Evaluation of seepage behavior considering tidal effect at offshore waste landfill with geosynthetic liner

Myounghak Oh & Haeyong Park
Coastal Disaster Prevention Research Center, KIOST, Korea

Hyunjin Shin
Infra Engineering Team 2, SK E&C, Korea

ABSTRACT: In this study, the seepage behavior according to the extended installation of geosynthetic liner upon seabed was evaluated. Transient external water level was applied based on the tidal variation. Results show that net discharge out of landfill is positive even the internal water level was same as mean seawater level. Net discharge kept minus value while the internal water level maintained two meter lower than seawater level. Strong seepage was shown at the joint part and the net discharge out of landfill was more than 1.5 m^3/year/m^2. The amount of discharge was significantly decreased even one meter of extension on seabed. It is recommended to extend the installation of geomembrane liner on the clayey seabed in order to prevent seepage from the joint part between two different cutoff layers.

Keywords: Offshore landfill, Seepage analysis, Tide, Geosynthetic liner, SEEP/W

1 INTRODUCTION

Liner system for preventing leachate is one of the most important components in landfill design and construction. In case of offshore landfill, thick seabed sediment layer can usually be regarded as bottom liner due to the low permeability. The sides of offshore landfill need to be surrounded with structures for outer shore protection such as caisson, steel pipe sheet pile, and revetment. Hydraulic barriers should be installed around the offshore landfill in accordance with the protecting structures. Vertical cut-off walls, geosynthetic liners, impermeable clay layers can be taken into account preventing leachate. The seepage out of landfill is governed by comprehensive structure which is the combination of bottom liner, surrounding hydraulic barrier, and outer shore protecting structure. In this study, rubble mound revetment with geosynthetic liner was selected as side structure of offshore landfill.

Park et al. (2016) studied that the embedment of High-density Polyethylene (HDPE) geomembrane liner upon low permeable seabed could enhance the prevention of discharge of internal water of landfill by numerical analysis using SEEP/W. However, the effect of sea level variations by ebb and flow of the tide was not yet considered meanwhile objective maintenance water level inside landfill was thought slight below than mean sea level. The flow characteristics of groundwater can be strongly governed by the intertidal phase in coastal areas. The outward groundwater flow can be occurred at low tide. Therefore, the seepage behavior considering tidal effect should be evaluated at offshore landfill. Especially, the west coast of Korea is famous for large tidal difference. Time-dependent groundwater flow would be taken based on transient flow analysis considering intertidal phase. Therefore, net discharge was calculated to evaluate the consequent effects from tidal variation since the direction of groundwater flow can be repeatedly changed between inward and outward. In view of the maintenance of internal water level at offshore landfill, the seepage behavior needs to be evaluated with different water level inside the landfill.

The purpose of this study is to evaluate the seepage behavior under the embedment of geosythetic liner on low permeable seabed considering the tidal effect on external water table.

2 MODEL DESCRIPTION

A commercial program SEEP/W which analyzes two dimensional groundwater flow problem numerically using finite element method was used in this study. A two-dimensional plane strain revetment was assumed for numerical analysis. The cross section of revetment was cited from case of landfill in Tachibana Port, Japan. The rubble mound revetment was covered by double fill sand layers with impermeable HDPE sheets in between the layers. Seabed is assumed to be mainly composed of clayey soil, while the bottom part of rubble mound revetment was assumed to be improved for supporting upper structures enough. The geometry and dimensions of model domain are shown in Figure 1. Hydraulic conductivity values applied to seepage analysis are summarized in Table 1. Hydraulic conductivities were applied based on the research of Kwon et al. (2012). Anisotropy was also considered that 0.1 was selected as K_v/K_h assuming moderately-grown sequence of strata (Han, 1989).

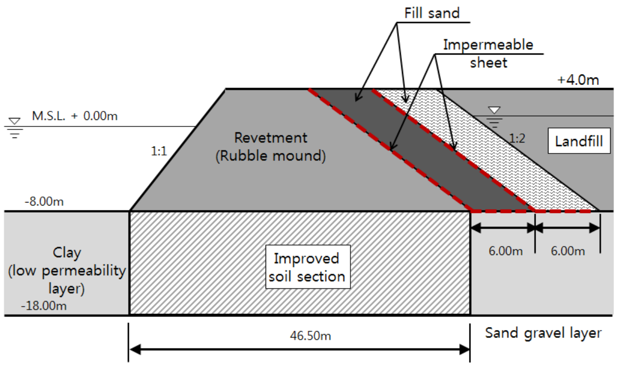


Figure 1. Two-dimensional model domain

Table 1. Hydraulic conductivity applied to seepage analysis

	k_h(cm/s)	k_v(cm/s)
HDPE(Impermeable) sheet	1.6×10^{-11}	1.6×10^{-11}
Rubble mound	1.0×10^{-0}	1.0×10^{-1}
Landfill	1.0×10^{-3}	1.0×10^{-4}
Fill sand	1.0×10^{-3}	1.0×10^{-4}
Soil improved section	5.0×10^{-4}	5.0×10^{-5}
Clay	1.0×10^{-5}	1.0×10^{-6}
Sand gravel layer	1.0×10^{-1}	1.0×10^{-2}

The revetment and fill sand layers are composed of triangular mesh, while seabed layers are composed of rectangular mesh (Fig. 2). The thickness of impermeable HDPE sheet is set as 3mm which follows Japanese standard for offshore landfill. The modeling area is limited in 200m of width and 60m of height. Outside seawater level was applied based on the one-year field records of tidal variation at west coast of Korea on 2015 from Korea Hydrographic and Oceanographic Administration (Fig. 3). Tidal variation was assumed to be repeated for 50 years. Internal water level was set as constant by intentional water management. Three different managing cases were assumed that water levels are -2m, 0m, and +2m compared to mean seawater level. Total simulation time was 50 years.

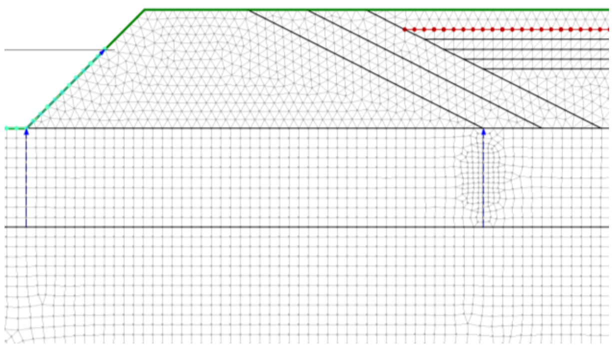


Figure 2. Mesh generation and boundary condition

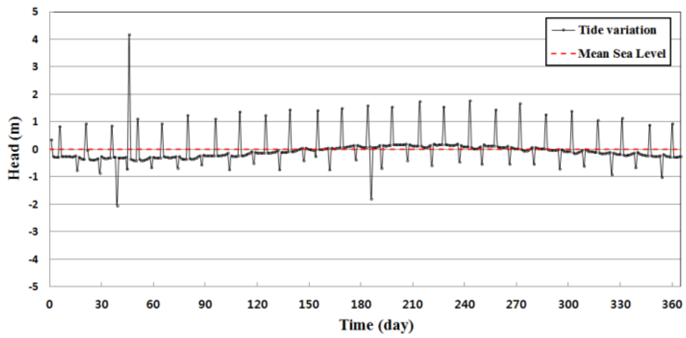
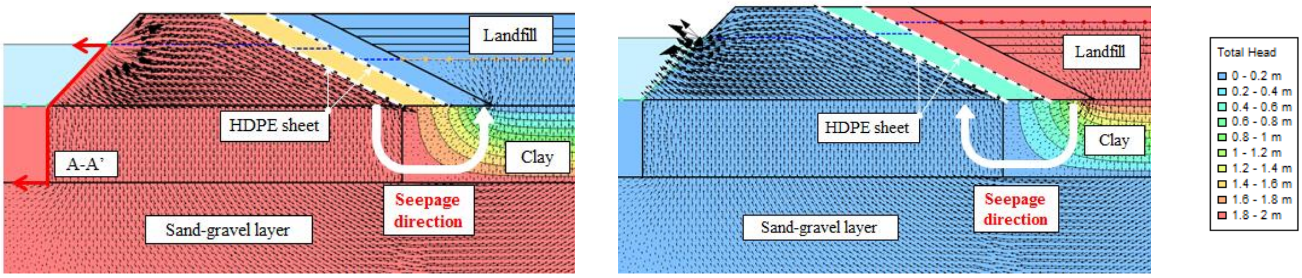


Figure 3. One-year field records of tidal variation

3 RESULTS AND DISCUSSION

Figure 4 shows total head distribution and velocity vector of model domain when seawater level correspond to the mean seawater level in steady-state flow condition. Groundwater does not flow when internal and seawater level is equal (simulation result does not need to show). Figure 4(a) shows the result when internal level is 2m lower than seawater level. Higher total head is shown at the external side of HDPE sheet and seawater infiltrates into the landfill is shown based on the velocity vectors. On the contrary, Figure 4(b) shows higher total head at the internal side of HDPE sheet. Leachate are discharged from landfill is shown based on the velocity vectors.



(a) Internal water level = -2.0m (b) Internal water level = +2.0m

Figure 4. Total head distribution and velocity vector with mean seawater level (Steady-state flow condition)

In transient flow condition, flow direction varies with time since the highest tidal is higher than any cases of internal water levels, and the lowest tidal is lower than any cases of internal water levels. Therefore, a reference section was needed to evaluate the net discharge during the simulation time. A-A' section shown in Figure 4(a) was selected as a reference line. The net discharge was calculated by accumulating the amount of discharge. In every case, results show that direction of groundwater flow had changed periodically. Figure 5 shows the cumulative discharge out of landfill over time. In case of internal water level = 0m, even the water level was maintained as well as the mean seawater level, the net discharge slightly increased to 0.11 m^3/m^2 for one year. In case of internal water level = -2m, changing pattern of net discharge seems similar to the result in case of internal water level = 0m. However, as expected, the net discharge gradually decreased to -1.80 m^3/m^2 for one year. In case of internal water level = +2m, contrastively, the net discharge gradually increased to 1.94 m^3/m^2 for one year. Table 2 shows the cumulative discharge for 50 years for each case.

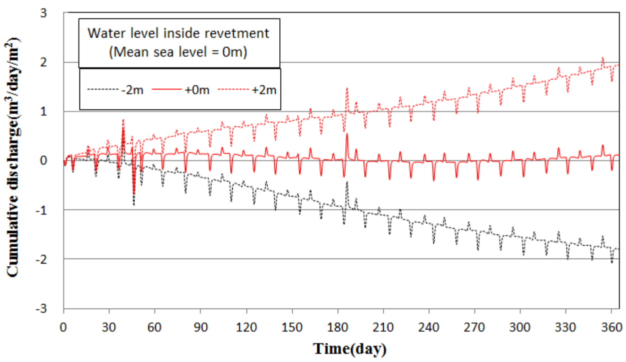
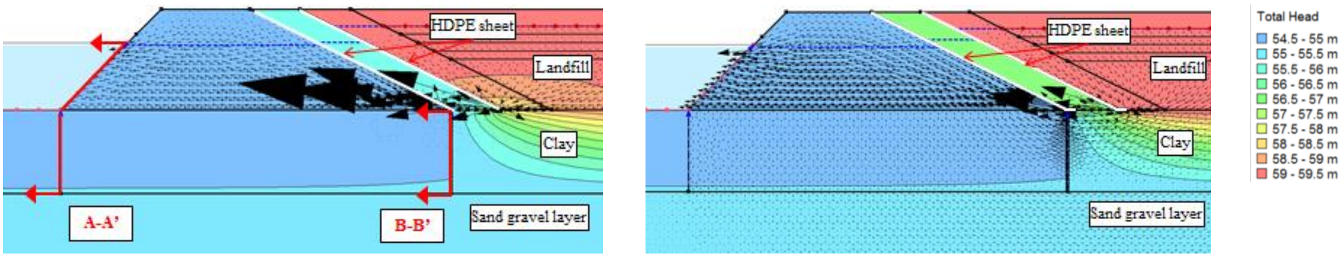


Figure 5. Net discharge out of landfill over time for one year with different water level management

Table 2. Cumulative discharge in section A-A' up to 50 years.

Water level inside revetment (m)	Cumulative discharge ($m^3/year/m^2$) with elapsed period					
	1 year	10 years	20 years	30 years	40 years	50 years
+2	1.94	20.5	41.12	61.73	82.39	102.95
0	0.11	2.27	4.64	7.02	9.40	11.77
-2	-1.80	-16.8	-33.46	-50.13	-66.80	-83.48

The seepage behavior according to the extension of geosynthetic liner was evaluated. The internal water level was assumed to be managed in unfavorable water level rising conditions such as local downpour or excessive reclamation. Hence, simulation was performed under the internal water was maintained over two meter than mean seawater level. The HDPE sheet assumed to be extended upon the seabed clay layer from 1m to 6m. Figure 6 (a) and (b) shows the seepage behavior under no extension and 1m of extension of HDPE sheet on seabed. Strong seepage was shown at the joint part between HDPE sheet and clayey seabed in case of no extension while reduced seepage was shown in case of 1m of extension. The net discharge out of landfill was calculated on A-A' and B-B' section as shown in Figure 6 to evaluate the seepage quantitatively. Figure 7 shows the net discharge through A-A' and B-B' section. The discharge was greatly decreased from 1.65 to 0.25 $m^3/year/m^2$ meanwhile additional decrement was not significant with increasing extension length.



(a) No extension of HDPE sheet on seabed (b) 1m of extension of HDPE sheet on seabed

Figure 6. Total head distribution and velocity vector with extended length of HDPE sheet

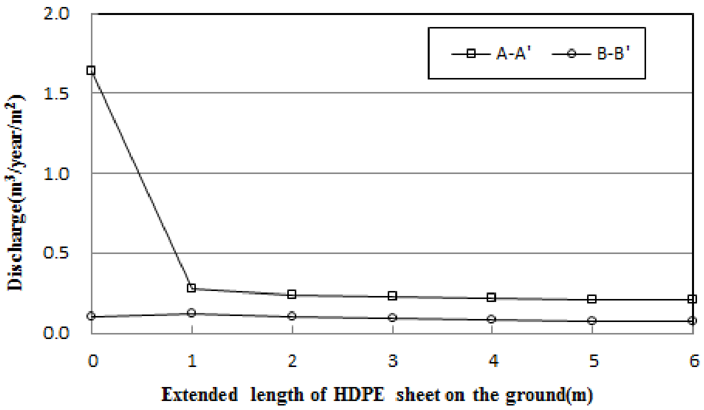


Figure 7. Discharge variation with extended length of HDPE sheet

4 CONCLUSION

The seepage behavior according to the extension of geosynthetic liner at offshore landfill was evaluated considering tidal effect using SEEP/W. The groundwater flow direction could be changed under tidal variation, so the net discharge out of landfill shows periodically fluctuating pattern. Although strong seepage was shown at joint between HDPE sheet and seabed clay layer, the net discharge could be greatly reduced by extended installation of HDPE sheet upon seabed. The decrement, however, was not significant as length of extension increased. Furthermore, analysis on contaminant transport based on seepage behavior is needed to be studied to ensure the prevention of contamination at offshore waste landfill.

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