Influence of water and rock particle contents on the mechanical behavior of soil-rock mixture

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ABSTRACT
Water and rock particle contents are two important factors affecting the mechanical strength of soil- rock mixture (SRM) filled subgrade in the western mountainous area of China. Therefore, the purpose of the paper is to study the mechanisms of reconstituted landslide deposits sample with different water and rock particle contents by analyzing its characteristics of the shear strength and volumetric strain via large-scale direct shear tests. The results show that the stress-strain curves can be divided into 3 different stages. Change laws of shear strength of the SRM specimens with same rock particle content and water content are also described in detail. The influence of water content on shear strength is greater than that of rock particle content under a lower normal stress, and the results are opposite in the case of a higher normal stress. It also indicates that the intercept of the Mohr failure envelope of the soil-rock mixture should be called the "pseudo-cohesion or equivalent-cohesion", not simply called the "cohesion". The effect of moisture content on the equivalent-cohesion is much bigger, especially for the high rock particle content sample. The internal friction angle of the specimen with same moisture content increases with increasing rock particle content, but when the number of rock particles increases to a certain extent, it has little effect on the friction angle. However, it decreases with increasing moisture content at the same rock particle content. It also can be concluded specimens with same rock particle content change from dilation to compression with the increase of the water content. However, the change law with the increase of the rock particle content of the SRM sample under the same water content is based on its optimum moisture content.

RÉSUMÉ
Des particules d'eau et rock contenu sont deux facteurs importants qui influent sur la résistance mécanique des roches (mrs) mélange sol - fondation zone montagneuse rempli dans l'ouest de la chine. par conséquent, le but de ce document est d'étudier les mécanismes de solution reconstituée de glissement (mrs) avec des échantillons différents dépôts de particules d'eau et rock contenu en analysant ses caractéristiques de résistance au cisaillement, la déformation volumétrique et le « saut » par les phénomène de cisaillement direct à grande échelle. les résultats montrent que les courbes contrainte - déformation peut être divisée en trois étapes. changer les lois de la résistance au cisaillement de la srm spécimens avec même rock contenu en particules et la teneur en eau sont également décrits en détail.l'influence de la teneur en eau sur la résistance au cisaillement est plus grande que celle du contenu en particules plus rock de la contrainte normale, et les résultats sont inversées dans le cas d'un plus grand stress normalement.il indique également que l'interception de mohr, enveloppe de rupture du sol rock mélange devrait être appelée « cohésion cohésion-, ou l'équivalent, pas simplement appelé la "cohésion". l'effet de l'humidité sur la cohésion équivalente est beaucoup plus importante, en particulier pour le contenu en particules de roche élevées. l'angle de frottement interne de l'échantillon avec la même teneur en humidité augmente avec la teneur en particules de roche, mais quand le nombre de particules de roche augmente dans une certaine mesure, elle a peu d'effet sur l'angle de frottement. toutefois, il diminue avec une augmentation de la teneur en humidité au même rock.il peut également être conclu des spécimens avec des particules de roches de même teneur dilatation à la compression avec l'augmentation de la teneur en eau. toutefois, le changement avec l'augmentation de la teneur en particules de roche mrs échantillon sous la même teneur en eau optimale est basée sur sa teneur en humidité.

1 INTRODUCTION

Soil-rock mixture (SRM) is the main material found in natural landslide deposits, alluvial deposits, diluvial deposits, and colluvial deposits, which have been subjected to transportation and widely graded, especially in the western mountainous area of China. The mechanical strength of SRM filled subgrade directly affects the safety and operation of the road section of the area, which is closely influenced by the external environment, such as rainfall, loads and human activities. Due to the complexity of its components, the soil-rock mixture is heterogeneous, inhomogeneous, nonlinear, anisotropic, spatial variability (Iqbal et al.,2005) and environmental dependence, which means that their physical, mechanical, and engineering properties are quite different and complex.

The mechanical behavior of soil-rock mixture depends upon various factors such as drainage condition, water content, void ratio, rock particle content, the rate of loading, level of loads, and stress path etc.. Water and rock particle contents may be the most important factors among them. The precipitation, infiltration, and groundwater can cause progressive changes in the mechanical parameters of SRM. A little increase in moisture content may lead to a marked reduction in strength and deformability (Vasarhelyi and Van 2006; Fahamifar and Soroush 2007). Mohamad et al. (2015) observed the effects of moisture content and strength reduction on weathered Malaysian granite of various grades. Jonas Ekblad & Ulf Isacsson (2007) experimented with the aid of time-domain reflectometry (TDR) and analyzed the relationship between relative apparent permittivity and volumetric water content for coarse granular materials used in road pavement. The influence of water on resilient properties of a coarse (maximum particle size 90 mm) granular material also has been done by them since 2006. The same applies to the work of Craig Nichol et al. (2003), who estimated the water content of coarse mine waste rock containing high solute concentrations in the pore water. H. F. Zhao (2013&2014) dedicated himself to studying the shear-strength behavior of unsaturated coarse-grained soils. The earliest work by N. R. Morgenstern (1978) presented the shear strength of an unsaturated soil in terms of two independent stress state variables. There are too many related papers studied the influence of water on the shear strength of coarse soils.

In addition, rock particle content is identified as another important factor influencing the material strength. At present, effects of rock particle on the mechanical properties of the soil-rock mixture is mainly based on the large shear test, such as large direct shear test, large triaxial test, and large in-situ test, etc.. Wei Gao et al. (2014) found that the strength parameters of Zhangmu deposit were correlated with the block proportion by weight (WBP) through in-situ S-RM and constant-head injection tests on a large scale. Coli et al. (2010) presented the bimrock strength parameters by taking into account the influence of the blocks via a non-conventional in situ shear test apparatus; A series of oedometer and triaxial tests were conducted on clay–steel bead and clay–fine gravel mixtures by Kang Fei (2016) to understand the effects of coarse particles on the mechanical behavior of clay–aggregate mixtures. Rohit Verma et al. (2016) performed direct shear tests of the soil-rock mixture with different rock particle size. Jian Chen et al. (2014) analyzed the physical and mechanical properties of the main slip zone of the landslide of loose deposits located in southwestern China. Zong-Liang Zhang et al. (2015) studied the mechanical behavior of soil and soil–rock mixture of the Nuozhadu embankment dam in depth through two large-scale compaction test fields and a series of in-situ direct shear tests. Soil-rock mixture with different stone/rock particle contents may form different soil skeleton structures, density, and micro-porosities, leading to different stress-strain behavior.

The aforementioned state-of-the-art review clearly shows that there is significantlyless knowledge of effects of water and rock particle content on the shear strength characteristics of the soil-rock mixture. A considerable effort is still needed to be studied and further investigated. In this paper, an effort was made to recognize the effect of moisture content and rock particle content on the strength properties of the soil-rock mixture (SRM) collected from a landslide deposit in the western mountainous area of China.

2 MATERIALS

2.1 Landslide Deposits Description

The lab specimens were taken from one of the loose deposits in Lueyang County of Hanzhong city, Shaanxi Province, west of China, where landslide deposits were widely distributed. According to the investigation, the landslide deposits were artificially excavated and the height of it was about 4 meters. Its components were mainly the mixture of limestone rock blocks and silty clay soils. Liquid limit (LL) for the soil matrix ranges between 28% and 31% and plastic limit (PL) is 19%-22%.The scales of the rock particle in the study area changes greatly and the largest block size may be larger than 0.2m (Figure 1). Lingyan road cuts across the landslide deposits and the other side of the road is Jialing river. The heaviest 1-month rainfall recorded was 689.9 mm in August. Because of frequent and heavy rainfall there, the stability of the landslide deposits slope was easily affected by the bad conditions.

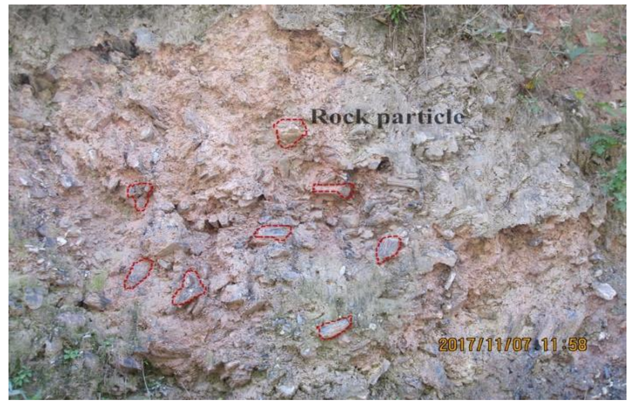


Figure 1. Soil and rock particles mixture of the sampling spot

2.2 Selection of Specimen

Due to the large size of rock particles, it's difficult to test its density by a general method, so the natural density was measured by the cutting ring method (a special large ring knife) and water pressure method. The natural density ranges between 1.92 and 2.37 g/cm3 and the natural water content range between 1.6% and 2.6%. According to the Test Methods of Soils for Highway Engineering/ JTG E40-2007 of China, two groups of deposits specimens were taken from the site and sieve tests were carried out, as shown in Figure 2. Even though by the uniformity coefficient criterion this sample is well graded, it fails the coefficient of curvature criterion. (Cu=133.11, Cc=11.14) indicating it is poorly graded.

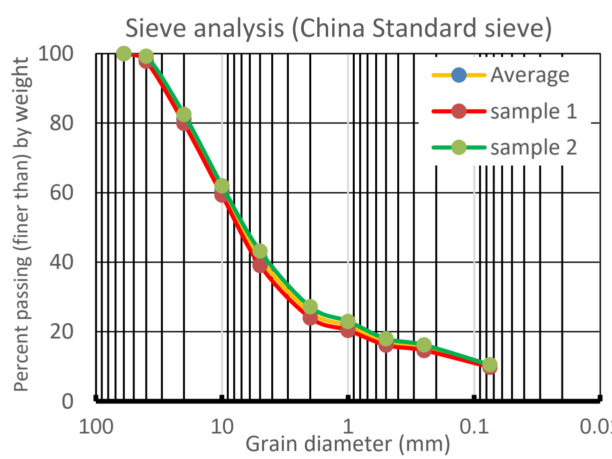


Figure 2. Grain size distributions of the natural samples

In the process of direct shear test, two important factors need to be considered. One is how to determine the threshold value of soil and rock, namely how to divide the "soil" and "rock", which has a great effect on the physical and mechanical properties of the SRM. The other is how to deal with over-size rock particles. For the first problem, according to the previous research of Lindquist et al. (1994,1995) and WJ Xu (2011) and combined with the height of a single shear box and the limitations of test equipment and refer to other researchers, we finally took 5 mm as the threshold value of S-RM (landslide deposits). The rock particle content of the natural landslide deposits ranges between 56% to 79% based on the results of sieve analysis. For those over-size rock particles, there are three commonly used methods at present: the ''scalping method'', the ''replace method'' and the ''parallel gradation'' (JTG E40-2007). Due to the ''large'' rock particles play a very important role in the mechanical behavior of landslide deposits, we chose the ''replace method'' finally considering more about the effect of rock particles. According to the ASTM standards and the limitations of the equipment used in this paper, we determine the maximum size of rock particle is 60 mm.

To investigate the influence of water and rock particle content on the mechanical behavior of SRM, we designed shear tests with 3 different rock particle proportion (35%,55%,75%) reconstructed samples with water content of 5%,8% and 12% under different normal stresses (141.5kPa,283.1 kPa,424.6 kPa,566.2kPa). Specimens shall be prepared using the compaction method, water content, and mass density prescribed by the individual assigning the test. Table 1 shows the basic parameters of group samples.

Table 1. Basic parameters of group samples

Sample	Water content(%)	Rock particle content (RPC) (%)	Void ratio e	Dry density ρ_d(g/cm^3)
1-1	5	35	0.273	2.081
1-2		55	0.256	2.109
1-3		75	0.261	2.101
2-1	8	35	0.309	2.024
2-2		55	0.292	2.051
2-3		75	0.298	2.042
3-1	12	35	0.358	1.951
3-2		55	0.340	1.978
3-3		75	0.346	1.969

3 EXPERIMENTAL APPARATUS

The equipment performed in this test is ZJ30-2G large shear test machine, which was developed by the Huaxi Institute of geotechnical instruments. The equipment is a special device for stress loading and is used for measuring the shear strength and deformation of coarse soil with a maximum particle size of 60 mm. The apparatus includes the main body, the measurement operation control system and the data acquisition system, as shown in Figure 3. All test parameters are automatically collected and stored by a special software, which also can display timely graphics. After tests completed, the data collected by the computer are processed accordingly.

The main technical parameters are as follows: Loading frame: "口" shape frame; Sample size: 300 x 300mm; The maximum horizontal and vertical loads: 250KN; Resolution: 0.1KN; The maximum horizontal and vertical displacement: 80mm; Stress loading speed: 0.02-1MPa/min; The vertical and horizontal stabilizing deviation: $\leqslant \pm 0.5\%$ F.S; Displacement sensor range: 0-50mm, indexing value 0.01mm; Displacement precision: 0.3% F.S.

Compared with the traditional direct shear apparatus, the direct shear apparatus used in this paper has remarkable advantages. It belongs to the closed frame structure, which is more stable and safer than the traditional large direct shear apparatus. Because of the integrity of the enclosed frame structure, it is not necessary to install the counterforce device alone. The internal force of the frame will counteract the vertical pressure and the horizontal force. Another advantage is the shape of the shear box. A circular shear box is used here because the stress condition and distribution of the circular shear box are better than the square or the rectangular one. The slotting ring designed in the position of upper and lower shear boxes can be used to control the needs of different tests on the size of soil. The load sensor and the high precision displacement measuring system can automatically collect the test results and effectively improve the efficiency and accuracy. Some items should be paid attention to in the operation of the test.

a. The type of slotting ring and roller balls should be well matched.

b. When fixing the shear box, the screw should be twisted diagonally to prevent the unevenness and the eccentricity of the shear box during loading.

c. The sample should be layered, compacted, and shaved to prevent stratification.

d. Check whether lines fall into the rolling groove before the soil sample in place, especially the horizontal displacement gauge line.

e. Strictly abide by the specifications and procedures.

Before the start of the test, all the samples should be ready. The procedure of the test is similar to the ASTMD3080M, so the specific steps are not detailed again.


Figure 3. Photo of the large-scale direct shear test apparatus

4 ANALYSIS OF TEST RESULTS

4.1 Characteristics of shear strength

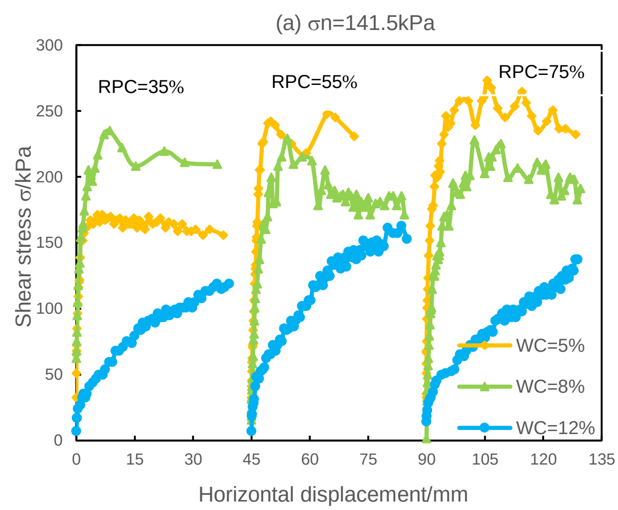
(1) Stress-strain characteristics

Based on the direct shear tests, the stress-strain behaviors of reconstituted landslide deposits sample were analyzed. Figure 4 shows the shear stress and horizontal displacement curves of the direct shear tests of the SRM mixing with different rock particle content (35%,55%,75%) and water content (5%,8%,12%) under same normal stress. RPC represents rock particle content and WC represents water content. Because of the large number of data, and for the convenience of comparison, the horizontal displacement of 55% and 75% rock particle content specimens increased by 45mm and 90mm respectively.

It can be seen from Figure 4 that most curves present 3 different stages. The first stage is liner elastic stage (WJ Xu 2011), in which the stress-strain curve is approximate to a near vertical straight line. At this stage, the stress at any point of the sample is less than the shear strength of the landslide deposits (SRM) and the shear deformation is mainly caused by the decrease of the void of the specimen. The second stage is the yielding stage, in which the slope of the curves shallows abruptly. The stress of some part of the specimen has reached the shear strength of the landslide deposits. The shear deformation is mainly caused by the compression of the void of the mixture and rotate, move, break of the "soil" particles (Vallejo L E,2000). The last stage is the strain-hardening stage, in which the stress value changes very little, but the strain increases a lot.

Figure 4 (a) indicates that the shear strength of the sample mixing with same rock particle content decreases with the increase of water content under a lower normal stress (141.5kPa) in addition to the sample with rock particle content of 35%. While the shear strength of the sample with rock particle content of 35% increases first and then decreases with the increase of water content. The reason may be at the lower rock particle content conditions, it is difficult to contact between the rock particles and the strength of “soil” plays a leading role in the SRM, so the strength of the SRM behaves “soil”. Vallejo et al. (2000) also thought when rock particles by weight in the mixtures were lower, the shear strength of the mixtures was basically controlled by the fine particles that surrounded the rock particles. The more the fine particles are, the greater the optimum water content will be for the SRM. So the closer of the water content of 8% to its optimum water content and the bigger of its density leads to a higher shear strength. It also can be seen the shear strength of the sample with the water content of 5% rises a little with the increase of the rock particle content. However, the shear strength does not increase significantly with the increase of the amount of rock particles when the water content increased to 8% and 12%, which illustrates that the shear strength of the SRM sample with the same moisture content will not increase obviously with the increase of the rock particle content under lower normal stress, while the shear strength of the sample with the same rock particle content drops significantly with the increase of water content. It is further indicated that the effect of water content on the shear strength of SRM is greater than that of rock particle content under low normal stress conditions.

With the increase of normal stress, the shear strength of the sample with the same moisture content appears to increase slightly with the increase of the rock particle content, but the increment is smaller, as shown in Figure 4(b). The shear strength of the specimen with the same rock particle content still decreases with the increase of water content, but it can be seen from the diagram that the difference between the shear strength of the sample with the same rock particle content is getting smaller and smaller except the sample of rock particle content of 55% under the condition of 5% and 8% water content, which indicates that the effect of water content on the shear strength of SRM is decreasing, while the effect of rock particle content is increasing.



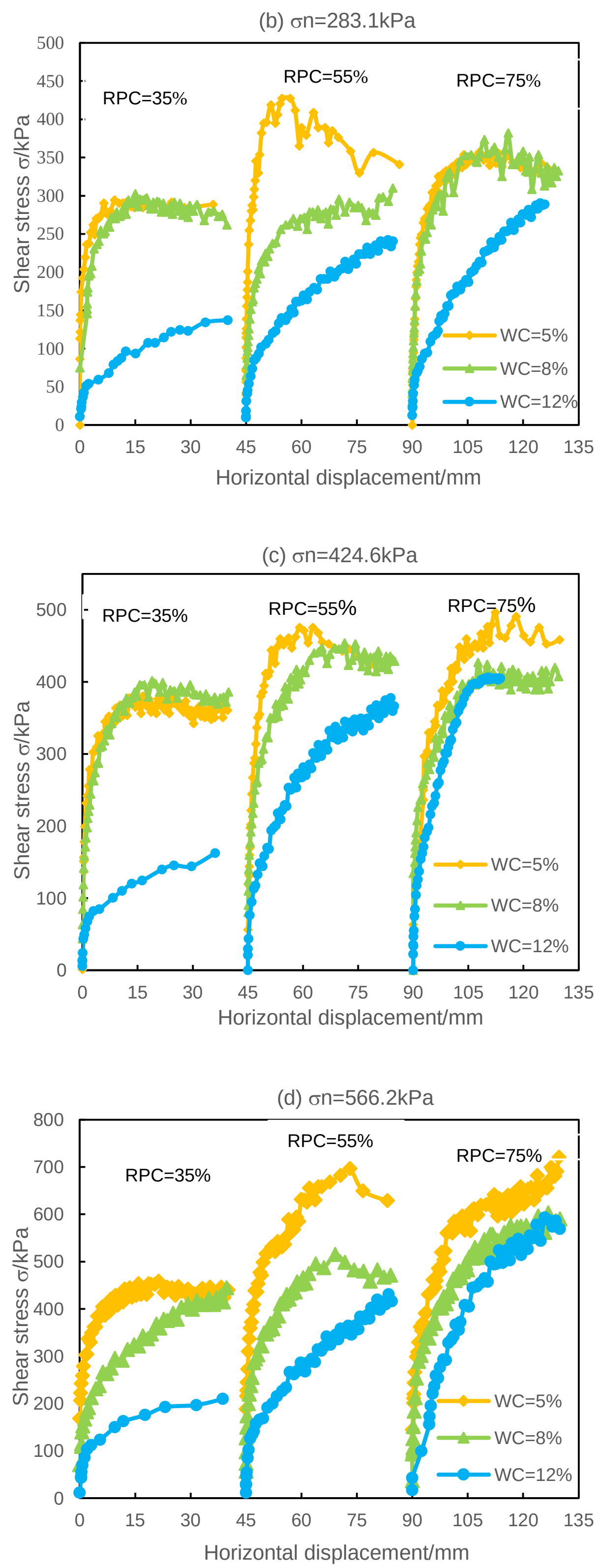


Figure 4. Shear stress and horizontal displacement curves of samples with different water and rock particle contents under the different normal stresses

With the further increase of normal stress, the shear strength of specimens with the same moisture content increases dramatically with the increase of rock particle content, especially for the specimens with the moisture content of 12%, as shown in Figure 4 (c) and (d). The shear strength of specimens with the same rock particle content goes down with the increase of moisture content like before in addition to the specimen with rock particle content of 35%, whose shear strength at its 8% water content has already exceeded the sample under the condition of 5% water content. With the increase of normal stress and water content, the increment of shear strength of the specimen with the same rock particle content decreases, especially obvious when the rock particle content is 75%, which shows the effect of water content on the shear strength decreases with increasing rock particles. It is further explained that the effect of the rock particle content to the shear strength of SRM is more significant than the water content with the increase of the normal stress.

It also can be seen from Figure 4 that the shear stress of the sample with the same water and rock particle content increases with the increasing normal stress. In fact, the shear strength of the loose deposits (or soil-rock mixture SRM) consists of cohesion of cohesive soils and the force of interlocking and rubbing (or "the bitten force", like chewing force of the upper and lower teeth contact) between the rock particles. Both of them worked together in the whole shear process, it was just who played the leading role and up to the balance between them. It is difficult for rock particles contacting at a lower rock particle content and the strength of SRM sample is mainly controlled by the "soil" surrounded the rock particles. With the increase of rock particle content, the improving force of interlocking and rubbing between rock particles leads to a higher shear strength. On the other hand, the higher the normal stress, the more limited the "rollover" phenomenon of the rock particles in the shear zone will be. Therefore, rock particles breakage and rearrangement mainly occur during the shearing process, the results of which improve the shear strength of the mixture to a certain extent.

(2) Shear strength parameters

Table 2 shows the equivalent-cohesion and the friction angle of the specimens.. As we all know, cohesion is the component of shear strength of a rock or soil that is independent of interparticle friction. It may be suitable for the general cohesive soil, but it is not accurate for the SRM, because SRM is a mixture of cohesive soil and cohesionless rock-like. Research ideas used by F. D. PATTO (1966) in the mechanics of rock mass can be borrowed here. It can be called pseudo-cohesion or equivalent-cohesion based on the bilinear strength criterion of PATTO (Figure 5).

As shown in Figure 5, it can be summed up as two kinds of shear processes when there are large rock particles on the shear surface. When normal stress $\sigma \le \sigma_\tau$, the specimen at the shear surface will be dilated to cross over the block of the rock particles, which is similar to the phenomenon of "climbing a slope". The strength of the SRM shows the friction strength as follows:

$\tau = \sigma \cdot \tan\varphi 1$,

where φ1 = φ +i, is related to the fluctuation of the shear plane, φ means the internal friction angle of the soil, i represents the sliding angle of the structural plane.

However, when normal stress $\sigma > \sigma_\tau$, it is difficult for the specimen to "climb" over the rock particles, the most likely way destroying the specimen is to cut off the rock particles (breakages) directly along the shear movement. At this time, it will be shown some "cohesion", as follows:

$\tau = c + \sigma \cdot \tan\varphi_2$,

where c means the equivalent-cohesion as a result of the cutting(breakage) of the rock particles, φ2 represents the internal friction angle.

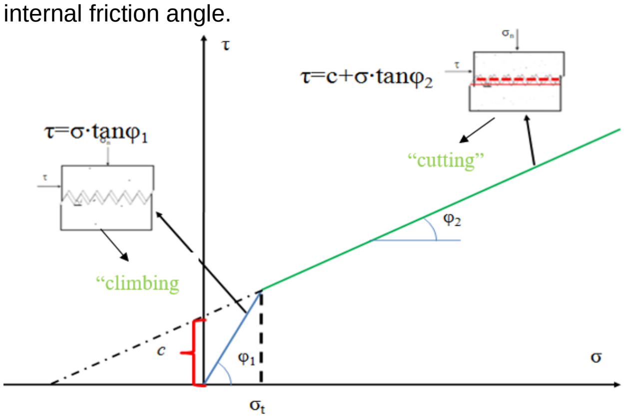


Figure 5. The bilinear strength criterion of PATTO

Table 2. Matrix of the equivalent-cohesion and the internal friction angle

Sample	Rock particle content (RPC)(%)	Water content(%)	Equivalent-cohesion (kPa)	Friction angle (◦)
1-1		5	89.172	33.82
2-1	35	8	164.19	27.20
3-1		12	91.295	11.86
1-2		5	113.23	44.57
2-2	55	8	126.68	35.30
3-2		12	68.648	33.54
1-3		5	82.803	46.21
2-3	75	8	117.28	39.59
3-3		12	26.893	43.86

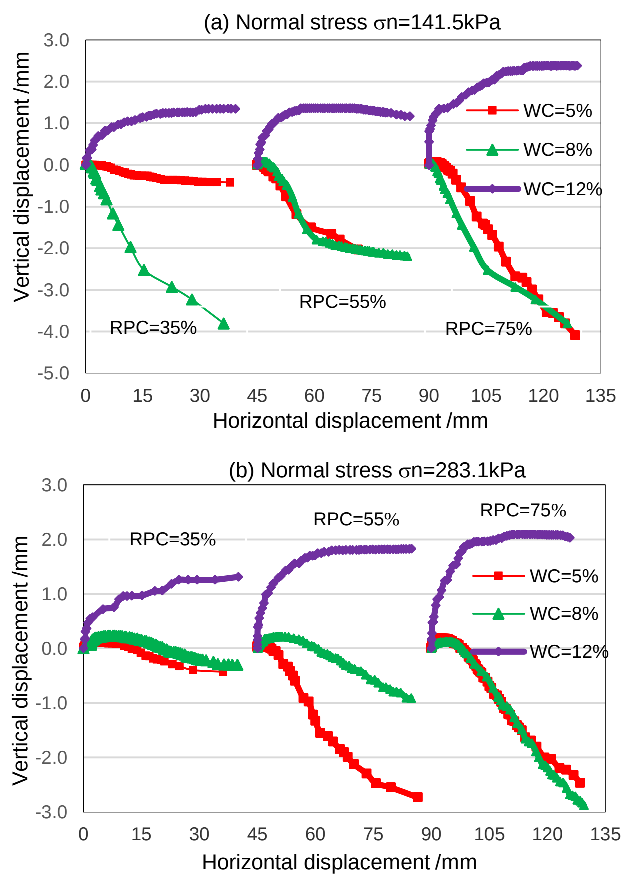
It can be seen from the Table 2 that the equivalent-cohesion increases first and then decrease with the increase of the water content. Mainly because the moisture content of 8% is closer to its optimum moisture content, leading to a larger density. At the water content of 5%, the equivalent cohesion of the sample with 55% rock particle content is the largest, which is because, on the one hand, there are more fine particles with a rock particle content of 35%, but the water content is much lower at 5%; on the other hand, the joint action of cohesion of soils and the force of interlocking and rubbing between the rock particles is larger because of more rock particles of 55%. According to the way of thinking, the joint action of rock particle content of 75% should be the largest, but it is actually not. This can be explained by two reasons. One is the increasing void ratio of the higher rock particle content sample will weaken the effect of soil and the gaps between rock particles cannot be filled with enough soil, leading to the reduction of the sample density. It may also cause the decrease of the equivalent cohesion and strength of the sample if the normal stress is not large enough to cut off lots of rock particles. The equivalent cohesion of the 8% and 12% water content samples reduces with the increase of the rock particle content. For one thing, the decreasing fine particles will cause the reduction of the equivalent cohesion. For another, the water in the soil with a lower water content is mainly in the form of combined water, which has the characteristics of viscosity, elasticity and shear resistance. It is also due to the presence of the matric suction of the capillary water. While with the increase of the water content, the increasing thickness of the combined water film will weaken the water viscosity and the matric suction in the soil decreases gradually until it disappears, leading to a decline of the cohesive force. It is shown from the table that the equivalent-cohesion of the specimen with 75% rock particle content is the smallest when the moisture content is 12%. The bigger decrease value explains the effect of moisture content on the equivalent-cohesion is bigger, especially for the high rock particle content sample.

Table 2 also shows the change law of the friction angle with the water content and rock particle content. The internal friction angle of the SRM reflects its friction characteristics, including overcoming the sliding friction caused by the roughness of the surface of the fine and rock particles, the occlusion friction of embedded, interlocking, rubbing and the force of "cutting" (breakage) between rock particles. Table 2 shows that the internal friction angle of the specimen with same moisture content increases with increasing rock particle content. As described in previous part, the higher the normal stress and the rock particle content, the more limited the "rollover" and "rotate" of the rock particles and the larger the force of "contacting" "interlocking" and "rubbing" of rock particles, which leads to a higher internal friction angle of the SRM sample. The increment of internal friction angle is larger when the rock particle content increased from 35% to 55%, while the increment is little when increased from 55% to 75%, which indicates that when the amount of rock particles is increased to a certain extent, it has little effect on the friction angle. However, the internal friction angle of the specimen with the same rock particle content decreases with increasing moisture content. The lubrication effect of water can reduce the sliding and occlusion friction force between particles. The higher the water content is, the lower the force is and the smaller the internal friction angle is. It was found that the friction angle increased a little from the sample 2-3 to 3-3. It is because the test performed under consolidated-drained conditions, the sample reforms the sliding and occlusion friction quickly through the drainage, so the internal friction angle might be slightly increased. Therefore, the most direct and effective way to improve the friction angle of SRM is to increase the rock particle content and reduce the moisture content.

4.2 Characteristics of Volumetric Strain

The behavior of volumetric strain of the SRM sample was analyzed through the curves of vertical vs horizontal displacement. Figure 6 shows the curves of vertical vs horizontal displacement of the sample with different water (3%,8%,12%)and rock particle contents (35%,55%,75%) under the same normal stresses. When the vertical displacement is negative, dilation takes place, and when it is positive, compression happens. It is assumed that the vertical and horizontal displacement is zero at the beginning of the shear.

It can be seen from the diagram that the specimens with 35% rock particle content exhibit obvious volumetric strain under the low normal stress (141.5kPa), while those under high normal stress are not obvious. However, the volumetric strain of samples with higher rock particle contents are all obvious whatever the normal stress is, which indicates that rock particle content in soil-rock mixture plays an important role in its volumetric strain characteristics, especially for the samples under high normal stress and high normal stress has little effect on the volumetric strain of specimens with low rock particle content.



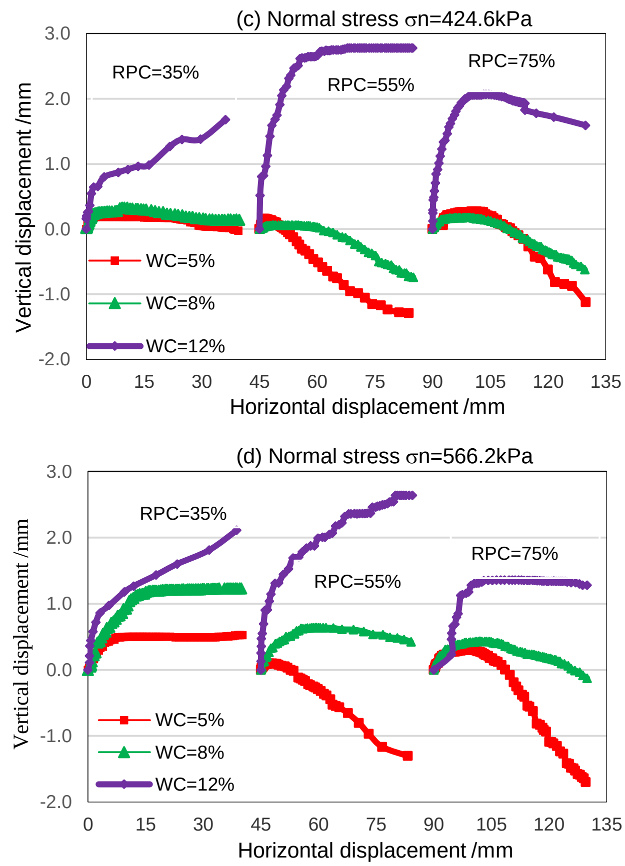


Figure 6. Vertical and horizontal displacement curves of the samples with different water and rock particle contents under the same normal stress.

Figure 6 also shows that specimens with same rock particle content change from dilation to compression with the increase of the water content. Here we assume the change process from dilation to compression is a complete process, if the specimen initially shows compression, the value of compression will increase with increasing normal stress and water content, such as samples with 35% rock particle content under a higher normal stress of 566.2kPa shown in Figure 6 (d). First, the increasing normal stress and water content lead to the enhancement of the consolidation and drainage, which can cause the transformation of dilation to compression. Second, due to the limitation of the compaction conditions, the particles are moved, filled and rearranged with the increase of the normal stress, leading to the particles inter-embedded with each other to fill the pores. Then the specimen is gradually compacted and the compression takes place. Third, the "rotate" or "roll-over" and "climbing" or "crossover" of the rock particles will inevitably lead to the dilation deformation of the sample. But the dilatancy value becomes smaller with the increase of the normal stress, which may be caused by the increase of the fine particles due to the "cutting" or breakage of some rock particles. So the fine particles fill some pores of the specimen, resulting in an increase of the density and a reduction of the dilation value. From the diagram, it also can be seen that the change law with the increase of the rock particle content of the SRM sample under the same water content is based on its optimum moisture content. When the moisture content is less than its optimum moisture content, the SRM sample changes from compression to dilation with the increase of the rock particle content. It is emphasized that we consider compression to dilation as a complete process here, if the specimen initially shows dilation, the dilatancy value will increase with increasing normal stress and rock particle content, such as samples with 5% and 8% water content under a higher normal stress of 566.2kPa shown in Figure 6 (d). When the water content is greater than its optimum water content, the sample generally shows compression (for example, samples of 12% water content are all shown compression), but the value of compression increases first and then decreases with the increase of the rock particle content. Because the increasing normal stress and water content lead to the enhancement of the consolidation and drainage, when the water is fully discharged, the specimen will show dilation due to the increase of the rock particles, which will lead to some reduction of the value of compression.

5 CONCLUSIONS

By analyzing the characteristics of the shear strength and volumetric strain of the reconstituted landslide deposits sample in China via large-scale direct shear tests, the following conclusions could be achieved:

1)Through the analysis of the SRM shear strength, the stress-strain curves can be divided into 3 different stages. The results show that the normal stress, moisture content and rock particle content have a significant influence on the whole shear test process of the soil and rock mixture (SRM) sample. The shear strength of the SRM specimens with same rock particle content drops significantly with the increase of water content in general whatever the normal stress is, while the shear strength of the SRM sample with the same moisture content will not increase obviously with the increase of the rock particle content under lower normal stress. The influence of water content on shear strength is greater than that of rock particle content under a lower normal stress, and the results are opposite in the case of a higher normal stress. While the influence of moisture content weakens and the influence of rock particle content enhances in between.

2) SRM behaves both Mohr-columb relationship and bilinear strength criterion of PATTO. Actually, SRM behaves more like “soil” at a lower rock particle content and more like “rock” at a higher rock particle content. In fact, the cohesion of SRM is made up of cohesion of cohesive soils and the force of “interlocking” “rubbing” and “cutting” (or “the bitten force”) between the rock particles, both of them worked together in the whole shear process, it was just who played the leading role and the balance between them. So the intercept of the Mohr failure envelope of the landslide deposits can’t be simply called the “cohesion”. It can be called pseudo-cohesion or equivalent-cohesion. The equivalent-cohesion increases first and then decreases with the increase of the water content, while the equivalent cohesion of the samples with 8% and12% water content reduces with the increase of the rock particle content. And the effect of moisture content on the equivalent-cohesion is much bigger, especially for the high rock particle content sample. The results also indicate the internal friction angle of the specimen with same moisture content increases with increasing rock particle content, but when the number of rock particles increases to a certain extent, it has little effect on the friction angle. However, the internal friction angle of the specimen with the same rock particle content decreases with increasing moisture content.

3) Through the analysis of the soil-rock mixture volumetric strain, it can be concluded that rock particle content plays an important role in the volumetric strain of the SRM sample under high normal stress and high normal stress has little effect on the volumetric strain of specimens with low rock particle content. Specimens with same rock particle content change from dilation to compression with the increase of the water content. However, the change law with the increase of the rock particle content of the SRM sample under the same water content is based on its optimum moisture content. If the moisture content is less than it, the SRM sample changes from compression to dilation with the increase of the rock particle content. When the water content is greater than it, the sample shows compression (for example, samples of 12% water content are all shown compression) in general, but the value of compression increases first and then decreases with the increase of the rock particle content.

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