Numerical analysis of earth pressure of foundation pit adjacent to composite foundation

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Abstract. It is necessary to consider the influence of the surcharge load of the existing building and the displacement of the retaining structure when excavating the foundation pit adjacent to the existing composite foundation. FEM analysis work were conducted with two working conditions (condition of loading and condition of translation). The distribution and diffusion mechanism of lateral earth pressure acting on the retaining structure adjacent to composite foundation was investigated. It was found that, when there is no displacement of the retaining structure, the magnitude of additional lateral earth pressure acting on retaining structure adjacent to the natural ground and the composite foundation in the shallow area is almost the same. Moreover, compared with the natural ground, the composite foundation can block the horizontal diffusion of the load, resulting in the reduction of lateral earth pressure acting on the shallow area of retaining structure adjacent to the composite foundation is larger than that of adjacent to natural ground when retaining structure translation outwards.

1. Introduction
With the development of urban economy, land has become a scarce resource. Moreover, underground engineering has been greatly developed. Because the buildings are very close to each other, it is very difficult to excavate the foundation pit adjacent to the existing buildings.

The critical issue in the design of excavation engineering is to accurately calculate the earth pressure acting on the retaining structure. Some scholars [1-6] have discussed the interaction between the existing buildings and the foundation pits. However, these scholars did not analyze the earth pressure acting on the retaining structure adjacent to composite foundation. In addition, these scholars have not conducted further research on the distribution and evolution mechanism of lateral earth pressure acting on the retaining structure when the retaining structure is displaced.

In order to understand the distribution and evolution of earth pressure acting on the retaining structure adjacent to composite foundation, this paper conducted two sets of FEM analysis. One FEM model is composite foundation and the other is natural ground. The FEM analysis has two working conditions. Condition 1 is to apply surcharge load to the foundation. And condition 2 is to maintain the surcharge load and then make the rigid retaining structure translation outwards.

2. Model for FEM
In this paper, two FEM models are established, one of models is composite foundation and the other is natural ground. In the model of composite foundation, the length of long pile is 11 m and the diameter
of long pile is 500mm, the length of short pile is 5 m and the diameter of short pile is 600mm. The distance between each pile is 1.5m. The size of soil is 12.5 m (length) × 9 m (width) × 20 m (height). The size of cushion is 6 m (length) × 4.5 m (width) × 300 mm (height). The size of loading plate is 6 m (length) × 4.5 m (width) × 300 mm (height). The arrangement of the finite element model is shown in figure 1.

![Fig 1. Arrangement of the FEM model.](image)

The soil and the cushion in finite element model were modeled as elastic-plastic materials following a Mohr-Coulomb criterion, while the piles and retaining structure were assumed to be linearly elastic material. The material properties of the various parts are shown in Table 1.

| Material          | ρ (kg/m³) | E (MPa) | ν  | c (kPa) | φ (°)  |
|-------------------|-----------|---------|----|---------|--------|
| Soil              | 1611      | 20      | 0.3| 0.2     | 33.42  |
| Cushion           | 1400      | 30      | 0.29| 5       | 33.9   |
| Rigid pile        | 2500      | 13000   | 0.2| -       | -      |
| Flexible pile     | 2500      | 400     | 0.2| -       | -      |
| Loading plate     | 7800      | 210000  | 0.2| -       | -      |
| Retaining structure| 7800    | 210000  | 0.2| -       | -      |

3. Result and discussion
Figure 2 shows the load sharing ratio of composite foundation under different surcharge load. It can be seen from the figure that the load sharing ratio of long pile increases with the increase of surcharge load, the load sharing ratio of soil between piles decreases with the increase of load, and the load sharing ratio of short pile increases slightly with the increase of load. This is because with the increase of the load, the stress concentration effect appears in the cushion, and the load sharing ratio at the top of the pile increase with the increase of the load. Because the stiffness of short pile is smaller than that of long pile, the change of load sharing ratio of short pile is not as large as that of rigid pile.

Figure 3 shows the distribution of the additional lateral earth pressure acting on the retaining structure under different surcharge load. It can be seen from the figure that at the beginning of loading, the increase of the additional lateral earth pressure acting on the retaining structure in the shallow area is larger than that in other areas. This is because the load sharing ratio of the pile is relatively small, and the ability of the pile to transfer the load to the deeper area has not yet begun to play, and most of the surcharge load is borne by the soil between the piles and spread to the retaining structure along the
45° direction. With the increase of loading, the increase of additional lateral earth pressure in the depth of 4 - 8 m begins to increase.

Subsequently, the increment of lateral earth pressure in the depth of 4 – 8 m began to be greater than that of other depths. This is because the load shared by the pile increases with the increase of surcharge load, resulting in that the load diffusing to the depth of 4 - 8 m of the retaining structure also increases with the increase of surcharge load.

Figure 4 shows the comparison of additional lateral earth pressure when the surcharge load acting on the soil is 90 kPa. At the depth of 0 - 4 m, the additional lateral earth pressure acting on the retaining structure adjacent to composite foundation is slightly less than that of the natural ground. This is because the shielding effect of piles weakens the ability of the soil to transfer load. At the depth of 4 – 10 m, the additional lateral earth pressure acting on the retaining structure adjacent to composite foundation is much larger than that of natural ground. This is because the ability of the composite foundation to transfer the load to the deeper soil is much larger than that of natural ground, and the surcharge load in the deeper area of the composite foundation increases, resulting in an increase in the additional lateral earth pressure acting on the retaining structure adjacent to composite foundation.

Figure 5 shows the load sharing ratio of composite foundation with different displacement of retaining structure. It can be seen from the figure that the load sharing ratio of long pile and short pile increases with the increase of the translational momentum of the retaining structure, while the load sharing ratio of the soil between piles decreases with the translation of the retaining structure. This is because the movement of the retaining structure weakens the lateral constraint of the soil. The vertical bearing capacity of the soil between piles decreases with the translation of retaining structure, which increase the settlement of the soil between piles, resulting in the load borne by soil between piles decrease with the translation. Because the surcharge load remains unchanged, the load sharing ratio of the piles increases in varying degrees with the translation of the retaining structure.
Figure 6 shows the distribution of the additional lateral earth pressure acting on the retaining structure under different translational momentum. It can be seen from the figure that the additional lateral earth pressure acting on the retaining structure decreases with the increase of translational momentum. It is considered that it can be explained from two aspects: with the translation of the retaining structure, the load sharing ratio of the long pile increases, because the end of the long pile is below the bottom of the retaining structure, which means that the surcharge load transferred by the long pile to the area below the ground of the retaining structure increases. The load transferred to the soil above the bottom of the retaining structure decreases.

In addition, with the translation of the retaining structure and the displacement of the soil, the contact between the soil particles is no longer close, resulting in that the load cannot be effectively transferred between the soil particles. Furthermore, with the increase of displacement of soil, the shielding effect of piles becomes more obvious, which weakens the ability of soil to transfer load.

It can be seen from figure 7 that the additional lateral earth pressure acting on the retaining structure adjacent to both natural ground and composite foundation decreases with the increase of the translation of the retaining structure. In addition, the reduction of the additional lateral earth pressure acting on the shallow area of the retaining structure adjacent to composite foundation is larger than that of the natural ground. Such a phenomenon can be attribute to the following reasons: with the translation of the retaining structure, the load sharing ratio of soil between piles decreases, resulting in that the surcharge load directly diffused from the soil between piles to the retaining structure reduced. In addition, the shielding effect of the pile weaken the ability of the soil between piles to transfer the load to the retaining structure. Furthermore, the ability of the natural ground to transfer surcharge load to the deep soil is weaker than that of composite foundation, resulting in that a large number of surcharge load cannot be transferred to the deep soil and the surcharge load in the shallow area of natural ground is still large. Therefore, the reduction of the additional lateral earth pressure acting on the shallow area of the retaining structure adjacent to the composite foundation is larger than that of natural ground.

At the depth of 5 - 10 m, the additional lateral earth pressure acting on the retaining structure adjacent to composite foundation is much larger than that of natural ground, this is because the ability of the composite foundation to transfer surcharge load to the deeper area is stronger than that of natural ground, resulting in that the additional lateral earth pressure acting on the retaining structure adjacent to composite foundation is greater than that of natural ground.
4. Conclusions

Based on the FEM analysis, it was found that:

1. When there is no displacement of the retaining structure and the surcharge load acting on the soil between piles of composite foundation is equal to that of natural ground, the magnitude of additional lateral earth pressure acting on retaining structure adjacent to the natural ground almost the same as adjacent to the composite foundation in the shallow area. Below this depth, the additional lateral earth pressure acting on retaining structure adjacent to composite foundation is larger than that adjacent to natural ground.

2. Compared with the natural ground, the composite foundation not only has a stronger ability to transfer the surcharge load to the deep soil, but also can block the horizontal diffusion of the load. Therefore, under translation mode, the reduction of lateral earth pressure acting on the shallow area of retaining structure adjacent to the composite foundation is larger than that of adjacent to natural ground.

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