

Comparative Analysis of Stress Mechanism and Engineering Applicability of Several Pile Slab Structures

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Abstract

Underground pile slab structure is a common form of foundation treatment structure for underground crossing, which has been applied in some projects at home and abroad. The mechanical mechanism and engineering applicability of several pile slab structures are compared and analyzed by means of engineering example summary, literature induction and theoretical analysis. The results show that the underground pile slab structure is mainly used for the foundation treatment of special soil, or for some special engineering sections, such as the transition section of road and bridge. Considering the differential settlement of pile foundation and the interaction between plate and soil, the simplified calculation model of underground pile slab structure is an urgent problem to be solved in engineering and academic circles. Establish the relationship model between axial displacement and bearing capacity of pile foundation, establish the elastic foundation beam model of layered soil, and then apply the two models to the simplified calculation model of underground pile slab structure, which is the most possible research direction. Underground pile slab structure can be divided into beamless supporting plate pile slab structure, supporting one-way beam pile slab structure and supporting two-way beam pile slab structure. Among them, the beamless supporting plate pile plate structure is only suitable for the case of small upper load. When the upper load is large and the requirements for deformation and settlement are strict, the supporting two-way beam pile plate structure shall be adopted.

Keywords

Pile Slab Structure; Stress Mechanism; Engineering Applicability; Uneven Settlement; Plate Soil Interaction.

1. Introduction

Underground pile slab structure is a common form of foundation treatment structure for underground crossing, which has been applied in some projects at home and abroad. This kind of structure is mainly used for foundation treatment related to special rock and soil, such as collapsible loess, structural soft soil, seasonal frozen soil, etc. According to the composition of structural components, underground pile slab structure can be divided into two categories: beamless supporting plate pile slab structure and beam supporting plate pile slab structure. Considering that there are no relevant specifications for the design of pile plate structure, this paper makes a comparative analysis of the stress mechanism and engineering applicability of the two types of pile plate structure by using the induction and summary method, so as to provide reference for relevant projects.

2. Application Example of Underground Pile Slab Structure Engineering

As shown in Table 1, some engineering examples of underground pile slab structure at home and abroad are shown. In China, the new Lintong station of Zhengzhou Xi'an Passenger Dedicated Line adopts the supporting plate underground pile plate structure in order to treat the collapsible loess foundation. In addition, subway or high-speed rail lines such as Suining Chongqing line, Chongqing Lijiang line, Baolan line, Beijing Tianjin Intercity Railway, Nuremberg Ingolstadt line in Germany, Amsterdam in the Netherlands Brussels line in Belgium, the connecting line of British French subsea tunnel, Milan Turin line in Italy and so on have adopted supporting plate underground pile plate structure for foundation treatment. In addition to the supporting plate underground pile plate structure, the supporting beam underground pile plate structure is also widely used in engineering. For example, in Shaoguan Huadu section of Wuhan Guangzhou passenger dedicated line, in order to control the settlement of soft soil foundation, the supporting beam underground pile plate structure is adopted, and the supporting beam underground pile plate structure is adopted for Shanghai Hangzhou passenger dedicated line, Guiyang Guangzhou line and Beijing Shanghai high-speed railway for foundation treatment. It can be seen from the table that the underground pile slab structure is mainly used for foundation treatment of special soil, or for some special engineering sections, such as road bridge transition section, etc.

Table 1. Typical application engineering examples of underground pile slab structure

Project Name	Structural style	Purpose of use
New Lintong station of Zhengzhou Xi'an Passenger Dedicated Line	Pallet type	Treatment of collapsible loess foundation
Shaoguan Huadu section of Wuhan Guangzhou Passenger Dedicated Line	Joist type	Control the settlement of soft soil foundation
Shanghai Hangzhou Passenger Dedicated Line	Joist type	Foundation treatment
Suining Chongqing Railway	Pallet type	Foundation treatment
Chongqing Lijiang Railway	Pallet type	Foundation treatment
Guiyang Guangzhou Railway	Joist type	Foundation treatment
Baolan line treatment	Pallet type	Foundation treatment
Beijing Tianjin Intercity	Pallet type	Foundation treatment
Beijing Shanghai high speed railway	Joist type	Foundation treatment
Nuremberg Ingolstadt line, Germany	Pallet type	Foundation treatment of road bridge transition section
Line from Amsterdam, the Netherlands to Brussels, Belgium	Pallet type	Soft soil foundation treatment
Anglo French Subsea Tunnel Link	Pallet type	Foundation treatment in swamp area
Milan Turin line, Italy	Pallet type	Foundation treatment area

3. Study on Stress Mechanism of Underground Pile Slab Structure

The stress mechanism analysis of pile plate structure is mainly carried out through theoretical analysis, in-situ test, model test and numerical simulation [1,2]. Simplifying the underground pile slab structure into a two-dimensional calculation model is a more general treatment method [3-4]. In this method, the pile-soil interaction is considered by the comprehensive stiffness of pile-soil. The plate is generally simplified as a two-way plate for load transfer only. The interaction between beam, plate

and soil is generally considered by the elastic foundation beam model, and then the statically indeterminate beam can be calculated. However, the model established in this way can not consider the problem of uneven settlement of pile foundation, which is common in engineering. In addition, the existing research shows that the interaction between plate and soil has an obvious influence on the stress of pile-slab structure [5]. Therefore, when using the elastic foundation beam model to consider the interaction between plate and soil, it is very important to select the reasonable parameters of the elastic foundation beam model that can consider the stratification of soil.

The test method is used to study the pile plate structure. At present, three methods, large-scale model test, centrifugal test and field test, are mainly used to study the stress characteristics and deformation mechanism of pile plate structure [5-8]. Considering the cost, the field test is generally carried out when the project really needs to be monitored. The internal force and deformation values of each member are obtained by test, and compared with the theoretical calculation results.

Numerical simulation is used to analyze and study the mechanical characteristics and deformation mechanism of pile plate structure, mainly with the help of existing commercial finite element software, mainly to study the regularity of single deformation [9-11]. Including the geometric dimensions and spacing of bearing plates, joists and piles.

At present, the theoretical research on pile slab structure lags behind the engineering practice as a whole, and is still in the stage of engineering application exploration. In the stress analysis of pile plate structure, there is still the problem that the supporting effect of soil under the bearing plate is not considered, which makes the design internal force of each structural member larger than the actual, and the amount of materials is more, resulting in the waste of pile plate structure in design and the reduction of technical and economic benefits. How to consider the favorable supporting effect of soil under the bearing plate and the differential settlement of pile foundation to establish the simplified mechanical model of pile plate structure remains to be studied.

4. Analysis of Advantages and Disadvantages of Several Underground Pile Slab Structures and Comparison of Engineering Applicability

According to the different combination forms of components, underground pile slab structure can be mainly divided into two categories: beam less supporting plate pile slab structure and beam supporting plate pile slab structure. The pile slab structure with beam supporting plate can be divided into one-way beam supporting pile slab structure and two-way beam supporting pile slab structure.

4.1 Beamless Supporting Plate Pile Slab Structure

As shown in Figure 1, the structure of beamless supporting plate pile plate structure is simple, which is mainly composed of bearing plate and pile foundation. The force transmission sequence is that the upper load is transmitted to the bearing plate, and the bearing plate is transmitted to the soil and pile foundation under the plate. In the design work, generally, the bearing plate and pile foundation are connected through reinforcement, and the punching shear bearing capacity must be checked between the bearing plate and pile foundation. In the specific construction, the construction process of beamless supporting plate pile plate structure is less, and the construction is not difficult.

Considering that the thickness of the plate is generally smaller than the height of the beam, when checking the punching shear capacity of the bearing plate, due to the small punching shear failure area of the plate, when the load above the bearing plate is large, in order to ensure the punching shear capacity, the plate thickness or pile diameter must be increased to increase the punching shear failure area to resist the punching shear force. In this case, even if the longitudinal reinforcement of the slab is only reinforced according to the minimum reinforcement ratio, its flexural bearing capacity will be much greater than the bending moment of the slab itself, which will cause great waste of materials and poor technical economy. Therefore, the beamless supporting plate pile plate structure is generally only used in the case of small upper load.

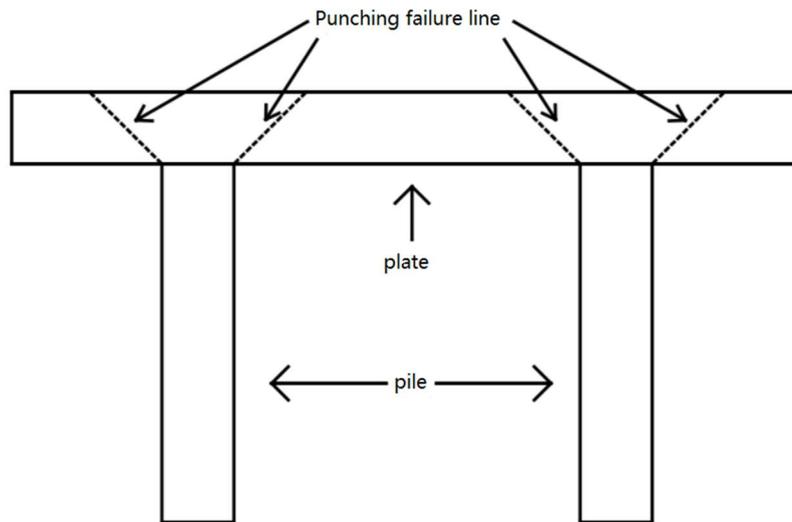


Figure 1. Beamless supporting plate pile slab structure

4.2 One Way Beam Supported Pile Slab Structure

As shown in Figure 2, compared with the supporting plate pile plate structure, the supporting plate pile plate structure increases the beam, and the pile foundation is connected through the beam, so that the stress of the whole structure is more reasonable and the force transmission path is more clear. The function of the beam mainly includes three aspects: transverse connection of the pile foundation, increase the transverse stiffness of the overall underground structure, and transfer the load borne by the bearing plate to the lower pile foundation.

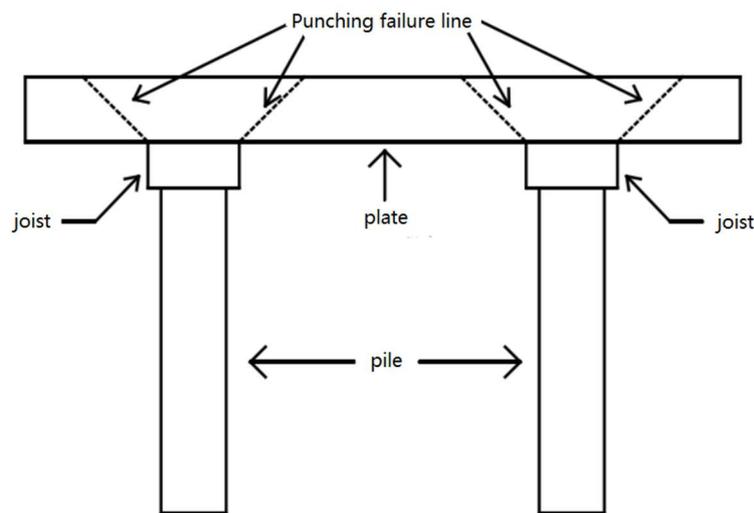


Figure 2. One way beam supported pile slab structure

Compared with the pile slab structure without beam supporting plate, it is obvious that the overall stress of the pile slab structure with one-way beam supporting plate is more reasonable. The force transmission way is that the upper load is transmitted to the bearing plate and soil, the bearing plate is transmitted to the joist, and finally the joist load is transmitted to the lower pile foundation and soil. Considering that after the action of the joist, the length of the anti punching failure surface of the bearing plate is the same as that of the joist, and the anti punching failure area is greatly increased compared with the beamless joist plate pile plate structure, the anti punching failure bearing checking calculation of the bearing plate is easy to meet.

Considering that the one-way beam supported pile slab structure generally has joists only in the transverse direction, which directly leads to the large difference in the longitudinal and transverse stiffness of the structure, the bearing plate needs to be equipped with more reinforcement in the longitudinal direction to bear the normal section bending moment. The one-way beam supported pile plate structure is generally used under the condition of small plate thickness and large load on the upper part of the plate.

4.3 Two Way Beam Supported Pile Slab Structure

Figure 3 shows the supporting two-way beam pile plate structure, which essentially adds a longitudinal beam on the basis of supporting one-way beam pile plate structure, so as to improve the longitudinal stiffness of the whole underground structure and further improve the bearing capacity of the structure, effectively reduce the internal force of the beam and bearing plate, further reduce the beam height and plate thickness, and reduce the amount of concrete and reinforcement. Generally, the pile, beam, longitudinal beam and bearing plate are fixedly connected with each other to form a whole. At the same time, after the longitudinal pile foundation is connected by the longitudinal beam, the whole two-way beam pile plate structure is very similar to the beam plate column structure in ordinary residential buildings, but the biggest difference is that the lower part of the pile plate structure is pile, while the lower part of the structure in the field of housing construction is column.

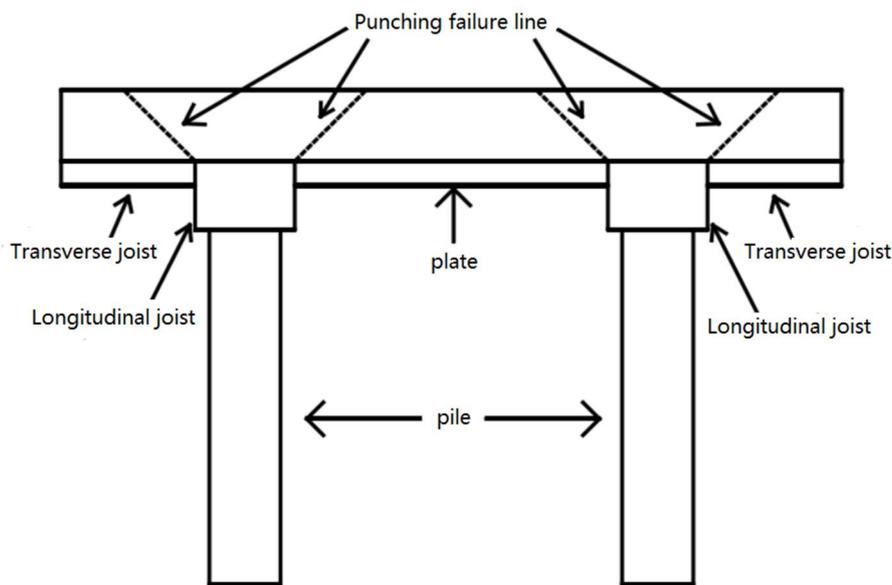


Figure 3. Two way beam supported pile slab structure

The load transfer path of the two-way beam supported pile plate structure is very clear. The upper load is transmitted to the bearing plate, the bearing plate transmits the load to the two-way beam and the soil under the plate, and the two-way beam transmits the load to the pile foundation. The integrity of the two-way beam supported pile plate structure is the best. The vertical and horizontal beams poured with the bearing plate are arranged between the pile and the bearing plate, so that the vertical and horizontal stiffness of the overall underground structure is greatly increased. In addition, due to the existence of longitudinal and transverse beams, the punching bearing area of the bearing plate can be greatly increased, and the punching performance can be brought into full play. The beam slab supporting the two-way beam pile slab structure is cast-in-situ, and some plates will be used as the flange of the beam. The bearing plate can be simplified into four-way stressed two-way plates, which can greatly reduce the mid span bending moment and deflection of the plate, and then reduce the plate thickness and reinforcement. In addition, considering the action of the plate, the longitudinal and transverse beams can be regarded as T-shaped beams, which can effectively reduce the mid span

bending moment and deflection of the beam, so as to reduce the beam height and reduce the reinforcement of the beam. Generally, the two-way beam sheet pile structure is cast-in-situ together. The whole system is a statically indeterminate structure with strong structural integrity. Due to the existence of redundant constraints, the safety and protection ability of the whole structure are good, and the ability to resist settlement and deformation is strong. The two-way beam pile slab structure has great stiffness in both transverse and longitudinal directions, which can ensure the stability of underground structure under transverse load. The two-way beam pile slab structure has the advantages of reasonable stress, high exertion rate of mechanical properties of materials and fast construction speed. Compared with the traditional pile slab structure without beam, its comprehensive technical and economic benefits are obviously higher.

Obviously, when the upper load is large and the requirements for deformation and settlement are strict, the two-way beam pile slab structure can be considered.

5. Conclusion

The mechanical mechanism and engineering applicability of several pile slab structures are compared and analyzed by means of engineering example summary, literature induction and theoretical analysis. The results show that:

- (1) Underground pile slab structure is mainly used for foundation treatment of special soil, or for some special engineering sections, such as road bridge transition section, etc.
- (2) The establishment of simplified calculation model of underground pile slab structure considering uneven settlement of pile foundation and plate-soil interaction is an urgent problem to be solved in engineering and academic circles. Establish the relationship model between axial displacement and bearing capacity of pile foundation, establish the elastic foundation beam model of layered soil, and then apply the two models to the simplified calculation model of underground pile slab structure, which is the most possible research direction.
- (3) Underground pile slab structure can be divided into beamless supporting plate pile slab structure, supporting one-way beam pile slab structure and supporting two-way beam pile slab structure. Among them, the beamless supporting plate pile plate structure is only suitable for the case of small upper load. When the upper load is large and the requirements for deformation and settlement are strict, the supporting two-way beam pile plate structure shall be adopted.

Acknowledgments

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