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STRESS-STRAIN BEHAVIOR OF SQUARE CONFINED CONCRETE COLUMN

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SUMMARY

The object of this study is to investigate the possibility of improving of square reinforced concrete with lateral reinforcement. Axial loading tests on four units of reinforced concrete columns with square core cross section (272x272x632 mm), and on one unit of plain concrete column with same cross section were carried out. The specimens were made of ordinary-strength concrete with compressive strength of 35 N/mm^2. The confined specimen were confined with ultra-high-strength steel reinforcement with yield strength of 1430 N/mm^2 as lateral reinforcement and with ordinary-strength steel reinforcement with yield strength of 404 N/mm^2 as longitudinal reinforcement. The configurations of lateral reinforcement were two types. One was assembled by a multi-spiral (a one-way steel reinforcement without breaks or welding) (type A) and another was assembled by a multi-spiral and intermediate tie reinforcement (type B). The test parameters included arrangement, spacing, and volumetric ratio of confinement reinforcement. Stress-strain relationships of core concrete ware extracted from the obtained load-deformation curves by using a stress-strain idealization of longitudinal reinforcement. The longitudinal stress-strain behavior was studied with respect to the effect of the intermediate lateral ties, the spacing of lateral reinforcement, the buckling of longitudinal reinforcement. In compression between longitudinal stress-strain curve of the specimens with configuration type A and that of the specimens with configuration type B, expected general improvements in the strength and ductility of the core concrete with configuration type B was observed. Test results indicated that the lateral reinforcement located near the perimeter of the cross section was not as effective as that located at the center of the cross section, and that the buckling of longitudinal reinforcement was a significant factor on the strength and ductility of the core concrete.

INTRODUCTION

It is generally accepted that the strength and ductility of reinforced concrete column can be improved through confinement of the plastic hinge regions. This improvement ensures seismic stability of the structure during a strong earthquake. Therefore, column confinement is an important component of earthquake resistant reinforced-concrete buildings. The characteristics of confined concrete have been researched extensively, and the primary parameters of confinement have been identified both experimentally and analytically. Analytical models have been developed, usually on the basics of a specific set of test data. These models, although producing good predictions in many applications, have limitations in terms of cross-sectional shape and reinforcement arrangement. Therefor the confinement effect of lateral reinforcement , perimeter hoops and intermediate tie bars, is not obvious. The research described in this paper was an experimental investigation of the confinement effect of intermediate tie bars.

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TEST PROGRAM

Description Of Test Unit

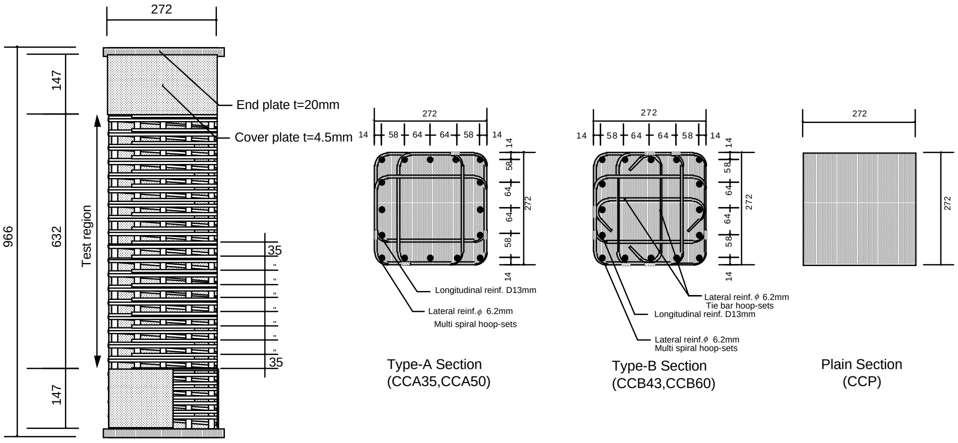
The parameters investigated were

(1) configurations (type A or type B) of lateral reinforcement,

(2) spacing (35 , 43 , 50 or 60 mm) of lateral reinforcement,

(3) volumetric ratio (2.60 or 1.80 %) of lateral reinforcement.

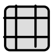
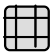
Four reinforced concrete columns and one plain concrete column with a square cross section shown in Fig.1 were cast vertically. Normal strength concrete with specified compressive strength of 35 N/mm^2 was used. The specifications of the test units are summarized in Table 1 The height was 966 mm including the bearing steel on top and bottom of the test units. Two different configurations were used for the lateral reinforcement with yield strength of 1430 N/mm^2. The diameter and cross sectional area of each longitudinal bars were 6.2 mm and 30 mm^2, respectively. Sixteen longitudinal bars with yield strength of 404 N/mm^2. The diameter and cross sectional area of each longitudinal bars were 13 mm and 127 mm^2, respectively.



Type-A Elevatin (CCA35)

Figure 1: Details of Test Specimens

Table 2: Mechanical properties of steel

Specimen	Concrete		Longitudinal reinforcement			Lateral reinforcement						
	f'c N/mm^2	Ei kN/mm^2	Number and size	Pg %	σ_{sy} N/mm^2	Section	Number and size	s mm	ps %	σ_{wy} N/mm^2	psσ_{wy} N/mm^2	dc,bc mm
CCA35	32.9	28.6	16-D13	2.87	4040		4-ϕ 6.2	35	2.60	1431	37.2	265.6
CCA50								50	1.80		25.8	
CCB43							5-ϕ 6.2	43	2.60		37.2	
CCB60								60	1.80		25.8	
CCP												272

f'c, Ei : compressive strength of elastic modulus of concrete cylinder
Pg: Steel ratio
σ_{sy}: Yield strength of longitudinal reinforcement
s: Spacing of lateral reinforcement
p_s: Volumetric ratio of lateral reinforcement
σ_{wy}: Yield strength of lateral reinforcement
dc,bc: Length of a side of core concrete section

The mechanical properties of the steel are summarized in Table 2. The top steel plates were attached by high-strength mortar after concrete hardened, and were welded with the both end of the longitudinal bars in the case of the reinforced concrete columns. Thus, axial compressive load was transferred directly to both concrete and longitudinal bars during loading. The region other than the test part, the both end of the test units, was confined by the steel plate with thickness of 4.5 mm in order to prevent from failure.

The mix proportion of concrete was:

Ordinary Portland cement	....	427	kg/m^3
Water	....	175	kg/m^3
Fine aggregate	....	808	kg/m^3
Coarse aggregate (Gmax 10 mm)	....	906	kg/m^3
Super plasticizer	....	6.83	kg/m^3
Water cement ratio	....	0.41	

The compressive strength had reached f'c= 32.9 N/mm^2 at the age of 30 days. The mechanical properties of the concrete are summarized in Table 3.

Table 2: Mechanical properties of steel

Size	Test series	Yield strength σ_y(N/mm^2)	Yield stress ε_y (*10^{-3})	Tensile strength σ_{su}(N/mm^2)
D13 (SD295A)	1	400	2.24	182
	2	410	2.09	200
	3	403	2.16	186
Average		404	2.16	187
ϕ 6.2 SPD1275/ 1420	1	1417	7.60	1503
	2	1439	7.51	1466
	3	1435	7.56	1499
Average		1430	7.56	1489

Table 3: Mechanical properties of concrete

Test series	Test age days	Compressive strength σ_B(N/mm^2)	Strain at peak strength ε_{co} (*10^{-3})	Elastic modulus* E_i (kN/mm^2)
1	30	32.6	1.79	31.0
2		33.8	1.94	26.7
3		32.1	1.77	28.1
Average		32.9	1.83	28.6

Elastic modulus* : Secant modulus at the stress of one-third of compressive strength

Test Procedures

Monotonic axial compression was applied up to failure by a universal test machine with 10000 kN capacity. During loading the machine head plate was fixed in order to keep the loading direction.
Two linear variable displacement transducers were used to measure the concrete axial strain over the middle section of specimen. The gage length was 632 mm (two times length of the depth (316 mm) of assumed column section) . The displacement transducers were attached to the surface of the test units via pin devises as shown in Fig. 2 .The strains in the longitudinal and lateral bars were measured using wire strain gages, are shown in Fig . 3 .

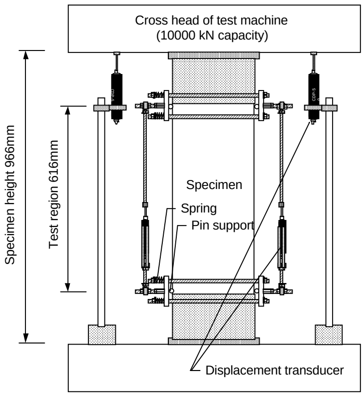
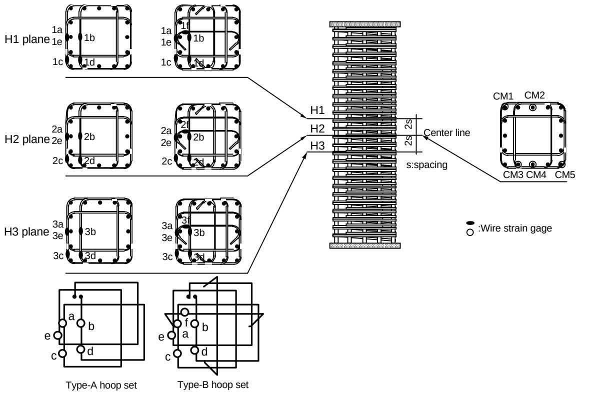


Figure 2: Loading setup and measuring devices



Location of wire strain gage on lateral reinforcement

Location of wire strain gage on longitudinal reinforcement

Figure 3: Strain gages on steel reinforcement

TEST RESULTS

General behavior of test units

Table 4 gives relevant test results and Fig. 4 shows final appearance of specimens. Stress-strain curves of confined concrete were extracted from the load-strain curves obtained experimentally by using stress-strain idealization of the longitudinal bars. In doing so it was assumed that the strain in the concrete is equal to the strain in the longitudinal and the strain is uniform over the gage length. For most specimens, the following events were observed during loading:

(1) yielding of longitudinal reinforcement (YL point in time),(2) yielding of lateral reinforcement (YH point in time),(3) buckling of longitudinal reinforcement (BL point in time),(4) peak of strength of the specimen (PS point in time),(5) fracturing of lateral reinforcement (FL point in time).

Fig. 5 shows each point of specimens indicated on stress-strain relationships obtained from the test. Yielding of longitudinal reinforcement was observed at a axial strain of approximately 0.15%-0.20%, before the first reduction in stiffness and strength, yielding of lateral reinforcement was observed until the strength reached to the peak, in all confined specimens. in unit type A (CCA35, CCA50) and type B (CCB43, CCB60), buckling of longitudinal reinforcement was occurred at the peak strength, and after the peak strength, respectively. The significant reduction in stiffness and strength was observed after buckling of longitudinal reinforcement in all confined specimens. In CCA35, CCA50 and CCB43, fracturing of lateral reinforcement was observed after buckling of longitudinal reinforcement.

Table 4 :Stress-strain results of specimens

Specimen	Yielding of longitudinal reinf.		Yielding of lateral reinf.		Buckling of longitudinal reinf.		Fracturing of lateral reinf.		Peak of strength	
	σ N/mm^2	ε %	σ N/mm^2	ε %	σ N/mm^2	ε %	σ N/mm^2	ε %	σ N/mm^2	ε %
CCA35	32.0	0.147	56.6	0.901	79.7	6.410	80.4	6.780	80.4	6.780
CCA50	32.1	0.223	55.2	1.979	57.1	3.332	43.1	5.299	57.0	3.332
CCB43	34.1	0.193	80.3	2.606	84.9	5.448	46.6	7.391	85.1	5.014
CCB60	27.8	0.150	62.1	1.851	59.5	2.974	-	-	62.2	2.226
CCP	-		-		-		-		39.0	0.230

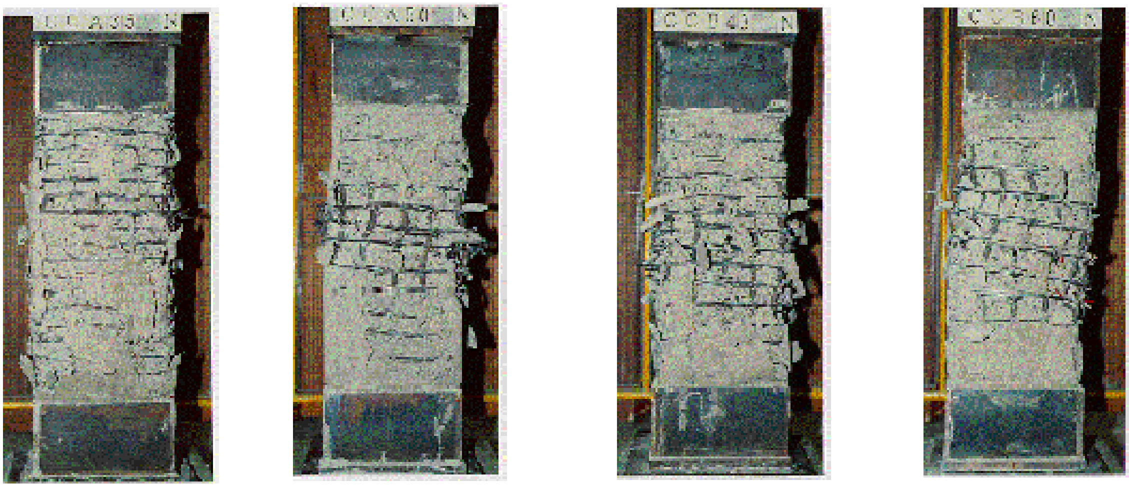


Figure 4: Final appearance of specimens

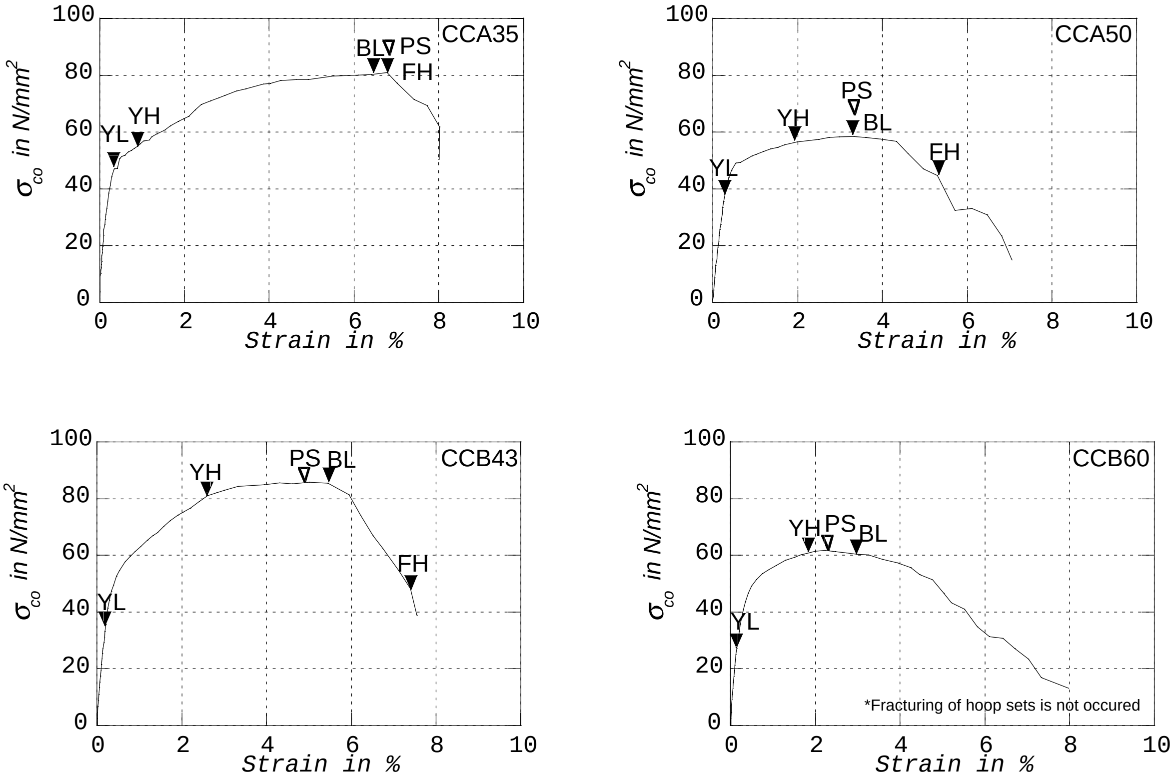


Figure 5: Comparison of stress-strain curves

Strain of lateral reinforcement

Fig.6 shows strain of lateral reinforcement is plotted against longitudinal strain in all confined specimens. In CCA35 confined by type A configuration the strain gain in all measuring points was moderate. In CCA50 the strain in the measuring point e significantly increased until its final fracture. In CCB43 the strain in the measuring point e and f significantly increased in the earlier stage of loading. In CCB60 the strain in the measuring point f significantly increased while the strain in the other point remained elastic. In the specimens confined by type A configuration the strain gain in the inner corner of outside hoops was significant while in the specimens confined by type B configuration the strain gain in the inner tie bar was significant.

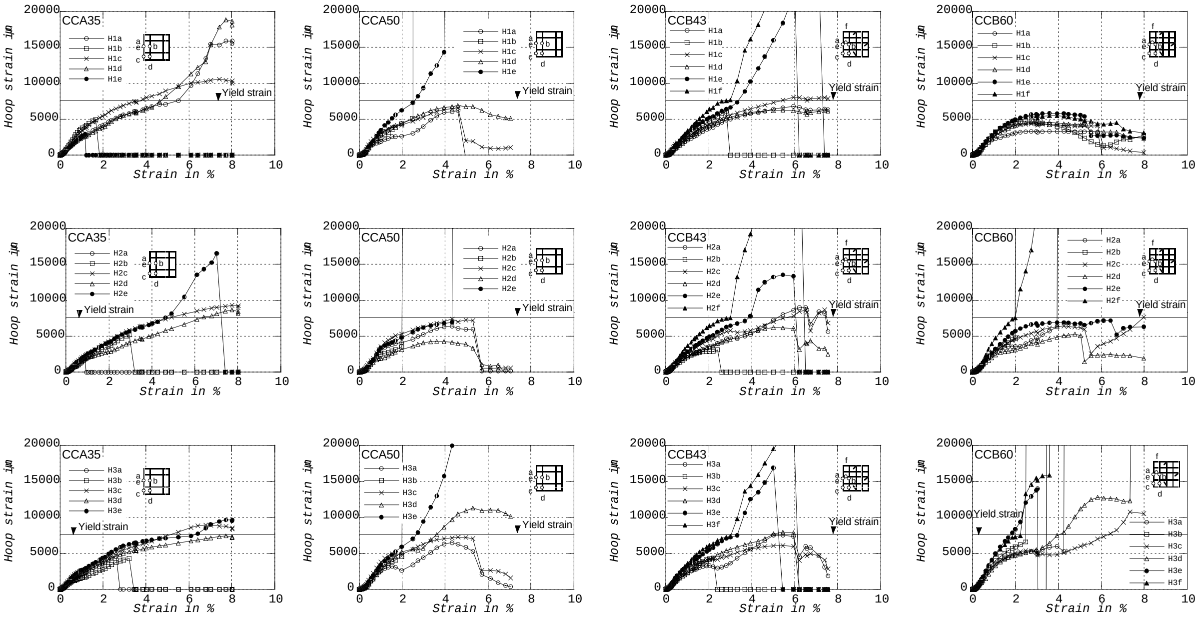


Figure 6: Strain of lateral reinforcement

DISCUSSION OF RESULTS

Comparison between experimental stress-strain curves and model curves proposed by Sheikh

Sheikh proposed to establish the stress-strain relationship of confined concrete. The model was based on the concept of the effectively confined concrete area within the concrete core. To discuss the effectively confined concrete area this model was compared with the experimental test results. Fig. 7 shows the comparison between the experimental curves and the model curves by Sheikh. Both curves were similar in the earlier stage of loading in each specimen.

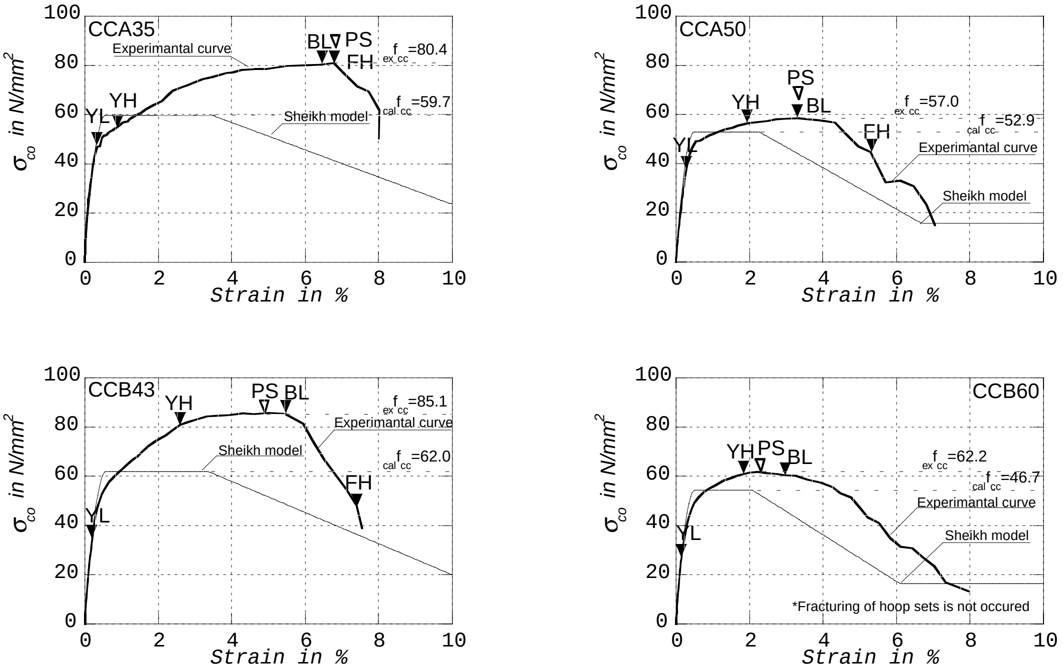


Figure 7: Comparison between experimental curves and model curves proposed by Sheikh

The model proposed by Sheikh consistently underestimated the strength of confined concrete after longitudinal strain of approximately 1%. The comparison between the experimental peak strength and the peak strength proposed by Sheikh in Table 5. The ratio ${}_{ex}f_{cc}/{}_{cal}f_{cc}$ varies between 1.08 and 1.37. The average value of this ratio is 1.22 and 1.35 in specimens confined by configuration type A and specimens confined by configuration type B, respectively. This indicates that the peak strength proposed in specimens confined by configuration type B is underestimated more than that proposed in specimens confined by configuration type A.

Table 5: Comparison between the experimental peak strength and the peak strength proposed by Sheikh

Specimen	Peak of strength of test results ${}_{ex}f_{cc}$ N/mm^2	Peak of strength by Sheikh model ${}_{cal}f_{cc}$ N/mm^2	Ratio ${}_{ex}f_{cc}/{}_{cal}f_{cc}$
CCA35	80.4	59.7	1.35
CCA50	57.0	52.9	1.08
CCB43	85.1	62.0	1.37
CCB60	62.2	46.7	1.33

Assumption of distributions of lateral pressure

The effectively confined concrete area proposed by Sheikh is based on the assumption that confinement pressure generated by the reinforced cage between each node is uniform (Fig. 8) . However, the test results can't be explained according to the concept of the effectively confined concrete area. Fig. 9 shows the distribution of lateral pressures assumed by the test results. This assumption is based on the premise that the rectangular column subjected to a compressive axial load is deformed to circular shape(Fig. 10). The confinement pressure is generated to restrain the lateral deformation. Passive confinement pressure exerted by a square hoop is dependent on the restraining force developed in the hoop. The hoop steel can develop high restraining forces at the corners, where it is supported laterally by transverse legs, but only low restraining forces between the laterally supported corners. The restraining force at the corners depend on the force that can be developed in the transverse legs, which, in turn, is related to the area and strength of the hoop steel. The restraining action of the hoop, which depends on the size and unsupported length of the bar. However, the flexural rigidity of the hoop between the laterally supported corner points is very small as compared to the restraining action of corners. Therefore, as the concrete expands laterally under axial compression, there will be larger deformation building up at the corner points than locations away from the corners. If cross ties or inside hoops are used to support the middle bar and outside hoop, higher lateral restraint is generated. Fig. 11 shows an example of effective tie configuration.

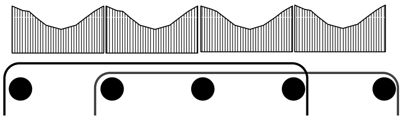
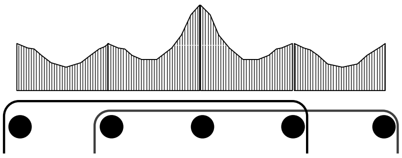
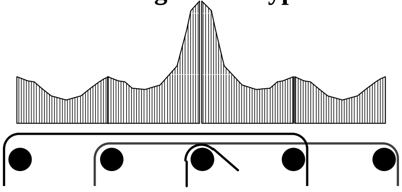


Figure 8: Assumed distributions of lateral pressure in model proposed by Sheikh



In configuration type A



In configuration type B

Figure 9: Assumed distributions of lateral pressure in this test

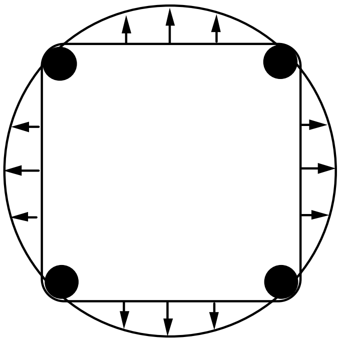


Figure 10: Lateral deformation of square column under axial compression loading

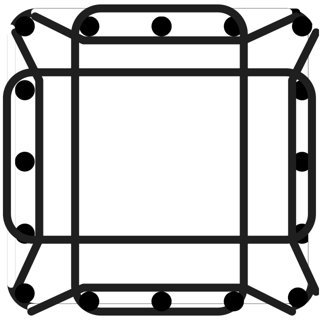


Figure 11: Effective tie configuration

SUMMARY AND CONCLUSIONS

An experimental program involving short concrete column with complex tie configurations was performed. The following conclusions can be drawn from the results of these tests:

1.Buckling of longitudinal reinforcement was a cause of the reduction in stiffness and strength of confined column.

2. Stiffness and ductility of confined column are effectively improved by increasing the number of inner tie bars.

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