Slaking behavior of Akita mudstone under confining stress and the shear strength evolution during slaking process

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1. Introduction

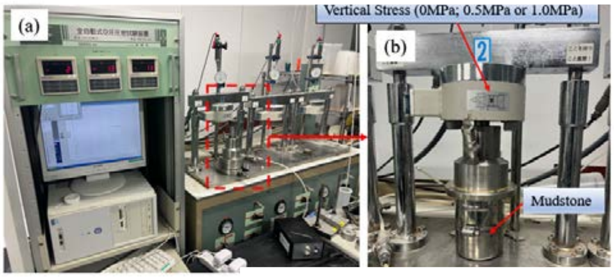
As a common engineering characteristic which is the main weathering mode from mudstones to soils, slaking behavior can severely affect the strength and particle size distribution of mudstone, and further cause engineering disasters (Perras, Wannenmacher and Diederichs, 2015). To study the slaking characteristic of different mudstones, slake durability test (Su *et al.*, 2020) and cyclic drying-wetting test (Sakai and Nakano, 2019) has been done. Besides, it has been proved that the confining stress applied to the mudstone during slaking accelerates slaking process (Zhang *et al.*, 2020). Recent years, Akita mudstone has been used in road embankments of expressways in Japan. In this study, the Akita mudstone was used for slaking tests under different vertical stresses and the material after the slaking test were used for direct shear tests to investigate the evolution of shear strength during slaking process.

Table 1 Fundamental properties of akita mudstone

Soil properties	Values
Soil particle density (Mg/m^3)	2.58
Montmorillonite content (%) (from methylene blue adsorption method)	15.7
Natural dry density (Mg/m^3)	1.18
Consistency limit	
Liquid limit (%)	73.0
Plastic limit (%)	56.1
Plasticity index	16.9

2. Materials, Equipment and Procedures

Table 1 shows some physical and chemical properties of natural Akita mudstone. According to JIS A 1202:2020, the soil particle density of Akita mudstone is 2.58 Mg/m^3, the average natural dry density is 1.18 Mg/m^3 and the value is measured following JGS 0191-2020. The liquid limit, plasticity limit and plasticity index are 73.0%, 56.1% and 16.9, respectively, measured according to JIS A 1205-2020. Assuming that the specific uptake capacity of pure montmorillonite for blue dye is 140 mmol/g. Then, the montmorillonite content measured using the methylene blue adsorption method (JIS Z2451 2019) is 15.7%.



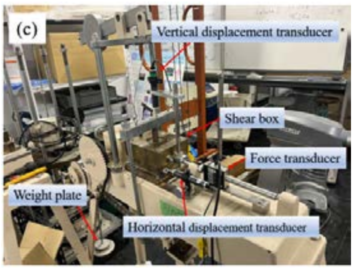


Fig. 1 Equipments used in this study

Equipment used in this study is shown in Fig. 1. For the procedure of the slaking test under vertical stress, a certain vertical stress is applied to the specimen in a steel container by the consolidation apparatus (see Fig. 1a and b), then water was injected for wetting. After 24h of wetting, the specimen was sieved with mesh sizes of 2.00, 0.85, 0.25 and 0.106 mm. After sieving, specimens were oven dried for 24h and weighed thereafter. It is worth noting that the sieve process was performed on saturated specimen because it was difficult to be separated after drying. The above procedure is one cycle and specimens after slaking were gathered and mixed for next cycle. Finally, 6 cycles were performed under different vertical stresses (i.e. 0MPa; 0.5MPa or 1MPa). And after that, the grading Akita mudstone were prepared according to obtained PSD for direct shear tests. Direct shear apparatus is shown in Fig. 1c. There are two displacement transducers to measure the horizontal and vertical displacement and one load cell for measuring the shear strength. The

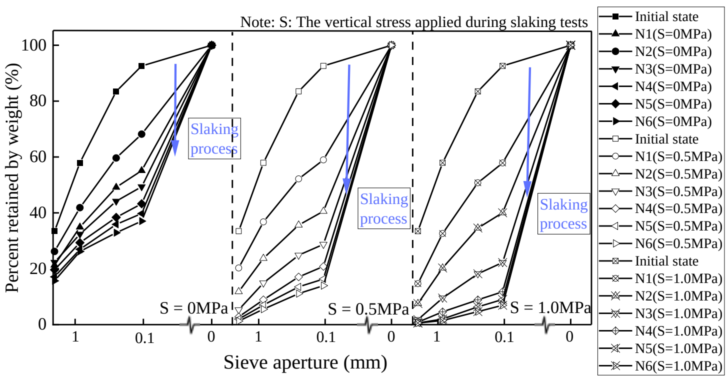


Fig. 2 Particles size distribution curves during slaking test under different stresses

Mudstone Slaking behavior Shear strength

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shear box diameter is 60mm and a shear rate of 1 mm/min was employed during tests. The tests were conducted with low normal stresses of 50, 100, or 150 kPa to avoid the breakage of mudstone caused by the confining stress during shear test. During the tests, the normal stress was first applied to the top of the saturated specimens. After the vertical displacement reached equilibrium, a shear force was applied to the lower box, while the normal stress was maintained at a constant level.

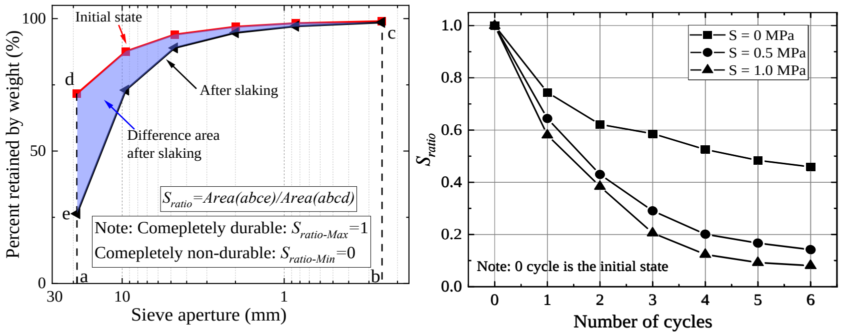

Fig. 3 (a) Mathematical derivation of the slaking ratio and (b) Evolution of S_{ratio}

3. Test results and discussion

The results of particle size distribution (PSD) curves during slaking test under different vertical stresses are shown in Fig. 2. Note that the vertical axis in Fig. 2 is precent remained by weight. As can be seen in Fig. 2, the distribution curves of slaking tests under either confining stress move downward with the increase in cycle numbers. Furthermore, PSD curves of the slaking tests with larger vertical stresses (0.5MPa or 1.0MPa) changes faster than the one without vertical stress (0MPa), which indicated that the slaking phenomenon of specimens slaking under stress is stronger than the one without stress.

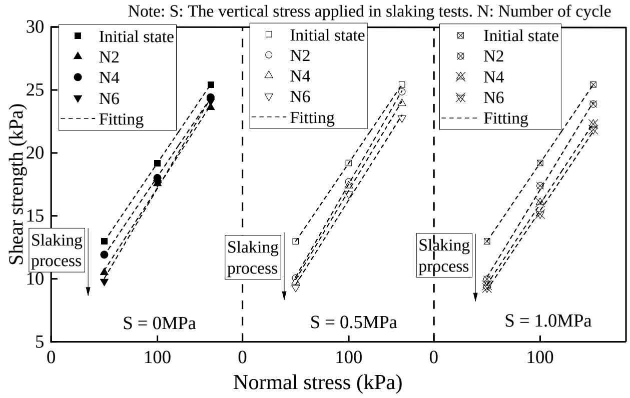

Fig. 4 Shear strength evolution with the slaking process

To characterize slaking state, the slaking ratio (S_{ratio}) proposed by Erguler and Shakoor. (2009) is used herein. It was defined, as shown in Fig. 3, as the ratio of area of a-b-c-e to that of a-b-c-d, where the red line (i.e. c-d line) indicates the original PSD curve and the c-e line denotes the PSD curve after slaking. The values 0 and 1 of S_{ratio} correspond to the completely non-durable (complete slaking) and completely durable condition (no slaking) to slaking, respectively. As can be seen in Fig. 3b, with the increase in cycle number, S_{ratio} with different stresses (0MPa, 0.5MPa and 1.0MPa) decreases from 1 to 0.46, 0.14 and 0.08, respectively. This indicates that the vertical stress can accelerate the slaking development. The shear strength evolution is shown in Fig. 4, with the slaking process under different stresses, the shear strength decreases due to the evolution of PSD. Furthermore, the evolutions of cohesion (c) and angle of internal friction (φ) during slaking process are summarized in Fig. 5. The c decreases from 7 kPa to 3kPa with the decrease of S_{ratio} from 1 to 0.4 and it remains almost constant through subsequent slaking process. On the other hand, the value of φ fluctuated slightly between 7° and 8° throughout the slaking, with no significant change.

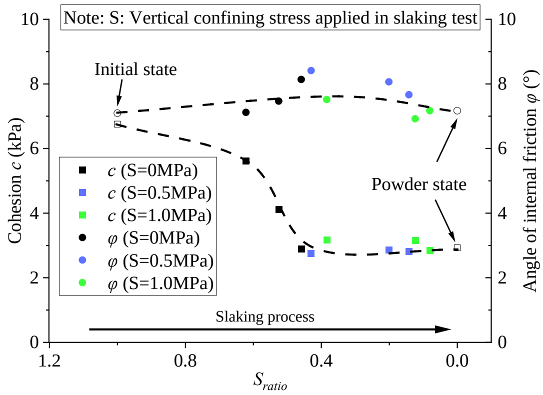

Fig. 5 Evolution of c and φ during slaking process

4. Conclusions

Stress accelerates the slaking process of Akita mudstone. And with the PSD change of specimens during slaking process, cohesion value decrease significantly until the S_{ratio} reaches 0.4 and then remain constant. Meanwhile, the change angle of internal friction is not visible during slaking process.

Reference: (1) Erguler, Z.A. and Shakoor, A. (2009) 'Relative contribution of various climatic processes in disintegration of clay-bearing rocks', *Engineering Geology*, 108(1–2), pp. 36–42. doi:10.1016/j.enggeo.2009.06.002. (2) Perras, M.A., Wannenmacher, H. and Diederichs, M.S. (2015) 'Underground excavation behaviour of the queenston formation: tunnel back analysis for application to shaft damage dimension prediction', *Rock Mechanics and Rock Engineering*, 48(4), pp. 1647–1671. (3) Sakai, T. and Nakano, M. (2019) 'ScienceDirect Effects of slaking and degree of compaction on the mechanical properties of mudstones with varying slaking properties', *Soils and Foundations*, 59(1), pp. 56–66. doi:10.1016/j.sandf.2018.09.004. (4) Su, X. *et al.* (2020) 'The role of pH in red-stratum mudstone disintegration in the Three Gorges reservoir area , China , and the associated micromechanisms', *Engineering Geology*, 279(October 2019), p. 105873. doi:10.1016/j.enggeo.2020.105873. (5) Zhang, Z. *et al.* (2020) 'Disintegration law of strongly weathered purple mudstone on the surface of the drawdown area under conditions of Three Gorges Reservoir operation', *Engineering Geology*, 270(November 2018), p. 105584. doi:10.1016/j.enggeo.2020.105584.