Evaluation on Long Term Durability of Cement Stabilized Soils under Sea Water Environment

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論　文　内　容　の　要　旨

Cement stabilization techniques have been developed and applied widely in practice for on land and marine constructions. It can be used in stabilizing foundation, reducing settlement, preventing liquefaction of ground and so on. The application of cement stabilization techniques has achieved great social and economic benefits. However, the long-term durability of cement stabilized soils in corrosive environment is concerned nowadays. Durability can be defined as the ability of cement stabilized soils to retain stability and integrity over years of exposure to corrosive environments. The corrosive environments include sea water invasion, acid rain, industrial pollution, landfill leachate, irrigation sewage. This research concerns on sea water invasion environment. Nowadays, sea water invasion is a worldwide problem, especially the long term durability. There are many failure cases in its application in seaside. The dike foundation located in Kyushu Island, Japan encounters leaking and forms swamps 20 years later. The application of cement stabilized soils in coastal areas of China exhibited lower strength and poor integrity several years later. It is obvious that the surrounding environment has critical influence on long-term durability of cement stabilized soils. This research concerns the influence of sea water environment on long term durability of cement stabilized soils.

In Japan, the total volume of cement stabilized soils by the deep mixing method from 1977 to 2010 reached more than 100 million m^3 which was initiated to improve the stability of port facilities such as breakwaters and revetments. The maintenance and rebuilding of these structures are highly cost. What's more, it is dangerous to our generations. The Chinese government will encounter the same issues in the near future. Therefore, it is

significant to evaluate the long-term durability of cement stabilized soils in sea water environment.

Field investigations indicate that the strength of cement stabilized soils decreases after several years' exposure to sea water environment. It is believed that the calcium leaching is the major cause of strength decreasing. A number of evaluation methods have been developed based on mechanism of calcium leaching and the predicted results have been verified through laboratory experiments. However, various factors have effect on long term durability of cement stabilized soils. The influence of sea water pressure in surrounding environment and initial strength of cement stabilized soils on long term durability are not considered yet.

Our research mainly investigates the influence of static and dynamic sea water pressure on long term durability of cement stabilized Ariake clay soils. It is found that the static sea water pressure has little influence on long-term durability. However, the dynamic sea water pressure exhibits a potential influence on long-term durability. The research results provide data basis for the application of cement stabilization techniques in sea side. The thesis proposes a predictive methodology to evaluate long term deterioration depth of cement stabilized soils in sea water environment. The predicted results have been verified through laboratory experiments. The method here is time saving and laboratory feasible. The mechanism of deterioration is clarified in this thesis. It provides theoretical basis for proposing countermeasures of preventing deterioration of cement stabilized soils in sea water environment.

The thesis consists of seven chapters. Chapter 1 outlines the framework of research. It clarifies the backgrounds of research. The targets and the originality contributions of the thesis are introduced. Chapter 2 gives a summary of previous researches on deterioration of cement stabilized soils. It introduces the detailed classification of cement stabilization method according to the construction methods, stabilization depth and cement injection type. The mechanism of deterioration is collected in this chapter. The applications of empirical formula in predicting long term deterioration depth is listed in this chapter. The numerical method of prediction based on calcium leaching mechanism is introduced also.

Chapter 3 introduces the details of research methodology. The procedures of preparing and testing specimen are described in details. The materials and apparatus used in this study are included in this chapter. The originated design of mould and curing chambers are clarified in this chapter. In Chapter 4 the experimental results of micro cone penetration resistance, unconfined compressive strength, water content and density are listed. The influence of static and dynamic water pressure on deterioration of cement stabilized soils is discussed. The static sea water pressure has little influence on long-term durability of cement stabilized soils. However, the dynamic sea water pressure exhibits a potential influence on long-term durability. The increasing of sea water concentration accelerates the deterioration of cement stabilized soils. The higher initial strength effectively enhances the long term durability of cement stabilized soils in sea water environment. Chapter 5 explains major deterioration mechanism of cement stabilized soils in sea water environment from chemical and microstructure aspects. The mechanism is clarified from: 1) Ca^{2+} and Mg^{2+} ions concentration distribution with depth of specimen; 2) Ca/Si ratio changes as curing time becoming long; 3) Comparison between porosity at different depths of specimen; 4) The scanning electron images at deteriorated area and non-deteriorated area of cement stabilized soils. 5) The compound constitute of cement stabilized soils.

Based on the analysis and validation of mechanism of deterioration, Chapter 6 proposes a new methodology on predicting long term deterioration depth of cement stabilized soils over 50 years under sea water environment. The method can be easily used since only two fitting parameters that need to be obtained. The two parameters, which are named a and b, can be derived through fitting experimental data of short period within one year. The parameter a is influenced by initial stabilization conditions, such as soil type, cement type, cement content, initial water content, mixing method and so on. The parameter b can be also named as half-rate time. When elapsed time equals to the parameter b, the deterioration rate becomes half of the initial deterioration rate. Although, the method is derived from limited data, it can be easily extended and applicable to other types of cement stabilized soils, because the method itself avoids the absolute effect of the initial condition of cement stabilized soils. It assumes that the increasing of sea water concentration is inversely proportional to parameter b. b_L is parameter under natural sea water concentration and b_H is parameter under higher sea water concentration. C_L is the natural sea water concentration and C_H is the higher sea water concentration. Therefore, the predictive methodology can be described as following steps. Firstly, fit the

experimental data of higher sea water concentration to estimate the values of a and b_H. Then, keep the parameter a as a constant and calculate the parameter b_L by using the assumption, $b_H/b_L=C_L/C_H$. Finally, the predictive equation in natural sea water concentration can be described by substituting the parameters a and b_L into it. The prediction results are fitting well with the experimental data. In addition, the prediction results are compared with previous experimental data in this thesis.

Chapter 7 gives out the conclusions and future works of evaluation on long term durability of cement stabilized soils in sea water environment.

論 文 審 査 の 結 果 の 要 旨

本論文は，粘性土を母材としたセメント安定処理土の汽水および海水環境での劣化特性を実験的に調べ，劣化深度を指標とした海水環境での劣化の進行が海水濃度，水圧の変動，安定処理土の初期強度に大きく影響されることを明らかにするとともに，セメント安定処理土の詳細な化学的分析と微視的な構造の観察に基づいて，海洋環境での劣化には，海水濃度に依存したCaイオンの溶脱とMgイオンの侵入の程度が深く関わることを明確にし，その成果を踏まえて塩分濃度の異なる海水環境下でのセメント安定処理地盤の長期的な劣化深度を予測するための手法を提案したものであり，地盤工学上寄与するところが大きい。よって本論文は，博士（工学）の学位論文に値するものと認める。