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Feasibility of Chain Conveyor Cutter for Ocean Disposal Site's Construction

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Abstract: The concept of ocean disposal site is proven technology. One of the most concerns in ocean disposal site is the leakage of pollutants into the ocean from waste materials. In order to prevent its happening, technically, a vertical impermeable wall is constructed around the disposal site. However, the conventional method fails to guarantee zero leakage due to method's limitation. This paper presents the use of CCC (chain conveyor cutter) method to construct vertical impermeable wall. The feasibility of CCC for ocean disposal site is evaluated by means of pollutant dispersion model, and moreover, the result is compared with conventional method. The result indicates that the CCC method is technically feasible for ocean disposal site's construction. Additionally, this method shows better as for technique and economic point of view than that of the conventional method. One of advantage of CCC method is the ability to construct homogeneous wall in regard to strength and permeability, which cannot be found in the conventional ocean disposal technology.

Key words: Chain conveyor cutter, ocean disposal, soil improvement.

1. Introduction

Ocean disposal sites may be able to give a good solution for a country likes Japan which has limited space for landfill. Ocean disposal is proven technology although still need improvement, particularly pertaining to issues related with leakage of pollutants from disposal to the ocean. The leakage usually is prevented by constructing a vertical impermeable wall around the disposal site. However, conventional method faces difficulty to create homogenous wall in regards to impermeability and strength which the wall may fracture easily over time. The inhomogeneous wall is created due to conventional method's limitation. The conventional method creates the wall by excavating the soil horizontally. Accordingly this method is unable to mix the cut soil vertically. It may induce weak strata and irregular impermeability on the wall. When a continuous pressure acts on these weak and/or uniform impermeability's areas of the wall, wall will leaky and pollutant release into the ocean accordingly.

From this point of view, the CCC (chain conveyor cutter) method, which has been developed for soft-ground stabilization technology, is considered to be applied to ocean disposal site's construction. This paper presents a feasibility study of CCC for ocean disposal site construction by comparing the performance of CCC method and another conventional method through the simulation of the spread of contaminants from the waste storage area with two-dimensional advection-dispersion program, namely Dtransu-2D. CCC method, for the first time, is introduced by Mitsui Miike Coal Mine, Japan for constructing impermeable walls surrounding large settling ponds [1]. This method improves the soft ground by injecting a mixing soils and cementing materials into the ground vertically (Fig. 1).

2. Construction of Impermeable Wall by CCC

In January 2010, the CCC was adopted to the public

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Fig. 1 Chain conveyor cutter method.

works of restoring Miike Harbor in Omuta City, Japan [2]. As a part of the entire works, two settling ponds were constructed for receiving dredged materials and the CCC took part in constructing impermeable walls of those settling ponds for preventing the contaminated water from flowing out, and from disturbing the environment of the surrounding area. The specifications of the first walls were 0.75 m in thickness, 7 to 8 m in depth, a total 1,128 m long and the total area was 8,470 m^2. The requested hydraulic conductivity value of the wall was less than 1.0×10^{-6} cm/sec. For ensuring the impermeability of the wall, soil samples were taken at the site and mix design tests were conducted. The obtained values were less than 2.0×10^{-7} cm/sec which is five times less than the designated value [3]. Based on the test, the mix design was decided as follows:

◎Type of cement blast furnace cement;

◎Cement factor 150 kg/m^3 of soil in-situ;

◎Water/cement ratio 150%.

The CCC started the wall works of the first settling pond on January 23, 2010 and finished spending 35 days. The core samples taken from the constructed wall showed good results as shown in Table 1.

The hydraulic conductivity of the constructed wall is much less than designated value that was obtained from the mix design test. The productivity of the CCC was 250 m^2/day and the cost of wall production was more than 20% cheaper than those using the conventional method. Fig. 2 shows the CCC working

Table 1 Hydraulic conductivity of the diaphragm wall.

Bore hole No.	Hydraulic conductivity		
	Upper	Middle	Lower
1	4.83×10^{-8}	5.51×10^{-8}	1.70×10^{-7}
2	2.63×10^{-8}	4.11×10^{-8}	2.82×10^{-8}

at the first site.

The second work was started in April 2010 and finished in July 2010 in Arao city where located southern of Omuta city [2]. The diaphragm wall surrounding 2nd pond of second construction of impermeable wall by CCC is given in Fig. 3. The specifications of the walls were 0.75 m in thickness, 8 to 10 m in depth, a total 1,197 m long and the total area was 10,420 m^2. The requested hydraulic conductivity value of the wall was same as the first wall such as less than 1.0×10^{-6} cm/sec. According to the mix design test, the cement factor and the water/cement ratio were changed from 150 to 200 kg/m^3 of soil in situ and from 150 to 100%, respectively. This was due to the occurrence of thick layers of sand and gravel which easily passes the water and makes it difficult to establish an impermeable wall.

The actual performance of the CCC had interference caused by the hard rock filled in the ground and hard soils that were encountered. The N value of the hard ground was more than 50. In spite of the adverse conditions, the CCC finished the second work as scheduled and the samples taken from the constructed wall satisfied the target value of 2.0×10^{-7} cm/sec.

3. Application of CCC Method to Construction of Ocean Disposal Sites

The performance of an impermeable wall to prevent the leakage of contaminants from the waste storage area is the most important parameter in ocean disposal sites. The vertical impermeable wall is usually constructed by the soil improvement; however, it is difficult to construct the wall using conventional method under the condition that the ground is hard. In

Fig. 2 First construction of impermeable wall by CCC; scenery of high power CCC.

Fig. 3 Second construction of impermeable wall by CCC; diaphragm wall surrounding 2nd pond.

order to construct the impermeable wall via soil improvement, the CCC method was developed, and it is highly expected to be applied to many cases such as ground improvement and the construction of impermeable walls.

The CCC method utilizes a pile driver even if it is a chain saw type. In this method, the soft ground is strengthened by mixing the soils and cementing materials which are injected into the ground from the top of the chain through the agitation and the mixing process. The advantages of this method are described as follows:

(i) Vertically homogeneous ground is formed by mixing the soils and the cementing materials in a vertical direction.

(ii) Continuous wall of equal thickness is constructed by the CCC method since the cross-section of improved area becomes a rectangular cross-section due to the cross-sectional shape of the equipment.

(iii) Its versatility and high economic efficiency.

When an impermeable wall is constructed in ocean disposal sites, the CCC method is useful for the construction since it allows us to construct the wall which strength and permeability are homogeneous in a vertical direction [1].

In the conventional method, an impermeable wall is constructed under the ground before the construction of the embankment, followed by the construction of an impermeable wall along the slope of the embankment as shown in Fig. 4a. Thus, caisson type, slope type, sheet pile type, and the combination of them in Fig. 4a have been introduced to the embankment in ocean disposal sites [4]. On the other hand, when the CCC method is applied to the construction of ocean disposal sites, an impermeable wall is constructed through the revetment and the ground after the construction of the revetment as shown in Fig. 4b. The difference in the structure of the impermeable wall in Figs. 4a and 4b may result in the change in performance of the impermeable wall. In order to apply the CCC method to the construction of the impermeable wall in ocean disposal sites, the performance of the impermeable wall constructed using CCC method, therefore, has to be compared with walls constructed using the conventional method.

4. Analysis for Application of Construction of Ocean Disposal Sites

4.1 Analysis Model

Fig. 5 shows a schematic view of the analysis model, and the input parameters are listed in Table 2. The model was set at 50 m in height and 110 m in width, and the riprap revetment with a 10 m height was set between the ocean area and the waste storage area. The ground was set until 40 m depth, and the impermeable wall was embedded into the ground. Whereas the impermeable wall constructed using the CCC method was set as illustrated in Fig. 6, the wall constructed by the conventional method was set along the slope of the embankment as shown in Fig. 4a. Additionally, the combination of the impermeable layer and an impermeable wall was set at the slope of the embankment in the disposal site constructed using the conventional method. The impermeable layer was composed of the protection mat, the impermeable sheets, and the backfilling materials as described in Fig. 6. The layer composed of alluvial clay with 40 m in thickness was set up as the ground II under the layer composed of alluvial clay with 10 m in thickness which was set up as the ground I, as illustrated in Fig. 5. The permeability of the ground I and II was set at 1.0×10^{-4} cm/sec and 1.0×10^{-5} cm/sec, respectively. The impermeable wall was embedded into the ground

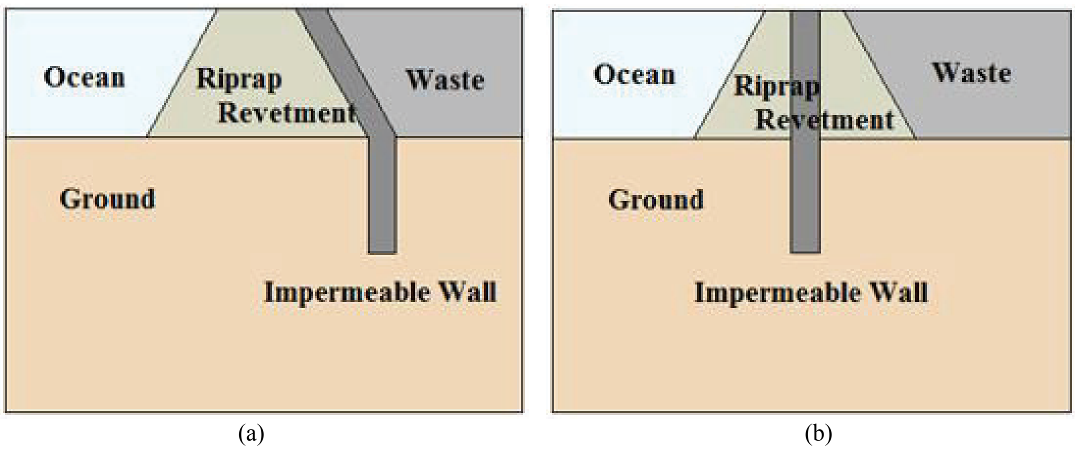

Fig. 4 Schematic view of the ocean disposal site: (a) Constructed using the current method (an impermeable wall with impermeable sheet); (b) Constructed using the CCC method.

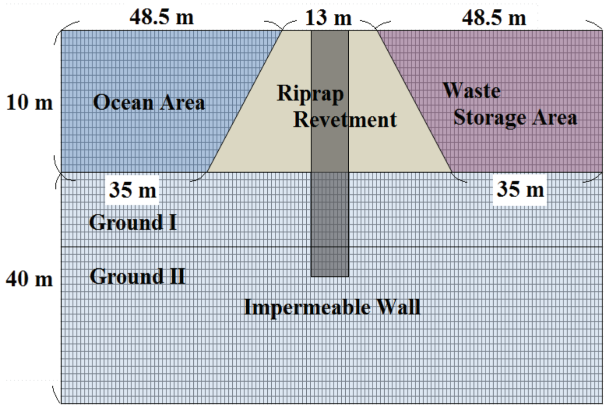

Fig. 5 Schematic view of the analysis model.

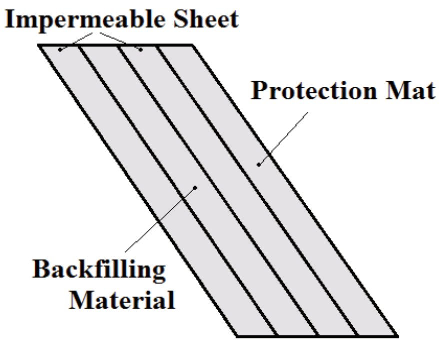

Fig. 6 Schematic view of the impermeability layer.

II until 2.5 m depth in the disposal sites constructed by the conventional method and the CCC method. The difference in hydraulic head between the ocean area and waste storage area was set at 1.0 m. The leakage of contaminants from the waste storage area was simulated for 50 years in the models. These input data was determined by reference to the past studies as summarized in Table 3 [4, 5].

4.2 Boundary Conditions

The boundary conditions of the analysis models are summarized in Table 4. The flow rate was set at zero at the bottom, right and left side of the analysis models and the top edge of the impermeable wall. Total hydraulic head was set at 10 m at the top edge of the ocean area and at 11 m at the top edge of the waste storage area as a fixed boundary: the difference in hydraulic head was set at 1 m. The concentration of contaminants was fixed at 1 in each location of the waste storage area.

4.3 Evaluation Method

Some of the regulations in the environmental standard and the acceptable concentration of contaminants in ocean disposal sites are listed in Table 5. The environmental standard referred to the regulation enacted by the Ministry of the Environment in Japan [6], and the acceptable concentration referred to the Ordinance of Prime Minister's Office [7]. The concentrations in the environmental standard are one-tenth of the acceptable standard. Therefore, it was

Table 2 Physical properties of the impermeable layer.

	Permeability (cm/sec)	Thickness (cm)
Impermeable wall	1.0×10^{-6}	100
Impermeable sheet	1.5×10^{-9}	0.3
Backfilling material Protection mat	1.0×10^{-3}	0.5

Table 3 Input data.

Permeability (cm/s)	Ground I	1.0×10^{-4}
	Ground II	1.0×10^{-5}
	Impermeable wall	1.0×10^{-7}
Effective porosity (-)	Ground	0.4
	Impermeable wall	0.1
Specific storage (1/m)		2.0×10^{-5}
Longitudinal dispersion (m)		1
Transverse dispersion (m)		0.1
Coefficient of molecular diffusion (cm^2/sec)		1.0×10^{-9}
Tortuosity (-)		0.5
Retardation coefficient (-)		1
Adsorption coefficient (1/sec)		0

Table 4 Boundary conditions.

Elements	Environmental standard	Acceptable concentration
Hydrargyrum	< 0.01 mg/L	< 0.1 mg/L
Hexavalent chromium	< 0.05 mg/L	< 0.5 mg/L
1-3-Dichloropropene	< 0.002 mg/L	< 0.02 mg/L
Tetrachloroethylene	< 0.01 mg/L	< 0.1 mg/L

Table 5 Environmental standard and acceptability standard for waste.

Hydraulic head (m)	Top edge of ocean area	10
	Top edge of waste storage area	11
Fixed concentration (-)	Top edge of waste storage area	1
Flow rate (-)	Bottom, right and left side of the model, and top edge of the impermeable wall	0

considered that the contaminants leaked from the disposal site when the relative concentration of the contaminants in the ocean area became one-tenth of the fixed concentration in the waste storage area in this study.

5. Result and Discussion of Analysis for Application of Construction of Ocean Disposal Sites

5.1 Comparison of the Performance of an Impermeable Wall

The performance of an impermeable wall constructed using the CCC method was compared to that constructed using the conventional method in an ocean disposal site. Fig. 7 shows the concentration of contaminants after 50 years in the analysis models. The area with red color indicates higher concentration of contaminants. The contaminants spread across a wide area in the disposal site constructed using the conventional method in Fig. 7a, in comparison with that by the CCC method in Fig. 7b. More than 0.1 of the concentration of contaminants was observed in the ocean area in Fig. 7a. On the other hand, the leakage of contaminants was not observed in the ocean area after 50 years in Fig. 7b. Compared to the result in the disposal site constructed using the CCC method in Fig. 7b, the contaminants, additionally, spread widely along the impermeable wall under the waste storage area in the site constructed using the conventional method in Fig. 7a. Thus, the difference in the structure of the impermeable wall in the disposal site constructed using the conventional method and the CCC method affected the performance of the impermeable wall for the prevention of the leakage of contaminants from the waste storage area. It can be said that the impermeable wall constructed using the CCC method is appropriate for the prevention of the leakage of contaminants based on the results.

Considering to the spread of pollutants along the impermeable wall in Figs. 7a and 7b, the water flow near the wall has to be discussed to clarify the transfer of pollutants. Figs. 8a and 8b show the total hydraulic head in the analysis models, and Fig. 8c illustrates the enlarged view of total hydraulic head near the impermeable layer in the site constructed using the conventional method. The equipotential lines between the points of same hydraulic head are, moreover, drawn in Fig. 8. Since the lines represent the difference in hydraulic head, the large distance between the lines indicates that hydraulic gradient becomes smaller with the decrease in water flow. Meanwhile, hydraulic gradient becomes larger with the increase in water flow when the distance of the line is small. It is in with research report of Kamon et al. [8]. In Fig. 8a, the distance of the lines is, especially, small near the impermeable wall, indicating that the flow rate is high with the increase in hydraulic gradient along the wall. Additionally, the distance of the lines became small near the impermeable layer along the slope of the revetment in

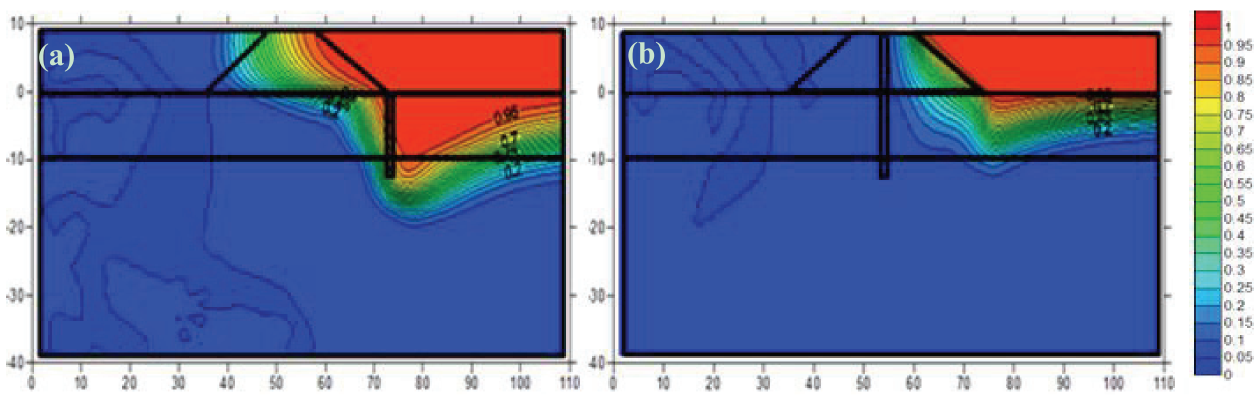

Fig. 7 Concentration of contaminants after 50 years in the ocean disposal site: (a) Constructed by the conventional method; (b) Constructed by the CCC method.

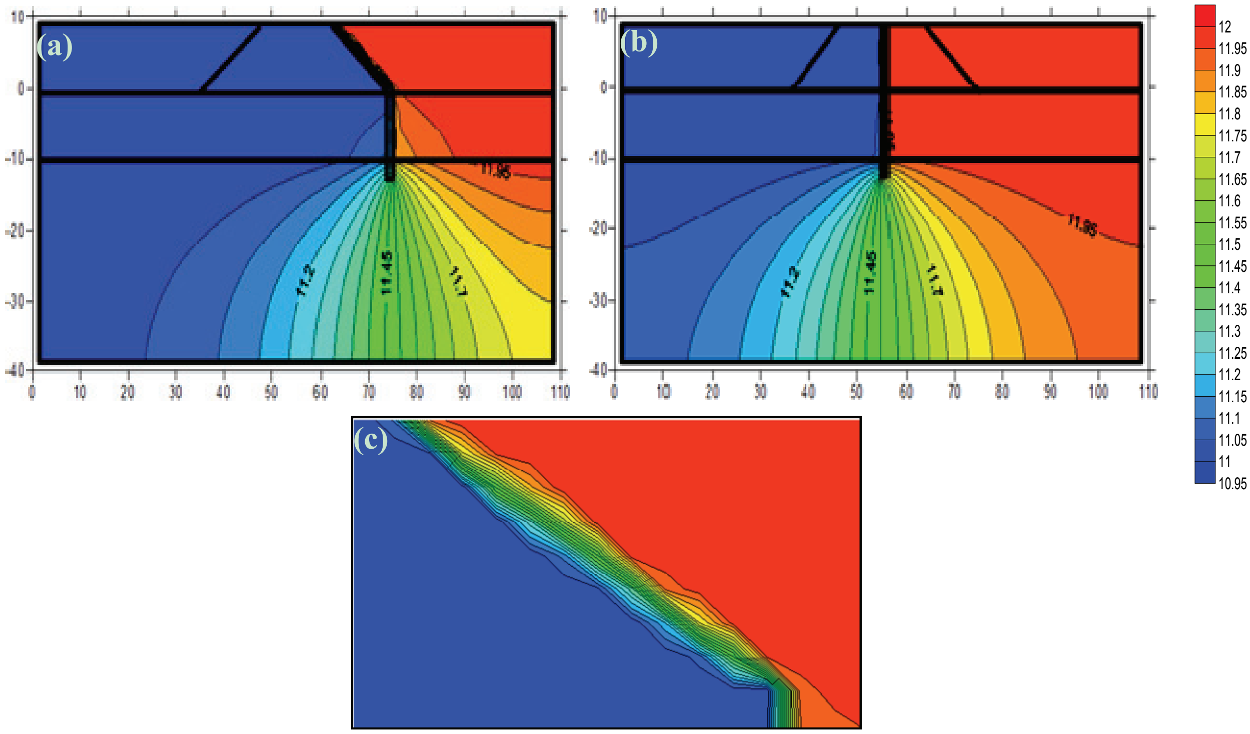

Fig. 8 Total hydraulic head after 50 years in the ocean disposal site: (a) constructed by the conventional method; (b) constructed by the CCC method; (c) enlarged view along the impermeable layer in the site constructed by the conventional method.

the site constructed by the conventional method as shown in Fig. 8c. This area corresponded to the boundary of the waste storage area and the revetment in Fig. 8a, where the concentration gradient is high since the difference in the concentration of pollutants is highest between the areas. According to the Fick's laws of diffusion, the diffusive flux is proportionate to the concentration gradient [9]. Therefore, the spread of pollutions was accelerated by diffusion and advection due to the high hydraulic gradient and concentration gradient along the slope of the revetment in the site constructed using the conventional method. In the disposal site constructed using the CCC method in Fig. 8b, hydraulic gradient was high along the impermeable wall, while the concentration gradient was high at the boundary of the waste storage area and the revetment. Hence, the contaminants spread across a wide area in the site constructed using the conventional method due to the confluence of the areas along the slope of the revetment, where the concentration gradient and the hydraulic gradient were high. In the area under the disposal storage area, the distance of the equipotential lines is small near the impermeable wall in the site constructed using the conventional method compared to that constructed using the CCC method in Figs. 8a and 8b. It also caused an increase in flow rate near the impermeable wall owing to the increasing hydraulic gradient, resulting in the spread of pollutants in a wide area in Fig. 8a.

5.2 Comparison of the Performance of an Impermeable Wall

Considering to the difference in the structure of an impermeable wall affects the spread of pollutants as discussed in the previous section, it is considered that the distance between an impermeable layer and the waste storage area may also affect the spread. For that reason, the effect of the distance of an impermeable wall and the waste storage area on the spread of pollutants was discussed in the three models as shown in Fig. 9: an impermeable wall was set at ocean side of

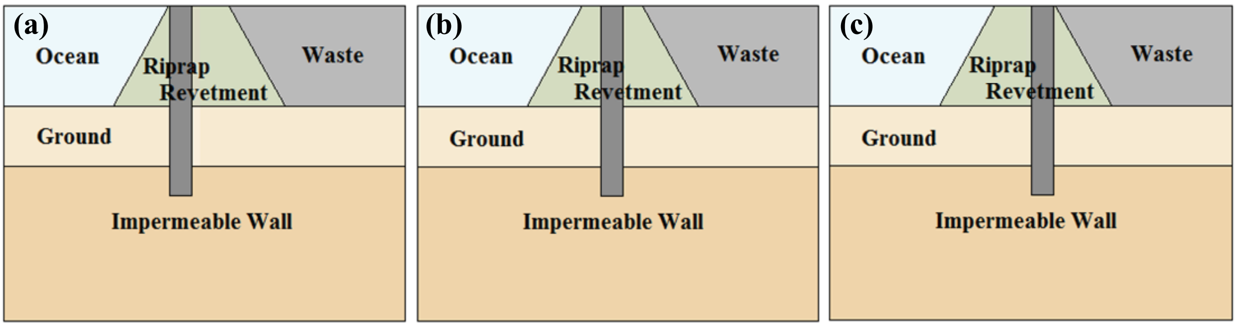

Fig. 9 Analysis model with the impermeable wall: (a) at ocean side; (b) at central point; (c) at waste storage area side.

Table 6 Time when the pollutants reach to the ocean area.

Location of impermeable wall	Ocean side	Center point	Waste storage area side
Time (year)	42	13	5

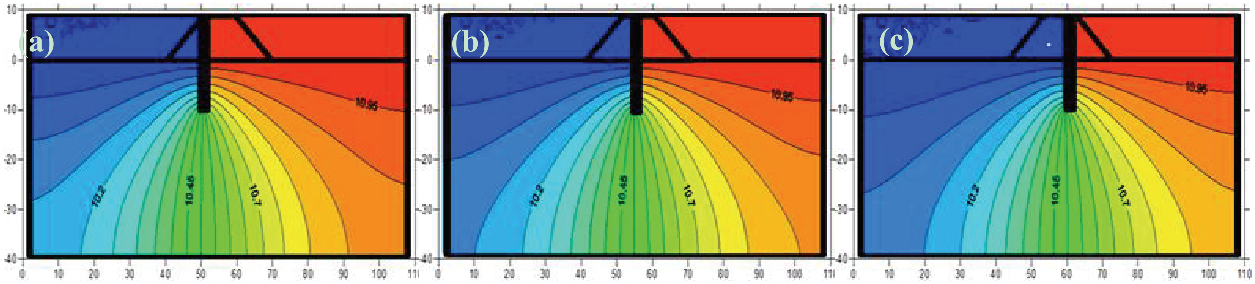

Fig. 10 Total hydraulic head in each model with the impermeable wall: (a) at ocean side; (b) at central point; (c) at waste storage area side.

the revetment in Fig. 9a, it was set at the center of the revetment in Fig. 9b, and it was set at the waste storage area side of the revetment in Fig. 9c. The location of the impermeable wall differed by 5 m in each model. In this case, the permeability of the impermeable wall was set at 1.0×10^{-6} cm/sec and that of the ground was set at 1.0×10^{-5} cm/sec in each location of the ground. The length of the embedded impermeable wall into the ground was set at 10 m from the bottom of the sea, and the thickness was set at 100 cm. The difference in total hydraulic head between the ocean area and the waste storage area was set at 1.0 m.

The time for the pollutants to reach the ocean area under each condition is summarized in Table 6. Fig. 10 shows the total hydraulic head with the equipotential lines in each model. The time decreased with the reduction of the distance between the permeable wall and the waste storage area as shown in Table 6. The distance of the equipotential lines became, furthermore, smaller in the area under the waste storage area with the decrease of the distance in Fig. 10. It shows that hydraulic gradient and flow rate were high near the impermeable wall under the waste storage area when the impermeable wall was constructed near the waste storage area. The increase in flow rate caused the leakage of pollutants from the waste storage area faster when the impermeable wall was constructed near the waste storage area. Therefore, the impermeable wall should be constructed on the ocean side for the prevention of the spread of pollutants.

6. Conclusions

Since the beginning of the development works of the CCC in 2002, the CCC demonstrated the advantage of its chain saw type mechanism in the field of constructing soil/cement mixed walls. The advantages of the CCC method include not only cost and the days spent for completing given works, but also the uniformity and quality of the constructed structure which is impossible for the existing conventional method.

Moreover, the spread of pollutants from ocean disposal sites was simulated with Dtransu-2D, aiming at comparing the performance of the impermeable wall constructed using the CCC method and the conventional method. The result indicated that the leakage and the spread of pollutants were prevented in the disposal site where the impermeable wall was constructed using the CCC method compared to the wall constructed using the conventional method. Therefore, the CCC method is proven technology that feasible to be applied to the construction of an impermeable wall in ocean disposal sites, and moreover an effective method to prevent pollutant leakage into the ocean.

Additionally, considering to the pollutants reaches to the ocean area earlier with the decrease in the distance between the impermeable wall and the waste storage area due to the effect of the high flow rate near the impermeable wall, the distance between the impermeable wall and the waste storage area in ocean disposal sites should be larger in order to minimize the effect of water flow near the impermeable wall on the spread of pollutants from the waste storage area.

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