

Application Status and Prospect of Slope Treatment of Foundation Pit with Special Soils

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Abstract. With the development of society, there are more and more special soil slope projects in the construction of building foundation pits and roads. Because of the characteristics of difficult treatment of special soil, the research on slope treatment of special soil foundation pits has become the focus of current scholars. In order to ensure the safety and long-term benefits of foundation pit projects built in special soil, in recent years, many scholars have carried out in-depth research on slope treatment of foundation pit with special soil. Based on the detailed investigation of engineering examples, this paper summarizes the characteristics and treatment measures of soft soil, collapsible loess and expansive soil slopes in special soil, and provides reference and technical guidance for the research and development of foundation pit slope treatment in special soil.

Keywords: Special soil, Protective measure, Application status, Foundation pit engineering.

1. Introduction

China has a vast territory, complex underground structure and diverse stratum types. With the continuous construction of infrastructure, especially the excavation of highway construction and building foundation pit, it is inevitable to deal with special soils, such as soft soil, collapsible loess and expansive soil. Due to the low strength and high rheology of some special soils, the safety and durability of the project are poor, the economic losses are serious and the social benefits are low. Therefore, scholars have regarded the slope treatment of special soil foundation pit as the current research focus. Usually, the soil with special engineering geology is called special soil. Due to large-scale construction, the situation of encountering special soil slopes is increasing. When the special soil is the slope of building foundation, if we don't pay attention to their particularity, it may cause accidents.

If proper slope treatment measures can't be selected or used irregularly, the slope soil will creep and deform, which will lead to cracks and water seepage in the sewer, and water will soak into the slope soil, which will lead to slope instability; The balance of support is broken, and cracks appear at the top of the slope, which makes the slope treatment ineffective. Foundation pit collapse is a common final consequence caused by poor selection of treatment measures for foundation pit slope, and it will also destroy the nearby buildings. If the foundation pit collapse is not warned before, the foundation pit collapse may cause life harm to the foundation pit and people near it (Figure 1).



Figure 1. Example 2 of harm caused by improper support [1]

In recent years, many research teams in our country have focused on the study of slope treatment of special soil foundation pit in order to reduce the geological disasters of slope instability and to carry out effective prevention and treatment. Kong Lingwei and others focused on the basic properties and engineering practice of collapsible loess, expansive soil and red clay in China [2]. Xie Yongli and others summarized the theoretical research achievements of engineering slopes in stability analysis methods, engineering design and analysis software, and the new theoretical research progress of loess, expansive soil, frozen soil and rocky engineering slopes [3].

In order to further explore the application status of soft soil, collapsible loess, and expansive soil in the treatment of foundation pit slopes, this article conducts research and prospects on the properties of the three types of special soil and their application status in the treatment of foundation pit slopes.

2. Properties and characteristics of special soil

The main regional special soils in China are soft soil, collapsible loess, expansive soil, red clay, frozen soil, saline soil, contaminated soil, weathered rock and residual soil. Under the influence of water, earthquake and human factors, special soil shows the characteristics of water sensitivity, temperature sensitivity and disturbance sensitivity [3]. The following three types of special soils, namely soft soil, collapsible loess and expansive soil, are analyzed.

2.1. Properties and characteristics of Soft soil

The natural void ratio of soft soil is not less than 1.0, and the natural water content is greater than the liquid limit fine-grained soil; It has the characteristics of high water content, large void ratio, high compressibility, low strength, poor permeability and organic matter, which lead to two kinds of hazards of soft soil foundation: thixotropy and rheology. Thixotropic refers to the phenomenon that soft soil foundation is prone to lateral sliding, settlement and base extrusion to both sides under vibration load; Rheology refers to the slow and long-term shear deformation of soft soil under load, which has great influence on foundation settlement.

2.2. Properties and characteristics of Collapsible loess

Collapsible loess is a kind of loess that is wetted by water under a certain pressure, and the structure of the soil is rapidly destroyed, resulting in significant additional subsidence. Collapsible loess has the characteristics of large gap and low strength, which is easy to collapse and uneven settlement.

2.3. Properties and characteristics of Expansive soil

Expansive soil is mainly composed of hydrophilic minerals (montmorillonite), which has two obvious deformations: water absorption expansion and water loss contraction. The change of volume will cause a large number of cracks in the soil, and the shear strength index will be greatly reduced after water absorption.

3. Special soil foundation pit slope treatment measures

Chinese "Code for the Design of Building Foundations" clearly points out that the reinforcement of slopes should be carried out on the basis of foundations according to the different characteristics of different regions, including the improvement of soft and wet soil inward subsidence, and the construction of foundations on the basis of expansive soils and red clays, etc. [4]. Actual engineering cases are listed below to summarize the current status of existing special soil foundation slope management measures (Figure 2-4).



Figure 2. Example 1 of Slope Support in Foundation Pit Engineering [5]



Figure 3. Example 2 of Slope Support in Foundation Pit Engineering [6]

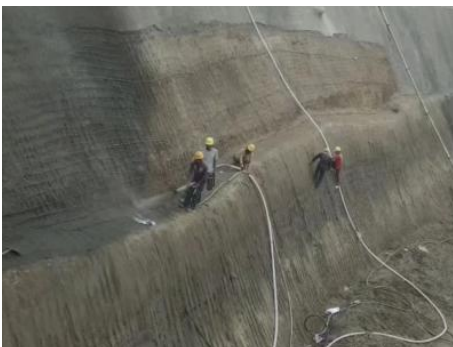


Figure 4. Example 3 of Slope Support in Foundation Pit Engineering [7]

3.1. Treatment measures and application cases of soft soil foundation pit slope

Soft soil refers to fine-grained soil with high natural moisture content, large pore ratio, high compressibility, and low shear strength deposited in coastal areas, lakes, valleys, and river banks. It is widely distributed in China. However, the mechanical properties of soft soil are poor, and it is not suitable to build highways or buildings on it. In order to better utilize the land resources of soft soil, the treatment of foundation pit slopes in soft soil is particularly crucial.

3.1.1 The buttress retaining wall is combined with double (single) row columns and treated with gravel

The slope is located in the Quaternary alluvial-proluvial facies, marsh facies, and alluvial-lacustrine facies, and is a complex soft soil slope with insufficient bearing capacity of the underlying strata. The combination retaining structure scheme adopts a buttressed retaining wall retaining system and a double (single) row column retaining structure system for retaining, and uses a gravel pile scheme for foundation treatment in areas with insufficient bearing capacity of the retaining wall.

Supporting measures are the basic measures in slope protection technology. Retaining wall is a structure to prevent slope deformation and instability and bear lateral earth pressure, with good economic effect, simple structure, wide trial range and convenient construction. The buttress retaining wall is a thin-walled reinforced concrete retaining wall, which is a light retaining structure. It relies

on its own weight and the weight of the fill above the wall floor to maintain its balance. It has the characteristics of small thickness, light weight, high height and good economic index. Using buttress retaining wall to support fill slope can meet the requirements of engineering safety and normal use [8]. When setting up a row of pile retaining structure, it should be ensured that the pile body is perpendicular to the slope direction as much as possible, and the outer edge line of the pile top should be vertically aligned with the outer edge line of the top beam. The stability of soil between piles should be ensured in the process of row column construction, and shotcrete treatment should be carried out in time in case of collapse [9].

3.1.2 Combination of upper slope and lower pile-anchor support

The mechanical properties of the upper soil in Xiaoqing River and Yellow River impact plain in the north of Jinan city are poor, and the strata are mainly cohesive soil and silt alluvial by Quaternary rivers. The excavation depth of this project is 6~8m, and the preliminary design scheme is graded slope soil nailing wall support; Finally, the slope treatment form of foundation pit combined with upper slope and lower pile-anchor support is adopted: the surrounding site is fully used for slope treatment within the depth of 2~3m in the upper part, and the slope deformation is controlled by cast-in-place pile and prestressed anchor cable in the lower part. This method can ensure the slope stability and avoid the creep deformation of soft soil near the pit bottom.

The applicability of soil nailing wall should be carefully considered for the soil with creep deformation. In case of soft soil slope, the supporting form of combining upper slope with lower pile anchor should be considered more than soil nailing wall [10]. Pile-anchor combined support has the advantages of good stability, low cost and easy operation, and is widely used in deep foundation pit engineering. Before the anchorage support, Midas/GTS and other software can be used to further optimize the pile spacing and pile depth [11].

3.2. Treatment measures and application cases of collapsible loess foundation pit slope

Loess has a distribution area of approximately 640000 square kilometers in China, accounting for approximately 6.7% of the national territory. Collapsible loess is widely found in semi-arid loess hilly areas such as northern Shaanxi, western Shanxi, Henan, eastern Gansu, and northern Hebei [12]. In collapsible loess areas, building houses without effective support measures is prone to disasters such as artificial landslides and mudslides; Under rainwater conditions, erosion, collapse, and other diseases are prone to occur, resulting in poor slope stability. Loess landslides have the characteristics of fast deformation speed, strong destructive force, and large scale [13]. The external cause of collapse loess slope disasters is mainly water, so waterproofing is crucial for the treatment of collapsible loess slopes.

3.2.1 Treatment of various compaction piles and cast-in-place piles in different buildings

The project is located in the residual area of the Loess Plateau, and the foundation collapse grade is IV, which is extremely serious. In addition, there are agricultural irrigation canals passing through this area, which further deepens the difficulty of controlling collapsible loess.

In the end, plain soil compaction pile, lime soil compaction pile and reinforced concrete cast-in-place pile were used to treat the foundation as a whole [14].

3.2.2 Several treatment measures for non-foundation pit cases such as slope protection method

The slope treatment methods of collapsible loess road include slope protection method, slope toe reinforcement method, compression pile reinforcement method, cushion method and so on. Among them, the compression pile reinforcement method is widely used because of its low cost and good effect. Cushion method is more traditional and has a wide range of application, which can be used for collapsible loess subgrade under different conditions [15]. At present, there are few reports on the collapsible loess foundation pit slope in the literature. This chapter analyzes the collapsible loess in Wuqi-Dingbian section and the Gansu section of Zhonglan Railway:

The Wuqi-Dingbian section of the highway is located in a complex landform: loess hilly and gully area, sandy grass beach area and beam-shaped low mountain hills. The collapsible loess in this area is widely distributed, which is easy to cause natural disasters such as landslides and debris flows in the area. The bored cast-in-place concrete pile with anti-slide pile reinforcement method is initially adopted in the project.

The Zhongwei-Lanzhou Railway adopts the integral steel formwork arch skeleton construction technology, which can reduce the demand of operators, improve the construction quality of skeleton slope protection and improve the production efficiency of arch skeleton slope protection project of loess slope.

3.3. Treatment measures and application examples of expansive soil foundation pit slope

Expansive soil has an extremely wide distribution in China, distributed in more than twenty provinces in China, such as Yunnan, Guizhou and Guangxi. The expansive soil distribution area is also a frequent place for slope landslide disasters. The landslide of expansive soil slope mainly includes deep landslide and shallow instability controlled by structural plane.

Traditional support methods are divided into rigid support and flexible support. Rigid support mainly relies on the self-weight and resistance of the structure to resist the active earth pressure and the thrust of the landslide to prevent the slope from instability. Rigid support includes retaining wall, anti-slide pile, prestressed anchor cable and anchor rod. The amount of work of flexible support is smaller than that of rigid support, and the construction is simple and more efficient [16].

3.3.1 Combination of replacement method and soil improvement method

The airport is generally located in the plain landform in front of the river alluvial fan. There are many cracks in the buildings in this area in the shape of "inverted eight" and "X". There are also cracks developing on the cement pavement in the area.

The treatment methods of runway expansive soil are generally soil replacement method, cushion method, humidity control method, compactness control method, soil improvement method and geosynthetics reinforcement method. Airplane runway requires higher deformation control, and the airport runway is longer and wider, so the replacement method and soil improvement method are suitable.

3.3.2 The implementation of slope rate method and other methods according to local conditions

The transportation hub has the geological conditions for the development of strong expansive soil represented by Honghe Mengzi, which has the characteristics of swelling when meeting water, sharp reduction of strength index, large swelling force, shrinkage and cracking after water loss.

The excavation and filling treatment area of the site is about 160,000m², the length of the excavated slope is about 1055 m, and the maximum height of excavation is about 17m. The length of the fill slope is about 1100m, and the maximum fill height is about 13m. The design area of this project is large, and the soil mass and filling and excavation conditions are different. Therefore, according to the different conditions in different regions, various forms of slope support are adopted, including slope ratio method, reinforced soil slope, cantilever retaining wall, buttress retaining wall, gravity retaining wall, anchor sheet retaining wall and anchor frame beam. For the expansion soil high slope, based on the expansion soil slope design idea of prioritizing water management, the expansion soil slope anti-drainage targeted design measures were taken. In addition, the shear strength index of expansive soil and the cohesive force between anchor rods and anchor cables and expansive soil were tested and studied, and the length of anchor cable was optimized, and the length of anchor section was reduced from 30m to 20m. At the same time, the pulling force dispersed anchor cable was adopted, which reduced the construction difficulty and construction period and the project cost on the premise of ensuring the safety of retaining structure [17].

Part of the supporting forms are applicable to various soils. The following is an analysis of the slope supporting methods involved in this project (Table 1).

Table 1. Description, characteristics and examples of various supporting methods

Slope support form	Formal description	Supporting characteristics	Other engineering examples (including non-foundation pit cases)
Slope rate method	Self-stability is achieved by controlling the height and slope of the slope	Low cost, more economical, with obvious economic and social benefits [18]	Kangjiaping Gupo and a residential project in Lanzhou
Reinforced soil slopes	A whole composite structure is formed by filling soil and arranging a certain strength of tape reinforcement in the filling soil	Light component, simple construction, short construction period, good adaptability, good tensile strength, small subgrade settlement and good ecological environment effect [19]	A Fill Slope in Qinba Mountain Area, Sub-project of the first phase of the SICOMINES copper drilling mine in the Democratic Republic of Congo
Cantilever retaining wall	A retaining wall composed of a bottom plate and a straight wall fixed to the bottom plate, which mainly relies on the weight of the fill on the bottom plate to maintain stability. It is mainly composed of three reinforced concrete components: a vertical wall, a toe plate, and a heel plate	Simple structure, light weight, excellent strength and adaptability to low bearing capacity foundation [20]	Subgrade of Nayong-Qinglong Expressway in Guizhou
Counterfort retaining wall	The structure was developed from a cantilevered retaining wall [21]	Small dead weight, good stability, strong durability, high strength, low cost, good integrity and low maintenance requirements	Duyun city Qingyun Lake Tourist Reception Center, An old city reconstruction project in Liuzhou
Gravity retaining wall	A wall built to prevent the soil from sliding and mainly bearing lateral earth pressure	Using local materials, the construction is simple; However, the importance of construction management needs to be high	Rectangular platform of a cement factory [22], Nanqin River flood control and revetment project
Anchor frame	By arranging prestressed anchors in the slope, the anti-sliding ability of the rock-soil layer is enhanced, and then the prestressed anchors on the slope are connected into a whole with a reinforced concrete frame, further enhancing the friction resistance and positive pressure of the rock-soil layer [23]	There are many construction procedures	A road in Baigong Street, Zhongxian County

Each support method has its own advantages and disadvantages. Considering the cost, construction period, quality and other aspects in real construction, usually multiple support methods are used in combination.

4. Conclusion

In this paper, we make a detailed investigation and analysis on special soil properties and foundation pit slope treatment measures, mainly including soft soil, collapsible loess and expansive soil. At the same time, through in-depth analysis of the forms of treatment measures in different

situations, it is expected to provide reference for the study of slope treatment of special soil foundation pit.

It is suggested that the new reinforcement material improvement technology, green treatment technology and intelligent monitoring technology should be applied to the slope of foundation pit with special soil in the later stage, so as to provide high efficiency and high quality technical guarantee for the slope protection technology of foundation pit with special soil and ensure the safety, applicability and durability of the project. It is suggested that the soil characteristics should be detected more accurately and the data records should be integrated in the later project, so that the treatment measures of foundation pit slope can be matched more quickly and accurately in the future project.

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