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EFFECTS OF REINFORCING DETAILS ON AXIAL LOAD CAPACITY OF R/C COLUMNS

Daisuke KATO[1] , LI Zhuzhen[2] , Katsuhiro SUGA[2] and Yukiko NAKAMURA[1]

SUMMARY

Final objective of this study is to prevent pancake type collapse of R/C old buildings during sever earth quake. For this purpose axial load carrying capacity of columns failing in flexure have been studied. In this study the scope was extended to shear failing columns, axial load capacity under residual deformation and effects of reinforcing details. Ten R/C specimens with square sections were tested. Two types of specimens were made with varying only reinforcing details. The hoop of H-series had 135 degrees hook. And the hoop of P-series had 90 degree hook details. Another main variable was loading methods; i.e. monotonic centric axial loading, eccentric axial loading under constant lateral drift and normal reversed lateral loading under constant axial load. Main conclusions were as follows. (1)Specimens with high axial load lost scheduled axial load far before it's axial deformation reached axial load - axial deformation relation of specimen with centric axial load. On the other hand, Specimens with low axial load lost scheduled axial load when its axial deformation reached axial load - axial deformation relation of specimen with centric axial load. (2)There was little difference of behavior between specimens with normal reinforcing details (H-series) and those with poor reinforcing details (P-series).

INTRODUCTION

Final objective of this study is to prevent pancake type collapse of R/C old buildings during sever earth quake. For this purpose axial load carrying capacity of columns have been studied [1]. But in these tests the objectives were only columns failing flexure. On the other hand some studies have been done about columns including shear failing columns and residual axial capacity (Santiago Pujol [2], J. P. Moehle [3] , Nakamura T.[4], Kitada T.[5]). So in this study the scope was extended to shear failing columns, axial load capacity under residual deformation and effects of reinforcing details

OUTLINE OF TEST

Specimens

1. Department of Architecture, faculty of Engineering, Niigata University, Niigata, Japan
Email:dkato@eng.niigata-u.ac.jp
2. Graduate student, Dep. of Architecture, faculty of Eng., Niigata University, Niigata, Japan

In order to understand axial load capacity centric axial loading test is the most basic testing method. But the actual axial load capacity should be discussed using columns subjected to axial load and lateral load reversals. These two cases have studied widely. But in this study eccentric axial loading tests were also done under constant residual deformation.

Figure 1 shows specimens. Table 1 shows properties of specimens. All specimens were rectangular reinforced concrete columns with steel footings at both ends for repeatable use. 180mm square section, longitudinal reinforcement (4-D10 bars) and hoop reinforcement (2D6@70) were commonly used for all specimens. Two types of specimens were made. Only reinforcing details were different. The hoop of H-series had 135 degrees hook. And the hoop of P-series had 90 degree hook details. The hook position was rotated along column's axis. Tables 2(a)(b) show material strength of concrete and steel.

Table 1 Properties of specimen

specimen	column size		main bar	hoop			
	section	height		hoop	hoop spacing	hook	anchorage length
H-series	180x180mm	360mm	4-D10	2-D6	70mm	135 deg	6d
P-series						90 deg	8d

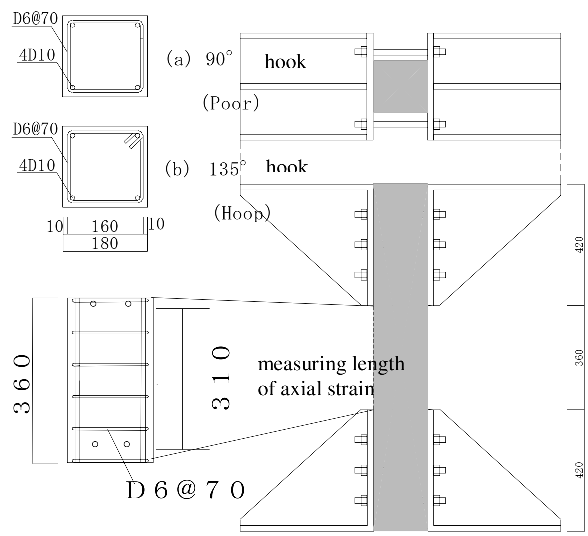


Figure 1 Specimen and reinforcement

Table 2 Strength of material (N/mm^2)

(a)steel

steel	yield strength	maximum strength
D10	383	521
D6	316	490

(b)concrete

specimen	concrete strength
H-0,1,2 P-	33.7
H-3,4 P-3,4	35.2

Tables 3(a)(b) show variables of loading method. Left table shows axial loading test series. Axial loading test was composed by preloading meaning reversed lateral loading and main loading meaning monotonic axial loading. Maximum drift angles of preloading were 1/50 or 1/100 rad. And drift angles at loading which means residual lateral drift were also 0, 1/50 or 1/100 rad. Note that specimen H-0 and P-0 without preloading were monotonic centric axial loading specimens which had been done widely enough. On the other hand right hand table shows lateral loading specimens. This series was composed by main loading which means normal reversed lateral loading test under constant axial load and post loading which means monotonic axial loading. Post loading was started after the specimen lost its axial load capacity to sustain scheduled constant axial load.

Table 3 Loading method

(a)axial loading test series

specimen	pre loading (reversed lateral loading)	main loading (monotonic axial loading)
	maximum drift angle(rad)	drift angle at loading (rad)
H-0	-	0
H-1	1/50	1/50
H-2	1/50	0
P-0	-	0
P-1	1/50	1/50
P-2	1/100	1/100

(b)lateral loading test

specimen	main loading (reversed lateral loading)	post loading (monotonic axial loading)
	axial load (kN)	drift angle at loading (rad)
H-3	400	free
H-4	200	free
P-3	400	free
P-4	300	free

Loading method

Figure 2 shows loading setup. Triangle steel footings were repeatable footings. Note that the confinement from the footing base could be different from that of normal type specimen with H shape type. But as far as failure occurs around the middle part of the specimen the difference can be neglected.

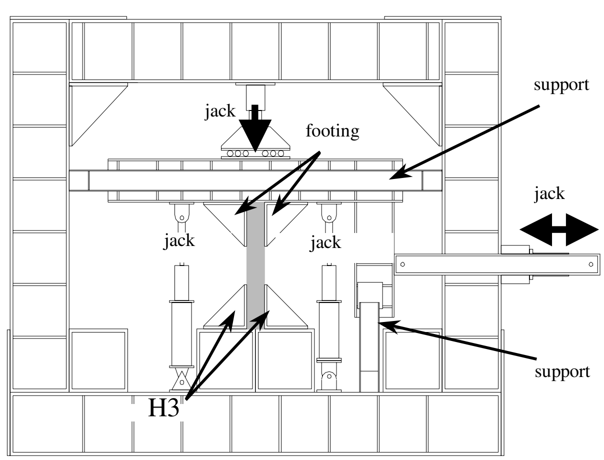


Figure 2 Loading setup

Eccentric axial loading test under constant residual deformation was applied as follows. At first column was subjected to lateral load reversals under constant axial load of 150kN. The lateral load was reversed twice for each drift angle of 1/100rad (H-1,2 P-1,2) and 1/50rad (H-1,2 P-1). After lateral loading axial load was subjected under constant residual deformation, which meant residual deformation.

TEST RESULTS

Test result of axial loading test series(H-0,1,2 and P-0,1,2)

Figures 3(a)-(f) show test results of axial loading test series (H-0,1,2 and P-0,1,2). Top figure shows axial load-axial deformation relationship and bottom figure shows lateral load-axial deformation relationship. Figures (a)(d) show the test results of monotonic centric axial loading test. The variable was reinforcing details. But little difference can be seen between behaviors of these two specimens.

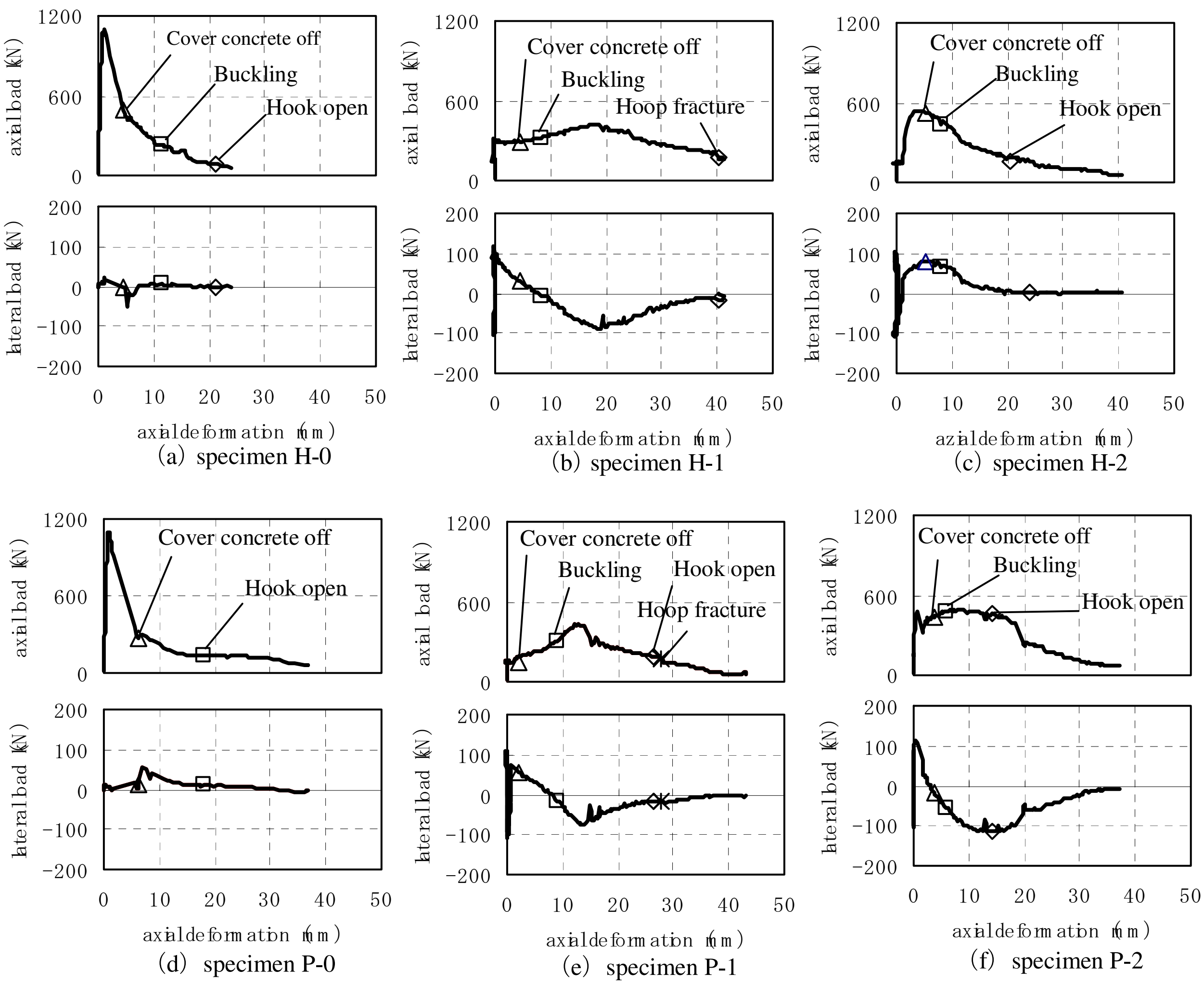


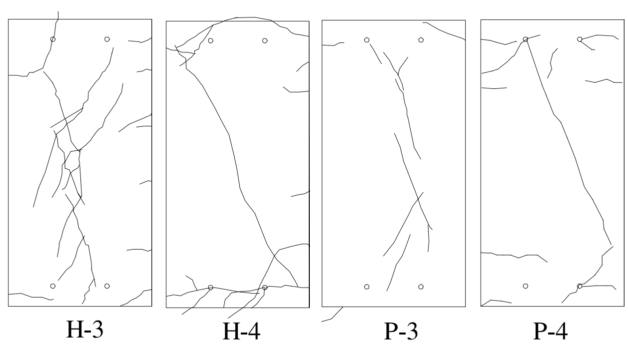
Figure 3 Test results of axial loading test series (H-0,1,2 P-0,1,2)

Figure (c) shows the test results of specimen H-2 subjected to preloading which means lateral load reversals up to the drift angle of 1/50 rad. Effect of preloading can be seen comparing to specimen H-0 subjected to monotonic axial loading, i.e. maximum axial load degraded by preloading and little difference can be seen about the behavior after peak point.

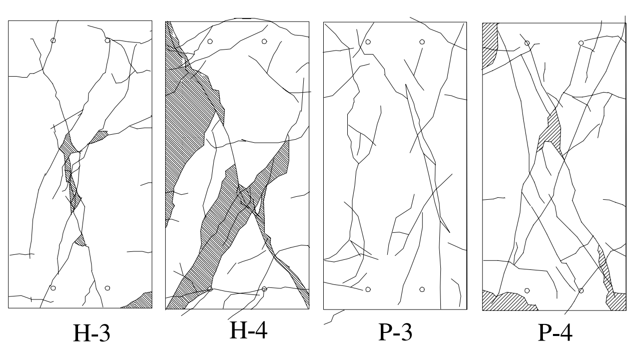
Figures (b)(e)(f) show the behavior of Specimens H-1,P-1,2 subjected to both preloading and eccentric axial loading. Effect of eccentric axial loading can be seen comparing to specimen H-0 subjected to monotonic axial loading, i.e. axial deformations at maximum axial load of specimens H-1 were much larger than that of specimen H-0. This was caused by lateral load to maintain constant residual deformation. The bottom figures show this lateral load. And the lateral load was much larger than that of specimen H-0.

Test result of lateral loading test series(H-3,4 and P-3,4)

Figure 4 shows crack patterns and failure mode. Figure (a) shows crack patterns at drift angle 1/100rad and Figure (b) shows failure mode after main loading test (lateral reversed loading). Figures 5(a)-(d) show test results of lateral loading test series (H-3,4 and P-3,4). Left figures show axial load-axial deformation relationship, middle figures show lateral load-axial deformation relationship and right figures show lateral load-lateral deformation relationship.

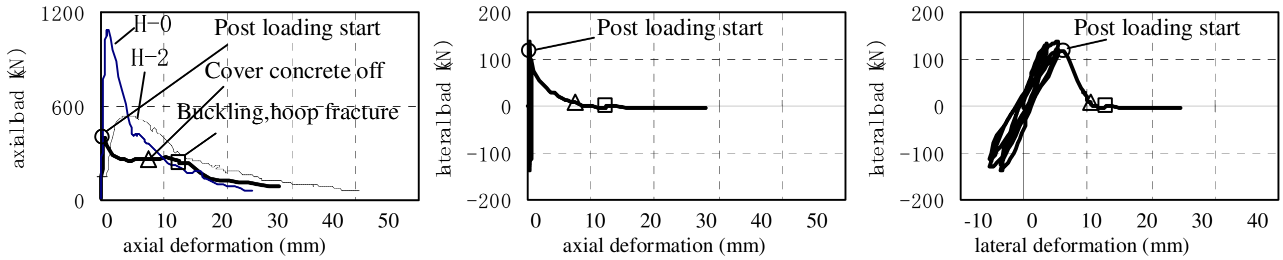


(a)drift angle 1/100rad

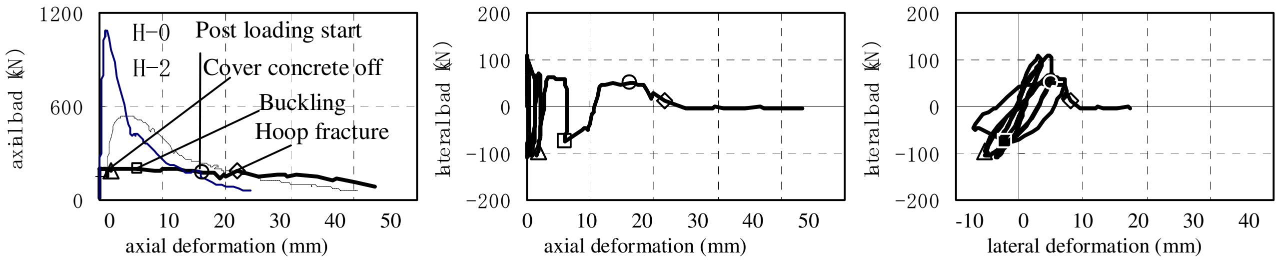


(b)after main loading test (lateral reversed loading)

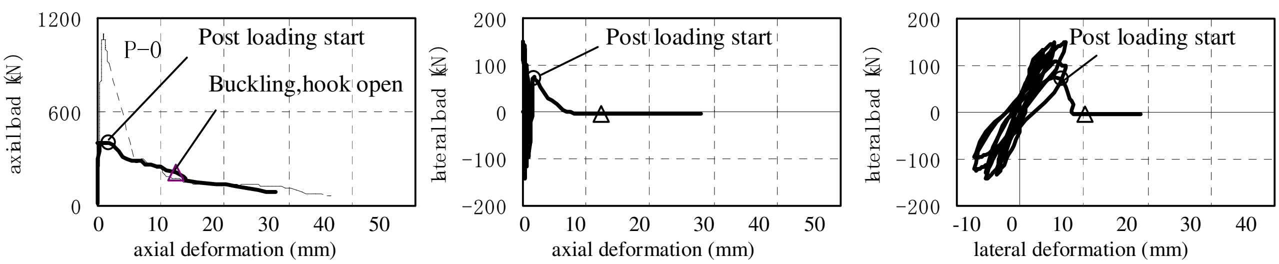
Figure 4 crack patterns and failure mode



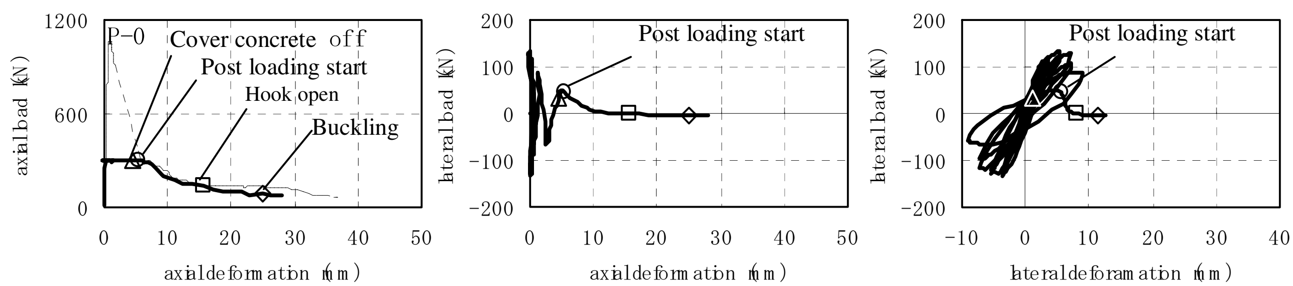
(a) specimen H-3



(b) specimen H-4



(c) specimen P-3



(d) specimen P-4

Figure 5 Test results of lateral loading test series (H-3,4 P-3,4)

Figures (a)(c) show the test results of lateral loading series specimens with high axial load. Specimens H-3 and P-3 were subjected to axial load of 400 kN which was large among 4 specimens. And circle marks represent starting points of post loading. In other words the specimens lost their axial load carrying capacities for scheduled axial load at these points. Post loading meaning eccentric axial loading started from this points. But at these cases lateral drifts were not confined. In left figures showing axial load – axial deformation relationship test results of accompanying monotonic axial centric loading specimen are also compared, indicating that axial load-axial deformation relationship of lateral loading specimens converged to that of centric axial loading specimen in the final loading stage. Also specimens H-3 and P-3 with high axial load lost scheduled axial load far before their axial deformation reached axial load – axial deformation relation of specimen with centric axial load.

Figures (b)(d) show the test results of lateral loading series specimens H-4 and P-4 with low axial load comparing to specimens H-3 and P-3. Specimens in these cases lost their scheduled axial load when their axial deformation reached axial load – axial deformation relation of specimens with centric axial load. This is understandable like that the scheduled axial load of these specimens could be sustained by friction of the failure surface only which was supposed to be a same condition as final part of centric axial loading test. In other words scheduled axial load of specimens H-3 and P-3 with high axial load could not be sustained by friction only. They needed cohesion to sustain high axial load. And this is why they lost their axial load capacity early. But this result should be examined further more.

EFFECTS OF REINFORCING DETAILS ON AXIAL LOAD CAPACITY

Evaluating method

Mohr's stress circle and Mohr-Coulomb's failure criterion are effective to understand the condition after maximum strength (Santiago Pujol[2], J. P. Moehle[3]). Trial to understand the effects of hoop reinforcement on axial load capacity using stress circle and failure criterion is shown in this section.

Figure 6 shows basic concept of stress circle and criterion. The original criterion has the value of cohesion C and friction μ. Once the stress circle touches the criterion the criterion degrades gradually and finally reaches origin point and after that keeps this line. The line crossing the origin point is called after slip criterion in this study. Note that the value of C=0.24f'c and μ=0.77 are used tentatively according to experimental data by Richart[6].

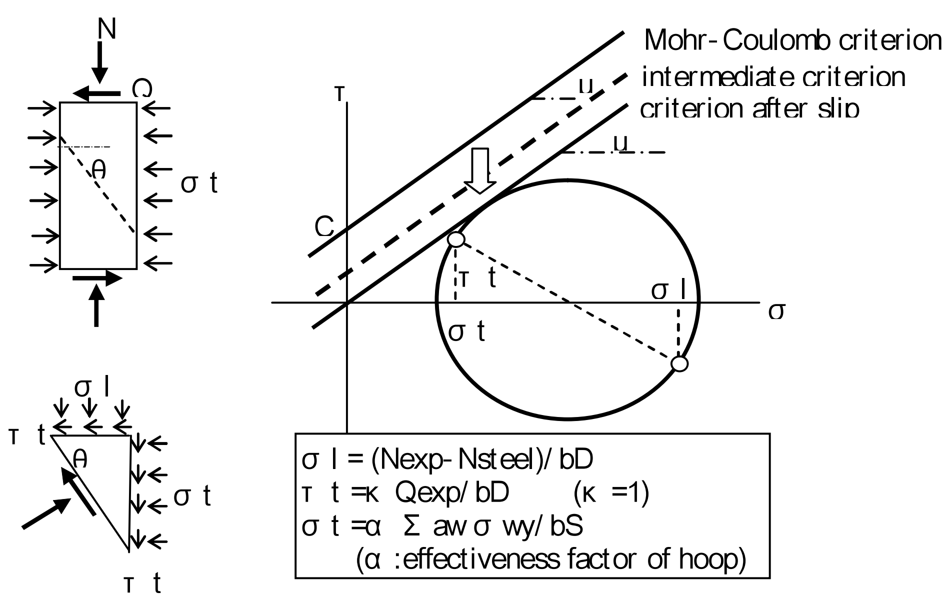
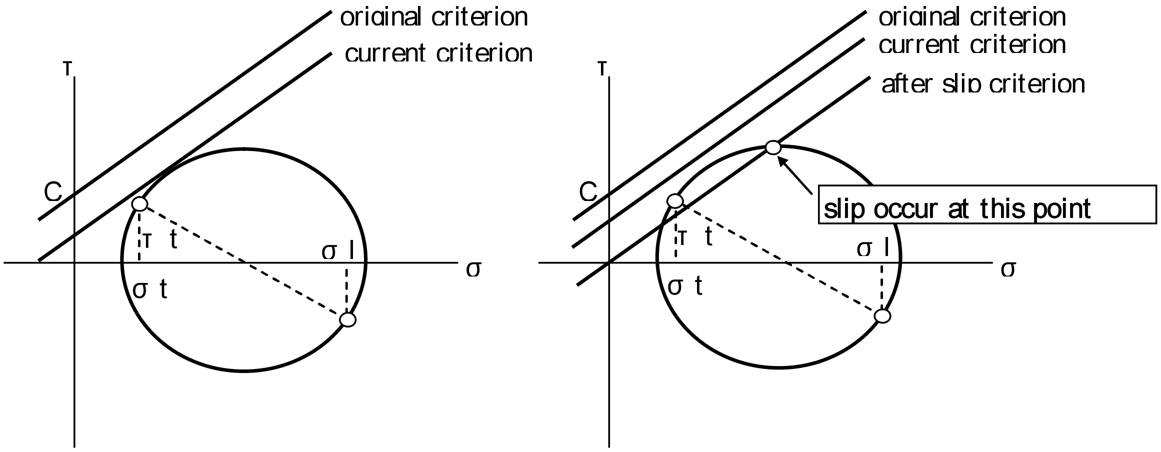


Figure 6 Basic concept of stress condition of concrete and failure criterion

In this study two types of failure conditions are considered. Figure 7 shows these two types of failure condition; i.e. (a)failure according to current failure criterion as shown in Fig. 6 and (b)slip failure along existing failure surface with the inclination of θe which has been developed in the previous loading step.



(a)according to current criterion **(b)slip along existing failure surface (inclination is θe)**

Figure 8 shows the procedure to obtain failure condition by slip along existing failure surface. For drawing stress circle using experimental data in this procedure there are two problems. Firstly effect of hoop reinforcement which is necessary to draw stress circle degrades according to loading step. So effectiveness factor of hoop α after slip occurred is introduced. And the procedure is as follows; i.e. assuming α, subtracting steel contribution and drawing stress circle. If slip occurs this means the collect value of α.

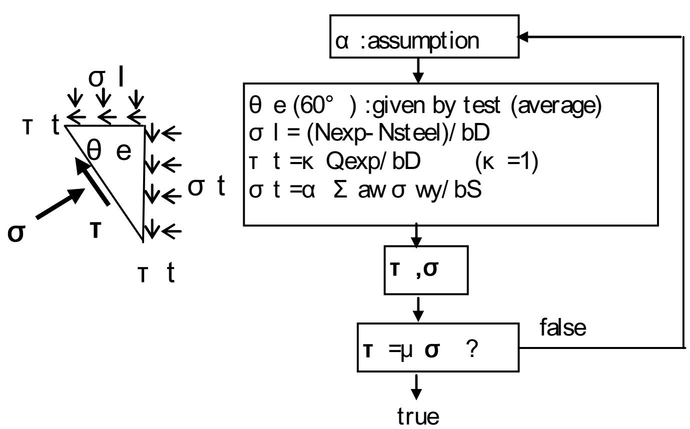
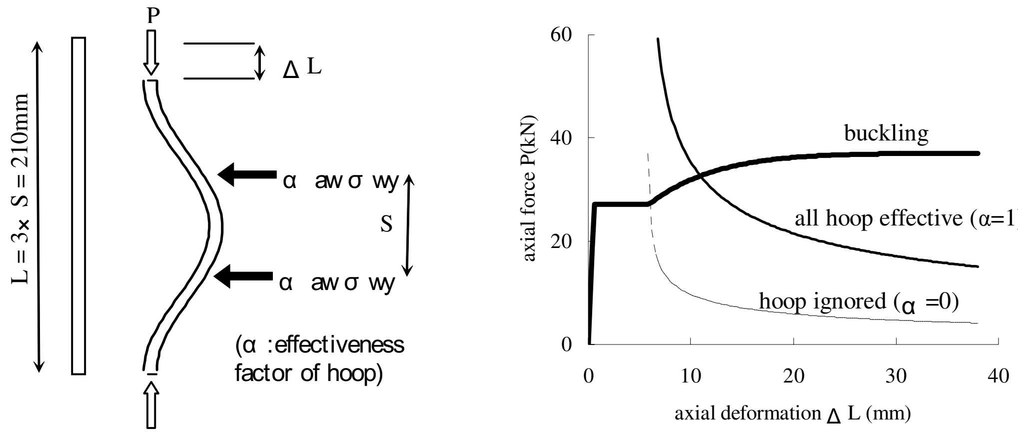


Figure 8 Estimation of effectiveness factor of hoop α from test results (failure type is slip along existing failure surface (inclination is θe=60°))

Second problem to obtain stress circle is the estimation of contribution of longitudinal steel . Figure 9 shows the estimated contribution of longitudinal reinforcement. As shown in the figure buckling is taken in account. The model was already proposed[7]. The figure indicates that behavior after buckling depends on effectiveness factor of hoop α.

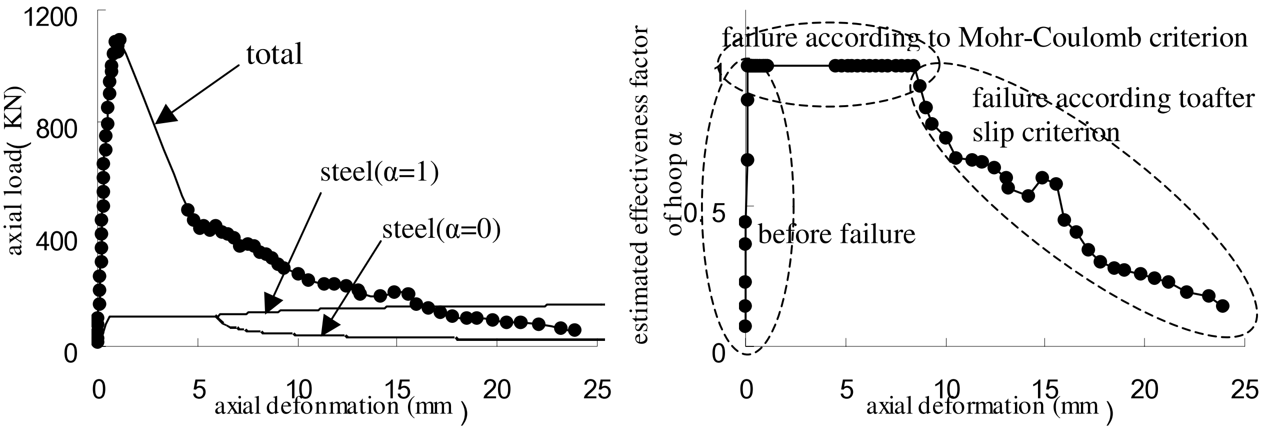


(a)buckling model (b)axial force – axial deformation relationship
Figure 9 Estimation of contribution of axial force supported by one longitudinal bar[7]

Effectiveness factor of hoop
Figures 10(a)(b) show an example of estimated effectiveness factor of hoop α of specimen H-0 with monotonic central axial loading. Figure (a) shows axial load - axial deformation relationship of the specimen. Contributions of longitudinal steels are also shown in the figure. And Figure (b) shows estimated α. Three dashed circles represent before failure, failure according to Mohr-Coulomb criterion and failure according to after slip criterion. This figure indicates that the value of α degrades with increasing value of axial deformation.

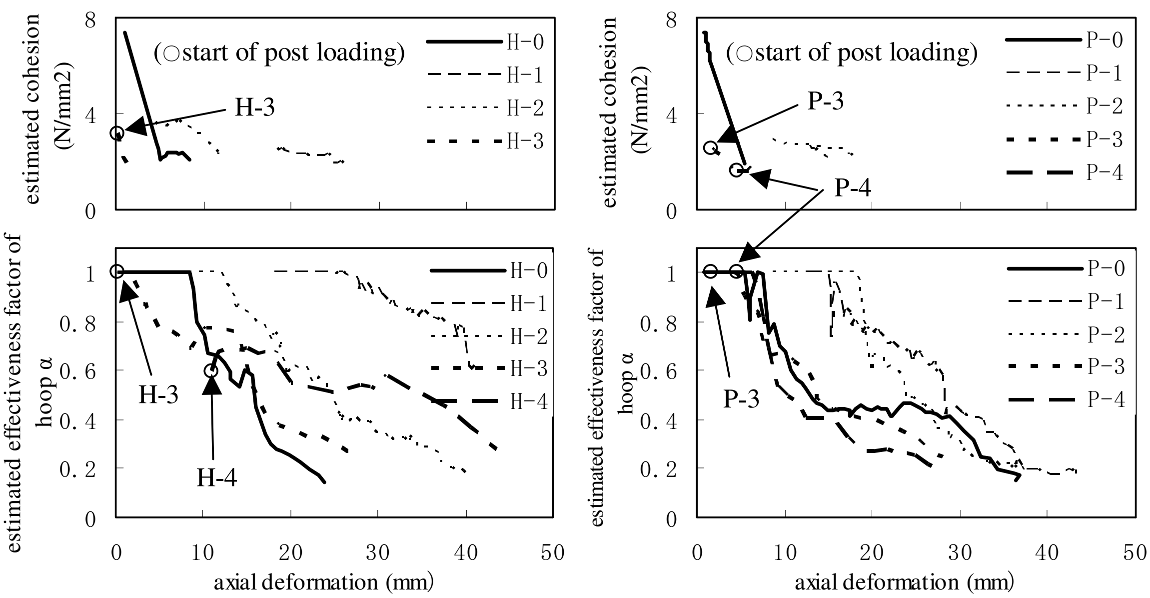
Bottom two figures of Figures 11(a)(b) show estimated effectiveness factor of hoop of all specimens. If the value of α cannot be obtained within the range from 0 to 1, which means slip does not occur, stress circle in this case is assumed to touch the current criterion as shown in Fig. 7(a). In this case cohesion can be obtained assuming α =0. Top figures show estimated cohesion. Horizontal axis of these figures represents axial deformation.

Figures indicate that estimated values degrade according to axial deformation. And circle marks represent starting point of post loading of lateral loading specimens. And specimen H-3 with high axial load lost its axial load capacity before it reached after slip criterion. And specimen H-4 with low axial load lost its axial load capacity in the after slip criterion range. And specimens of P-series (P-3 and P-4) show similar behavior as specimens of H-series.



(a)Axial load-axial deformation (b)Estimated effectiveness factor –axial deformation

Figure 10 Example of estimated α (specimen H-0)



(a)H-series (b)P-series

Figure 11 Estimation of effectiveness factor of hoop α and cohesion of specimens after peak points (maximum axial load point(H-0,1,2,P-0,1,2) or starting point of post loading(H-3,4,P-3,4))

CONCLUSIONS

(1)Effect of preloading :

Maximum axial load degraded by preloading meaning lateral load reversals. But little difference was observed after the peak point.

(2)Effect of eccentric loading :
Axial deformations at maximum axial load of specimens with eccentric loading were much larger than those of other specimens. This is caused by lateral load to maintain constant residual deformation. But axial load-axial deformation relationship of lateral loading specimens converged to that of centric axial loading specimen in the final loading stage.

(3)Losing point of scheduled axial load :
Specimens with high axial load, which required cohesion and friction to sustain axial load, lost scheduled axial load far before it's axial deformation reached axial load - axial deformation relation of specimen with centric axial load. On the other hand, Specimens with low axial load, which required only friction to sustain axial load, lost scheduled axial load when it's axial deformation reached axial load - axial deformation relation of specimen with centric axial load.

(4)Effect of reinforcing details :
There was little difference of behavior between specimens with normal reinforcing details (H-series) and those with poor reinforcing details (P-series).

(5)Effectiveness factor of hoop :
Effectiveness factor of hoop α was introduced and obtained using experimental data. Obtained factors degraded with increasing axial deformation but they should be examined furthermore

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