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EFFECT OF EXTERNAL HIGH STRENGTH HOOPS ON SEISMIC RETROFIT OF LOW STRENGTH CONCRETE R/C COLUMN UTILIZING ROUND REBAR

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ABSTRACT

In this study, a new seismic retrofit utilizing pre-tensioned high strength steel bars and steel plates is made a challenge to the low strength concrete R/C column with round rebar and poor shear reinforcement under axial force ratio of 0.31 and 0.57. As a result, it is clarified that both the ductility and the lateral capacity of the specimens can be improved significantly. This paper describes these experiment results and analytical investigation.

Introduction

In the standard for seismic evaluation (The Japan Building Disaster Prevention Association 2001) of existing R/C buildings of Japan, lower limit of concrete compressive strength is 13.5 MPa, and the R/C building is fundamentally considered to be out of seismic retrofit if the concrete compressive strength is under the value. However, in the existing R/C buildings, there are still a lot of ones whose concrete compressive strengths are not satisfied with 13.5 MPa. Such buildings are obliged to be rebuilt before the earthquake comes. So that the burden of economic increases. Taking account of this problem, it is more suitable for seismic retrofit than rebuilding, if an appropriate seismic retrofit technique is possible for these buildings. In this study, a new seismic retrofit utilizing pre-tensioned high strength steel bars and steel plates is made a challenge to the low strength concrete R/C column with round rebar and poor shear reinforcement under axial force ratio of 0.31 and 0.57.

Test specimens and test setup

The mechanical properties of reinforcement are shown in Table 1. The details of seismic retrofit are illustrated in Figure 1. The list of R/C column specimens is shown in Table 2. In these specimens with low compressive strength of concrete, cross section of the column is 200 mm x 200 mm, height of the column is 800 mm, and shear span to depth ratio of the column is 2.0. The 4 round steel bars (13ϕ) have been arranged as longitudinal reinforcement (longitudinal reinforcement ratio, p_g = 1.33%). The reinforcing steel 4ϕ has been placed as hoop at 155 mm interval (hoop steel ratio, p_w = 0.08%). The R/C column test specimens introduced in this report

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is 1/3 scale model of the original column (600 mm x 600 mm) in the general mid-rise reinforced concrete buildings of Japan.

Table 1. Mechanical properties of material.

Reinforcement		a(cm2)	f_y(MPa)	ε_y (%)	E_s(GPa)
Rebar	13 ϕ	1.33	299	0.15	199
Hoop	4 ϕ	0.11	199	0.31	197
PC bar	5.4ϕ	0.23	1220	0.61	200
Steel plate	2.3 mm (thickness)		263	0.13	205
	3.2 mm (thickness)		261	0.13	197

Note : a = cross section area, f_y = yield strength of steel , ε_y = yield strain of steel , E_s = modulus of elasticity.

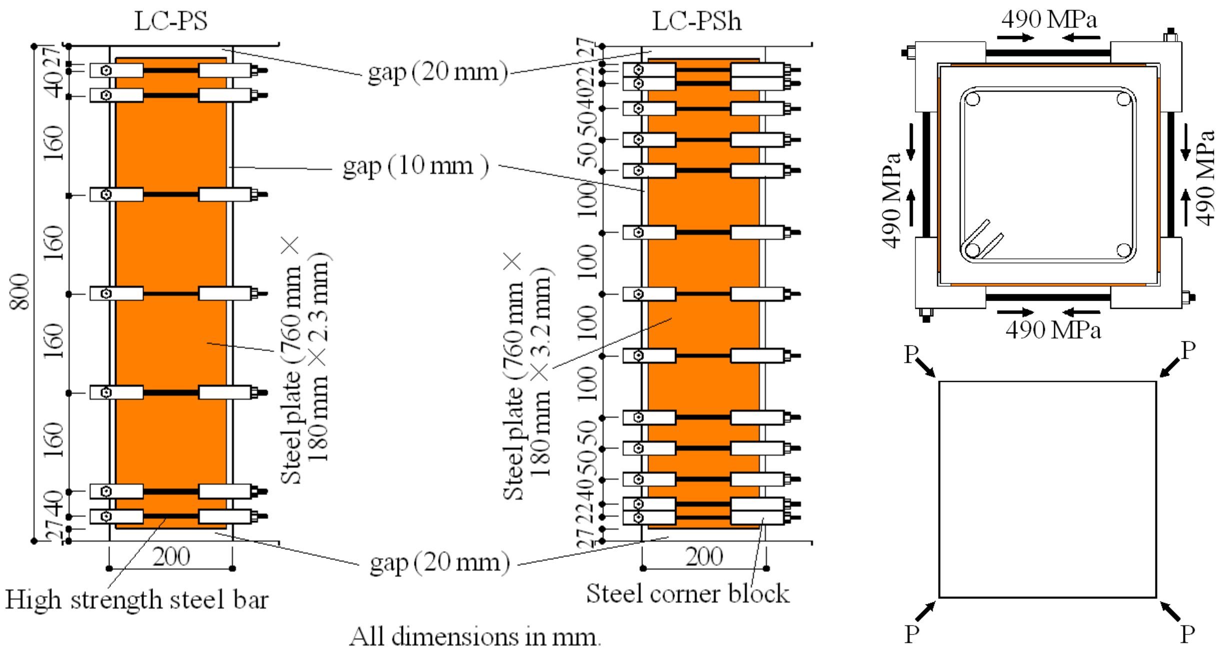


Figure 1. Details of retrofitted specimens LC-PS and LC-PSh.

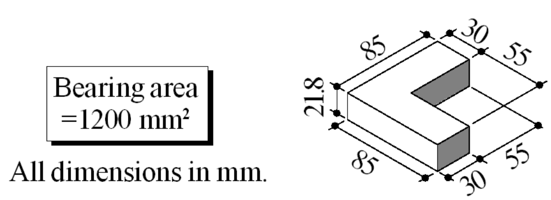
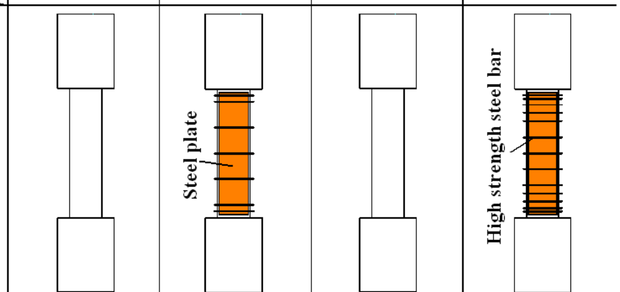


Figure 2. Details of steel corner block.

The axial force ratio of test specimens LC-P0 and LC-PS is set with 0.15, and the ratio of test specimens LC-P0h and LC-PSh is set with 0.3, basing on design compressive strength of concrete as 18 MPa. Therefore, in the test specimens LC-P0 and LC-PS whose real concrete compressive strength σ_B is 8.7 MPa, the actual loading axial force ratio becomes 0.31. In addition, in the test specimens LC-P0h and LC-PSh whose real concrete compressive strength σ_B is 9.5 MPa, the actual loading axial force ratio becomes 0.57. In this study, LC means the specimen with low concrete compressive strength, P0 means non-retrofitted specimen, PS means the specimen retrofitted by high strength steel bar and steel plate, and h means the specimen under high axial force ratio.

Table 2. Column specimens.

	LC-P0	LC-PS	LC-P0h	LC-PSh
Specimen				
σ_B	8.7MPa		9.5MPa	
$N/(bD\sigma_B)$	0.31		0.57	
Prestress		490MPa		490MPa
Common details	$M/(QD)$=2.0, Hoop : 4ϕ-@155 (p_w=0.08%), Rebar : 4-13ϕ(p_g=1.33%)			

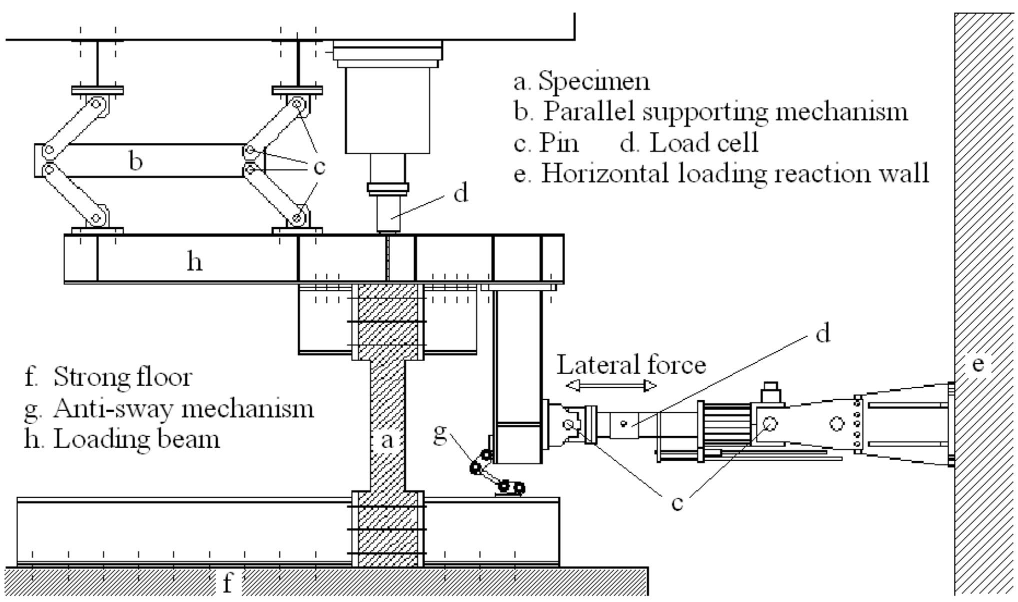


Figure 3. Details of test setup.

LC-P0 and LC-P0h are standard column specimens which are without seismic retrofit. LC-PS and LC-PSh are retrofitted by pre-tensioned high strength steel bars and steel plates of

760 mm (height) x 180 mm (width). The thickness of steel plate of LC-PS and LC-PSh is 2.3 mm and 3.2 mm respectively. In this retrofit technique, the steel plates are attached to column region from four sides, and then the column is pressed by the steel plates utilizing high strength steel bar prestressing. The steel bars surround the column like external hoops which are supported by the steel corner blocks at four corners of square (see Figure 1), and the prestressing is introduced into the high strength steel bar by torque wrench through corner block and nut. The details of steel corner block are given in Figure 2. This technique can be applied quickly and easily without utilizing heavy machinery on site. However, in order to restrain the compressive failure, the confinement in the end of column is increased. The diameter of all high strength steel bars utilizing in this study is 5.4ϕ. And the pretressing strain of all steel bars is near 2450μ of about 1/3 of yield strain of them. The prestressing force is about 11.3 kN per steel bar.

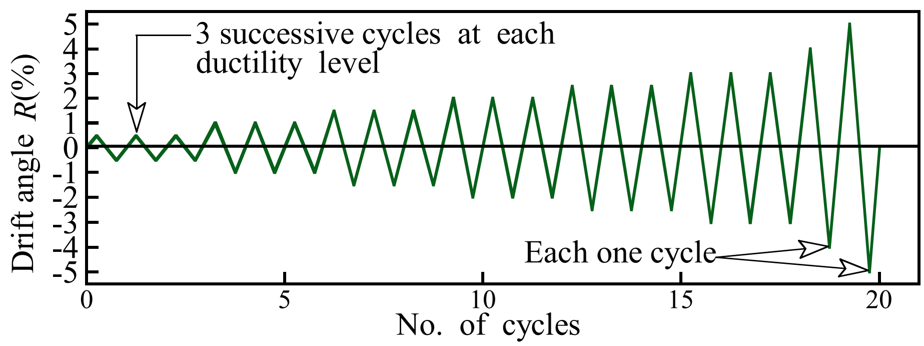


Figure 4. Loading program.

Loading apparatus which can simultaneously apply a constant axial force and cyclic lateral force is illustrated in Figure 3. And loading beam is always parallel to strong floor. Lateral loading cycles include three successive cycles at each drift angle of R = 0.5, 1.0, 1.5, 2.0, 3.0%. To investigate the behavior under the large deformations, the loading test is continued for a drift angle R = 4.0% and 5.0% with one cycle for each as depicted in Figure 4. The $R = \delta/h$ is the drift angle of the column. Where, δ is the story drift, and h is the inner height of the column.

Experimental results

Crack patterns of the columns after cyclic loading test by removing the steel plates are illustrated in Figure 5. The variations of experimental lateral shear force Q during the cyclic loading test subjected to a constant axial force simultaneously with the drift angle R, are presented in Figure 6. The dotted lines drawn in these curves are the calculated flexural strength by the simplified equation (Architectural Institute of Japan 1990) including the P-δ effect and ignoring the active confinement effect of high strength steel bars that will be described in Analytical investigation. The measured average vertical strain ε_v along the column axis versus drift angle R hysteresis loops are illustrated in Figure 7. The measured strain ε of round rebar at top region of column is shown in Figure 8. The broken lines in this figure are yield lines of round rebar.

In every specimen, initial crack is flexural one occurred at the boundary region between the column and beam when drift angle R approximates 0.5%. In the non-retrofitted test specimen

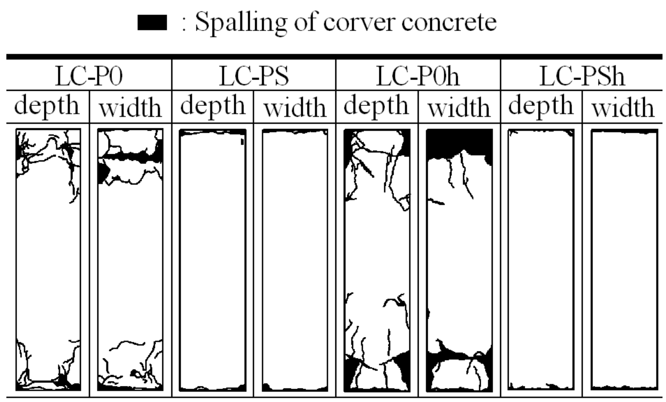


Figure 5. Observed crack patterns of columns after cyclic loading test by removing steel plates.

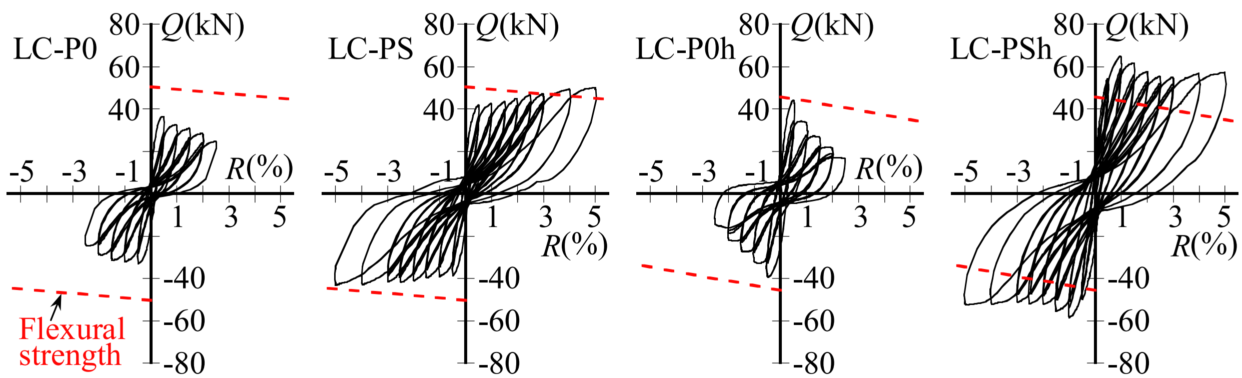


Figure 6. Measured shear force Q versus drift angle R relationships.

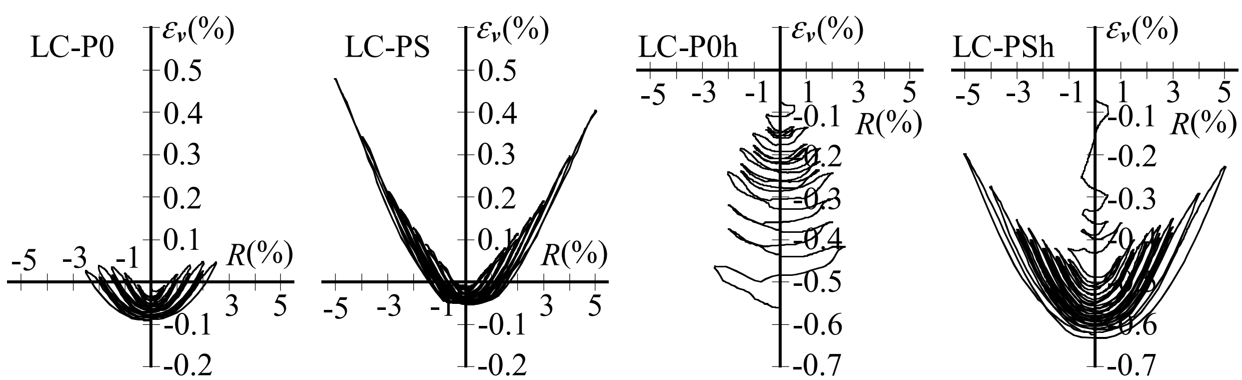


Figure 7. Measured average axial strain of column ε_v versus drift angle R relationships.

LC-P0 whose axial force ratio is 0.31, at R = 0.5%, the experimental lateral shear force reaches the maximum strength (36.4 kN) which is smaller than the calculated flexural strength. After that, flexural compressive failure of cover concrete happen at the both ends of column. As a result, lateral capacity lowers gradually. The round rebar at top region of column do not yield (see Figure 8). However, in the test specimen LC-PS retrofitted by pre-tensioned high strength steel bars and steel plates under the axial force ratio of 0.31, the experimental lateral shear force does not decrease with the increase of R, and the experimental lateral capacity (50.2 kN) reaches the flexural strength. Because hinges form in the both ends of column, this hysteresis response with good ductility remains stable until the final drift angle R = 5%. The strain of rebar at top region finally reaches the yield level and the experimental lateral capacity of this one is about 1.4 times of that of LC-P0. The progress of ε_v in the positive side (lengthening of axial length) is remarkable with the increase of R (see Figure 7). In addition, there is no crack occurred in the retrofitted region of column (see Figure 5). It is considered that the improvements of such seismic performance are attributed to the active and passive lateral confinement effect of high strength steel bars and lateral confining pressure of steel plates.

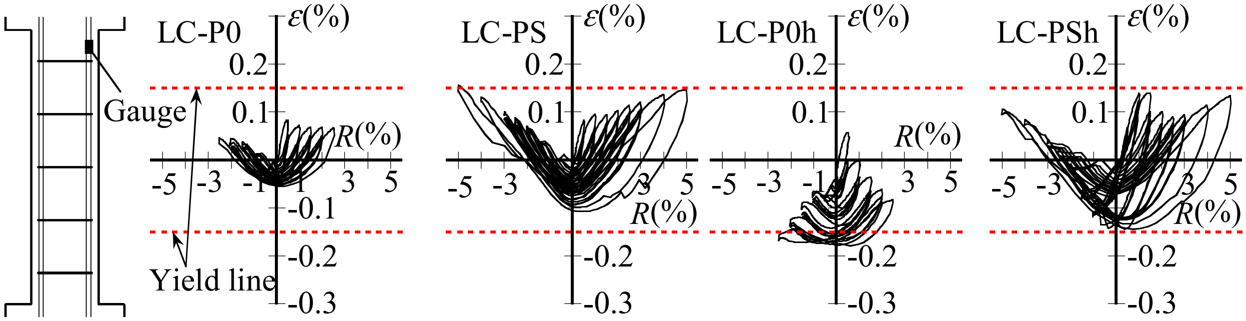


Figure 8. Measured strain of round bar at top region.

In the non-retrofitted test specimen LC-P0h whose axial force ratio is 0.57, the failure mode similar to that of LC-P0 is observed during cyclic loading test. However, because the axial force ratio is bigger, the flexural compressive failure of cover concrete at the both ends of column becomes more remarkable, the spalling of cover concrete is also more violent, the shear force decreases faster after maximum strength, and the progress of ε_v in the negative side (shortening of axial length) increase quicker also, while LC-P0h is compared with LC-P0. The strain of rebar at top region of LC-P0h reaches the compressive yield level. On the other hand, in the test specimen LC-PSh retrofitted by high strength steel bars and steel plates under the axial force ratio of 0.57 , the experimental lateral shear force reaches the experimental lateral capacity (65.0 kN) at R = 1.0%. Simultaneously, the strain of rebar at top region approaches the yield level. Thereafter, the rapid degradation of lateral shear force like LC-P0h is not observed. And the experimental lateral capacity of this specimen is about 1.5 times of that of LC-P0h. Moreover, the rapid increase of ε_v in the negative side is measured until first cycle of R = 1.0% (see Figure 7). It is conceivable that the flexural strength of column becomes larger owing to the confinement effect of high strength steel bars and steel plates, and the parts of column without pressing by the steel plates are shortened at a stretch due to the increment of compressive stress by the bending moment which acts on the column section. However, ε_v is restrained effectively because of this retrofit technique after that.

The representative presentation of measured strains of high strength steel bars is illustrated in Figure 9. The measured strains of high strength steel bars are shown in Figure 10. The changing of the strain of high strength steel bars located in column at bottom region and in the center region of both specimens is small with increasing of drift angle R. This fact seems the whole column except for the boundary region between column and beams (hinge zones) almost shows the rigid rotation behavior.

The variations of accumulated absorbed energy (W) with drift angle for all specimens are presented in Figure 11. The differences of W between every specimen are very small before R = 0.7%. But, after that, the W of retrofitted specimen is larger than that of corresponding non-retrofitted specimen with increasing of drift angle R.

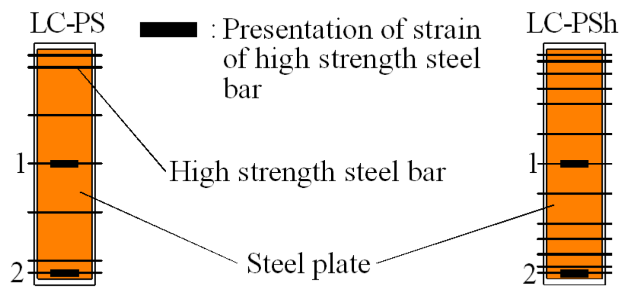


Figure 9. Presentation of measured strain of high strength steel bars in depth side of column.

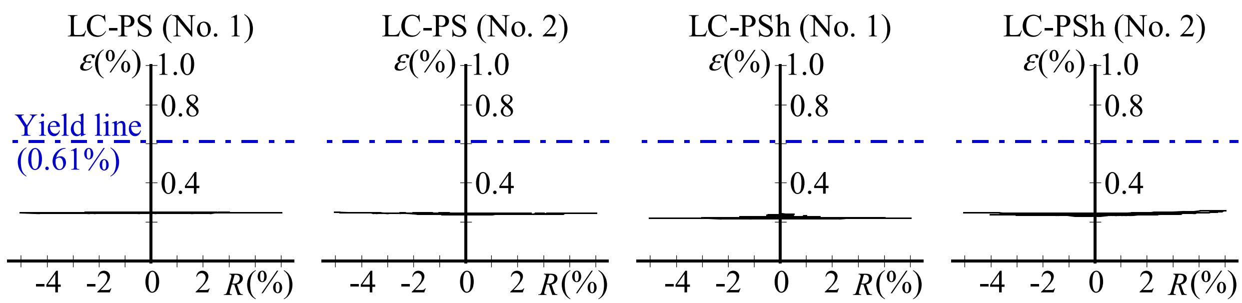


Figure 10. Measured strain of high strength steel bars.

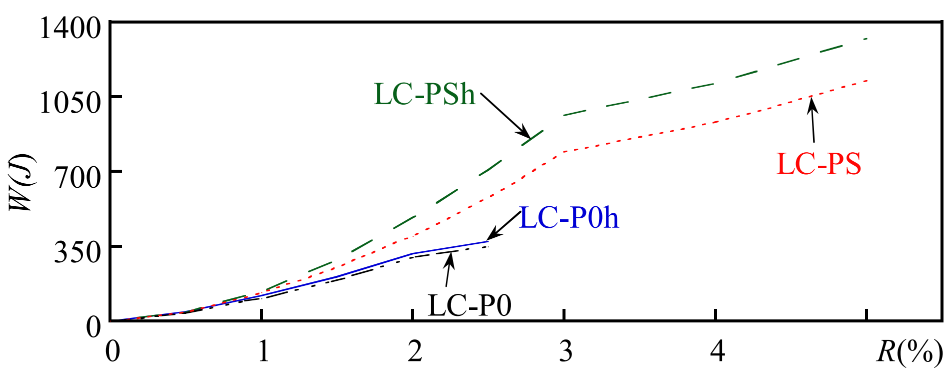


Figure 11. Accumulated absorbed energy.

Analytical investigation

In this retrofit technique, the confining forces act through the steel corner blocks as illustrated in Figure 1. The effectively confined area is taken into account according to Mander's model (Mander 1988) as shown in Figure 12. In the case of active confinement provided by the pre-tensioned high strength steel bars, the lateral confining pressure σ_r can be obtained from the following equation:

$$\sigma_r = k_e \cdot 2 \cdot \sigma_p \cdot a_p / (s \cdot D) \tag{1}$$

where, σ_p is initial prestressing stress of the high strength steel bars, a_p is the cross sectional area of each steel bar, s is c/c spacing of steel bars and D is depth of the column. The k_e is confinement effectiveness coefficient (the ratio of effectively confined concrete area to the total

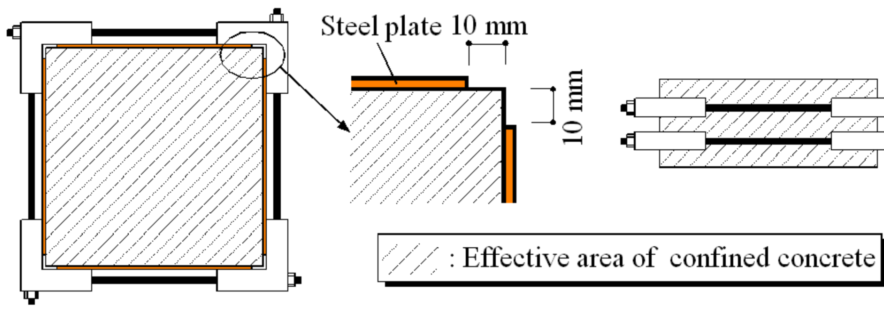


Figure 12. Effectively confined concrete.

area of cross section). In this study, the column is retrofitted by steel plates from four sides, and then, if the prestressing is applied to the high strength steel bars, the whole cross section of column will be confined by the steel plates. As a result, the effective area of confined concrete is the whole cross section of column. So k_e is equal to 1.0.

The increment of concrete strength σ_{ac} (active lateral confinement effect) due to introduction of the pretension force into high strength steel bar can be obtained according to Richart's formula (Richart 1928) as the following equation.

$$\sigma_{ac} = 4.1\sigma_r \tag{2}$$

A comparison of the experimental results and the calculated N-M interaction curves by simple addition method (Matsuyi 2004) is shown in Figure 13, where N is the axial force of column, M is the bending moment. In this figure, the broken lines are the calculated results

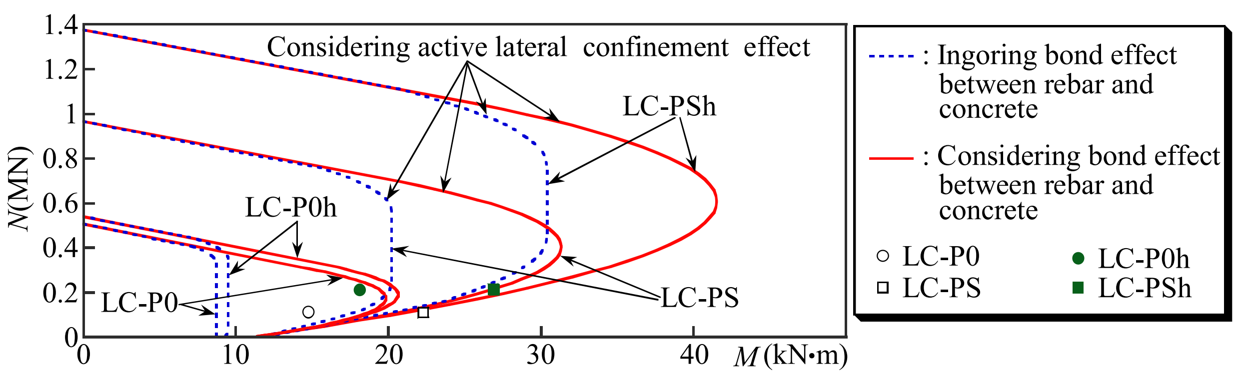


Figure 13. Calculated N-M interaction diagrams by simple addition method and experimental results.

without considering the bond effect between round rebar and concrete, and the solid lines are the calculated results considering sufficient bond strength between them. Furthermore, in the retrofitted test specimens, increment of concrete strength σ_{ac} is also considered. According to Figure 13, experimental results of all specimens are under the balanced axial load ratio. In addition, with the increase of lateral confinement, the *N-M* curve expands outward and the flexural strength is increased. The experimental results of non-retrofitted specimens are plotted on this graph at the position between the both corresponding *N-M* curves (broken line and solid line). However, these ones of retrofitted specimens are plotted almost near the corresponding solid line, which is considering not only bond effect between rebar and concrete, but also active lateral confinement effect.

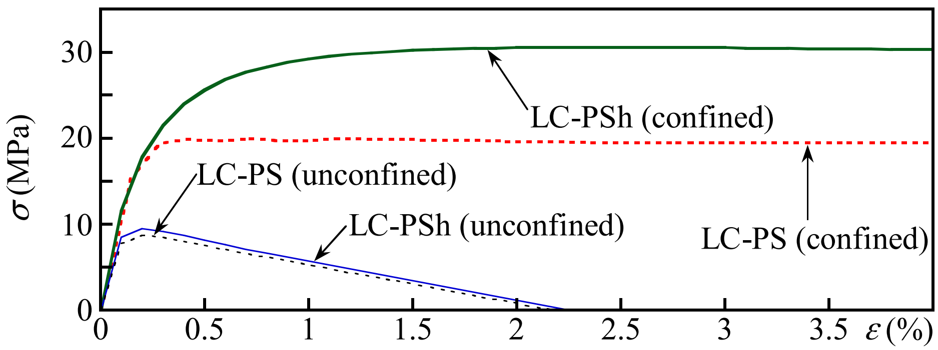


Figure 14. Calculated stress-strain curves for concrete of LC-PS and LC-PSh.

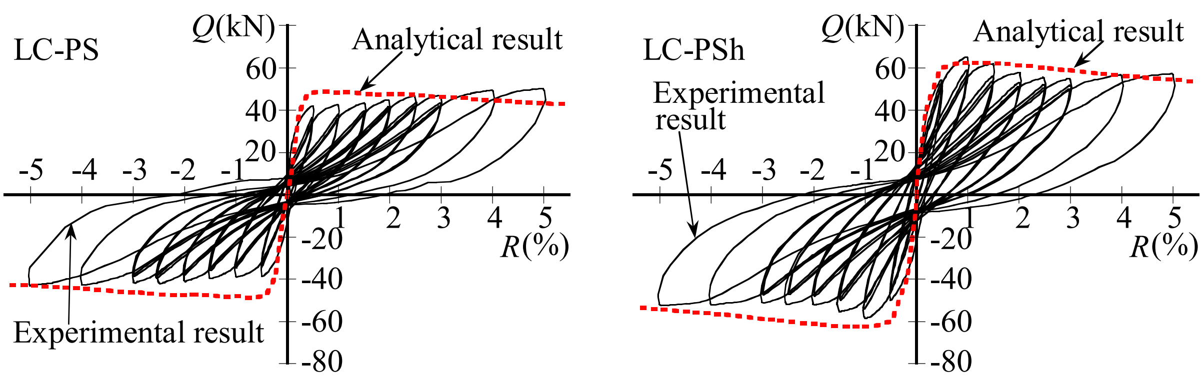


Figure 15. Comparison of experimental and analytical results of *Q-R* relationships (LC-PS and LC-PSh).

The stress (σ)-strain (ε) curves for concrete of LC-PS and LC-PSh illustrated in Figure 14 are calculated by the constitutive law of Mander (Mander 1988). In the two confined curves, the active lateral confinement effect σ_{ac} is added in the compressive strength of concrete σ_B according to Richart's formula (Richart 1928). The passive confinement effect of high strength steel bars, steel plates and hoops is also considered. According to this Figure, it is proven that the compressive strength of concrete increases with the increment of lateral confinement utilizing this seismic retrofit technique.

A comparison of experimental and analytical results of *Q-R* relationships of LC-PS and LC-PSh is shown in Figure 15. The broken line (analytical result) is calculated flexural strength based on the fiber modeling analysis and the assumption that the round rebar is yielded. This flexural strength of section analysis is figured out utilizing the constitutive law of confined concrete shown in Figure 14. The Bernoulli-Euler assumption that a plane section remains plane, is the fundamental assumption of the sectional strain distribution in this analysis. And the inclusion of bond-slip deformation is a challenging problem, which is beyond the scope of this analysis. According to Figure 15, the analytical results of LC-PS and LC-PSh almost approach the experimental results.

Conclusions

(1) If four sides of the low strength concrete R/C column with round rebar was pressed by the steel plates utilizing steel corner blocks and pre-tensioned high strength steel bars, the lateral capacity and ductility of column were increased together remarkably. It was possible to be applied to this kind of column by the retrofit technique introduced in this study.

(2) If four sides of R/C column was pressed by the steel plates utilizing steel corner blocks and pre-tenioned high strength steel bars and the interval of high strength steel bar in the end of column region was well contrived especially, the expansion of concrete was controllable even the column owned low strength concrete, round rebar and high axial force ratio.

(3) It is proven that the compressive strength of concrete increases with the increment of lateral confinement utilizing this seismic retrofit technique.

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