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A Study to Determine the Location of Perforated Drainpipe in a Levee for Controlling the Seepage Line

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Abstract

Levees are facilities constructed along river to protect floodplains against flooding. However, levee failures are also possible if seepage reaches landside surface of the levee. The seepage on the surface of the landside slope can be prevented by efficient design of levee drainage systems. This study aims to show the seepage control potential on levees by installation of perforated drainpipes, which was verified through hydraulic experiments. Scenarios were performed with four different water stages at riverside. For each scenario, the piezometric heads located at the bottom of the experimental levee were measured. The results of the hydraulic experiments showed that the precise positioning of perforated drainpipes is vital since it greatly affects the amount of seepage in the levee. The SEEP/W model that was calibrated and verified with the experiment results was used to suggest appropriate installation location range of the perforated drainpipe. From the numerical simulation, as the central location of perforated drainpipe is closer to landside levee toe horizontally and to foundation surface vertically, the safety of levee was increased from the seepage failure.

Keywords: *seepage, levee, perforated drainpipe, hydraulic experiment, SEEP/W*

1. Introduction

A levee is a soil-made hydraulic structure constructed along the stream to prevent scouring (Korea Water Resources Association (KWRA), 2009). Levees should be designed and constructed accordingly to avoid levee failures, since the main purpose of the structure is to protect lives and properties. However, due to the occurrence of heavy torrential rainfall, especially during summer season, small and large levees were frequently failed in many places throughout the world. Levee failures of Gwangam, Baeksan, and Gahyeon levees resulted to extensive damages to surrounding areas in the Republic of Korea (Kang *et al*., 2014). In the case of Sacramento–San Joaquin River Delta in the United States, levee failures were yearly observed at a rate of 1.3, after 1990. Furthermore, the levees around the Mississippi River were devastated, due to hurricane Katrina in 2005 and heavy rainfall in 2011, which caused massive property and life casualties.

Levees are primarily made of soil and rock embankments. These embankments can fail due to various reasons, such as: 1) overtopping; 2) erosion; 3) excessive seepage, through the levee or its foundation, where the fluid velocity exceeds the threshold required to initiate erosion of the material in the levee, causing internal erosion called piping; and 4) structural failure (Hopf, 2011; Yoon, 2004). In this study, the appropriate design techniques to prevent levee failure due to excessive seepage will be discussed. KWRA (2009) introduced three seepage control methods to address the issue: 1) enlargement of the levee body; 2) the covering method, by paving the slope of levee in riverside; and 3) the construction of cutoff wall to prevent seepage line in foundation of levee. Though these seepage control methods are proven to be effective, the constructions for these methods are complex and expensive.

The U.S. Army Corps of Engineers (USACE) (2000) proposed a drainage system with riprap on the landside levee toe which can reduce the height of the seepage line and prevents the occurrence of surface saturation at the landside slope of the levee. Japan Institute of Construction Engineering (JICE) (1998) also presents a similar approach of drainage system for levees. The only difference between the two drainage systems is the shape of the drainage systems. In the case of the USACE (2000), the drainage system is triangular; while the JICE (1998) utilizes a rectangular drainage system. However, studies regarding the utilization of such drainage systems for seepage control are limited. In Japan, the drainage systems installed, from year 1995, were designed based from hydraulic experiments, and it is suggested to design the levee with twice the safety factor (Kang *et al*., 2013).

In 1960s, when numerical analyses were already actively

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conducted, investigations on the seepage mechanism in soil or other mediums were also initiated (Taylor and Brown, 1967; Neuman and Witherspoon, 1970; Desai, 1973). Recently, studies regarding levee seepage control are continuously being investigated. Liu and Yang (2001) utilized an integrated method, by combining both the analytic method and one-dimensional finite difference method, to analyze the levee safety against blowup failures, by weighing the soil layer like berm at the toe of levee at the landside. Korea Institute of Construction & Transportation Technology Evaluation and Planning (2006) analyzed the seepage controlling effects of the rectangular drainage system with riprap, through the utilization of a numerical analysis program called SEEP/W. Choi (2007) also evaluated the safety of installing levee cutoff walls, which was tested in different installation locations, in preventing seepage in levee foundations through SEEP/W program. Gong *et al.* (2012) determined the efficiency of the levee drainage system with ripraps as a seepage controlling measure, through the comparison of the results from experimental and numerical analyses. As a result, the rectangular drainage system introduced by JICE (1998) was found to be slightly more effective than the triangular drainage system introduce by the USACE.

The utilization of perforated pipe is more convenient in terms of construction technicality and is also economically efficient. Numerous countries such as Netherland, Germany, Europe, and more, are currently utilizing the perforated drainpipe in levees for seepage control measure (JICE, 1998). However, there are no current specifications regarding the installation of perforated pipes. Therefore, various hydraulic experiments and numerical analyses on the efficiency and safety of utilizing perforated drainage pipe, as seepage control measure, will be evaluated in this study. Furthermore, the installation position of the perforated pipe, to maintain the safety of the levee, will be presented as a dimensionless index.

2. Methodologies

2.1 Concept of Seepage Control by Perforated Drainpipe

Concept of seepage control method by drainage system with riprap that is located in landside levee toe is to prevent piping by draining quickly rainfall and stream seepage flow through levee body (JICE, 1998). The drainage system with riprap drain of levees consists of three parts as shown in Fig. 1. First, it consists of a drain located at the landside levee toe to drop seepage line in the levee body. Second, a filter that prevents fine soil particles from the levee to be transported to the ripraps that can eventually lead to perforation blockages. And lastly, drainage discharges

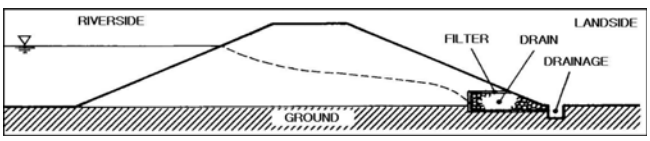


Fig. 1. Plan View of a Levee with Riprap Drain System (JICE, 1998)

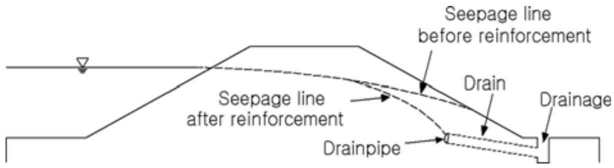


Fig. 2. Cross-sectional View of a Levee with the Perforated Drainpipe

seepage flow to landslide.

The aim of this study is to determine the applicability of utilizing perforated drainpipe, instead of utilizing drain with riprap system, as seepage control measure. Fig. 2 shows the cross-sectional view of a levee installed with perforated drainpipe.

2.2 Levee with Perforated Drainpipe Design

2.2.1 Experimental Levee Design

To be able to experiment on seepage control on levees, an experimental levee with dimensions of 12.5 × 0.6 × 1.05 m was built inside a water tank. Furthermore, 13 piezometers and measuring tape were installed, at 0.3 m interval, to be able to determine the piezometer head of the levee during seepage.

Figure 3 shows the schematic diagram of the experimental levee with dimensions. The experimental levee has the following dimensions: bottom width of 2.8 m, top width of 0.4 m, levee height of 0.6 m, levee foundation height of 0.3 m and it has a slope of 1:2.

KWRA (2009) suggests that the levee slope be observed at 1:3. However, the specification codes were changed in year 2005, and most of the existing levees use the 1:2 slope design. Therefore, in this study, for the purpose of representing most of the existing levees, the experimental levee slope of 1:2 was used for the hydraulic experiments.

2.2.2 Design of Perforated Drainpipe

JICE (1998) stated that the design criteria for the hydraulic gradient of the drainage system should be less than 0.3. However, detailed description of these specific design criteria is not found in any design specifications document. In practice, Japanese engineers determine the size of the drainage system based on the results of the hydraulic experiments performed. Therefore, in this study, a simplified approximate equation of determining the saturation surface length, L, in landside (Das, 2005), was utilized to determine the expected seepage line, and is summarized in Table 1.

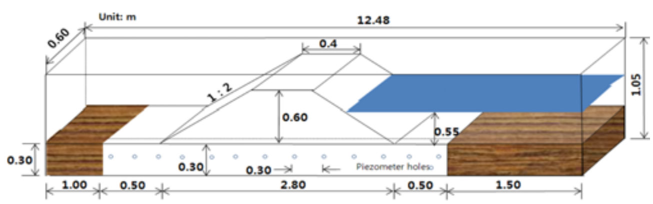
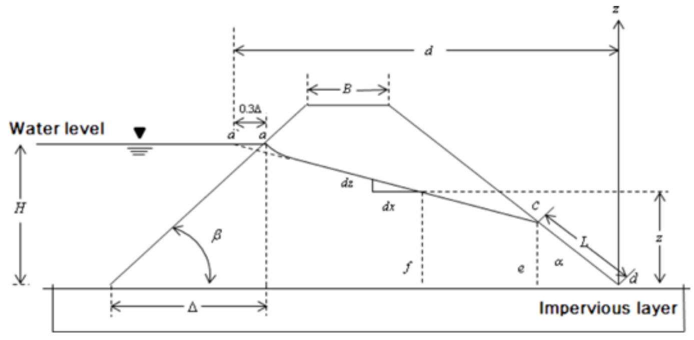


Fig. 3. Schematic Diagram of the Experimental Levee with Dimensions

Table 1. Calculation of Saturation Surface Length on the Landside of Levee



α	$\alpha = \tan^{-1}(0.5) = 26.565°$
Δ	$\Delta = 550 \times 2 = 1100$ mm
d	$d = 2800 - 0.7\,\Delta = 2800 - 0.7 \times 1100 = 2030$ mm
L	$L = \frac{d}{\cos\alpha}\sqrt{\frac{d^2}{\cos^2\alpha} - \frac{H^2}{\sin^2\alpha}}$ $L = \frac{2030}{\cos(\tan^{-1}0.5)} - \sqrt{\frac{2030^2}{\cos^2(\tan^{-1}0.5)} - \frac{550^2}{\sin^2(\tan^{-1}0.5)}}$ $L = 362$ mm

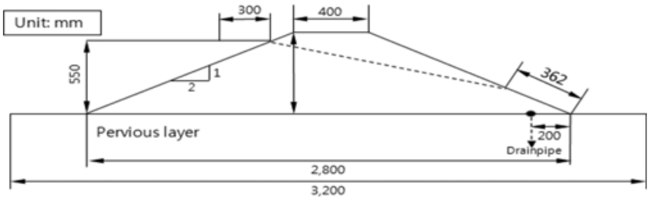


Fig. 4. Design of Experimental Levee with the Perforated Drainpipe

By considering the determined saturation surface length, the location of the perforated drainpipe was determined to be 0.2 m horizontly from the landside levee toe. And the thickness of the foundation layer from the bottom of the levee, which is where the perforated drainpipes are installed, was determined to be 0.3 m. The hydraulic gradient of the perforated drainpipe was determined to be 0.23 and thus satisfies the design criteria of the drainage system in accordance with the JICE (1998), and as shown in Fig. 4.

Figure 5(a) shows the installation of the perforated drainpipe within the foundation of the levee. And Fig. 5(b) shows the front view of the experimental levee with the perforated drainpipe installed.

2.2.3 Material Used for the Experimental Levee and Perforated Drainpipes

Permeability tests and particle size analyses were conducted on the material used for the construction of the levee body. The permeability test results are summarized in Table 2. The hydraulic conductivity of the material was determined through permeability experiment, and the result was 3.06×10^{-3} cm/sec. And the material

Table 2. Permeability Test Results for the Material of Experimental Levee

Hydraulic conductivity k (cm/sec)	Water content ω (%)	Initial void ratio e_0	Dry specific weight γ_d (gf/cm^3)	Wet specific weight γ_t (gf/cm^3)
3.06×10^{-3}	7.820	0.721	1.525	1.644

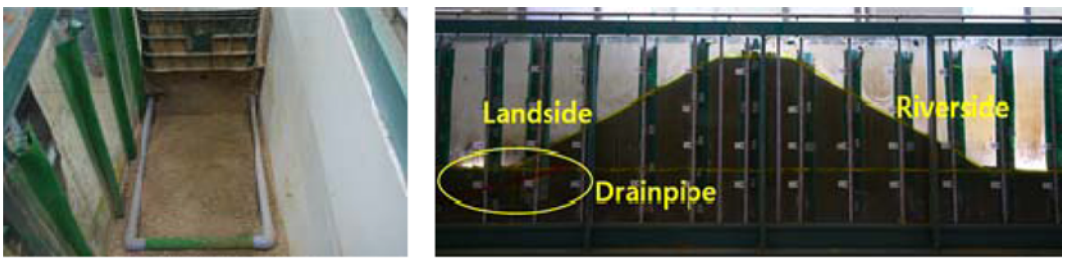
Table 3. Particle Size Analysis for the Material of Experimental Levee

USCS	Specific gravity (G_s)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
SM	2.63	19.49	64.79	8.02	7.69

was classified as Silty Sand (SM), according to the Unified Soil Classification System. The results of the particle size analyses for the material used for the construction of experimental levee are summarized in Table 3.

KWRA (2009) stated that soil materials with hydraulic conductivity of 1.0×10^{-3} cm/sec or less should be used for levee construction. However, in this study, the hydraulic conductivity of the material used is three times higher than that of the standard stated by KWRA (2009). A material with higher hydraulic conductivity means that the material is not suitable to be used for levee construction, as it opposes its purpose to avoid seepage from the riverside to the landslide of the levee. Nevertheless, the material silty sand was used to determine the effectiveness of utilizing perforated drainpipes as seepage control in levees.

Meanwhile, JICE (1998) utilized a material of drainage system with hydraulic conductivity a hundred times greater than the



(a) (b)

Fig. 5. Construction of Experimental Levee with the Perforated Drainpipe: (a) Installation of Perforated Drainpipe, (b) Experimental Levee with Perforated Drainpipe

hydraulic conductivity of levee body. Although hydraulic conductivity of perforated drainpipes is very high, the coefficient was determined as conductivity of non-woven fabric because the perforated drainpipe would be wrapped by the non-woven fabric to prevent soil particle influx into the system. In this study, the hydraulic conductivity of the non-woven fabric used was 1~100 cm/sec which is a hundred time greater than the hydraulic conductivity of the levee body, and thus satisfies the standards given by JICE (1998).

2.3 Experiment Results for Seepage Control of Levee by Perforated Drainpipe

To determine the seepage control of the levee, the water inflow into the water tank was managed to maintain steady state of the seepage line. The experiment was performed with four different stages at the riverside (i.e., 60, 70, 80, and 85 cm). Moreover, three cases were performed based on the installation height of the drainpipe and ratio of the perforation area which is summarizes in Table 4. The main purpose of this experiment focuses on determining the effectiveness of the drainage system as a seepage control measure by measuring piezometric heads and monitoring state transformation of the landside levee slope.

Figure 6 shows the results of the hydraulic experiment using perforated drainpipe for seepage control measure for the three cases. For Case 1, the maximum water stage at the riverside was 85 cm, the ratio of the perforation was 5%, and the installation height of the perforated pipe was at 30 cm from the foundation bottom as shown in Fig. 6(a). Though the water stage at the riverside was almost same as the levee top elevation (i.e., 95 cm), the seepage flow through the levee body was properly drained through the perforated pipe steadily. However, a certain amount of ponding had been developed on the foundation surface in the landside. Meanwhile, the water stage at the riverside for Case 2 was 80 cm, the ratio of the perforation was 5%, and the installation height of the perforated pipe was at 27 cm from the foundation bottom as shown in Fig. 6(b). In the case of Case 2, the landside slope started collapsing 10 minutes after the water stage at the riverside was maintained to 80 cm. In other words, some seepage flow was not drained into the perforated drainpipe and the saturation surface of the landside slope was exposed and thus caused failure due to piping. Therefore, there are no measured results for experiments with two water stages (80 and 85 cm) for the Case 2 (Fig. 6(b)). For Case 3, the maximum water stage at the riverside was 85 cm, the ratio of the perforation was 10%, and the installation height of the perforated pipe was at 30 cm from the foundation bottom as shown in Fig. 6(c). Similar with Case 1, the seepage flow was properly drained through the drainage pipe. However, there were no visible ponding at the foundation surface in the landside.

Table 4. Experiment Cases by Height of Drainpipe and Ratio of the Perforation Area

Case	Height of drainpipe center from the bottom	Ratio of the perforation area (%)	Water stage in riverside (m)	Remark
1	30 cm	5	0.60, 0.70, 0.80, 0.85	Ground surface level: 0.3 m
2	27 cm	5		
3	30 cm	10		

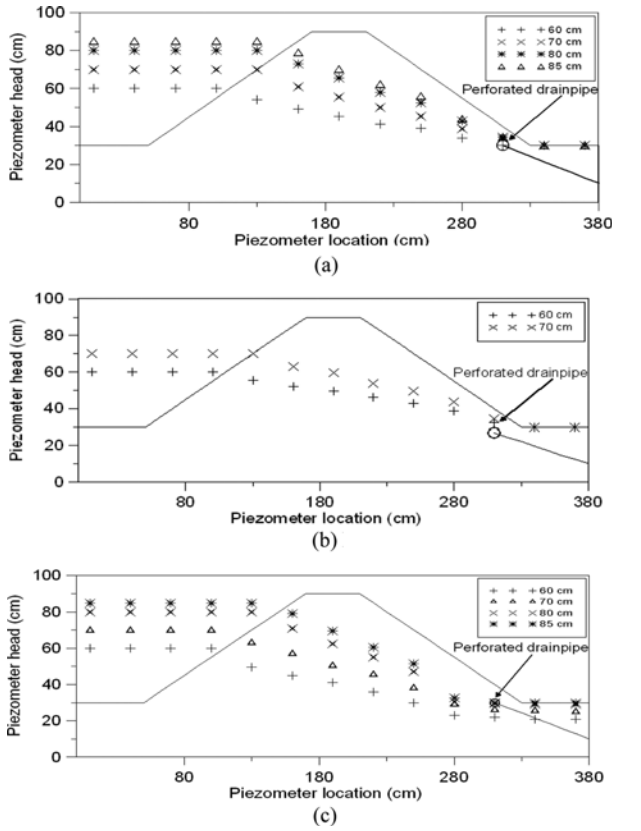


Fig. 6. Hydraulic Experiment Results of the Perforated Drainpipe for Seepage Control: (a) Height of Drainpipe Center: 30 cm; Rate of Perforation, Per Unit Area: 5% (Case-1), (b) Height of Drainpipe Center: 27 cm; Rate of Perforation, Per Unit Area: 5% (Case-2), (c) Height of Drainpipe Center: 30 cm; Rate of Perforation, Per Unit Area: 10% (Case-3)

Based from the hydraulic experiments performed it was confirmed that for utilizing the perforated drainpipe for seepage control, both the installation location and ratio of perforation, per unit area, of the perforated drainpipe should be considered. In the Case 1, it was not sure if the seepage was drained well through the perforated drainpipe since the perforation area is small. While in Case 2, as the location of the perforated drainpipe lowers, in comparison with the foundation surface elevation, the drainage efficiency decreases and thus causing levee failure.

3. Analysis by Numerical Simulation Model for Seepage Control of Levee

3.1 Numerical Simulation Model

The SEEP/W model, an accurate universal geotechnical analysis program was used to simulate the performed experiments in this study. The SEEP/W enables us to resolve analyses for various formulations ranging from simple conditions of full saturation under steady state to complicated problems of partially saturated soil under unsteady state (Geo-Slope International Ltd., 2009).

The governing equation of the SEEP/W model is a differential equation for two-dimensional seepage and is expressed in Eq. (1). It states that the net flow (flux) entering and leaving an elemental volume at a point in time is equal to the change in storage of the soil systems.

$$\frac{\partial}{\partial x}\left[k_x\frac{\partial H}{\partial x}\right]+\frac{\partial}{\partial y}\left[k_y\frac{\partial H}{\partial y}\right]+Q=\frac{\partial\theta}{\partial t} \quad (1)$$

where, H is the total head; k_x and k_y are hydraulic conductivities in the x and y directions, respectively; Q is the applied boundary flow; θ is the volumetric water content; and t is time. Under steady state conditions, the flux entering an elemental volume equals to the leaving flux at all times, and thus the right side of the equation can be neglected.

Changes in volumetric water content are dependent on changes in the stress state and the properties of the soil as presented in Eq. (2).

$$\partial\theta = m_v\partial u_w \quad (2)$$

where, m_v is the slope of the storage curve; and u_w is the pore-water pressure. And the total hydraulic head is defined in Eq. (3), which can also be rearranged to Eq. (4).

$$H=\frac{u_w}{\gamma_w}+y \quad (3)$$

$$u_w=\gamma_w(H-y) \quad (4)$$

where, γ_w is the unit weight of water; and y is the elevation. Substituting Eq. (4) into Eq. (2) gives Eq. (5), which now can be back-substituted into Eq. (1), resulting to Eq. (6). Since the elevation is a constant, the derivative of y with respect to time is eliminated, and thus leaving the following governing differential equation shown in Eq. (7); which is used in SEEP/W finite element formulation (Geo-Slope Interantional Ltd., 2009).

$$\partial\theta = m_w\gamma_w\partial(H-y) \quad (5)$$

$$\frac{\partial}{\partial x}\left[k_x\frac{\partial H}{\partial x}\right]+\frac{\partial}{\partial y}\left[k_y\frac{\partial H}{\partial y}\right]+Q=m_w\gamma_w\frac{\partial(H-y)}{\partial t} \quad (6)$$

$$\frac{\partial}{\partial x}\left[k_x\frac{\partial H}{\partial x}\right]+\frac{\partial}{\partial y}\left[k_y\frac{\partial H}{\partial y}\right]+Q=m_w\gamma_w\frac{\partial H}{\partial t} \quad (7)$$

3.2 Validation of Numerical Simulation Model

3.2.1 Composition of Numerical Simulation Model

Setting of the grid cell size, boundary conditions, and parameters, are required in order to perform numerical analysis using the SEEP/W.

Korea Institute of Construction & Transportation Technology Evaluation and Planning (2005) suggested to apply grid cell size less than 1/10 of the total dam height. Grid cell size was determined as triangular shape with 0.5×3.0×3.0 that is about 1/30 of the levee height in this study. However, in the case of the perforated drainpipe, a more detailed grid was used because there is circular perforation within the system. Fig. 7 shows composed mesh for the numerical simulation model.

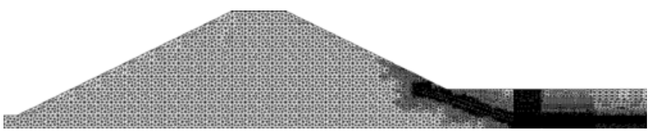


Fig. 7. Mesh for Numerical Simulation Model

The boundary conditions of the SEEP/W can be defined by parameters such as the total head, pressure head, total flux and unit flux. In the study, the boundary conditions for areas of riverside slope of which elevation is lower than or equivalent to the water surface were set to total head (the stage of the riverside). The landside slope that saturation surface could be occurred was defined potential seepage face and its total flux was set to 0.

3.2.2 Calibration and Verification of Numerical Simulation Model

The major parameters of the SEEP/W for steady stage analysis are the hydraulic conductivity ratio of vertical to horizontal $k_r = k_y/k_x$ and the relationship of hydraulic conductivity-pore water pressure. The numerical simulation model with the SEEP/W was calibrated by the experiment results. And the hydraulic conductivity ratio of vertical to horizontal and the relationship of hydraulic conductivity-pore water pressure were estimated to minimize Root Mean Square Error (RMSE) of piezometric heads between numerical simulation and experiment results (Eq. (8)). From the calibration, the hydraulic conductivity ratio of vertical to horizontal was determined to 1 and the relationship of hydraulic conductivity-pore water pressure was estimated as shown in Fig. 8.

$$RMSE=\sqrt{\frac{1}{N}\sum_{i=1}^{n}\left(Q_i-X_i\right)^2} \quad (8)$$

where, Q_i and X_i are the measured and computed time series respectively; and N is the number of data.

The numerical simulation model was calibrated to fit the

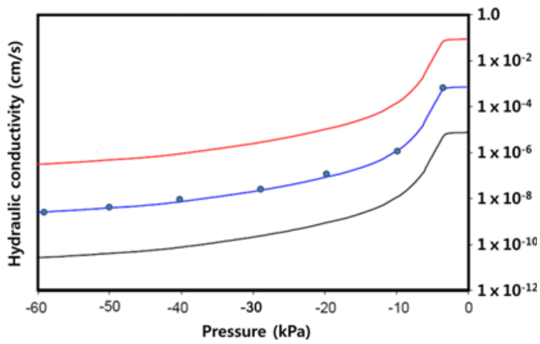


Fig. 8. Estimation of the Hydraulic Conductivity and Pore Water Pressure Relation

Table 5. Calibration Results for the Numerical Simulation Model using Case-3

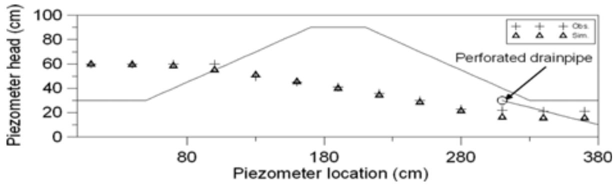
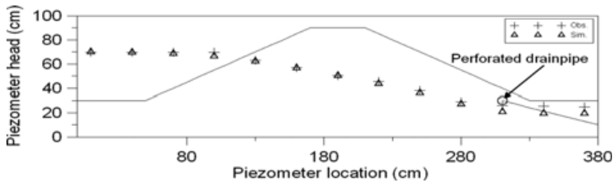
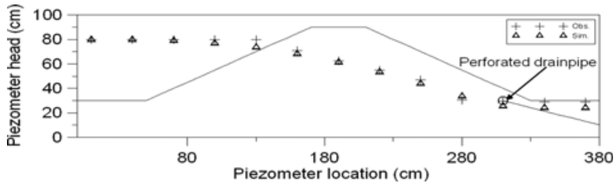
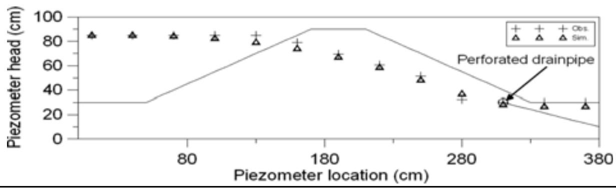
Classification		Comparison between experiment data and numerical analysis	RMSE (cm)
Case	Water stage at riverside		
Case-3	60 cm		0.86
Case-3	70 cm		0.81

Table 6. Verification Results for the Numerical Simulation Model

Classification		Comparison between experiment data and numerical analysis	RMSE (cm)
Case	Water stage at riverside		
Case-3	80 cm		0.85
Case-3	85 cm		0.90

measured data from the Case-3, where the water stages in the riverside were 60 cm and 70 cm, which are shown in Fig. 6(c). The calibration results for the model are summarized in Table 5. In order to measure the accuracy of the calibration, the RMSE for each water stage of riverside was statistically evaluated. The RMSE for each simulation using the 60 cm and 70 cm water stages were found to be 0.86 cm and 0.81 cm, respectively, which indicates that the numerical simulation model accurately simulated the results of the hydraulic experiments performed.

The calibrated model was verified with the experiment results of the Case-3, where the water stages in the riverside were 80 cm and 85 cm. The verified results were compared and were statistically analyzed by the RMSE. From the verification, for the 80 cm and 85 cm water stages at the riverside the RMSE values were 0.85 and 0.90, respectively, which shows high similarity between both data. The verification results for the numerical simulation model for the Case-3 are summarized in Table 6. Based from these results, it is evident that the numerical simulation model can accurately simulate the measured data.

3.3 Determination for Location of Perforated Drainpipe

3.3.1 Safety Evaluation for Various Locations of Perforated Drainpipe

Since the SEEP/W model was already verified in terms of performing seepage simulation, an additional analysis was performed in order to analyze the appropriate location of perforated drainpipe to secure levee safety from seepage failure. The height of the foundation was elevated from 30 cm to 80 cm, and the water stage in the riverside was also increased to 135 cm in order to analyze the safety of installing perforated drainpipe in various locations.

In this study, the safety of the perforated drainpipe based on its installing location was evaluated in three different vertical levels, and nine different horizontal distances and thus evaluating a total of 27 locations. The critical hydraulic gradient method suggested by KWRA (2009), which can be calculated using Eq. (9), was used to determine the levee safety in this study. For performing safety analysis of the levee, the hydraulic gradient (i_e) calculated through the seepage analysis should be less than the critical hydraulic gradient (i_c). Substituting the values of specific gravity

Table 7. Levee Safety Evaluation Based on the Installation Location of Perforated Drainpipe

Distance from the levee toe towards the riverside (cm)	Elevation from the foundation ground surface				Remark
	0 cm		-10 cm	-20 cm	
10	Safe	0.34	Safe (0.41)	Safe (0.47)	If $i_e < 0.5\ i_c$, safe; else, unsafe; where $i_c = 0.95$
20	Safe	0.37	Safe (0.43)	Unsafe (0.50)	
30	Safe	0.39	Safe (0.46)	Unsafe (0.54)	
40	Safe	0.42	Unsafe (0.50)	Unsafe (0.58)	
50	Safe	0.46	Unsafe (0.54)	Unsafe (0.63)	
60	Unsafe	0.50	Unsafe (0.59)	Unsafe (0.68)	
70	Unsafe	0.55	Unsafe (0.65)	Unsafe (0.75)	
80	Unsafe	0.61	Unsafe (0.72)	Unsafe (0.83)	
90	Unsafe	0.69	Unsafe (0.81)	Unsafe (0.94)	

( ): value of i_e

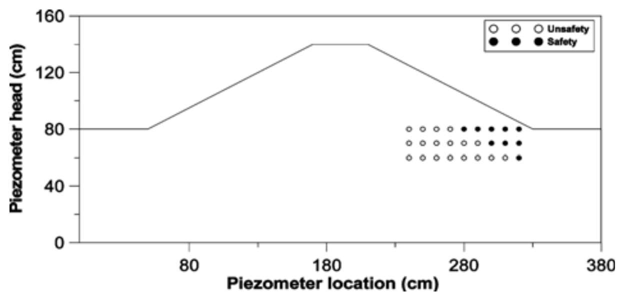


Fig. 9. Safe and Unsafe Locations for the Installation of Perforated Drainpipes

(G_s) and void ratio (e), which were previously determined through experiment and are summarized in Tables 2 and 3, in Eq. (9), the value of i_c was determined to be 0.95.

$$i_c = (G_s - 1)/(1 + e) \tag{9}$$

Table 7 summarizes the evaluation results of the levee safety by different installation locations of perforated drainpipe through the comparison of the calculated and critical hydraulic gradients. The hydraulic gradients in Table 7 are values near the perforated drainpipe calculated by the SEEP/W.

Figure 9 shows a schematic diagram of Table 7. From the results, as the central location of perforated drainpipe is closer to landside levee toe horizontally and foundation ground vertically, the safety of levee was increased from the seepage failure.

3.3.2 Dimensionless Index for Perforated Drainpipe Installation

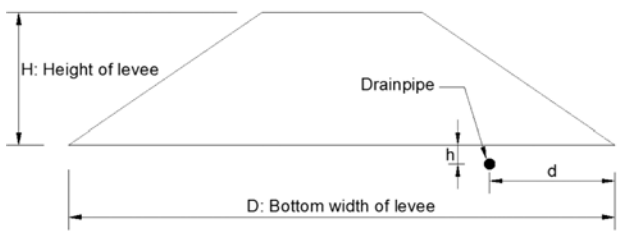
Appropriate range for installation location of perforated drainpipe was determined by using the relationship between distance of the center of perforated drainpipe from landside levee toe (*d*) and bottom width of levee (*D*), and the relationship between distance of the center of perforated drainpipe from foundation surface (*h*) and levee height (*H*) in Table 7.

Figure 10 shows the definitions for calculating the dimensionless index for perforated drainpipe installation. Based from the performed analyses the levee is considered safe from levee failure, due to seepage, if one of the following criteria is achieved: 1) h/H exceeds 0 and the value of d/D is less than 0.18; 2) h/H is greater than -0.17 and d/D is less than 0.11; 3) h/H is greater than -0.33 and the d/D is less than 0.04.

4. Conclusions

A seepage control method that prevents seepage through a levee body was evaluated by hydraulic experiments and numerical simulations in the study. Twelve experiments were conducted according to four cases condition for riverside stages variation and three cases for location of perforated drainpipe and perforation ratio. From the results, it was required that we should install a drainpipe with perforation that can drain seepage flow sufficiently and installation location of perforated drainpipe was also very important factor to prevent levee failure.

Meanwhile, the SEEP/W that is a numerical simulation model was calibrated and verified with the experiment results. Appropriate range for installation location of the perforated drainpipe that can secure safety from seepage though a levee body was determined by the model. The critical hydraulic gradient method was used to suggest levee safety from seepage and 27 locations were evaluated



Condition		Remarks
h/H	d/D	
≧ 0	≦ 0.18	Safe
≧ -0.17	≦ 0.11	Safe
≧ -0.33	≦ 0.04	Safe

Fig. 10. Dimensionless Index for Safe Installation of the Perforated Drainpipe

in the levee body. From the results, appropriate installation location of drainpipe was suggested in dimensionless index by the relationship between distance of the center of perforated drainpipe from landside levee toe (d) and bottom width of levee (D), and the relationship between distance of the center of perforated drainpipe from foundation surface (h) and levee height (H). The dimensionless indexes are as follows: (1) $h/H \geqq 0$, $d/D \leqq 0.18$, (2) $h/H \geqq -0.17$, $d/D \leqq 0.11$, (3) $h/H \geqq -0.33$, $d/D \leqq 0.04$.

Typical seepage control methods of levee body are enlargement of levee body and covering method, by paving the slope of levee in riverside. Those methods need not only additional levee site and material for levee body but also heavy cost for construction of embankment to use the enlargement method. The covering method is also expensive because concrete placing is required on riverside slope of levees. A seepage control method by perforated drainpipes can be an alternative method, which is cheaper and simpler method than the levee body enlargement method and covering method. The drainage system with perforated drainpipe also may have less the construction period than drainage system with riprap used in the USA and Japan, because the perforated drainpipe can be obtained from manufactured material and don't require quarry. So, the seepage control method with perforated drainpipes proposed in the study may be useful to secure a levee safety from seepage failure.

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