Soft Foundation Treatment Based on Xiangjiaba Project Slag Yard

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Abstract. Foundation treatment is a crucial aspect of practical engineering. A stable foundation plays a vital role in enhancing building stability, ensuring structural durability, and minimizing environmental impact. However, dealing with soft foundations presents a challenging problem in foundation treatment. This paper aims to study common methods for treating soft foundations based on data analysis, exploring the fundamental mechanisms and advantages and disadvantages of various treatment methods. Simultaneously, the paper combines new methods for treating soft foundations in China, analyzing the practical treatment of the Xiangjiaba Project slag yard. The study identifies that, in practical engineering, the overall soft layers of the site are treated using the replacement method. Sections requiring treatment employ the block-stone replacement (squeeze consolidation) method, functioning as integral structural retaining walls. Additionally, due to the local precipitation reaching 1003.1 to 1305.6mm, drainage treatment is necessary for the site. By combining these three treatment methods, the study achieves the requirements for structural load-bearing capacity and stability while simultaneously achieving the effects of shortening construction time and saving costs. This research on soft foundation treatment is beneficial for providing insights into achieving the development goals of Western China.

Keywords: Soft foundation, high precipitation, replacement method, stone compaction method.

1. Introduction

Foundation treatment is a fundamental aspect of engineering processes that can enhance the stability of buildings. As the cornerstone of entire structures, the foundation directly bears the load from above. In all engineering projects, the stability of the foundation is a paramount consideration. Improper foundation treatment may lead to risks such as settlement, tilting, or even collapse of the structure. Adequate foundation treatment can improve the stability of the structure, ensuring its ability to withstand design loads and maintain a stable state over the long term. Proper foundation treatment is essential for ensuring the durability of the structure, as improper treatment may lead to structural accidents and significantly impact its normal lifespan. Foundation treatment also reduces the environmental pollution and hazards caused by construction projects. Appropriate foundation treatment can minimize the footprint of the building structure, enhance land resource utilization, and prevent adverse effects on underground water systems. In foundation treatment, addressing soft foundations is a crucial component, as the stability of the foundation is vital for engineering projects.

The most common issue with soft foundations is deformation failure. The low bearing capacity and shear strength of soft soil make foundations susceptible to extrusion failure. Additionally, the high compressibility of soft soil leads to significant settlement and deformation, which may cause the foundation to sink, potentially damaging buildings or structures. Failure to address soft foundations can lead to severe engineering problems. Considering the geological characteristics of the southwestern region of China, especially factors like high altitude, red clay, karst caves, and high seismic intensity, this area has been a focal point for theoretical research in geotechnical engineering [1]. Domestic scholars have conducted extensive research in this regard. For instance, Shang Zhi and others used high-pressure rotary jet grouting piles combined with qualitative analysis, semi-quantitative analysis, and fuzzy comprehensive analysis to study the stability analysis and reinforcement treatment of soft foundations in karst caves [2]. Ge Jiandong applied CFG pile technology to high-speed railways [3]. Liu Sen and his team employed a method involving slope retardation combined with geotechnical composite materials to treat weak foundations in flood embankments [4]. Foundation treatment should adhere to principles such as energy efficiency, environmental friendliness, conservation of space and materials, cost-effectiveness, short construction periods, and excellent results [5].

The Xiangjiaba Project in Sichuan Province, providing water supply to several cities, serves as an illustrative example. It is located at the junction of Sichuan and Yunnan provinces along the downstream section of the Jinsha River with abundant precipitation and complex geological conditions. Therefore, this paper analyzes the treatment of soft foundations in the Xiangjiaba Project. The study begins with a literature analysis of common ground treatment methods and their characteristics, combined with research on new developments in foundation treatment technology. Subsequently, the paper investigates the treatment methods of the Xiangjiaba spoil area based on practical approaches.

2. Common Methods and Characteristics of Foundation Treatment

The common foundation treatment methods currently include the replacement method, stone compaction method, cement soil deep mixing pile method, and high-pressure rotary jet grouting pile method.

(1) Replacement method

The replacement method involves excavating the soil of the weak layer and backfilling it with coarse sand and crushed stone using a layer-by-layer compaction method [6]. This method is commonly applied in the construction of shallow soft foundation treatment. However, it is not suitable for situations with groundwater influence due to its economic inefficiency and prolonged construction period when the replacement depth exceeds 3 meters. It is suitable for treating soft soils such as sludge, sludge-like soil, loose fill soil, and uneven foundations in dry working conditions, as well as for fill foundation treatment in low-lying areas.

(2) Stone insertion method

This method is suitable for soft soil layers with mud or high water content at the bottom of pipes, and when there is no additional load such as additional soil cover on the pipe foundation [4]. In this method, large stones with diameters of 20 to 40 cm are mechanically pressed into the soft soil layer beneath the pipe, reducing excavation depth, lowering support costs, enhancing foundation bearing capacity, and facilitating rapid construction. It is a commonly used method for treating soft foundations [7]. However, it may result in significant foundation settlement.

(3) Cement soil deep mixing pile method

The principle of this method involves mixing and blending cement stabilizers with the original soft soil in situ to form a reinforced body with a certain strength. Although the construction method is simple, it poses difficulties in testing, requires comprehensive process control, and has relatively poor durability.

(4) High-pressure rotary jet grouting pile method

Developed based on static pressure grouting and hydraulic coal mining technology, this method uses jets to cut and mix the strata, altering the original structure and composition. Cement slurry or composite slurry is injected to form a solidified body, achieving both foundation reinforcement and waterproofing. It features high construction efficiency, good quality, minimal footprint, low vibration, and relatively low noise. However, it presents challenges in construction, is prone to environmental pollution, has higher costs, and is not suitable for soils that cannot be solidified by the ejected slurry [8].

3. The Latest Technology and Development of Weak Foundations in China

Since the 1980s, the technology for treating soft foundations in China has rapidly advanced. This section focuses on the introduction of composite foundation technology and solidifying agent stabilization methods.

3.1. Composite Foundation Technology

China's composite foundation technology has evolved from narrow-sense composite foundations to broad-sense ones, forming a systematic theory for broad-sense composite foundations. The development includes the design and optimization of composite foundations based on settlement control [9]. New types of rigid and semi-rigid piles continue to emerge, enriching the development of composite foundation technology and theory. Examples include combination-type composite foundations, variable-diameter cement-soil pile composite foundations, long-short pile composite foundations, and pile grid composite foundations. The Institute of Geotechnical Engineering at Southeast University, combining carburization solidification methods with mixing pile technology, successfully developed integrated carburization solidification equipment and processes for shallow soft soil construction. This was demonstrated in the carburization solidification project in the silt at the bottom of the Yichang Expressway [10].

3.2. Solidifying Agent Stabilization Method

For the reinforcement of soft soil foundations, cement or lime is commonly used as a solidifying agent. However, both of these types of solidifying agents have issues such as high energy consumption, high emissions, and high costs. Therefore, scholars both domestically and internationally have been actively exploring and developing new environmentally friendly, energy-efficient, and green solidifying agents. Extensive research has explored the utilization of industrial waste in geotechnical engineering, resulting in significant progress [11]. Australian scientist Harrison invented reactive MgO cement, which, compared to traditional Portland cement, exhibits better durability, carbonation resistance, and salt resistance. Moreover, the calcination temperature of MgO is lower than that of cement, and after hydration, it can absorb nearly the same weight of carbon dioxide gas, significantly reducing greenhouse gas emissions.

3.3. Intelligent control technology

To better promote the development of composite foundation technology, compared with the solidification agent stabilization method, people also need to pay attention to intelligent control technology. Intelligent compaction technology refers to a compaction control system that uses on-site measured compaction machine conditions to self judge and automatically adjust compaction performance parameters during the compaction process of a vibrating roller, achieving the best compaction effect. The research on intelligent compaction control technology started relatively late in China. In 2010, XCMG Group developed the XD142 double steel wheel vibration roller, which combines CAN and PLC bus technology organically, allowing the control system to display vibration parameters in real time and automatically alarm faults. Zhang Xuejin et al. [12] conducted a correlation analysis between a large amount of CMV (Compaction Meter Value) data collected on site and conventional detection indicators to verify the applicability of intelligent compaction of asphalt pavement.

4. Analysis of the Foundation Case of Xiangjiaba

4.1. Project Overview

The Xiangjiaba Irrigation Area Project is a supporting project determined by the comprehensive development and utilization task of the Xiangjiaba Hydropower Station Project. It is divided into two major parts, the South Main Canal Irrigation Area and the North Main Canal Irrigation Area, with the Yangtze River as the boundary. The slag yard in Xiangjiaba Irrigation District is responsible for stacking the waste materials and earthwork generated after excavation. The slag yard needs to set up retaining walls to fix the waste and prevent accidents caused by the sliding of the waste. However, the geological conditions of the waste disposal site indicate that the Quaternary loose accumulation layers mainly include Q4dl+el, Q4dl+pl, Q4col+dl, and other accumulation layers, mainly distributed in gentle slope platforms, valleys, and low-lying areas. The exposed bedrock strata on the site are sandstone interbedded with sandy mudstone in the upper K2gk and K2s of the Cretaceous system and sandstone interbedded with sandy mudstone in the lower K1d and K1w of the Cretaceous system. Silty mudstone, muddy siltstone, and sandstone interbedded with varying thicknesses in the upper J3p, J3s, and middle J2s of the Jurassic system. Silty mudstone and sandstone interbedded with varying thicknesses in the middle and lower J1-2z of the Jurassic system. Silty mudstone and sandstone interbedded with varying thicknesses in the upper T3xj of the Triassic system. Limestone in the lower T1j of the Triassic system. Some sites have rock debris type weak interlayers, which have an impact on the bearing capacity of the site.

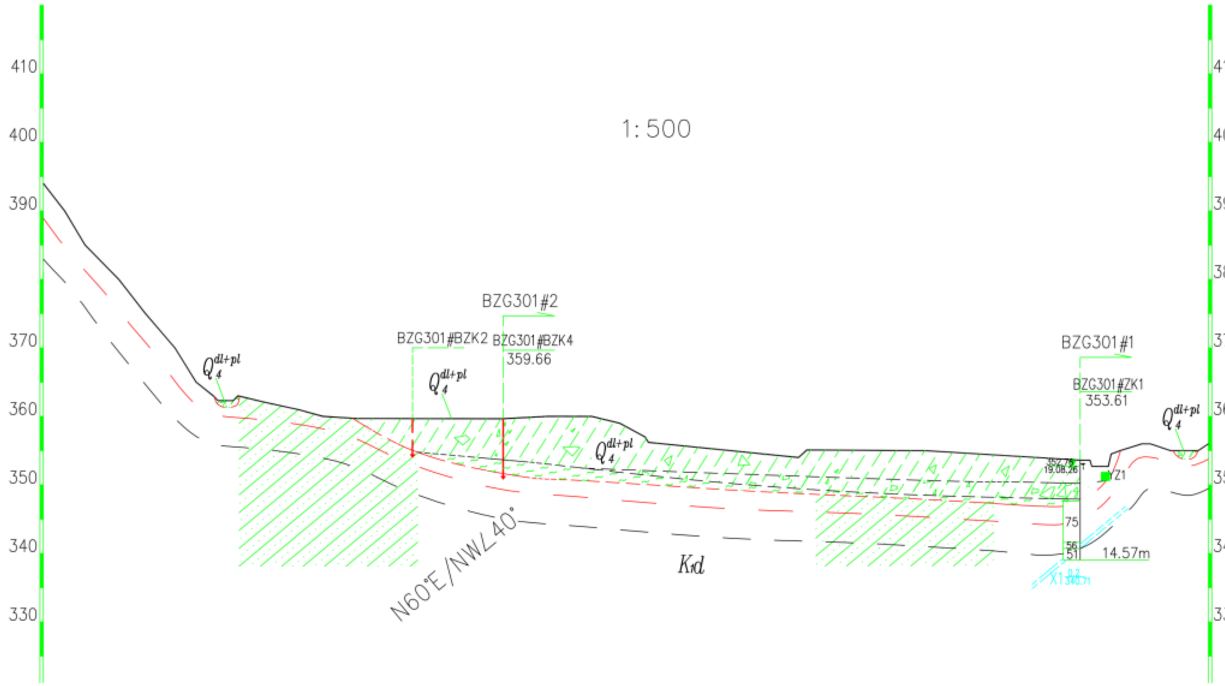

Fig. 1 Survey map of slag site [11].

4.2. Actual Measures

The method of using block stones to replace and fill (squeeze silt) the soft foundation that needs to be used as a retaining wall foundation can reduce the excavation depth, minimize the deflection of the surrounding soil on the construction site, and lower maintenance and support costs. On the other hand, it can also enhance the bearing capacity of the foundation soil in this area, thereby meeting the needs of engineering construction. The most important thing is that its construction is convenient and the construction period is short, which can ensure the strength of the soil and quickly complete the construction.

To address the continuous soft soil layer in the entire slag yard, the replacement and filling method is employed.The replacement and filling method also has the advantages of convenient construction, strong bearing capacity of the treated foundation, small deformation, and low cost. The replacement method has a weak treatment capacity for environments with high water content and the presence of groundwater. However, by combining the replacement method with block stone replacement (squeezing silt), it can effectively meet the requirements of low cost, fast construction, and good foundation treatment strength.

The engineering area belongs to the subtropical humid monsoon climate zone, which is characterized by: a warm winter and hot summer, no scorching heat in summer, warm climate throughout the year, high evaporation, early spring and late winter, long free period, abundant rainfall, but uneven distribution, and high frequency of drought

The average annual temperature in the engineering area ranges from 17.4 to 18.2 ℃, with an average annual precipitation of 1003.1 to 1305.6mm, an average annual relative humidity of 80-84%, an average annual sunshine duration of 1053.0 to 1939.8 hours, an average annual evaporation of 885.7 to 1286.5mm, and an average annual wind speed of 0.8 to 1.6m/s.

The distribution of rainfall in the engineering area is uneven throughout the year, with precipitation mostly concentrated from May to September, accounting for 73-80% of the annual rainfall. Among them, the water volume is particularly concentrated in July and August, accounting for 30-40% of the annual rainfall. Drainage measures need to be completed for the site. Drainage is carried out through concrete drainage ditches, and after completing the cleaning of the site cover layer and site drainage, the waste is piled up to meet the overall stability requirements of the waste disposal site.

5. Conclusion

This paper conducts research on common foundation treatment methods through literature search and analysis. This paper concludes that the replacement method can improve the bearing capacity of the foundation while reducing settlement, but if the replacement depth exceeds 3 meters, the economy is poor, the construction period is extended, and it is not suitable for situations affected by groundwater. The stone compaction method reduces excavation depth, support costs, and enhances foundation bearing capacity, but leads to relatively large settlement. The cement soil deep mixing pile method can effectively improve the bearing capacity of the foundation, and the construction is simple, but the detection difficulty is high, requiring full process control, and the durability is poor. The high-pressure rotary jet grouting method has high construction efficiency and good quality, with less construction land, low vibration, and low noise. However, the construction difficulty is high and it is easy to pollute the environment. The cost is high, and it is not suitable for special soil that cannot solidify the sprayed slurry. Through literature search and analysis, the current soft foundation treatment technology in China was studied. In terms of composite foundation technology, a systematic generalized composite foundation theory is formed, and the design ideas of settlement controlled composite foundation and composite foundation optimization are developed. New types of piles are used to optimize the design. In terms of curing agent stabilization method, researchers will optimize the curing agents that were previously highly polluting, emitting, and costly, and conduct research toward green and energy-saving directions. In terms of intelligent technology, by combining with intelligent technology, utilizing intelligent technology to strengthen the detection and automation of engineering.

This paper conducts research and analysis on the soft foundation treatment of the actual Xiangjiaba slag yard. The Xiangjiaba irrigation area slag yard is a facility used to treat waste residue and materials generated during the construction process. It must be equipped with retaining walls, and the pollution generated by waste residue cannot spread to the surrounding environment. For the soil layers in the site that are not used as load-bearing structures, the replacement method is adopted to achieve the goal of quickly processing the site and saving time and cost. For the soil layer that needs to be used as the foundation of the retaining wall, the method of block stone replacement (squeezing silt) is used to treat it, reduce the excavation depth, reduce the deflection of the surrounding soil on the construction site, enhance the bearing capacity of the foundation soil in this area, and meet the needs of engineering construction. This can ensure the strength of the soil and quickly complete the construction. However, due to excessive precipitation on the site, failure to implement drainage measures may lead to landslides, and the construction of drainage measures on the site is also necessary. This paper analyzes soft foundation engineering in high precipitation areas in western China, which can provide a reference for the treatment of soft foundations in high precipitation areas.

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