Effects of Pile Interaction on Pile Load Distribution and Force in Connection of Precast Bearing Wall Structure

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Abstract

This paper presents the effect of pile interaction on pile load distribution and forces in connection of precast bearing wall. In this study, a simple spreadsheet was developed to calculate the displacement and reaction at each pile. The study of pile interaction is based on Fleming et al. (2008). The paper is an analytical solution of the precast bearing wall by assuming that the wall panels are rigidly connected using springs at the bottom of the panels. The pile load distribution and force in connection are calculated with and without the consideration of pile interaction. Results of this study reveal that even though pile interaction does not have significant effects on pile load distribution, it significantly affects forces in connection of precast wall. When pile interaction is considered, the reaction at the connection is higher than without pile interaction. Therefore, it can conclude that taking pile interaction into consideration will be safer to design the precast bearing wall than without pile interaction.

Keywords: *Pile interaction, Pile load distribution, Forces in connection, Precast bearing wall structure*

1. Introduction

In practice, design engineers usually use the tributary area method to calculate pile load distribution. However, Ritchitpean (2010) showed that the tributary area method cannot be applied in case of a reinforced concrete bearing wall which is much stiffer than a beam column structure. Moreover, Julasak (2017) found that pile load distribution of precast concrete wall structure, even though its stiffness is less than that of the reinforced concrete wall, does not also follow the tributary area pattern. He found that piles at the edge of the structure carry larger loads than those computed using the tributary area method.

The pattern of the pile load distribution has significant effects on the force in connections of the precast wall structure. The larger the load at the edge piles, the larger the force in the connections. Therefore, the calculation of the forces in connections based on load distribution by the tributary method will be unsafe. Moreover, due to the interaction between piles, the stiffness of piles at the edge of structure is usually larger than that at the center, piles at the edge will take more loads, and as a result, the actual forces in connections are even larger.

The purpose of this paper is to determine whether the pile interaction has significant effects on the load distribution and forces in the connections or not. From this paper, it is expected that the behavior of pile with pile interaction can be fully understood.

The scope of the study is on a typical two-story precast concrete townhouse with 7 units. The study is limited to Bangkok subsoil condition. Pile interaction will be calculated using the method proposed by Flemming et al. (2008).

2. Objectives

The objectives of the study are as follows:

1. To develop a simple method for calculating load distribution on piles of a precast concrete structure.
2. To develop a simple method for calculating loads in connections of a precast concrete structure
3. To study the effects of pile interaction on pile load distribution.

3. Materials and Methods

In this study, a simple computer model to calculate pile load distribution under precast bearing wall structure was developed. In developing the model, precast bearing wall structure was assumed to be rigid panels connected by linear springs at the bottom of the wall panels, and supporting piles were assumed to be linear springs with varying stiffness due to pile interaction. Stiffness of the piles was computed using the method proposed by Flemming et al. (2008). By this method, pile stiffness and interaction between piles can be calculated using closed-form equations. The following sections explain the details of the model.

3.1 Precast Wall Structure Model

Figure 1 shows a typical layout plan of a townhouse in Bangkok. Since the back wall is the longest wall, it is the most critical structure in terms of forces in connection. As a result, only the back wall will be discussed in this study.

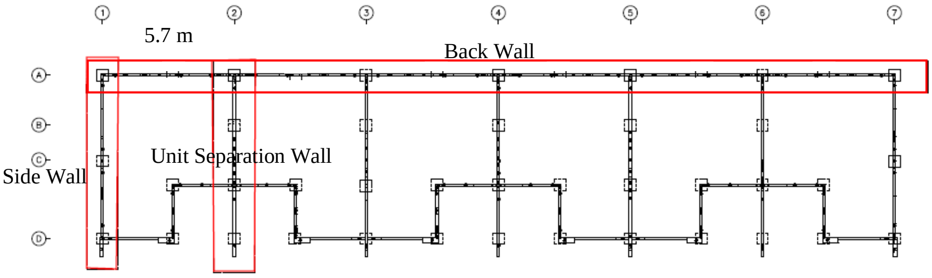

Figure 1 Typical layout of a townhouse in Bangkok

Figure 2 shows a model of the back wall. As mentioned earlier, precast bearing wall structure is assumed to be rigid panels connected by tie bars which are assumed to be linear springs whose stiffness is K_t. The supporting piles are assumed to be linear springs whose stiffness K_{pi} varies due to pile interaction. When loads are applied, the wall will deform as shown in the figure. This deformation shape induces compression at the top and tension at the bottom of the wall. As the wall is assumed to be rigid, the compression at the top will be a concentrate compression force, C_i, applied at the corner of the panel, while the tension force, T_i, will be taken by the tie bars located at the bottom of the panel.

The tension at joint i, T_i, can be computed as:

$$T_i = K_t H\left(\frac{-D_{i-1}+2D_i-D_{i+1}}{S}\right) \tag{1}$$

Where Di is settlement of each pile, H is panel height, S is panel width.

Alternatively, the tension T_i, can be computed from the bending moment, M_i, at joint I, as:

$$T_i = \frac{M_i}{H} = \frac{\sum_{j=1}^{i-1}(K_{pj}.D_j.r_{ji})-AM_i}{H} \tag{2}$$

Where r_{ji} is a distance from joint j to i, and AM_i is bending moment from applied forces at point i

Equating equation (1) and (2) and rearranging we will get

$$\sum_1^{i-1}\left(K_j.d_j.r_j\right) - K_t H^2\left(\frac{-D_{i-1}+2D_i-D_{i+1}}{S}\right) = AM_i \tag{3}$$

Appling Equation (3) to all the interior joints together with the equations of moment and vertical forces equilibrium, we can solve the all the displacement D_i.

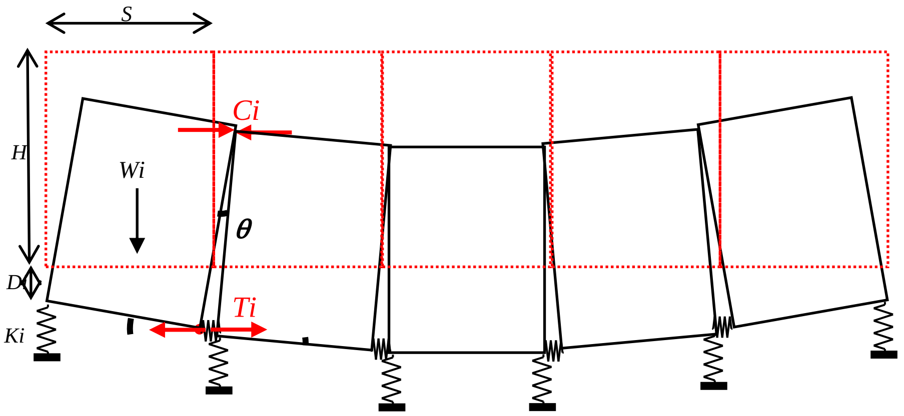

Figure 2 Model of the back wall.

In this study, a simple spreadsheet was developed to calculate the displacement and reaction at each pile.

3.2 Pile Interaction

Flemming et al. (2008) presented a simple method to calculate the deformation of the single pile as well as the interaction between piles in a group. The deformation at the top of the single pile, *Wt*, due to the applied load, *Pt*, can be computed as:

$$\frac{P_t}{w_t d G_L} = \frac{\frac{2}{(1-v)G_L/G_b} + \frac{2\pi}{R_i}\frac{\tanh(\mu L)}{\mu L}\frac{L}{d}}{1 + \frac{8}{\pi\frac{E_p}{G_L}(1-v)\frac{G_L}{G_b}}\frac{\tanh(\mu L)}{\mu L}\frac{L}{d}} \qquad (4)$$

Where d is pile diameter, G_L is shear modulus of soil along pile shaft, G_B is shear modulus of soil at the pile base, v is Poisson's ratio of soil, E_P is Young's modulus of pile, L is length of pile, R_i is a measure of radius of influence of pile and μL is measure of pile compressibility.

The measure of radius of influence of pile, $R_{i,}$ can be computed as:

$$R_i = ln[2r_m/d] \qquad (5)$$

Where r_m is the maximum radius at which the deflections in the soil are assumed to become vanishingly small. R_i can be estimated by:

$$R_i = ln[5(1-v)L/d] \qquad (6)$$

The measure of pile compressibility μL is defined as:

$$\mu L = 2\sqrt{\frac{2}{R_i\,(E_p/G_L)(L/d)}} \qquad (7)$$

Fleming et al. (2008) stated that the usage of the interaction factor is one of the practical methods to determine pile deformation. The interaction factor, α is the fractional increase in deformation the pile head resulted from the neighboring pile which is loaded similarly. The interaction factor may be expressed as the product of two terms representing the logarithmic decay and a 'diffraction factor', ξ, given by:

$$\alpha = \frac{ln(r_m/s)}{R_i}\,\xi \qquad (8)$$

For soil that is homogenous without taking the relatively minor interaction at pile base, the diffraction factor, ξ is expressed in non-dimensional terms Ω and μL as:

$$\xi = \frac{2\mu L + sinh(2\mu L) + \Omega^2[sinh(2\mu L) - 2\mu L] + 2\Omega[cosh(2\mu L) - 1]}{2\,sinh(2\mu L) + 2\Omega^2 sinh(2\mu L) + 4\Omega cosh(2\mu L)} \qquad (9)$$

The Ω term is given by:

$$\Omega = \frac{P_b}{w_b(E_p A_p \mu)} \qquad (10)$$

Where Ap is cross-sectional area of pile and P_b/W_b may be expressed by:

$$\frac{P_b}{w_b} = \frac{2d(G_b)}{(1-v)} \qquad (11)$$

3.3 Calculation Procedure

The case study was conducted on the typical two-story townhouse, of which the layout plan is shown in Figure 1. As mentioned earlier, the back wall is the longest wall, thus, the most critical wall in terms of forces in the precast connection. Therefore, this study concentrated on the back wall and covered three, five, and seven units of townhouses. The span length of the back wall is 5.7 m. The wall is constructed in the following sequence. First, the footings are cast. Then the first-floor slab is constructed, hereafter, the first-floor wall is installed and all the panels are connected. Then the second-floor slab is constructed, and all the panels of the second floor are placed and connected. Finally, the roof is constructed. Since the first-floor wall panels are connected before major portion (the second-floor slab and wall and the roof) of the total load, in this study, it is assumed that the first-floor wall of 2.43 m in height is the main structure transferring all the loads to the foundations. This will give slightly overdesign of forces in the connections.

Results of pile load tests in Bangkok area showed that for a single I 22 piles of 20 inches length have a stiffness of about 5,000 t/m. In this study, magnitudes of the shear modulus of soil along the pile shaft and pile base used in Eq. 4 were, therefore, calibrated to get the stiffness of a single pile of about 5,000 t/m Moreover, another set of the shear modulus of soil that gives the stiffness of a single pile of about 2,500 t/m was also used in this study to represent areas where the subsoil is softer such as the areas in the south of Bangkok.

4. Results and Discussion

Results of the study on pile load distribution are presented in Figures 3 to 8. The results show that, as expected, pile interaction affects the pattern of pile load distribution. With pile interaction, piles at the edge of the structure carry larger loads while piles at the center carry smaller loads than those without pile interaction. However, the effects of pile interaction depend on relative stiffness between wall and piles. For stiff pile (Kp = 5,000 t/m), the effects are not large but for soft pile (Kp = 2,500 t/m), the effects are more significant. The effects of pile interaction for a shorter wall are larger than those of longer piles.

Results of the study on forces in connections are presented in Figures 9 to 14. The results reveal that, for all the cases, forces in connections calculated by taking pile interaction into consideration are larger than those without pile interaction. The results also show that connections forces for the wall on soft piles are larger than those for the wall on stiff piles.

It should be noted that the pattern of pile load distribution has significant effects on forces in the wall connections. A slight increase in load at the edge piles can induce larger forces in the connections. The effect of pile interaction is more pronounced in a more rigid wall panel and less stiff piles.

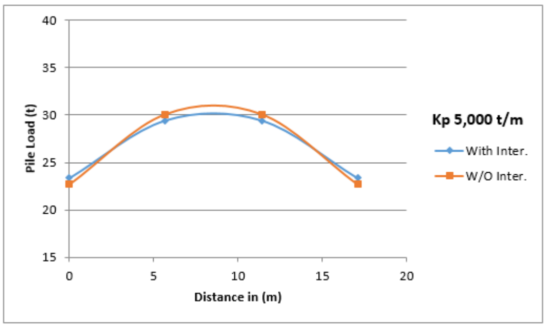

Figure 3 Pile load distribution for 3 units wall panel with higher pile stiffness

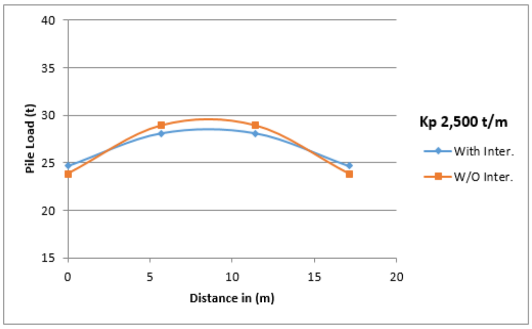

Figure 4 Pile load distribution for 3 units wall panel with lower pile stiffness

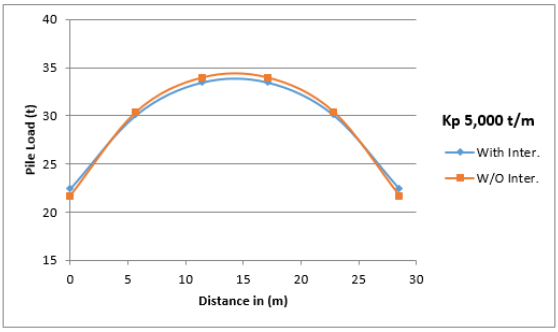

Figure 5 Pile load distribution for 5 units wall panel with higher pile stiffness

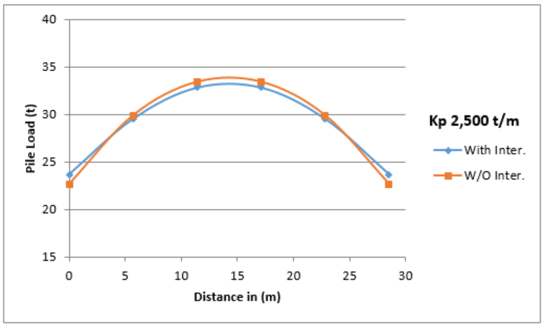

Figure 6 Pile load distribution for 5 units wall panel with lower pile stiffness

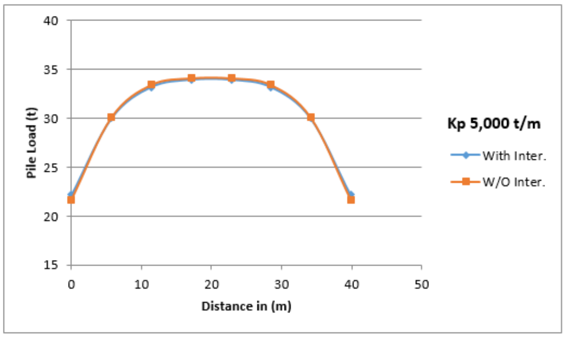

Figure 7 Pile load distribution for 7 units wall panel with higher pile stiffness

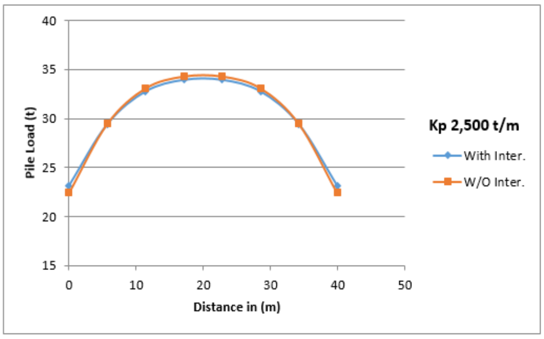

Figure 8 Pile load distribution for 7 units wall panel with lower pile stiffness

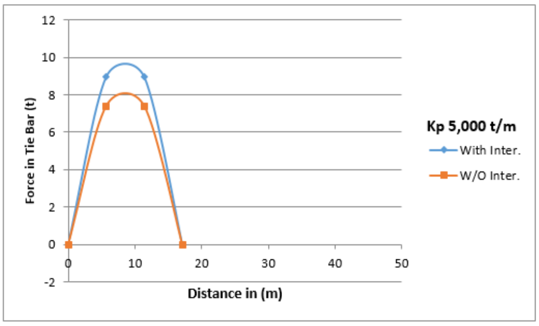

Figure 9 Force in connections for 3 units wall parallel with higher pile stiffness

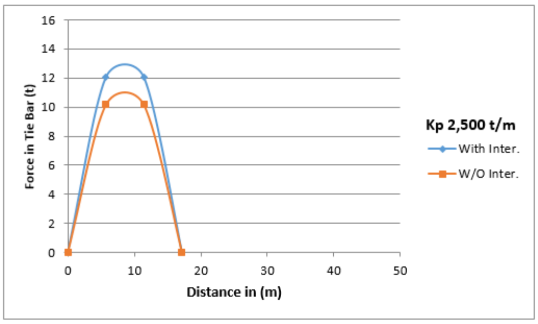

Figure 10 Force in connections for 3 units wall parallel with lower pile stiffness

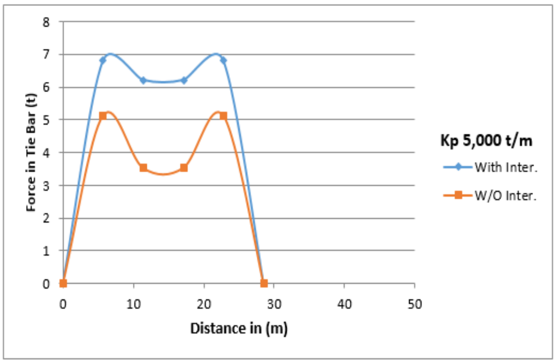

Figure 11 Force in connections for 5 units wall parallel with higher pile stiffness

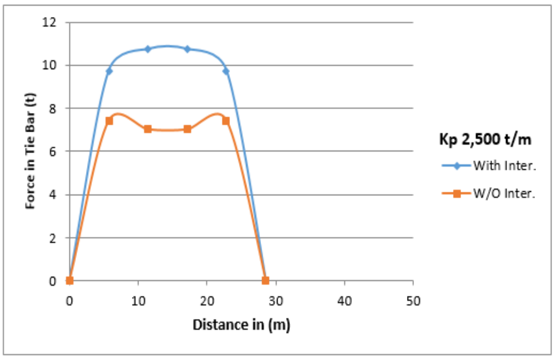

Figure 12 Force in connections for 5 units wall parallel with lower pile stiffness

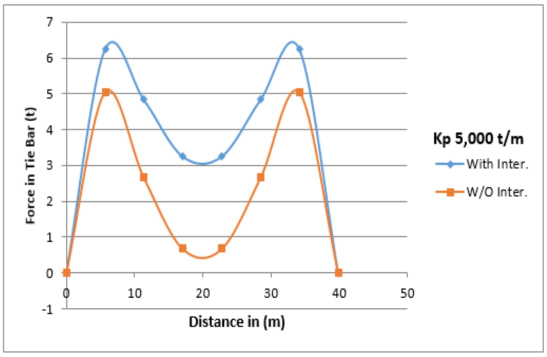

Figure 13 Force in connections for 7 units wall parallel with higher pile stiffness

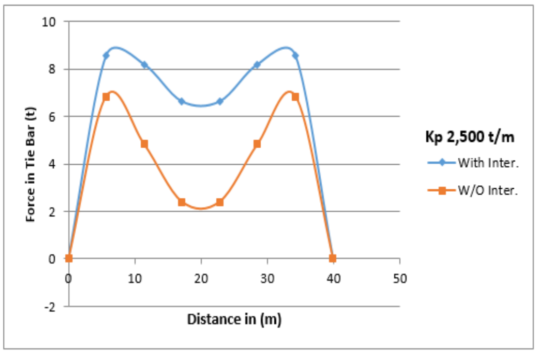

Figure 14 Force in connections for 7 units wall parallel with lower pile stiffness

5. Conclusion

Results of this study reveal that even though pile interaction does not have significant effects on pile load distribution, it significantly affects forces in connection of precast wall. It should be noted that in practice when designing, the wall is assumed as rigid wall panels connected by springs. When the pile interaction is considered, the reaction at the connection is higher than without the pile interaction. The effect of the pile interaction is much more pronounced in a rigid wall panel with less stiff piles. In this case study, the pile distribution with and without interaction does not have much variance while the force in connections with and without interaction have a very distinct variance. Further studies need to be conducted for a very stiff wall as well as for very soft piles. Therefore, it can conclude that taking pile interaction into consideration will be safer to design the precast bearing wall than without pile interaction.

6. Acknowledgements

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