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Evaluating the hydraulic barrier performance of soil-bentonite cutoff walls using the piezocone penetration test

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Abstract

When using cutoff walls to prevent the migration of mobile contaminants in aquifers, we should ensure that these cutoff walls maintain both low hydraulic conductivity and high homogeneity before the start of their operation. However, the on-site assessment of the properties of their main component, soil-bentonite (SB), is challenging because of the difficulty in the obtention of high-quality solid core samples after installation. This paper discusses an experimental approach for on-site quality control/quality assurance (QC/QA) immediately after installation to enhance the reliability of SB cutoff walls as containment barriers. In particular, the piezocone penetration test (CPTU) was conducted using a large-scale soil tank in which SB – prepared with different contents of bentonite powder – was filled to simulate vertically homogeneous or heterogeneous SB cutoff walls. The response to the penetration test varied according to the bentonite content, suggesting that the piezocone penetration test can be used for QC/QA of constructed soil-bentonite cutoff walls. Corrected cone resistance values were larger in layers prepared with lean SB mixture than in those prepared with rich SB mixture, with a difference similar to that of undrained shear strength as evaluated by triaxial compression tests. It was also found that the hydraulic barrier performance of SB cutoff walls could be assessed via a pore pressure dissipation test during CPTU, within one order of magnitude accuracy in a short period. A basic process for QC/QA using the piezocone penetration test in the field is proposed for the practical interpretation of experimental results.

Keywords: Soil and groundwater contamination; Cutoff walls; Containment; Piezocone penetration test; Quality control/quality assurance; Homogeneity; Hydraulic conductivity; Environmental geotechnics

1. Introduction

The reutilization of contaminated land should be accelerated with the adequate management of contaminants to minimize environmental risks, especially in small countries such as Japan. Vertical cutoff walls are often constructed at contaminated sites to contain the contaminants and to prevent their migration in the aquifer, as shown in Fig. 1 (Evans, 1994; Evans et al., 2008). Soil-bentonite (SB) is one of the most common barrier materials used owing to its extremely low hydraulic conductivity (k) and high deformability (Grube, 1992).

The main concerns regarding containment barriers are the assurance of a sufficient hydraulic barrier performance and homogeneity. The design of SB cutoff walls is usually conservative, with laboratory hydraulic conductivity values, k, lower (e.g. one order of magnitude lower) than the target ones after considering the various factors affecting the k of SB (e.g., Katsumi et al., 2008; Malusis and McKeehan, 2013; Takai et al., 2013). The hydraulic barrier performance in field should, however, be verified after installation, since the on-site k may vary because of heterogeneities. While it is considered possible to achieve high homogeneity when constructing SB

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cutoff walls by the trench cutting and re-mixing deep wall (TRD) method, the construction quality cannot be directly or visibly verified because the ground is invisibly cut and blended with slurry and powder of bentonite, as shown in Fig. 2 (Katsumi et al., 2008). Furthermore, the softness of SB cutoff walls, even after construction, complicates the quality control/ quality assurance (QC/QA) process, since it is difficult to collect high-quality solid core samples from the constructed walls. In addition, the assessment of k based on the samples taken during or after construction, which is the most commonly used method, leads to the calculation of hydraulic conductivity for small scale test sections, not suited to estimate field behavior. Furthermore, variation in bentonite content might also occur during construction.

The main objectives of this paper are to experimentally verify the feasibility of using the piezocone penetration test (CPTU) to evaluate the bentonite content of SB cutoff walls and its effect on the hydraulic conductivity, and to propose a possible on-site QC/QA flow using CPTU. First, hydraulic conductivity test was conducted on SB specimens, which were made with different contents of bentonite powder (C_{BP}) to evaluate its effect on the k value of SB. Then, the mechanical properties of SB affected by C_{BP} under unconsolidated-undrained conditions were evaluated by unconsolidated-undrained triaxial compression (UU) test. Later, piezocone penetration test (CPTU) was conducted using a large-scale soil tank filled with various compositions of SB. Since the physical properties–corrected cone resistance (q_t), sleeve friction (f_s), and pore pressure (u) –change according to the soil characteristics, CPTU is widely applied on-site investigations to estimate the soil profiles (e.g., Jeffries and Davies, 1993; Eid and Stark, 1998; Mimura and Yoshimura, 2007; Mayne et al., 2009; Robertson, 2009). Thus, CPTU can be expected to detect the zone with lean-mix of bentonite in SB walls from the CPTU data. In addition, a pore pressure dissipation test was conducted to assess k value during pauses in cone penetration to determine the suitability as in situ k value measurement technique, compared with laboratory results.

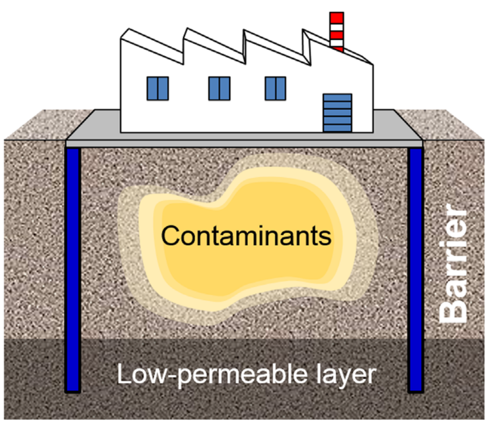

Fig. 1. Schematic view of in situ containment technique.

2. Literature review

2.1. Variability in k value of SB

The homogeneity of k plays a fundamental role on the quality of containment barriers because a larger variability in k leads to a higher flux of contaminant out of the barrier system, even if average k values are equal (Britton and Filz, 2007; Yesiller and Shackelford, 2010). Thus, assurance of homogeneity after the installation in the field is an important step to prevent the spread of a contamination plume.

While laboratory hydraulic conductivity testing devices can only permeate relatively small specimens, in situ tests offer the opportunity to test larger, more representative volumes of material and to include flow through secondary features, e.g., macropores, fissures, and slickensides, in a manner that often cannot be simulated properly in small laboratory test specimens (Daniel, 1989). Besides this scale effect, many other factors may cause variability in the k value of cutoff walls in

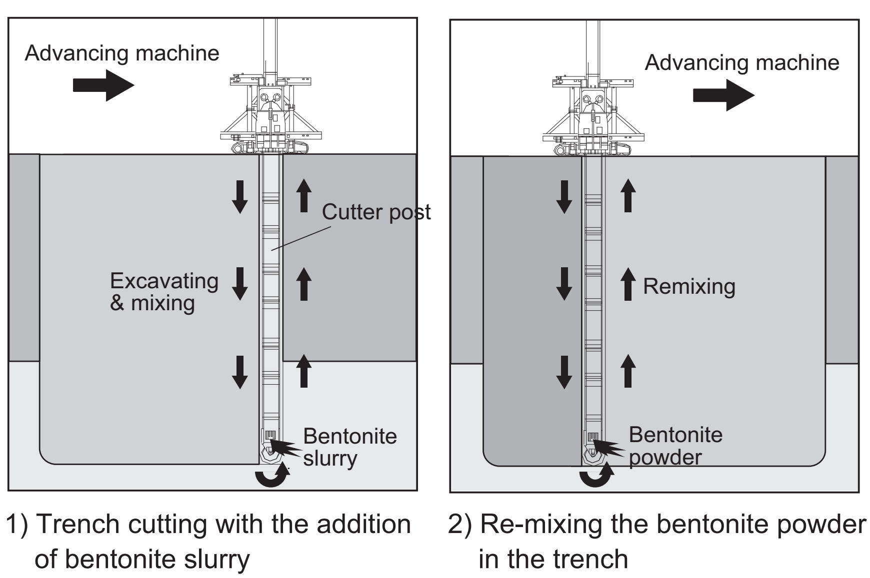

Fig. 2. Construction process of SB cutoff walls by TRD method (Katsumi et al., 2008).

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