Journal of World Architecture, 2022, Volume 6, Issue 4
http://ojs.bbwpublisher.com/index.php/JWA
ISSN Online: 2208-3499
ISSN Print: 2208-3480

The Application of Pile Foundation Bearing-Retaining Wall Combination Structure in a Mountainous Urban High Fill Project

Hongmei Wang[1,2]*, Xiaoguang Mao[3], Qi Su[4]

[1]College of Urban Construction, Chongqing Energy Vocational College, Chongqing 402260, China

[2]College of Architecture and Engineering, Chongqing Engineering College, Chongqing 400056, China

[3]Chongqing Branch of Ningxia Highway Survey and Design Research Institute, Chongqing 400061, China

[4]Jilin Water Conservancy and Hydropower Survey and Design Institute, Changchun 130021, China

***Corresponding author:** Hongmei Wang, 807736186@qq.com

Abstract: Pile foundation bearing-retaining wall combination structure is a new type of support structure developed in recent years. This article focuses on the characteristics, advantages, and application scope of the support structure, while combining a variety of algorithms, according to different geological conditions and slope stability, as well as summarizes the pile foundation bearing-retaining wall combination structure force analysis and design methods, taking a high-fill road project in Chongqing as an example. The application of this support structure under special conditions, such as thicker soil layer, steeper sliding surface, weak foundation, and limited slope release conditions, is presented, which illustrates the technical advantages of this support structure and proving that it has several other advantages, including clear force mechanism as well as economic and reasonable structure, thus providing reference for similar projects.

Keywords: Pile foundation bearing-retaining wall; Combined support structure; Design calculation method

Online publication: July 27, 2022

1. Introduction

After numerous theoretical research and engineering practice, conventional retaining wall structures, such as gravity retaining walls, weighted retaining walls, reinforced earth retaining walls, and arm retaining walls, have been widely used and developed in highway [1], urban road [2], railroad [3], and water conservancy [4] projects. The anti-slip pile reinforced high and steep slope has a large sliding thrust [5]; the shear force or bending moment is large, and the pile cross-sectional size and pile length are often large [6]; when considering the effect of rainfall [7], reservoir level change [8,9], earthquake [10,11], the geometric size of the anti-slip pile may be larger, and even require the use of multiple rows of anti-slip pile support. When gravity retaining walls are used for slope reinforcement, the foundation bearing layer of the retaining wall is required to meet the bearing capacity requirements. However, with the demand of urbanization and industrial park construction, there are often high-fill grading areas, high-fill roadbeds, or steep slope embankments in mountainous urban construction, and the foundation of retaining walls often cannot be embedded in the bedrock, resulting in issues with the foundation's bearing capacity, anti-slip, and anti-overturning requirements, or the retaining wall being too high and uneconomical.

As a result, pile foundation bearing-retaining wall combination structure as a new combination of support structure came into being. This structure can solve the problems of high fill, the foundation's insufficient bearing capacity, the retaining wall's deep foundation bearing layer, and the inadequate space for slope release. Its pile foundation part can provide bearing capacity and corresponding anti-slip force for the upper retaining wall structure, effectively reduce the height of the retaining wall, and save investment. It has been effectively applied in projects. The structure can be used when the thickness of the fill behind the wall is greater than the height of the retaining wall, when the foundation of the retaining wall is a weak soil layer and the natural foundation cannot be used, or when the height of the sloping steep slope embankment support exceeds the height of the conventional retaining wall (see **Figure 1**).

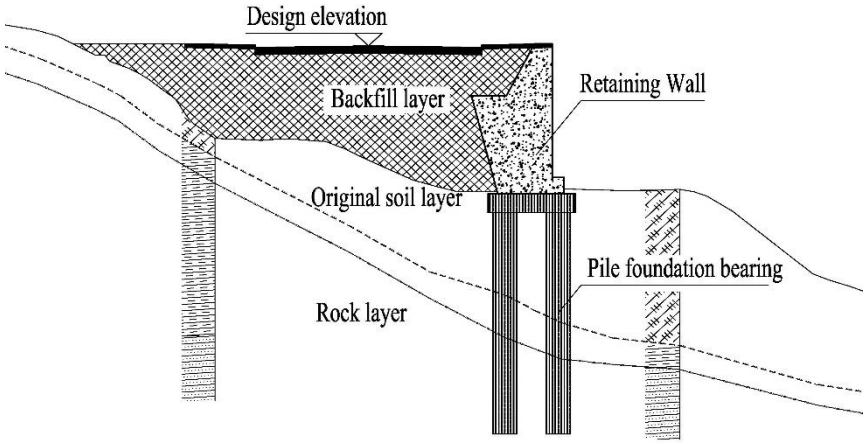

Figure 1. Schematic diagram of pile foundation bearing-retaining wall structure

In regard to anti-slip pile structure with tie beam and H-type double-row pile, Zhou Cuiying and several researchers used the finite element theory and the elastic foundation beam method to establish an internal force calculation model of portal double-row anti-slip pile [12]; Qian Tonghui considered the double-row portal anti-slip pile with tie beam and frame beam as a space structure for calculation [13,14]; Sun Yong proposed two new m-methods for the design calculation of double-row anti-slip pile with tie beam [15]; Chen Guoxiong and other researchers proposed a design calculation method for portal antiskid piles while considering the stiffness condition of the connecting beam and the displacement coordination condition [16]; Shen Yongjiang and several researchers proposed a design calculation method for double-row antiskid piles with connecting beam in consideration of the elastic-plastic deformation of landslide geotechnical body [17]; Wang Junjie and several researchers proposed a theoretical design calculation method for double-row pile combination support structure considering both foundation resistance and pile-bearing platform coordination [18]; Xiao Shiguo proposed that the H-type anti-slip pile structure can be analyzed by the plane rigid frame model with transverse elastic foundation restraint under the action of landslide thrust to determine the internal force of the loaded section and the anchored section by the elastic foundation beam, in which the outcomes were optimistic when applied to Sichuan Guangba Expressway [19]. The theoretical calculation methods for such structures have achieved more maturity. On the one hand, when considering the pile-soil reaction force, the aforementioned scholars often assume the reaction force as rectangle, triangle, or trapezoid, but the foundation reaction force is a complex curve equation, and the assumption is somewhat different from engineering reality, which may produce large calculation errors. On the other hand, the horizontal forces, vertical forces, and force couples transferred from the upper structure cause the lower structure to experience different forces, and thus the reference significance of this structure to the double-row pile combination structure is also limited.

For the above reasons, further research is required for the design calculation of pile foundation bearing-retaining wall combination structure, so as to reveal the force characteristics of each member. In engineering practice, there is an urgent need for a convenient and practical calculation method to guide the design. Therefore, a design calculation method for pile foundation bearing-retaining wall combination structure has been proposed in this paper.

2. Features and advantages of pile foundation bearing-retaining wall combination structure

2.1. Features

Pile foundation bearing-retaining wall combination structure consists of three parts: pile foundation, bearing platform, and retaining wall. The bearing platform is located at the top of the pile foundation; the bottom of the retaining wall position plays a connecting bearing role, so that it forms a more reasonable force system; the load on the retaining wall through the pile foundation is transferred to the deeper stable rock layer, in order to meet the support structure of the foundation's bearing capacity and the requirements for settlement deformation control.

2.2. Advantages

The height of the upper retaining wall of the combined pile foundation bearing-retaining wall structure does not exceed the height of the conventional gravity retaining wall, and the lack of its foundation's strength can be compensated by the composite foundation pile's bearing capacity, thus the safety hazards caused by the large area of excavation of deep foundation pits, the issues with super high retaining wall and super long cantilever anti-slip pile, and the poor effect of anchor cable in soil can all be avoided; additionally, the problem of weak foundation of gravity type or weight type retaining wall in the support design can be effectively solved. It offers unique advantages in some lots where high embankment retaining wall or high shoulder retaining wall is required in addition to cases with poor foundation conditions.

3. A discussion on the calculation method of pile foundation bearing-retaining wall combination structure

Since pile foundation bearing-retaining wall combination structure is a combination structure that is suitable for thick soil slope, based on the active soil pressure and landslide thrust after the wall size, the two forces to support the slope can be determined using two calculation methods. When the active soil pressure is greater than the landslide thrust, the divisional calculation method can be used, whereas when the landslide thrust is greater than the active soil pressure, the overall calculation method can be used.

3.1. Divisional calculation method

The divisional calculation method is applicable to cases where the slope is stable or basically stable and the active soil pressure is greater than the remaining sliding force of the slope (landslide thrust). Assuming that the retaining wall is a natural foundation, the force on the wall is calculated based on conventional retaining walls. The calculation theory of this part is more mature. The active soil pressure can be used to calculate the retaining wall size. After calculation, the horizontal slip force, overturning moment, eccentricity distance, vertical pressure of the retaining wall, and the distribution of the retaining wall are obtained. Thus, the loads and effects of the retaining wall footings on the top of the pile foundation bearing are clarified. They provide important reference for the design of the connection between the retaining wall and the bearing platform, so as to solve the anti-slip and anti-overturning issues of the retaining wall itself. The pile foundation bearing is then used as the subject of force analysis, and the forces and moments exerted on the bearing by the upper retaining wall and the soil pressure borne by the pile body are jointly applied to the pile foundation bearing. The horizontal load of this calculation method is the sum of the sliding force of the

retaining wall caused by the soil pressure acting on the upper retaining wall and that borne by the pile body; the bending moment is the sum of the overturning moment of the upper retaining wall and the reverse moment formed by the soil pressure; the vertical force is the sum of the gravity of the wall body and the upper soil body. Finally, the calculation and design of the pile foundation bearing are carried out based on the calculation theory of the composite foundation pile, thus completing the overall analysis and design of the combined structure of pile foundation bearing-retaining wall. The force analysis is shown in **Figure 2**.

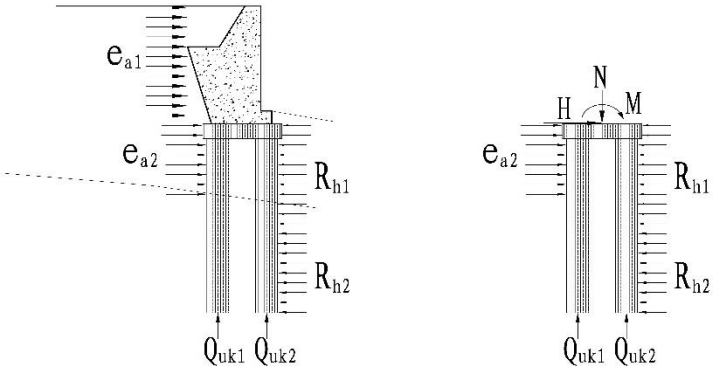

Figure 2. Force analysis of pile foundation bearing-retaining wall structure

3.2. Overall calculation method

The overall calculation method is applicable to cases where the slope is basically stable or unstable and the remaining sliding force of the slope is greater than the soil pressure. Firstly, the overall stability of the slope is analyzed by using the transfer coefficient method to determine the suitable supporting position and the remaining sliding force to be supported. Then, assuming that the retaining wall is a natural foundation, the forces on the wall are calculated according to conventional retaining walls; the horizontal slip force, overturning moment, eccentricity distance, vertical pressure of the retaining wall, and the distribution of the retaining wall are obtained. The horizontal load of this calculation method is the horizontal component of the remaining sliding force of the side slope; the bending moment is the sum of the overturning moment of the upper retaining wall and the reverse moment formed by the soil pressure; the vertical force is the sum of the gravity of the wall body and the upper soil body. Finally, the calculation and design of the pile foundation bearing are carried out based on the calculation theory of the composite foundation pile, thus completing the overall analysis and design of the pile foundation bearing-retaining wall combination structure. The force analysis is shown in **Figure 3**.

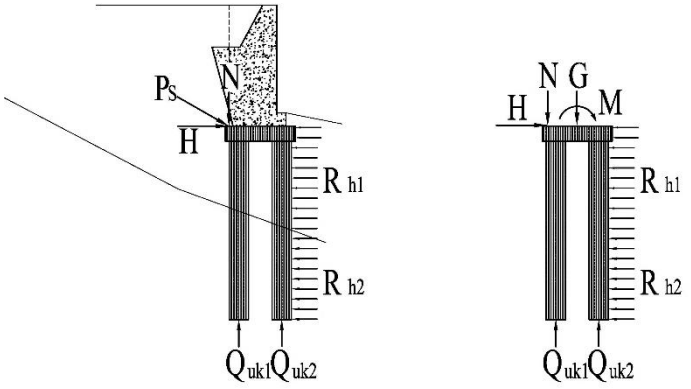

Figure 3. Force analysis of pile foundation bearing-retaining wall structure

3.3. Connection design of the upper and lower parts of the pile foundation bearing-retaining wall combination structure

According to the above calculation principles, in order to complete the design calculation of the pile foundation bearing-retaining wall combination structure, the final step is to analyze the condition of the forces on the pile foundation bearing structure. First of all, assuming that the retaining wall is a natural foundation, it is necessary to ensure the reasonableness of the size of the retaining wall structure under the action of soil pressure in the range of the horizontal thrust assumed by the upper retaining wall. This part of the calculation theory is more mature. The active soil pressure can be used for the calculation design of the retaining wall size. The horizontal slip force of the retaining wall, overturning moment, eccentricity distance, vertical pressure of the retaining wall, and its distribution can be calculated. In the design, the horizontal slip resistance issue of the upper retaining wall can be solved by pre-buried stub bars in the bearing platform; the overturning resistance issue can be solved by the anchorage length of the stub bars.

4. Case application

4.1. Project overview

The project is located in Chongqing Dadukou District's heavy steel area, Ge Laoxi. The road begins with a steel flower road and ends at the north-south trunk road; it is 1,072 meters long, with a standard width of 26 meters, and serves as a mountain city road, with a sizeable portion of the roadbed made of either half-filling, half-digging roadbed or steep slope fill roadbed.

The transverse terrain slope angle of the road section is about 30°, and the longitudinal terrain slope angle is 5° to 20°. Based on the road design elevation, the road side of the formation of the fill side slope has a side slope height of 10 meters to 20 meters because the red line restrictions do not have the slope conditions. The original river silt is present at a certain range at the bottom of the side slope, in which the depth is unknown, and there is new fill at a certain range at the side slope, with its slope surface being extremely irregular.

4.2. Project difficulties

According to a ground survey report and geological profile, the roadbed is situated on a slope distribution of 5 meters to 20 meters after the powder clay ($Q4^{el+dl}$) and miscellaneous fill ($Q4^{ml}$); at the bottom of the ditch below the former river, there are numerous silts and saturated powder clays; however, the thickness is not known, and there is poor water drainage. The existing miscellaneous fill on the half-slope is natural landfill, and the slope has not been released according to the stable slope rate. If compression deformation or displacement occurs at the foot of the slope, the upper slope is very likely to be pulled down, thus causing a landslide. After analysis, the shoulder type support structure must be used for support. However, the vertical height from the road edge to the stable rock layer is 20 meters to 40 meters, which basically excludes the gravity type retaining wall. If the pile plate wall is used, the soil in front of the wall is not stable and the cantilever length is too long, which does not bring economic benefits. If the anchor pull pile is used, a large area behind the wall is soil; the anchor cable anchoring effect is poor and is clearly affected by the settlement of the fill roadbed, which may lead to the destruction of the anchor cable.

4.3. Design application

After the analysis, the use of pile foundation bearing-retaining wall combination structure is undoubtedly the best solution. According to the different sections of the road slope using the transfer coefficient method for analysis and calculation, the unstable or basically stable state of the road fill roadbed forming slope in the case of no support structure, and the greater remaining sliding force than the soil pressure, the selection of calculation method two (overall calculation method) is apt for structural force calculation. After

calculation, the bearing pile base row spacing (axis spacing) of 4 meters and the pile column spacings of 5 meters and 3.5 meters are selected to meet the different soil thickness and landslide thrust cases.

4.4. Construction process

The pile foundation is selected from 1.8 m diameter circular section piles, which are easily and quickly constructed by rotary drilling. The pile and bearing platform are poured with C30 reinforced concrete, with water seepage, and the construction is carried out by the underwater pouring process. In order to compensate for the uneven stresses caused by the load and bending moment in the middle of the bearing, the piles' longitudinal reinforcement should be 76 Φ 28 Φ 25HRB400, through-length reinforcement, uniformly arranged; spiral hoop reinforcement Φ 10@100 HRB400; bearing reinforcement using a six-sided 28 reinforcement network; and column reinforcement between the reinforcement to meet the front and back rows of piles. In pile foundation pouring concrete, pre-buried sound pipe (seam steel pipe Φ 57 * 3) should be used, and when pile construction is completed and testing conditions are appropriate, pile quality inspection should be performed.

5. Conclusion

The benefits of pile foundation bearing-retaining wall combination structure over conventional retaining wall are clearly seen after the practical application of several projects. The structure addresses the slope issues that are not supported by traditional retaining structure, such as those cause by thick soil layer, steep sliding surface, weak foundation, and limited slope release conditions. Moreover, the structure can be easily constructed and is fair in terms of force, particularly when there is no room for slope release or a deeper foundation bearing layer. It offers sound guidance for similar projects; thus, it merits promotion and application.

Geological, geotechnical, structural, and engineering economic knowledge are all integrated into the design of retaining walls. The program selection of retaining wall type must be based on the site's actual engineering geological conditions. In this paper, a variety of algorithms are combined based on various geological conditions and slope stability, and two pile foundation bearing-retaining wall combination structure force analysis and design methods are proposed. This paper summarizes the calculation methods and briefly introduces its application in actual engineering cases, in hope to provide reference for domestic equivalents.

Funding

Youth Project of Science and Technology Research of Chongqing Municipal Education Commission "Research on the Promotion of Pile Foundation Bearing-Retaining Wall Combined Structure Technology" (Project Number: KJQN201905601)

Youth Project of Science and Technology Research of Chongqing Education Commission "Research on Construction Monitoring and Risk Warning of Deep Foundation Pit Project Based on BIM+Internet of Things" (Project Number: KJQN201904306)

Disclosure statement

The authors declare no conflict of interest.

References

[1] Yu Y, Liu H, 2016, Application of Supporting Wall Type Retaining Wall in Mountainous Highway.

Transportation Science and Technology, 2016(5): 104–106.

[2] Xie D, 2020, Application of Reinforced Earth Retaining Wall in Urban Riverine Roads. Building Materials and Decoration, 2020(17): 277–278.

[3] Huang Y, 2015, Application of H-Type Pile Plate Retaining Wall in Railroad Engineering. Science and Technology Innovation Herald, 12(25): 34–35.

[4] Cheng J, Yin H, 2019, Design Points of Retaining Wall of Supporting Wall Applied in Hydraulic Buildings. Science and Technology Innovation and Application, 2019(12): 71–72.

[5] Luo Y, 2005, An Analysis of the Advantages of the New Retaining Structure in the Railway Line. Subgrade Engineering, 2005(5): 90–91.

[6] Wang J, Liang Y, Zhang H, et al., 2014, A Loess Landslide Induced by Excavation and Rainfall. Landslides, 11(1): 141–152.

[7] Sarma SK, 2006, Determination of Critical Slip Surface in Slope Analysis. Geotechnique, 56(8): 539–550.

[8] Wang J, Zhang H, Zhang L, 2012, Experimental Study on Heterogeneous Slope Responses to Drawdown. Engineering Geology, 147–148: 52–56. https://doi.org/10.1016/j.enggeo.2012.07.020

[9] Yan Z, Wang J, Chia H, 2010, Influence of Water Level Fluctuation on Phreatic Line in Silty Soil Model Slope. Engineering Geology, 113: 90–98.

[10] Wang J, Zhao D, Liang Y, et al., 2013, Angle of Repose of Landslide Debris Deposits Induced by 2008 Sichuan Earthquake. Engineering Geology, 156: 103–110.

[11] Wang J, Zhang H, Chai H, et al., 2008, Seismic Passive Resistance with Vertical Seepage and Surcharge. Soil Dynamics and Earthquake Engineering, 28(9): 728–737.

[12] Zhou C, Liu Z, Shang W, et al., 2005, Portal Double Row Anti Slide Pile Design Calculation of the New Model. Rock and Soil Mechanics, 26(3): 441–449.

[13] Qian T, Tang H, 2009, The Calculation Model of Pile Space Portal Double Row Anti Slide. Rock and Soil Mechanics, 30(4): 1137–1141.

[14] Qian T, Xia W, Chao Z, et al., 2011, Calculation Method of Frame Anti Slide Pile Considering Spatial Coordination. Journal of China University of Geosciences, 36(6): 1143–1148.

[15] Sun Y, 2009, Study on the Calculation Method of Anti Slide Pile Structure with Double Row Under Sliding Surface. Rock and Soil Mechanics, 30(10): 2971–2977.

[16] Chen G, Xie S, 2013, Study on Calculation Method and Engineering Application of Portal Double Row Anti Sliding Piles. Highway Engineering, 38(5): 176–179.

[17] Yong J, Teng B, Yang M, et al., 2010, Plasticity Analysis Model and Calculation of Pile Elastic Anti Sliding Gate Type Double Row. Rock and Soil Mechanics, 31(7): 2146–2151.

[18] Wang J, 2017, Calculation Method for the Design of Double-Row Pile-Bearer-Retaining Wall Combination Structure. Journal of Underground Space and Engineering, 13(2): 442–452.

[19] Xiao S, 2010, Analysis Method and Engineering Application of H Type Combined Anti Slide Pile in Slope Treatment. Rock and Soil Mechanics, 31(7): 2146–-2151.