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Experimental investigations of groundwater inflow-induced piping phenomenon in compacted bentonite buffers for HLW repository

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Field Code Changed

Abstract

This study introduces a series of laboratory-scale experimental tests of piping erosion in buffer in order to investigate the phenomenon of piping erosion around the buffer material when rapid groundwater inflow occurs in a disposal repository. In a cylindrical cell, specimens of compacted bentonite were exposed to continuous water injection under varying conditions of flow rate, chemical composition, and flow direction. The erosional behaviors of bentonite buffer in piping are analyzed, including the formation of piping channels, critical inflow water pressure, and self-healing. In addition, X-ray CT scanning was utilized to analyze the post-erosion characteristics of the bentonite buffer. The outcomes will inform the development of requirements for the reference design and construction of a secure HLW repository.

1. Introduction

The bentonite buffer is a crucial component of the engineered barrier system of a deep geological repository for high-level radioactive waste (HLW). When a groundwater inflow is introduced through an excavation-damaged zone early in the disposal process, the bentonite buffer adjacent to the rock interface undergoes saturation, swelling, and erosion [1]. Specifically, the piping erosion phenomenon occurs when the hydraulic pressure buildup exceeds the swelling pressure of saturated buffer, resulting in a degradation of the buffer material's performance [2]. For the safe design of the HLW disposal repository, it is necessary to comprehend the piping phenomenon surrounding the buffer material, as it can affect the long-term physical stability of the EBS.

In this study, a series of piping erosion experiments are conducted to examine the groundwater inflow-induced piping erosion behavior of compacted Ca-bentonite block with varying flow rate, chemical composition, and flow direction of water. In the first phase of the experiment, the hydraulic pressure buildup, saturation, and occurrence of pipe channels were analyzed during constant-rate water injection. After sufficient piping erosion has occurred, the water flow has been stopped and the self-healing and gradual desiccation crack generation behaviors have been analyzed. In addition, post-injection X-ray CT scanning of the sample was performed to analyze the degradation of the compacted bentonite. The findings in this study will be utilized to the development of reference design and construction of a HLW repository.

2. Experimental Procedures and Results

Bentonite blocks (100 mm x 200 mm) were produced using Bentonil WRK with an initial water content = 17% by cold isostatic pressing at 40 MPa to achieve an initial dry density of 1.6 g/cm^3 in consideration of design values satisfying the buffer material's function. The compacted bentonite block was placed in a transparent cell to observe gradual wetting and the formation of a pipe channel at the block-cell interface (Fig. 1a), with a 1 mm gap between the block and cell through which water flowed. The water inlet was located at the bottom of the cell, while the outlet was located at the top. The cell was injected with water at a constant flow rate (1, 10, or 100 ml/min) using a dual syringe pump (ISCO syringe 500D). The maximum injection rate was established based on

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the allowable flow rate per disposal hole [3]. Inlet water pressure was monitored and the eroded bentonite fraction in the effluent was analyzed. After the stage of water injection, X-ray CT scanning was performed to analyze the geometry of the piping channel and the formation of dessication cracks on the surface of the bentonite block.

Fig. 1b depicts the result of preliminary experiments with bentonite block and distilled water (10 ml/min). As water was injected into the bottom of the cell, the bottom buffer material began to swell and the pressure of the inlet water increased (Stage 1). The micro-channels were formed at the forefront of the horizontal piping channel, and the lateral propagation of the wetting front to the unsaturated region led to the saturation of the trapped area (Stage 2). After the water flow stopped, the eroded bentonite particles in the piping channel and interface settled down, and the piping channels were sealed by swelling (Stage 3). After 48 hours of flow stoppage, the saturated region becomes dehydrated due to dessication, and the cracks appear primarily in the main piping channel (Stage 4).

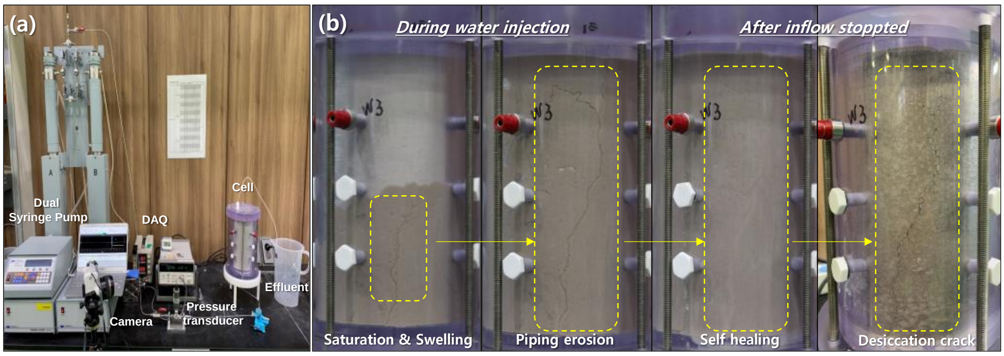

Figure 1. Piping erosion test for compacted bentonite. (a) experimental setup, and (b) piping pheonomena scenario

3. Conclusions

In this study, the Ca-bentonite piping erosion tests in laboratory-scale are introduced. The gradual saturation of buffer material by in-flowing water prompted the formation of piping channels in the gap region. After the inflow ceased, the eroded area is partially healed with swelling, but showed susceptibility to desiccation cracking. Further testing considering chemical composition of water and flow direction is required to establish the possible scenario of piping phenomenon in bentonite buffer system.

Contributor statement

Lee, M: Conceptualization, Investigation, Methodology, Writing-Original Draft, **Hong, C.H.**: Conceptualization, Methodology, Writing-Review & Editing, **Kim, J.W.**: Investigation, **Cho, G.C.**: Validation, **Kim, J.S.**: Project administration, Funding acquisition, Writing-Review & Editing

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