CYCLIC WETTING AND DRYING INDUCED CREEP DEFORMATION OF CRUSHED MUDSTONE IN DIRECT SHEAR TEST

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1 INTRODUCTION

A soft rock such as mudstones is likely to be subjected to the slaking, which defined as the breakup of the rocks due to swelling and contraction caused by repeating wetting and drying (denoted as W/D). When high embankment made of these materials is considered, long term stability and settlement problems may possibly arise from the occurrence of slaking of geo-materials due to repeated W/D cycles (Cetin et al., 2000; Tovar et al., 2011). Several methods have been developed to assess the influence of cyclic W/D of geo-material under unconfined conditions. However, cyclic W/D in the field typically occurs in the presents of normal and shear stresses. In this study, three cycles of W/D were carried out, under three different anisotropic consolidation conditions to analysis the deformation and strength characteristics as well as slaking characteristics by using a modified direct shear apparatus.

2 TESTING APPARATUS AND MATERIALS

A modified direct shear apparatus having inside dimensions of 20 cm* 20 cm* 9.14 cm with 10 mm initial opening was used. A moisture sensor was inserted into shear box to measure the water content (w) of the specimen instantaneously. Crushed mudstone from the earthquake-induced landslide dam, Hattian Bala, Pakistan (Kiyota et al., 2011) was used for specimens. The specimens of oven dried crushed mudstone were prepared by removing particles finer than 2 mm and larger than 4.75 mm as a necessary adjustment to the apparatus dimension. The specimens were not thoroughly compacted to prevent from particle-breakage. The average initial void ratio of samples was about 0.68. The slaking index (JGS 2132) of the mudstone was evaluated as level 1, while the slaking ratio (NEXCO-110, 2006) was 96.86 %.

In this study, loading process during the test consisted of three stages. 1) Initially both shear and normal stress were applied gradually maintaining prescribed stress ratio, R (= τ/σ_v). 2) Three cycles of W/D were carried under three different anisotropic consolidation conditions (i.e. R = 0.3, 0.5 and 0.7, σ_v = 50 kPa) to analysis the deformation and strength characteristics as well as Slaking characteristics. a) Water was supplied from the bottom of the shear box until the specimen was fully immersed. b) Water was drained out. Dry air was pumped from the bottom of the shear box and the shear box was covered by silica gel to absorb moisture from the specimen. During W/D process, when *w*, shear deformation (*s*) and vertical deformation (*v*) were reached to almost constant then, next stage was started. 3) Finally, after the third wetting and deformations stabilization, a monotonic shear loading (denoted as ML) was applied at a constant rate of *s* (0.2 mm/min) under constant σ_v until the specimen's residual state was reached.
A series of the ML tests on dry and saturated specimens were also performed to compare strength and deformation characteristics with those of the cyclic W/D creep test. After completing direct shear test, the tested sample was dried in oven and sieve analysis was performed.

3 TEST RESULTS AND DISCUSSION

Figure 1 shows the typical instantaneous response of *s*, *v* and *w* of the specimen during the W/D cycles. The influence of wetting in the first cycle upon *s* appears to be significant for all specimens. Similarly, negative *v* occurs due to wetting. This expansive behavior of crushed mudstone would consist of two phases; swelling caused by water absorption of clay mineral and dilatancy due to shearing. For the second and third wetting processes, the increment of *s* is relatively very small, almost 1/8 times the increment of *s* in the first wetting. This may be attributed to the specimen densification due to previous W/D processes. However, substantial negative *v* occurs during the second and third wetting processes. Figure 1 also shows that *w* decreases gradually during the first and second drying processes. Initially, no appreciable creep deformation is found to occur at higher *w*.

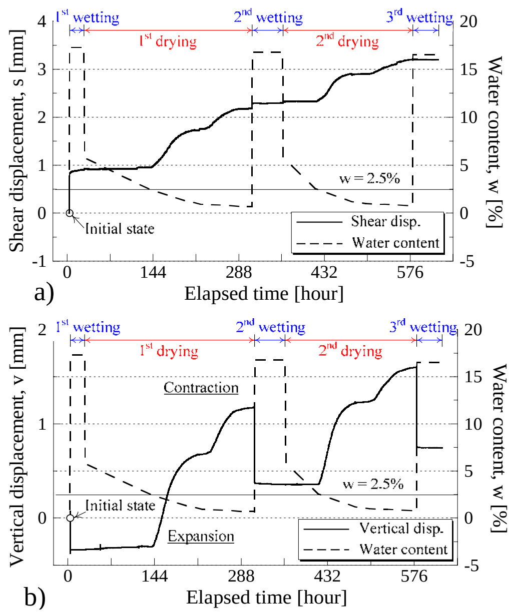

Fig. 1 Time histories of *w*, *s* and *v* (a) *s* b) *v*) under cyclic W/D for 3 times for R= 0.5

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When the *w* becomes about 2.5 %, both *s* and *v* occur progressively with water loss and finally tend towards an asymptotic value at *w* of about 0.7 %.

The above test results are summarized in Fig. 2, showing increment values of *s* and *v* at each *R*. The wetting-induced maximum creep *s* of 3.4 mm was observed at *R*= 0.7 during the first wetting (see Fig. 2a)). Similarly, wetting-induced creep failure was observed at *R*= 0.8 on the same material as the one in this study. Therefore, it seems that the *s* during wetting is proportional to the value of *R*, which would indicate high risk of slaking-induced instability at steep slopes. It can be understood that the maximum *s* was observed during the first wetting because the specimen in this study was prepared by oven-dried crushed mudstone (Panabokke and Quirk et. al., 1956). Figure 2 b) shows considerable *v* that occurred in each wetting step. The *v*, however, in case of *R*= 0.3, is almost negligible except in the first wetting because of having higher *w* (more than 3 %) of specimen before the second and third wettings. The *v* in the wetting is affected by both *R* values during creep shear loading and the progress of W/D cycles. One of the noticeable behaviors observed in these experiments is a quite large creep deformation during the drying processes. As shown in Fig. 2, the creep *s* during drying increases with the increase in the value of *R*. However, in the case of *R*= 0.3, the lowest *w* during the drying step is quite larger (about 3 %). This may be reason for relatively small *s* and *v* during the drying process at R= 0.3.

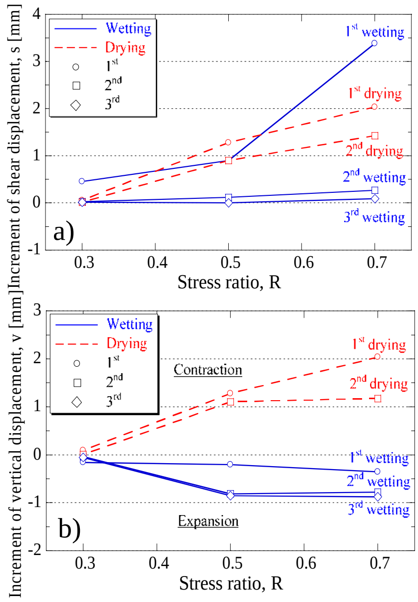

Fig. 2 Increment value of creep a) *s* b) *v* at each *R*

Figure 3 shows the *s*-*v* relationship for the three testing conditions under same *R*. All specimens under the three different testing condition exhibited dilative behavior during monotonic shear loading. However, it is seen that the residual state is no longer unique. Generally, the position of residual state is unique under constant stress. The position of residual state also varies with the degree of saturation. So, this result indicates that particles crushing due to cyclic W/D cause the difference in position of residual state.

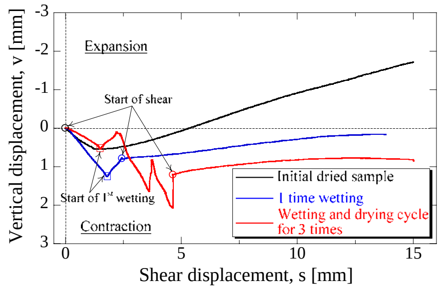

Fig. 3 Relationship between *s* and *v* for *R* = 0.5

Figure 4 shows the relationship between the *R* and *s*. The saturated specimen and the one with cyclic W/D history exhibited largely different stress-displacement features from that of dry specimen. The peak shear strength of the saturated and cycle test samples are reduced by about 20 % as compared to the dry test.

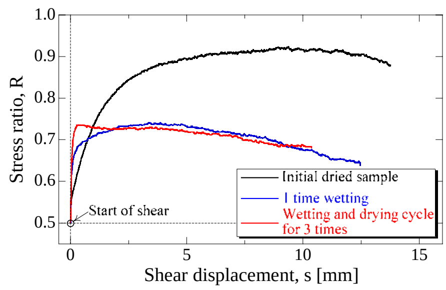

Fig. 4 *R*-*s* relationship under different test condition for R = 0.5

Particles are crushed due to immersion and cyclic W/D. It is found that about 1.5 %, 6.0 % and 9.0 % particles by mass became finer than 2.0 mm after the dry, saturated and cyclic test respectively. Similarly, the Degradation indexes were 0.067, 0.11 and 0.16 for dry, saturated and cyclic test. This results show higher value for the cyclic test due to repeated W/D (see Fig. 5).

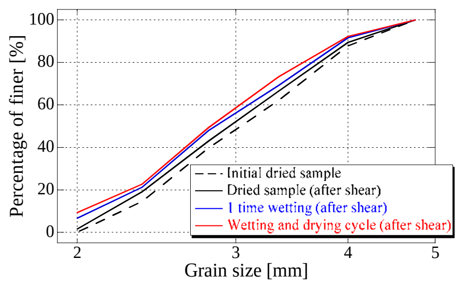

Fig. 5 Particle size distribution before and after experiment

4 CONCLUSIONS

A significant *s* could be found in the first wetting process. However, the amount of *s* during wetting is decreased with progress of the drying and wetting cycles. Almost equal *v* occurs in each wetting step if the *w* of the specimen before wetting becomes quite smaller. During the drying process, a significant *s* & *v* is found to occur when *w* becomes less than 2.5 %. Both s & v during drying is increased with the increase in *R*. A reduction in the peak shear strength by 20 % and about 3 % more particles crushing of the mudstones samples after cyclic W/D were found.

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