11th ICAAR / 11e CIRAG Québec 2000
11th International Conference on Alkali-Aggregate Reaction
11e Conférence Internationale sur les Réactions Alcalis-Granulats

STRENGTHENING METHOD FOR ASR AFFECTED CONCRETE PIERS USING PRESTRESSING STEEL WIRE

Kazuyuki Torii, Yoshiaki Kumagai
Department of Civil Engineering, Kanazawa University2-40-20 Kodatsuno,
Kanazawa, Ishikawa, Japan 920-8667

Yoshinori Okuda, Koji Ishii, Ken-ichi Sato
PS Corporation Co.Ltd.1-13-17 Kita-Otsuka, Toshima,
Tokyo, Japan 170-0004

ABSTRACT

The strengthening method using prestressing steel wire has been developed for ASR damaged concrete piers, which is presently named "PC confined method" in Japan. Reinforced concrete columns containing reactive andesitic aggregates were prepared in order to examine the effects of prestressing force on the confinement of the cracks due to ASR and the improvement of load-bearing capacity of ASR damaged concrete columns. The compression strength test was carried out for damaged concrete columns strengthened with and without prestressing steel wire.

From the results, it was found that the prestressing force given around the concrete column could effectively improve both the strength and the ductility of ASR damaged concrete column. Based on the experience of the laboratory test, the PC confined method was successfully applied in the strengthening of ASR damaged RC piers of the Toyokawa bridge in Japan.

Keywords: ASR, strengthening, prestressing steel wire, concrete pier, bridge, confinement effect, compression loading test, monitoring.

INTRODUCTION

After the Hyogo-ken Nanbu Earthquake in 1995, it has become a matter of concern to improve the seismic response ability of the old-type designed concrete piers (Okuda et al.1996). Now in Japan, the steel plate bonding method or the carbon fiber sheet bonding method is usually applied to the rehabilitation of concrete piers in the bridge, but these methods are not necessarily suitable to that for concrete structures deteriorated by ASR. With respect to the strengthening method for ASR damaged concrete piers, a new-type strengthening method with prestressing steel wire, PC confined method, has recently been developed. PC confined method can expect the following effects for the strengthening of ASR damaged concrete piers; (1) confining the cracks by prestressing force and decreasing the expansion of concrete, (2) increasing the ductility of concrete piers against the seismic force, and (3) securing the precast panel to concrete piers by pressuring forces and increasing the durability (The Institute of Structural Engineers 1992).

The purpose of this paper is to clarify the effects of the prestressing force around the column on the improvement of the load-bearing capacity of ASR damaged concrete column in compression strength test. The procedure of design and excution of the strengthening for the ASR damaged RC piers using PC confined method is also introduced.

EFFECT OF PRESTRESSING FORCE ON ASR CRACK CONFINEMENT

Mix Proportions and Exposure Condition

The cement used was the ordinary Portland cement with the equivalent Na_2O of 0.68%. An andesitic crushed stone from the Noto Peninsula in Ishikawa Prefecture was used as a reactive coarse aggregate ; the sand and the gravel from the Hayatsuki river as a non-reactive fine and coarse aggregate, respectively. The evaluation of alkali reactivity of the andesitic coarse aggregate according to JIS A 5308 was not innocuous ; soluble silica (Sc) and reduction in alkalinity (Rc) at the chemical method : 228 mmol/l and 131 mmol/l,respectively, expansion ratio at 6 months at the mortar bar test : 0.11%. The main reactive components identified in the texture of the andesitic crushed stone were volcanic glass and cristobalite. Mix proportions of concretes with and without reactive aggregates are presented in Table 1. Fig. 1 shows the dimensions of RC column which is 300 mm in diameter and 900 mm high. The D10 mm deformed bar and D6 mm round bar were used as a axial and hoop steel reinforcement of RC column, respectively.

TABLE 1: Mix Proportions of Concrete

Mix type	Slump (cm)	W/C (%)	Air (%)	s/a (%)	Unit Content (kg/m^3)				
					Water	Cement	Sand	Non-reactive Gravel	Reactive Gravel
N Mix.	8±2	53	2±1	42	164	308	784	1125	—
A Mix.	8±2	53	2±1	42	164	308	784	562	563

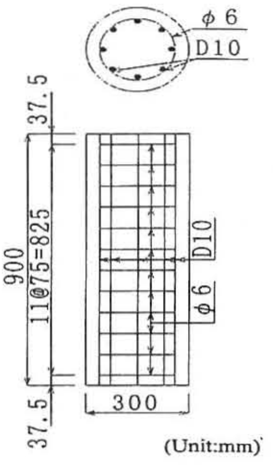

Fig. 1: Dimensions of RC column used in compression test

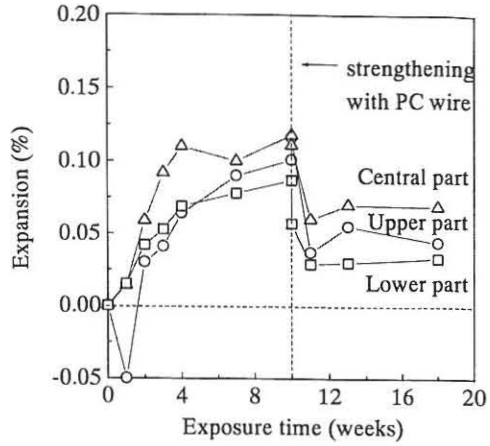

Fig. 2: Expansion behavior of column before and after strengthening

Measurement of Expansion Behavior and Load-bearing Capacity

RC columns were demolded at 3 days after placing the concrete, which was followed by the steam-curing at the condition of maximum temperature of 60℃ for 1 month in order to accelerate the expansion of concrete due to ASR. After the steam curing, RC columns were exposed outdoors. When the width of crack along the longitudinal steel reinforcement of RC columns attained to 0.2 mm, the column was strengthened with prestressing wire (SWPR2N) at the intervals of 75 mm, where the initial tensile stress induced was 20% of its yield strength. After strengthening, RC columns were exposed outdoors again, and the effect of confinement of cracks was investigated. After the steam-curing, contact gauge tips with a distance of 100 mm were attached on the surface of RC column, and expansion behavior was measured at the portions of upper, central and lower. After the outdoor exposure of a couple of months, the unconfined compression test was carried out using the testing machine with the maximum capacity of 1,000 tons. Axial stress-strain curves for RC columns were calculated by measuring the deformation of RC column by means of displacement apparatus. In the loading test, the load was held on at a constant strain rate until the stress of RC column had decreased to 70% of the maximum one.

Confinement Effect of ASR Cracks Using Prestressing Steel Wire

Fig. 2 shows the expansion behavior of RC column before and after strengthening using prestressing steel wire. RC column showed a significant expansion after they had been exposed outdoors, its expansion being 0.1% to 0.15% at the time which the strengthening was applied. With respect to the confinement effect of ASR cracks by strengthening, when RC column was prestressed, it shrank about 0.03%, which doubled after 1 week. This shows that the prestressing force given around RC column can effectively confine ASR cracks and reduce the expansion of concrete. Also, it is certified that the effect of initial tensile stress on the confinement of ASR cracks will gradually demonstrate with the time after prestressing.

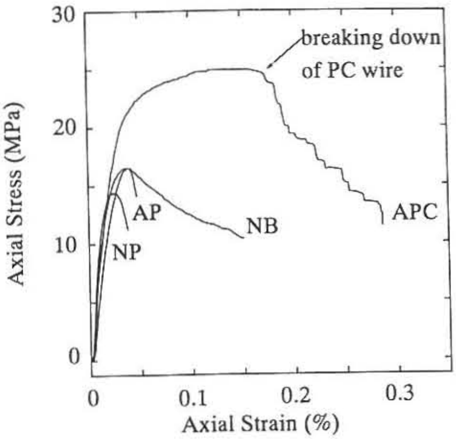

Fig. 3: Axial stress-strain curves in compression test for RC column

Fig. 4: RC column with the breaking down of PC wire at failure

Load-bearing Capacity of RC Column Strengthened with Prestressing Steel Wire

Fig. 3 shows axial stress-strain curves of RC column in compression test. Plain concrete column without steel reinforcement (type NP and AP) failed immediately when the stress had reached the maximum one. Plain concrete column with reactive aggregates (type AP) showed a little bit higher strength than that with normal aggregates (type NP), which resulted from the difference in the compressive strength of both concrete cylinders. RC column (type NB) showed the same maximum stress as type AP, but its stress gradually decreased after failure. On the other hand, RC column with prestressing steel wire (type APC) showed a quite different behavior in axial stress-strain curve. That is to say, the stress of RC column with prestressing steel wire gradually increased until the strain attained to 0.2%, although the stress-strain curve at the early stages of strain within 0.05% was very similar for type NB, and then it decreased along with the breaking down of prestressing steel wire. Fig. 4 shows the breaking down of prestressing steel wire at the final failure of RC column. This shows that the strength and ductility of ASR damaged RC column can be greatly increased by strengthening with prestressing steel wire due to the hoop confinement effect provided by a high yield strength of prestressing steel wire (Torii et al. 1998).

APPLICATION OF PC CONFINED METHOD TO ASR AFFECTED RC PIERS

Survey on ASR Affected RC Pier

The Toyokawa bridge, which is located in the highway in the Noto peninsula in Ishikawa prefecture, was constructed in 1979. It was found around 1990 that RC piers, which is 30 m high and a sguare shape of 2.5 m with wall structure, were severely deteriorated by ASR. Fig. 5 and 6 show ASR cracks occurred on the surfaces of the column and the beam beneath the shoes, respectively. The survey on the expansion behavior of RC piers showed that the crack width increased at the extention rate of about 0.2 mm per year, as shown in Fig. 7. Also, it was assumed from the results of expansion test in the saturated NaCl solution at 50℃ for the cores that the residual expansion capacity of concrete was still high although it had already passed about 20 years after the construction, as shown in Fig. 8.

Fig. 9 shows the relations between the ratio of the modulus of elasticity to compressive strength and compressive strength in the cores taken from the various posisions of RC piers. It was observed in ASR affected cores that the reduction in the modulus of elasticity was more significant than that in the compressive strength, which was dependent on the degree of ASR which was associated with the micro-climate condition around the wall, the beam and the footing.

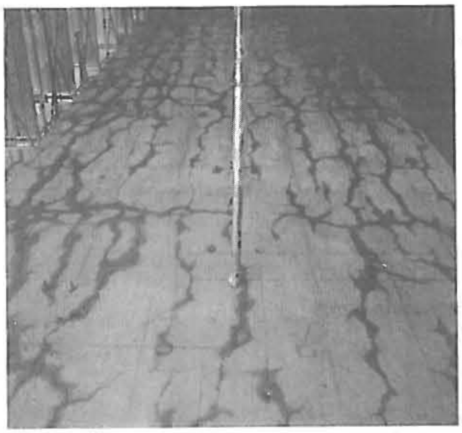

Fig. 5: ASR cracks occurred on the surface of the column

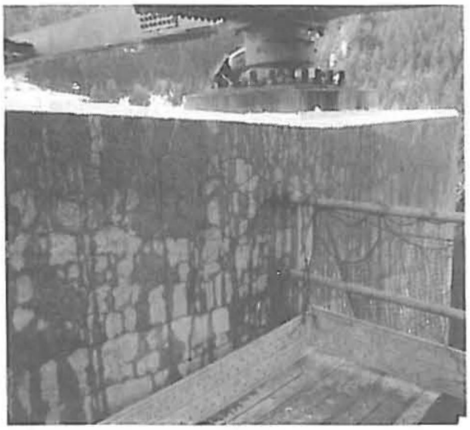

Fig. 6: ASR cracks occurred on the surface of the beam beneath the shoes

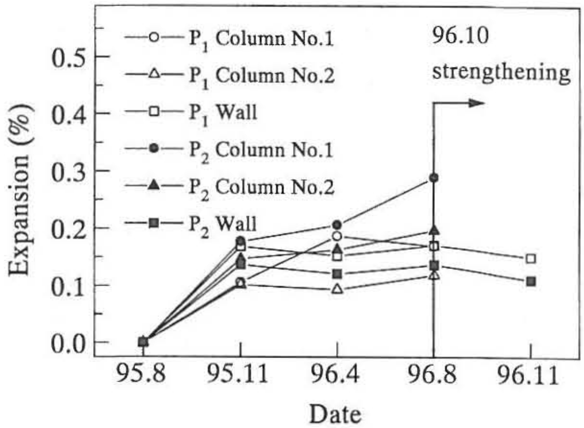

Fig. 7: Expansion behaviors of column and wall in P1 and P2 piers (Distance of measurement by contact gauge; 100mm)

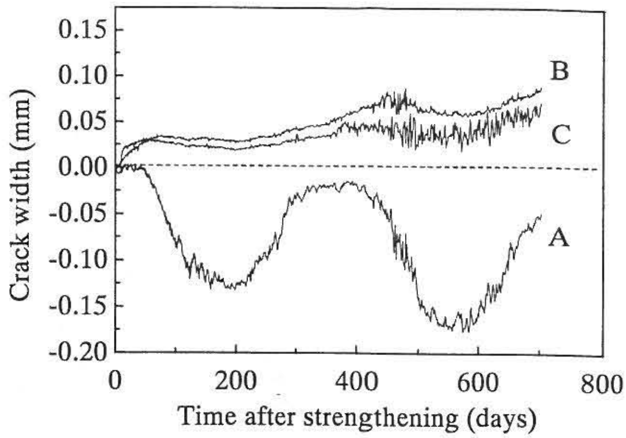

Fig. 14: Changes in crack width in RC pier

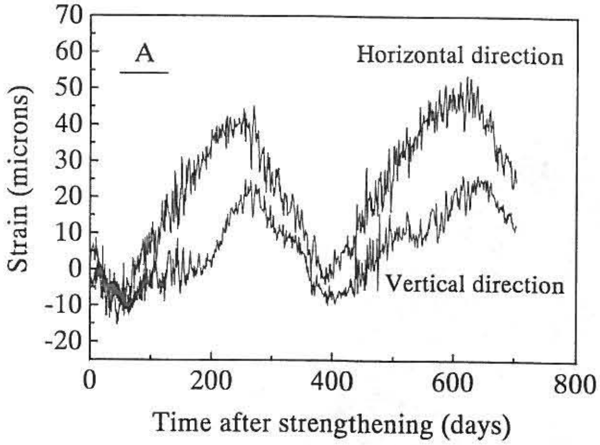

Fig. 15: Changes in strain induced in RC pier

strengthening work the change with time in the strain of in-situ concrete was monitored everyday for about 2 years and automatically filed in the data-recorder. Fig. 14 and 15 show the change in the strain induced in concrete and the crack width of RC piers. The strain of concrete in the filler section showed a cyclic change depending on the seasonal variations in temperature, but it maintained in the compression side for two years. On the other hand, the increase in the crack width after strengthening was effectively controlled, which was reduced to a quarter of the value measured before strengthening.

CONCLUSIONS

The new-type strengthening method using prestressing steel wire "PC confined method" was developed especially for ASR affected RC piers. From the experimental results of RC column strengthened by prestressing steel wire, it was concluded that the prestressing force given around RC column could confine the cracks due to ASR and increase both the strength and the ductility of RC column in the compression test. Based on the results of the laboratory test, the PC confined method was successfully adopted in the strengthening for ASR damaged RC piers of the Toyokawa bridge in the Noto peninsula in Ishikawa prefecture. After finishing the strengthening work of the Toyokawa bridge, the monitoring of both the induced stress in concrete and the confinement of cracks due to ASR is ongoing. The monitoring data for 2 years also have shown that the prestressing force given around the existing RC piers of the Toyokawa bridges is effectively controlling the extention of ASR cracks and the expansion of concrete.

ACKNOWLEDGMENTS

The authors give their thanks to Prof. Mitsunori Kawamura, Department of Civil Engineering, Kanazawa University, for his useful advise in the experiment and monitoring.

REFERENCES

Okada, K., Fujii, M., Yamaguchi, Y. and Imada, K., 1996. "Maintenance System for Highway Structures Damaged by ASR", Proc. of 10th Inter. Conf. on Alkali-Aggregate Reaction in Concrete, Melbourne, pp.995-1002.

Okuda, Y., Suzuki, Y., Mori, T., and Kubo, K., 1997. "Strengthening Method with PC Wires for Concrete Piers Damaged by ASR (PC Confined Method)", Concrete Journal, Vol.35, No.8, pp.9-14, (in Japanese).

The Institute of Structural Engineers, 1992. "Structural Effects of Alkali-silica Reaction-Technical Guidance on the Appraisal of Existing Structures-", SETO Ltd., London.

Torii, K., Okuda, Y., Ishii, K. and Kubo, K., 1998. "Strengthening Method with Prestressing Steel Wires for ASR-damaged Reinforced Concrete Columns", Proc. of 2nd Inter. RILEM/CSIRO/ACRA Conf. on Rehabilitation of Structures, pp.38-47.