Indoor model test of red clay slope under evaporation-rainfall

Kaisheng Chen¹, Qinqin Wang²*, Dipu Luo¹, Bo Zhou¹ and Kun Zhang¹

¹Civil engineering College, Guizhou University, Guiyang, Guizhou, 550025, China
²Qiannan traffic test and detection Co., Ltd, Douyun, Guizhou, 558000, China

*Corresponding author’s e-mail: 359396260@qq.com

Abstract: Evaporation-rainfall is one of the main causes of red clay slope failure. In order to explore the evolution law and mechanism of red clay slope failure under evaporation-rainfall, this paper takes Guizhou red clay as the research object, establishes slope model in laboratory, and analyzes the failure characteristics, failure mode and failure mechanism of red clay slope under evaporation-rainfall. The test results show that the failure mode of red clay slope under evaporation-rainfall is: splash erosion and surface erosion stage → crack development stage → gully formation stage → gully development stage → local collapse stage → slope foot collapse stage. During the test, there is no obvious sliding surface on the slope. In the process of rainfall, the free water inside the slope converges to the foot of the slope under the action of gravity, which results in the maximum moisture content at the foot of the slope, and the strength of the soil decreases sharply. The local collapse occurs at the foot of the slope first. When several collapses are connected and the structure of the slope foot cannot support the weight of the upper shallow soil, the collapse occurs to the middle and upper part of the slope exhibition.

1. Introduction

Due to the special physical properties of red clay, such as high water content, high plasticity, and high porosity ratio, the failure form of red clay slopes is different from ordinary soil slopes¹[2][3]. Some engineering examples showed that although the red clay slope was designed according to the specifications, the slope was damaged in the early operation stage and even the construction stage. The engineering technicians have not given a good explanation for this. In recent years, domestic and foreign scholars have made preliminary explorations on the failure characteristics, failure mechanism and crack development rules of soil slopes under the action of dry and wet cycles. Zhang et al. conducted the indoor expansive soil slope test under the dry-wet cycle, and measured the changes in suction, pore water pressure, horizontal and vertical displacement inside the slope during the whole test process through the buried depth sensor, and recorded the crack development law of the slope surface⁴. Kong et al. tracked and tested the relationship between slope deformation and atmospheric change by monitoring gentle slopes, steep slopes, and grass planting on slopes and other expansive soil slopes⁵. The shear stress at the The above research shows that evaporation-rainfall is one of the main causes of slope failure. The research results are mainly concentrated on expansive soil. Due to the special nature of red clay, the failure characteristics, failure mode and failure mechanism of the slope need further study. Therefore, comprehensively grasping the destruction characteristics and mechanism of red clay slope during evaporation-rainfall has important academic and engineering application value for perfecting the design of red clay slope.

Content from this work may be used under the terms of the CreativeCommons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

Published under licence by IOP Publishing Ltd
2. Experimental Scheme

2.1 Raw Materials
According to the relevant requirements in "Road Geotechnical Test Regulations", its basic physical properties are obtained, as shown in Table 1.

| Optimal moisture content /% | Plastic limit /% | Liquid Limit /% | Plasticity index | Uneven coefficient | Curvature coefficient |
|-----------------------------|------------------|-----------------|------------------|-------------------|----------------------|
| 22.2                        | 26.06            | 55.98           | 29.92            | 30                | 2.7                  |

2.2 Slope Model
The slope model box is composed of two sides, a back and a bottom, in which the side is tempered glass, the back is a steel plate, and the bottom is a steel frame. The soil material is arranged according to the optimal water content of 22.2%, and the soil samples are divided and compacted according to the degree of compaction of 90%. After the filling is completed, the slope is cut at a slope ratio of 1:1.5 (length × width × height = 3 m × 1.5 m × 1.4 m) to obtain the slope shown in figure 1.

2.3 Evaporation-rainfall Device
The rain device uses the QYJY-501 (502) artificial simulated rain device produced by Xi'an Qingyuan Measurement and Control Technology Co., Ltd. This rain system can simulate the continuous change of rain intensity from 10 to 200 mm/h; the drying device uses 6 bath heaters (1kw) uniformly placed on both sides of the slope model, three on each side, in order to ensure that the slope soil is heated evenly, the bath heaters moves at a constant speed. An electric fan is used under the foot of the slope to increase the air flow and accelerate the drying of the slope, see figure 2.

2.4 Evaporation-rainfall Scenario
The rainfall intensity is 60 mm/h. First rain for 1 hour, then stand for 24 hours to fully penetrate the water, and finally use a bath heater to heat up and dry. During the drying period, the width and depth of the cracks at each selected point in the area are measured every hour until the crack width and depth no longer change. At the end of the drying process, turn off the bath heater and complete an evaporation-rain test.

3. Analysis of Test Results

3.1. Failure Characteristics of Slope
It can be seen from figure 3(a): After the first rainfall, the surface and shallow soil of the slope softened and disintegrated under the erosion of the rain, that is, the slope appeared erosion and surface erosion, but it was relatively stable overall. It can be seen from figure 3(b) that after the first drying, the cracks are fully developed, and the shape of the cracks is similar to the "eight", defined as "eight" cracks, and the slope surface is divided into several relatively independent soils by the "eight" cracks block, and there are large cracks at the shoulder of the slope, with an average depth of 2 cm and a width of 1.4 cm; combining with figure 3(c), we can see that: 10 minutes before the second rain, the rainwater basically entered the cracks generated by the first drying, small The cracks absorb water and close; after 20 minutes of rain, the rainwater gradually fills the cracks, and the soil absorbs water close to saturation. At this time, the runoff of the rainwater is greater than the infiltration, and the rainwater flows down the slope from the crack. At the same time, due to the large amount of rainwater collected at the top of the slope and the large crack of the shoulder, the rainwater flows along the large crack of the shoulder to the slope surface; 25 minutes of rainfall at the shoulder of the slope, the water flows along the crack to form a shallow gully. At the same time, a large crack located in the middle of the slope surface formed an "eight" crack block under the erosion of rain; after 50 minutes of rainfall, the crack extended from the shallow gully of the shoulder to the slope below, forming three longitudinal shallow gully, the width of the gully increases and the depth deepens in 58 minutes, and the gully penetrates to the bottom; after 1 hour and 41 minutes, the "eight" crack in the middle of the slope appears to fall off. After the second rainfall, the slope gullies were 3.2 cm wide and 5 cm deep. From figure 3(d), we can see that after the second drying, large cracks appeared on the original shedding area of the slope. For the first time, the "eight" character strip appeared at the foot of the slope; as can be seen from figure 3(e) and (f): After the third rain, at the place where the "eight" character block fell off, the partial shedding gradually changed into local collapse, The width of the gutter increased to 4.5 cm and the depth to 8 cm. After the third drying, cracks continued to occur, and the number of cracks increased. At the second partial collapse, "eight" strips appeared on the slope surface, and some soil blocks began to fall off. From figure 3(g) to figure (j), we can see: In the fourth rainfall, under the joint action of the "eight" crack and the soil strip, the original collapsed area was further expanded. A new "eight" shaped crack was formed on the right side of the collapsed site, and collapsed again as the rain progressed; during the fifth rainfall, the original two collapsed sites penetrated and all the slope foot collapsed.
3.2. Destruction Mode
It can be seen from figure 3 that the failure evolution law of red clay slope under evaporation-rainfall is: splash erosion and surface erosion stage → crack development stage → gully formation stage → gully development through stage → local collapse stage → slope foot collapse stage, such as figure 4 shows.

(a) Splash erosion and surface erosion stage. During the first rainfall of the newly built slope, the rain drops freely and impacts the small particles on the surface soil of the slope, causing splashing and surface erosion. In the initial stage of the test, the complete slope soil has a high degree of compaction, and the permeability of the red clay is low. Less rainwater seeps into the slope. The rainwater at the top of the slope collects towards the shoulder, and the water at the slope collects towards the foot of the slope, causing increased rainwater at the shoulder and foot of the slope, resulting in surface erosion and micro-ditching at the shoulder and foot.

(b) Stage of crack development. During the drying period, the soil loses water and shrinks, and cracks start to appear on the top of the slope. The shape of the crack is usually "eight" and it develops in and around the slope. The "eight" crack splits the complete slope into several relatively independent "eight" soil blocks, and part of the soil on the slope surface falls off.

(c) Stage of gully formation. After the rain, the rainwater enters the crack. After the crack is full, the rainwater at the top of the slope flows along the vertical crack at the shoulder of the slope to the slope surface, scouring the crack, making the crack wide and deep, and then forming a gully.

Figure 4. Slope failure mode under dry and wet cycles
(d) The development and penetration of gullies. After the gullies were washed by rain, the soil strength decreased sharply. During the drying period, the degree of water loss cracking of the soil is more severe, the density of cracks is greater, and the number of "eight" soil blocks is greater. Partially connected gullies turn the slope into several relatively independent strips of soil.

(e) Stage of partial collapse. As the evaporation-rainfall continues, the width, length, number, and depth of cracks in the evaporation stage further develop, and the gully is deepened to the middle and lower parts of the broken surface. During the rain phase, rainwater flows down the original gully and continues to the foot of the slope. When the rainfall intensity is large, the original slope shoulder gully cannot bear the flow, and the rainwater will flow down along the other vertical cracks on the slope shoulder to form a new gully. At the same time, the "eight-shaped" soil blocks and soil strips on the slope surface were partially detached and collapsed due to the rain.

(f) Stage of slope foot collapse. Because all the rainwater on the slope is collected at the foot of the slope, the runoff at the foot of the slope increases, the water content of the soil at the foot of the slope increases, the pore water pressure also increases, the shear stress at the slope foot increases, the shear strength decreases, and the slope foot first appears collapsed.

3.3. Destruction Mechanism
The failure mechanism of red clay slope is closely related to evaporation-rainfall. During rain, raindrops fall freely, impact the slope under the action of gravity, and lift up the soil particles on the slope, causing splash erosion; as multiple soil particles are lifted, the splash erosion expands into surface erosion; the temperature increases during the dry period, the water content of the shallow layer of the slope decreases, and with the decrease of the water content, the intergranular pores gradually lose water, the free water layer becomes thinner, and the weakly bound water layer plays a major role in the connection of the soil particles. Two adjacent soil particles The joint adsorption of the weakly bound water layer makes the connection of the soil particles firm. When the water content is further reduced, the weakly bound water layer gradually changes to the strongly bound water. The greater the adsorption force, the stronger the connection ability of the soil particles. At this time, the soil body Matrix suction increases. Under the action of suction, the soil on the surface of the slope continuously shrinks. When the suction of the matrix is greater than the tensile strength of the soil, cracks are formed, and the depth and width of the cracks gradually increase with time. The occurrence of cracks forms a good infiltration channel for rainwater infiltration. The soil absorbs water during rainfall, the matrix suction is weakened, and the cracks are closed. When runoff occurs during the rainfall period and some cracks are not completely closed, runoff scours along the cracks, and gullies are easily formed. With the generation of runoff, rainwater mainly gathers at the foot of the slope, and the water inside the slope gradually seeps toward the foot of the slope under the action of gravity. The moisture content and pore water pressure at the foot of the slope are large, and the shear strength of the soil is low. Under scour, slope foot is prone to damage.

4. Conclusions
4.1. The failure mode of red clay slopes is different from that of general soil slopes. The failure modes of red clay slopes under evaporation-rainfall is: splash erosion and surface erosion stage → crack development stage → gully formation stage → gully development through stage → local Stage of collapse → stage of slope collapse.

4.2. The generation of cracks not only reduces the strength of the slope, but also provides a convenient channel for the evaporation of water inside the slope. Gullies often appear at the vertical cracks on the shoulders of the slopes. The “eight” cracks divide the slope into “eight” cracks. The shedding of the “eight” cracks during the rainfall period caused local collapse, and lateral cracks on the shoulders and the top of the slope. After impoundment, the horizontal thrust, horizontal thrust and slope cracks are formed on the sliding body, which makes the red clay slope failure form different from the traditional
are sliding.

Acknowledgment
The majority of work presented in this study is supported by the National Natural Science Foundation of China (Grant No. 51668011, No. 51368010), Guizhou Provincial Science and Technology Support Plan Project (Grant No. Qianke Science Support [2016] 2005).

References
[1] Liu, T.Y., Wang, J.Z., Wu, L.J. (2015) Research on failure mechanism and stability calculation method of red clay slope[J]. Highway Transportation Technology (Applied Technology Edition), (8): 47-490.
[2] Chen, N., Wu, L.J., Zhou, Y., Deng, J. (2016) Shallow failure mechanism and stability evaluation method of red clay slope[J]. Highway Transportation Technology, 33: 37-42, 88
[3] Zhang, L.Y., Huang, H.H., Zheng, J.J. (2014) Stability analysis of red clay slope of guizhou expressway [J]. Journal of Guizhou University (Natural Science Edition), 31: 105-110
[4] Zhang, Y.Z., Wang, L.J., Liu, S.H., Lin, Y.W. (2015) Model test of the response of expansive soil slope under dry and wet cycles [J]. Journal of Zhengzhou University (Engineering Science Edition), 36: 114-118.
[5] Zhang, Y.Z., Wang, L.J., Liu, S.H., Lin, Y.W. (2015) Model test of expansive soil slope response under dry and wet cycles[J]. Journal of Zhengzhou University (Engineering Science Edition), 36: 114-118.