Restricted Effect of Two Plant Root Systems on the Crack Expansion of China Yunnan Laterite under Dry-wet Cycle

Weiwei Zhu*, Guojian Feng, Jun Du
School of Architecture and Civil Engineering, Kunming University, Kunming, Yunnan, China
*Corresponding Author: Weiwei Zhu

Abstract:
In order to research the restricted effect of hedera nepalensis root systems and heteropogon contortus root systems on the crack expansion of Yunnan laterite under dry-wet cycle, this paper prepares Yunnan laterite with certain moisture content, and makes the compacted samples of pure laterite and composite soil mixed with root systems by adopting hedera nepalensis root systems and heteropogon contortus root systems respectively, and then simulates the dry-wet cycle of laterite in engineering (i.e., rainfalls and evaporations), measures the crack width of samples experiencing different cycles, and makes statistical analysis on the average maximum crack width of samples in all groups by adopting the method of indoor spraying and natural drying. The result indicates that, 10% and 20% mixed hedera nepalensis root systems can exert obvious restrictions on the crack expansion of Yunnan laterite after dry-wet cycle, while 30% mixed hedera nepalensis root systems and 10% mixed heteropogon contortus root systems can also restrict the crack expansion of Yunnan laterite, but the restricted effect is weaker. As for 20% and 30% mixed heteropogon contortus root systems, composite soil samples will disintegrate after the 2nd dry-wet cycle.

Keywords: Yunnan laterite, Hedera nepalensis root systems, Heteropogon contortus root systems, Dry-wet cycle, Crack resistance.

I. INTRODUCTION
Yunnan is one of the most developed regions of laterite in China. Laterite refers to the soil mass that is in the primary color of red and formed by iron-enriched parent rocks under warm-wet climate conditions after complete weathering, micro-pelletization and soil forming process [1].Yunnan laterite is a special soil, featured of high clay content, high liquid limit, big natural void ratio, low osmotic coefficient, high dispersity, weaker expansibility, but stronger contractility, etc. [2-4]. Yunnan is now facing lots of laterite slope problems as railway and highway projects are commenced, and laterite slopes after construction completes must
experience dry-wet cycle. According to researches, Yunnan laterite will generate cracks after dry-wet cycle, which will expand with the number of cycles [5], and then generate severe water and soil loss as well as slope instability. Since plant root systems have certain mechanical strength [6-8], and the shear strength of root-soil composites is higher than plain soil under certain root content [9], root systems can exert certain reinforcing effect on the superficial layer of the slope [10]. As slope vegetation and ecological slope vegetation are advocated, it is necessary to study the influence of typical slope-protective plant root systems on the crack expansion of Yunnan laterite under dry-wet cycle.

In the research, it simulates natural rainfall and evaporation cycle indoor, intuitively reflects the crack and its expansion phenomenon in the dry-wet cycle of pure Yunnan laterite, and the composite soil mixed with hedera nepalensis root systems and heteropogon contortus root systems, and reveals the restricted effect of these two plant root systems on laterite cracks, and discusses the restricted mechanism of two plant root systems for the crack expansion of Yunnan laterite after dry-wet cycle. In general, the restricted effect of hedera nepalensis on the crack expansion of Yunnan laterite under dry-wet cycle is stronger than heteropogon contortus root systems. The research results can provide reference for the protection of Yunnan laterite engineering.

II. TESTING PROGRAMS

2.1 General Ideas

Dry up and pulverize Yunnan laterite samples, take two types of typical plant root systems for slope vegetation (Hedera nepalensis K.Koch var.sinensis (Tobl.) Rehd., and Heteropogon contortus (L.) Beauv.), control the volume fraction of root systems in the compaction mould, regard the volume fraction of 0% (pure laterite), 10%, 20% and 30% as the standard to control root content, prepare the composite soil mixed with Yunnan laterite and root systems (stir up evenly), put the composite soil in the compaction mould, and compact the composite soil as per the test method of heavy-type II-I [11]. Use a wire saw to cut out composite soil samples from the compaction mould, cut out 3 samples for each root content, and carry out the 1st, 2nd, 3rd, 4th, 5th, 6th, 7th and 8th dry-wet cycle respectively, and then observe the maximum crack width of samples after each dry-wet cycle with crack observer, analyze data and evaluate the restricted effect of two plant root systems on the crack expansion of Yunnan laterite under dry-wet cycle.

2.2 Sample Preparation and Dry-Wet Cycle Control

The laterite for the test is brown when it is dried, and will turn red brown after immersed in water. As for the grain composition, it consists of 41.25% clays, 47.93% powder particles, and 10.82% sand grains. Refer to TABLE I for the basic physical mechanical properties index. The maximum dry density ($\rho_{\text{dmax}}$) confirmed by the standard compaction test is 1.62g/cm3, and the best moisture content ($\omega_{\text{opt}}$) is 17.8%.
TABLE I. Basic physical and mechanical properties of lateritic soil

<table>
<thead>
<tr>
<th>Natural wet density $\rho$ (g/cm$^3$)</th>
<th>Specific density of solid particles $G_s$</th>
<th>Natural moisture content $\omega$ (%)</th>
<th>liquid limit $\omega_L$ (%)</th>
<th>Plastic limit $\omega_P$ (%)</th>
<th>Plasticity index $I_P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.76</td>
<td>2.64</td>
<td>29.2</td>
<td>52.0</td>
<td>28.0</td>
<td>25</td>
</tr>
</tbody>
</table>

Preparation of pure laterite samples: Prepare soil samples for the test as per the moisture content of $\omega=21\%$, seal up the prepared soil samples in a plastic bag for 24h, to ensure even moisture content, and then place in the compaction mould (inner diameter: 100mm; height: 127mm) for compaction. The dry density of soil mass ($\rho_d$) and the compaction coefficient of the compacted soil mass are respectively 1.53 g/cm$^3$ and 94.4%. Lift up the soil mass in the compaction mould slowly with a jack, cut out soil samples that are 20mm in thickness gently with a wire saw, and prepare a total of 3 pure laterite samples as per the method.

Preparation of composite soil mixed with Yunnan laterite and root systems: take typical hedera nepalensis and heteropogon contortus root systems, clean it up and make it dry naturally for 8h, and then measure the root system density; cut short the root system, control the length of each root system at no more than 2/3 of the inner diameter of compaction mould, and the diameter of the root system at no more than 2mm; control the volume fraction of root systems in compaction mould, and regard the volume fraction of 10%, 20% and 30% as the root content control standard, prepare the composite soil of Yunnan laterite mixed with hedera nepalensis and the composite soil of Yunnan laterite mixed with heteropogon contortus, mix up and stir up evenly, and place in the compaction module for compaction. Lift up the soil mass in the compaction module slowly with a jack, and then cut out a soil sample that is 20mm in thickness gently with a wire saw, and prepare a total of 18 composite soil samples as per the method. Since the surface root system in the compaction module can be damaged in the compaction process, abandon the composite soil in top 5cm of the compaction module after compaction completes.

Dry-wet cycle in the test doesn’t indicate absolute “dry” and “wet”, but the indoor simulated moistening and dehumidifying process of Yunnan laterite in the natural world. The control standard of “dry” is to: place the soil sample in the laboratory and make it dry naturally for 48h. The control standard of “wet” is to: (1) spray water on the sample surface slowly with a needle injector filled with water (Control the distance between the needle and the sample surface at 1cm, and the spray speed at 0.5ml/s), cover up the sample surface with water, and then continue to spray after water is absorbed by the sample and stop after 5mins as the water surface is kept stable; or (2) if the water sprayed on the sample surface can always be absorbed in 5min, it is requested to spray until free water leaks from the bottom of the sample.
III. TEST RESULT AND ANALYSIS

Crack expansion conditions of pure laterite samples after the 2nd, 4th and 8th dry-wet cycle are as shown in Fig 1. We can see clear cracks on the sample surface in different dry-wet cycles. After the 1st dry-wet cycle, all pure laterite samples will develop annular micro-cracks, and the width of crack will expand gradually as dry-wet cycle continues. The annular cracks formed in the initial phase will radiate peripherally, and after the 4th dry-wet cycle, the maximum crack will reach to millimeter-level width. After the 6th dry-wet cycle, crack expansion will become stable, with no increase in width.

Fig 1: Crack expansion of pure laterite samples

The crack expansion conditions of composite soil mixed with hedera nepalensis root systems after the 2nd, 4th and 8th dry-wet cycle are as shown in Fig 2. We can observe intuitively that, within the scope of mixing amount in the test, hedera nepalensis root systems can effectively restrict the crack expansion of Yunnan laterite, and the higher tensile strength of its root system can bear bigger expansion and shrinkage stress. As hedera nepalensis root systems were mixed, the composite soil sample showed different crack forms from pure laterite samples under dry-wet cycle, without obvious annular cracks, and the mechanism may be related to the placeholder of the root system, which has changed the shrinkage axle in the sample dehumidifying process, i.e., the sample won’t shrink evenly along the center as a whole.
Fig 2: Crack expansion of composite soil samples mixed with hedera nepalensis root systems

The crack expansion conditions of composite soil mixed with 10% heteropogon contortus root systems after the 2nd, 4th and 8th dry-wet cycle dry-wet cycles are as shown in Fig 3. We can observe intuitively that, after 10% heteropogon contortus root systems were mixed, composite soil samples showed different crack forms from pure laterite samples, without obvious annular cracks, but crack width was still bigger. When the mixing amount of heteropogon contortus root systems was 20% and 30%, composite soil samples disintegrated after the 2nd dry-wet cycle (Fig. 4). We can hold that when the mixing amount of heteropogon contortus root systems is 20% and 30%, there is no restriction on the crack expansion of Yunnna laterite under dry-wet cycle. On one hand, the surface of heteropogon contortus root systems is smoother than hedera nepalensis root systems, which will cause weaker link between heteropogon contortus root systems and laterite particles. On the other hand, lots of heteropogon contortus root systems have blocked the effective link of laterite particles, and caused the disintegration of composite soils after the 2nd dry-wet cycle.
Fig 3: Crack expansion of composite soil samples mixed with 10% heteropogon contortus root systems after the 2nd dry-wet cycle, 4th dry-wet cycle, and 8th dry-wet cycle.

We can observe the maximum crack width of samples with 100 times of crack observer (Fig. 5), and get the average maximum crack width of samples after experiencing the 0th, 1st, 2nd, 3rd, 4th, 5th, 6th, 7th, and 8th dry-wet cycle as shown in Fig 6.
The average maximum crack width after the dry-wet cycle of 5 groups of samples is listed in TABLE II, so as to judge the restricted effect of two plant root systems on crack expansion of Yunnan laterite under dry-wet cycle from the perspective of statistical analysis.

TABLE II. The average maximum crack width after the dry-wet cycle of samples (mm)

<table>
<thead>
<tr>
<th>Groups</th>
<th>No. of dry-wet cycles</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>group A</td>
<td>0</td>
<td>0.20</td>
<td>0.52</td>
<td>0.90</td>
<td>1.31</td>
<td>1.66</td>
<td>1.68</td>
<td>1.69</td>
<td>1.68</td>
<td></td>
</tr>
<tr>
<td>group B</td>
<td>0</td>
<td>0.17</td>
<td>0.21</td>
<td>0.23</td>
<td>0.25</td>
<td>0.28</td>
<td>0.28</td>
<td>0.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>group C</td>
<td>0</td>
<td>0.15</td>
<td>0.18</td>
<td>0.20</td>
<td>0.22</td>
<td>0.24</td>
<td>0.27</td>
<td>0.28</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td>group D</td>
<td>0</td>
<td>0.21</td>
<td>0.58</td>
<td>0.94</td>
<td>1.29</td>
<td>1.32</td>
<td>1.34</td>
<td>1.36</td>
<td>1.37</td>
<td></td>
</tr>
<tr>
<td>group E</td>
<td>0</td>
<td>0.28</td>
<td>0.49</td>
<td>0.79</td>
<td>1.26</td>
<td>1.62</td>
<td>1.63</td>
<td>1.64</td>
<td>1.65</td>
<td></td>
</tr>
</tbody>
</table>

Group A: pure laterite; group B: 10% hedera nepalensis root systems; group C: 20% hedera nepalensis root systems; group D: 30% hedera nepalensis root systems; group E: 10% heteropogon contortus root systems

Using SPSS software to carry out non-parameter inspection on 5 groups of data, and then get the probability, \( P = 0.00003 < 0.01 \), which indicates that 5 groups of data have statistical differences. The mean rank for these 5 groups of data is respectively 4.33, 1.89, 1.44, 3.67 and 3.67, indicating that the average maximum crack width of 4 mixed root system groups is lower than A group. The crack width of B and C groups is smaller, while the crack width of D and E groups is bigger. 20% mixed hedera nepalensis root group can exert the most obvious restricted effect on the crack expansion of samples.

IV. DISCUSSION

The crack development process of pure laterite samples under dry-wet cycle can be divided into 3 phases: crack development phase, crack expansion phase and crack stability phase. The 1st dry-wet cycle is called as crack development phase, during which the humidifying of laterite samples only happens in holes of original samples, and the humidifying effect is to make red clay
absorb water, while the dehumidifying effect is to remove partial moistures in holes, but it will cause moisture content gradient in laterite samples, and lots of moistures in samples, which will soften the connection of laterite particles, and cause micro-cracks of samples. The 2\textsuperscript{nd}—4\textsuperscript{th} dry-wet cycle indicates the crack expansion phase. After crack development process, the main effect for the pure laterite samples to absorb water and humidify is to increase the thickness of water film among laterite particles, and cause the expansion cracks of laterite samples; the main effect of dehumidifying is to decrease the thickness of water film among laterite particles, and cause the shrinkage cracks of laterite water due to water loss, and micro-cracks will develop into macro-cracks gradually. After the 5th dry-wet cycle, it is the crack stability phase, during which the main effect for the pure laterite samples to absorb water and humidify is not to continuously expand the thickness of water film among laterite particles and cause expansion cracks, but to fill up current cracks; the main effect of dehumidifying is to decrease moistures of laterite particles in the current cracks, but due to bigger crack width and more moisture content, shrinkage crack won’t deepen in a short term due to water loss, and won’t pull the soil apart or cause new cracks.

According to the test and the statistic analysis of data, 10\% and 20\% mixed hedera nepalensis root systems can exert obvious restrictions on the crack expansion of Yunnan laterite after dry-wet cycle. On one hand, plant root systems have higher tensile strength [8,12], and can bear higher expansion and shrinkage stress in the moisture absorption expansion and dehumidifying shrinkage process of laterite. On the other hand, hedera nepalensis root systems have coarse surface, and can form better friction link with laterite particles as well as stronger integrity of root-soil composite. 30\% mixed hedera nepalensis root systems can also restrict the crack expansion of Yunnan laterite, but such restricted effect is obviously lower than 10\% or 20\% mixed hedera nepalensis root systems, which may be caused by the excessive root systems, for it may block the effective link with laterite particles in large scales, and then reduce the crack resistance, the research of reference [13] also considers that there is an optimal root content in the increasing effect of root on soil strength. Heteropogon contortus roots have smoother surface than hedera nepalensis roots, and weaker link with laterite particles, so 10\% mixed heteropogon contortus root systems can restrict the crack expansion of Yunnan laterite, but the restricted effect is weaker. As for 20\% and 30\% mixed heteropogon contortus root systems, the composite soil samples disintegrated after the 2\textsuperscript{nd} dry-wet cycle, which is the result jointly incurred by the smooth surface of heteropogon contortus roots and the block of links for laterite particles by excessive root systems in large scales, and under the spraying effect of water, loose laterite particles will be washed away by water flow directly.

This test has revealed the crack and its expansion phenomenon of pure laterite samples as the dry-wet cycle increases as well as the restricted effect of mixed plant systems on the crack expansion of laterite.

There are uncertain factors in the test method adopted by the paper, such as artificial disturbance in sample preparation, small sample size, the simultaneous compaction treatment of root systems and laterite. In addition, the reference [14] also considers that the reinforcement
effect of capillary root system and its biological activity in the actual root-soil complex is better than that of human added root system in the soil. However, the test method in this paper also has advantages in sample size, compaction rate, moisture content, etc. In consideration of the actual difficulties in studying the crack of Yunnan laterite and root system crack resistance, the method adopted by the paper is still recommended. This test method can make it possible to study the restricted effect of plant root systems on the crack expansion of Yunnan laterite after dry-wet cycle based on conventional soil test instruments, and then provide reasonable and effective basis for analyzing engineering problems related to Yunnan laterite.

V. CONCLUSION AND SUGGESTIONS

(1) Use a simple but reasonable test method to test the crack width of pure Yunnan laterite and the composite soil mixed with root systems in the dry-wet cycle process. The test has reflected the crack and its expansion phenomenon of pure Yunnan laterite and the composite soil mixed with root systems in the dry-wet cycle process, and revealed that 10% and 20% mixed hedera nepalensis root systems can exert an obvious restricted effect on the crack expansion of Yunnan laterite under dry-wet cycle.

(2) In general, the restricted effect of hedera nepalensis on the crack expansion of Yunnan laterite under dry-wet cycle is stronger than heteropogon contortus root systems. In the test, 20% and 30% mixed heteropogon contortus root systems disintegrated after the 2nd dry-wet cycle. As for 10% mixed heteropogon contortus root systems, the restricted effect is equivalent to that of 30% mixed hedera nepalensis root systems.

(3) In the paper, it discusses the restricted mechanism of two plant root systems on the crack expansion of Yunnan laterite under dry-wet cycle. On one hand, plant root systems have higher tensile strength, and can bear higher expansion and shrinkage stress in the moisture absorption expansion and dehumidifying shrinkage process of laterite. On the other hand, the friction between root systems and laterite particles can reinforce the integrity of root-soil composites, but excessive root systems can cut off the effective link of laterite particles in large scales, and then decrease block capacity. The surface of heteropogon contortus roots is smoother than that of hedera nepalensis, and the link with laterite particles is weaker.

(4) The restricted effect on the crack expansion of Yunnan laterite can vary with different plant root systems and different content of the same root system. Always remember to be careful when selecting Yunnan laterite slope vegetation, prevent from blindly pursuing for high-density planting, and further study the restricted effect of different plant root systems on the crack expansion of Yunnan laterite under different dry-wet cycle control conditions and big sample conditions.

ACKNOWLEDGMENT

This research is funded by the Joint Special Fund Project of Basic Research in Local Undergraduate Colleges of Yunnan Province (2018FH001-050).
REFERENCES


