An Evaluation on Discharge Capacity of Perfabricated Vertical Drains Using Large Scale Test Apparatus

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**ABSTRACT:** Discharge capacity is the most important factor to evaluate the well resistance of prefabricated vertical (PV) drains. In this study, large-scale test apparatus were devised to investigate the accurate discharge capacity of plastic board drain (PBD) and fiber drain (FD). A series of laboratory flow test of PBD and FD has been carried out to evaluate those discharge capacities with same condition in the field. Drain sample length tested ranging from 0.7m to 30m by confining the drain in clay. It is found that discharge capacity $q_w$ of PV drains decreases with increasing the confining pressure, the hydraulic gradient, and drain length. It is strongly recommended that for determining the design value of $q_w$ and $k_w$ the discharge capacity test should be performed using a half sample length of real field depth. It is found out that well resistance calculated from Onoue’s equation is underestimated comparing to that of Hansbo’s one.

**1 INTRODUCTION**

One of the largest changes in the last ten years of the use of prefabricated vertical (PV) drains and has been the change in terminology and common acceptance of their use as a soft ground improvement tool throughout the world. PV drains, in conjunction with embankment preloading and/or vacuum systems, have been widely used to accelerate primary consolidation and to eliminate most of the anticipated secondary settlements of the soft ground.

There are two kinds of PV drains; one is plastic board drains (PBD), the other is natural fiber drains (FD). PBD is band shaped products consisting of a geosynthetic filter jacket surrounding a plastic core. The size of a PBD is typically 10 cm (4in) wide by 3 mm (1/8 in) in thickness.

Lee et al. developed FD (1995), it has been used in several countries of Southeast Asia. FD is also band shaped products consisting of 4coir strands of coconut fiber core enveloped by two layers of jute burlap filter. The size of FD is 10 cm (4in) wide by 9 mm (3/8 in) in thickness.

Hansbo (1979) modified the equations developed by Barron (1948) for PV drain applications. The modified general expression for average degree of consolidation is given as:

$$U_h = 1 - \exp\left[-\frac{87}{F}\right]$$  

(1)

and  

$$F = F(n) + Fs + Fr$$  

(2)
Where, $F$ is the factor which expresses the additive effect due to the spacing of the drains, $F(n)$; smear effect, $F_s$; and well resistance, $F_r$.

Since the prefabricated vertical drains have limited discharge capacities, Hansbo (1979) developed a well resistance factor, $F_r$, assuming that Darcy’s law can be applied for flow along the vertical axis of the drain. The well resistance factor is given as:

$$F_r = \frac{\pi (L - z) k_h}{q_w}$$  \hspace{1cm} (3)

Where $z$ is the depth of the drain under consideration; $L$ is the length of the drain having one-way drainage or half this value for two-way drainage; $k_h$ is the coefficient of permeability in the horizontal direction in the undisturbed soil; and $q_w$ is the discharge capacity of the drain.

The discharge capacity defined as $q_w = A_w K_w$ is a parameter of the longitudinal permeability which can be determined by: $q_w = Q/i$. Where $A_w$ is hydraulic cross section of the drain; $k_w$ is longitudinal permeability of the drain; $Q$ is water flow through the drain; $i$ is hydraulic gradient ($\Delta h/L$).

Ordinary case, the application of PV drains is ranged from 20m to 40m. Discharge capacity $q_w$ is one of the most important factors to evaluate the drainage performance of PV drains.

Discharge capacity of PV drains considerably depends on its length. But, most of the laboratory tests have been performed using sample length of 10 $\delta$ to 100 $\delta$. They may have some problem to evaluate accurate discharge capacity. It is reasonable to perform the laboratory test using long sample, which is adjusted same length in the field. Oostveen and Troost (1990) reported the discharge capacity of the drain, depending on the drain condition, the rate of water flow, and the long discharge behavior. This paper describes variation of discharge capacity due to sample length of PV drains using middle and large scales test apparatus. And this paper is also discussed the rational sample length of PV drain in laboratory test to evaluate the discharge capacity in the field.

2 TEST APPARATUS

In this study, middle scale test apparatus (main cylinder diameter: 30 $\delta$, height: 100 $\delta$) and large scale test apparatus (diameter: 120 $\delta$, height: 200 $\delta$) as shown in Figure 1, 2 was used for evaluation of discharge capacity due to change of drain length. Test apparatus consists of large-scale steel cylinder which is similar type of triaxial device, miscellaneous equipment of outlet & inlet water tank, compressor etc.

3 TESTING METHOD

3.1 Test Procedure

The drain sample is set inside the cylinder similar to that of setting the triaxial test sample. The top and bottom pedestals are fixed at the top and bottom of the cylinder and connected to outlet and inlet water flow systems respectively.

Hansbo (1983) recognized the importance of confining the drain by clay on determining the discharge capacity. Miura et al. (1997) recommended the laboratory test that and recommended for determining the design value, the discharge capacity test should be conducted by confining the drain in clay. So, all of drain sample tested were inserted inside flexible vinyl hose with diameter of 10cm by 0.8mm in thickness.

The remolded clay with water content of 150% for easy filling in the hose is put into vinyl hose layer by layer keeping the drain in center.
One end of vinyl hose with the drain sample is fixed and sealed at the bottom pedestal, after the drain sample is arranged in the cylinder; the other end of vinyl hose is fixed and sealed at the top pedestal. The arrangement of the drain set spiral type in case of the drain length is longer than cylinder height to investigate the discharge capacity of full size length in the field.

Constant head discharge capacity test has been performed. The position of inlet water tank was changed to control the constant hydraulic gradient. But, it was very difficult to adjust the difference of water head in case that sample length is longer than 2m. In such cases, motor pump and regulator system was used. For example, drain sample length is 20m. The inlet water pressure, controlled by regulator, was adjusted 1kg/cm² (100kpa) to control the hydraulic gradient of 0.5. The water to measure the discharge capacity was mixed with seawater and distilled to keep the same degree of salinity of the field located in the coastal area.

After settling of drain, steel cylinder is filled with water for applying the confined pressure. Measurement of discharge capacity under desired hydraulic gradient is performed after 1 day for the finish of consolidation of clay.

Figures 3, 4 show test results about variation of $q_w$ with elapsed time adopted two kinds of water supplying system for the control of desired hydraulic gradient by keeping of constant head water level and controlling of regulator and pump system. The difference of discharge capacity of both systems is less than 3% after 24 hours as shown in Figures 3 and 4. That means water-supplying system used in this study has no problem to measure the discharge capacity.
4 MATERIALS USED

The PV drains adopted in this study are two kinds (PBD and FD). Figure 5 shows the picture of each sample tested. The clay was sampled from site of Busan New Port. Its index properties are: specific gravity, \( \rho_s \) of 2.68, liquid limit, \( w_L \) of 27%, passing ratio of 200# sieving of 9.83% and classified CH by USCS.

![Shape of PBD(MD88) type and FD1-D type](image)
![Shape of FD1-F type and FD3-C type](image)

Figure 5. Shape of PBD and FD tested

5 TEST RESULTS AND DISCUSSIONS

5.1 Effect of confining pressure

The effect of magnitude of confining pressure on the discharge capacity of the drain \( q_w \) is depicted in Figures 6, 7. The results show that \( q_w \) decreases with increasing confining pressure. From a practical viewpoint, it is considered reasonable to assume a linear relationship between \( q_w \) and \( \sigma_3 \) over the range of from the 1 kgf/cm² (100kpa) to the 4 kgf/cm² (400kpa). Comparing to Figures 6 and 7, \( q_w \) of the longer drain sample much more decrease due to increased of confining pressure than that of the shorter one. It may predict that the long sample occurred the relatively large creep deformation of drain due to increase of confining pressure.

![Variation of \( q_w \) with confining Pressure](image)  
(Drain length of 0.7m)  

![Variation of \( q_w \) with confining Pressure](image)  
(Drain length of 20m)
5.2 Effect of hydraulic gradient

Pradhan et al. (1991) reported that although the hydraulic gradient is the same, the resulting $q_w$ varies depending on the hydraulic head difference. Hence, it is important to execute the laboratory tests adopted the flow gradient suitable for the site condition.

To calculate the hydraulic gradient that is applicable at the site, the equation can be used:

$$i = \frac{\Delta H}{(L/2)}$$  \hspace{1cm} (4)

Where, $\Delta H$ is head of water ($= \Delta P / \gamma_w$).

Nakanodo et al. (1991), by varying the head distribution of the drain at the site, found out that the hydraulic gradient ranges from 0.03 to 0.8. Figures 8, 9 show the variation of $q_w$ with the hydraulic gradient. $q_w$ decreases with increasing hydraulic gradient. In the laboratory, the flow of water inside the drain may change from laminar flow to turbulent flow. Hence, Darcy’s law may not be applied.

Moreover, $q_w$ becomes almost independent of the hydraulic gradient. It is reasonable to assume that the flow of water from the subsoil with low permeability into the drain in laminar flows. It is therefore recommended to adopt hydraulic gradient ranges from 0.2 to 0.5 in the laboratory test. We can evidently consider from typical field example as follow: In case of drain lengths are 40m and 20m, embanking height of 3m-unit weight of embankment material of 1.8tf/m³. $i=\Delta H / (L/2)=5.4/20=0.29$. If the length of drain in 20m, we can get hydraulic gradient of 0.54.

5.3 Effect of drain length.

Figures 10, 11 show the variation of $q_w$ with the drain length. $q_w$ decreases with increasing drain length. It may come out the increase of well resistance with increasing drain length.
Typical equations for calculation of well resistance are two proposed by Hansbo(1983) and Onoue(1988) as follows:

\[ F_r = \pi (L - z) \frac{k_h}{q_w} \]  

\[ L_{CWR} = \frac{32 k_h}{\pi^2 k_w} \left(\frac{L}{d_w}\right)^2 \]  

Where, \( L_{CWR} \) is the coefficient of drain well resistance; \( k_w(q_w/A_w) \) and \( k_h \) are the permeability coefficient of drain and undisturbed soils respectively; \( d_w \) is diameter of drain.

The Standard Drain Discharge Test is not defined the drain sample length. From this investigation, it shows that the drain sample length is important factor affecting the discharge capacity. Table 1 shows the variation of \( q_w \) and \( k_w \) with the drain sample length. Figures 12~15 show calculated well resistance; \( F_r \) and \( L_{CWR} \) of PBD and FD adopted typical clay \( (k_h = 1 \times 10^{-7} \text{cm/s}) \) and silty \( (k_h = 1 \times 10^{-5} \text{cm/s}) \) ground. It seems that the well resistance can vary with increasing of drain length.

### Table 1. The variation of \( q_w \) and \( k_w \) with drain sample length

<table>
<thead>
<tr>
<th>Sample length (m)</th>
<th>PBD</th>
<th></th>
<th>FD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( q_w ) (cm³/s)</td>
<td>( k_w ) (cm/s)</td>
<td>( q_w ) (cm³/s)</td>
</tr>
<tr>
<td>0.4</td>
<td>96</td>
<td>4.889</td>
<td>-</td>
</tr>
<tr>
<td>0.7</td>
<td>18</td>
<td>0.916</td>
<td>3.4</td>
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<tr>
<td>2.0</td>
<td>8.5</td>
<td>0.432</td>
<td>1.8</td>
</tr>
<tr>
<td>4.0</td>
<td>7.4</td>
<td>0.376</td>
<td>1.6</td>
</tr>
<tr>
<td>10.0</td>
<td>5.5</td>
<td>0.280</td>
<td>1.4</td>
</tr>
<tr>
<td>20.0</td>
<td>5.0</td>
<td>0.254</td>
<td>1.2</td>
</tr>
<tr>
<td>30.0</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
</tr>
</tbody>
</table>
In basis of a series of laboratory test, test result using short sample at the discharge capacity test may lead to underestimate the well resistance. It is recommended that drain sample length should be adjust a half of installed one is the site. It may consider that the accurate well resistance can calculate using long sample with a half of real length in the field. Onoue (1988) modified Yoshikuni and Nakanodo (1974) equation for axisymmetric flow the average degree of consolidation, $\bar{U}_h$ on a horizontal place as follow:

$$
\bar{U}_h = 1 - \exp \left( \frac{-8T_h}{(F(n') + 0.8L_{CWR})} \right)
$$

(7)

Onoue (1988) considered $0.8L_{CWR}$ of well resistance for calculation of average degree of consolidation with radial flow as shown in equation (7).
Figure 16 shows the comparison of Fr by Hansbo (1981) and $0.8L_{CWR}$ by Onoue (1988). It seems that well resistance calculated from Onoue’s equation is underestimated compared to that of Hansbo’s one.

7 CONCLUSION

From the discharge capacity test of PV drains in the laboratory, following conclusions can be drawn:

1) It is confirmed that large-scale test device is available to evaluate the discharge capacity of PV drains with the same condition of in-situ.

2) The discharge capacity of PV drains is largely depending on the drain sample length. It is strongly recommended that for determining the design value of $q_w$ and $k_w$, the discharge capacity test should be performed using a half sample length of real field depth.

3) Well resistance calculated from Onoue’s equation is underestimated compared to that of Hansbo’s one.

8 REFERENCES


