Understanding water migration behavior of unsaturated bentonites for HLW-disposal project

Hideo Komine i)

i) Professor, Department of Civil and Environmental Engineering, Waseda University, 3-4-1, Ohkubo, Shijuku, Tokyo, 169-8555, Japan.

ABSTRACT

This study discussed water migration behavior in a bentonite-based buffer from an unsaturated state to saturation by the laboratory experiments measuring water absorption and swelling pressure. It investigated and considered water migration behavior in an unsaturated bentonite from the viewpoint of material specifications such as the kinds of bentonite and dry density. From the experimentally obtained results, water migration behaviors in various unsaturated bentonites as buffer are analogous to water-diffusion from initial water content to around 90% saturation degree.

Keywords: bentonite; water absorption; montmorillonite; unsaturation; radioactive waste disposal

1 INTRODUCTION

Bentonite is attracting greater attention in Japan and some other countries as a buffer for use in repositories of high-level radioactive waste (HLW) as shown in Fig. 1 (Nuclear Waste Management Organization of Japan, 2016; Svensk Kärnbränslehantering AB, 2006) Bentonite-based buffers for HLW disposal are expected as an artificial barrier for separating dangerous HLW from surrounding environment. The condition of bentonite-based buffer changes from unsaturated to saturated according to groundwater seepage at relatively early stage of high-level radioactive waste disposal facilities. Therefore, the behavior of bentonite-based buffer must be investigated quantitatively under unsaturated conditions.

This study investigated water migration behavior in bentonite-based buffer from an unsaturated state to saturation in terms of material specifications such as kinds of bentonite and dry density.

2 EXPERIMENT AND SAMPLE

This section describes the outline of experiments for measuring water absorption amount of bentonite-based buffer and the fundamental properties of the used samples.

Figure 2 presents the schematic drawing of the experiment measuring water absorption amount and swelling pressure with elapsed time. This experiment measured the water absorption amount using a double tube burette and a differential pressure gauge at prescribed time intervals. In addition, the swelling pressure was measured by the load transducer. The minute vertical displacement of the specimen was measured using the displacement transducer as presented in Fig. 2. This article has focused relations of the water absorption amount and elapsed time.
Table 1 presents fundamental properties of the bentonite of three kinds used for this study. The author selected the three powders because of their different montmorillonite contents and exchangeable cation conditions. Bentonite A, actually Kunigel-V1, is a candidate buffer material in Japanese projects.

### 3 WATER ABSORPTION OF BENTONITES FROM UNSATURATED TO SATURATED CONDITION

This section describes the results of experiments for measuring water absorption amount with elapsed time. From the obtained results, the dominant phenomena for water migration in bentonite has considered and discussed. Figure 3 presents relations of the water absorption amount into a specimen per unit of elapsed time. The upper figure (a) is the relation between the amount of water absorption and elapsed time, and the bottom figure (b) shows the relation between the amount of water absorption and square root of elapsed time. Regarding the relation between the amount of water absorption into the specimen and elapsed time, the water absorption amount into the specimen, \( Q \), can be evaluated as a linear function of the square root of elapsed time as in Eq. (1) if the water-absorbing behavior is analogous to water-diffusion phenomena in the specimen (Komine et al., 2018).

\[
Q = Q_0 - b = a \sqrt{t} \tag{1}
\]

Therein, \( Q_0 \) represents the amount of inflow water measured by the double tube burette presented in Fig. 2, which includes the amount of absorbed water in the porous metal, filter paper, and the pipes between the double tube burette and the bottom of the specimen; also, \( a \) is the amount of water absorption per the unit of square root of time (\( \mathrm{mL/\sqrt{min}} \)). \( t \) represents the elapsed time from the starting of water supply, \( b \) can be assumed as the amount of absorbed water in the porous metal, filter paper, and pipes between the double tube burette and the bottom of the specimen. Therefore, the water absorption into the specimen is calculable by Eq. (1).

The bottom panel (b) of Fig. 3 shows that water absorption amount \( Q \) into the specimen is directly proportional to the square root of elapsed time from \( t=0 \) to \( t_d \). Results in this panel of Fig. 3 show an inflection point in the relation of water absorption amount and elapsed time at \( t_d \).

Fig. 4 show the obtained results of the relations between the amount of water absorption and square root of elapsed time for Bentonites B and C. Similarly to results for Bentonite A, \( Q \) is directly proportional to the square root of elapsed time from \( t=0 \) to \( t_d \) for Bentonites B and C.
At \( t = 0 \) to \( t_d \), water migration in the bentonite-based buffer specimen can be regarded as diffusion of water molecules because \( Q \) is directly proportional to the square root of elapsed time. After \( t = t_d \), the degree of saturation is regarded as almost 100%. For that reason, water migration in the bentonite-based buffer specimen can be regarded as hydraulic conduction according to Darcy’s law.

The initial air-void volume in a specimen is calculable from the dry density, water content, and specimen volume in the initial condition. From those values and measured inflow water amounts at \( t_d \) of each bentonite shown in Figs. 3, 4, the degree of saturation at \( t_d \) is calculable as presented in Table 2.

Results shown in Table 2 indicate that the degrees of saturation at \( t_d \) for bentonites A, B, and C are around 90%. Therefore, water migration in the bentonite-based buffer specimen can be regarded as diffusion of water molecules at the initial condition to \( t_d \) of about 90% saturation degree. After \( t_d \) of about 90%, water migration is regarded as acting dominantly as hydraulic conduction (Komine, 2008, 2010).

Takeuchi et al. (1995) also reported the water diffusivity of bentonites with some dry density and degrees of saturation. Figure 5 shows the relationship between water diffusivity and degree of saturation. This figure indicates that water diffusivities of bentonites are almost constant from initial condition to around 90% saturation degree. Especially, water diffusivity of bentonites is almost constant under condition of 50% to 90% of saturation degree at relatively high dry density. Those means that water migration into bentonite-based buffer can be regarded as diffusion of water molecules at the less than 90% saturation degree. The consideration and the results shown in Fig. 5 by Takeuchi et al. (1995) are almost conformable to the author’s consideration for the experimental results shown in Figs. 3 and 4. Consequently, water migration in bentonite-based buffer can be regarded as diffusion of water molecules at the initial condition to around 90% saturation degree from the both of discussions and experimental results in Takeuchi et al. (1995) and this study. At more than around degree of saturation of 90%,

Table 2. Relations of initial void volume (\( V_{a0} \)), inflow water amount (\( Q \) at \( t_d \)) and degree of saturation (\( S_r \) at \( t_d \)) at \( t_d \)

<table>
<thead>
<tr>
<th>Bentonite ( \rho_d ) (Mg/m(^3))</th>
<th>( w_0 ) (%)</th>
<th>( S_{r0} ) (%)</th>
<th>( V_{a0} ) (cm(^3))</th>
<th>( Q ) at ( t_d ) (cm(^3))</th>
<th>( S_r ) at ( t_d ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.32</td>
<td>8.37</td>
<td>20.97</td>
<td>11.70</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>1.59</td>
<td>8.47</td>
<td>31.31</td>
<td>8.41</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>1.85</td>
<td>8.07</td>
<td>44.31</td>
<td>5.35</td>
<td>4.5</td>
</tr>
<tr>
<td>B</td>
<td>1.34</td>
<td>11.24</td>
<td>28.52</td>
<td>10.59</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>1.56</td>
<td>11.28</td>
<td>39.04</td>
<td>7.90</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>1.71</td>
<td>11.24</td>
<td>48.31</td>
<td>5.86</td>
<td>5.0</td>
</tr>
<tr>
<td>C</td>
<td>1.21</td>
<td>14.30</td>
<td>31.26</td>
<td>10.79</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>1.38</td>
<td>14.72</td>
<td>41.39</td>
<td>8.21</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>1.47</td>
<td>14.30</td>
<td>45.94</td>
<td>7.00</td>
<td>6.2</td>
</tr>
</tbody>
</table>

Fig. 4. Relations between the amount of water absorption and square root of elapsed time for Bentonites B and C

Fig. 5. Relationship between water diffusivity and degree of saturation of bentonites.

O: \( \rho_d = 1.8 \) g/cm\(^3\), □: \( \rho_d = 1.6 \) g/cm\(^3\), △: \( \rho_d = 1.0 \) g/cm\(^3\),

At relatively high dry density, water diffusivity of bentonites is almost constant under condition of 50% to 90% of saturation degree.
water migration is regarded as acting dominantly as hydraulic conduction. Based on the discussion presented above for the bentonite-based buffer, the dominant mechanism of water migration behavior is shown in Fig. 6.

4 CONCLUSIONS

Experiments measuring water absorption in bentonite-based buffer were done in an unsaturated state to a saturated state. The following conclusions were drawn from the experimentally obtained results and discussion.

Water migration behaviors in various powder bentonites as buffer are analogous to water-diffusion from initial water content to around 90% saturation. At more than a 90% degree of saturation, the water migration is regarded as acting dominantly for hydraulic conduction.

ACKNOWLEDGEMENTS

This study was supported through funding by a Grant-in-Aid for Scientific Research (B) from the Japan Society for the Promotion of Science (JSPS). It has also been performed as a part of activities of the Research Institute of Sustainable Future Society, Waseda Research Institute for Science and Engineering, Waseda University. Furthermore, some research was conducted with support from “Human Resource Development and Research Program for Decommissioning of Fukushima Dai-ichi Nuclear Power Station” by the Japan Ministry of Education, Culture, Sports, Science and Technology. The author also thanks all members and students of the geotechnical laboratory, Waseda University, for their kind assistance and discussion.

REFERENCES