Ductility Assesment of Damaged RC Bridge Piers w with Lap-Spliced Bars

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ABSTRACT

This research is to evaluate the seismic performance of reinforced concrete bridge piers with lap-spliced longitudinal reinforcement steels in the plastic hinge region, and to develop the enhancement scheme of their seismic capacity. Six circular columns of 0.6m diameter and 1.5m height were made with two confinement steel ratios. They were damaged under series of artificial earthquakes that could be compatible in Korean peninsula. Directly after the pseudo-dynamic test, damaged columns were retested under inelastic reversal cyclic loading simultaneously under an axial load, $P=0.1f_{ck}A_g$, and residual seismic performance of damaged columns was evaluated. Test results show that RC bridge piers with lap-spliced longitudinal steels behaved with minor damage even under artificial earthquakes with 0.22g PGA, but failed at low ductility subjected to the subsequent quasi-static load test. This failure was due to the debonding of the lap splice. The specimens externally wrapped with composite FRP straps in the potential plastic hinge region showed significant improvement both in flexural strength and displacement ductility.

1. INTRODUCTION

This experimental study was undertaken to evaluate the performance of reinforced concrete columns enhanced by different composite materials. Six test specimens in the aspect ratio of 2.5 were made with following test parameters: two confinement ratios, lap splices, and three retrofitting FRP materials. To provide different levels of transverse confinement, test specimens were designed in accordance with the nonseismic design code and the limited ductile design code. Since the placement of lap splices of longitudinal steels in bridge piers are sometimes practically unavoidable, four test specimens were made with 50% lap splice and three of them were retrofitted using glassfiber sheet, aramid sheet and carbon sheet, respectively. Six RC columns were damaged under the pseudo dynamic test, and then retested under the quasi static test. The damage was incurred considering the probable seismic ground motion in Korean peninsula. This is why it is very important to estimate the residual seismic performance of RC bridge piers after experiencing series of low and moderate earthquakes. Test results show that FRP could be effective retrofitting materials for the seismic enhancement of damaged RC bridge piers.

2. TEST PROGRAM

Six circular test columns with an aspect ratio of 2.5 were made with 0.6m diameter and 2.4m height. D16 deformed steel was used as longitudinal steel in RC test specimens, of which confinement steels were laterally used with D10 deformed steel. The achieved compressive strength, f_c', of concrete was 246 kgf/cm^2. Max. aggregate size is 25 mm. As shown in Fig. 1, nonseismic test specimen was designed to model existing roadway bridge columns non-seismically designed based on the pre-1992 design code. Limited ductile test specimen was designed with a limited ductility. Table 1 shows details of all teat specimens. For four test specimens, DN-SP05-R0, RA, RC, RG of Table 1, the longitudinal reinforcing steels of the column were

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extended into the footing using starter bars that were lapped with the main longitudinal steels of the column over a length of $0.007f_yd_b$, i.e., 270 mm. Three columns, DN-SP50-RA, RC, RG, were strengthened using the K-49, SK-N300, SEH-51 of which tensile strength are 2,058 MPa, 3,497 MPa and 549 MPa, respectively. The required thickness of glass, carbon and aramid fiber sheets were computed as 1.42mm, 0.39mm and 0.40mm, respectively. Three nonseismic test specimens with 50% lap splice were wrapped with two layers of fiber sheets in 750mm above from the top of the footing, because test specimens were thought to be in flexural-shear failure mode.

The test setup was designed for testing column-footing assemblages subjected to the combining axial and lateral loadings. Two independent loading systems were used to apply the load to the specimens. First, the axial load of 67.8 tonf was applied to the top surface of column. Next, the lateral forces were applied to the column. Each column was instrumented to monitor the applied displacement and corresponding loads and deformations. Measurements were obtained through two instrumental equipments: the calibrated load cell and displacement transducer of the actuator and inclinometers mounted on the plastic hinge region of the column to measure the curvature.

The Test was conducted two step. First step is the pseudo dynamic test to damage RC bridge piers and next step is the quasi-static test to estimate the residual seismic performance of damaged RC bridge piers. The applied moderate artificial earthquake is proposed in Korea Highway Corporation. Peak ground acceleration for four input ground motions are 0.0803g, 0.11g, 0.154g, and final 0.22g for 200 years, 500 years, 1000 years, and 2000 years of the return period, respectively. Directly after the pseudo dynamic test, the quasi-static test was carried out in a displacement-controlled way. ±0.25%, ±0.5%, ±1.0%, ±1.5%, ±2.0%, ±2.5%, ±3.0%, ±4.0%··· and ending the final drift level at failure. The drift level is computed as the ratio of the input displacement to the column height.

Table 1 Characteristics of test specimens

Classification	Lap-Splice	Nomenclature	Retrofit	Confinement Steel Ratio (%)	Confinement Steel Space(cm) PHR/NPHR	Axial Force (tonf)
Nonseismic Design	0%	DN-SP00-R0	None	0.23	23 / 23	$0.1f_{ck}A_g$ =67.8
	50%	DN-SP50-R0				
		DN-SP50-RG	SEH-51			
		DN-SP50-RA	K-49			
		DN-SP50-RC	SK-N300			
Limited Ductile Design	0%	DL-SP00-R0	None	1.08	8.2 / 10	

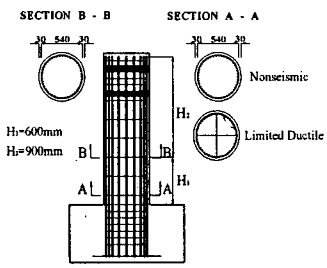
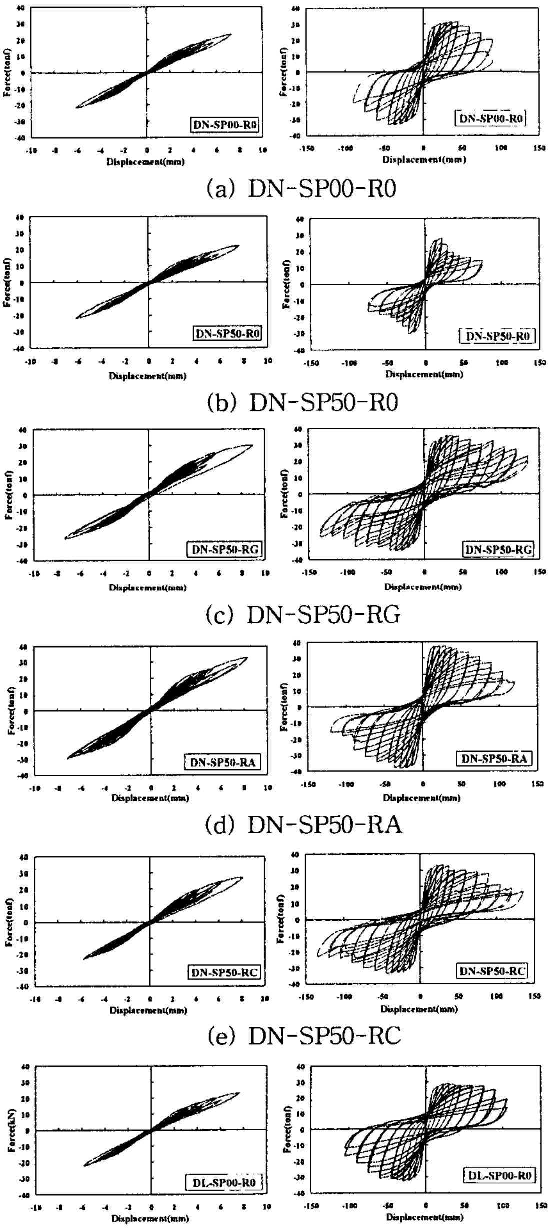


Fig. 1 Test specimen details

3. TEST RESULTS

Hysteretic behaviours of all test specimens both under pseudo dynamic test and Quasi-Static Test are shown in Figs. 2~3. Left figures of Figs. 2 and 3 show results of pseudo dynamic test that all specimens were almost linearly behaved up to the earthquake motion with 0.22g PGA, regardless of different confinement. Three retrofitted specimens have higher lateral force than those of the corresponding non-retrofitted specimens(DN-SP50-R0). Figures 2~3(a, b) show that nonseismic test specimen (DN-SP00-R0) without lap splices developed more ductile hysteresis loops than nonseismic test specimen (DN-SP50-R0) with 50% lap splice. As shown in Figs. 2~2(b), (c), (d), and (e), it was observed that the fiber sheets remarkably increased the displacement ductility. In addition, Figs. 2~3(a) and (f) showed that test specimens with more transverse reinforcement steels could have higher displacement ductility. The lap-spliced specimen (DN-SP50-R0) showed a rapid decrease of the strength, while the other specimen (DN-SP00-R0) without lap splice showed a gradual decrease of the lateral strength. Figure 2~3(b~e) show the effect of retrofitting material, which considerably increases the strength and the displacement. ductility of retrofit columns with lap spliced bars to reach the seismic capacity of the limited ductile test specimen, L-SP00-R0.



(a) DN-SP00-R0

(b) DN-SP50-R0

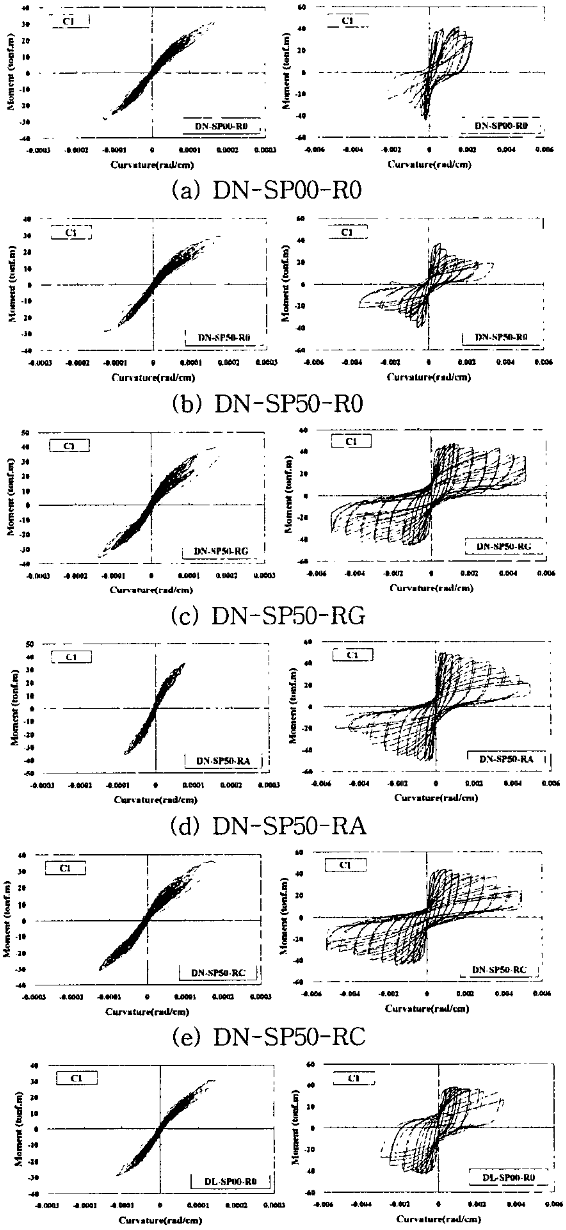
(c) DN-SP50-RG

(d) DN-SP50-RA

(e) DN-SP50-RC

(f) DL-SP00-R0

Fig. 2 Lateral Force-Displacement Hysteresis Curve



(a) DN-SP00-R0

(b) DN-SP50-R0

(c) DN-SP50-RG

(d) DN-SP50-RA

(e) DN-SP50-RC

(f) DL-SP00-R0

Fig. 3 Moment-Curvature Hysteresis Curve

Table 2 show the test result and displacement and curvature ductility. The ultimate displacement was defined as the experienced maximum displacement before the fracture point when longitudinal or confinement steel exceed its fracture state, or the strength on the descending branch of the force-displacement envelope curve becomes less than $0.85V_{max}$. The yield displacement Δ_y was the displacement corresponding to V_y, which was computed by extrapolating a straight line from the origin through $0.75V_{max}$. The displacement ductility and curvature were computed in Table 2. Compared to the non-seismic specimen (DN-SP00-R0), the limited ductile specimen (DL-SP00-R0) showed an increase of the ultimate displacement by 39.4%, as shown in Table 2. A significant reduction of the displacement and curvature ductility were observed for test specimens with lap splices in longitudinal steels. Composite fiber sheets for retrofitted specimens (DN-SP50-RG, RA, RC) increased the displacement ductility about 1.8~2.4 times with respect to the corresponding reference test specimen(DN-SP50-R0). The displacement ductility ratio of lap-spliced test specimen(DN-SP50-R0) was significantly reduced to approximate 1.5 times of that of the reference specimen(DN-SP00-R0).

Table 2 Displacement and Curvature Ductility

Specimen	Displacement (mm)		Curvature (rad/cm)		Ductility	
	Yield	Ultimate	Yield	Ultimate	Displacement	Curvature
DN-SP00-R0	10.82	66.00	0.00025959	0.00203	6.10	7.82
DN-SP50-R0	9.82	24.08	0.00021185	0.00089	2.45	4.22
DN-SP50-RA	9.50	70.00	0.00019800	0.00250	7.37	13.16
DN-SP50-RC	11.19	74.93	0.00021782	0.00337	6.70	15.47
DN-SP50-RG	10.65	88.00	0.00022081	0.00293	8.26	13.27
DL-SP00-R0	10.13	92.00	0.00020589	0.00326	9.08	15.81

4. CONCLUSIONS

a) Even under the 0.22g earthquake motions in the pseudo dynamic test, test specimen with lap-spliced longitudinal steels behaved with minor damage.
b) Nonseismically designed RC bridge piers, with lap splice of longitudinal reinforcement steels in the plastic hinge region, failed at significant low displacement and curvature ductility.
c) Retrofitting material considerably increased flexural strength and displacement ductility of retrofit columns with lap spliced bars, which showed similar seismic capacity of the limited ductile specimen.

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