Effects of vegetation root on hydro-mechanical properties of debris flow source

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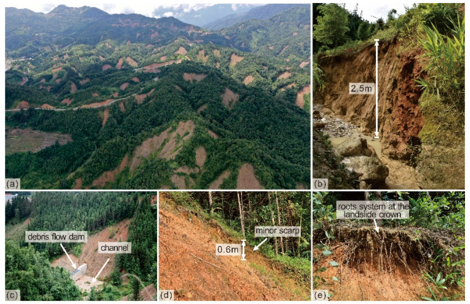
1. Introduction



On September 2nd, 2018, Mengdong village, in the southeast of Yunnan Province, China, was hit by heavy rainfall, which lasted for 8 hours and the peak reached 97.4 mm/h , and then shallow landslides occurred in the area (Fig.1a). The sliding mass merged and accumulated in the channel (Fig.1b) and mixed with water to form debris flows (Fig.1c). The debris flow destroyed towns, resulting in road traffic, network communications, and electricity interruptions. The number of people affected by the disaster reached 12,070, with 10 dead and 11 missing, causing a direct economic loss of $196 million.

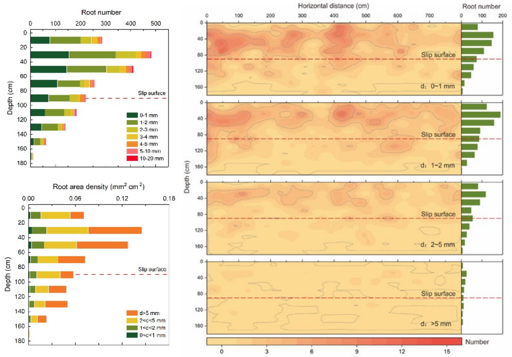
It shows the failure mass accumulated in the channel after the occurrence of shallow landslides, providing the material source for debris flow. And the quantity of the failure mass determines the scale of debris flow. Therefore, it is an important basis for debris flow disaster management in vegetated mountainous areas to deeply understand the influence of vegetation on the hydro-mechanical properties of debris flow sources.

In the current research, the rainfall-induced 2018 shallow landslide cluster in a forest-covered region was selected to explore the mechanism of the root system on the slope hydrological process as well as the slope failure process. The study area was first introduced, and then the materials and methods involved in field investigation and laboratory tests were introduced. In the results, the statistical results of root distribution and related experimental results are introduced. Finally, the change of soil porosity and permeability caused by roots and the failure mode of vegetated slope induced by this is further discussed.

3. Root distribution

The profile counted a total of 2054 roots in the depth range of 0-180 cm, with the grassroots primarily distributed in the depth range of 0-20 cm. The maximum penetration depth of the roots in the slope reaches 175.2 cm. Within the depth range of 0-100 cm, the root number of all diameters in each layer is greater than 200. After the depth exceeds 100 cm, the root number decreases from 183 to almost none. The distribution of root numbers in the whole profile reflects that tree roots are mainly distributed in the soil below 20 cm, and the number and depth of tree roots are greater than those of the grassroots. According to the variation of root number with depth, the root number density (RND) obeys an exponentially decayed polynomial model at the slope scale. Compared with other root architecture functions , this function describes the distribution of roots in more than one plant.

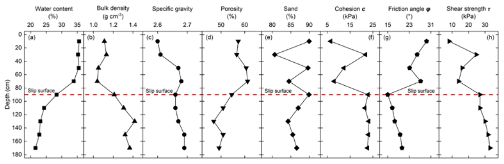
$$y=(x+8.37)^{1.86}e^{-0.04x}$$



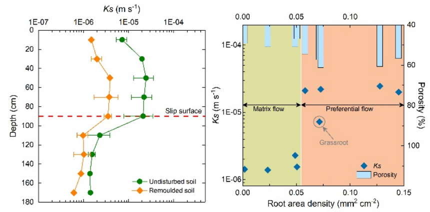
It shows that the RAD in each layer relates to the number of thick roots and thin roots. In addition, the number of root hairs and fine roots in each layer is larger, but their RAD is smaller. Especially, the RAD at 120-140 cm depth is greater than that at 100-120 cm depth, where the total number of RAD in each layer is contrary. A distribution cloud diagram of different root diameters is obtained that reflects the uneven distribution on the whole profile. The root hairs and fine roots are concentrated at 0-80 cm depth, while the thin roots and thick roots are more evenly distributed throughout the profile. Although the roots were not evenly distributed across the section, they were almost all above the slip surface which is the boundary.

4. Hydro-physical properties

The soil above the slip surface has different physical properties than the soil below, and the slip surface is also the boundary. And the saturated hydraulic conductivity of this profile is tree-root soil > grass-root soil > rootless soil.



According to the results, the soil infiltration process under different root content is divided into two types. One type is infiltration dominated by matrix flow. In this situation, the permeability of root-soil acts like that of rootless soil, meaning that the root content is too small to affect the connectivity of pores in soil. Another type is infiltration dominated by the preferential flow. Figure shows that Ks increases rapidly in the process of increasing root content. In this process, the roots interlace with each other and form a root network in the soil.



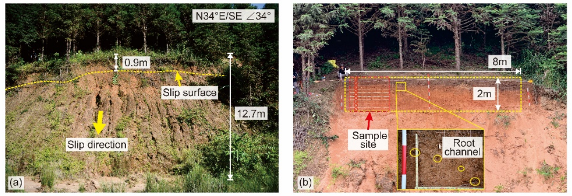
The interconnected macropores induce the permeability of root-soil to increase several times, reaching more than ten times that of rootless soil. As vegetation grows, the rate of root growth and decay tends to be stable, and the permeability of root-soil may reach a relatively stable upper limit in this state. The shear strength forms a low-value region that provides support for the failure of the slip surface. Due to the remarkable difference in hydraulic conductivity of soil, the rainfall will infiltrate rapidly and the water will accumulate at the end of the root channel, when it will form a high pore-water pressure surface. In this study, the region of low shear strength is consistent with the potential high pore-water pressure surface, which is 50-100 cm deep, and this fails the hillslope from a depth of nearly 90 cm.

2. Materials and methods

This study selected a shallow landslide with a depth of less than 1.2 m in the basin for investigation. This shallow is located beside the debris flow channel and has a vertical height of 12.7 m, a width of 43.5 m, an average inclination of 34° , and a sliding mass thickness of 90 cm. And we excavated a profile on the shallow landslide crown to investigate root distribution and collect root-soil material. The profile was excavated at 8 m and included four trees. The depth of the profile is 2 m, which is over the maximum root depth by 20 cm and the distance of the nearest tree to the profile was 0.5 m. After the profile was excavated the position and diameter of the root system including herb roots and tree roots were gathered into statistics in each square, measured with a Vernier caliper.

$$RAD=\frac{A_r}{A_s}=\frac{\sum_{i=1}^{n}\frac{\pi d_i^2}{4}}{A_s} \qquad RND=\frac{n}{A_s} \qquad p=1-\frac{\rho_d}{G_s\times\rho_w} \qquad K_s=2.3\frac{(a_b+a_s)L}{At}\log_{10}\frac{H_1}{H_2}$$

The distribution of the root system was described by root area density (RAD) and root number density (RND). The root-soil physical and hydraulic properties were obtained by laboratory tests, including moisture content, bulk density, particle size distribution, specific gravity and saturated hydraulic conductivity.



5. Conclusion

Field investigations and laboratory tests were conducted to explore the effect of root distribution at slope scale on soil physical and hydrological properties and summarize the failure mode of vegetated shallow slopes in Mengdong Village, Yunnan Province, Southwest China that occurred in a shallow landslide cluster on September 2, 2018.

The exponentially decayed polynomial function is used to quantitatively describe the distribution of roots at the slope scale. Moreover, this function can be used as a sink term as a key factor to model root-water uptake driven by plant transpiration.

Roots can significantly change soil permeability, and the saturated hydraulic conductivity of root-soil can reach 4-10 times that of rootless soil, which is mainly due to preferential flow generated by root channels. In addition, roots increase the porosity of soil by approximately 10% and change other physical properties of soil, such as reducing its density and specific gravity. These changes in hydrological and physical properties may have negative effects on slope stability.

In a rainstorm scenario, due to the hydraulic conductivity of the root-soil above the slip surface being 14-17 times that of below, the rainfall infiltration will be accelerated and form high pore-water pressure at the end of the root channel. When a high pore-water pressure surface is formed on the entire hillslope, the slope fails along this surface. In the study area, the vegetation and slope conditions were almost the same, so after the rainstorm, the shallow landslide cluster occurred in this area.