A simplified algorithm of bending moment for passive pile

Fenghui Zhang1*, Xudong Wang1 and Lin Li2, 1Capital Construction Department, Tianjin University of Technology and Education, Tianjin, China
2School of Civil Engineering, Tianjin Cheng Jian University, Tianjin, China

*Corresponding author e-mail: 18526249812@163.com

Abstract. Firstly, Interaction between soil and pile which is caused by pit opening is analysed through FLAC3D, the flexural moment and earth pressure of pile can be extracted through the program. Secondly, through the analysis of the soil pressure on the pile side, a simplified algorithm that engineers can simply estimate the flexural moment is obtained. Finally, the earth pressure is obtained by geotechnical centrifuge experiment and then the flexural moment is recalculated through this algorithm, the two results are basically consistent, the feasibility of the method is verified.

1. Introduction
Excavation will cause lateral of surrounding soils. Lateral movement of soil will cause additional internal forces to adjacent pile foundation, which will seriously damage adjacent pile foundation. But designers do not consider this lateral force when they design the pile foundation. When calculating the bending moment of pile foundation, caused by excavation, scholars calculate the moment of bending through the finite element software or the pile deformation curve [1, 2, 3]. It's inconvenient and impractical for engineers, therefore, it is necessary to provide a simple and feasible bending moment algorithm.

2. Model parameters
The horizontal width of model was 6m (X), the longitudinal length was 34.6m (Y), the depth was 30m (Z), as shown in figure 1. pile diameter was 0.6m. The model size of front view was displayed in figure 2.

Figure 1. Three dimensional finite difference model
Bending rigidity of parapet wall was $2.7 \times 10^4 \text{kN} \cdot \text{m}^2$, bending rigidity of pile was $1.9 \times 10^5 \text{kN} \cdot \text{m}^2$, the center distance between the pile and the wall was 3.3m, the foundation ditch was excavated three times, the first excavation depth was 2.5m, the second excavation depth was 2m, the third excavation depth was 1.5m. The pile head was free from any restrictions. The retaining walls and piles were respectively arranged in contact with the soil. The Soil constitutive relation was simulated by Cam-Clay which was modified and considered to be nonlinear stress-strain. The soil is considered to be undrained throughout the simulation. Soil parameters were obtained from [4], as shown Table 1.

### Table 1. Soil parameters

| Numble | $\gamma$ (KN/M²) | $e$ | $K_0$ | $M$ | $\mu$ |
|--------|-----------------|-----|-------|-----|-------|
| 1      | 1.9             | 0.62| 0.61  | 0.91| 0.35  |
| Numble | OCR             | $\lambda$ | $\kappa$ | $\phi'$ | $C$ |
| 2      | 1.0             | 0.9 | 0.0093| 23  | 22.62kpa |

### 3. Numerical analysis results and case verification

#### 3.1. Numerical analysis results

Figure 3 and figure 4 are graphs of the flexural moment and the pile earth pressure, the positive flexural moment indicates that one side far from foundation pit of pile is pulled. The positive value of soil pressure represents that the soil pushes the pile toward the foundation ditch, on the contrary, when soil pressure is negative, soil hinders the movement of pile. As shown in figure 3, with the increase of excavation depth, pile bending moment curve shape changes from "S" to "C". The position of the maximum flexural moment value moves up gradually with the increase of dig deep, but it is always under the excavation surface. As shown in figure 4, the soil pushes the pile toward the foundation ditch, and the soil prevents the pile from moving toward the foundation pit. If the pile length is long enough, this phenomenon will alternately appear. With the increase of excavation depth, the soil pressure value above the excavation surface changes from negative to positive value, and the absolute value of soil pressure decreases first and then increases. With the increase of excavation depth, the shape of earth pressure above pile gradually changes from triangle to trapezoid, and finally approximates rectangle. The shape of pile middle earth pressure is always approximately triangular, and the shape of the earth pressure at the bottom of the pile is approximately triangular. The first position where the earth pressure is zero appears pile head. The second position where the earth pressure is zero will appear below the excavation surface. The deeper the excavation depth is, the closer the position is to the excavation surface. The third position where the earth pressure is zero will appear between the bottom of the wall and the excavation face. The fourth soil pressure zero is mainly located in a certain range above the pile bottom.
3.2. New bending moment algorithm

Pile is regarded as beam and soil pressure zero is regarded as hinge support in this new algorithm. When you use this algorithm, firstly, you need to determine the position of the earth pressure at zero point. The pile head is not regarded as hinge support, although the earth pressure at the pile head position is zero, because the pile head is not restrained by any restriction in numerical simulation. The zero point of soil pressure near the pile head and bottom is ignored, because the pressure around them is relatively small. The hinge supports are installed at the position of zero point earth pressure. They are located between the bottom of the foundation ditch and the bottom of the retaining wall. Secondly, the unbalance force is calculated according to the analysis of force balance, and then the unbalance force is converted into uniform load, which is loaded in the opposite direction between the pile bottom and the hinge bearing nearest to the pile bottom. Finally, the bending moment is solved after the original soil pressure is applied.

Figure 5, Figure 6 and Figure 7 separately replays the comparison diagram of pile bending moment after each excavation. The original method represents that the bending moment is extracted by the application after numerical analysis, the new method represents that the bending moment is calculated by the new method, according to the original soil pressure. It can be concluded from Figure 5, Figure 6 and Figure 7 that the maximum bending moment of pile and its position are basically same, which are calculated separately using two different methods. The comparison results are shown in table 2.
3.3. Case verification

Case 1

D.E.L.O ng (2006) has made a series of geotechnical centrifuge experiments, in the case that the soil was clay and the retaining structure was in a stable state, he studied the influence on pile by foundation ditch cantilever excavation. Finally, he carried out numerical analysis, and the results were consistent with the experimental results. The soil pressure in this paper are taken from fig.5 (d) in reference [5], which was measured after 50 days of foundation pit excavation. The numerical value of soil pressure is displayed in figure 8. The maximum bending moment calculated by new method is in good agreement with the actual maximum value, as shown in figure 9. The aggregate maximum value is 96KN·m, and the actual maximum value is 92KN·m, the error is 4.3%, the aggregate value is larger than the actual value.

| Excavation number | Original method KN·m | New method KN·m | Error   |
|-------------------|----------------------|----------------|---------|
| 1                 | 38.5                 | 40.6           | 5.5%    |
| 2                 | 58.2                 | 54             | 7.8%    |
| 3                 | 141.1                | 137.9          | 2.3%    |
Case 2
C.F. Leung (2000) has made a series of geotechnical centrifuge experiments, in the case that the soil was sandy soil, he studied the influence on pile by foundation ditch cantilever excavation. Finally, he carried out numerical analysis, and then the results of the two experiments are consistent. The bending moment in this paper are taken from figure 8(a) pile-1 in reference [6], which was measured when enclosure wall was under a state of collapse. Pile lateral soil pressure was obtained from the data given by the author in the following discussion, which was shown in figure 10. The maximum bending moment calculated by new method is in good agreement with the actual maximum value, which was shown in figure 11. The aggregate maximum value is 222KN·m, and the actual maximum value is 206KN·m, the error is 7.8%, the aggregate value is larger than the actual value.

4. Conclusion
In engineering, if the ultimate soil pressure and distribution form of pile are known, the maximum bending moment of pile can be estimated easily by using this method. Engineers can make a preliminary estimate of the possibility of the pile being damaged without using large software for complex analysis.

This paper only studies the new algorithm of pile bending moment, when the pile head is not restrained. But, the constraint conditions of pile head, the distance between pile and foundation ditch, the supporting forms of foundation ditch, etc., all have certain influences on the application range of this algorithm. These factors will be studied at a later stage.
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References
[1] Poulos H G. Analysis of piles in soil undergoing lateral movement [J]. Journal of the soil mechanics and foundations division, 1973, 99(5): 391-406.
[2] Randolph M F. The response of flexible piles to lateral loading [J]. Geo technique, 1981, 31(2): 247-259.
[3] Goh A T C, Teh C I, Wong K S. Analysis of piles subjected to embankment induced lateral soil movements [J]. Journal of geotechnical and geo environmental engineering, 1997, 123(9): 792-801.
[4] Meng, L. (2009).”Study on structural property and constitutive model for Tianjin soft clay.” Master's Thesis, Tianjin University, Tianjin, China (in Chinese).
[5] Ong D E, Leung C E, Chow Y K. Pile behavior due to excavation-induced soil movement in clay. I: Stable wall [J]. Journal of geotechnical and geo environmental engineering, 2006, 132(1): 36-44.
[6] Leung C F, Chow Y K, Shen R F. Behavior of pile subject to excavation-induced soil movement [J]. Journal of geotechnical and geo environmental engineering, 2000, 126(11): 947-954.