INTERPRETATION OF SLAKING BEHAVIOUR OF CRUSHED MUDSTONE IN DIRECT SHEAR

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1 INTRODUCTION

The slaking process involves the rupture of bonds of aggregates or particles and thus the material degradation, due to swelling and shrinking associated with repeated wetting and drying cycles (hereafter denoted as W/D). The occurrence of extreme weather events such as heavy rainfalls and severe droughts will undeniably result in a higher incidence of natural disasters such as landslides. Assessing the effects of wetting and drying cycles is of prime importance in the failure of slopes or embankments composed of slakable geomaterials. In this regard, in order to analyze the effects of slaking on the strength and deformation characteristics of the mudstones, a series of direct shear tests including three cycles of W/D were carried out on the mudstones from the Hattian Bala landslide dam, under different anisotropic consolidation conditions (i.e. R = 0.3, 0.5 and 0.7, σ_v = 50 kPa), followed by monotonic shear loading at a constant rate of 0.2 mm/min under constant σ_v until the specimen's residual state was reached. The test procedures and results are presented in detail in another paper by Sharma et al. (2012). In the present paper, attempt was made to interpret the slaking behavior of the crushed mudstones which was observed in these tests.

2 INTERPRETATION OF MAIN TEST RESULTS OF CYCLIC W/D DIRECT SHEAR TESTS ON CRUSHED MUDSTONE

Previous studies such as Okamoto, R. et al. (1981) and Botts, M. E. (1998) have shown that the sample's pre-emersion drying temperature, length of drying and initial water content had a strong, if not more important influence on the slaking and swelling properties of mudstones and clay shales respectively. Figure 1 shows a typical instantaneous response of deformations and water content of the specimen during wetting and drying cycles. The influence of the first wetting upon shear deformation appears quite significant for all specimens, compared to the second and third wetting. This is consistent with previous findings as it could be explained by the fact that the pre-emersion drying condition was more severe for the 1st wetting than the following ones. As a matter of fact, the crushed mudstones prior to test were oven-dried for about 6 hours at a temperature of 105C which corresponds to a much higher drying rate than the following drying rates.

The most notable results of the direct shear tests performed by Sharma et al. (2012) are as follow:

1. Creep behavior during the drying steps

In addition to slaking and swelling behaviors occurring during wetting, relatively large creep deformations during the drying steps were exhibited, they moreover increased with the increase in the value of R, suggesting that drying-induced slaking effects are more important than wetting-induced ones. During the drying process, initially, no appreciable creep deformation was found to occur at higher water content (Figure 1). When about half of their saturated water content has evaporated, both vertical and shear deformation occur progressively with water loss and finally tended towards an asymptotic value at very low water content. It can be seen that both creep curves are composed of two well defined curvilinear parts.

This drying-induced slaking behavior could be explained by the concept of macro and micro pores by Braudeau et al. (2004) who assumed that soil consists of two pore systems, interpedal (macro pores)

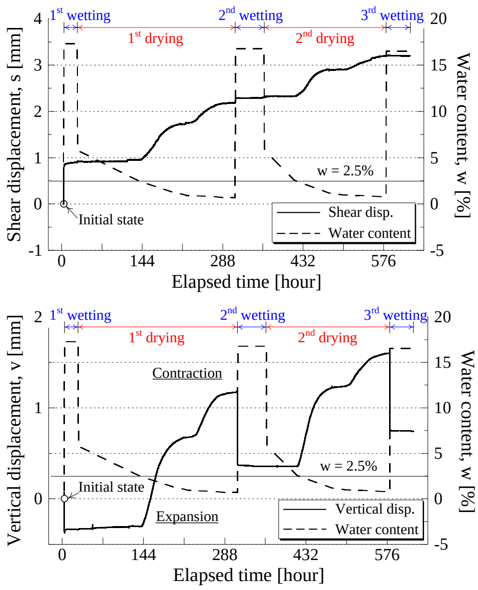

Fig. 1 Time histories of w, s and v (a) s b) v) under cyclic W/D for 3 times for R= 0.5 (after Keshab et al. 2012)

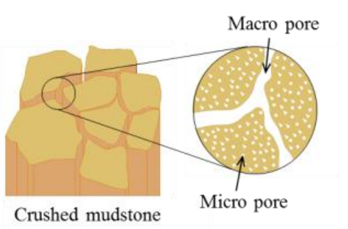

Fig. 2 Macropores and micropores system (after Braudeau et al.)

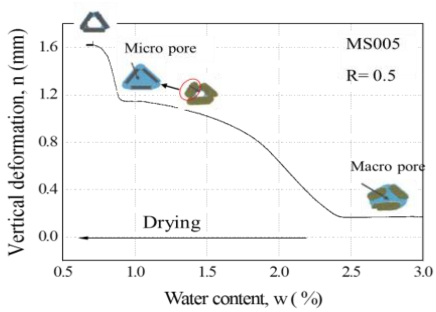

Fig. 3 Relationship between water content and drying induced vertical deformation (after Keshab et al. 2012)

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and intra-primary (micro pores) porosity as seen in Figure 2. It was assumed that water leaves the crushed mudstones from pores of gradually decreasing sizes that is to say: first: water leaves from inter-pedal porosity (macro pore) without air intake causing shrinkage of inter-pedal pore (first part of curvilinear in Figure 3). When inter-pedal pore empties, intra-primary pore begins to shrink, losing its water content (second part of curvilinear) while being replaced by air. Particles slide on each other during shrinkage causing shear deformation simultaneously.

2. Drying-induced shear and vertical displacements occur when the water content is lower than a threshold value of 2.5% as can be seen in Figure 1. It appears that during the drying step, there is a threshold value below which particle crushing occurs

3. A reduction in the peak shear strength by 20% after wetting was found (Figure 4)

4. For a same stress ratio, the residual state is no longer unique as shown in Figure 4. This result shows that this result violates the basic principles of soil mechanics for which the peak and residual strength in our figure should be unique for the three conditions, in drained conditions. The significant difference between residual states of the test in dry condition and that of the test including W/D cycles suggest that particle crushing between particles during the W/D cycles are likely to be the reason of the soil degradation.

5. As a matter of fact, about 3% more particle crushing of the mudstone samples was retrieved for tests with cyclic W/D compared to that of the dry condition test (Figure 5).

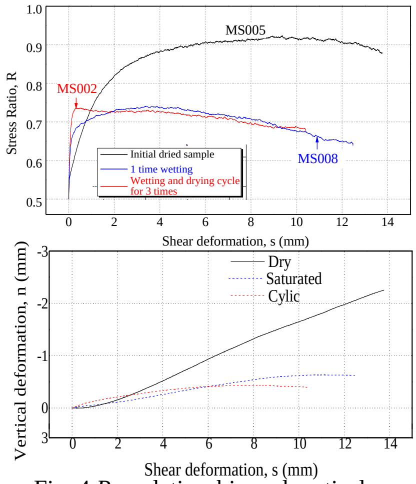

Fig. 4 *R-s* relationship and vertical deformation under different test condition for R = 0.5 (after Keshab et al)

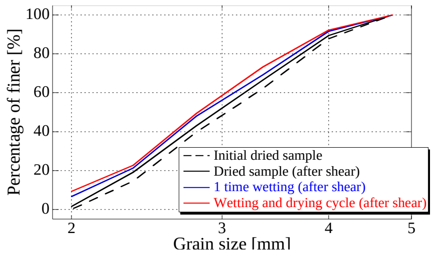

Fig. 5 Particle size distribution before and after experiment (after Keshab et al)

3 DESCRIPTION OF THE SIMPLE AND UNIFIED MODEL BY NAKAI ET AL (2011) AND EFFECT OF Ig GRADING STATE INDEX

A simple and unified constitutive model for soils based on the critical state theory and considering the influence of density, bonding, time-dependent behavior properties was proposed by Nakai et al. (2011) and may be used to incorporate the effects of slaking.

During W/D cycles, the grading of a soil irreversibly changes as particle crushing occurs, as it was shown in the post-test sieving analysis. This leads to the increase of fine materials and to the broadening of the particle size distribution (if no seepage occurs). Muir Wood et al. (2008) defined a simple scalar index denoted as grading state index Ig which represents the current grading behavior. By using this index, effects of particle crushing, thus slaking can be included in the model. In our case, it was observed that deformation during the drying phases occurred when w went below the value of 2.5%. In that case the state parameter relation can be defined and incorporated in the simple model. Considering that the soil contracts due to particle crushing: the NCL may shift downward.

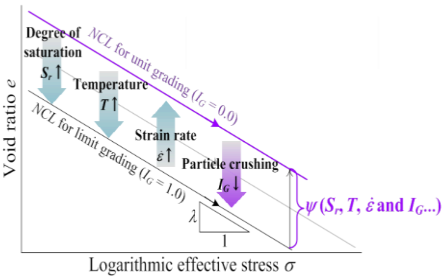

Fig. 6 Change of void ratio for a soil with different parameters Sr, Ig etc.

Finally, we can obtain a e-lnσ''graph such as Figure 6 in which the effect of each important parameter on the soil behavior can be assessed. Additional laboratory tests are needed in order to determine the position of the Critical State lines as well as the evolution laws of each parameter, to attempt a model of slaking behaviour

4 CONCLUSIONS

Experimental results showed that during the drying-induced slaking has very important effects on soil through particle crushing. The incorporation of the seemingly complex slaking phenomenon in the simple and unified constitutive model of soils by Nakai et al. (2011) by the definition of the state variables Ig could greatly simplify the understanding of its effect on soil behavior and thus help future monitoring and prediction of changes in the strength of slaked materials

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