Study on Numerical Simulation Analysis of Foundation Pit Excavation Stability on Expansive Soil Slope

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Abstract. Expansive soil, also known as "expansive soil", is a kind of cohesive soil whose volume expands violently after soaking in water and shrinks significantly after losing water. This kind of soil will cause serious harm to buildings. In the excavation of foundation pit on expansive soil slope, because the protective layer on the surface is destroyed, it is easy to form seepage channels and lead to landslides. In this paper, based on the excavation of foundation pit on the expansive soil slope of the Yangtze River to Huaihe River, the temperature field is equivalent to the humidity field, and the influence of foundation pit excavation on expansive soil slope is studied by numerical simulation method. The results show that when the protective structure of foundation pit on the slope is seriously damaged, the horizontal displacement of slope soil can reach more than 10cm under conditions of heavy rainfall, and the soil mass of the slope is deformed greatly, so there is a certain risk of landslide on the slope. The maximum horizontal displacement of the supporting structure of the foundation pit is about 8.9cm, and the supporting structure is deformed greatly, so there is a risk of collapse of the foundation pit. Adding anti-slide piles can improve the slope stability to some extent, but under the condition of long-term rainfall, the improvement range of slope stability by installing additional anti-slide pile gradually decreases.

Keywords: Expansive soil, slope, foundation pit excavation, rainfall, numerical simulation.

1 Introduction

Expansive soil is a kind of clay with significant expansion and shrinkage, high dispersibility and high plasticity, which is formed in the natural geological process. In general, the expansion and shrinkage deformation of expansive soil is irreversible after wet and dry cycles, and it increases with the number of cycles[1,2]. The process of swelling caused by water absorption of expansive soil is essentially a process in

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which water film is formed and its thickness increases, and a "wedge" force is formed between clay particles, which increases the distance between particles and enlarges the pores[3]. The expansion rate is closely related to the initial state. Basma et al[4] found that the initial moisture content or suction state is one of the controlling factors of the deformation characteristics of the sample during the dry-wet cycle. The expansion deformation is also affected by the number of dry-wet cycles and external stress conditions[2,5], and the pore distribution in Lin et al[6] soil is directly related to the strength of swelling.

Under the influence of rainfall and soil moisture, the weight of expansive soil slope increases, the expansion force increases, the strength decreases after hygroscopic, and the safety of the slope decreases significantly[7,8]. When the foundation pit of the bridge is excavated on the expansive soil slope, the integrity of the slope is destroyed, and the probability of the soil moisture inside the slope increases greatly due to construction and rainfall, and the risk of slope instability further increases. Therefore, this paper studies the stability of expansive soil slope under the influence of rainfall during the excavation of foundation pit.

2 Research Content

2.1 Similarity between Temperature Field and Humidity Field

Table 1. Expansive soil model parameters

water content (%)	15	20	25	30	35	60
density(g/cm^3)	1.67	1.7	1.74	1.77	1.81	1.95
elastic modulus(mPa)	49.9	29.75	13.8	11.1	9.45	8.94
cohesive force(/kPa)	65.02	50.49	28.14	14.56	11.83	10.02
internal friction angle (°)	49.54	31.53	12.35	7.37	6.3	4.12
specific heat /kJ(m^3·k)	2188	2448	2662	2911	3052	4078
expansibility(kPa)	0	70.14	132.88	163.84	177.26	182
equivalent temperature (°C)	15	39.7	83.78	113.4	122.19	131.33
thermal conductivity coefficient (kw/(m·k))	0.87	1.1	1.2	1.23	1.26	1.32

The landslide of expansive soil slope is mainly caused by the change of soil moisture content in the slope. Therefore, the stability analysis of expansive soil slope should first analyze the change and distribution of soil moisture content in the slope. The control equation of temperature field is similar to that of seepage field and humidity field. The change of temperature field will cause the change of soil volume, and the change of humidity field will also cause the change of soil volume. Therefore, the change of soil moisture content is regarded as temperature change, and the conversion relationship between temperature field and humidity field is established, and the humidity field is simulated by temperature field, so as to realize the simulation of expansive soil slope stability[9].

Table 1 shows the mechanical and heat conduction indexes of expansive soil with an initial dry density of 1.45g/cm^3 and an initial water content of 15% under different subsequent water content conditions by a series of soil sample tests.

2.2 Numerical Calculation Process

2.2.1 Model Establishment.

Simplify the design drawings appropriately: Replace the first-class and slope protection panels with shell units with a thickness of 200mm; Grade 3 ~ 7 slope protection is replaced by shell elements with a thickness of 1200mm; The reinforced anchor rod is a truss unit with a length of 10m; The anti-slide pile is replaced by beam element with a length of 12.2 m; Replace the foundation pile with beam element, with a length of 49m; The foundation pit supporting cast-in-place pile is replaced by beam element, and the supporting beam and internal support are also replaced by beam element. The established numerical calculation model is shown in Fig.1. The numerical model of foundation pit support is shown in Fig.2. The soil layer model is shown in Fig.3.

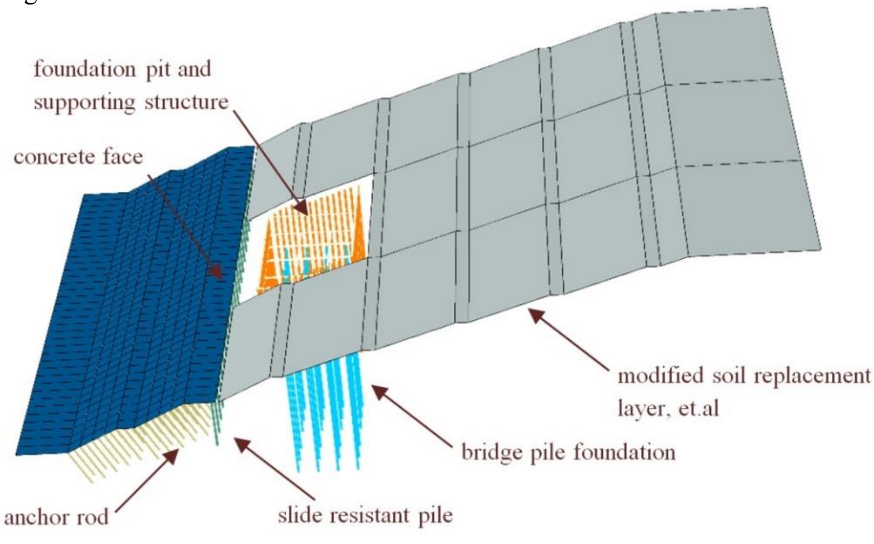

Fig. 1. Numerical model of slope protection structure and foundation pit supporting structure (left bank main pier)

Two working conditions are mainly considered in the preliminary calculation: 1) numerical simulation of foundation pit excavation is carried out in the preliminary design mode of foundation pit support. In the simulation, the foundation pit soil is excavated in three layers, with the first excavation depth of about 3m, the second excavation depth of about 5m and the third excavation depth of about 4 m; 2) After the excavation, rain occurs, and the stability of canal slope and bridge foundation pit under the condition of rain is numerically simulated.

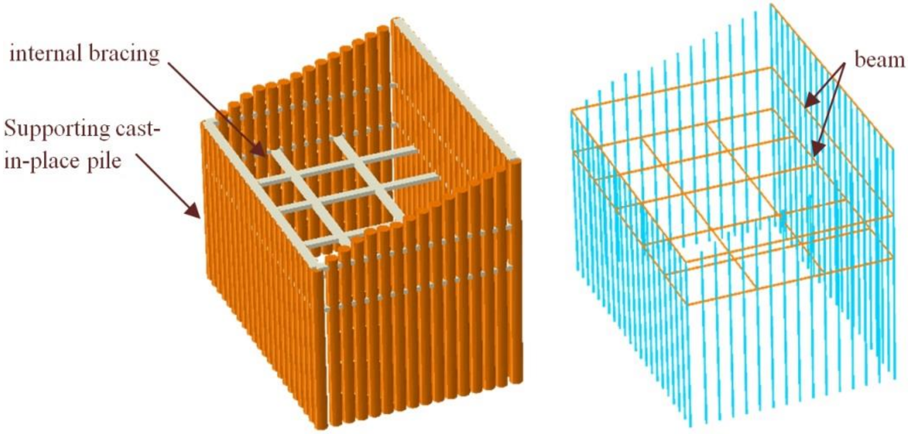

Fig. 2. Numerical model of foundation pit support (main pier)

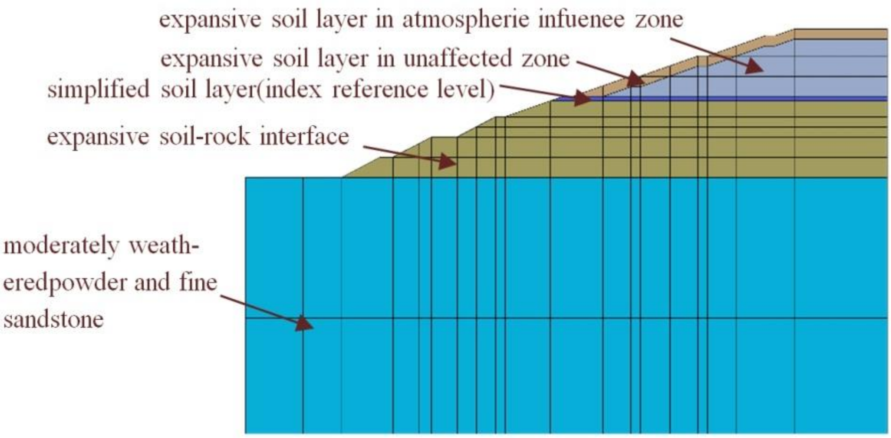

Fig. 3. Slope Numerical Model (Left Bank Main Pier)

2.2.2 Calculation Results.

After the third step of excavation is completed, the maximum horizontal displacement of the slope soil perpendicular to the river course is about 4.1cm, as shown in Fig.4. Under the condition of rainfall after excavation (assuming that the slope protection structure is seriously damaged), the horizontal displacement of slope soil is shown in Fig.5. The horizontal displacement of slope soil is about 32.6cm after 4 hours of rainfall.

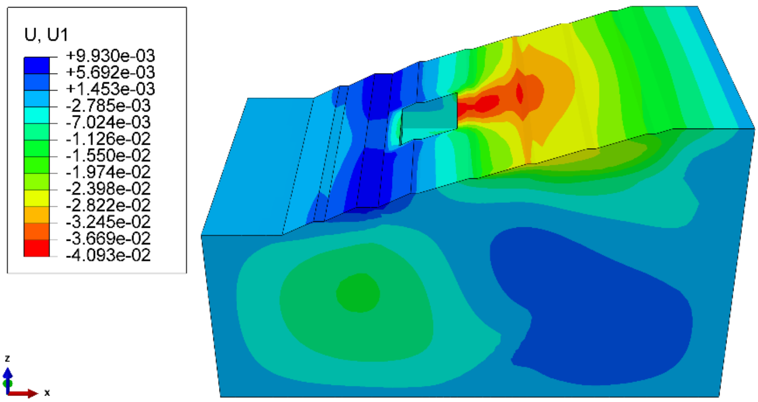

Fig. 4. Horizontal displacement of slope soil after excavation in the third step (vertical river course direction, unit: m)

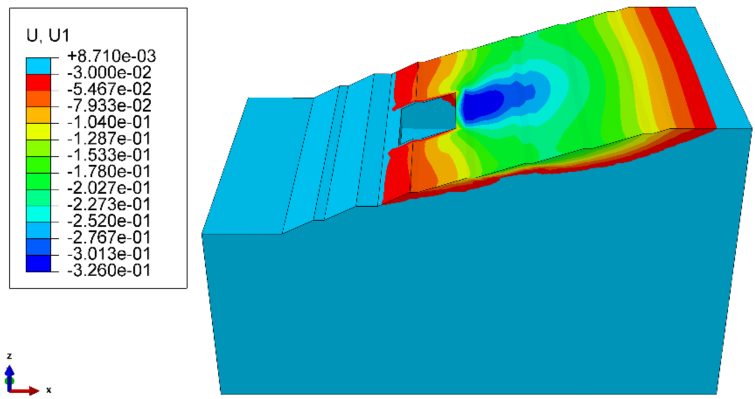

Fig. 5. Horizontal displacement of slope soil after 4 hours of rainfall (vertical river course direction, unit: m)

2.3 Add Anti-slide Piles (The Slope Protection Structure is Intact)

According to the analysis, although the displacement of slope soil is reduced after adding anti-slide piles, there is still the possibility of landslide after long-term rainfall. Therefore, it is very important to protect the slope protection structure and ensure the slope to be impervious in bridge foundation construction. This section will analyze the displacement change of slope soil after excavation without water seepage. The horizontal displacement of slope soil is shown in Fig.6. In the rain stage, with or without damage to the protective structure, the relationship between slope soil displacement and rain time is shown in Fig.7. With the increase of rainfall time and the intact protective structure, the slope soil grows slowly, and the slope stability is greatly improved compared with the serious damage of the protective structure.

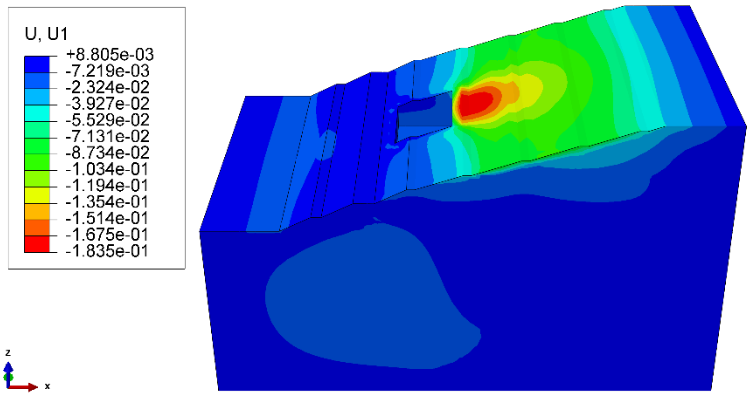

Fig. 6. Horizontal displacement of slope soil after 48 hours of rainfall (vertical river course direction, unit: m)

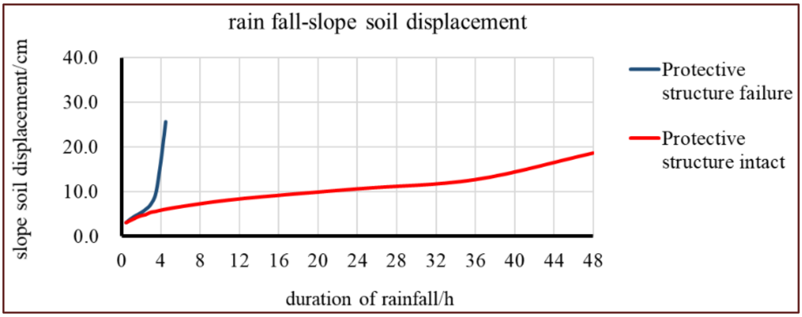

Fig. 7. Variation of Horizontal Displacement of Slope Soil with Rainfall Duration

3 Suggested Measures and Conclusions

3.1 Suggested Measures

The canal slope protection structure is the key to ensure the slope safety, so the protection of the protection structure should be done well in the process of bridge foundation construction, and drainage and monitoring should be done well at the same time, as follows:

1. Shorten the excavation period of foundation pit as far as possible, and do a good job in waterproof and drainage of slope and foundation pit during construction. 1) Do a good job in construction organization design, shorten the construction period of foundation pit excavation, and try to avoid the rain period in foundation pit excavation; 2) During the construction period, do a good job of waterproof and drainage of the slope affected by the construction to avoid the damage of the protective structure in this area from penetrating into the soil through the damage cracks of the protective structure, and at the same time, install drainage grooves to discharge rainwater in time; 3) Do a good job in waterproof and drainage of the foundation pit. If there is

water in the foundation pit, it should be discharged in time, and the foundation pit should be kept dry as much as possible.

2. Protect the protective structure of the existing slope to avoid cracking and damage of the protective structure. 1) Before construction, the construction organization design should be done well, and construction materials should be avoided as much as possible; 2) The construction machinery should delimit a fixed area to avoid damage to a large-scale protective structure; 3) Pave 40cm clay on the top surface of the protective layer in the operation area of construction machinery, and after compaction, pour 20cm thick concrete hardening layer on its upper part. Steel plates should also be laid on the walking route of construction machinery; 4) Strengthen the protection of the slope protection structure within 30m around the foundation pit. In this area, first lay 40cm clay and compact it, then pour 20cm concrete on its upper part, and cover the waterproof layer on the concrete surface.

3. Strengthen the monitoring of slope and foundation pit displacement during construction. If the displacement is too large or the displacement change is unstable for a long time, the construction should be stopped, the reasons should be analyzed, and the slope should be further strengthened if necessary. The monitoring arrangement is mainly as follows:

(1) During the construction process, it is mainly necessary to monitor the displacement of the supporting structure of the foundation pit. Choose a pile around the middle of the foundation pit to arrange the inclinometer, and the length of the inclinometer and the length of the pile, etc. At the same time, measure the displacement of the top of the pipe with total station during the construction process;

(2) In order to prevent the adverse impact of drilling construction on the river slope, inclinometer holes are no longer arranged on the slope, and only the surface displacement of the river slope soil on the upper and lower sides of the central axis of the foundation pit is monitored. At least one monitoring point should be selected for each level of slope, and two monitoring points should be arranged on each level of slope for the two levels of slope above the main pier and the two levels of slope below the side pier.

3.2 Conclusion

The stability of the slope and foundation pit under the conditions of excavation and rainfall is studied through the simulation of the excavation and rainfall influence of the foundation pit of the bridge of Hefei section of S19 Huaitong Expressway. The following conclusions are drawn:

1. Due to the low soil strength index and poor soil quality in the survey data, the displacement of slope soil and foundation pit supporting structure is relatively large under excavation conditions. The maximum displacement of main pier slope soil is about 4.1cm, the maximum displacement of supporting structure is about 3.4cm, the maximum displacement of side pier slope soil is about 6.6cm, and the maximum displacement of supporting structure is about 5.5cm. Although the local displacement of slope and foundation pit is large, it is relatively safe as a whole.

2. In the numerical simulation, the maximum displacement of soil mass of pier slope after excavation is greater than that of main pier slope, and the development speed of soil mass displacement of side pier slope is greater than that of main pier slope under rainfall conditions, and the stability of side pier slope is worse than that of main pier slope under excavation and rainfall conditions.

3. If the protective structure is seriously damaged, adding anti-slide piles can improve the slope stability to some extent under the condition of short-term rainfall (3 hours of rainfall), and the improvement range of slope stability under the condition of long-term rainfall is gradually reduced;

4. For the main pier slope supported by bored pile and the side pier slope supported by steel sheet pile, when the protective structure is well protected after taking the measures in Section 3.1, the slope displacement increases slowly during the whole rainfall process, and the possibility of slope landslide is low.

5. The influence of excavation of foundation pits on expansive soil slopes also needs to be taken seriously, and further research is needed on the effects of construction water, loading, vibration, and other factors on slopes.

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