SEISMIC DESIGN OF PILE FOUNDATION USING SEMI-RIGID PILE HEAD CONNECTION METHOD

Katsumi KOBAYASHI [1]

ABSTRACT; The structural method of semi-rigid pile head connection for cast-in-place concrete piles or drilled shafts has been developed. By this method, it is possible to reduce the bending moment of pile head to about half as much as the case of the conventional method. This paper presented the outline of loading tests of pile head connections, the analytical method for seismic design, and the trial calculation results applied for a 15-story apartment building.

INTRODUCTION

In 1995 Hyougo-ken Nanbu Earthquake, the damages to foundations using cast-in-place concrete piles were also detected. Those foundations suffered compression or tension failure of pile head, large cracks at the deeper part of pile due to liquefaction, or/and serious failure of foundation beam or pile cap, as shown in Fig.1 (Report on the Hanshin-Awaji Earthquake Disaster,1998). The foundation damages showed that the effect of ground displacement should be taken into consideration and the design of foundation beam and pile cap were also important in the seismic design.

A feature of the cast-in-place concrete pile is having large bending stiffness. In case of fixed head connection using conventional structural method, the large bending moment acts on the pile head due to the inertial force of building and ground displacement during earthquake. This bending moment is important for the design of not only pile but also foundation beam and pile cap (Kobayashi and Maru et al.(1999)). Therefore, we can get large merit if this bending moment is reduced. In this report, the structural method of the semi-rigid pile head connection for cast-in-place concrete pile is newly proposed, and results of structural experiments and a case study are presented.

OUTLINE OF SEMI-RIGID PILE HEAD CONNECTION METHOD

Fig.2 shows the bending moment distributions of pile in three cases of different pile head conditions. (a) is the bending moment due to inertial force of building and (b) is due to ground displacement respectively. They were computed using the simple p-y method as

[1] Research Engineer, Technology Research Institute, Fujita Corporation, Japan.

mentioned later. In case of the hinge head connection, the bending moment of pile head is reduced to zero, but it's difficult to develop the realistic detail with minimum costs. In this study, the target of development is to reduce the bending moment of pile head to about half as much as the case of the conventional method.

Fig.3 shows structural details of the conventional method and the newly devised semi-rigid connection method. Those details could be applied to 15-story apartment buildings. In case of the conventional method, many longitudinal steel bars of pile must be anchored in the pile cap. In the semi-rigid connection method, the longitudinal steel bars are not anchored in the pile cap, and the pile and pile cap are connected by means of relatively a few steel bars located near the center of pile section. In addition, the joint part between pile head and pile cap is filled by concrete and confined by steel pipe in order to reduce rotational stiffness and improve ductility.

In order to make such as the connection method practicable, the main subjects to be resolved are follows.

- Estimation of rotational stiffness of joint
- Ductile performance under axial and shear force during large earthquake
- Analytical method for seismic design taking SSI effects into consideration

Some structural experiments and case studies are conducted for verification about those points (Kobayashi and Onishi et al.,1999).

STRUCTURAL EXPERIMENTS

Fig.4 shows the outline of test specimens, the loading system and the bending moment distribution under loading. In this experiment, the pile cap was fixed and the another end of pile was supported by pin-roller. The pile was loaded with axial force and shear force. The reaction force and the strains of longitudinal steel bars were measured by load cells and strain gauges respectively.

Fig.5 shows the bending moment distribution when the loads are equivalent to the middle earthquake. Therefore, the piles remain on elastic condition. In case of the conventional method, the measured values of bending moment coincide with the theoretical values of the fixed head condition. On the other hand in case of the semi-rigid connection method, the measured values are plotted between theoretical values of the fixed head condition and hinge head condition. Namely, it was shown that by the semi-rigid connection method the bending moment of pile head is reduced to half as much as the case of the conventional method.

Fig.6 shows the final damages to pile head after the experiments. These piles were subjected to fluctuating axial force that was equivalent to large earthquake, and final deformation angles of pile head were about 1/25 radian. In case of the conventional method, concrete of pile head was seriously crushed and the pile couldn't keep the shear force any more. This damage pattern coincided with the seismic damage detected in 1995 Hyougo-ken Nambu Earthquake as shown in Fig.1. On the other hand in case of the semi-rigid connection method, the damage to pile head was very slight because the deformation concentrated on the part of joint. Additionally, the pile could keep the shear force even under the large deformation.

Consequently, it was shown that the semi-rigid pile head connection had ductile performance. Furthermore, the estimation methods for rotational stiffness and bending strength of semi-rigid pile head joint were also verified by the test results. For further details, see the reference (Kobayashi and Onishi et al. (1999)).

CASE STUDY ON 15-STORY BUILDING

Some case studies were conducted in order to apply the practical seismic design of building foundations. The analytical model is described in Fig.7. In order to take the SSI effect and the rotational stiffness of pile head joint into consideration, simple p-y method was used. This model is composed of a beam representing a pile with nonlinear M-ϕ(Moment - curvature) relation, a nonlinear rotational spring representing a pile head joint, and nonlinear Winkler type springs representing subgrade reaction. The rotational spring of pile head joint was modeled by tri-linear type M – θ relation, in which the crack bending moment of Mcr, the yielding bending moment of My, the ultimate bending moment of Mu and the yielding rotational angle of θy were take into account. The inertial force was applied to the top of the pile, and the support of the Winkler type springs was moved by the ground displacement.

A computation example on a 15-story apartment building is presented as follows. Locations of piles and the boring log are described in Fig.8. The superstructure consists of RC frames in the longitudinal direction and walls in the transversely direction. The piles have diameters of 2.0m and the length is about 25m. The ground displacement was computed by 1D dynamic response analysis. The displacement at the ground surface was about 10 cm in the assumed major earthquakes.

The results of computations in the longitudinal direction of building were shown in Fig.9. The three cases were computed respectively both for the conventional and the semi-rigid connection method. In case of the conventional method, the bending moment of pile increases when ground displacement is taken into consideration, and the distribution shape changes according to the direction of ground displacement. On the other hand in case of the semi-rigid connection method, the effect of ground displacement on the bending moment of pile is relatively small. Consequently, it was shown that we could reduce the reinforcing bars of pile head and the depth of foundation beams by use of the semi-rigid pile head connection method.

CONCLUTION

The semi-rigid pile head connection method for cast-in-place concrete pile was newly proposed and verified by some experiments and analyses. By this method, it is possible to reduce the bending moment of pile head during earthquake to about half as much as the case of the conventional method.

REFERENCES

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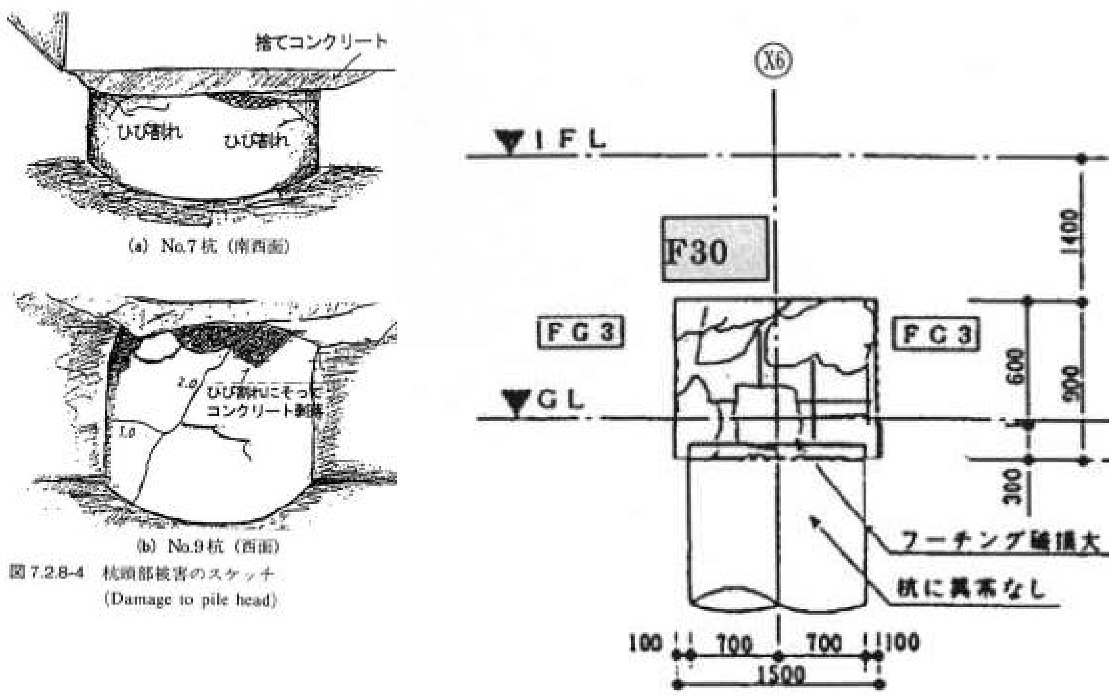
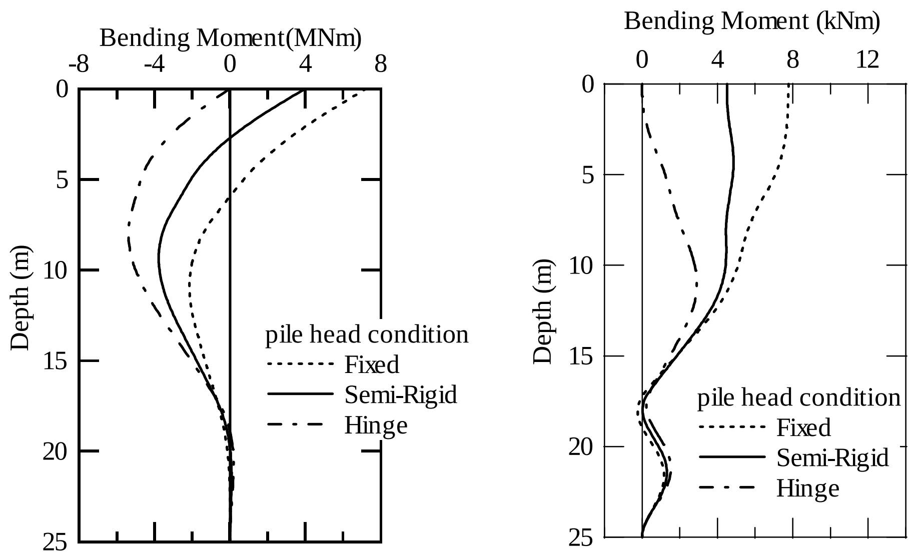


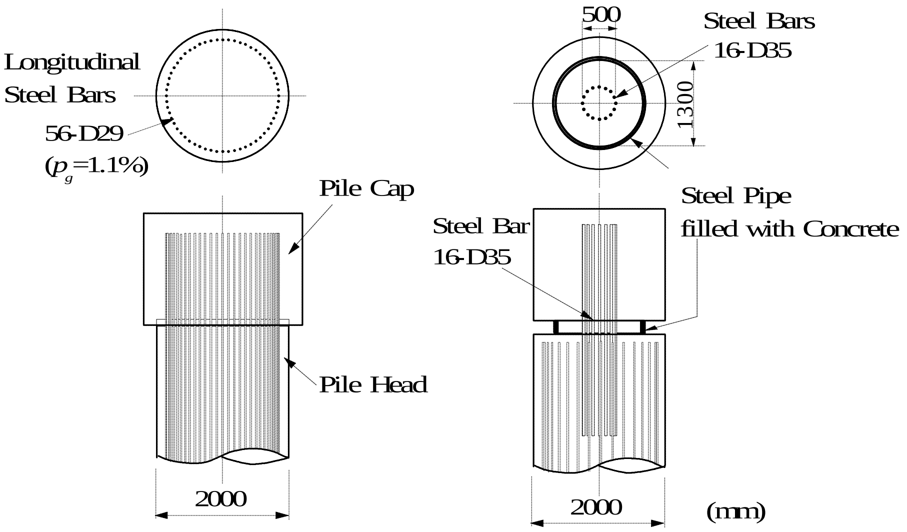
(a) damage to pile head (b) damage to pile cap

Fig.1 Damage to cast-in-place concrete pile in 1995 Hyogo-ken Nambu Earthquake



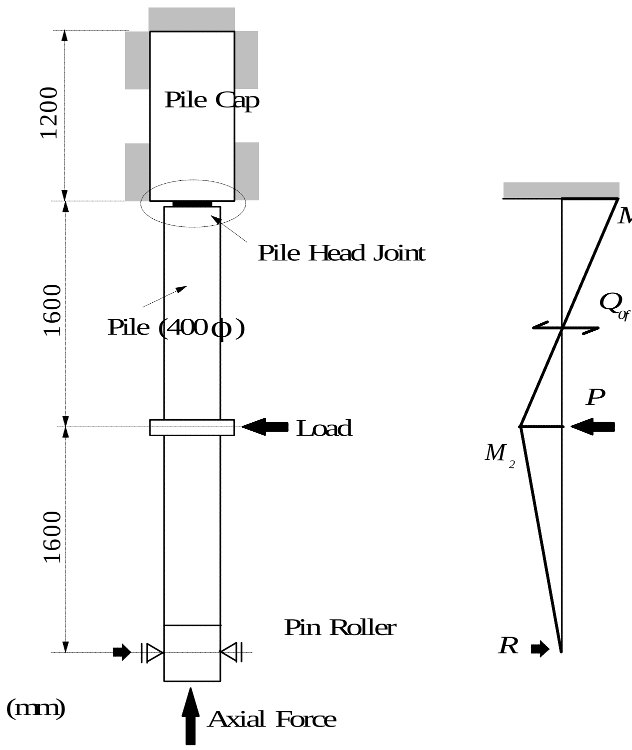
(a) due to Inertial Force (b) due to ground displacement

Fig.2 Bending moment of pile due to inertial force and ground displacement



(a) Conventional Method (b) Semi-Rigid Pile Head Connection Method

Fig.3 Structural method of pile head for cast-in-place concrete pile



(a) Test Specimen (b) Bending Moment

Fig.4 Test specimen and bending moment of pile under loading

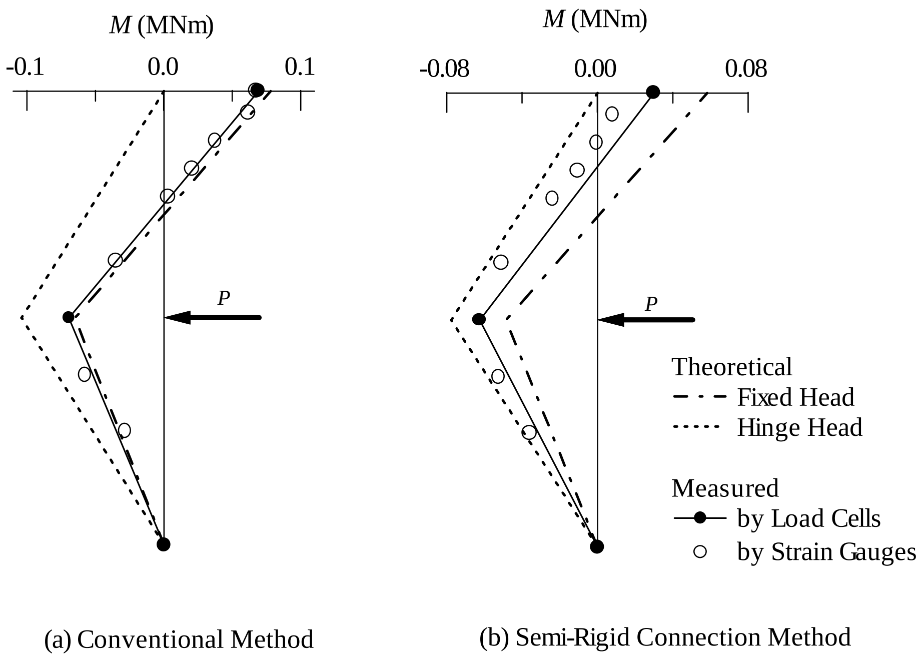


Fig.5 Bending moment distribution of both the conventional method and semi-rigid connection method

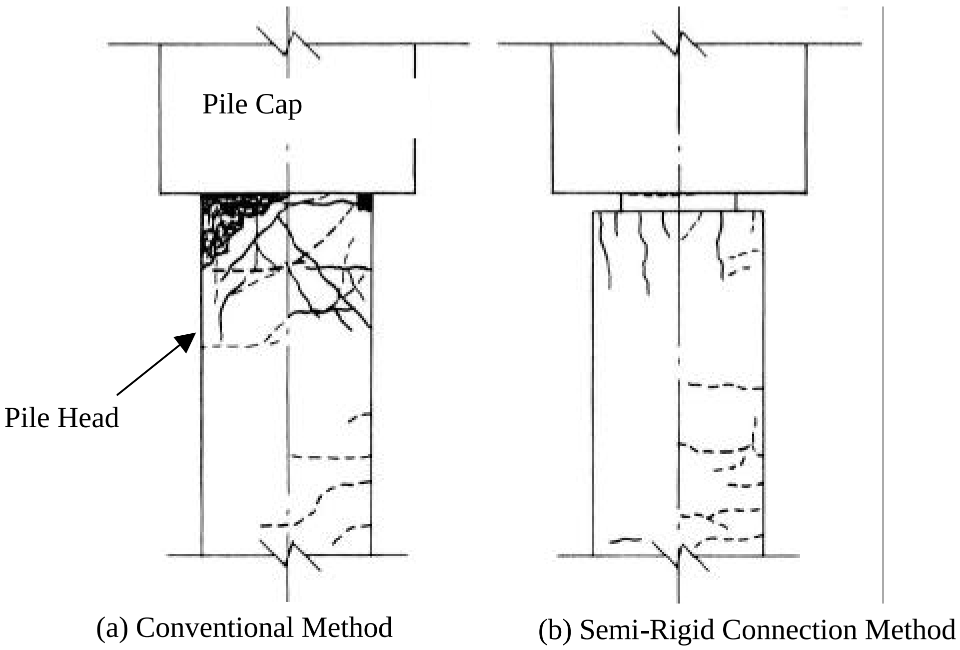
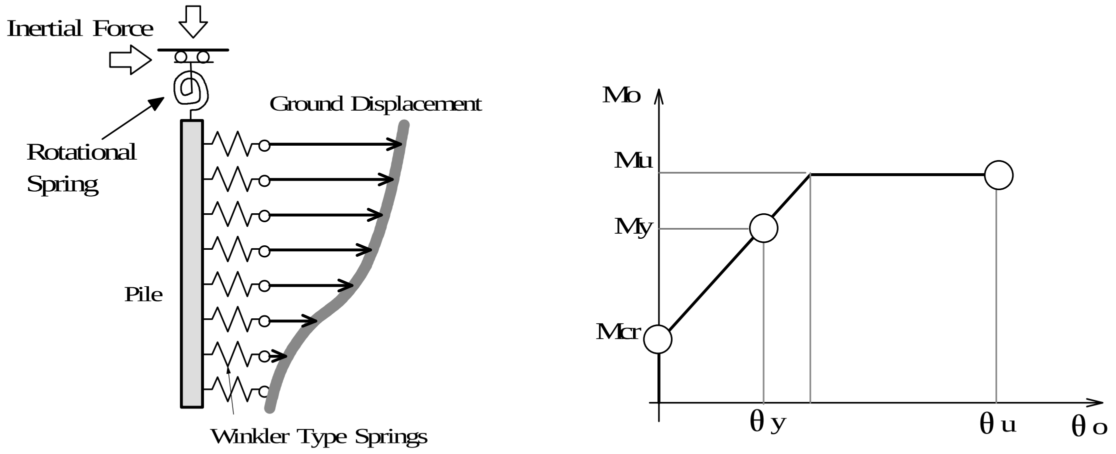


Fig.6 Final damage to pile head due to loading



(a) Simple p-y method (b) Rotational Spring of pile head joint

Fig.7 Analytical model of a pile for seismic design

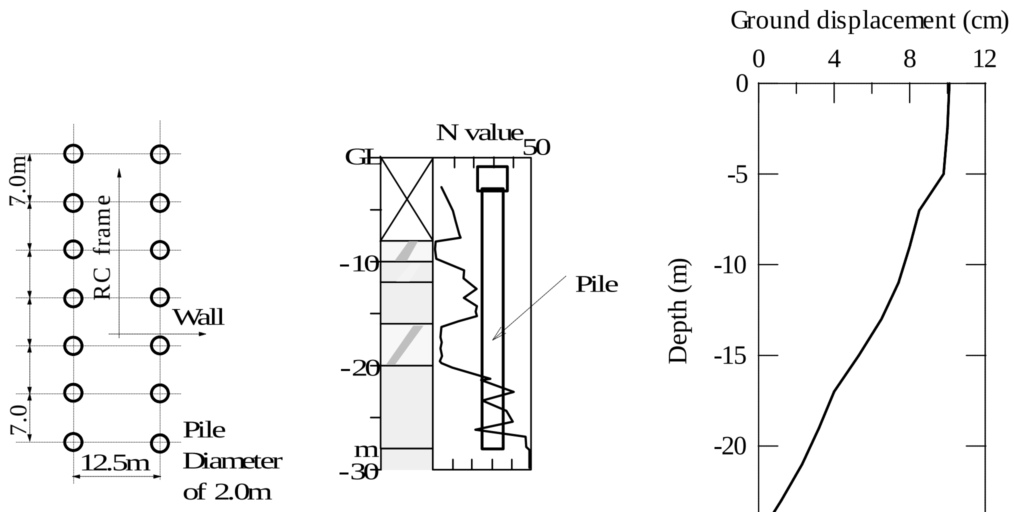


Fig.8 Locations of piles, boring log and ground displacement for seismic design

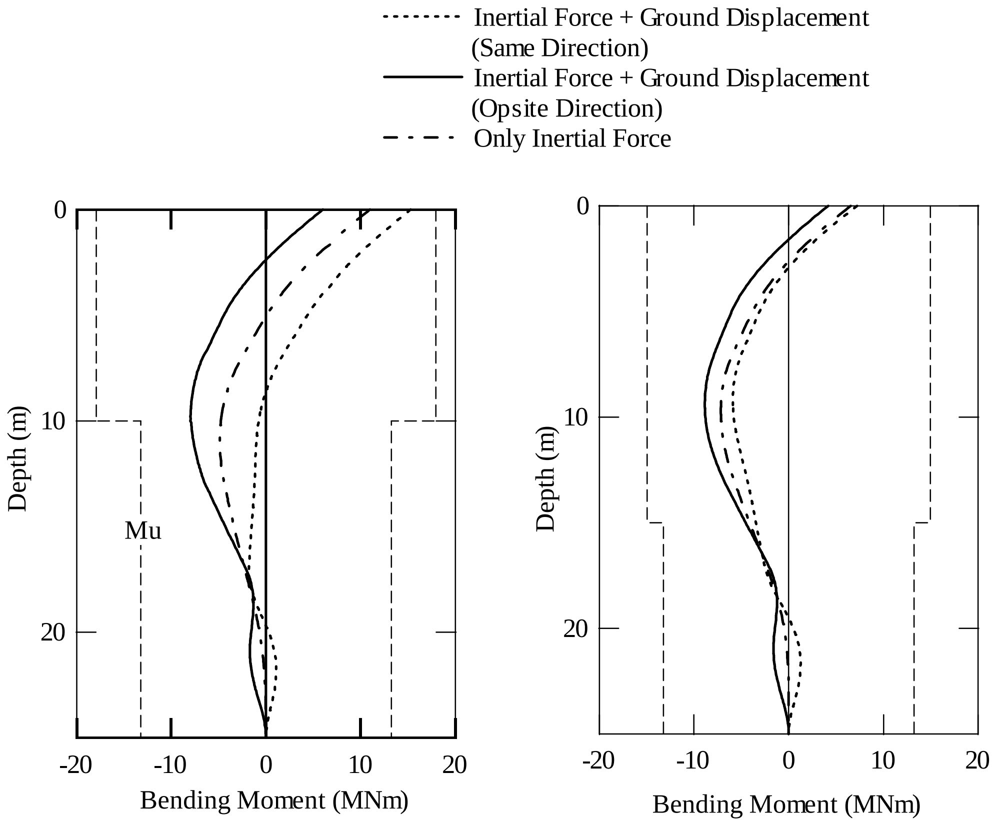


Fig.9 Bending moments of piles by simple p-y method