Graduate School of Creative Science and Engineering
Waseda University

博 士 論 文 審 査 報 告 書
Doctoral Dissertation Review Report

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

申　請　者
(Applicant Name)
Danxi SUN
孫　丹曦

Department of Civil and Environmental Engineering　Research on Geotechnical Engineering

October, 2023

Mudstone has been selected as the embankment filling material for a highway in Japan. The thesis focuses on the engineering properties (e.g., slaking, cracking, volume change and shear strength) of mudstones. In this thesis, the slaking mechanisms of mudstone are investigated by the new testing method that the author developed - multi-view technic. As a result, a new slaking mechanism caused by inhomogeneous water distribution is proposed. Furthermore, the influence of stress on slaking and the loss of shear strength in mudstone due to slaking are investigated. Another issue studied in this research is the NaCl influence on volumetric change of mudstone induced by swelling and shrinkage of the minerals in mudstones. And the alter shrinkage property of mudstone further influence the cracking evolution. Based on the experimental observations, the important suggestions for the application of mudstone as highway embankment filling material are proposed.

The thesis has been undergone the department preliminary screening on 11th May 2023 and has been revised on 17th May. The revised thesis has been inspected from 18th May to 26th May 2023. The thesis has been accepted by the department meeting on 15th June 2023 and the Graduate School of Creative Science and Engineering Steering Committee on 27th July 2023. The doctoral dissertation defense has been held on 7th September 2023. The research ethics course has been taken by the applicant before the acceptance and the check on the doctoral dissertation in terms of plagiarism by electronic tools has been finished.

The thesis is organized into ten chapters. The contents of the chapters and their evaluations are as follows:

Chapter 1 provides a concise introduction to the thesis, outlining the background, a review of prior research, and presenting the thesis's objectives, organization, and innovations.

Chapter 2 illustrates the materials including Akita mudstone used in this study. The physical parameters of the materials and testing programs are introduced.

Chapter 3 investigates the effects of dry density, NaCl solution and applied vertical stress on swelling properties of mudstone. The results indicate that the swelling strain of Akita mudstone decreases with the increase of vertical stresses and increases as the dry density increases. The swelling strains of Akita mudstone increase when saturation liquid changed from distilled water to NaCl solutions. The mechanism of this phenomenon is explained by the transformation of some calcium-based montmorillonite to sodium-based montmorillonite. Furthermore, the NaCl solution has limited effect on the swelling strain of Akita mudstone as applied stress increases. These results are significant phenomena in engineering, as it enables the prediction of the evolution of swelling properties in coastal highway

embankments under various conditions.

Chapter 4 proposes a developed multi-view approach by applying an artificial background plate. The good performance of this improvement is proved by computed tomography tests. Moreover, the influences of camera and reconstruction resolutions are studied. This method can be applied to other research studies in the geotechnical field.

Chapter 5 proposes a new slaking mechanism of Akita mudstone from the results of the particle shape analysis by using muti-view approach. The new mechanism indicates that the inhomogeneous distribution of water during wetting process may result in the differential swelling of specimen, leading the further breaking of specimen structure. Besides, atmospheric and vacuum drying–wetting cycle tests for Akita mudstone are conducted for quantitatively evaluating the contribution of different slaking mechanism in the slaking process. According to the particle size distribution (PSD) curves evolution, the air-breakage phenomenon and differential swelling contribute nearly equally to the slaking, each accounting for approximately 50%. These findings can serve as valuable references for understanding and addressing the slaking problem.

Chapter 6 evaluates the influence of vertical confining stresses (0.0, 0.5 and 1.0MPa) on the slaking process by the change of PSDs. And the shear strength evolution during the slaking process is also investigated. The results show that the vertical confining stresses accelerate the slaking behavior. The shear strength decreases with the progress of slaking, which may lead to the landslide of embankment. These data show that additional strength for mudstone should be considered during the design and construction process.

Chapter 7 explores shrinking and cracking evolution of mudstone saturated by NaCl solutions with different concentrations. The results indicate that NaCl solution weakens the development of cracks by suppressing the shrinkage of Akita mudstone. The development of cracks has a strong correlation with the shrinkage characteristics. For the engineering application, these studies suggest that although NaCl suppresses the development of cracks, the decrease in strength due to low dry density caused by NaCl cannot be ignored.

Chapter 8 studies the slaking behavior of natural and remodeled mudstones. Meanwhile, the pores and the particles orientation distributions of crushed mudstone during compaction are studied by scanning electron microscope technology. The results show that the slaking performance of dried mudstone is stronger than that of natural mudstone. Moreover, with the increase of dry density, the particle orientation concentrates in the direction perpendicular to the compacting direction.

And anisotropy index (I_a) increases with the increase of dry density. These results can provide data on the anisotropy of the soil structure, allowing further research on the anisotropic properties of soil strength and permeability.

Chapter 9 provides suggestions for the application of the research findings in both the academic and practical fields. The multi-view approach can be applied to other research areas related to specimen deformation or particle shape analysis during particle breakage processes. Additionally, engineering recommendations for coastal highway embankments are derived from the results of the thesis. It is recommended that sufficient overburden stress be applied to control the swelling deformation of mudstone, particularly in coastal embankment scenarios. Furthermore, the reduction in strength caused by slaking and exposure to salt solutions should be carefully considered during the design and construction phases.

Chapter 10 concludes the experimental observations. The limitations and recommendations of this study are also addressed, along with future directions for research.

This dissertation investigates the influence of slaking and NaCl solution on the properties (e.g., slaking, swelling, shrinkage and cracking) of mudstone using the new testing method. In the practical field, the results can provide clues and suggestions for the construction of mudstone embankments. In the academic field, this dissertation proposes a new differential swelling mechanism in slaking, which provides valuable insights for more effective prevention of slaking occurrences.

The referees recognize that this dissertation is dedicated to the development of geotechnical engineering and transportation engineering and meets the given requirements for a doctorate (Doctor of Engineering).

September 2023

Principal Referee:

Prof. of Waseda Univ. Dr. of Eng. (Waseda University) Hideo Komine .....

Sub Referees:

Prof. of Waseda Univ. Dr. of Eng. (Waseda University) Hirokazu Akagi .....

Prof. of Waseda Univ. Dr. of Eng. (Tohoku University) Mitsuyoshi Akiyama .....

Assoc. Prof. of Waseda Univ Dr. of Eng. (The University of Tokyo) Hailong Wang .....