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Design of Large Diameter Pre-Tensioned High Strength Concrete Pile Reinforced by In-Filled Concrete and Reinforcing Bars

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ABSTRACT

This paper presents an analytical and experimental investigation on the large diameter pre-tensioned high strength concrete (PHC) pile reinforced by in-filled concrete and reinforcing bars to increase the flexural strength of PHC pile. The effect of reinforcement of longitudinal rebar and in-filled concrete on the flexural strength of conventional PHC pile was analytically evaluated. The analytical results were compared with the flexural strength measured from the bending test. From the test results, it was found that the analysis results accurately predicted experimental flexural strength by considering the effect of in-filled concrete and additional reinforcements of PHC pile.

1. INTRODUCTION

In recent years, the utilization of large diameter pre-tensioned high strength concrete (PHC) piles to resist heavy static loads has been increased due to the rise in the construction of mega structures in Korea. It has been recognized that PHC pile foundations constructed in the soft soil strata could be seriously damaged during major lateral loadings due to the lack of flexural and shear strength and ductility of the pile than that of steel pile. Kishida (1998) reported that for smaller deformations, brittle failure occurs in a large diameter PHC pile due to the horizontal loading. Moreover,

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Mitsuyoshi (2012) reported that the brittle failure mode of the pile due to the shear failure of concrete should be considered when increasing the flexural strength of the pile. Therefore, pile performance should be secured to ensure sufficient flexural and shear strength when PHC pile is applied to the soft soil. However, Ozden (2008) reported that increasing the dimension of the pile or the area of rebar may not be adequate to resist heavy lateral loads and to improve strength of the pile. To overcome this problem, Bang et al. (2014) proposed a new PHC pile reinforced by in-filled concrete and the longitudinal reinforcement in hollow area of the PHC pile. Test results showed that the strength capacity of new PHC pile is approximately double of that of normal PHC pile. In this current study, the effect of reinforcement of longitudinal rebar and in-filled concrete on the flexural strength of conventional PHC pile was analytically evaluated. The analysis results were compared with the flexural strength through bending test.

2. MATERIALS AND FABRICATING SPECIMEN

The diameter and thickness of the PHC pile was 1,000 mm and 130 mm, respectively. Concrete with a compressive strength of 80 MPa was used to manufacture the PHC pile. Nineteen pre-stressed tendons with a diameter of 11.2 mm and a tensile strength of 1,450 MPa were used in PHC pile. The initial pre-stressing stress was 70% of the yield strength of the tendon. The 16 mm diameter rebar having a yield strength of 400 MPa was used as a transverse reinforcement. Fig. 1(a) shows the installation of transverse reinforcement. The shape of transverse reinforcement was double star. The effective spacing between the transverse reinforcements was 150 mm. Sixteen rebar with a diameter of 29 mm and yield strength of 400 MPa were used as longitudinal reinforcements. These rebars were installed in the hollow portion of the PHC pile as seen in Fig. 1(b). Concrete with a compressive strength of 27 MPa and a slump of 180 mm was used as in-filled concrete. The length with 10,000 mm PHC specimens were manufactured for bending test.

(a) Transverse rebar (b) Longitudinal rebar and casting concrete

Fig. 1 Reinforcement of large diameter PHC pile

3. ANALYTICAL EVALUATION OF P-M INTERACTION

The analysis was conducted to predict the nominal axial compression and bending moment (P-M) interaction based on the conventional layered sectional approach that considers the section of the PHC on concrete, tendons, and longitudinal rebar of specimen. The initial pre-stressing of tendon was taken into account in the analysis. The theoretical stress-strain relationships of concrete, tendons, and longitudinal rebar are based on the experimental results (Bang et al. 2014). The maximum axial compression of the pile (P_0) was calculated by Eq.1.

$$P_0 = 0.85\sigma_{PHC}(\varepsilon_{PHCini} + \alpha)A_{PHC} + \sigma_t(\varepsilon_{ttendonini} + \alpha)A_t + 0.85\sigma_C(\alpha)A_c + \sigma_s(\alpha)A_s \quad (1)$$

where, ε_{PHCini} is an initial strain of pile concrete, α is a strain of in-filled concrete and longitudinal rebar corresponding to the maximum axial compression. $\sigma_{PHC}(\varepsilon_{PHCini} + \alpha)$ is a stress of pile concrete when the strain of PHC concrete is a strain of $\varepsilon_{PHCini} + \alpha$, A_{PHC} is a total area of pile concrete, $\varepsilon_{ttendonini}$ is an initial strain of the tendon. $\sigma_t(\varepsilon_{ttendonini} + \alpha)$ is stress of the tendon when the strain of the tendon reaches a $\varepsilon_{ttendonini} + \alpha$ and A_t is the total area of tendons. $\sigma_c(\alpha)$ is a stress of in-filled concrete corresponding to a strain of α, and A_c is a area of in-filled concrete. $\sigma_s(\alpha)$ is a stress of longitudinal bar corresponding to strain of α, A_s is a area of longitudinal rebars. The initial neutral axis is assumed to be 1/2 of the pile diameter. The internal forces of all the materials related with neutral axis in the PHC pile can be calculated using Eq. 2.

$$F = \int_0^d [\sigma_{PHC}\big(\varepsilon(h_i)\big) \times w_{PHC}(h_i) + \sigma_{tendon}\big(\varepsilon(h_i)\big) \times w_{tendon}(h_i) + \sigma_c\big(\varepsilon(h_i)\big) \times w_c(h_i) + \sigma_s\big(\varepsilon(h_i)\big) \times w_s(h_i)]dh_i \quad (2)$$

After comparing an assumed initial axial compression (P_0) and a total internal force (F) of materials, the bending moment corresponding to this axial compression was calculated using Eq. 3 when the allowable error is lower than 0.1%. The calculating process is continued until the P and P_0 satisfies same value. The analysis stops when a compressive strain in a concrete layer reaches the ultimate strain of 0.003.

$$M = \int_0^d [\sigma_{PHC}\big(\varepsilon(h_i)\big) \times w_{PHC}(h_i) \times h_i + \sigma_{tendon}\big(\varepsilon(h_i)\big) \times w_{tendon}(h_i) \times h_i + \sigma_c\big(\varepsilon(h_i)\big) \times w_c(h_i) \times h_i + \sigma_s\big(\varepsilon(h_i)\big) \times w_s(h_i) \times h_i]dh_i \quad (3)$$

4. RESULTS AND DISCUSSION

Fig. 2 shows the results of the P-M interaction analysis for conventional PHC pile and PHC pile reinforced with longitudinal rebar and in-filled concrete. The experimental results can be compared with the pure bending moment in Fig. 2 because the bending test was carried out without axial load. Based on the previous study (2016), flexural strength of the conventional and reinforced PHC pile is 1.37 MN·m and 3.01 MN·m.

The pure bending moments of conventional and reinforced PHC pile calculated by P-M correlation analysis are 1.21 MN·m and 2.59 MN·m, respectively. Analysis results are approximately 10 % lower than experimental results, which means the analysis can consider effectively the effect of in-filled concrete and reinforcements of PHC pile. The experimental flexural strength of the conventional and reinforced PHC pile was approximately 1.16 and 1.13 times higher than that of the analyzed bending moment, respectively. Moreover, the contribution of each reinforcing material to the flexural strength of reinforced PHC pile was calculated as 78% for the PHC pile body, 5% for the tendon, 3% for the in-filled concrete and 14% for the longitudinal rebar. From the results, it can be seen that the in-filled concrete and the longitudinal rebar independently contribute to the enhancement of the flexural strength. Moreover, the reinforcing materials increase the flexural strength of PHC pile concrete and tendon itself.

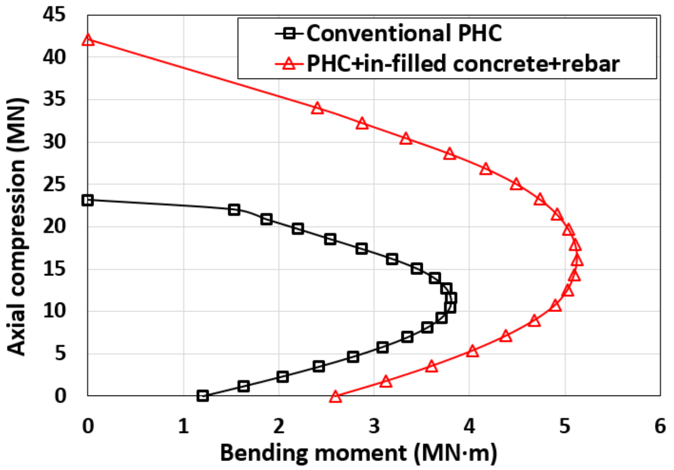

Fig.2 P-M interaction of pile specimens

5. CONCLUSIONS

In this study, the flexural strengths of conventional PHC and reinforced PHC pile were predicted on the basis of analysis. From the P-M interaction results it was found that the analysis was able to consider the effect of in-filled concrete and longitudinal reinforcing bars on the flexural strength enhancement of PHC pile.

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REFERENCES

Bang, J.W., Lee, B.Y., Lee, B.J., Hyun, J.H., and Kim, Y.Y. (2014), “Effects of infilled Concrete and Longitudinal rebar on Flexural Performance of Composite PHC Pile”, *Struct Eng and Mech*, **52**(4), 843-855.

Bang, J.W., Park, C.K., Yang, S.Y., Kim, Y.Y. (2016), “Flexural Behavior of Large-Diameter Composite PHC pile Using In-Filled Concrete and Reinforcement”, *J. Korea Inst. Struct. Maint. Insp*, **20**(5), 109-115.

Gurkan O., Cihan T. A. (2009), “Lateral load response of steel fiber reinforced concrete model piles in cohesionless soil”, *Constr and Build Mater*, **23**, 785-794.

Kishida S. (1998), “Experimental study on shear strength of the phc pile with large diameter”. *J. Struct and Constr Eng*, **510**, 123-130.

Mitsuyoshi A., Satoshi A., Nao A., Motoyuki S. (2012), “Flexural test of precast high-strength reinforced concrete pile prestressed with unbonded bars arranged at the center of the cross-section”, *Eng Struct*, **34**, 259-270.