Title	Experimental Study on Near-surface Stabilization of Slopes in Cold Region using Bio-mediated Geotechnical Engineering [an abstract of dissertation and a summary of dissertation review]
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Degree Grantor	北海道大学
Degree Name	博士(工学)
Dissertation Number	甲第14247号
Issue Date	2020-09-25
Doc URL	https://hdl.handle.net/2115/79492
Rights(URL)	https://creativecommons.org/licenses/by/4.0/
Type	doctoral thesis
File Information	Sivakumar_Gowthaman_abstract.pdf, 論文内容の要旨

学　位　論　文　内　容　の　要　旨

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学　位　論　文　題　名

Experimental Study on Near-surface Stabilization of Slopes in Cold Region using Bio-mediated Geotechnical Engineering
(生物を利用した地盤工学による寒冷地の法面表層安定化に関する実験的研究)

Near-surface instability poses challenges regarding the maintenance of natural and engineered slopes. The strength characteristics of the near-surface zone are progressively altered in response to climatic variations, leads the near-surface more prone to soil loss and deteriorations. Near-surface failures are also often reported to be triggered during or immediately after prolonged rainfalls or snow melting events. Therefore, stability of the near-surface requires more attentions in terms of eliminating risks and saving economy. Although the chemical treatments in the past were found to be reliably enhancing the near-surface conditions, most of them are reported to be toxic and hazardous, and manufacturing process of such materials causes considerable environmental damage by the release of greenhouse gases. This necessitates and urges the development of new pathways for an effective stabilization of slope near-surfaces.

As an emerging technique, microbial induced carbonate precipitation (MICP) has drawn substantial attentions in the past years. The technique has been emerged through relatively a novel interdisciplinary pitch at the confluence of microbiology, geochemistry, and geotechnical engineering. MICP persuades the calcium carbonate bio-cement within the soil matrix as a consequence of bio-chemical reactions, resulting the decrease in particle mobility and increase in strength and stiffness. The objective of the research presented in this dissertation is to assess the viability of MICP as a novel alternative for near-surface stabilization of slopes. The pathway utilizing the native bacteria has potentially been chosen in this work. From the perspective of bio-geotechnical engineering, yet significant effort has been given on understanding biological responses, mechanical responses, durability responses and application strategies to facilitate reliable treatment and to promote the technique nearly to field implementation stage.

Chapters 1 and 2 present the preamble of the research work. Chapter 1 introduces the background, scope, originality and significance of the research work. In Chapter 2, comprehensive literature review performed on various aspects related to MICP process and near-surface stability, are discussed.

In Chapter 3, fundamental scientific approach of MICP technique is presented. An erosion prone expressway slope located in Hokkaido, has been chosen as representative for the investigation. Hokkaido, the northernmost island of Japan, is located in subarctic region, experiencing a cold climate. Giving the emphasis on the intrinsic climate of the study region, a comprehensive experimental work has been performed. The ureolytic bacteria isolated from the target slope soil were characterized to be *Lysinibacillus xylanilyticus*, worth noting that these bacteria have not previously been reported for urea hydrolysis. The urease performances were evaluated under different temperature and chemical conditions. The results revealed that the bacteria could effectively mineralize the calcium carbonate between 15 ℃ and 25 ℃, showing in more robust performance under native cold climatic conditions. The effects of various MICP recipes were also investigated to deepen the understanding on biochemical

processes. The results indicated that the initial concentration of resources should not be more than 1 mol/L for an efficient and reliable precipitation of calcium carbonate. Further increase in resource concentration was found to be suppressing the mobility of ions, leading to ineffective MICP.

In Chapter 4, the physical and mechanical responses of MICP treated slope soils are discussed. Giving emphasis on comprehending desirable range of cementation level, the slope soils were treated to various levels within the possible range, and their physical states, shear-wave velocities and mechanical behaviors across the range of cementation levels were extensively studied and compared. The mechanical test program comprised of unconfined compression test, shear test and permeability test. The study demonstrated that precipitated calcium carbonate is one of the most important factors determining the responses of MICP soils. The increase in cementation level resulted the increase in both peak and residual strengths. However, to enable a stable skeleton, the slope soils should be essentially treated to shear wave velocity of above 1 km/s. The findings also confirmed that cementation at particle contact attributed to peak strength, increasing both friction angle and cohesion, and particle roughness of grains attributed to the residual strength of slope soils.

In Chapter 5, a comprehensive study was conducted to investigate the influence of key climatic parameters on the long-term performance of MICP treated slope soils. As the cold regions experience periodic snowfalls and rainfalls, the cyclic freeze-thaw (FT), wet-dry (WD) and acid rain (AR) tests were chosen and investigated as potential indicators of durability. The results showed that the WD damages were not significant as those obtained under FT and AR conditions. However, level of cementation had a foremost role on long-term performance of MICP slope soil. The specimens treated to high content of calcium carbonate showed minor damage with high aggregate stability in all the durability analysis.

In Chapter 6, the work dealt with the treatment strategies in order to promote the technique towards real application and commercialization. A series of bench-scale slope models was treated by different strategies including grid-injections, single-phase and two-phase sprayings with several variables. The non-destructive needle penetration tests were used to evaluate all the treated slope surfaces. The results revealed that the two-phase technique sprayed 1 mol/L resources could be more effective and feasible for real-scale applications. Given the optimum treatment, the scaled-up slope under temperature uncontrolled conditions achieved marked increase in near-surface unconfined compressive strength (UCS) ranging between 1.6 and 2.8 MPa.

In Chapter 7, the conclusions drawn in each chapter are summarized, along with some prospects for future works. In addition, based on the outcomes derived from the above works, the application guidelines are outlined regarding optimal MICP recipe, implementation strategy and conditions, along with the evaluation process that would help to ensure the durability performance of MICP treated slope near-surfaces under the effects of climate.