

# Study on Stability of Long and Deep Foundation Pit of Railway under Rainfall

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**Abstract:** In this study, the influence of rainfall conditions on the stability of foundation pit and the mechanical behavior of supporting structure was analyzed by numerical simulation. The results show that dewatering excavation can reduce the pore water pressure of soil by lowering the groundwater level, and effectively restrain the deformation of supporting structure and surface settlement. Heavy rainfall (such as once-in-a-decade and once-in-a-century rainfall) significantly aggravates the surface settlement and deformation of supporting structures, especially the deep supporting structures. With the increase of rainfall intensity, the mechanical properties of soil tend to be stable after saturation, and the increase of settlement and deformation gradually slows down. The research shows that dewatering excavation and reasonable support design can effectively improve the stability of foundation pit under complex hydrological conditions, which provides theoretical support for engineering practice.

**Keywords:** Foundation pit stability, dewatering excavation, rainfall influence, supporting structure, numerical simulation.

## 1. Introduction

Under the background of global climate change, extreme weather, especially rainstorm, frequently occurs in China, which brings great challenges to deep foundation pit construction. [1] It is difficult to predict heavy rainfall because of its complex and accidental development process. If the construction of deep foundation pit can't avoid the rainy season and the response is insufficient, it will easily lead to safety accidents, ranging from delaying the construction period and causing economic losses to collapse of foundation pit and threatening life safety [2].

The influence of heavy rainfall on deep foundation pit includes supporting deformation, construction delay, even foundation pit instability and slope collapse. During rainfall, surface rainwater flows into the foundation pit, forming secondary scouring, and the accumulated water in the pit soaks the bottom soil and seeps down, which leads to the rise of groundwater level and the decrease of shear strength of soil, which leads to the deformation of supporting structure and surface settlement, and reduces the safety factor of foundation pit [3]. Sun Zhenhua [4] and others found through field tests that the influence depth of rainfall on clay silt is about 0.9 m, and the continuous action of light rain has more significant influence on foundation pit. Liu Bin [5] pointed out through ABAQUS simulation that rainfall intensity is the key factor of foundation pit stability, which will lead to the increase of pit displacement and the decrease of safety factor. Qiu Haibing [6] used MIDAS software to analyze the comprehensive influence of rainstorm and continuous rain on supporting structure. Li Yanlong [7] quantified the slip characteristics of foundation pit slope under rainfall conditions based on ABAQUS. Xiao Chaoyun [8] and other studies show that the deformation in desilting stage after rainfall is the most significant, and the displacement of retaining piles can reach 1.5 times before rain. Zhang Xiaoqian [9] and others used PLAXIS analysis to find that rainfall infiltration will aggravate the topsoil and reduce the negative pore water pressure, thus weakening the soil strength and aggravating the deformation in the pit. Rainstorm disaster is an urgent problem to be solved in deep foundation pit

construction.

## 2. Finite Element Analysis

### 2.1. Introduction to the project

On July 30, 2023, Xiong'an New Area upgraded the rainstorm emergency response to Class I, requiring all units to strictly implement flood control measures. In order to study the influence of heavy rainfall on foundation pit engineering, this paper compares and analyzes the response of foundation pit under normal excavation conditions with once-in-a-decade (100mm) and once-in-a-century (300mm) rainstorm conditions. Deep and large foundation pits such as subway stations are mostly constructed by cut-and-cover method, which has long construction period and large exposed surface, and is easily affected by precipitation in rainy season, so it is necessary to pay special attention to the stability of foundation pits caused by heavy rainfall.

### 2.2. Analysis of ground settlement of foundation pit before and after rainfall

They are nephograms of surface settlement displacement after excavation and heavy rainfall respectively. In order to intuitively reflect the change trend of surface settlement around the foundation pit before and after heavy rainfall, the settlement value within 100m from the edge of the foundation pit is extracted and drawn into a surface settlement curve as shown in the following figure:

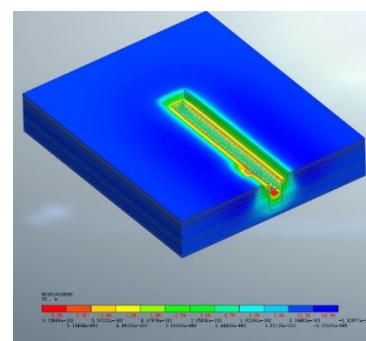


Figure 1. Settlement nephogram of normal foundation pit

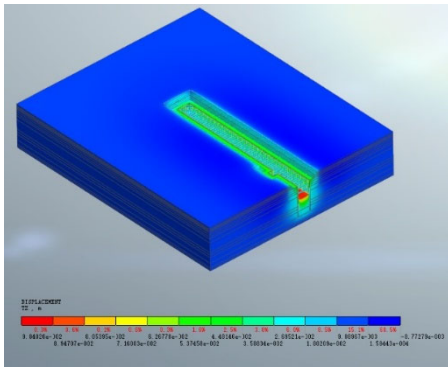


Figure 2. Settlement nephogram of rainfall foundation pit

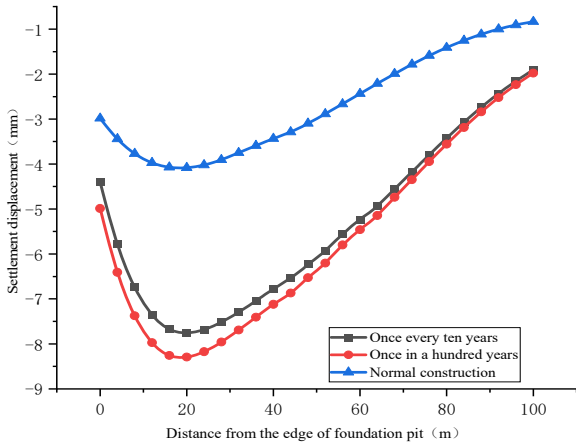


Figure 3. Comparison diagram of rainfall foundation pit settlement

The surface settlement around the foundation pit presents typical "single peak" distribution characteristics. With the increase of the distance from the edge of the foundation pit, the settlement value first increases and then decreases: it reaches the peak value of 4mm at about 16m away from the foundation pit, and then gradually decays and stabilizes at about 1.1 mm. The peak position of settlement is inclined to one side of foundation pit, and excavation unloading has great influence on the area near pit. Under the condition of 100mm/d heavy rainfall, the maximum settlement increased to 7.6 mm, which was 90% higher than that under the condition of no rain. Rainwater infiltration leads to the dissipation of negative pore water pressure and reduces the effective stress of soil; Seepage takes away fine particles, resulting in weakening of soil structure; The combined action of accumulated water pressure and seepage force makes the soil skeleton bear extra load. The synergistic effect of these factors enlarges the influence range of settlement and greatly reduces the overall stability of the soil around the foundation pit.

### 2.3. Analysis of ground settlement of foundation pit before and after rainfall

#### Displacement analysis of diaphragm wall before and after rainfall

Fig. 4 and Fig. 5 are the nephogram of pile displacement after excavation and heavy rainfall respectively, and the graph made by extracting the displacement data of diaphragm wall before and after heavy rainfall is shown in Fig. 6.

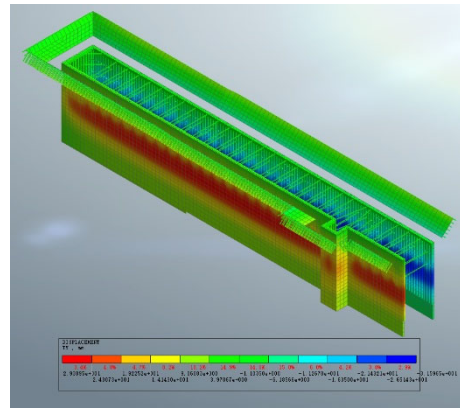


Figure 4. Displacement nephogram of normal foundation pit

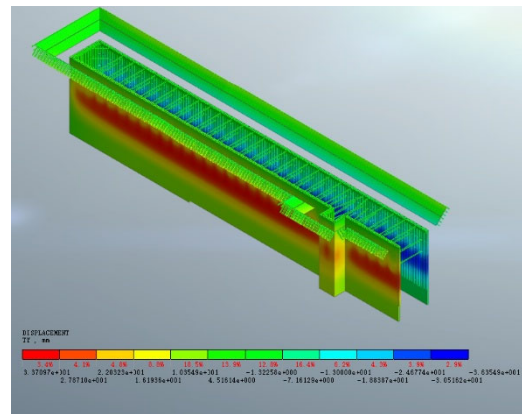


Figure 5. Displacement nephogram of rainfall

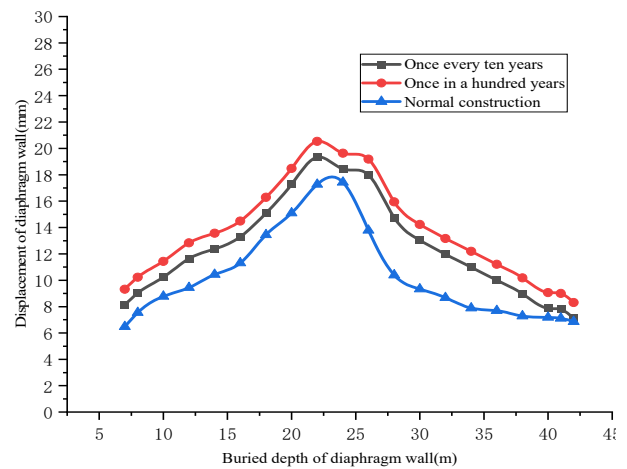
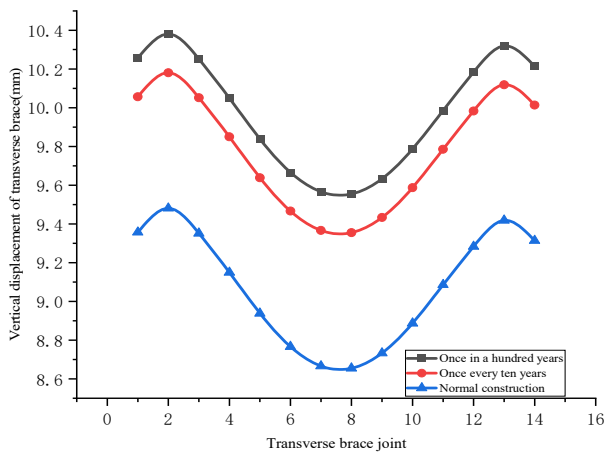


Figure 6. Displacement map of diaphragm wall in rainfall

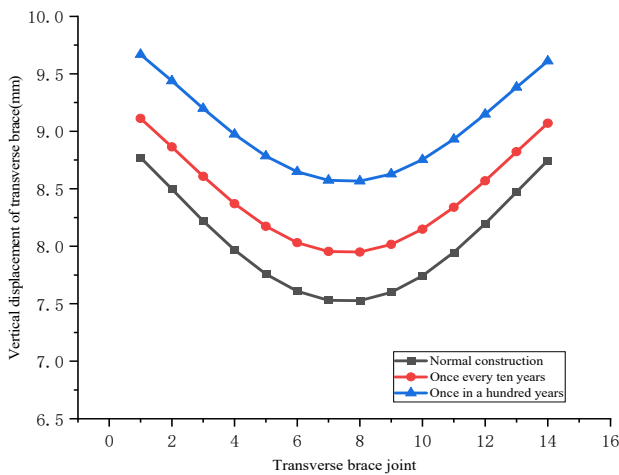
Heavy rainfall significantly increased the displacement of retaining piles, and the displacement at the depth of 22.5 m (0.6 h) increased the most, from 17.2 mm to 19.3 mm (+12%); The displacement of pile top increased from 6.5 mm to 8.1 mm (+24%). The displacement curve shows a typical bow distribution. The process of rainfall infiltration can be divided into three stages: at the initial stage, rainwater quickly infiltrates the upper layer of high permeability fill, increasing the weight of soil and breaking the balance; Continuous water infiltration in the middle stage increases pore water pressure; In the later stage, the upper layer is saturated to form accumulated water load, which squeezes the envelope together. When the soil is close to saturation, the influence of rainfall intensity on displacement weakens.

## 2.4. Deformation analysis of steel transverse brace before and after rainfall

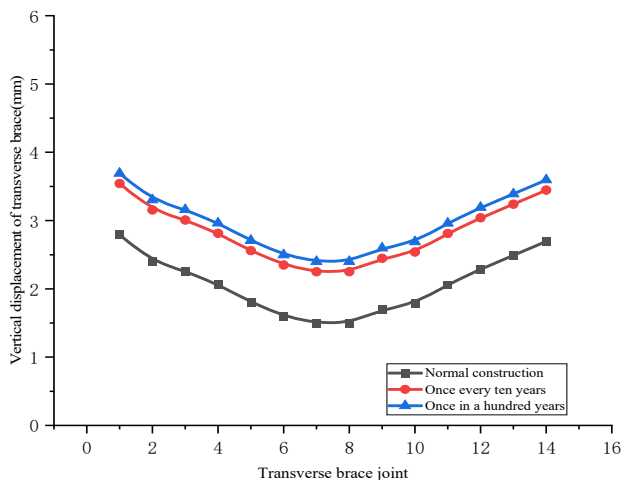
The transverse brace will be deformed due to earth pressure, and the brace deformation is shown in Figure 7 below:



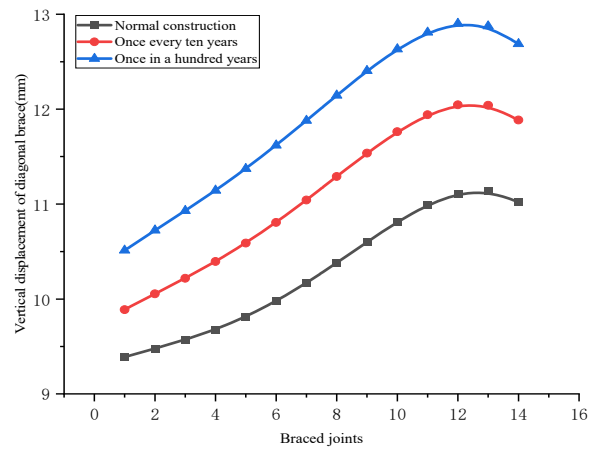
(a) Displacement of the first layer of supporting structure



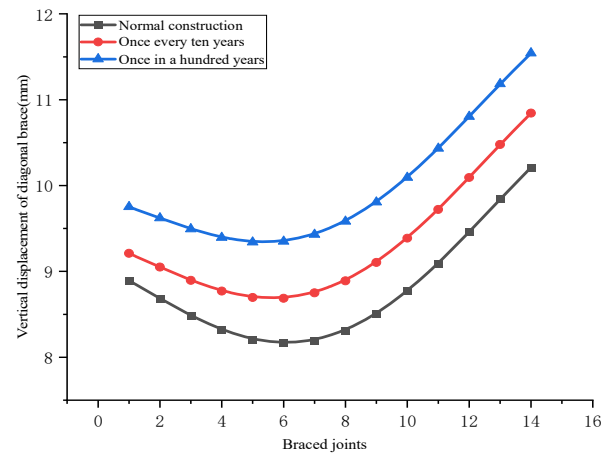
(b) Deformation diagram of the second layer of steel supporting structure



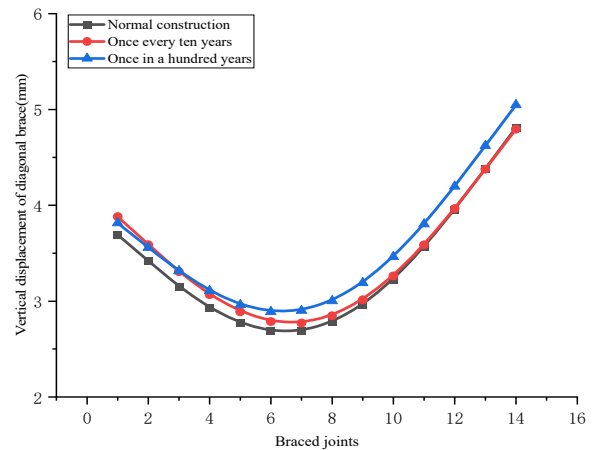
(c) Deformation diagram of the third layer transverse brace



(d) Deformation diagram of the first layer diagonal brace



(e) Deformation diagram of the second layer of steel support



(f) Deformation diagram of the third layer of steel support

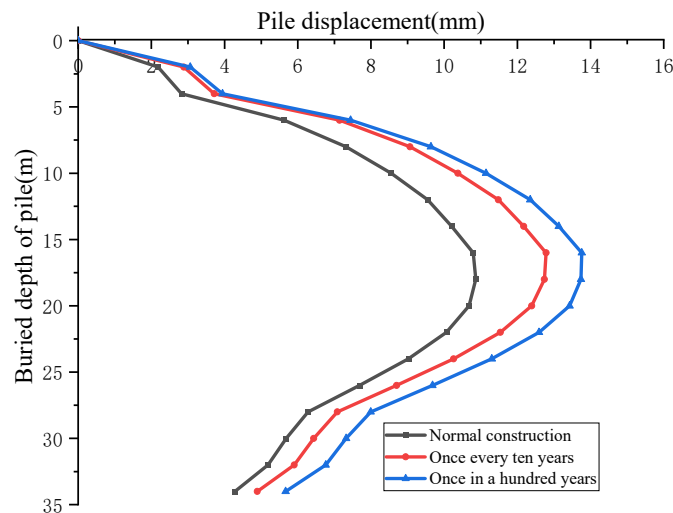
**Figure 7.** Deformation diagram of rainfall support

According to the analysis in Fig. 7, the displacement of the first layer transverse brace increased by 0.7 mm, and the displacement of the diagonal brace increased by 8.6 mm; The displacement of the second layer transverse brace increased by 0.4 mm, and the vertical displacement of the diagonal brace increased by 8.3 mm; The displacement of the third layer transverse brace increased by 0.76 mm, and that of the diagonal brace increased by 0.27 mm. It can be seen that the influence of rainfall once every ten years on the displacement of diagonal brace is obviously greater than that of transverse brace, especially in the first and second floors, the increase of displacement of diagonal brace is much higher than that of

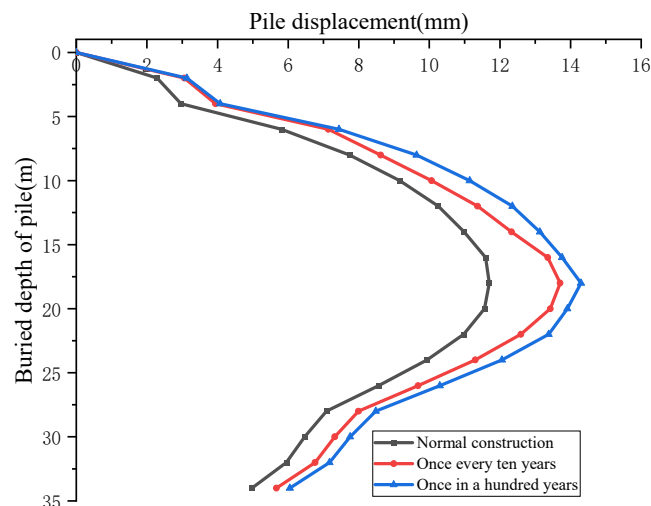
transverse brace, which is related to the higher sensitivity of diagonal brace to resist the change of lateral earth pressure. Further analysis of the situation of once-in-a-century rainfall, compared with once-in-a-decade rainfall, the displacement increase of transverse brace and diagonal brace is less than that of once-in-a-decade rainfall compared with normal construction. Once-in-a-decade rainfall has significantly changed the physical and mechanical properties of soil (such as heavy increase and shear strength decrease), resulting in a large increase in displacement of supporting structure, while once-in-a-century rainfall further loads on the basis of once-in-a-decade rainfall, but because the saturation of soil tends to the limit, the marginal effect of its mechanical properties changes weakens, so the displacement increase is relatively small.

## 2.5. Deformation analysis of steel transverse brace before and after rainfall

From the perspective of soil mechanics, the influence of rainfall on foundation pit engineering is mainly reflected in three aspects: first, soil saturation leads to heavy increase, and according to Rankine theory, lateral earth pressure increases significantly, which may exceed the design bearing capacity of supporting structure; Secondly, the increase of pore water pressure reduces the effective stress and shear strength of soil and increases the sliding risk; Thirdly, hydraulic seepage may cause seepage damage such as quicksand and piping. In engineering geology, rainfall erosion will lead to soil loss, instability of supporting structure, buoyancy effect caused by groundwater level fluctuation and accelerated material deterioration. These coupling effects will significantly reduce the stability of foundation pit, so it is necessary to take targeted prevention and control measures in the design and construction stages.



(a) Displacement diagram of protective pile at corner of rainfall foundation pit



(b) Displacement diagram of protective pile at middle part of rainfall foundation pit

**Figure 8.** Displacement diagram of foundation pit protection pile

Under rainfall conditions, compared with normal construction conditions, the lateral displacement of protective piles increased significantly by 18.46% due to once-in-a-decade rainfall events; Compared with the once-in-a-decade rainfall and the once-in-a-century rainfall (300mm), the lateral displacement of protective piles under the once-in-a-

century rainfall increased by 7.61% compared with the once-in-a-decade rainfall. This significant change in displacement can be attributed to the significant influence of rainfall on the mechanical properties of soil. Rainfall infiltration causes the increase of soil water content around foundation pit, which leads to the decrease of effective stress and shear strength of

soil, thus weakening the lateral support ability of soil to protective piles. With the increase of rainfall intensity, the rise of groundwater level further aggravates the softening effect of soil, and induces local seepage pressure, which makes the lateral earth pressure acting on the protective pile increase significantly. Under the condition of once-in-a-century rainfall, continuous heavy rainfall leads to a significant increase in soil saturation, and may even lead to local liquefaction, thus further aggravating the lateral displacement of protective piles.

### 3. Conclusion

In this paper, the influence of rainfall on the stability of long and deep foundation pit of railway is analyzed by numerical simulation. Rainfall once in a decade (100mm) and once in a hundred years (300mm) significantly aggravated the surface settlement around the foundation pit, the deformation of supporting structure and the lateral displacement of protective piles. The maximum settlement during normal excavation is 4mm, and increases to 7.6 mm after rainfall once in ten years, with an increase of 90%; The maximum displacement of diaphragm wall increased from 17.2 mm to 19.3 mm, with an increase of 12%. The displacement of diagonal brace is more affected by rainfall, and the displacement of diagonal brace in the first layer increases by 8.6 mm, which exceeds 0.7 mm of transverse brace. The lateral displacement of protective piles increased by 18.46% under the rainfall once in ten years, and further increased by 7.61% under the rainfall once in a hundred years. Rainfall leads to the increase of soil weight, the decrease of shear strength and the increase of pore water pressure. The once-in-a-decade rainfall has significantly changed the soil properties, while the once-in-a-century rainfall weakens the marginal effect of the change of mechanical properties when the soil is close to saturation. The research shows that dewatering excavation and reasonable support design can effectively improve the stability of foundation pit, and heavy rainfall still poses a significant threat to deep support structure and diagonal brace, so effective drainage and support measures

should be taken to cope with extreme rainfall conditions. This study provides theoretical basis and data support for the design and protection of deep foundation pit engineering under rainfall conditions.

### References

- [1] Tian Yugang, Qin Donghua, Du Yuanhui, Huang Yi. Temporal and spatial characteristics of rainstorm in flood season in Yangtze River Delta region [J]. Safety Science in China Newspaper, 2012, 22 (09): 3-9.
- [2] Tao Shiyan. Rainstorm in China [M]. Beijing: Science Press, 1980.
- [3] Qiu Haibing. Study on the influence of rainfall infiltration on the stability of retaining structure of foundation pit in unsaturated soil [D]. Xi'an Building Science and Technology University School, 2013.
- [4] Sun Zhenhua, Jiang Chuang, Xin Quanming, Shao Lingfeng. Study on the influence of rainfall on soil-water characteristics and stability of unsaturated silty clay foundation pit [J]. Engineering Survey, 2021, 49 (11): 6-12 +47.
- [5] Liu Bin. Study on behavior of foundation pit and slope considering unsaturated soil effect [D]. Zhejiang University, 2012.
- [6] Qiu Haibing. Study on the influence of rainfall infiltration on the stability of foundation pit retaining structure in unsaturated soil [D]. Xi'an University of Architecture and Technology, 2013.
- [7] Li Yanlong, Chen Bo, Ma Chengcheng, Zhou Qipeng. Stability analysis of foundation pit slope under rainfall infiltration based on ABAQUS [J]. Journal of Applied Mechanics, 2017, 34 (01): 155-161 +203-204.
- [8] Xiao Chaoyun, Li Mingguang, Wang Dafa, Chen Jinjian. Test and analysis of deformation characteristics of deep foundation pit in residual soil under the influence of rainfall [J]. Journal of Shanghai Jiaotong University, 2020, 54 (08): 873-880.
- [9] Zhang Xiaoqian, Li Mingguang, Chen Jinjian, Lin Lihua. Mechanism study on the influence of rainfall on the stress and deformation of foundation pit in unsaturated residual soil [J/OL]. Journal of Engineering Geology: 1-10.2020-202.