PERMEABILITY BEHAVIOR OF DRAIN MATERIALS USED FOR PREVENTING SAND-BOIL DUE TO LIQUEFACTION

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1. INTRODUCTION

Preceding studies showed the capability of the drain method in preventing sand-boil phenomena based on static (Nguyen *et.al.,* 2019) and dynamic centrifuge test results (Nuradi *et.al.,* 2019). The result showed the capability of highly-permeable drain material to dissipate earthquake-generated pore-water pressure quickly. Also, the use of drain material in the shallow ground was proven useful to prevent uneven deformation on the ground surface even though liquefaction occurred at a deeper soil layer. Considering such importance of drain material, in this study, a series of model tests was conducted to measure the permeability coefficient of two types of new drain materials which are proposed to be applied for the sand-boil prevention method.

2. MODEL TESTS

A model test system (Fig.1) was prepared to measure the axial-direction permeability of drain materials. The drain material (length of 2 m) was connected to two water tanks: water tank (2) and outflow water tank (3) that were set up to reproduce water head difference conditions. Overflow water tank (1) is used as a place of a water source to be filled to the water tank (2). Outflow measurement tank (4) is used to collect and measure water-overflow from the water tank (3) during the test. To ensure the drain material was placed precisely flat, triangle-shaped standing support was utilized. A submersible pump was placed in the tank (1) to pump up water from tank (1) to tank (2), and in the tank (4) to pump out water after each measurement.

In this study, there were two types of drain material tested (Fig.3 and Fig.4): Drain A (inner diameter of 8 cm) and Drain B (spiral; inner diameter of 7.6 cm). In drain A, a netron pipe is used and covered with a textile filter while in drain B the textile filter as a part of drain body is strengthened by a polyethylene frame. Additional vinyl sheets (to prevent water leakage) and carbon fiber sheets (to prevent deformation of the drains during water flowing) were attached on the peripheral surface of both drain material types using an epoxy-based adhesive. A special jig connection between the drain material and the water tank was also created to prevent water leakage.

Inner-side condition (before)

wrapped with vinyl and carbon sheet (after)

Fig. 3 Drain A

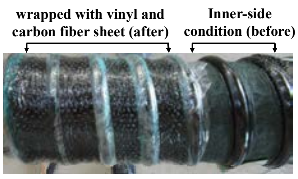

Fig. 4 Drain B

Upon starting, the water temperature was measured and the divider box (see Fig.2) was positioned to lock water flowing from tank (3) to tank (4). Using the submersible pump, tank (2) was filled with water until reaching the determined water-head level (a meter tape was attached on the water-tank to facilitate easy visual check) then keeping it at a constant water level. A hose was utilized for water-head level adjustment. Further, the water streamed down through the drain material to reach the outflow water tank (3). A timekeeper was set, then the divider box was opened to allow water flows from tank (3) to tank (4) at a given time. To reach stable water-flow for optimum experiment result, 30s and 50s measurements were set. Finally, the water-head level in tank (4) was measured after closing divider box. Water temperature after each test was also recorded. The same procedure was performed for water-head different cases (20 cm, 40 cm, 60 cm, 80 cm, 100 cm); measurement period (30s, 50s); and for both drain materials.

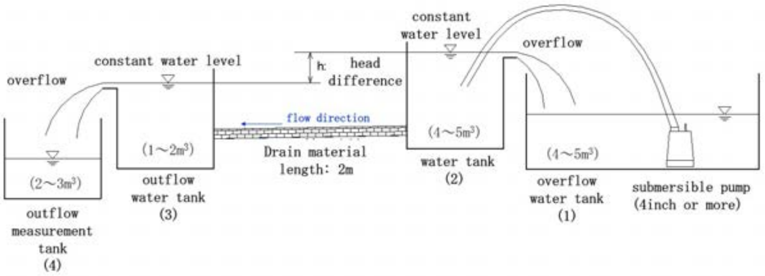

Fig. 1 Drain permeability test (sketch)

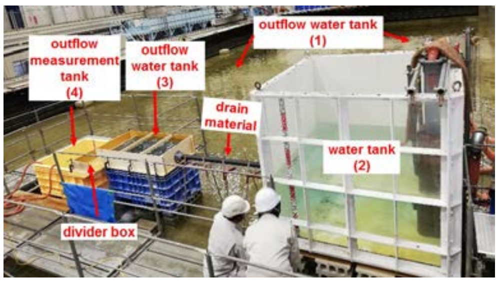

Fig. 2 Drain permeability model test

Keywords: drain material, permeability coefficient, sand-boil, DEPP
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3. EXPERIMENT RESULT AND DISCUSSION

Adopting the main principle of Darcy's law, permeability coefficient (k_T) cm/s was calculated from Eq.1, where Q is outflow volume (cm^3), i is the hydraulic gradient of drain material, A is the cross-sectional area of drain material (cm^2), and t is measurement period (s). Outflow volume Q is obtained from the head difference (initial and end) measured in tank (4) times by bottom surface area of tank (4), whereas hydraulic gradient i is the ratio of head difference (between tank (2) and tank (3)) over the length of drain material (2 m). Correction of water viscosity at a temperature of 15 degrees (k_{15}) was considered as shown in equation (2), where η_{15}/η_T is the correction factor. Thus, the permeability coefficient shown in the experiment result further is corrected permeability coefficient based on Eq.2.

$$k_T = \frac{Q}{i.A.(t_2 - t_1)} \quad \ldots(\text{Eq.1}) \qquad k_{15} = k_T.\frac{\eta_{15}}{\eta_T} \quad \ldots(\text{Eq.2})$$

Results of the experiment are provided in a non-linear reverse relationship between permeability coefficient and hydraulic gradient as shown in Fig.5. In general, the result explains that the permeability coefficient decrease as the hydraulic gradient increase which is proportional to the increase of head difference. Also, the measurement period contributes an insignificant effect on permeability coefficient behavior. Although there is a slight difference on the result of permeability coefficient as shown in Fig.5, the two new drain materials are considered to have almost the same permeability property.

The effect of head-loss is prominently seen in which permeability coefficient is higher if head-loss was considered (Fig.5b) than without considering head-loss (Fig.5a). Head-loss was taken into account in affecting permeability coefficient due to different media shapes of water flowing. In this experiment test, water flows from a square-shaped water tank (2) to a cylindrical drain. Such shape-factor is defined by a factor of $f_{e,inlet}$=0.5 and $f_{e,outlet}$=1.0 following *Weisbach* equation given by: $h_e = f_e.V^2/2g$, where h_e is head-loss over the distance (m), f_e is water head-loss factor, V (equals to Q/A) is flow velocity (m/s), g = 9.8 m/s^2. Water head-loss h_e reduced initial water head difference that also reduced hydraulic gradient in proportional. As hydraulic gradient decreased, the permeability coefficient becomes increased. In the case of considering the head-loss effect, the permeability coefficient is within the range of 1000 cm/s to 4000 cm/s that is almost more than two times higher than without considering head-loss (500 cm/s to 1500 cm/s).

The use of drain material with permeability coefficient k=100 cm/s has shown remarkable effective results in preventing sand-boil as explained in previous studies by Nguyen *et.al.* (2019) and Nuradi *et.al.* (2019) using static and dynamic centrifuge model test. It can be said that drain material with k=100 cm/s is sufficient to prevent sand-boil.

For a safety purpose, considering the well-resistance effect and inaccuracy of drain material installation, the permeability coefficient without considering the head-loss (Fig. 5a) shall be adopted in design as well as for efficiency evaluation of drain material used for earthquake-induced sand-boil prevention. Referring to Dissipation of Excess Pore Water Pressure Construction Method manual (DEPP 工法研究会, 2011) as shown in Fig. 6, the permeability coefficient of the spiral drain is similar to that of drain B in this study which head-loss was not considered, that is in the range of 500 cm/s to 1500 cm/s.

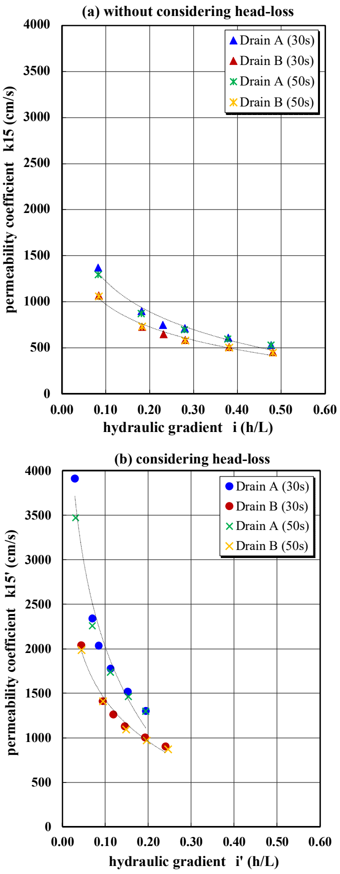

Fig. 5 Permeability of Drain A and B:
(a) without considering head-loss
(b) considering head-loss

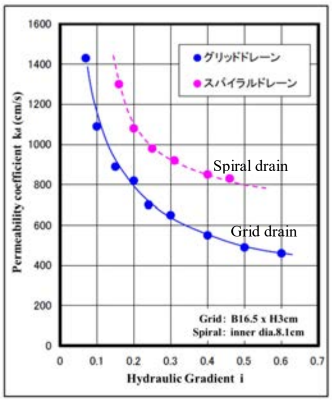

Fig. 6 Permeability of grid and spiral drains (DEPP 工法研究会, 2011)

4. CONCLUSION

A series of model tests was conducted to measure the permeability coefficient of two types of drain material. The permeability coefficient of both drains decreases with the increasing of the hydraulic gradient. The permeability coefficient was summarized in both cases of with and without considering the head-loss. Though head-loss shall be taken into account, permeability coefficient without considering head-loss should be adopted for safety design purpose. From the model test result, both drain A and B exhibit a permeability coefficient in a range of k=500 cm/s~1500 cm/s. By having such a relatively higher permeability coefficient than preceding studies, these new drain materials property can perform well to prevent sand-boil.

REFERENCES

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