (6)	f_{yh} (MPa) (7)	f_{co}' (MPa) (8)	f_{cc}' (MPa) Experimental (9)	f_{cc}' (MPa) Analytical (10)	Analytical/ experimental (11)
CS-1	3.33	type 1	218.7	11.3	55	400	105.4	120.8	116.3	0.96
CS-2	1.62	type 2	223.5	6.5	55	570	105.4	121.6	114.9	0.94
CS-3	2.16	type 3	223.5	6.5	55	570	105.4	129.1	121.4	0.94
CS-4	2.17	type 2	222.5	7.5	55	1000	105.4	123.4	121.7	0.99
CS-5	1.32	type 3	222.5	7.5	120	1000	105.4	122.5	114.8	0.94
CS-6	1.05	type 2	223.5	6.5	85	400	105.4	115.7	110.6	0.96
CS-7	0.99	type 3	223.5	6.5	120	400	105.4	115.0	111.5	0.97
CS-8	3.23	type 2	218.7	11.3	85	400	105.4	117.8	122.5	1.04
CS-9	3.06	type 3	218.7	11.3	120	400	105.4	134.2	124.7	0.93
CS-11	4.58	type 1	218.7	11.3	40	400	68.9	93.9	83.4	0.89
CS-12	3.33	type 1	218.7	11.3	55	400	68.9	82.1	79.1	0.96
CS-13	1.62	type 2	223.5	6.5	55	570	78.2	85.9	87.6	1.02
CS-14	2.16	type 3	223.5	6.5	55	570	78.2	94.3	94.9	1.01
CS-15	2.17	type 2	222.5	7.5	55	1000	68.9	95.5	89.3	0.94
CS-16	1.87	type 3	222.5	7.5	85	1000	68.9	95.2	87.4	0.92
CS-17	1.05	type 2	223.5	6.5	85	400	68.9	75.2	73.5	0.98
CS-18	1.4	type 3	223.5	6.5	85	400	68.9	76.4	77.2	1.01
CS-19	3.23	type 2	218.7	11.3	85	400	78.2	104.2	96.1	0.92
CS-20	4.32	type 3	218.7	11.3	85	400	78.2	106.3	105.4	0.99
CS-22	1.4	type 2	222.5	7.5	85	1000	51.0	68.0	61.0	0.90
CS-23	1.32	type 3	222.5	7.5	120	1000	51.0	71.3	61.5	0.86
CS-24	3.23	type 2	218.7	11.3	85	400	51.0	69.7	69.1	0.99
CS-25	3.06	type 3	218.7	11.3	120	400	51.0	72.6	70.1	0.97
CS-26	2.16	type 3	223.5	6.5	55	570	51.0	76.7	70.2	0.92

Table 3.3 Strength enhancement in square columns tested by Nishiyama et al. (1993)

Column label (1)	ρ_h (%) (2)	Tie configuration (3)	B_c (mm) (4)	d_h (mm) (5)	s (mm) (6)	f_{yh} (MPa) (7)	f_{co}' (MPa) (8)	f_{cc}' (MPa) Experimental (9)	f_{cc}' (MPa) Analytical (10)	Analytical/ experimental (11)
Unit-1	4.06	Type 3	214	6	31	813	92.4	145.0	135.5	0.93
Unit-2	4.06	Type 3	214	6	31	813	92.4	137.0	135.5	0.99
Unit-3	4.06	Type 3	214	6	31	813	92.4	145.0	135.5	0.93
Unit-4	2.78	Type 3	214	6	45	813	92.4	122.0	117.1	0.96
Unit-5	2.10	Type 3	214	6	60	813	92.4	120.0	109.1	0.91
Unit-6	2.10	Type 3	214	6	60	813	92.4	110.0	109.1	0.99
Unit-7	2.10	Type 3	214	6	60	813	92.4	120.0	109.1	0.91
Unit-8	1.78	Type 3	216	4	31	840	92.4	120.0	105.9	0.88
Unit-9	4.06	Type 3	214	6	31	462	96.2	134.0	120.9	0.90
Unit-10	4.06	Type 3	214	6	31	462	96.2	133.0	120.9	0.91
Unit-11	2.78	Type 3	214	6	45	462	96.2	117.0	113.4	0.97
Unit-12	2.10	Type 3	214	6	60	462	96.2	115.0	109.6	0.95
Unit-13	2.10	Type 3	214	6	60	462	96.2	115.0	109.6	0.95
Unit-14	1.78	Type 3	216	4	31	481	96.2	115.0	107.5	0.93

Table 3.4 Strength enhancement in square columns tested by Nagashima et al. (1992)

Column label (1)	ρ_h (%) (2)	Tie configuration (3)	B_c (mm) (4)	d_h (mm) (5)	s (mm) (6)	f_{yh} (MPa) (7)	f_{co}' (MPa) (8)	f_{cc}' (MPa) Experimental (9)	f_{cc}' (MPa) Analytical (10)	Analytical/ experimental (11)
HH08LA	1.73	Type 3	199.9	5.1	55	1387	98.8	122.8	112.0	0.91
HH10LA	2.12	Type 3	199.9	5.1	45	1387	98.8	122.5	116.5	0.95
HH13LA	2.73	Type 3	199.9	5.1	35	1387	98.8	131.5	123.6	0.94
HL06LA	2.03	Type 3	200	5	45	807	100.4	118.2	117.0	0.99
HL08LA	2.62	Type 3	200	5	35	807	100.4	133.2	122.6	0.92
LL05LA	1.67	Type 3	200	5	55	807	51.3	68.9	65.4	0.95
LL08LA	2.62	Type 3	200	5	35	807	51.3	79.4	77.3	0.97
LH08LA	1.73	Type 3	199.9	5.1	55	1387	51.3	70.9	65.5	0.92
LH13LA	2.73	Type 3	199.9	5.1	35	1387	51.3	85.7	88.6	1.03
HH13MA	2.73	Type 3	199.9	5.1	35	1387	100.4	131.8	124.5	0.94
HH13HA	2.73	Type 3	199.9	5.1	35	1387	100.4	129.2	124.5	0.96
LL08MA	2.62	Type 3	200	5	35	807	51.3	79.6	74.9	0.94
LL08HA	2.62	Type 3	200	5	35	807	51.3	78.0	74.9	0.96
HH13LD	2.45	Type 2	199.9	5.1	25	1387	100.4	128.2	121.9	0.95
LL08LB	3.39	Type 3	200	5	27	807	52.4	82.4	84.1	1.02
LL08LD	2.36	Type 2	200	5	25	807	52.4	77.3	71.1	0.92
HH13MSA	2.73	Type 3	199.9	5.1	35	1387	100.4	129.7	123.8	0.95
HH13HSA	2.73	Type 3	199.9	5.1	35	1387	100.4	134.8	123.8	0.92
LL08MSA	2.62	Type 3	200	5	35	807	52.4	79.0	75.5	0.96
LL08HSA	2.62	Type 3	200	5	35	807	52.4	80.5	75.5	0.94

Table 3.5 Strength enhancement in square columns tested by Sheikh and Uzumeri (1980)

Column label (1)	ρ_t (%) (2)	Tie configuration (3)	B_c (mm) (4)	d_h (mm) (5)	s (mm) (6)	f_{yh} (MPa) (7)	f_{co}' (MPa) (8)	f_{cc}'/f_{co}' Experimental (9)	f_{cc}'/f_{co}' Analytical (10)	Analytical/ experimental (11)
2A1-1	0.80	Type 5	267	4.76	57.2	490	31.9	1.18	1.11	0.94
2A1H-2	0.80	Type 5	267	4.76	57.2	269	31.5	1.26	1.07	0.85
4A3-7	1.66	Type 5	267	7.94	75.0	507	34.7	1.28	1.23	0.96
4A4-8	1.59	Type 5	267	4.76	28.7	533	34.7	1.36	1.22	0.90
4A5-9	2.39	Type 5	267	9.53	75.0	364	34.4	1.23	1.32	1.07
4A6-10	2.32	Type 5	267	6.35	35.0	470	34.5	1.31	1.31	1.00
2A5-14	2.39	Type 5	267	9.53	75.0	450	26.6	1.38	1.46	1.06
2A6-15	2.32	Type 5	267	6.35	35.0	490	26.6	1.47	1.43	0.97
4A1-13	0.80	Type 5	267	4.76	57.0	533	26.6	1.30	1.14	0.87
4C1-3	0.76	Type 6	267	3.18	50.0	571	30.9	1.21	1.16	0.96
4C6-5	2.27	Type 6	267	4.76	38.1	490	29.7	1.64	1.53	0.93
4C6-H6	2.27	Type 6	267	4.76	38.1	269	29.2	1.53	1.30	0.85
4C3-11	1.62	Type 6	267	6.35	95.0	470	34.5	1.27	1.29	1.02
4C4-12	1.52	Type 6	267	3.18	25.4	723	34.5	1.46	1.35	0.93
2C1-16	0.76	Type 6	267	3.18	50.0	767	27.6	1.36	1.20	0.88
4C1H-4	0.76	Type 6	267	3.18	50.0	288	31.1	1.20	1.11	0.92
2C5-17	2.37	Type 6	267	7.94	100.0	470	28.0	1.36	1.53	1.12
2C6-18	2.27	Type 6	267	4.76	38.1	533	27.6	1.70	1.64	0.96
4B3-19	1.80	Type 3	267	7.94	100.0	470	28.4	1.43	1.38	0.96
4B4-20	1.70	Type 3	267	4.76	38.1	526	29.4	1.52	1.38	0.91
4B6-21	2.40	Type 3	267	6.35	47.7	490	30.2	1.54	1.51	0.98
4D3-22	1.60	Type 4	267	7.94	82.5	470	30.2	1.44	1.38	0.96
4D4-23	1.70	Type 4	267	4.76	28.7	526	30.4	1.54	1.41	0.92
4D6-24	2.30	Type 4	267	6.35	38.1	490	30.4	1.63	1.55	0.95