Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.III)

5-3-10

IMPROVEMENT OF DEFORMABILITY OF HIGH-STRENGTH PRESTRESSED CONCRETE PILES

Seiji KOKUSHO[1], Akira WADA[1]
Shizuo HAYASHI[1], Katsumi KOBAYASHI[2]
Masahiro HORII[3] and Yasuo SAITO[3]

[1]Tokyo Institute of Technology, Tokyo, Japan
[2]Fukui University, Fukui, Japan
[3]Tokyo Technical Center, NIKKEN SEKKEI, Tokyo, Japan

SUMMARY

We have investigated the necessity of deformability in the plastic range for high-strengh prestressed concrete (PHC) piles under lateral force, and have developed a method for improving such deformability after testing 70 specimens since 1981. This paper shows that the use of PHC piles having large deformability results in savings in construction cost, and also shows an effective method for increasing the deformability of piles under the lateral and axial forces expected during large earthquakes.

INTRODUCTION

All structures of buildings in Japan have been designed in accordance with the "New Aseismic Design Code" since 1981. Under the code, the seismic bearing capacity required for a structure with large deformability in the elastic range is small. However, this new idea was applied only to the superstructure, not the substructure.

Meanwhile, it has been reported that the piles of some buildings in Japan suffered brittle rupture in earthquakes since 1978, although the incidence of such failures is hard to determine. A number of methods for improving the deformability of PHC piles have been proposed (Ref. 1) ~ 3)).

Against this background, the writers started to research the deformability of currently-used PHC piles in 1981 in order to establish a rational aseismic design method for substructures, and have developed a method for improving deformability, with special consideration given to the change in axial force acting on the piles.

As the result of many experiments, the major parameters which affect the deformability of piles were found to be the amount of spiral reinforcement, presence or absence of fill concrete in the hollow part of the piles, and the axial force on the piles.

In this paper, we report the relationship between lateral rigidity and strength of piles under various strengths of axial force, and propose a method for improving the deformability of PHC piles.

DEFINITION OF CRITICAL POINTS ON LATERAL FORCE-DEFLECTION CURVE

First, in order to make evaluation of the results easier, we defined 3 critical points on a lateral force-deflection curve obtained from each experiment (See Fig. 1).

1) Yield Strength Point ; where the lateral force has reached 80% of the maximum value

2) Maximum Strength Point ; where the lateral force indicates maximum value

3) Ultimate Deformation Point; where the lateral force has declined to 80% of the maximum value

LATERAL RIGIDITY AND STRENGTH OF PILES UNDER AXIAL FORCE

Fig. 2 shows the schematic shapes of the test specimens. The diameter of the piles was 300 m/m.

When the lateral forces due to an earthquake are acting on a building, external axial forces caused by an over-turning moment on the building are generated on the piles supporting it. The value of the axial force depends on the proportion (height/width) of the building, and on the location of each pile in the building. In this section, the relationship between the lateral rigidity and strength of piles under axial force will be examined using the data at the yield strength point.

The experimental data used for the examination is derived from the five series of experiments conducted with four strengths of axial force (N = 0, 35, 70 and 105 tf). The values of lateral rigidity of piles are the average values of the secant rigidities at the positive and negative loadings.

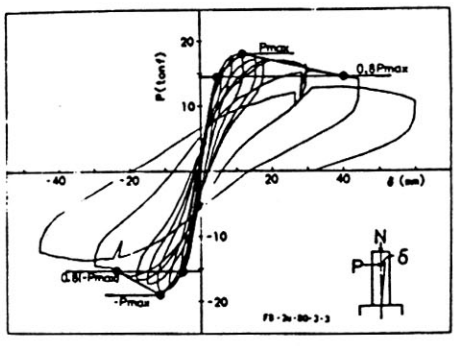

Fig. 1 Modified Lateral Force-Deffection Curve

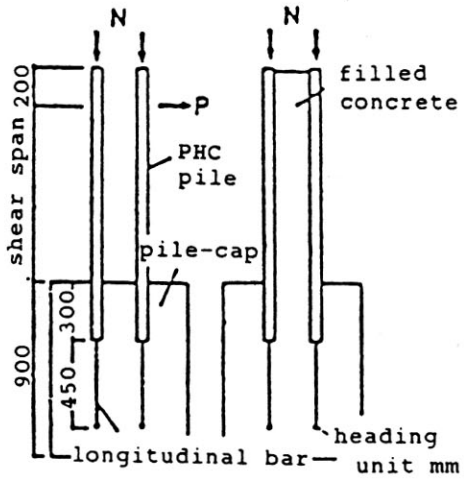

Fig. 2 Schematic Shapes of Specimens

Fig. 3 shows the relationship between the axial force acting on the pile and the lateral rigidity. Although somewhat varying, the lateral rigidity of the pile increases almost linearly with increased axial force. When an external axial force of 35 tf (ie. N = 70 tf) acts on a pile, the lateral rigidity of the pile increases by 30 ~ 60% over its normal value under the permanent axial force (N = 35 tf)acting on it. As can be seen, this change in the value is not negligible. Applying this result to a multi-span rigid frame structure, external axial force due to over-turning moment on the structure is concentrated generally on the exterior columns. Therefore, the lateral forces carried by the piles under exterior columns will increase or decrease more than on piles under interior columns, while horizontal force on the building due to an earthquake is increasing.

Meanwhile, Fig. 4 shows that the yield strength of the pile also increases linearly with increased axial force.

Fig. 5 shows the relationship between the lateral rigidity and the yield strength due to a change in the axial force. The point K(N)/K35=1, P(N)/P(35)=1 represents the permanent axial force acting on the pile, ie. without any over-turning moment. If a plotting of the experimental result lies on the dotted line crossing the aforementioned point and the origin, change in the lateral rigidity of the pile is equal to change in the yield strength of it. When the plotted result lies below the dotted line, the change in lateral regidity is greater.

Fig. 5 indicates that the yield strength under congressive axial force of the exterior piles is reached earlier than that of the interior piles. If the deformability of piles is small, the exterior piles will be ruptured one after another. This is the reason that large deformability is required for PHC piles to perform to this limit of their full yield strength.

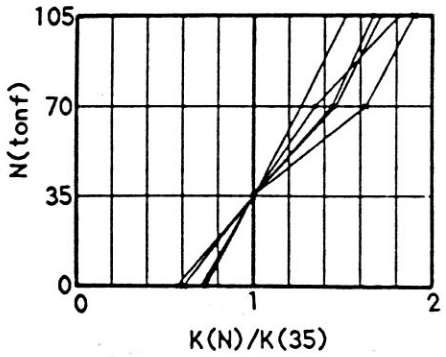

Fig. 3 Change in Rigidity due to Axial Force

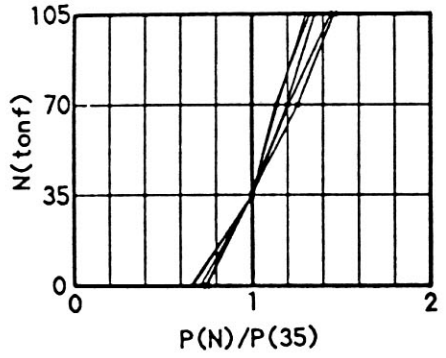

Fig. 4 Change in Yield Strength due to Axial Force

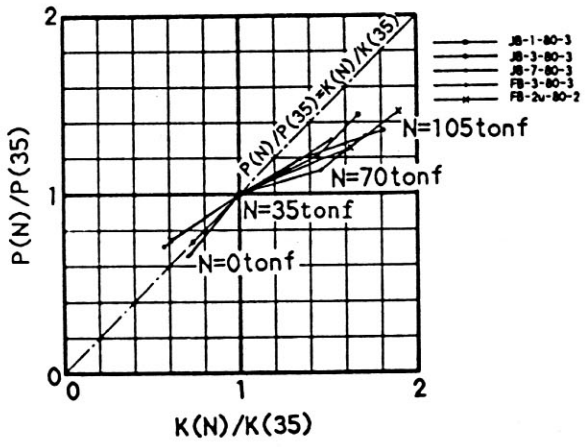

Fig. 5 Change in Rigidity and Strength due to Axial Force

Effects of Spiral Reinforcement of Piles

Fig. 6 shows a comparison between the deformability of the currently used pile (JB-1) and that constructed with an increased amount of spiral reinforcement. When axial force is 0 tf, the deformability of the piles has no relationship to the amount of spiral reinforcement, because the rupture of the axial reinforcement determines the limit of deformation. When the axial force is 35 tf, both JB-3 and JB-7 types show improved ultimate deformation over the JB-1 type. When the axial force is 70 tf, the JB-7 type which uses the most amount of spiral reinforcement, has the greatest ultimate deformation point, while JB-1 and JB-3 types differ little. When axial force is further increased to 105 tf, the amount of spiral reinforcement makes little difference to any type. The reason why the effect of the spiral reinforcement gradually declines with increasing axial force is that the axial reinforcement buckling will cause the compressive rupture of the concrete in the pile, and no amount of spiral reinforcement will be enough to restrain the buckling of the axial reinforcement. The amount of spiral reinforcement greatly affects the deformability of the pile when the axial force is about 35 ~ 70 tf.

Effects of Fill Concrete in Hollow Part of Pile

Fig. 7 gives a comparison between the deformabillity of piles with fill concrete in the hollow part and piles without fill concrete. The deformability of the concrete-filled pile (FB-3) is greater than that of the one not filled with concrete (JB-3) under an axial force of 70 tf, however at an axial force of 105 tf, the presence of fill concrete was not enough to prevent its compressive rupture.

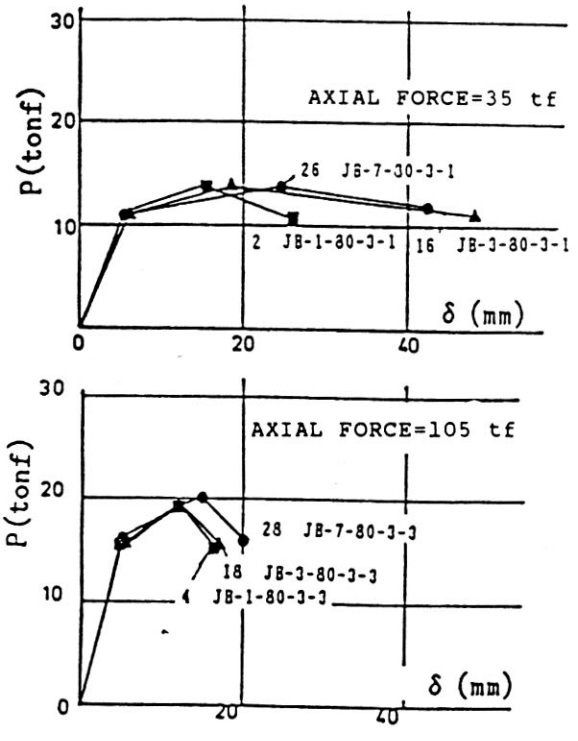

Fig. 6 Effects of Spiral Reinforcement

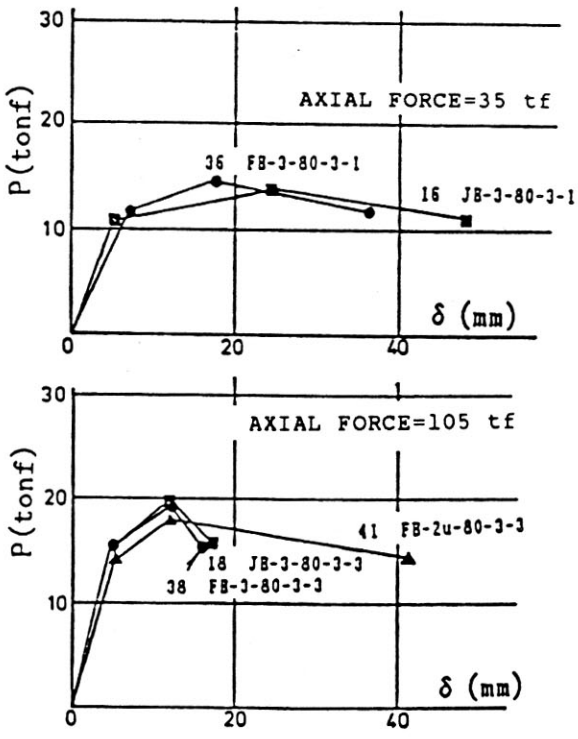

Fig. 7 Effects of Filled Concrete

High-tension steel bars were then used as spiral reinforcement for a concrete filled pile (FB-2U). This demonstrated an extremely large deformability at an axial force of 105 tf.

CONCLUSIONS

The conclusions obtained from this study are as follows.

(1) While the rigidity and yield strength of piles increase linearly with the increase in axial compressive force, the ratio of increase of the yield strength is smaller than that of the rigidity. This indicates that it is necessary to provide PHC piles with large deformability in order to attain their full yield strength under earthquake forces.

(2) The strength of the axial force acting on the pile greatly affects the type of rupture. In the case of low axial force, the failure of the axial reinforcement comes first, while in the case of high axial force, the compressive rupture of the concrete and buckling of the axial reinforcement are the primary causes of pile failure.

(3) Piles with large deformability in the plastic range can be designed by filling the pile hollow core with concrete and by placing a sufficient amount of a spiral reinforcement in the pile.

(4) If piles can be depended upon to perform to the full limit of their yeild strength under earthquake forces, smaller piles may be able to be used, and this could result in a significant reduction in the construction cost of the foundation.

ACKNOWLEDGEMENTS

The useful advice of Mr. Hideaki Kishida, Professor of the Tokyo Institute of Technology, Mr. Hiromi Kihara of Nikken Sekkei and staff members of Maeta Concrete Industry Ltd. is gratefully acknowledged. This study was carried with the aid of the subsidies from the Ministry of Education.

References

1) Yoshihiro Sugimura et al. "Seismic Damage to High Strength Prestressed Concrete Piles and their Reproduction Experiment," Journal of Structural and Construction Engineering, Trans. of AIJ. NO. 340, P.40 ~ 50, 1984.

2) Shoji Ikeda et al. "Study on Improvement of Toughness of Prestressed Concrete Piles," the 4th Conference Japan Concrete Institute, p. 365 ~ 368, 1982.

3) Hiroshi Muguruma, Fumio Watanabe et al. "Improvement of Flexural Toughness of Super High Strength Prestressed Concrete Piles," the 7th Conference, Japan Concrete Institute p. 465 ~ 468, 1985.

4) Seiji Kokusho et al. "Experiment on Mechanical Properties of High Strength Prestressed Concrete Piles Subjected to Axial Forces and Lateral Forces," Journal of Structural and Construction Engineering, Trans. of AIJ. No. 376, p. 71 ~ 80, 1987.