Influence Analysis of Rainfall Infiltration on Stability of Slope and Existing Small Diameter Bias Double Tunnels

Chen Hang¹*, Yan Qixiang¹ and Chen Wenyu¹

¹ Key Laboratory of Transportation Tunnel Engineering, Ministry of Education, Southwest Jiaotong University, Chengdu, Sichuan 610031, China
*Corresponding author

Abstract
Rainfall infiltration is one of the main causes of slope instability, and it is of great significance to study the influence of rainfall infiltration on the stability of existing small diameter bias double tunnels and slope. Based on the theory of infiltration, the finite difference FLAC3D software was used to establish the numerical model of the existing small diameter bias double tunnels and slope under rainfall infiltration. The characteristics of stress, velocity, displacement and shear strain increment of tunnel lining and slope under different rainfall intensity conditions are studied, and the stability and safety of existing small diameter bias double tunnels and slope are analyzed. The results show that the slope and tunnel lining are affected by the affected area and the unaffected area of the rainfall, and the vertical stress, velocity and displacement of the slope and tunnel lining are increasing with the increase of rainfall intensity in the case of the same duration of rainfall; The effect of rainfall infiltration on the vertical stress, horizontal velocity and horizontal displacement of slope foot is greater than that of top of slope and slope waist; When the rainfall intensity is 25mm/h to 65mm/h, the horizontal displacement of the slope gradually extends from the middle of the slope to the slope top and the slope foot and the internal slope surface, and the horizontal displacement of the left tunnel is larger than that of the right tunnel; The shear strain increment of the tunnel lining is first aggregated at the left and right shoulders and the right hance of the right tunnel, and gradually increases with the increase of rainfall intensity, and the effect of the shear strain increment on the left and right shoulders of the right tunnel is greater than that of the right hance.

Keywords: Rainfall infiltration; Small diameter; Bias tunnel; Slope stability; Numerical simulation
INTRODUCTION

A large number of examples confirm that rainfall is the most important factor affecting slope stability and leading to slope instability[1-3]. Especially in the rainy areas in southern China, when the rainy season comes, the slope instability caused by the surrounding houses were buried, road interruption, bridge collapse and other events are common. The rainwater infiltrates the slope soil, the water content of the slope increases, the pressure of the negative pore water decreases, the suction force decreases significantly, and the shear strength decreases significantly, when a certain degree is reached, slope instability may occur[4].

In recent years, domestic and foreign scholars have made a lot of research on the stability of various soil slopes for rainfall infiltration. Tan Wenhui et al.[5] studied the stability of the slope based on the saturated-unsaturated seepage theory of rock-soil medium and the solid-liquid coupling principle, and modified Mohr-Coulomb criterion and 2-D limit equilibrium method are used to evaluate the stability of the slope. Li Longqi et al. [6] conducted a large-scale geomechanical model test with some specific techniques. Physical characteristics, including displacement and water content, have been studied aiming at bedding rock slope with different bedding angles and with and/or without supporting. Wang Yihan et al.[7] is based on the saturated-unsaturated seepage theory and the soil-hydraulic permeability coefficient characteristic curves of rock slope, the variation of suction in unsaturated region and transient saturated zone formation of rock slope were analyzed. Combined with engineering example, the strength reduction methods were adopted to analyzing the rock slope stability influence factors considering unsaturated seepage with different rainfall intensity and duration. Zhang Lei et al. [8] used the finite element method to simulate the interaction between subsurface and infiltration under rainfall infiltration, and analyzed the effects of initial saturated permeability coefficient, inflow value parameter on infiltration and slope stability influences. Li Huanqiang et al. [9] constructed physical models for slopes with different slope angles and experimented under rainfall infiltration, variations of the slopes are monitored by layers continuously, and the variations of monitored indexes of the slopes are obtained under rainfall infiltration. Qin Xiaohua et al.[10] considered the seepage of the saturated zone, combined with the rainfall infiltration model and the limit equilibrium method, analyzed the variation of the stability of the bedrock surface and the wetting surface, in the analysis of bedrock-type layered slope stability. The analytical expression of the safety factor of the bedrock layered slope is obtained.

The above studies are based on the theory of unsaturated soils and seepage and the relevant methods to analyze the stability of various soil slopes, and do not consider the variation law of slope stability under different rainfall intensity conditions, in the presence of existing small diameter bias double tunnels. Based on the strength reduction method, the gravity increase method and the calculation method of rainfall intensity and shear strength, this paper studies the influence of rainfall infiltration on the stability of existing small diameter bias double tunnels and slope by using FLAC3D finite difference software. The change characteristics of stress, velocity,
displacement and shear strain increment of tunnel rock and slope are analyzed, so as to provide some theoretical basis for relevant design and construction.

1. ANALYSIS METHOD OF TUNNEL AND SLOPE STABILITY UNDER RAINFALL INFILTRATION CONDITION

1.1 Strength reduction method

A new set of cohesion and internal friction angles \( (c' \text{ and } \varphi') \) are obtained by dividing the cohesive force \( c \) of the shear strength of the slope and the internal friction angle \( \varphi \) by the reduction factor \( F \), and then the \( c' \) and \( \varphi' \) values are calculated as a set of new material parameter inputs. Increasing the value of \( F \), until the slope reaches the limit state, the occurrence of instability damage, then the corresponding value \( F \) is the slope of the stability coefficient \([11]\). With the formula as follows:

\[
\tan \varphi' = (\tan \varphi) F \tag{1}
\]

\[
c' = \frac{c}{F} \tag{2}
\]

Where: \( F \) is the reduction factor; \( c \) is the initial cohesion of the rock slope, \( kPa \); \( \varphi \) is the initial internal friction angle of rock slope, (°); \( c' \) and \( \varphi' \) are the reduced cohesive force and internal friction angle, respectively.

1.2 Gravity increase method

To maintain the cohesion of soil and internal friction angle unchanged, and gradually increase the gravity acceleration \( G \) repeated calculations (gradually increase the gravity acceleration is equivalent to increasing the bulk density of rock), until the slope damage, at this time the ratio of the gravitational acceleration to the actual gravitational acceleration (usually 9: 8) is the safety factor of the slope \([12]\), which is:

\[
F_s = \frac{G_{\text{limit}}}{G_0} \tag{3}
\]

1.3 Shear strength and rainfall infiltration intensity

When the slope soil is in a saturated-unsaturated state, the pore water pressure above the water level is negative. On the other hand, the negative pore water pressure affects the size of the substrate suction, which affects the stability of the tunnel rock and slope. In order to describe the effect of matrix suction on shear strength and tunnel surrounding rock and slope safety factor, Fredlund \([13]\) modified the Mohr-Coulomb criterion to represent the shear stress \( \tau \) and shear strength \( \tau_f \) of the formula:

\[
\tau_f = c' + (\sigma - u_n) \tan \varphi' + (u_u - u_w) \tan \varphi \tag{4}
\]

Where \( \tau_f \) is the shear strength of the unsaturated soil; \( c' \) is the effective cohesion, \( \sigma \) is the total stress of the soil, \( u_n \) is the normal total stress; \( u_w \) is the pore water pressure; \( (\sigma - u_n) \) is the net normal stress on the failure surface; \( \varphi' \) is the internal
friction angle of the soil; \((u_{aw} - u_{w})\) is the matrix suction on the failure surface; \(\phi^b\)
is the internal friction angle with the shear strength varying with the substrate suction.

Liu Zizhen et al. \([14]\) established the relationship between unsaturated soils shear strength and water content, as well as the calculation formula of shear strength and rainfall time, and obtained the relationship between water content and reduction strength of slope soil:

\[
c_f = \left[ A(\lambda \epsilon T + \omega_0) \right]^2 + B(\lambda \epsilon T + \omega_0) + D + Ge^{-H_s} \tan \phi^b / F_f
\]

\[
\phi'_f = \tan^{-1}((\tan(E\ln(\lambda \epsilon T + \omega_0) + F)) / F_f)
\]

Where: \(c_f\) and \(\phi'_f\) are the soil after the reduction of the shear strength index; A, B, D, E, F, G and H are undetermined coefficients; \(\lambda\) is undetermined parameter, \(mm^{-1}\); \(e\) is rainfall infiltration intensity, \(mm/s\); T is the duration of rainfall (take 3h), s; \(\omega_0\) is the initial state of soil water content.

2. EXAMPLE ANALYSIS

2.1 Project overview

A high slope of Lanzhou Railway Minjiang lage bridge is located in Sichuan County of Jiuzhaigou Province, where the slope rock pile No. 2 roughly fan-shaped distribution on the slope. Rock mass longitudinal slope is steep, the slope is about 30 degrees -38 degrees, the slopes are covered with miscellaneous trees, dense forest. The region is China’s most volatile landscape step deep steep mountain canyon. The lithology of the slope area is complicated and bad geological distribution is widespread. Under the condition of self-weight, lateral displacement of rock and soil in slope will lead to slight landslide. The shallow buried bias section of a tunnel opening is selected as the research object. The tunnel is a double track tunnel, and the horseshoe section is 11.7m high and wide 13.92m.

The systematic bolts are used to reinforce the tunnel surrounding rock, the length is 5m, and the thickness of the secondary lining is 0.6m. The distance between the left tunnel and the slope is 15.1m, and the distance between the right tunnel and the slope is 23.2m.

2.2 Calculation model

2.2.1 The establishment of the model

The numerical calculation model of slope and tunnel is established by finite difference software FLAC3D. The relevant dimensions of the model are as follows: the left border is 60m high, the right boundary is 120m high, the bottom boundary is 220m long, the upper part of the slope is the rainfall affected area, the thickness is 5m, and the lower part is unaffected area. The location of the relevant slope and tunnel lining is shown in Figure 1.
2.2.2 Distribution of monitoring points

In order to study the effect of rainfall infiltration on the existing small diameter bias double tunnels and slope, the monitoring points are set up on the slope of the rain affected area and the unaffected area and the tunnel lining, and record the monitoring point of the data in different rainfall intensity conditions. The arrangement of each monitoring point is shown in Fig 2.

2.2.3 Calculation scheme and soil parameters

In order to study the changes of the stress, velocity, displacement and shear strain increment of slope soil and lining with the increase of rainfall from self-weight conditions to the increase of rainfall. According to the actual rainfall situation, set the rainfall duration of 3 hours, rainfall intensity of different conditions as shown in Table 1.

<table>
<thead>
<tr>
<th>Condition setting</th>
<th>Rainfall intensity</th>
<th>Duration(t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>weight condition</td>
<td>Natural state (0)</td>
<td>3</td>
</tr>
<tr>
<td>Rainfall condition 1</td>
<td>R=25mm/h</td>
<td>3</td>
</tr>
</tbody>
</table>
Based on the weight condition, the shear strength parameters of rock soils are reduced by the strength reduction method. The physical parameters of the relevant soil are determined according to the data obtained from the site survey with reference to the gravity increasing effect of rock mass in rainfall infiltration are shown in Table 2.

Table 2: Physical parameters of rock and soil under different rainfall conditions

<table>
<thead>
<tr>
<th>Group</th>
<th>Name</th>
<th>Bulk density</th>
<th>Cohesion</th>
<th>Internal friction angle</th>
<th>Elastic Modulus</th>
<th>Poisson's ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-weight</td>
<td>Gravel soil</td>
<td>2100</td>
<td>1.11E+04</td>
<td>40.0</td>
<td>8.10E+08</td>
<td>0.23</td>
</tr>
<tr>
<td>25mm/h</td>
<td>Gravel soil</td>
<td>2210</td>
<td>9.44E+03</td>
<td>34.0</td>
<td>8.10E+08</td>
<td>0.23</td>
</tr>
<tr>
<td>35mm/h</td>
<td>Gravel soil</td>
<td>2230</td>
<td>8.62E+03</td>
<td>31.4</td>
<td>8.10E+08</td>
<td>0.23</td>
</tr>
<tr>
<td>45mm/h</td>
<td>Gravel soil</td>
<td>2247</td>
<td>8.11E+03</td>
<td>29.2</td>
<td>8.10E+08</td>
<td>0.23</td>
</tr>
<tr>
<td>55mm/h</td>
<td>Gravel soil</td>
<td>2262</td>
<td>7.82E+03</td>
<td>27.4</td>
<td>8.10E+08</td>
<td>0.23</td>
</tr>
<tr>
<td>65mm/h</td>
<td>Gravel soil</td>
<td>2274</td>
<td>7.52E+03</td>
<td>26.3</td>
<td>8.10E+08</td>
<td>0.23</td>
</tr>
</tbody>
</table>

3. ANALYSIS OF THE RESULTS

3.1 Influence of rainfall infiltration intensity on slope and tunnel lining stress

Figure 3 shows the distribution nephogram of vertical stresses for slope and tunnel lining under the weight condition and different rainfall intensities. As you can see from Figure 3, the vertical stress of the rainfall affected area of the slope and the area...
not affected by the rainfall increases with the increase of the rainfall intensity when the duration is 3h. But in the existing small diameter bias double tunnels, there is a small change in the soil near the tunnels, that is, in the same buried depth, the closer to the tunnel lining, the vault and the bottom of the tunnel, the smaller the vertical stress.

\[(1) \text{ Vertical weight condition} \]

\[(2) \text{ Rainfall intensity } R = 25 \text{mm/h} \]

\[(3) \text{ Rainfall intensity } R = 35 \text{mm/h} \]

\[(4) \text{ Rainfall intensity } R = 45 \text{mm/h} \]

\[(5) \text{ Rainfall intensity } R = 55 \text{mm/h} \]

\[(6) \text{ Rainfall intensity } R = 65 \text{mm/h} \]

**Figure 3:** Vertical stress distribution nephogram of slope and tunnel lining

Figure 4 shows the vertical stress distribution curve of the slope under self-weight condition and different rainfall condition. From Figure 4, within the range of 0 to 65mm/h rainfall intensity, the stress value of each monitoring point of slope increases with the increase of rainfall intensity. By Figure 4 (1) and 4 (2) of the contrast can be seen, both the slope foots stress position relative to other slope are maximum, affected by rainfall area reached the maximum ,rainfall unaffected the area reached the maximum. The vertical stress distribution of the slope top is opposite to that of the slope foot. The maximum value of the vertical stress at the slope top of the affected area is 0.197MPa, and the maximum value of the vertical stress at the slope top of the unaffected area is 0.375MPa. At the same time, The magnitude of the slope stress of the affected area is: the lower part of the slope > the middle of the slope > the upper part of the slope; The magnitude of the slope stress of the unaffected area is: the upper
part of the slope > the lower part of the slope > the middle of the slope.

(1) Vertical stress distribution in rainfall affected area of slope
(2) Vertical stress distribution in rainfall unaffected area of slope

Figure 4: Distribution of vertical stress curve of slope

It is concluded that under the rainfall condition, due to the influence of the gravity, the water pressure and the soil pressure gradually transfer and accumulate from the slope to the slope foot, resulting in the increase of the foot force, the vertical stress is larger than the other part of the slope. Thus, effects of rainfall infiltration on the vertical stress of the slope foot are greater than the middle slope and the slope top.

Figure 3 shows that the vertical stress of tunnel lining increases with the increase of rainfall intensity in the range of 0 to 65mm/h rainfall intensity.

The stress distribution of the left and right tunnel lining are roughly the same, and the stress of the vault and the bottom relative to the shoulder and the hance is too small, which is due to the stress of the tunnel vault and the bottom at a certain extent have been released after excavation of the tunnel.

Figure 5 shows the vertical stress curve of the tunnel lining. As can be seen from Figure 5, the change of stress value of tunnel lining increases with the increase of rainfall intensity. On the change trend, the initial stage, from the initial stress to the rainfall intensity of 45mm/h, the vertical stress growth of the tunnel lining is relatively slow. The right hance of the left tunnel only increased from 0.056MPa to 0.235MPa, an increase of 0.179MPa; the left shoulder of the right tunnel increased from 0.057MPa to 0.357MPa, an increase of 0.3MPa. In the later stage, when the rainfall intensity reaches 45mm/h or more, the vertical stresses increases rapidly, resulting in a sudden change. In the vertical stress of the left tunnel lining, the right hance increased from 0.235MPa to 1.457MPa, increased by 1.222MPa. In the vertical stress of the right tunnel lining, the left arch shoulder increased from 0.357MPa to 1.786MPa, increased by 1.429MPa.
The results show that with the increase of rainfall infiltration intensity, the soil moisture content increases, the matrix suction decreases, the $c$, $\varphi$ values decrease, and the shear strength of the soil decreases. When the shear strength reaches the critical value, the soil is unstable and the vertical stress increases rapidly.

It can be seen that the influence of rainfall infiltration on the vertical stress of the right hance and the left arch shoulder of the left tunnel lining is larger than that of other parts of the left tunnel, and the effect on the vertical stress of the left arch shoulder and the bottom of the right tunnel lining is greater than Other parts of the right tunnel.

### 3.2 Influence of rainfall infiltration intensity on slope and tunnel lining speed

Figure 6 is the horizontal velocity curve of the slope. It can be seen from Figure 6 that the horizontal velocity of each monitoring point increases with the increase of rainfall intensity, and the horizontal velocity increase of the rainfall affected area is larger than that of the unaffected area in the range of 0 ~ 65mm/h rainfall intensity. In the initial stage, the rainfall intensity is between 0 and 45mm/h, and the growth rate of the monitoring points on the slope is relatively slow. The horizontal velocity of the lower part slope of the affected area is increased from 0 to 0.0735 m/s, and the horizontal velocity of the lower part slope of the rainfall unaffected area is increased from 0 to 0.0681 m/s. In the later stage, the rainfall intensity exceeds 45mm/h, and the horizontal speed of each monitoring point of slopes is greatly increased. The horizontal velocity of the lower part slope affected by rainfall is increased from 0.0735m/s to 0.39m/s, an increase of 5.3 times; the horizontal velocity of the lower part slope of unaffected area is increased from 0.0735m/s to 0.39m/s, an increase of 5.3 times. At this point, the anti-sliding force of the slope is less than the sliding force, slope instability.
The results show that the rainfall infiltration intensity is small in the early stage, the slope soil moisture content is small, has a high shear strength, slope soil displacement is small. In the later stage, with the increase of rainfall intensity, the water content increased, the soil weight increased, the substrate suction decreased, $c, \varphi$ value decreased, shear strength decreased. The sliding force is greater than the anti-slide force, the slope instability, so the horizontal displacement increases dramatically. It can be seen that with the increase of rainfall intensity, the horizontal velocity of the monitoring points on the slope waist is larger than that of the slope foot and the slope top. It shows that the rainfall intensity has a great influence on the horizontal velocity of slope waist.

Figure 7 is a graph of the horizontal velocity of a tunnel lining. It can be seen from the figure, in the rainfall intensity of 0 to 65mm/h range, the horizontal velocity of each monitoring point of tunnel lining increases with the increase of rainfall intensity. In the early stage, the horizontal velocity value of the tunnel lining increases more slowly in the initial state to the rainfall intensity of 45mm/h. The horizontal velocity of the left arch shoulder of the left tunnel increased from 0 to 0.11m/s, and the left arch shoulder of the right tunnel increased from 0 to 0.073m/s. In the later stage, the rainfall intensity exceeds 45mm/h, the horizontal velocity of the lining increases greatly, and the left arch shoulder of the left tunnel increases from 0.11m/s (R=45mm/h) to 0.313m/s (R=65mm/h), an increase of 2.845 times.
The analysis shows that, in the early stage of rainfall intensity, the soil matrix suction is larger, there is large shear strength, tunnel lining movement is relatively slow. When the rainfall intensity reaches 45 mm/h later, the shear strength of the soil is reduced, the tunnel lining is moved greatly, and the horizontal velocity of the tunnel lining increases rapidly. It can be seen that the horizontal displacement of the left arch shoulder and the left hance and the vault of the tunnel lining is larger than that of other parts.

### 3.3 Influence of rainfall infiltration intensity on slope and tunnel lining displacement

As shown in Fig. 8, the horizontal displacement distribution nephogram of the slope and tunnel lining. From figure 8 we can see that the rainfall intensity at 25mm/h to 65mm/h, the horizontal displacement of slope increases with the increase of rainfall intensity, and starting from the middle of the slope region gradually to the top and foot of the slope and the internal diffusion.
Fig. 9 is the horizontal displacement curve distribution of slope. As can be seen from Figure 9, in the early stage, the rainfall intensity is small, from the initial state to $R=45 \text{ mm/h}$, the horizontal displacement increment of each monitoring point of the slope is slow. The lower part of the slope waist of the rainfall affected area is increased from 0 to 0.2132m, and the lower part of the slope waist of unaffected area is increased from 0 to 0.1167m. In the later period of rainfall, when the rainfall intensity is greater than 45mm/h, the horizontal displacement of the slope monitoring point increases sharply. The horizontal displacement of the lower part of the slope of the rainfall affected area is increased from 0.2132m to 0.8603m, increased by 4.035 times; the lower of middle slope of the rainfall unaffected area increased from 0.1167m to 0.6956m, increased 5.96 times, the slope failure has occurred.

**Figure 8:** Horizontal displacement distribution nephogram of slope and tunnel lining

**Figure 9:** Horizontal displacement curve distribution of slope
It is concluded that the rainfall intensity is small in the early stage, the soil shear strength is large, the horizontal displacement is small and the growth rate is slow, and the soil has some safety reserves. In the later stage, the rainfall intensity reaches a certain degree, because the soil weight increases, with the soil c, φ value decreases, resulting in lower soil shear strength. The slope sliding force is larger than the anti-sliding force, and the instability failure occurs, so the horizontal displacement increases rapidly. It can be seen that the rainfall intensity has a great influence on the horizontal displacement at the lower part of the slope waist and spread to the middle and the bottom of the slope as the rainfall intensity increases.

At the same time, from the distribution nephogram in Figure 8 shows that the rainfall intensity of 25mm/h to 65mm/h between the horizontal displacements of the tunnel lining is also increased with the increase in rainfall intensity.

With the increase of rainfall intensity, rainwater infiltration, the lower part of the slope has the largest displacement, gradually reduced to the surrounding, and then spread to the tunnel lining. The left arch shoulder and the vault of the left tunnel have a greater horizontal displacement than the other parts.

Figure 10 shows the distribution of the horizontal displacement of the tunnel lining. It can be seen from Fig 10 that when the rainfall intensity is relatively small (from initial state to 45mm/h), the horizontal displacement of the tunnel lining is more gentle, the left arch shoulder of the left tunnel is increased from 0 to 0.115m, the left arch shoulder of the right tunnel increased from 0 to 0.11m. In the later stage, when the rainfall reaches 45mm/h, the horizontal displacement of the tunnel lining increases sharply. The left arch shoulder of the left tunnel increased from 0.115m to 0.756m, an increase of 6.574 times; the left arch shoulder of the right tunnel increased from 0.11m to 0.705m, an increase of 6.41 times. at this point, the tunnel lining has a greater movement. The horizontal displacement of the monitoring points in the left tunnel is: left arch shoulder> vault> left hance> bottom> right arch shoulder> right hance. The horizontal displacement of the monitoring points in the right tunnel is: left arch shoulder> left hance> vault> bottom> right hance> right arch shoulder.

![Figure 10: Horizontal displacement curve distribution of tunnel lining](image-url)
It is concluded that the soil has a certain shear strength in the early stage of low rainfall intensity, and the horizontal displacement of the tunnel lining is more gentle under certain buried depth. At the later stage of the rainfall intensity, the soil gravity increases, $c$, $\varphi$ decreases, the shear strength decreases, and the soil has a large horizontal displacement. It can be seen that with the increase of rainfall intensity, the influence of the horizontal displacement of the tunnel lining is as follows: the early stage is relatively slow and the latter period produces a large increase. However, in the case of numerical size and distribution, the horizontal displacement of the left tunnel is larger than that of the right tunnel.

3.4 Effects of rainfall infiltration intensity on shear strain increment of slope and tunnel lining

Figure 11 shows the distribution nephogram of shear strain increment of slope and tunnel lining. It can be seen from Figure 11 that the shear strain increment of the whole slope tends to be consistent with the rainfall intensity, and there is no shear strain increment concentration zone. With the increase of rainfall intensity, the shear strain increment gradually concentrate to the slope foot, the right tunnel right upper soil shear strain increment gradually extending to the top of the slope, and to the upper slope diffusion, finally, in the top of the slope, the middle of the slope, the lower part of the slope and the bottom of the slope to form a certain shear strain increment through the area.

(1) Rainfall intensity $R = 25\text{mm/h}$

(2) Rainfall intensity $R = 35\text{mm/h}$

(3) Rainfall intensity $R = 45\text{mm/h}$

(4) Rainfall intensity $R = 55\text{mm/h}$
It is concluded that the soil suction is relatively large and the soil has better stability in the early stage of rainfall intensity. With the increase of rainfall intensity, the infiltration rainwater gradually converges to the slope foot due to the gravitational force, the matrix suction decreases, the soil weight increases, and the effective stress of the slope is reduced, and the shear strain increment increases gradually. It can be seen that the rainfall infiltration has a great influence on the shear strain increment of the slope foot and the top of slope, and slip foot prone to slip and instability.

At the same time, from Figure 11 (1) ~ (5) shows that the tunnel lining shear strain increment first appeared in the right tunnel arch shoulder and arch waist with the increase of rainfall intensity, and extends to the upper part of the soil until the top of the slope and the upper part of the slope. The shear strain increment of the left tunnel then appears in the left arch shoulder and the left hance and gradually extends to the slope. It can be seen that at first, the shear strain increment of the tunnel lining first aggregates in the left and right arch shoulders and the right hance of the right tunnel and increases with the increase of the rainfall intensity, therefore, the shear strain increment has the greatest influence on the right and left arch shoulders and the right hance of the right tunnel.

3.5 Rainfall intensity and safety factor

(Figure 12) Rainfall infiltration intensity and safety factor
Figure 12 shows the variation curve of the safety factor with rainfall intensity under rainfall conditions. It can be seen from Figure 12, when the rainfall intensity is 0, the safety factor of self-weight conditions is 1.525, the slope is in a stable state. With the increase of rainfall intensity, the slope stability decreases gradually. When the rainfall infiltration intensity is 45mm/h, the safety factor is 1.015, at this time the slope is in the critical state, and there is a slight adverse effect, which will lead to slope instability. When the rainfall intensity is 55mm/h, the safety factor is 0.955, and the sliding force of the slope is greater than that of the sliding force at this time, and the slope is unstable. When the rainfall intensity is 65mm/h, the safety factor is 0.845, and the slope has a serious instability failure. When the rainfall intensity exceeds 45mm/d, the monitoring and reinforcement measures should be strengthened in the design and construction process to ensure the safety of construction.

4. CONCLUSION

Based on the soil seepage theory, a numerical model of the existing small diameter bias double tunnels and slope under rainfall infiltration is established by using the finite difference FLAC3D software. The variation characteristics of stress, velocity, displacement and increment of shear strain under different rainfall infiltration intensity are studied, and the following conclusions are obtained:

(1) Under the same rainfall duration, with the increase of rainfall intensity, the vertical stress, velocity and displacement of the slope of the rainfall affected area and the rainfall unaffected area and the tunnel lining are gradually increasing.

(2) The influence of rainfall infiltration on vertical stress, horizontal velocity and horizontal displacement of slope foot is larger than that of slope waist and the top of slope. For the tunnel lining, the vertical stress on the right hance and the left shoulder of the left tunnel lining is greater than that of the other parts, and the effect on the left shoulder and the bottom is greater than that of the other parts.

(3) During the rainfall intensity of 25mm/h to 65mm/h, the horizontal displacement of the slope began to gradually spread from the middle of the slope to the top of the slope and the slope foot and the interior of the slope, and the horizontal displacement of the left tunnel is larger than that of the right tunnel.

(4) With the increase of rainfall intensity, the shear strain increment gradually converges to the slope foot, and the shear strain increment of the right upper part of the right tunnel gradually extends to the top of the slope and spreads to the upper part of the slope. The rainfall infiltration has a great influence on the shear strain increment of the slope foot and the top of the slope, and the slope foot is prone to slip and slope instability. The shear strain increment of the tunnel lining is first gathered in the left and right arch shoulders and the right hance of the right tunnel, and gradually increases with the increase of the rainfall intensity. The shear strain increment has the greatest effect on the left and right arch shoulders and right hance of the right tunnel.
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