Analysis For Force And Deformation Of The Pile And Wall Interaction Based On Three Methods

Yi Tao\textsuperscript{1,2,3,4}, Zhang Lijuan\textsuperscript{1,2,3,4}, Wen Zhongyi\textsuperscript{4,5,6}

\textsuperscript{1}School of Civil and Transportation Engineering, Guangdong University of Technology
\textsuperscript{2}No.100 Waihuan West Road, Guangzhou University City, Panyu District, Guangzhou 510006, China
\textsuperscript{3}Funded by the Natural Science Foundation of Guangdong Province, project number 2016A030313692
\textsuperscript{4}Guangzhou Science and Technology Plan Project Funding
\textsuperscript{5}Guangzhou Urban Planning &Design Survey Research Institute
\textsuperscript{6}Pearl River International Building, No. 10-12 Jianshe Da Ma Road, Yuexiu District, Guangzhou, 510006.,China
476413863@qq.com (YiTao),zhanglijuan1969@126.com (Zhang Lijuan)

Abstract. This paper adopts: 1. LiZheng deep foundation software; 2. Equivalent Beam Method; 3. Midas GTS NX. As to the study of pile-wall interaction structure, how to distribute the horizontal load based on the three methods. The results of comparative analysis show that there are consistency in the distribution discipline and trend of bending moment diagram and shear diagram obtained by the three methods. The piles in row bear most of the horizontal earth pressure and the basement exterior wall can reduce the thickness. In addition, the technology has a wonderful engineering economy and can provide reference for future engineering applications.

1. Preface
In recent years, the utilization rate of urban underground space has continuously increased, which has prompted the rapid development of foundation pit support technology. The complex structure is linked the piles in row and basement exterior wall by a Transfer Girder. In this way, it is avoided that the piles are abandoned in the ground, and the permanent support of the piles in rows can be taken into consideration in design to reduce the thickness of the basement exterior wall, so that the basement sidelines are closer to the red line of the ground, and the use space of the basement is increased.

The Pile And Wall Interaction Structure technology has been initially applied in engineering and has achieved good results\textsuperscript{[1-2]}. This paper adopts three kinds of design calculation methods to study the horizontal load distribution of the pile and wall complex structure and hope that it can be used for reference in similar projects.
2. Background engineering situation
The project located in Guangzhou Nansha Free Trade district, three 28-floor office buildings on the ground and three storey basements. The depth of pit of the engineering is 13.50m. In the excavation range of the foundation pit, the first 1 miscellaneous fill layer was 2.1 m thick, the second silty clay layer was 5.1 m thick, the third silt layer was 3.2 m thick, and the fourth layer of fine sandstone (slightly weathered) The layer thickness is 1.4 meters, and the fifth layer conglomerate to the bottom of the pit is 1.7 meters thick. The soil parameters are shown in Table 1.

| number | Soil layer name         | thickness | modulus | natural unit weight | cohesion | internal friction angle |
|--------|-------------------------|-----------|---------|---------------------|----------|------------------------|
| 1      | miscellaneous fill      | 2.1 m     | 10 MPa  | 17.5 kN/m           | 10 kPa   | 15°                    |
| 2      | silty clay              | 5.1 m     | 22 MPa  | 18.7 kN/m           | 20 kPa   | 21°                    |
| 3      | Silt                    | 3.2 m     | 20 MPa  | 18.5 kN/m           | 25 kPa   | 22°                    |
| 4      | fine sandstone (slightly weathered) | 1.4 m | 40 MPa  | 22 kN/m           | 50 kPa   | 25°                    |
| 5      | conglomerate (slightly weathered) | >6 m     | 40 MPa  | 20 kN/m           | 100 kPa  | 33°                    |

The Pile And Wall Interaction Structure are used at the background engineering, the piles in row and basement exterior wall are linked by a transfer girder with the same elevation for floor slab. the pile made for Rotary Drilling Cast-in-place Pile.Pile diameter 1m, pile spacing 0.25m. Because of the basement has entered the rock, the piles are inserted 3m below the basement. Three-axis cement-soil mixing pile and waterproof curtain with φ800@900mm is installed on the outer side of the pile in rows.

3. Research Contents And Technical Route
When the ground surface in the excavating stages, The Pile And Wall Interaction technology is the same as traditional technology. This paper adopts the Lizheng deep foundation software 6.0 to check the horizontal loads that the piles are subjected to when the pit is excavated. In the basement construction process, the load will be distributed by the row of piles and the underground structures that are gradually made. When the building is put into use, the row of piles will be working with the underground outdoor wall together to jointly bear the load from the horizontal direction. At present, there is no norm to give the ratio of The Pile And Wall Interaction technology exterior wall and the envelope structure to the horizontal load.

At present, there is no Standard offer a coefficient for The Pile And Wall Interaction Structure how to distribute the horizontal load. The empirical design and calculation in engineering lacks theoretical verification. The main of this paper adopts a stiffness ratio to distribute the load and three kinds of method to show the results. 1. LiZheng Deep Foundation Pit software 6.0 to checking the horizontal loads of piles under excavation; 2. Analysis the force exerting mode of the structure by the Equivalent Beam Method; 3. Established a finite element model including Basement Exterior Wall, enclosed Row Piles, Bottom Plate, Transfer Girders……from whole process by Midas GTS NX. The results of the three methods are given by following sentences in a comparative manner.

4. Results And Comparative Analysis
4.1. The Result of Lizheng deep foundation software
As shown in Figure 1, the results of the Lizheng software by classical method and the elastic method. The ground surface is overloaded with a 20KN/m ground overload. The results show that the whole stability, basal heave stability, formula of stability, and check of soil resilience on the inside of the embedded section of foundation pit meet the Standard requirements. This paper is based on the principle of engineering practice. The classical method (red) is taken as the rational calculation result. From the value point of view, the peak value of row pile bending moment is 266.7KN • m, and the peak value of shear force is 139.86KN.

Lizheng Software is the inheritance and development of traditional calculation methods. The above results are used as a reference in this article, from which we can draw the conclusion that the entire foundation pit project theoretically satisfies the safety requirements. However, it is difficult to analyze and verify the advantages and rationality of The Pile And Wall Interaction Structure by the software.

**Figure 1. The Result of Lizheng deep foundation software**               **Figure 2. Rankine earth pressure**

### 4.2. Equivalent Beam Method

Using rankine earth pressure theory to calculate the excavation to the bottom of the pit, the earth pressure experienced by the underground continuous wall is basically the same as the result of the rationality. As shown in Figure 2.

When calculated The Pile And Wall Interaction Structure by the stiffness ratio, assume that the soil pressure shared by the pile is \(x\), and the soil pressure shared by the outdoor wall is \(y\). Then there is the following formula:

\[
x + y = F_x \cdot \frac{E_1 I_1}{X} = \frac{E_2 I_2}{Y}
\]

In the formula:

- \(x\) — the pile load;
- \(y\) — the basement exterior wall load;
- \(F_x\) — the earth pressure;
- \(E_1\) — the modulus of pile;
- \(E_2\) — the modulus of basement exterior wall;
- \(I_1\) — the moment of inertia for pile;
- \(I_2\) — the moment of inertia for basement exterior wall;

The equivalent beam method regards the calculated width of the retaining pile (wall) as a vertical beam, and considers that the bending moment of the beam is also zero at the zero point of the static earth pressure below the excavation surface. regards the calculated width of the retaining pile (wall) as a vertical beam, and considers that the bending moment of the beam is also zero at the zero point of the static earth pressure below the excavation surface. Break the beam into two sections at the zero point, then the bending moment of the broken beam is the same as the bending moment of the original whole beam, that is, the broken beam is the equivalent beam of the original beam. In this way, the
moment-shear shear diagrams of the building envelope and the basement exterior wall are given below, as shown in Figure 3.

![Diagram of moment-shear shear diagrams](image)

**Figure 3. The results of Equivalent Beam Method**

After the load distribution, the peak moment of the building envelope is 233.6KN•m, the peak shear is 117.7KN, and the peak moment of the basement exterior wall is 22.1KN•m, the peak shear is 20.54KN, and the peak of moment ratio is about 10:1. The peak of shear ratio is 6:1. The building envelope and basement exterior wall resist the load together when the structure add the transfer girder. The piles can ensure that the basement wall has a sufficient safety factor, while the underground outdoor wall also bears a part of the horizontal load. This is precisely the use of the equivalent beam method to prove the reliability of The Pile And Wall Interaction structure technology.

The results of the moment, shear diagram, and equivalent beam method compare with Lizheng Software have a good consistency in the trend of graph changes. The row piles has no adverse load on the main structure and is combined with a good structure, which makes the implementation of the foundation pit project more scientific. The comparison between the two method shows that the configuration of the transfer girder makes the row pile to bear a large part of the earth pressure during normal use, will make the basement wall more safety.

The limitation of the Equivalent Beam Method: 1. no deformation influence in the calculation process. When the seepage is not considered, the influence of the foundation pit on the surrounding environment is generated by the deformation of the side wall of the foundation pit, and the deformation of the side wall of the foundation pit is related to the deformation of the supporting structure. 2. the assumption of the rankine earth pressure is Retaining Wall Backing vertical and smooth, the filling oil is level. However, the computation and rationalization of the equivalent beam method and Lizheng software can only verify from the theory that The Pile And Wall Interaction structure technology is scientific and reasonable.

### 4.3. Midas NX

The paper studies the distribute the horizontal load, the main point is neglected the influence of groundwater than the structure how to resistance earth pressure, so as its research emphasis. In order to make the calculation result more accurate and reduce the impact of horizontal to soil quality changes, the row piles transfer to a diaphragm wall in accordance with the principle of stiffness equivalence. The bored pile diameter can be set as D, the net spacing of the pile is t, then the single pile should be equivalent to the underground diaphragm wall of D+t, so that the thickness of the underground diaphragm wall after conversion is h, according to the principle of stiffness equivalence, we can have:
If the pile arrangement is tangency in one row, \( t < D \), then \( h \approx 0.838D \). In the background project, the pile diameter is 1m and \( t = 0.4m \), and the calculation is \( h \approx 0.75m \).

The three-dimensional finite element model was established on the design scheme. Retaining walls are simulated plate elements, support systems are modeled with beam elements, soil spring elements are placed in the pits, and Morcolun constitutive models are used. According to the construction conditions and engineering geological conditions, the pressure load outside the pit is determined, and the internal force and deformation of the support structure are calculated.

Graph 4 and Graph 5 show the simulated results of the excavation to the bottom foundation. The line graphs with moments and shear values varying with depth can be more intuitively displayed. From the numerical point of view, the maximum moment value of the building envelope with equivalent beam method is 233.6 kN\( \cdot \)m, and the maximum bending moment value of the finite element method is 291 kN\( \cdot \)m. The error in the two results is due to: 1. The basic assumptions of the Langmuir pressure model adopted by the value beam method and the finite element method are different. 2. The influence of the number of stress analysis points on the two methods shows that the shear resistance of the structure is well consistent. Therefore, it can be considered that the same as the equivalent beam method and the finite element method.

In addition, in the results of numerical simulation, at the situation of the main structure basement is completed, the positive moment ratio of the pile wall is 6:1, and the peak ratio of the shear force is 4:1, which is greater than the ratio of the bending stiffness distribution (about 3:1). In this way, it can be seen the distribution ratio of The Pile And Wall Interaction Structure is safe.

To sum up, the design of the foundation pit enclosure structure is in line with the specifications and is somewhat safe are prove by Lizheng design software. The load sharing pattern of The Pile And Wall Interaction Structure distributed according to the bending stiffness also meets the requirements of 《Technical Code for Ground Treatment of Buildings》 from the the calculation of the equivalent beam method. The calculation results to be more in line with actual engineering through the use of the finite element analysis software Midas NX. From the results of the three methods, the distribution law of bending moment and shear force has a high consistency, indicating that the background engineering design is safe and reliable. According to the experience that the actual stress results in the foundation pit engineering are all less than the theoretical calculation results, it is shown that the “combination of pile and wall” technology is safe and feasible.
5. Conclusions
Because of the Pile And Wall Interaction Structure technology, the thickness of the underground outdoor wall is reduced from the traditional 0.8-1m to 0.5m, which greatly reduces the amount of reinforced concrete and 0.4m is left between the enclosure row piles and the underground exterior wall for construction of waterproof insulation and accommodation of construction deviations. The horizontal loads and interactions are shared between the row of piles and the basement by a basement floor and a 350 mm transfer girder of force placed at the floor elevation. In this paper, the finite element analysis is performed on the structure of the Pile And Wall Interaction Structure. The theoretical analysis of the stress state of the structure in the pile-wall-in-one technique for horizontal loads shows that it is feasible to distribute loads according to the stiffness ratio. The following conclusions are drawn:

1. By setting up the force-transmitting beam, the gradually completed outdoor wall of the basement interacts with the envelope structure and participates in "working" against horizontal loads. Until the normal use stage, the pile wall together resists the static earth pressure and the post-wall water pressure.

2. Through the simulation of the whole process, from the leveling site to the design elevation to the completion of the main underground structure, the bending moment and shearing force diagram of the “Pile Wall” structure are in line with the standard [5].

3. The bending moment and shear force diagrams obtained by the three methods of Lizheng deep foundation pit 6.0 design software, the equivalent beam method, and the finite element analysis software Midas GTS NX proved to be in same result, demonstrating this design calculation method. It is safe and reliable.

4. The peak bending moment of the pile wall calculated by the equivalent beam method and the finite element method, the result is 10:1 and 6:1 respectively, which is greater than the stiffness ratio (3:1), which indicates that the load sharing mode in the theoretical calculation is safe and reliable.

5. This paper only conducts numerical simulations from the leveling site to the design elevation to the completion of the main underground structure, and it lacks the loading analysis of the building during normal use. Besides, the research on the characteristics of the load-distribution pattern of the Pile And Wall Interaction Structure still requires the inspection of a large number of measured data.

References
[1] WANG Wei-dong, SHEN Jian. Design and analysis of unity of support piles and basement external walls[J]. Chinese Journal of Geotechnical Engineering, 2012, 34(supplement):303–308.
[2] HU Yun, WANG Wei-dong, SHEN Jian. Field monitoring and analysis of stresses for dual-purpose pile wall[J]. Chinese Journal of Geotechnical Engineering, 2015, 37(supplement):197–201.
[3] 《Technical Code for Ground Treatment of Buildings》 GB50007-2011
[4] ZHAO Minghua, YU Xiao. Soil Mechanics and Foundation Engineering 【M】. Wuhan: Wuhan University of Technology Press, 2009.
[5] LIU Guobin, WANG Weidong. Excavation engineering manual 【M】. Beijing: China Architecture & Building Press, 2009. (in Chinese) 《Technical Code for Ground Treatment of Buildings》 GB50007-2011