Study on Effect of Reinforcement using Helical Bars on Circular RC Columns under Cyclic Lateral Load

Kim, Do-Yeon
Department of Civil Engineering, Kumoh National Institute of Technology

Shin, Ja-Eun
Department of Civil Engineering, Kumoh National Institute of Technology

Kim, Seong-Kyum
Department of Civil Engineering, Kumoh National Institute of Technology

Jang, Il-Young
Department of Civil Engineering, Kumoh National Institute of Technology

https://doi.org/10.15017/2552899

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 5, pp.4-8, 2019-10-24. 九州大学大学院総合理工学府
バージョン：

Study on Effect of Reinforcement using Helical Bars on Circular RC Columns under Cyclic Lateral Load

Do-Yeon Kim[1], Ja-Eun Shin[2], Seong-Kyum Kim[3], Il-Young Jang[4]
[1,2,3,4] Department of Civil Engineering, Kumoh National Institute of Technology, Korea
correspondence should be addressed to Il-Young Jang; jbond@kumoh.ac.kr

Abstract: *To improve an earthquake-resistance of highway bridge constructed in South Korea before 1992, in this study, it was conducted quasi-static test according to the displacement-controlled (strain control) method on RC columns reinforced helical bar. In the experiment, fracture behavior of the circular column and its lateral load-displacement was investigated using three types of reinforcing bar, which has 6, 8 and 10 mm of the diameter. As a result, it was confirmed that seismic performance was dependent on reinforcement of helical bar and its size. During the test, the specimen reinforced using helical bar with 8 mm in the diameter was highest in maximum lateral load, of which the value accounted for 130.9 kN. For a diameter of 10 mm, however, it showed an over-reinforcement effect. Therefore, it would be cautious in reinforcing the helical bar, considering the given conditions including cross-section of a pier, amounts of steel bar in the pier and requirement of seismic performance.*

Keywords: Quasi-static test, Helical bar, Seismic reinforcement, Circular column, Spiral reinforcement

1. INTRODUCTION

It has been evaluated South Korea as a safe zone from earthquakes, but the frequency of the disaster is increasing recently [1]. From the survey and analysis of observation records, additionally, it is confirmed that approximately 70 times occurred annually in South Korea from 1999 to 2018 since the observation was started from 1988 [2]. Although there have been no accidents such as collapse and failure of reinforced concrete (herein RC) structures due to the earthquakes with various magnitudes in recent years, it could not be excluded the possibility of an occurrence of earthquakes causing damage to the structures in South Korea.

In South Korea, the seismic design was firstly introduced in 1992 and legally required for the RC structures [3]. This seismic design was applied to newly constructed facilities, but most of the structures built in the previous introduction of the earthquake-resistant design in 1992 were designed and constructed without considering the effects of an earthquake. Also, the structures have been aged due to an extended period. As a result, the majority of the bridges constructed in South Korea before 1992 do not satisfy current seismic design criteria.

In the plastic zone of the bridge piers, lateral reinforced steel prevents buckling of longitudinal rebars and a loss of compressive strength of the concrete during earthquakes [4]. Simultaneously, it plays a vital role as shear reinforcement, which increases the shear strength of the piers [5]. After completion of construction by the initial design, however, it is challenging to enhance the performance of the piers; by increasing the amounts of rebars and/or varying the section of the concrete. Therefore, various types of materials and its reinforcing methods are used to increase cross-sectional force for seismic performance [6].

In this study, it was conducted the quasi-static method using a specimen fabricated with quarter-scale for bride pier according to the design before 1992 in South Korea. At that time, the lateral load according to the displacement ratio of the pier was input by the displacement control method. After reinforcing the circular pier outside using the helical bar to increase the resistance to earthquakes, it was analyzed the fracture behavior and characteristics of load-displacement through a laboratory test.

2. EXPERIMENTAL WORKS

2.1 Materials

The deformed rebar with a yield strength of 400 MPa and concrete with a design strength of 25 MPa were used in this study. The concrete mix design is given in Table 1. Also, in order to improve the performance of the specimen against-earthquake, in terms of the lateral load, it was used reinforcement in a specified section outside the column. As organic materials may result in separation and spalling from the concrete, inorganic material with similar physical properties of the conventional reinforcement was adopted [7]. A helical bar used as the reinforcing material originates from nickel-chrome alloy and has high resistance against corrosion. Moreover, the reinforcement possessing spirally twisted shape exhibits an enhanced ductility and tensile strength, of which the strength accounts for about 1,100 MPa, compared to the rounded form [8]. These properties can produce the increased binding force to external force, and simultaneously not be easily cut off due to high elongation rate [8]. Therefore, it is expected to show excellent performance as a reinforcing material by resistance to earthquake. The helical bar with different types of diameter was used in the present works, and its schematic diagram is shown in Fig. 1.

Table 1. Mix properties of concrete

Strength (MPa)	Slump (mm)	W/B (%)	s/a (%)	Quantity of material per unit volume of concrete (kg/m^3)			
				W	C	S	G
24	120±25	514	49.1	148	288	857	899

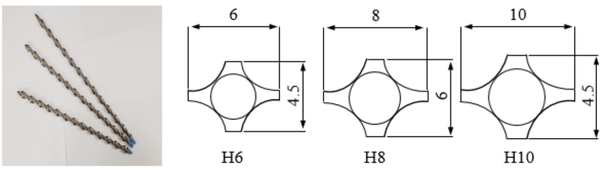

Figure 1. Helical bar and section

2.2 Specimen preparation

The specimen with a quarter-scale of the circular pier was designed dividing into a foundation part and a column one. The former was fabricated with formwork (1,200×600×600 mm in length) using normal rebars to ensure a restraining force when loaded laterally to the circular column, and the latter was manufactured with a transverse reinforcement ratio of 0.25% and an aspect ratio of 3.0, which equals to a height of 1,250 mm and a diameter of 400 mm. Fig. 2 shows the detail and picture of the RC specimen, respectively.

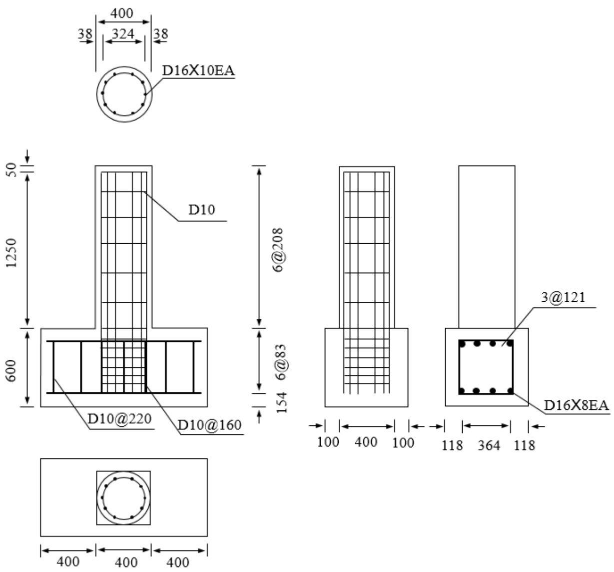

Figure 2. Design section and arrangement of specimens

After removing the concrete cover of about 20-30 mm from the surface of the RC specimen, the helical bar was installed along the furrow. Then, ends of the reinforcement were fixed in a hole of 50 mm using high strength epoxy as if a vertical anchor to achieve sufficiently restraining force. In turn, the buried space was filled out using rapid hardening grout with a strength of 40 MPa, followed by an adhesive agent was used for enable to behave integrally between old and new cross section. Reinforcing the helical bar in the column is shown in Fig. 3 as schematic diagram.

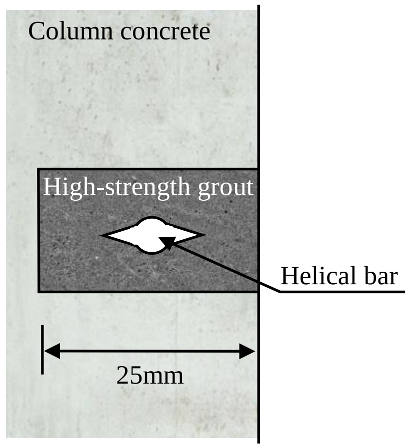

Figure 3. Reinforced section of setting helical bar

2.3 Plan to lateral force loading

To determine the load ratio in lateral force to the RC specimen, the yield displacement was verified through the control specimen, of which a value of the displacement(δy) was 22 mm. Based on the result, the drift level (δ/ δy) was 0.25% (5.5 mm), 0.5% (11 mm), 0.75% (16.5 mm), 1.0% (22 mm), 1.5% (33 mm), 2.0% (44 mm), 2.5% (55 mm), 3.0% (66 mm), 4.0% (88 mm) and 5.0% (110 mm). Fig. 4 show an experimental setup for cyclic loading adopted in this study.

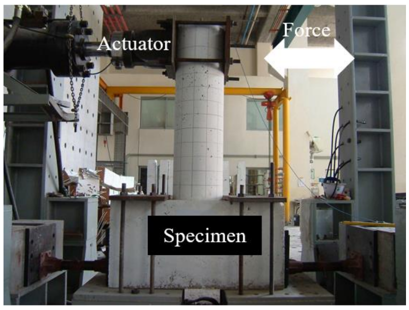

Figure 4. Experimental setup for cyclic loading test

3. EXPERIMENTAL RESULTS

3.1 Failure behavior by load stages

In all experiments, the same environmental conditions were maintained. During the course of the experiment, interesting surfaces of the specimens were focused and observed at every 100 mm from the base - column junction to the upper direction. All of the specimens were destroyed in the plastic hinge section and showed typical bending-shear failure behavior. There was a difference in the size and degree of the final failure depending on the presence of reinforcement and the variables of each experiment. However, in general, the cracks tended to be uniformly distributed throughout the initial period after the start of the experiment, and in the latter period, the cracks rapidly concentrated on the plastic hinge region, leading to the decline of the concrete covering and the detachment of the deep concrete. In the case of circular column specimens with reinforcement, the stiffness was increased due to the increase of lateral confining force of the column members due to the effect of stiffeners until the middle of the experiment, which was confirmed by increasing the ultimate displacement and decreasing the lateral displacement. The following is a summary of behavioral characteristics of each specimen.

Control specimen After flexing up to 109.6 kN of the maximum lateral load with a non-reinforced specimen, concrete sheath was removed from the test specimen at a height of 500 mm from the base joint, the section of the plastic hinge after 2.5% of the drift level, and rebars were exposed and severely bent in the same direction as the loading direction. In other words, due to the loss of concrete, some resistance to transverse loads was lost, and only the capitulation of axial rebar and the core concrete resisted. After the drift level 3.0%, the core restraint concrete inside the axial rebars was destroyed due to severe cracks, and its resistance to transverse loads was reduced rapidly. Since the large amount of core concrete loss occurred, the axial rebar has decreased its bonding performance with the concrete, causing a slip behavior, and showed the severe rebars buckling in the plastic hinge region, which is a 200 mm height section from the base joint. Fig. 5 shows specimen destroyed after the experiment.

Figure 5. Control specimen experimental result

H6 specimen The specimen is spiral-reinforced with a 6 mm diameter helical bar that extends the danger cross section from the base joint to a height of 500 mm. The spacing of the reinforcing helix is 100 mm. During the test, the maximum lateral load applied to the specimen was 105.2 kN, and after the drift level 3.0%, the helical bar was first cut by lateral load, and then the reinforcement was severely cut off. Due to the lateral confinement loss as a stiffener, it showed a drastic decrease in performance as in the case of unreinforced specimens. In this test condition, the sectional force of 6 mm diameter helical bar is weaker than that of unreinforced specimen in order to obtain high lateral load resistance. Fig. 6 shows specimen destroyed after the experiment.

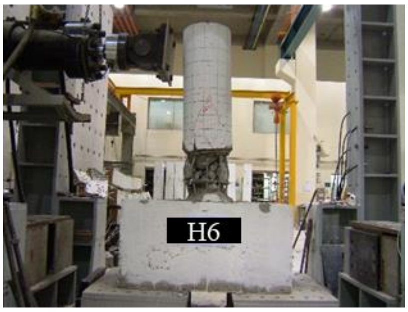

Figure 6. H6 specimen experimental result

H8 specimen It is a specimen reinforced up to 500 mm, the dangerous section, with a spiral gap of the column of 100 mm using a helical bar of 8 mm in diameter. The maximum lateral load of the specimen during the test was 130.9 kN. After the drift level 3.0%, the first reinforcing bar, helical bar, was cut by lateral load, but unlike the 6 mm diameter reinforcement, no additional cuts occurred elsewhere. Because of the reinforcement of the spiral, it is considered that even if the reinforcement is cut in one section, it does not cause severe damage to the entire reinforcement effect. Therefore, the remaining sheath showed less failure due to cracks, and the energy absorption capability for the lateral load even to the end of the experiment was demonstrated without the loss of lateral resistance. It is shown that the lateral load strength is reduced from 3.0% of the drift level and 60 mm of displacement, but is not sudden and is decreased smoothly. Fig. 7 shows specimen destroyed after the experiment.

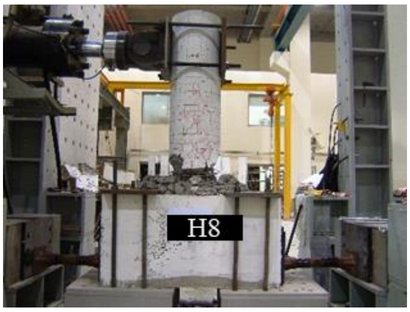

Figure 7. H8 specimen experimental result

H10 specimen It is a specimen reinforced up to 500 mm, the dangerous section, with a spiral gap of the column of 100 mm using a helical bar of 10 mm in diameter. It is a reinforcement to be used when a relatively large reinforcing performance is required, and it has a disadvantage that it is difficult to construct due to a high sectional force and is expensive. The maximum lateral load of the specimen during the test was 123.1 kN. It shows high energy absorption at more than 4.0% of the drift level. However, due to the use of reinforcement having too large section force relative to the performance of existing members, the main reinforcement was cut from the drift level lower than in the case of H8 due to its high lateral binding force. Fig. 8 shows specimen destroyed after the experiment.

Figure 8. H10 specimen experimental result

In H6 and H8, there was no amputation of the rebar. Because of the low lateral confinement force, concrete and steel bars did not behave at all during plastic deformation and slip behavior occurred. It is judged that the lateral binding force is applied from 8mm in diameter. Only H10, of all reinforced specimens other than H6, did not have a helical bar-section cut. When reinforcing material with a diameter of 10 mm was used, the shape was maintained until the subject reached failure and the axial rebars were cut inside the column, and sudden failure of the reinforced bar was shown compared to the degree of external failure. The fracture of the cast iron was found to be at a drift level of 4.0%, which is faster than the other specimens. As the lateral binding force due to reinforcement increases, it is believed that the strength development of the confined concrete has improved, thus failing to induce ductile behavior and resulting in brittle fracture. Table 2 shows the results of the characteristics of each specimen by each loading cycle.

Table 2. Behavior property of entire specimens

		Specimens			
		Control	H6	H8	H10
Drift Level (%)	0.25	◎	◎	◎	◎
	0.5	●○	●		●■
	0.75	■	■	●○	
	1.0		○	■	○□
	1.5	□		□	◇
	2.0		□		
	2.5	◆	◇		◆
	3.0		☆◆	☆◆	
	4.0				★
	5.0			★	

◎ : Initial crack
● : Shear crack
○ : Diagonal crack
◆ : Axial main reinforcement exposure
★ : Axial main reinforcement cut-off
□ : Concrete cover fall-off
■ : Column joint crack
◇ : Helical bar exposure
☆ : Helical bar cut-off

3.2 Load-displacement envelope

The envelope was created by deriving the maximum lateral load for each displacement from the load - displacement curves obtained through the experiment. The area formed with the x-axis below the graph is considered to be the ductile strength of a structure that can absorb external energy in the event of an earthquake, at a envelope consisting of displacement of the transverse axis and lateral load of the longitudinal axis. It can be seen that the performance is drastically degraded from the drift level of 2.5% (55 mm) as compared with the Control specimen which is not reinforced. All of the reinforced specimens show a difference in magnitude, but generally show an improvement in reinforcing performance after this section. Fig. 9 is the load-displacement envelope of the entire specimen displayed on one coordinate. At the load-displacement envelope obtained when the reinforcement diameter is variable, with all the reinforcement spacing of 100 mm, the performance of the 8 mm diameter reinforcement was best demonstrated. It is shown that the reinforcement spacing of the 8 mm diameter reinforcing materials with the best performance is different from the reinforcing spacing in the envelope test to improve both stiffness and ductility.

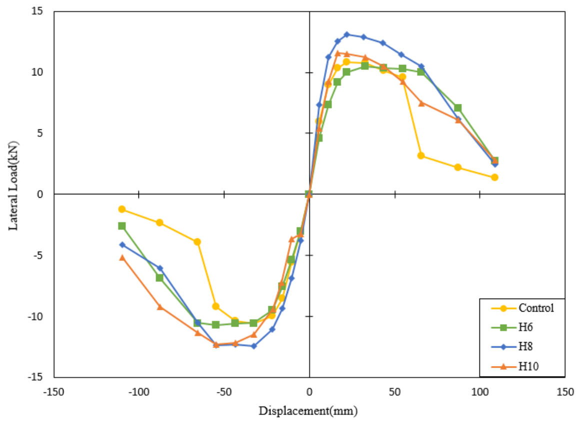

Figure 9. Lateral load – Displacement envelope of all specimens

4. CONCLUSIONS

The seismic performance for the specimen simulated circular bridge pier was evaluated by quasi-static experiments after reinforcement using helical bar. The conclusions of the present works are summarized as follows.

(1) Reinforcement of the helical bar to piers effectively inhibited the spalling of cover concrete arising from the failure by increasing the lateral displacement of the column (i.e., Drift level). Due to this phenomenon, the core restraint effect of the concrete was continued at a certain level after the column failure (109.6 kN), and eventually the specimen was collapsed when the lateral load reached at 130.9 kN.

(2) The actual failure of RC specimens with the helical bar appeared within the reinforced section of the pier (500 mm from the foundation), which would induce the ductile failure of the column due to the reinforcing effect. The further reinforcement for the broad area of the bridge piers seems to improve the resistance against earthquake by preventing the non-uniform loading, but it can result in an uneconomical and oversized design.

(3) For effective seismic reinforcement, it is necessary to select an appropriate level for reinforcement using a helical bar, considering the

amounts of longitudinal steels in the pier. The specimen using the helical bar with a diameter of 6 mm exhibited a lower ductility, while the case of 10 mm diameter showed an over-reinforcement effect. It should be cautious in the use of the helical bar for reinforcing bridge piers due to behavior of brittle fracture resulted from over-reinforcement.

5. REFERENCES

[1] Lee, H. M., Baek, K. L., Kim, J. H., Earthquake Occurrence Frequency and Magnitude Analysis for South Korea on the Basis of Ground-Observed Data, Journal of the Korean Society of Hazard Mitigation, 14 (2015) 268-268.
[2] Korea Meteorological Administration website : http://www.weather.go.kr/weather/earthquake_volcano/domestictrend.jsp (accessed 19.06.29).
[3] Design Code for Highway Bridges in Korea, Ministry of Land, Transport and Maritime Affairs, 2010.
[4] Anil K. Chopra, “dynamic of structures theory and application to earthquake engineering”, Prentice Hall, Pakistan, 2001.
[5] Chung, Y. S., Park, J. H., Park, H. S., Seismic Performance Evaluation and Enhancement of Circular Reinforced Concrete Bridge Piers by Pseudo Dynamic test, Journal of the Korean Society of Civil Engineers, KSCE, 22 (2002) 499-509.
[6] M. J. N. Priestley, F. Seible, G. M. Calvi., Seismic Design And Retrofit Of Bridges, John Willey and Sons, Inc., New York, 1996.
[7] Chung, Y. S., Park, J. H., Park, H. S., Seismic Performance Evaluation and Enhancement of Circular Reinforced Concrete Bridge Piers by Pseudo Dynamic test, Journal of the Korean Society of Civil Engineers, KSCE, 22 (2002) 499-509.
[8] Kim, J. B., Won, Y. S., Cho, C. H., An Experimental Study on the Structural Behavior of Reinforced Concrete Columns Rehabilitated with Epoxy-Bonded Steel Plates, Journal of the Korea Institute for Structural Maintenance and Inspection, KSMI, 3(3) (1999) 269-277.