Internal Erosion Characteristics Focusing on the Seepage Flow Energy Using Artificial Granular Material

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1. Introduction

Internal erosion is a natural phenomenon in which fine soil particles are removed from the ground through seepage. Figure 1 illustrates the mechanism of internal erosion through dikes and embankments. Consequently, the voids within the soil profiles increase, causing a remarkable decrease in the bearing capacity of the embankment. It is considered one of the most common factors for embankment collapse and deterioration.

Based on previous studies, permeability tests were conducted using several soil mixtures by varying the fines content (FC). The term FC refers to the mass percentage of fine soil particles to the total mass of the sample. Several studies focused on the incremental increase in the hydraulic gradient over time, representing the rising water levels in dams or levees. However, in reality, the water level fluctuates with time. A study focusing on the effect of the reduction of hydraulic gradient over time is lacking. Therefore, it is also essential to understand the mechanics of internal erosion under decreasing water levels. This study aims at investigating the water level fluctuation, increasing, and decreasing patterns, on the internal erosion behavior of internally unstable soils.

2. Methodology

According to the internal stability index proposed by Kenny, T. C., and Lau D.[1] and Kezdi, A.[2], the soil mixture is classified as internally unstable. A soil with high susceptibility to erosion, FC 10%, was adopted in this study to investigate the influence of internal erosion on fluctuating water levels. Figure 2 shows the grain size distribution curve of the FC10% soil used for this experiment. Figure 3 illustrates the experimental apparatus used to conduct permeability tests. First, artificial glass beads are mixed with the designated proportions, and the initial water content is set to 3%. Next, the sample is placed in 5 horizontal layers, each compacted gently using a rammer to ensure a flat, even surface, and uniform density. Then, the compacted sample is saturated with water for 24 hours before starting the test. Flow rate measurement is done every 30 minutes, and eroded soil particles are collected at the bottom of the specimen mold every 60 minutes. Figure 4 shows the adopted hydraulic gradient patterns in this study. Case 1 and Case 2 represent an increasing pattern of hydraulic gradient, while Case 3 and Case 4 correspond to the decreasing pattern.

3. Results and Discussion

Figure 5 shows the cumulative erosion rate by mass over time for 1-hour interval. The erosion rate by mass can be expressed as the following:

$$Erosion\ rate = \frac{cumulative\ FC\ mass}{Total\ initial\ FC\ mass} \times 100\% \quad (1)$$

It can be observed, as shown in Figure 5, similar erosion rate by mass trends can be observed for Case 1 and Case 2 for the initial 6 hours.

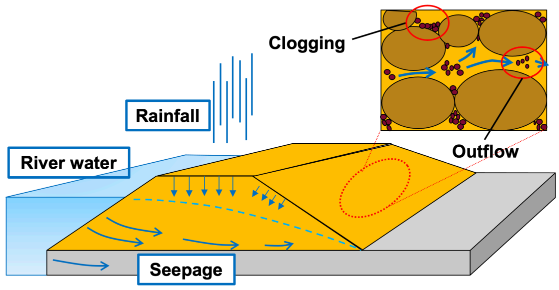

Fig. 1 Seepage flow in soil structures

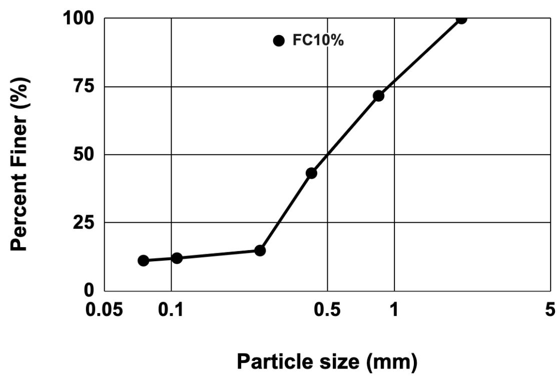

Fig. 2 Soil particle distribution curve

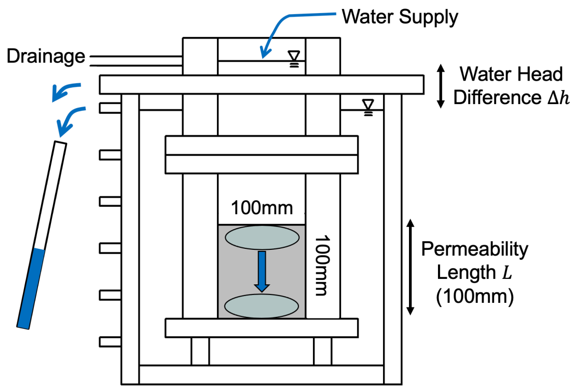

Fig. 3 Permeability testing device

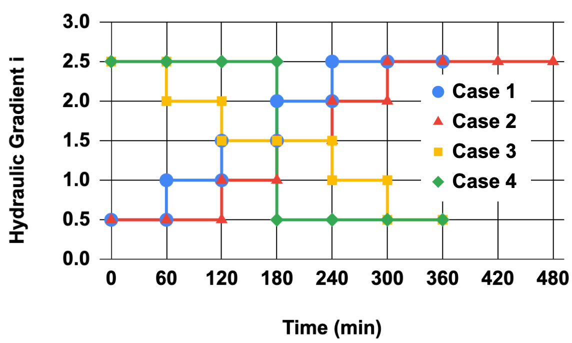

Fig. 4 Test conditions (hydraulic gradient)

The seepage energy can be expressed by

$$E_{flow}(J) = Q\gamma_w \Delta h t \quad (2)$$

where $E_{flow}(J)$ = seepage energy; Q = flow rate; γ_w = unit weight of water; Δh = head difference; and t = time.

Figure 6 represents the erosion rate increment with time for Case 2 and Case 3. It was found that the two cases subjected to inverse hydraulic gradient lines exhibit symmetrical erosion rate increments associated with the applied conditions. By comparing the erosion rate increments with their respective hydraulic gradient for the two cases, strong similarities can be seen, especially for hydraulic gradients $i = 0.5$ and $i = 2.5$.

Figure 7 shows the seepage flow history for Case 2, Case 3 and Case 4. Similar flow rates pattern could be seen for Case 3 and Case 4 during $t = 0$ to 60 (min) and $t = 270$ to 360 (min), with hydraulic gradients $i = 2.5$ and $i = 0.5$, respectively. In comparison with Case 2, the flow rate values for Case 3 and Case 4 during $i = 0.5$ yield higher than when Case 2 is subjected to $i = 0.5$ at the beginning of the experiment. It can be associated with the relatively higher initial applied seepage force for Case 3 and 4, resulting in a greater change in the voids within the soil structure, ultimately leading to higher water flow.

Figure 8 illustrates a comparison between seepage energy and cumulative erosion rate by mass percentage for Case 2, Case 3, and Case 4. For this study, it is assumed that Case 2, Case 3, and Case 4, theoretically, contain the same seepage energy level. This graph shows a converging trend towards a designated value. Although the initial seepage energy values are different for Case 3, Case 4, and Case 2 due to different hydraulic gradient patterns, the final accumulated energy converge towards the same trend and value. In the same manner, the erosion rate by mass for the three cases in Figure 8 also converges at a specific value after 6 hours. Hence, this suggests a strong relationship between seepage energy and erosion rate by mass.

4. Conclusion

Differences in hydraulic gradient line patterns result in a unique seepage flow history and erosion rate increment. The order of water seepage force exertion affects the following flow history outcome and erosion rate increment greatly. On the other hand, internal erosion (cumulative erosion rate) can be closely associated with seepage energy principles within 6 hours for the tested conditions. Regardless of the hydraulic gradient line pattern, the cumulative erosion rate by mass of specimens can be generally assumed to be equal for the case where the theoretical seepage energy is equal.

References

1) Kenney,T.C and Lau,D:Internal stability of granular filters, Canadian Geotechnical journal, Vol22, No2, pp215-225, 1985.

2) Kezdi, A.: Soil Physics: Selected Topics (Developments in Geotechnical Engineering), Amsterdam, New York, US, Elsevier Science, 1979.3

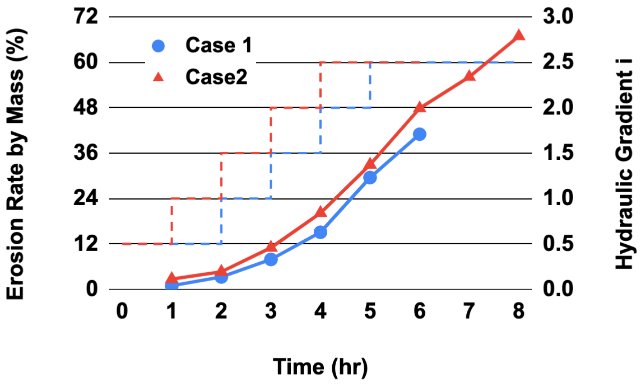

Fig. 5 Cumulative erosion rate by mass with time

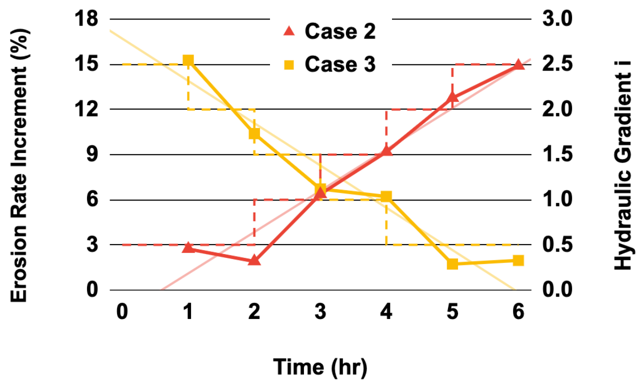

Fig. 6 Erosion increment with time

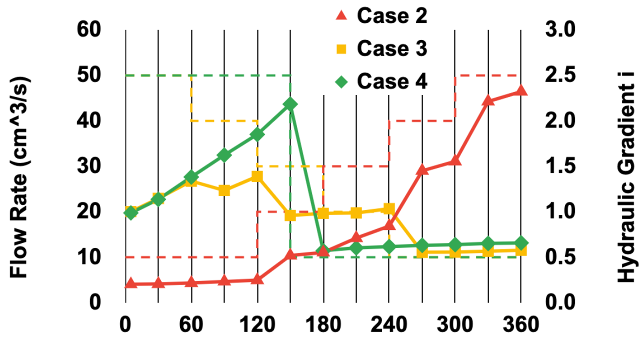

Fig. 7 Seepage flow history comparison

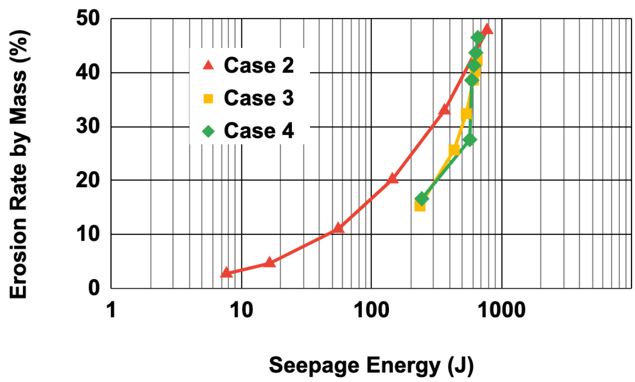

Fig. 8 Cumulative erosion rate vs. seepage energy