

## Article

# Experimental Study on the Permeability of Microbial-Solidified Calcareous Sand Based on MICP

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**Abstract:** In the construction of artificial islands in distant seas, calcareous sand has been widely used as a foundation filler due to its excellent mechanical properties and extensive availability in the marine environment. How to store more fresh water on the artificial islands by reducing its permeability is currently a great challenge. Microbial-induced carbonate precipitation (MICP) has always been considered as a great potential method to improve the cemented properties of calcareous sand, but the effect of grain gradation on the permeability of MICP-improved calcareous sand remains unclear. In this research, a self-made device was developed to conduct MICP grouting and permeability tests, where the permeability coefficient ( $k$ ) under different grain gradations (curvature coefficient ( $C_c$ ) and uniformity coefficient ( $C_u$ )) was measured. A CT scan was conducted to investigate the variation in the porosity ( $n$ ) of sand samples before and after MICP treatment. The weighting method was adopted to measure the content of induced calcium carbonate ( $M$ ). A scanning electron microscopy (SEM) technique was used to further study the micromechanism of the MICP treatment. Finally, the correlations between the  $k$  of MICP-treated sand and  $C_u$ , as well as  $C_c$ , were semiquantitatively analyzed. The results show that the magnitude of  $M$ ,  $k$  and  $n$  changes are closely related to  $C_c$  and  $C_u$ . The reduction amount of  $k$  and  $n$  increased with the rise in  $C_c$  and  $C_u$ , and the increased amount of  $M$  increased with the rise in  $C_c$  and  $C_u$ . The SEM results show that the particle surface became rough due to the coating effect of  $\text{CaCO}_3$  crystals, and the pore spaces were reduced because of the partially filling effect of the crystals, which was responsible for the decrease in permeability and porosity. Furthermore,  $k$  fitted well with  $C_u$  and  $C_c$ , respectively, and the fitting curve reveals that larger  $C_u$  ( $C_u \geq 6.0$ ) and smaller  $C_c$  ( $2.0 > C_c > 0.5$ ) were more suitable for MICP treatments and lead to a large reduction in permeability. The above results indicate that the grain gradation of calcareous sand had a significant influence on its permeability improved by MICP.

**Keywords:** MICP; calcareous sand; grain gradation; permeability coefficient; porosity



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## 1. Introduction

The construction of artificial islands is in full swing all over the world due to space limitation in coastal areas [1,2] and transfer transportation requirements in distant seas (e.g., Fiery Cross Island in the South China Sea). On the artificial islands, the storage and access of fresh water are important fundamental conditions for human living [3,4]. In China, it has been reported that the cost of transporting high-quality tap water from the mainland to one island reaches USD 370 thousand per year [5]. How to store more fresh water on the artificial islands is of great significance to cost savings. Previous efforts have found that the permeability of island-building materials dominates the water storage on the island. General consensus has been achieved that the application of less permeable island-building materials can increase freshwater storage [6,7].

Regarding island-building materials, calcareous sand, formed by the accumulation of coral debris and other biological debris, has been widely used as a foundation filler [8–10] due to its excellent mechanical properties and extensive availability in marine environments [11,12]. However, the reclamation in distant seas using sand is often carried out via

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