第２回地震時保有耐力法に基づく橋梁の耐震設計
に関するシンポジウムの講演論文集（1998年12月）

SEISMIC BEHAVIOR OF PARTIALLY PRESTRESSED CONCRETE PIERS

Wael ZATAR[1]. Hiroshi MUTSUYOSHI[2]

[1] Member of JSCE, MSc., Dept. of Civil Eng., Saitama University (338-8570 Urawa shi, 255 Shimo-Okubo)
[2] Member of JSCE, Ph.D., Dept. of Civil Eng., Saitama University (338-8570 Urawa shi, 255 Shimo-Okubo)

1. ABSTRACT

Highway concrete bridges commonly consist of prestressed concrete (PC) girders and reinforced concrete (RC) piers [1]. The benefits of using the RC piers are to obtain high energy dissipation capacities and high values of ductility factor during earthquake excitations. During the Hyogo-ken Nanbu 1995 earthquake, some bridge piers suffered from severe damage. Additionally, high residual displacement values [2] were observed for the same piers after the earthquake. Yet not enough researches have been conducted aimed to achieve lower residual displacements. Consequently, the objective of this study is to reduce such residual displacements.

The usefulness of using the PC elements are to obtain low dead loads and achieve low values of residual displacements while they suffer from low energy absorption capacities and ductility factor. As a consequence, a new technique is being examined in this study in which partially prestressed concrete (PRC) piers [3] were implemented in such a way to make a compromise between the merits and demerits of both RC and PC piers.

Four specimens representing such PRC piers were examined using reversed cyclic loading and pseudo-dynamic tests in which amplified excitations of the 1995 Hyogo-Ken Nanbu earthquake (NS direction) were used. Two specimens are control RC specimens while the other two specimens are PRC pier specimens. Experimental results in terms of hysteretic load-deformation characteristics and time histories were obtained. The plastic deformability in terms of ductility factor was also examined. The study revealed that the usage of PRC piers has a tendency to reduce the residual displacements after earthquake excitations.

2. TEST SPECIMENS

Four specimens were tested in this study. The main difference between specimens is the existance of ungrouted prestressing tendons. Details of specimens are shown in Table 1 and in Fig. 1. Concrete compressive strength is about 36 N/mm^2. Yielding stresses of reinforcement are 401 N/mm^2 for D13 and 360 N/mm^2 for D10 while the yielding stress of prestressing tendons SBPR12.7 is 1421 N/mm^2. Specimens were tested using the test setup shown in Fig. 2. The bottom parts of specimens were rigid enough to represent footings for these piers. All specimens were fixed to the testing floor.

Table 1: details of specimens

Spec.	Reinforcing bars		Prestressing tendons		Test
No.	Rein.	(As/bd) %	Tendons	(Aps/bd) %	Type
S-1	32D13	2.65	------	------	Cyclic
S-2	16D10	0.79	8D12.7	0.63	Cyclic
S-1P	32D13	2.65	------	------	PSD
S-2P	16D10	0.79	8D12.7	0.63	PSD

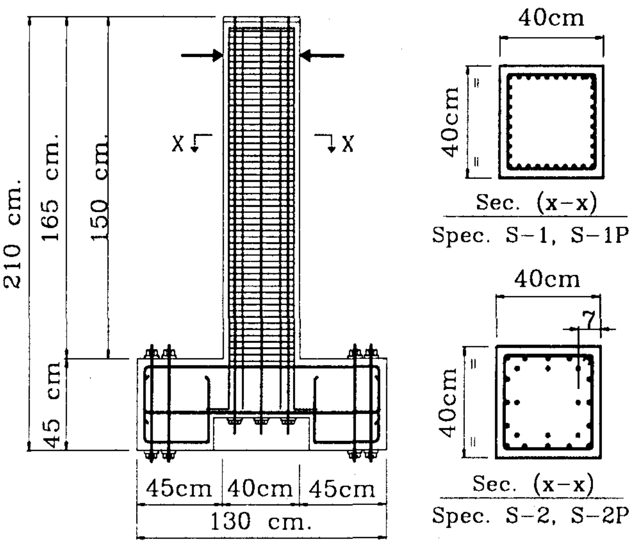

Fig.1: Details of specimens

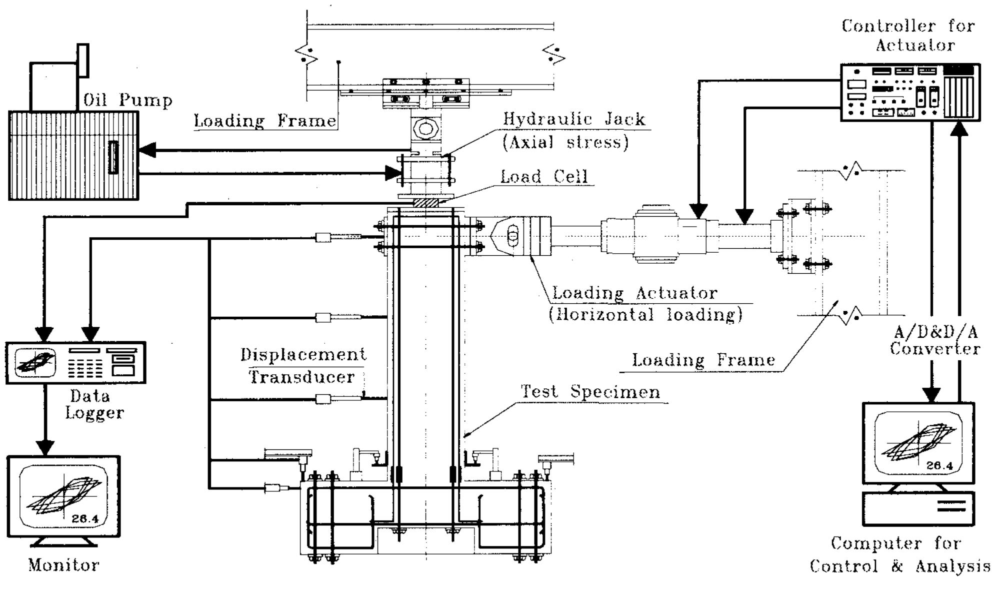

Fig.2: Loading setup and instrumentation

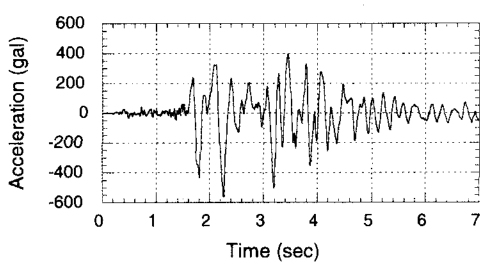

Fig. 3: acceleration for specimen S-1P

3. EXPERIMENTAL PROCEDURES

In order to obtain inelastic characteristics of PRC piers, reversed cyclic loading tests were conducted for specimens S-1 and S-2 and pseudo-dynamic (PSD) tests [4] were conducted for specimens S-1P and S-2P. In the PSD tests, load was applied quasi-statically during the test and the restoring force was measured directly from the loading test system. The used ground acceleration was the modified Hyogo-Ken Nanbu 1995 (NS direction) earthquake excitation. Time scale was kept the same as the original one while the maximum acceleration was considered as 563 gal (Fig. 3) and 474 gal for S-1P and S-2P respectively. The time interval was taken as 0.01 sec. An axial stress level of 1 Mpa was applied at the top of the pier specimens. The used testing system consisted of the specimen, loading actuator, loading jack, loading cell, displacement transducers, data logger, personal computer that analyzes the inelastic earthquake response and controls the input data and another personal computer that controls the output data.

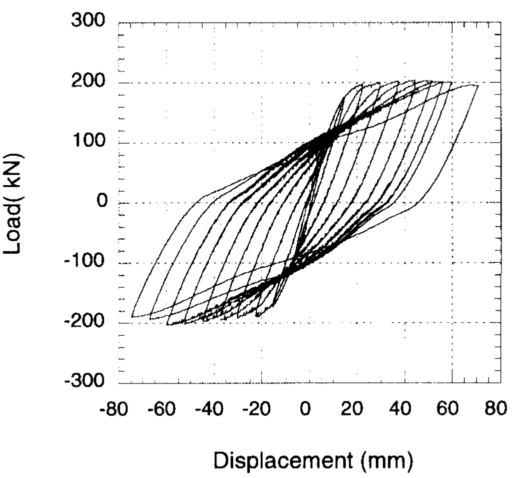

Fig. 4: Load-displacement curve for specimen S-1

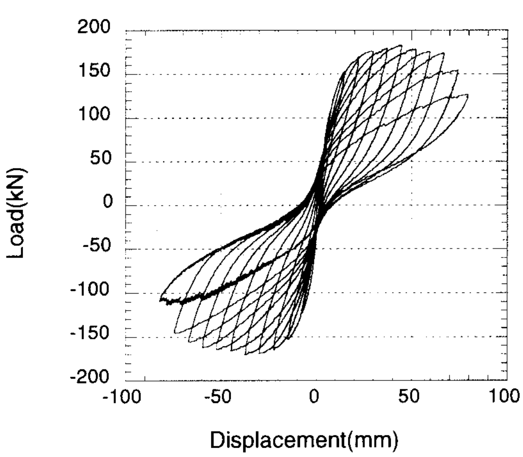

Fig. 5: Load-displacement curve for specimen S-2

4. CYCLIC TEST RESULTS

Behavior of specimens is presented graphically in the form of column shear force versus tip deflection relationships. For all specimens, failure occurred at expected plastic hinges located nearby footings.

First sign of distress in specimens were flexural cracks formed in the expected plastic hinge locations.

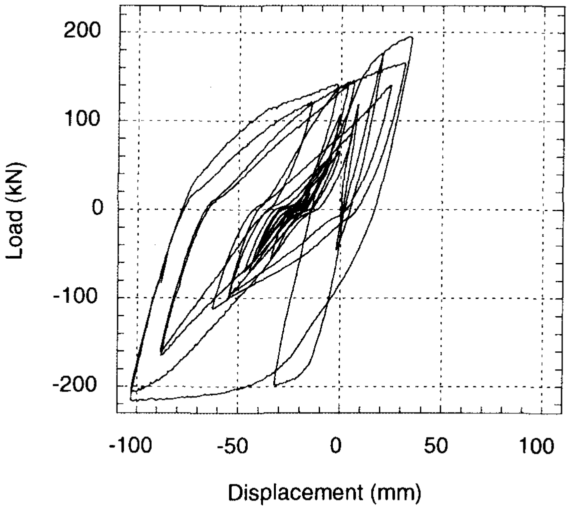

Fig. 6: Load-displacement curve for specimen S-1P

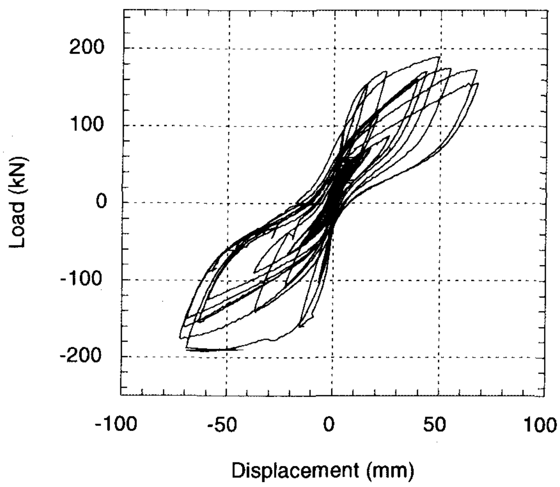

Fig. 8: Load-displacement curve for specimen S-2P

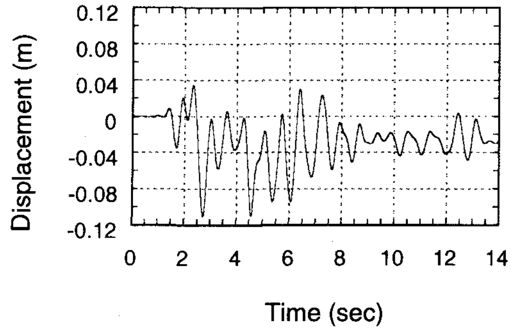

Fig. 7: Displacement time history for specimen S-1P

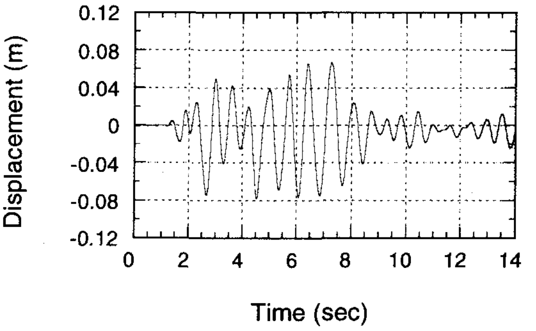

Fig. 9: Displacement time history for specimen S-2P

Ductility factor is defined here as the displacement corresponding to either 80 percent of P_u or P_y, whichever is smaller, divided by yield displacement (where, P_u is the ultimate load while P_y is the yielding load of the cross section). Yield displacement is defined as intersection of stiffness after cracking and stiffness after yielding (strain hardening portion). Because of the existence of closely spaced transverse ties, crushing was delayed inside core concrete and buckling occurred only between two successive ties in the plastic hinge region. Both specimens S-1 and S-2 failed in flexural mode.

It was found, for RC specimen S-1, that fat hysteretic load-displacement curve was obtained allowing for high energy dissipation during cycles. No pinching was recorded and very stable loops were obtained. Almost no strength degradation was observed as can be seen in Fig. 4. Ductility factor at both directions of loading is as high as 9.42.

Fig. 5 shows the hysteretic load-displacement curve of specimen S-2. Pinching [5] manifested in marked change of slope during reloading was clear. Pinching can be attributed to the fact that prestressing tendons usually show marked elastic recovery even after considerable inelastic deformations. Consequently, energy absorbed during test cycles was less than that of RC specimen S-1. Residual tensile forces in PC tendons enabled to close previously opened cracks. Flexural crack widths were less than that of specimen S-1 that can be considered as a merit of using such PRC piers. Prestressing tendons yielded in the plastic hinge location when the tip displacement was equal to 68 mm after which strength degradation was clearly pronounced. Maximum attained ductility factor is about 7.83 that is lower than that of specimen S-1. Ductility factor reduction for specimen S-2 can be attributed to the low ratio of non-prestressing reinforcement exist in specimen S-2.

5. PSEUDO-DYNAMIC TEST RESULTS

Fig. 6 shows the load-displacement curve for specimen S-1P obtained from the pseudo-dynamic test. Stiffness degradation can be observed from the curve. The maximum displacement reached about 13.1 times the yielding displacement in the left side of the curve while it was about 4.5 times the yielding displacement in the right side of the curve, showing that the deformations occurred due to the earthquake excitation were drifting in the negative direction of loading. It can also be observed from the figure that high energy was dissipated during the test. Fig. 7 shows the displacement time history for S-

1P obtained during the test. The maximum attained displacement was about -0.11 m that occurred at the negative excursion after which the displacement time history showed a shift towards the negative side. At the end of the test a residual displacement of about -2.5 cm was observed.

Fig. 8 shows the load-displacement curve for specimen S-2P. It can be observed that softening occurred after unloading as a result of bauschinger effect of the reinforcing bars. Stiffness degradation during unloading was clear in both directions of loading. Also, pinching [5] was clear. Pinching can be attributed to marked elastic recovery of prestressed tendons even after considerable inelastic deformations. The maximum displacement reached about 8.22 times the yielding displacement in the left side of the curve while it was about 7.85 times the yielding displacement in the right side of the curve. Energy absorption was less than that of a comparable RC specimen S-1P. Flexural crack widths were less than that of specimen S-1P. The residual tensile forces in the PC tendons enabled to close previously opened cracks. Fig. 9 shows the experimentally obtained displacement time history. The maximum displacement was about -0.075 m. Although the difference between the maximum negative amplitude and the following positive amplitude is higher than that of a comparable one in Specimen S-1P, almost no shift of the response in the negative side was observed. Additionally, at the end of the test, the residual displacement was much smaller than that for specimen S-1P that can be considered as an advantage of using such PRC piers. On the other hand, damping was lower than that of RC specimen S-1P.

6. CONCLUSIONS

In order to clarify the inelastic response behavior of partially prestressed concrete (PRC) piers under severe earthquake, Four small-scaled specimens were tested. Specimen S-1 and S-1P were control RC specimens while specimens S-1P and S-2P were PRC specimens. Two specimens were tested using reversed cyclic loading tests while the other two specimens were tested using pseudo-dynamic tests. It can be concluded that the usage of PRC piers has the following merits and demerits:

1. The usage of PRC piers has the advantage of decreasing the residual displacement, as compared to RC piers, when excited with the Hyogo-Ken Nanbu (NS direction) 1995 ground acceleration.
2. The residual cracking patterns, after earthquake excitation, of PRC piers are better than that of ordinary RC piers. Reduced cracking widths can be obtained when higher values of prestressing tendons are used.
3. The damping for PRC piers is smaller than that of comparable RC piers.
4. A lower energy dissipation capacity, depending on the used relative ratio of prestressing tendons, is obtained. Consequently, the ratio of prestressing tendons, to be used, should be chosen in such a way that balances the merits and demerits.

ACKNOWLEDGMENT

This research work has been conducted under Prestressed Concrete Pier Research Project (Chairman: Prof. S. Ikeda) established in Japan Prestressed Concrete Engineering Association. The authors would like to acknowledge the cooperation provided by members of R/C lab. of Saitama university.

REFERENCES

[1] Priestley, M. J. N., Seible, F., and Calvi, G. M., : Seismic Design and Retrofit of Bridges, *John Wiley & Sons Inc.*,1996.

[2] Ito, T., Yamaguchi, T., and Ikeda, Shoji, : Seismic Performance of Reinforced Concrete Piers Prestressed in Axial Direction, *Proc. of JCI*, Vol. 19, No. 2, 1997, pp.1197-1202.

[3] Thompson, K., J., and Park, R., : Seismic Response of Partially Prestressed Concrete, Journal of the Structural Division, *ASCE, Vol. 106*, No. ST8, paper 15598, Aug., 1980, pp.1755-1775.

[4] Zatar, W., and Mutsuyoshi, H., : Dynamic Response Behavior of Prestressed Concrete Viaduct Under Severe Earthquake, *Proc. of JCI*, Vol. 19, No. 2, 1997, pp.429-434.

[5] Saatcioglu, M., : Modeling Hysteretic Force-Deformation Relationship for Reinforced Concrete Elements, Earthquake Resistant Concrete Structures, Inelastic Response and Design, *ACI SP-127-5*, 1991,p.153-198.