Review of research progress on key disposal techniques of pile foundation in karst area

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Abstract. It is necessary to study the key disposal technology of pile foundation in karst area during the development of pile foundation. In this paper, the development status of the key disposal technology of pile foundation was compared and analyzed from two aspects: the research progress of the comparison and selection of pile foundation design and construction scheme, the problems encountered in the construction of pile foundation in karst area and the research progress of treatment methods. The shortcomings and problems in the research of key disposal technology of pile foundation in karst area were studied, and the following conclusions were drawn: It is the priority among priorities to formulate scientific and quantitative reference basis for pile foundation construction scheme and convert engineering geology into data information. It is an important way to solve the problem of pile foundation construction in karst cave area to develop new piles and increase their adaptability to geological conditions. In the construction of pile foundation in karst area, the probability of accidents should be reduced as much as possible and the possible accidents should be stopped at the prevention stage. The research results provide technical support and scientific guidance for the calculation of bearing capacity of pile foundation and the key disposal technology in karst area.

Keywords: karst area; pile foundation; scheme comparison; construction problems; disposal scheme.

1. Introduction

Karst landform refers to a special geological type formed by long-term dissolution and erosion of soluble rocks by flowing water containing carbon dioxide, and is a common unfavorable geological type. The coverage area of karst areas in China accounts for about one-third of the total land area and is widely distributed in Yunnan, Guizhou, Sichuan, Guangdong, Guangxi, Hunan, and other places. With the development of engineering construction, the expansion of railways, bridges, and urban areas, it is inevitable to encounter the situation of having to build structures in karst areas during engineering construction. The research on karst disposal technology is a problem that we have to face.

There is a widespread distribution of groundwater and karst caves of different shapes in karst areas, resulting in frequent engineering problems such as uneven settlement of foundation, surface cracking, collapse of karst roof, and water gushing, which have become important factors limiting the rapid construction of karst engineering. Pile foundation has the advantages of high load-bearing capacity, good stability and small settlement, and has become the preferred foundation type for large buildings in karst areas. After decades of development, outstanding developments have been made in pile foundation types, construction techniques, construction equipment, and design specifications. The design and construction of pile foundations in karst areas have developed a mature set of theories, techniques, and construction equipment. However, due to the complex geological environment of karst caves, there are still many unresolved engineering problems during the construction process in

karst areas, and pile foundation design and construction accidents occur frequently, For example, during the construction process of bored cast-in-place piles, engineering accidents such as mud leakage, stuck drilling, and drill falling are prone to occur. Currently, engineering accidents related to pile foundations in karst areas have not been systematically resolved.

In order to reduce engineering accidents during the construction of pile foundations in karst areas, domestic and foreign scholars have conducted extensive research on the key technologies of pile foundation construction in karst areas, and have achieved rich results. This article will focus on summarizing and analyzing the research results of key disposal technologies for pile foundations in karst areas from two aspects: comparison and selection of construction plans and handling of construction problems, providing reference for promoting the research and development of key disposal technologies for pile foundations in karst areas.

2. Research progress of pile foundation construction design scheme

The different construction scheme for pile foundations in karst areas have a significant impact on the bearing characteristics of pile foundations [1]. It is necessary to choose the optimal pile foundation construction scheme that is safe, technically feasible, and economically reasonable based on factors such as engineering geological conditions, upper structure system, load size and distribution, construction technology feasibility, and engineering economy.

2.1 Research progress on pile foundation types in karst areas

At present, cast-in-place pile and prefabricate pile are the two most commonly used pile foundation in engineering, and these two different pile types are facing opportunities and challenges when constructing in karst areas. To solve the problem of pile foundation construction in karst areas, some scholars have further innovated on the basis of traditional pile types and obtained new types of piles with stronger adaptability in karst areas, enriching the selection of pile types in karst pile foundation design.

Zheng Xiaohui [2] broke the traditional design concept and changed the original method of filling and blocking karst caves, proposing an environment-friendly friction type cast-in-place pile, and obtained the stress calculation formula for this pile type through model tests. When constructing cast-in-place piles in karst areas, due to the presence of karst caves, soil caves, and cracks, it is easy to encounter construction accidents such as mud leakage during the construction process, resulting in huge construction costs and poor pile quality. Therefore, compared to cast-in-place piles, prefabricated piles are more suitable for use in pile foundation engineering in karst areas. In recent years, prefabricated piles suitable for construction in karst areas have also been invented, such as while Drilling with PHC Pipe Cased Piles [3-5]. The integrated construction method of drilling, pile sinking, soil dumping, and pile splicing can effectively penetrate the karst cave roof with insufficient bearing capacity, and can protect the pile body from huge impact and fracture. The lateral pile grouting can greatly improve the lateral friction resistance of the pile [6], and to a certain extent, reduce the impact of the stability of the underlying karst cave roof on the overall bearing capacity of the pile foundation. It is a new pile type with good adaptability in karst areas. However, there are few engineering examples of this pile type in karst areas, and theoretical research needs to be improved. The flow and diffusion mechanism of slurry on the pile side still needs to be further revealed by scientific researchers through practical construction and simulation, etc.



(a) Cast-in-place pile (b) Drilling with PHC pipe Cased Pile

Fig.1. Pile foundation

2.2 Research progress on pile foundation design and selection in karst areas

The design and selection of pile foundations in karst areas has formed a comprehensive theoretical system and has achieved great success in engineering practice.

Liu Gaozi et al. [7] pointed out the key to the reasonable selection of pile foundations in karst areas, and combined with different engineering conditions and geological conditions, listed the applicability of various foundation forms in different foundation conditions, and compared the advantages and disadvantages of various foundation forms when applied in karst areas. Zheng Weiguo et al. [8] pointed out the pain points of pile foundation selection, summarized the methods of pile foundation selection in different geological conditions in karst areas through reviewing two excellent engineering cases, and provided detailed and constructive suggestions for various foundation conditions. Zheng Weiguo [9] pointed out that when encountering unfavorable geological conditions such as karst caves and soil caves, strategies should be followed to avoid risks during deep burial, share risks during medium burial, and eliminate hazards during shallow burial. He also provided a detailed explanation of the geological conditions and foundation selection corresponding to the three strategies, and provided several suggestions for foundation selection. Li Wensheng [10] introduced the foundation treatment pile foundation selection measures taken under the geological conditions of the project based on engineering examples and objectively explained the advantages and disadvantages of this measure. Based on the problems that will be encountered during construction discovered during the survey, solutions were proposed, and reasonable foundation treatment and selection were used to save engineering costs while ensuring the progress and quality of the project. Li Xiang et al. [11] utilized the idea of risk avoidance to apply the post-grouting technology at the pile toe and the design concept of long and short piles in deep covered karst areas, and achieved good results. Pari et al. [12] pointed out the important position of pile foundation design in engineering and proposed an efficient pile foundation design method. This method incorporates factors that have a significant impact on construction, and improves the pile foundation design process using results obtained from dynamic and static load experiments and dynamic formulas. Li Guosheng [13] pointed out that soil caves are special forms of karst caves and pose greater harm than karst caves, and provided general treatment methods for soil caves. He summarized the foundation treatment and design methods for karst in shallow and thick geological conditions. He Shimao et al. [14] proposed that when the load on the upper structure is not large, the foundation should be buried as shallow as possible. For high-rise buildings with large loads, pile-raft foundations should be selected to avoid safety hazards caused by undiscovered adverse geological conditions on the upper structure.

In summary, a systematic approach has been developed in the design and construction of pile foundations in karst areas, including foundation evaluation and treatment, bearing capacity analysis, pile foundation selection, and construction technology. However, there are still many areas for improvement and improvement. Although the finite element method has developed rapidly in

quantitative analysis of foundation evaluation, there is still no accurate solution for processing data and simulating material mechanical properties. It is more necessary for engineering decision-makers to comprehensively analyze and calculate the optimal construction plan based on on-site conditions, which poses great uncertainty. In terms of the invention of new piles, the newly invented pile types have to some extent overcome the limitations of certain aspects, but there is still a need to optimize and innovate in-depth research to better play its functions.

3. Research on the problems encountered in pile foundation construction in karst areas and their treatment methods

During the construction of pile foundation in karst areas, in principle, it is necessary to avoid karst caves as much as possible, but sometimes it is inevitable to encounter the situation that it is impossible to avoid karst caves. The existence of karst makes it easy to encounter problems such as hole collapse, stuck drill, mud leakage, etc. during the construction of pile foundation. Therefore, in the construction phase of pile foundations in karst areas, it is necessary to have a thorough understanding of the problems that may be encountered during construction and the corresponding engineering phenomena when problems occur, and to have an accurate solution when encountering various problems.

3.1 Solution to the problem of hole collapse

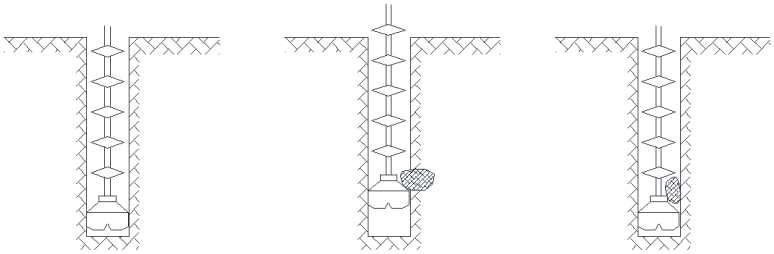
As shown in Figure 2, insufficient negative pressure and slurry density in the hole are the main reasons for hole collapse, and the collision of the drill bit or steel-reinforced cage with the hole wall is also one of the reasons for hole collapse. During the construction process, close attention should be paid to the changes in the height of the slurry surface. When a hole collapse accident is discovered, drilling should be immediately stopped and corresponding measures should be taken according to the depth and scale of the hole where the collapse occurred [15-17]. When the hole collapse is located at the aperture, the pile casing should be removed and the entire hole should be backfilled with block stones and clay, and then the pile casing should be reburied to the impermeable layer for construction drilling; When hole collapse occurs at a deeper depth in the hole, the pile casing can be pressed into the impermeable layer below the hole collapsed, and then backfilled and compacted with dry clay and flag stone for reconstruction; If the hole collapse is severe and cannot be remedied by general methods, all pile holes should be backfilled and compacted, and then the internal casing follow-up step should be used for construction; During the construction process, methods such as raising the casing to increase water pressure, selecting slurry with a density of 1.30 to 1.35 for wall protection [18], and timely grouting, as well as avoiding collisions between drill bits and steel-reinforced cage on the hole wall and multiple small stroke punching can effectively prevent the occurrence of hole collapse.



Fig.2. Site hole collapse diagram of Cast-in place pile

3.2 Solution to the problem of stuck drill

When drilling near the karst cave roof, excessive stroke, uneven hole size, stuck cones on the probe stones on the hole wall, hard blocks falling from the orifice, or the punching cone being too worn and not repaired in a timely manner, resulting in reduced hole size and subsequent welding of the cone and large stroke drilling, can easily cause stuck of the drill, as shown in Figure 3. When the drill bit gets stuck in the karst cave roof due to rapid drilling, depending on the position of the drill bit stuck in the top plate, choose to use up and down movable drill bits, use small drill bits to expand the hole, or use manual digging to drill. After removing the drill bit, throw flag-stones into the hole and repeatedly punch the hole to flatten the underlying top plate of the karst cave to prevent further stuck [16,18]. When encountering situations where the drill gets stuck due to uneven drilling, the drill bit should be moved up and down, and the drill bit should be moved to a slightly larger direction and then being lifted [17]. When encountering situations where the probe stone or hard object is stuck, the drill bit can be used to top down or auxiliary tools can be used to punch holes. The measures to prevent sticking during construction include small stroke drilling when drilling near the top plate of the underlying karst cave, and timely throwing and filling flag-stones to stabilize and level the top rock surface. The drill bit should be replaced or repaired in a timely manner.



(a) Drill stuck after repair welding (b) Partial exposed rock stuck drill (c) The falling object stuck the drill

Fig.3.Schematic diagram of stuck drill cause

3.3 Solution to the problem of drill burying

Drill burying is a high-frequency and difficult to handle accident in engineering, which can be roughly divided into two types: hole collapse and burying drilling and sediment buried drill [16]. The occurrence of hole collapse during the drilling process can easily lead to hole collapse and burying drilling accidents. When a large stroke hits the top plate of a karst cave without filling and with a thin top plate, such accidents are very likely to occur; The occurrence of sediment buried drill accidents is generally caused by the long residence time of the drill bit at the bottom of hole; When encountering a drill burying accident, the "recoil method" can be used to handle it. During the construction process, the drill bit should be avoided from staying low in the hole for a long time. When passing through karst caves, small stroke drilling should be carried out. If any mud leakage accidents are found, the drill bit should be promptly raised and supplemented with mud to prevent hole collapse and lead to drill burying accidents.

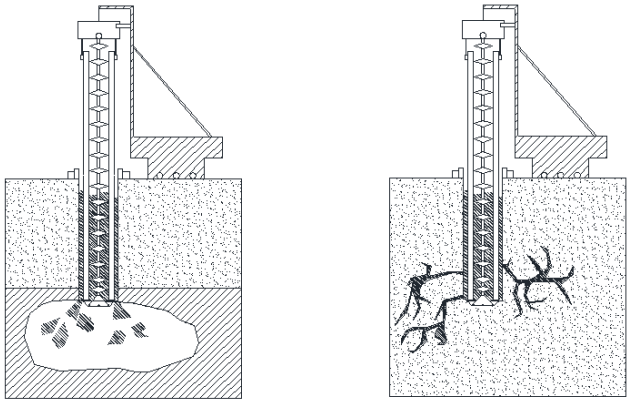
3.4 Solution to the problem of drilling deviation

The main reason for drilling deviation during construction is due to encountering isolated rocks, encountering different hardness strata or rock layers during drilling, resulting in uneven force on the drill bit during drilling, or due to uneven drilling base, uneven extension rod, and bending of the drill rod. Drilling deviation can significantly reduce the bearing capacity of a single pile, so efforts should be made to avoid such situations during the construction process. If drilling deviation is found, it should be corrected in a timely manner. When encountering uneven geological conditions, methods such as backfilling pebbles or flag-stone for leveling and short impact high-frequency drilling can be used to correct the deviations. It is also necessary to regularly correct the verticality of the drilling

hole, check the verticality of the drill pipe on the street, and adjust the bent drill pipe with a jack in a timely manner.

3.5 Solution to the problem of mud leakage

The occurrence of mud leakage occurs when there are permeable cracks on the hole wall or when the karst roof suddenly penetrates, as shown in Figure 4. Mud leakage can lead to a rapid decrease in liquid level and a decrease in water pressure inside the hole. Failure to handle it in a timely manner can lead to the problem of hole collapse. When encountering mud leakage in engineering, different methods should be used to deal with the problem based on the different reasons for the leakage [16,19]: When the crack is not large and the water pressure inside the hole can be controlled, the drill bit should be immediately pulled out while maintaining grouting, and then filled with clay, flag-stone, or cement. The drill bit should be repeatedly punched with a short stroke to strengthen the strength of the hole wall and block the leak; When the crack is large and the mud leakage is severe, the drilling speed of the drill bit should be slowed down and the mud density should be increased to handle it; When the penetration is not fully filled with karst roof, if the water pressure can be controlled, the method of throwing clay and flag-stone and repeatedly punching holes to improve the strength of the hole wall is adopted for treatment; If the water pressure is difficult to maintain, drilling should be stopped immediately and a large amount of leakage blocking mixture should be thrown and filled, or underwater rapid setting concrete [20] should be poured for treatment.



(a) Sudden penetration of karst roof leads to leakage of mud (b) Permeable cracks in the pore wall lead to leakage of mud

Fig.4.Schematic diagram of mud leakages

4. Conclusion

The construction process of pile foundations in karst areas is relatively complex. This article compares and analyzes the key disposal technologies in pile foundation construction in karst areas, and draws the following conclusions:

The selection of pile foundation construction scheme requires the development of scientific reference basis, which converts engineering geological conditions into data form, facilitating engineering personnel to make correct engineering decisions in complex construction environments. Continuous efforts are also needed in the innovation and research of new types of piles, designing pile foundation types that are more suitable for complex geological conditions, and deepening the understanding of the working mechanism of pile types with excellent engineering performance.

For potential problems encountered in engineering, further research is needed on their characterization, causes, prevention and treatment measures to minimize the probability of problems occurring. Research and optimize treatment measures to find faster and more economical methods for solving construction problems.

In the construction of pile foundations in karst areas, the probability of accidents should be minimized as much as possible, and potential accidents should be stopped at the prevention phase.

Before starting the project, engineer should have a thorough understanding of the problems that may be encountered during construction and the corresponding engineering phenomena when problems occur, and have an accurate solution when encountering various problems.

For the problems encountered in the construction of cast-in-place piles in karst areas, such as hole collapse, stuck drilling, drill burying, drilling deviation, and mud leakage, some treatment plans have been explored. However, there is still no efficient solution for the problems of drilling deviation, stuck drilling, and mud leakage of prefabricated piles in karst areas. Engineer should try their best to exert their initiative and creativity on the basis of familiarizing themselves with existing treatment plans, and continuously enrich the treatment methods for the problems encountered in construction.

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