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ВЛИЯНИЕ ГРУНТОВЫХ ВОД НА УСТОЙЧИВОСТЬ ГЛУБОКИХ КОТЛОВАНОВ НА ОСНОВЕ КОНЕЧНО-ЭЛЕМЕНТНОГО АНАЛИЗА

ХАОСЮАНЬ ЮЙ[1], ЭГБАЛНИК САНАЗ[2]
[1]студент специальности 7-06-0732-01 «Строительство»
[2]к.т.н., доцент

В связи с воздействием грунтовых вод на стабильность при строительстве глубоких котлованов была разработана связанная числовая модель, учитывающая деформацию подземных вод и ограждающих конструкций. На основе сопоставления процессов выемки глубоких котлованов в различных условиях грунтовых вод был проведен анализ воздействия грунтовых вод на склоны, опорные структуры и окружающие почвы глубоких котлованов, проведена оценка стабильности глубоких котлованов и предложены методы и меры контроля за воздействием грунтовых вод, такие как осадки, дренаж, гидроизоляция и т.д. Результаты этого исследования могут служить научной основой и техническим руководством для проектирования, строительства и управления глубоководными котлованами.

Ключевые слова: конечный метаанализ; глубокий котлован; стабильность котлована

THE INFLUENCE OF GROUNDWATER ON THE STABILITY OF DEEP FOUNDATION PITS BASED ON FINITE ELEMENT ANALYSIS

Haoxuan Yu[1], Eghbalnik Sanaz[2]
[1]student of the specialty 7-06-0732-01 «Civil Engineering»
[2]PhD in technical sciences, associate professor
Belarusian National Technical University
Minsk, Republic of Belarus

This article focuses on the impact of groundwater on stability in deep foundation pit engineering. A coupled numerical model considering groundwater flow and deformation of retaining structures is established. By comparing the excavation process of deep foundation pits under different groundwater conditions, the influence of groundwater on the slope, retaining structures, and surrounding soil of deep foundation pits is analyzed, and the stability of deep foundation pits is evaluated, And proposed some methods and measures to control the impact of groundwater, such as precipitation, drainage, and water sealing. The research results of this article can provide scientific basis and technical guidance for the design, construction, and management of deep foundation pit engineering.

Keywords: finite element analysis, deep foundation pit, foundation pit stability.

INTRODUCTION

Deep foundation pit is a common deep foundation in civil engineering, and its stability is directly related to the safety and quality of the project. However, in the process of deep foundation pit excavation, the existence and change of groundwater will have a significant impact on the stability of the deep foundation pit, resulting in the instability and deformation of the deep foundation pit slope, and even the instability phenomena such as sliding, overturning, and destruction of the deep foundation pit, resulting in project delays, losses, and accidents [1]. Therefore, analyzing and controlling the influence of groundwater on the stability of deep foundation pit is an important technical issue to ensure the smooth progress of deep foundation pit engineering.

At present, there have been many theoretical and experimental studies on the influence of groundwater on the stability of deep foundation pits, but most of these studies are based on simplified assumptions and conditions, which cannot fully and accurately reflect the complex site conditions, and there is also a lack of effective control measures and suggestions. The purpose of this paper is to establish a numerical model that can simulate the influence of groundwater on the stability of deep foundation pit during the excavation process of deep foundation pit by using the finite element method, analyze the influence mechanism and degree of influence of groundwater existence, change and control on the stability of deep foundation pit, evaluate the stability of deep foundation pit, and put forward some feasible methods and measures to control the influence of groundwater, so as to provide reference for the design, construction and management of deep foundation pit.

2.The influence of the presence of groundwater on the stability of deep foundation pits

The presence of groundwater will reduce the effective stress and shear strength of the soil, increase the lateral pressure and seepage force of the soil, and lead to the instability and deformation of the deep foundation pit slope. The presence of groundwater will increase the pore water pressure in the soil, thereby reducing the effective stress between soil particles and reducing the shear strength of the soil [1]. At the same time, groundwater produces seepage in the soil, which will exert a hydrodynamic pressure on the soil particles and increase the lateral pressure of the soil [2]. These effects will reduce the stability of the deep foundation pit slope, increase the deformation of the deep foundation pit, and even cause the instability phenomena such as sliding, overturning and destruction of the deep foundation pit [3]. The following is a comprehensive analysis of the influence of the presence of groundwater on the stability of deep foundation pits.

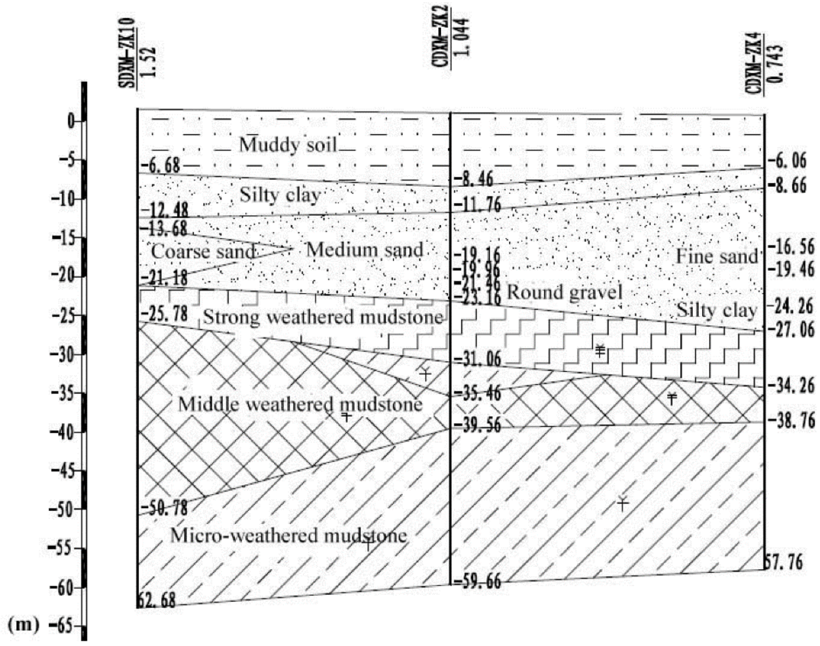

Fig 1 Geological profile of groundwater

2.1 Excavation depth and scope of deep foundation pit

The excavation depth and scope of the deep foundation pit determine the geometry and size of the deep foundation pit, which affects the slope angle and floor area of the deep foundation pit, and also affects the relative position and contact area between the deep foundation pit and the groundwater [4]. Generally speaking, the greater the excavation depth and scope of the deep foundation pit, the worse the stability of the deep foundation pit, and the greater the impact of groundwater [5], as shown in Figure 1. In order to comprehensively analyze the influence of the excavation depth and scope of the deep foundation pit on the stability of the deep foundation pit is as follows:

2.1.1 Anti-uplift stability of deep foundation pits.

After the excavation of the deep foundation pit, due to the weightlessness of the soil in the pit, the soil outside the pit is pushed by the horizontal earth pressure, which will produce a tendency to move to the pit, resulting in the uplift of the soil at the bottom of the pit. The anti-uplift stability of deep foundation pit refers to the deep foundation pit being excavated.

The ability to resist the damage of the pit bottom uplift is usually measured by a safety factor or reliability index. The anti-uplift stability of deep foundation pit is related to the excavation depth, excavation range, type of enclosure structure, embedding depth, support spacing, soil gravity, internal friction angle, cohesion, ground overload and other factors. In general, the larger the excavation depth of the deep foundation pit, the smaller the excavation range, the smaller the embedding depth of the enclosure structure, the larger the support spacing, the smaller the gravity of the soil, the smaller the internal friction angle, the smaller the cohesion, the greater the ground overload, and the worse the anti-uplift stability of the deep foundation pit [6].

2.1.2 The maximum amount of pit bottom uplift in deep foundation pits

The maximum amount of pit bottom uplift in the deep foundation pit refers to the maximum rise of the soil at the bottom of the pit relative to the original ground after the excavation of the deep foundation pit, which reflects the deformation degree of the deep foundation pit. The maximum amount of pit bottom uplift of deep foundation pit is related to the excavation depth, excavation range, type of enclosure structure, embedding depth, support spacing, soil gravity, internal friction angle, cohesion, ground overload and other factors. In general, the larger the excavation depth of the deep foundation pit, the larger the excavation range, the smaller the embedding depth of the enclosure structure, the larger the support spacing, the smaller the gravity of the soil, the larger the internal friction angle, the smaller the cohesion, the greater the ground overload, and the greater the maximum pit bottom uplift of the deep foundation pit [6,7].

2.1.3 The maximum lateral displacement of the enclosure structure of the deep foundation pit

The maximum lateral displacement of the retaining structure of the deep foundation pit refers to the maximum horizontal displacement of the enclosure structure relative to the original ground after the excavation of the deep foundation pit, which reflects the deformation degree of the deep foundation pit. The maximum lateral displacement of the retaining structure of the deep foundation pit is related to the excavation depth, excavation range, type of enclosure structure, embedding depth, support spacing, soil gravity, internal friction angle, cohesion, ground overload and other factors. In general, the larger the excavation depth of the deep foundation pit, the smaller the excavation range, the smaller the embedding depth of the retaining structure, the larger the support spacing, the greater the gravity of the soil, the smaller the internal friction angle, the smaller the cohesion, the greater the ground overload, and the greater the lateral displacement of the maximum enclosure structure of the deep foundation pit [8].

2.1.4 Surrounding surface settlement of deep foundation pits

The surrounding surface settlement of the deep foundation pit refers to the subsidence of the surrounding surface of the deep foundation pit relative to the original ground after the excavation of the deep foundation pit, which reflects the impact of the deep foundation pit on the surrounding environment. The surrounding surface settlement of deep foundation pit is related to the excavation depth, excavation range, type of enclosure structure, embedding depth, support spacing, soil gravity, internal friction angle, cohesion, ground overload and other factors. In general, the larger the excavation depth of the deep foundation pit, the larger the excavation range, the smaller the embedding depth of the enclosure structure, the larger the support spacing, the greater the gravity of the soil, the smaller the internal friction angle, the smaller the cohesion, the greater the ground overload, and the greater the surface settlement around the deep foundation pit [9].

2.2 The type and nature of the soil

The type and properties of soil determine the physical, chemical, and mechanical properties of soil, and affect the porosity, permeability, water content, saturation, consolidation, softening, shear strength, lateral pressure coefficient and other parameters of soil, as well as the mode and degree of interaction between soil and groundwater [10]. The more complex the type and properties of the soil, the greater the deformation and plasticity of the soil, and the greater the influence of groundwater [11].

2.2.1 The gravity and shear strength of the soil

The gravity and shear strength of the soil are the basic parameters that determine the self-weight and shear resistance of the soil, which affect the magnitude and direction of the earth pressure in the deep foundation pit, as well as the uplift and sliding stability of the deep foundation pit [12]. In general, the greater the severity of the soil, the greater the self-weight and earth pressure of the soil, the worse the stability of the deep foundation pit, and the greater the shear strength of the soil, the stronger the shear resistance of the soil, and the better the stability of the deep foundation pit [13]. The shear strength of the soil is related to the internal friction angle and cohesion of the soil, the larger the internal friction angle, the greater the cohesion, and the greater the shear strength of the soil.

2.2.2 Permeability and seepage state of soil

The permeability and seepage state of the soil are the main factors affecting the groundwater level and seepage field of deep foundation pits [14], which will affect the water pressure distribution of deep foundation pits, as well as the phenomenon of pipe gushing and seepage in deep foundation pits. Under normal circumstances, the greater the permeability of the soil, the stronger the seepage capacity of the soil, the smaller the water pressure of the deep foundation pit, the better the stability of the deep foundation pit; the seepage state of the soil is related to the water content and saturation of the soil again, the greater the water content, the higher the saturation, the more unfavorable the seepage state of the soil, and the worse the stability of the deep foundation pit.

2.3 Types and properties of groundwater

The type and nature of groundwater determine the physical, chemical, and mechanical properties of groundwater, as shown in Figure 2It affects the parameters of groundwater level, water pressure, flow velocity, flow direction, permeability coefficient, water chemical composition, water temperature, etc., and also affects the force and mode of action of groundwater on soil [15]. The more complex the type and nature of groundwater, the greater the dynamics and activity of groundwater, and the greater the impact of groundwater [16].

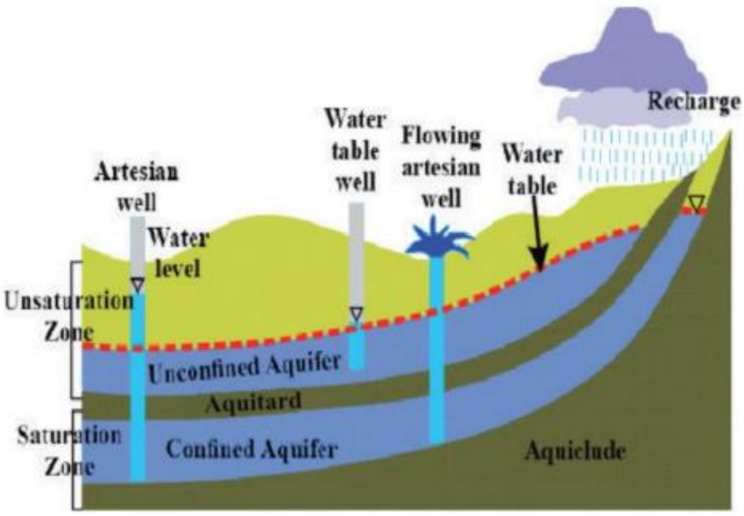

Fig 2 Diagram of groundwater types and their physical properties

3. The influence of groundwater changes on the stability of deep foundation pits

The change of groundwater will cause the consolidation and softening of the soil, resulting in the inrush and pipe surge of the bottom plate of the deep foundation pit, and destroying the overall stability of the deep foundation pit. The change of groundwater mentioned here mainly refers to the rise and fall of the groundwater level and the change of groundwater flow. The rise and fall of the groundwater level will cause the consolidation and softening of the soil. When the groundwater level rises, the pore water pressure in the soil increases, the effective stress of the soil decreases, and the volume of the soil decreases [17]. When the groundwater level decreases, the pore water pressure in the soil decreases, the effective stress of the soil increases, and the volume of the soil increases, which is called softening. Consolidation and softening will cause deformation of the soil and affect the stability of the deep foundation pit [18]. Especially when there is a confined aquifer below the floor of the deep foundation pit, the excavation of the deep foundation pit will reduce the thickness of the overlying aquifer of the aquifer, and when the weight of the overlying soil is less than the jacking force of the confined water, the head pressure of the confined water can crack or wash out the deep foundation pit floor, causing a surge. Sudden surge refers to the phenomenon of confined water suddenly gushing out of the floor of the deep foundation pit, which will lead to the destruction of the floor of the deep foundation pit, the water and sand gushing in the deep foundation pit, and the instability and collapse of the deep foundation pit. Changes in groundwater flow will cause soil loss, resulting in pipe gushing in the floor of deep foundation pits. Pipe gushing refers to the fact that the fine particles of the foundation soil are washed away under the action of water flow with a certain seepage velocity (or gradient), and the voids in the soil gradually increase, slowly forming a thin tubular seepage channel that can pass through the foundation, so as to hollow out the foundation or dam body, make it deformed and unstable, this phenomenon is pipe surge. It generally occurs in non-cohesive soil layers. Pipe gushing will lead to the destruction of the floor of the deep foundation pit, the water and sand gushing in the deep foundation pit, and the instability and collapse of the deep foundation pit [19]. The open-pit deep foundation pit for finite element analysis is shown in Figure 3.

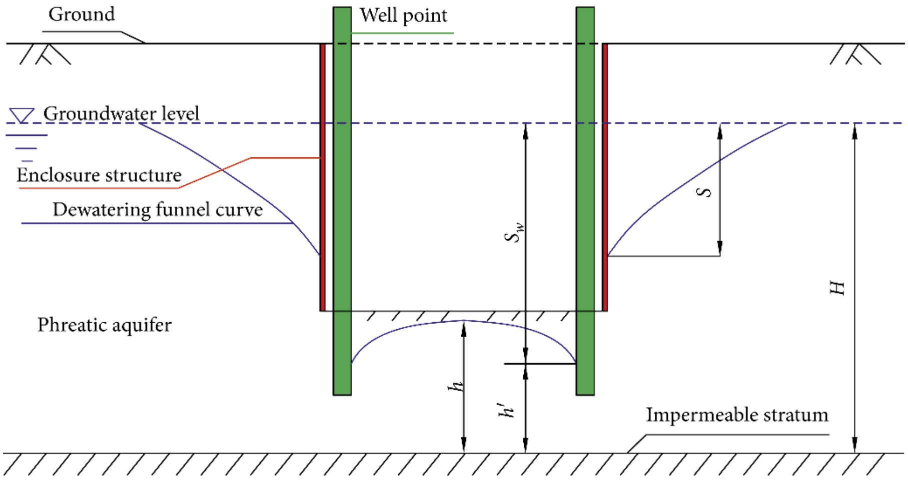

Fig 3 Schematic diagram of finite element analysis of open pit deep foundation

In Figure 3, H denotes the thickness of the aquifer, e.g., the original water table in a deep foundation pit, m; S represents the maximum dewatering depth m outside the deep foundation pit; Sw represents the dewatering depth of the well point m; h′ represents the head at the bottom of the central axis of the envelope, m; h represents the water level m after dewatering of the deep foundation pit.

It is well known that the groundwater outside the pit provides flowing water for the groundwater inside the pit; Therefore, the amount of water flowing inside the pit is equal to the amount of water flowing outside the pit, so a simplified calculation model that takes into account seepage forces can be established, as shown in Figure 4.

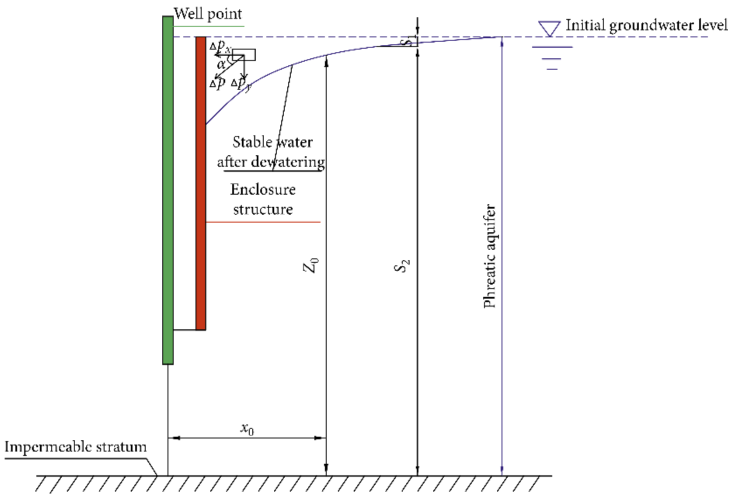

Fig 4 Calculation model of seepage force

3. The influence of groundwater control on the stability of deep foundation pits

The control of groundwater will affect the supporting structure of deep foundation pits. For example, the bond strength and friction between the soil nail wall and the pile anchor wall and the soil will be reduced, and the restraining effect will be weakened. The control of groundwater mainly refers to the precipitation and drainage of deep foundation pits. The precipitation of deep foundation pit is to reduce the water level difference between inside and outside the deep foundation pit, reduce the seepage force of the deep foundation pit slope, and improve the stability of the deep foundation pit. The drainage of the deep foundation pit is to prevent water accumulation in the deep foundation pit, keep the deep foundation pit dry, and improve the safety of the deep foundation pit. However, precipitation and drainage from deep foundation pits can also adversely affect the supporting structure of deep foundation pits [20]. In order to analyze the influence of groundwater control on the stability of deep foundation pits, the analysis of groundwater control is important.

3.1 The mode and scope of precipitation of deep foundation pits

The precipitation mode and scope of the deep foundation pit determine the precipitation effect and precipitation cost of the deep foundation pit, which affects the water level, water pressure, seepage and other parameters of the deep foundation pit, and also affects the changes of soil and groundwater around the deep foundation pit. Generally speaking, the precipitation mode and scope of deep foundation pit should be comprehensively considered according to the form, scale, depth, geological conditions, groundwater conditions and other factors of deep foundation pit, and appropriate precipitation methods should be selected, such as well point precipitation, deep well precipitation, annular precipitation, etc., to reasonably determine the amount and time of precipitation, ensure that the water level difference between inside and outside the deep foundation pit is within the allowable range, and avoid soil consolidation and softening caused by excessive precipitation [21]. Therefore, the influence of soil type and nature on the stability of deep foundation pit can be considered from the following aspects:

3.1.1 The gravity and shear strength of the soil

The gravity and shear strength of the soil are the basic parameters that determine the self-weight and shear resistance of the soil, which will affect the magnitude and direction of the earth pressure of the deep foundation pit, as well as the anti-uplift stability and anti-sliding stability of the deep foundation pit. In general, the greater the severity of the soil, the greater the self-weight and earth pressure of the soil, and the worse the stability of the deep foundation pit, and the greater the shear strength of the soil, the stronger the shear resistance of the soil, and the better the stability of the deep foundation pit [22]. The shear strength of the soil is related to the internal friction angle and cohesion of the soil, the larger the internal friction angle, the greater the cohesion, and the greater the shear strength of the soil.

3.1.2 Permeability and seepage state of soil

The permeability and seepage state of the soil are the main factors affecting the groundwater level and seepage field of the deep foundation pit, which will affect the water pressure distribution of the deep foundation pit, as well as the pipe gushing and seepage phenomena of the deep foundation pit. In general, the greater the permeability of the soil, the stronger the seepage capacity of the soil, the smaller the water pressure of the deep foundation pit, and the better the stability of the deep foundation pit, and the seepage state of the soil is related to the water content and saturation of the soil, the larger the water content and the higher the saturation, the more unfavorable the seepage state of the soil and the worse the stability of the deep foundation pit [23].

3.1.3 Compressibility and deformation modulus of soil

The compressibility and deformation modulus of soil are the main parameters affecting the deformation characteristics of deep foundation pits, and they will affect the deformation indexes such as the amount of pit bottom uplift, lateral displacement of the retaining structure, and surrounding surface settlement of deep foundation pits. In general, the greater the compressibility of the soil, the stronger the deformation capacity of the soil, the greater the deformation of the deep foundation pit, the greater the deformation modulus of the soil, the higher the stiffness of the soil, and the smaller the deformation of the deep foundation pit. The greater the water content, the higher the saturation, the greater the compressibility of the soil, and the deformation modulus of the soil is related to the density and shear strength of the soil, and the greater the density, the greater the shear strength, and the greater the deformation modulus of the soil [24].

3.2 Drainage facilities and effects of deep foundation pits

The drainage facilities and effects of the deep foundation pit determine the drainage speed and drainage quality of the deep foundation pit, which affects the phenomena of water accumulation, water inrush and sand gushing in the deep foundation pit, and also affects the drying and safety of the deep foundation pit. Generally speaking, the drainage facilities and effects of deep foundation pits should be comprehensively considered according to the form, scale, depth, geological conditions, groundwater conditions and other factors of deep foundation pits, and sufficient drainage facilities, such as drainage ditches, drainage pipes, drainage pumps, etc., should be set up to eliminate the accumulated water in the deep foundation pit in time, keep the deep foundation pit dry, and prevent the inrush and pipe surge of the deep foundation pit floor [25].

3.3 The type and material of the supporting structure of the deep foundation pit

The type and material of the supporting structure of the deep foundation pit determine the stiffness and strength of the supporting structure, which affects the deformation and failure of the supporting structure, and also affects the interaction between the supporting structure and the soil. Generally speaking, the type and material of the supporting structure of the deep foundation pit should be comprehensively considered according to the form, scale, depth, geological conditions, groundwater conditions and other factors of the deep foundation pit, and the appropriate type and material of the supporting structure should be selected, such as soil nail wall, pile anchor wall, reinforced concrete wall, etc., to reasonably determine the size and location of the supporting structure, increase the stiffness and strength of the supporting structure, improve the bonding strength and friction between the supporting structure and the soil, and enhance the restraining effect of the supporting structure [26].

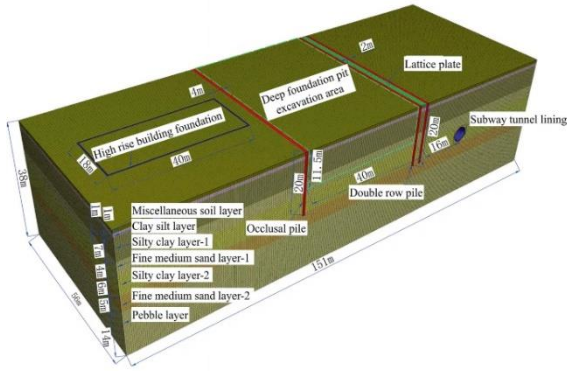

Fig 5 Finite element analysis of the foundation deep foundation pit model

Considering the above factors, we can establish a numerical model based on the finite element method to simulate the influence of groundwater on the stability of the deep foundation pit during the excavation of the deep foundation pit, analyze the stress, strain, displacement, safety factor and other indicators of the deep foundation pit, evaluate the stability of the deep foundation pit, and provide reference for the design, construction and management of the deep foundation pit, as shown in Figure 5. The numerical model code for the finite element method is shown in Appendix I.

CONCLUSION

This paper analyzes the influence of groundwater on the stability of the foundation in the excavation of deep foundation pits, points out the influence mechanism and degree of the existing, change and control of groundwater on the stability of deep foundation pits, establishes a numerical model based on the finite element method, simulates the influence of groundwater on the stability of deep foundation pits during the excavation of deep foundation pits, evaluates the stability of deep foundation pits, and puts forward some feasible methods and measures to control the influence of groundwater, which provides a reference for the design, construction and management of deep foundation pits.

After analyzing the influence of groundwater on the stability of deep foundation pits, it can be concluded that the existence of groundwater will reduce the effective stress and shear strength of the soil, increase the lateral pressure and seepage force of the soil, lead to the instability and deformation of the slope of the deep foundation pit, and affect the stability of the deep foundation pit. The change of groundwater will cause the consolidation and softening of the soil, resulting in the inrush and pipe surge of the bottom plate of the deep foundation pit, and destroying the overall stability of the deep foundation pit. The control of groundwater will affect the supporting structure of the deep foundation pit, reduce the bond strength and friction between it and the soil, weaken its restraining effect, and affect the stability of the deep foundation pit. The finite element method is an effective numerical method to analyze and control the influence of groundwater on the stability of deep foundation pits, which can simulate the influence of groundwater on the stability of deep foundation pits during the excavation process of deep foundation pits, evaluate the stability of deep foundation pits, and provide a reference basis for the design, construction and management of deep foundation pits. The methods and measures to control the impact of groundwater include optimizing the design of deep foundation pits, taking effective precipitation and drainage measures, selecting reasonable supporting structures and reinforcement measures, and strengthening the monitoring and observation of deep foundation pits, which can improve the stability and safety of deep foundation pits.

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