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Experimental Study on Seismic Performance of Prestressed Concrete Columns

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I. Introduction

Introducing prestress into flexural members has some definite advantages, such as greatly increasing serviceability and restoration capability. Therefore excellent seismic performance could be obtained by introducing the prestress into a concrete column in such a way that serviceability must not be decreased and that residual displacement must be kept small after the earthquake. In order to investigate the utilization of vertical prestressing in bridge piers, a systematic research has been carried out. Seventeen single column type specimens were made for the experiments of reversed cyclic loading test. The reversed cyclic loading tests showed that reinforced concrete columns with appropriate prestress have enough ductility and remarkably decrease the residual displacement.

This paper describes the results of the experiments and the evaluation of seismic performance achieved by introducing prestress into a concrete column.

II. Outline of Specimens and Experiments

The specifications of the specimens are shown in Table 1 and the typical reinforcing bar and prestressing tendon layouts are shown in Fig. 1 And the mechanical properties of the steels are shown in Table 2. The vertical re-bars were basically arranged for RC specimens to satisfy the required bending strength. For PC specimens some of re-bars were replaced with prestressing tendons in accordance with the required prestress level. The prestressing tendon is tensioned up to 50 percent of the yield strength. In the vertical direction, the constant axial force was applied to each specimen by using hydraulic jack. The lateral reversed cyclic load was applied by the push-pull type hydraulic jack.

Table 1 Specifications of Specimens

Specimen No.	Cross Section	Reinforcing bars	Prestressing tendons	Bond Condition	Shear reinforcement	Axial stress	Concrete compressive strength	Prestress	Flexural Capacity (kN)
S-1		32D13	--	--				--	194.7
S-2		16D13	4*SWPR7B12.7	Bonded				2MPa	175.3
S-3		16D10	8*SWPR7B12.7		D6@3cm	1MPa	35MPa	4MPa	193.9
S-4				Unbonded					188.9
S-5	Solid	8D10	8*SWPR19-17.8	Bonded	D10@4cm			8MPa	277.3
S-6							60MPa		311.6
S-7		32D13	--	--				--	233.9
S-8		16D13		Bonded	D6@3cm		35MPa		222.5
S-9		16D10	8*SWPR7B12.7	Unbonded		4MPa		4MPa	224.3
S-10				Bonded	D10@4cm		60MPa		249.8
S-11		8D10	8*SWPR19-17.8					8MPa	335.4
S-12		32D13	--	--				--	185.6
S-13		16D10	4*SWPR7B12.7	Bonded		1MPa	35MPa	4MPa	125.6
S-14	follow	8D10	4*SWPR19-17.8		D6@3cm			8MPa	152.5
S-15		32D13	--	--				--	209.4
S-16		16D10	4*SWPR7B12.7	Bonded		4MPa	60MPa	4MPa	160.6
S-17		8D10	4*SWPR19-17.8					8MPa	188.4

III. Results of Reversed Cyclic Loading Tests

1. Hysteresis Characteristics and Failure Conditions

Fig. 2 shows the load-displacement curve for the representative specimens. The RC specimens have a typical spindle-shaped hysteresis. While for the PC specimens, the residual displacement is smaller than that of RC specimens

Table 2 Properties of Re-bar and Prestressing Tendon

Steel type		Yield strength (MPa)	Tensile strength (MPa)	Young's modulus (MPa)
Reinforcing bar	D6(SD345)	387	566	
	D10(SD345)	401	565	2.06E+05
	D13(SD345)	391	567	
Prestressing tendon	SWPR7B12.7	1753	1935	1.91E+05
	SWPR19-17.8	1790	1967	1.90E+05

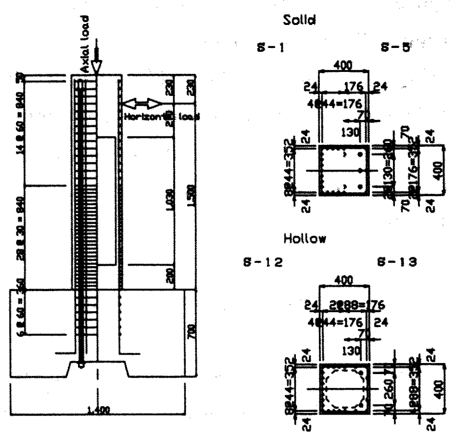

Fig. 1 Detail of Specimen

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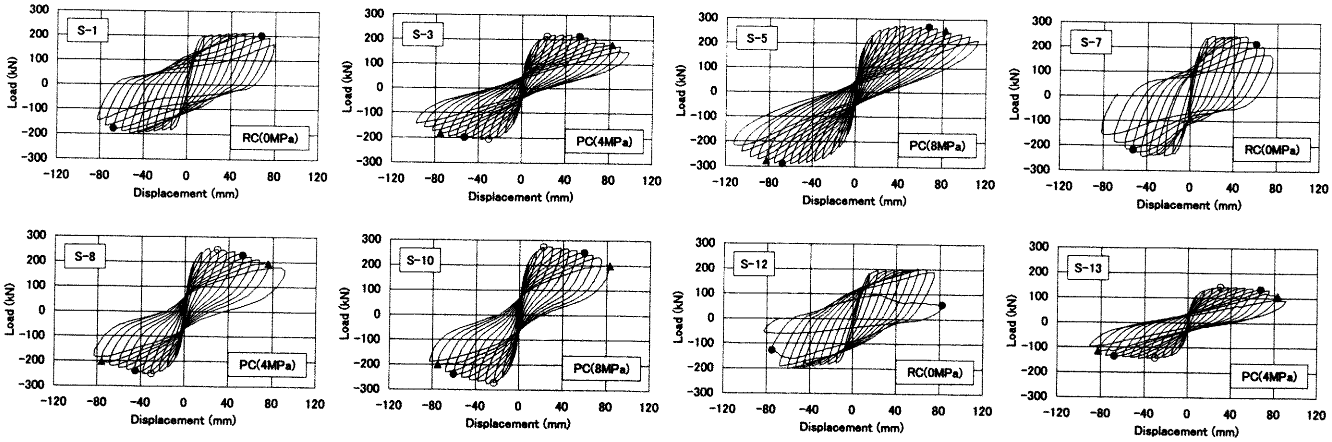
Keywords: prestressed concrete, column, seismic performance, bending behavior, ductility



○ : PC-steel yielding, ● : re-bar buckling, ▲ : re-bar breaking, (): Level of introduced prestress

Fig. 2 Experimental Result of Load-Displacement

and the hysteresis during unloading tends to strengthen their origin-oriented behavior depending on the applied prestress level. For the RC specimens, the applied load decreased rapidly after the buckling was occurred in the vertical reinforcement. For the PC specimens, however, no rapid decrease was observed in the applied load even after the buckling of the reinforcement. Furthermore, yield of the prestressing tendon tended to be delayed with increasing the amount of prestressing tendon.

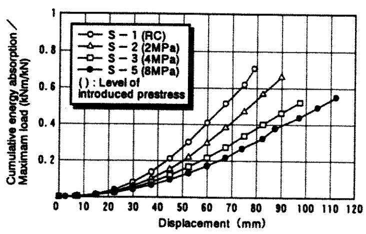


Fig. 3 Cumulative Energy Absorption

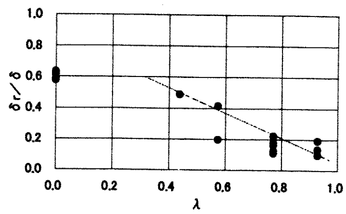


Fig. 4 Relationship between Residual Displacement Ratio and Sharing Factor of Prestressing Tendon

2. Effect of Level of Introduced Prestress

Fig. 3 compares the cumulative energy absorption of the individual specimens with the level of prestress. The cumulative energy absorption decreased as the level of prestress increased and this decreasing ratio did not largely varied with displacement.

Fig. 4 shows the relationship between residual displacement ratio (residual displacement δr/loading point displacement δ) at 3/100 radian state and the sharing factor of prestressing tendon λ, as defined by the following :

$$\lambda = (Aps*Fpy)/(As*Fsy+Aps*Fpy) \quad \cdots\cdots \quad (1)$$

where Aps = Area of prestressing tendons
Fpy = Yielding stress of PC steel
As = Area of reinforcing bars
Fsy = Yielding stress of reinforcing bars

The residual displacement ratio of RC specimens is about 60%, and the residual displacement ratio of PC specimens decreases as λ increases. But when λ is less than about 40%, the residual displacement ratio is same as that of RC specimens. Thus, columns designed on the condition that λ is more than about 40% are expected to perform better restoration capability after an earthquake than RC columns.

IV. Conclusions

Reversed cyclic loading tests were conducted to investigate the basic earthquake resistant performance of prestressed concrete bridge columns. The following conclusions were drawn.

(1) The applied load to the PC specimens did not drop significantly even after the vertical reinforcement buckling, but they showed ductile behavior. While the applied load to the RC specimens dropped rapidly after the vertical reinforcement buckling. Furthermore, for the PC specimens, the hysteresis curve showed that the origin-oriented behavior during unloading increased as the level of the introduced prestress.

(2) As the level of the introduced prestress, the energy absorption decreased. However, the higher sharing factor of prestressing tendon made the residual displacement smaller. And, columns designed on the condition that λ is more than about 40% are expected to perform better restoration capability after an earthquake than RC columns.