Graduate School of Creative Science and Engineering
Waseda University

博　士　論　文　概　要
Doctoral Dissertation Synopsis

論　文　題　目
Dissertation Title

Evaluation of slaking and crack evolution using photographic method and the effects on shear strength of mudstones

写真技術を活用した泥岩のスレーキングおよびひび割れ進展状況の評価とせん断強度への影響

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Mudstone, a world widely distributed soft stone, has been extensively used as the embankments filling material for expressways in Japan. The slaking and cracking evolution caused by swelling and shrinkage of mudstone may result in some severe effects on its engineering properties. These effects may cause such as slope failure, uplifts, or settlements of embankments. Therefore, it is necessary to study the mechanism of slaking, volumetric change and cracking evolution of mudstone and evaluate their effects on the properties of mudstone.

This thesis focused on the slaking mechanism of three mudstones by applying drying-wetting slaking tests and particle size distributions (PSDs) analysis. Particularly, novel testing method to apply vacuum during slaking tests to separate different type of slaking mechanism, and improved multi-view technic to process digital images to quantitatively evaluate effect of different types of slaking mechanism were newly introduced in this study. From the tests, a new slaking mechanism caused by uneven water distribution was proposed. Another issued studied in this research was the volumetric change of mudstone induced by swelling and shrinkage of the minerals in mudstones. It was found that NaCl increases the swelling strain and decreases the shrinkage capacity of Akita mudstone.

This thesis was divided into 10 chapters.

In Chapter 1 and Chapter 2, the backgrounds of this research, materials used, and physical parameters of mudstones were carefully interpreted, respectively.

In Chapter 3, the swelling properties of three mudstones were studied. Among them, the swelling strains of Akita and Terashima mudstones are larger than that of black mudstone. The swelling properties of natural and remolded Akita mudstone were compared. The effects of dry density, salt solution and applied vertical stress on swelling properties of remolded Akita mudstone were investigated. Results imply that the swelling strain of Akita mudstone decreases with the increase of applied vertical stress and increases as the dry density increases. The swelling strains of Akita mudstone increase when saturation liquid changed from distilled water to NaCl solutions. This phenomenon may be because some calcium-based montmorillonite was transferred to sodium-based montmorillonite. As applied stress increases, the saturation liquid had limited effect on the swelling strain of Akita mudstone.

In Chapter 4, a developed muti-view approach was proposed by applying an artificial background plate. By this method, the depression area between holder plate and specimen can be reconstructed precisely. Besides that, the influence of camera resolutions was explored, and results indicated that common resolution camera (1920×1080 pixels) is sufficient for the laboratory tests.

In Chapter 5, atmospheric and vacuum drying–wetting cycle tests for Akita

mudstone were conducted. At the same time, 3D models of mudstone particles were built by a muti-view approach and the shape parameters were extracted from these models. It was found that, the slaking process is slower in vacuum condition due to the lack of air-breakage process. During the slaking process, different slaking mechanisms might lead to different mudstone particle shapes. Based on the results of the particles' shapes, a new slaking mechanism of Akita mudstone was inferred from the differential swelling caused by the uneven distribution of water.

In Chapter 6, the slaking behavior of mudstone under different applied vertical confining stresses (0.0, 0.5 and 1.0MPa) was studied with PSDs. The shear strength for mudstone with different PSDs was studied by direct shear tests. It was discovered that vertical stresses accelerate the slaking process of Akita mudstone. With the increase of applied vertical stress, the slaking phenomenon was intensified. The cohesion values of specimens with different PSDs obtained from shear strength test decreased from 7 to 3kPa during slaking process. Upon slaking ratio (SL_{ratio}) reaching 0.4, the cohesion value remained constant. Additionally, the angle of internal friction was fluctuating between 7 and 8°.

In Chapter 7, shrinkage behavior of mudstone saturated by NaCl solutions with different concentrations was studied. Cracking tests were also conducted by digital camera to explore the influence of NaCl solution on cracking evolution. The relationship between the shrinkage behavior and the cracking evolution of mudstone was investigated. The testing results showed that the NaCl solution weakened the development of cracks by suppressing the shrinkage of Akita mudstone. The development of cracks has a strong correlation with the shrinkage characteristics, as: final crack ratio linearly decreases with the reduction of shrinkage capacity. The development of cracks can be divided into four stages, namely Stage I - No crack stage; Stage II - Primary crack stage; Stage III - Sub-crack stage; and Stage IV - Crack extension stage. The saturation of specimens by NaCl solution significantly shortened Stages II and III, and prolonged Stage I.

In Chapter 8, the slaking behavior of natural and remodeled mudstones were studied. At the same time, the pores and the particles orientation distributions of crushed mudstone during compaction were studied by scanning electron microscope technology. From the testing observations, it can be concluded that dried mudstone has stronger slaking performance than natural mudstone. Moreover, with the increase of dry density, the particle orientation concentrates in the direction perpendicular to the compacting direction. The pore orientation distribution gradually generally concentrates on the directions which are perpendicular to and parallel to the compacting direction. The results imply that anisotropy index (I_a) increases with the

increase of dry density. The growth of I_a slowed down upon maximum dry density.

In Chapter 9, conclusions of this thesis and suggestions for the application of mudstone in practical field were illustrated. Terashima and Akita mudstones are larger than black mudstone. Thus, when using Terashima and Akita mudstones as embankment filling materials, it is necessary to consider the swelling properties of them due to the large swelling strains. When the embankment was constructed in coastal area, Akita mudstone with the dry density larger than 1.0Mg/m^3 is recommended. For coastal embankments, although NaCl suppressed the development of cracks, the decrease in strength from low dry density caused by NaCl cannot be ignored and should be paid more attention. To avoid the potential failure caused by slaking, it is recommended to allocate an additional shear strength of at least 3.8 kPa during the design phase. Finally, in order to avoid the proceeding of mudstone slaking, means should be adopted for preventing wetting-drying cycles.

In Chapter 10, conclusions of the thesis are summarized.

The following conclusions were obtained from this study:

1. Adopting an improved muti-view approach, the particle shape evolution of mudstone during slaking process was studied. Based on the testing results, a new insight into slaking was proposed, as: slaking is caused by the differential swelling from uneven water distribution.

2. Applied vertical stresses accelerate the slaking process of Akita mudstone. The particle size distributions evolutions of mudstone lead to the decrease of cohesion, which directly results in the reduction of shear strength.

3. It was found that for Akita mudstone, its volume increases (i.e. swells) more after saturated by NaCl solution comparing to pure water case, which is usually opposite for expansive soils. Additionally, the volumetric shrinkage of this mudstone was also weakened during drying after adding NaCl solution. The saturation of specimens by NaCl solutions significantly shortened the primary crack and the sub-crack stages and delayed the development of the first crack.

4. During compaction process, the anisotropy index of soil structure increase with the increase of dry density. The growth of the anisotropy slows down when dry density reaches the maximum dry density. Further investigation should be conducted to relate the anisotropy of soil to strength and structure.

5. To avoid failure caused by slaking, additional shear strength of 3.8kPa should be allocated during the design phase when using grading Akita mudstone. Akita mudstone with the dry density larger than 1.0Mg/m^3 is recommended for coastal expressway embankments. Also, sufficient overburden stress should be applied to suppress the swelling behavior of mudstone.

List of research achievements for application of Doctor of Engineering, Waseda University

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