ENVIRONMENTAL IMPACT EVALUATION ON CONSTRUCTION OF VERTICAL CUTOFF WALLS IN LANDFILL SITES

S. Inazumi[1], M. Kimura[2]

ABSTRACT: Steel pipe sheet pile cutoff walls built up by installing steel pipe sheet piles (SPSPs) in coastal waste landfill sites are important elements for preventing leakage of leaching from the reclaimed waste to the open sea. Adhesion with the peripheral ground has to be maintained in the installation of SPSPs for manifestation of the cutoff function of the SPSPs with joint sections. In this study, attention is paid to the disturbed area generated in the peripheral ground around the steel pipe sheet pile cutoff walls. Moreover, by using seepage and advection/dispersion analysis, we evaluated the impact of the disturbed area on the environmental preservation function of coastal waste landfill sites as a whole, the effect of the installation method which suppresses the formation of the disturbed area and the influence of soil improvement by the sand compaction pile method. One of the results of this study has shown that the disturbed area generated in the lower deposition clay layer greatly influences the quantity of leakage of toxic substances in a specific route. On the other hand, the installation of SPSPs by using soil cement, in which the soil improvement of the periphery ground is undertaken, is effective in suppressing the leakage of toxic substances.

Keywords: containment, environmental impact, steel pipe sheet pile, vertical cutoff wall, waste landfill site.

INTRODUCTION

In Japan, conventionally, waste landfill sites (inland landfill sites) were sought mostly in valleys among mountains in the water resource belt. However, for the purpose of preservation of water resources and for reducing the risk of pollution of the underground water environment due to seepage from the waste landfill sites, recently there is a trend to go from relatively small-scale inland reclaimed landfills to coastal metropolitan areas (coastal landfill sites) with a larger capacity for the location of waste landfill sites. According to statistical data for the year 2003, out of the total waste landfill sites, coastal landfill sites comprised 23.3% of the total capacity and, especially in the metropolitan regions, at least 80% capacity was in the coastal regions (Shimizu 2003).

Shore protection by reclamation (by using waste) in the coastal landfill sites is undertaken by making use of waste, soil generated in construction and dredging earth and sand, while planning coordination with the preservation of harbors. This is for assuring there is space for reclamation by using waste. Shore protection by waste landfill is expected to play the role of protecting the coast from external forces peculiar to the sea, namely or waves, high tides and tsunami, or any other hazardous forces such as earthquakes. At the same time, it is necessary to preserve the environment by the sideway cutoff of water, by not allowing seepage from the waste to the sea.

Recently, from the viewpoints of execution of construction works and economy, steel sheet piles are widely used mainly in coastal landfill sites for the protection of the coast by waste-reclamation (hereafter "steel pipe sheet pile cutoff wall") (Kamon and Inui 2002; Waterfront Vitalization and Environment Research Center 2002).

[1]Assistant Professor, Graduate School of Engineering, Kyoto University, K.U. Katsura Campus, Nishikyo, Kyoto 615-8540, JAPAN, Tel: +81-75-383-3262, Fax: +81-75-383-3264, (Corresponding author: Email: inazumi.shinya.3c@kyoto-u.ac.jp)

[2] Professor, Innovative Collaboration Center, Kyoto University, K.U. Katsura Campus, Nishikyo, Kyoto 615-8520, JAPAN, Tel: +81-75-383-3053, Fax: +81-75-383-3031, Email: kimura@icc.kyoto-u.ac.jp

Here, it is presumed that in the installation of jointed SPSPs, adhesion with the peripheral ground is necessary, so that it can function as a side cutoff wall.

Installation of SPSPs, which are to work in the ocean, differs from that on the ground, and transportation of long SPSPs is possible through maritime transport. Mostly one long SPSP is installed. However, the resistance during the installation of long SPSPs is great and it is not possible to install them by using the normal vibro-hammer, even if the size of the hammer is increased. Sometimes the jet method is used as an auxiliary method (*see* Fig.1). The auxiliary method by using jet injection may disturb the ground around the surface and the end of the SPSP causing water ways at the interface of the steel pipe sheet and peripheral ground (*see* Fig.2) or it may reduce the supporting strength and thus there is the fear of decreasing the functioning of the SPSP cutoff wall. Further, even when a vibro-hammer alone is used, a disturbance in the ground takes place due to pulling and pressing of the SPSP (Japan Vibro-hammer Association 2003).

In this study, attention is paid to the disturbance of the ground in the use of a normal vibro-hammer in the installation of SPSPs cutoff wall, and the impact of the formation of the disturbed area around the SPSPs cutoff wall on the coastal reclamation landfill site as a whole was evaluated by using seepage and advection/dispersion analysis. Further, the possibility of the method of the installation of SPSPs by improving the ground around the steel sheets (hereafter "SC improvement method") by soil cement, which is expected to result in a mechanically and hydraulically stable SPSPs installation with improved adhesion between the SPSPs and peripheral ground, was compared with one of the conventional methods for ground improvement, known as the sand compaction pile method (hereafter "SCP improvement method").

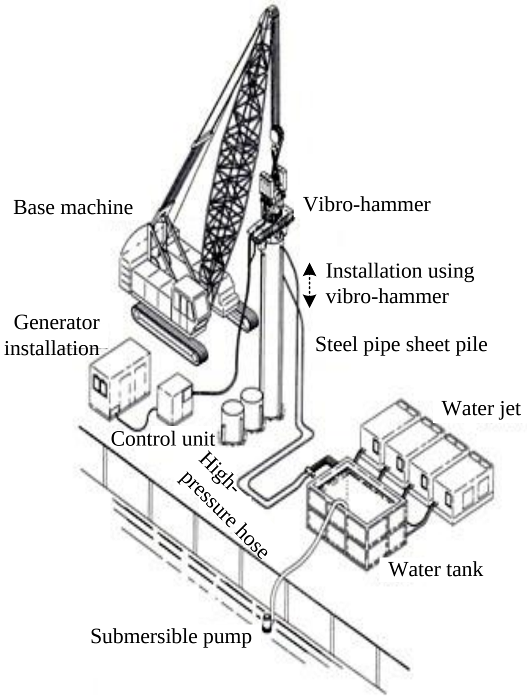


Fig. 1 Installation of SPSPs using vibro-hammer method with jet injection as an auxiliary method

INSTALLATION OF SPSPS CUTOFF WALL

A SPSPs cutoff wall has to be mechanically stable against water pressure, pressure of waves, geostatic pressure due to waste and reclaimed soil, earthquake pressure, its own weight, the load put on it and from other outside forces.

Usually in coastal landfill sites, ground improvement is carried out by using the sand compaction pile method (SCP improvement method) in the lower deposition clay for making the SPSPs cutoff wall mechanically stable, while installing it by using a vibro-hammer (*see* Fig.1) (Waterfront Vitalization and Environment Research Center 2002). In the SCP improvement method, after a casing is inserted into the ground by using the vibro-hammer, sand is filled into the casing and it is pressed into the ground by the upward-downward and vibration movement of the casing, or by impact, to form a sand post having its diameter compressed heavily, to make the ground stable. It is a combination of the improvement of the strength of the soft clay by using a compound ground consisting of a group of sand posts and the base ground and drain function. However, in the SCP improvement method, the sand post is constructed on the lower deposition clay on the sea bed (which is the bottom cutoff wall) and therefore, the hydraulic conductivity of the bottom cutoff wall increases and the lower deposition clay layer may lose its bottom cutoff function.

For overcoming various problems encountered in the installation of SPSPs by the vibro-hammer method and the SCP improvement method mentioned above, the method for the installation of SPSPs by soil cement (SC improvement method) has been proposed (Kimura et al. 2002).

In the SC improvement method, soil cement is filled up in the contact surface of the SPSPs and the peripheral ground and it is expected to efficiently overcome the problems, including water leakage at the interface, of the less permeable SPSP and peripheral ground (*see* Fig.2) and insufficient supporting force. The procedure for this method of installation is as follows:

1. The SPSP is erected in water by using a vibro-hammer and it is embedded to such a depth that it stands on its own
2. A beating type excavator with an expanding head is inserted into the steel pipe of the SPSP installed in 1. above, and cement milk is inserted through the end of the steel pipe and mixed to form a soil cement wall at the base ground, which is down below.
3. Before the soil cement wall constructed at the bottom end of the SPSP becomes solidified, the upper post of the SPSP, which is welded at the site, is pressed into the soil cement wall.
4. Improvement of the ground by soil cement at the lower end of the SPSP and the gap in the welding of the upper post of the SPSP and the installation cycle are inspected and the ground at the end of the sheet pile is improved. Then installation processes 1.-3. are repeated.

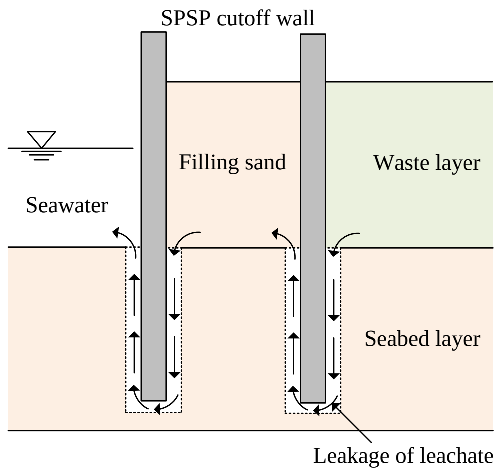


Fig. 2 Leakage of leachate caused by formation of disturbed area around SPSPs cutoff wall

Here, Fig.3 shows the water leakage route of seepage water along the SPSP installed by ground improvement by means of soil cement. When the ground improvement by soil cement is done only at the sand layer situated at the lower portion of the upper clay layer (*see* Fig.3(a)), there is the possibility that the seepage of water from the waste leaks into the sand layer from the interface of the SPSP and the upper clay layer. As a result, the upper layer of sticky clay may deteriorate the functionality of the bottom cutoff base ground. Thus, if this method of installation has to contribute to the improvement of the water cutoff of the SPSP cutoff wall, it is necessary to make the improvement up to the interface of the upper sticky layer of clay and SPSP by means of soil cement (*see* Fig.3(b)). In other words, it is important to erect the steel pipe sheets temporarily in the upper sticky clay layer and to improve the ground below the upper sticky clay layer (which is also the bottom cutoff base), by soil cement.

The sheet length of the lower post of steel pipe sheets shown in step (1) of the installation can be adjusted according to the thickness of the upper sticky clay layer and its supporting strength characteristics. Further, it is also possible to lower the SPSP lower post by means of a crane.

This installation method has the following features:

1. As the soil cement wall before solidification (curing) is constructed up to the required depth of the steel pipe sheet, the insertion of an SPSP becomes easy.
2. The resistance in the soil (sticking and blockage), which becomes a problem in the installation of SPSPs by a vibro-hammer, can be reduced.
3. Disturbance at the periphery of the steel sheet piles and at the ground due to the installation of SPSPs can be prevented and the flow of water from the surrounding area can also be prevented.
4. By adjusting the blending ratio of soil cement, the specific level of water cutoff and supporting strength can be obtained.
5. By inserting the SPSPs below the bottom of the sea and improving their lower portion by soil cement, the solidification agent to be mixed by injection does not leak into the sea, due to the presence of the upper sticky clay.
6. Water cutoff treatment at the joint sections is not required below the bottom post of SPSPs.

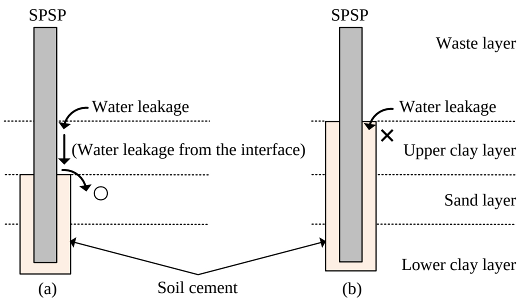


Fig. 3 Water leakage route along SPSP installed by using SC improvement method.

The SPSPs installed by using this method will benefit from the vertical and horizontal support strength of the ground thanks to the integrated nature of SPSPs and the soil cement, as shown in Fig.4 (Kimura et al. 2002).

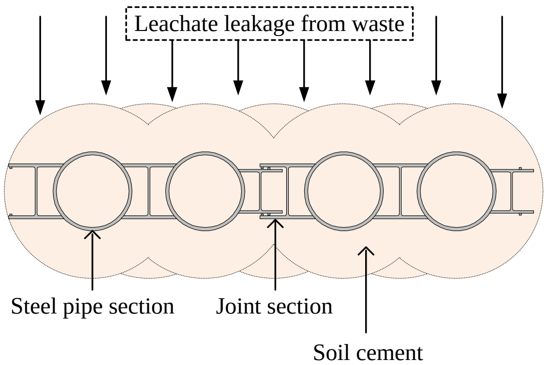


Fig. 4 SPSPs installed by using SC improvement method

SEEPAGE AND ADVECTION/DISPERSION ANALYSIS

In seepage and dispersion analysis, Dtransu-2D-El, which is a finite element analysis code, (expressing the movement of water and solutes in underground water based on saturated and unsaturated percolation and flow dispersion) was used (Nishigaki et al. 1995). In this analysis code, a 2-step analytical method is used for treating the hydraulic pressure head and concentration, in the seepage and dispersion, respectively. In the scattering method, percolation flow analysis is done by the Garlerkin method and the scattering is done by the back difference method by using only the time item. The flow dispersion problem was sorted out by the Eulerian-Lagrangean method (EL method) proposed by Neuman. The entire analysis was done in the saturated region. The basic equation of seepage and flow dispersion of this analytical code was equation (1).

$$\{\beta S_s + C_s(\theta)\}\frac{\partial \varphi}{\partial t} = \frac{\partial}{\partial x_i}\left[K_{ij}^s\{K_r(\theta)\}\frac{\partial \varphi}{\partial x_j} + K_{i3}^s\right] - Q_c \quad (1)$$

Here, β: 1 (saturated region), 0 (unsaturated region), S_s: specific storage coefficient, C_s: specific water capacity (volume), φ: hydraulic pressure head, K_{ij}^s: saturated permeation tensor, $K_r(\theta)$: specific permeation (percolation) coefficient, Q_c: seepage and soaking item. Further, the flow dispersion formula (2) is as follows:

$$R\theta\rho\frac{\partial c}{\partial t} = \frac{\partial}{\partial x_i}\left(\theta\rho D_{ij}\frac{\partial c}{\partial x_j}\right) - \frac{\partial}{\partial x_i}\left(\theta\rho v_i c\right) - \theta\rho\lambda R c - Q_c \quad (2)$$

Where, R: delay coefficient, D_{ij}: dispersion tensor, v_i: actual rate of flow, λ: damping constant, θ: volume percent of water content. Further, the dispersion tensor is denoted by formula (3).

$$D_{ij} = \alpha_T\|V\|\delta_{ij} + (\alpha_L + \alpha_T)\frac{V_i V_j}{\|V\|} + \alpha_m \tau \delta_{ij} \quad (3)$$

Where, α_T: transverse dispersion length, α_L: vertical dispersion length, V_i: actual rate of flow vector, $\|V\|$: norm of actual rate of flow, α_m: molecular diffusion coefficient, τ: percent of bending, δ_{ij}: Kronecker delta.

water cutoff structure. Especially for evaluating the toxic substance cutoff ability of gravitational force-type caisson protection of the coastal landfill site, quantitative evaluation of the discharge of toxic substances from the landfill sites has been evaluated as a flow dispersion problem. Further, Inazumi et al. (2008) noticed the effect of an SPSP cutoff wall at the coastal landfill site on the sealing of toxic substances, and studied the relation between the performance of an SPSP cutoff wall and setting up conditions and environmental compatibility. In the seepage and advection/dispersion analysis of this research, the abovementioned paper is mainly referred.

EVALUATION OF EFFECT OF SPSPS CUTOFF WALL ON ENVIRONMENT

Object of analysis

Figure 5 shows the basic cross section of a coastal landfill site having an SPSP cutoff wall set up by using this analysis. The basic cross section shown in Fig.5 refers to the Tokyo port and harbor authority and the A block north side shore protection standard cross section from new coastal landfill site. The sea bed ground in the coastal landfill site has naturally deposition soil layers, namely an upper deposition clay layer of 8 m, medium sand layer of 5 m and lower deposition clay layer of 13m, respectively. Moreover, the total width of the ground improved by using the SCP improvement method around the upper deposition clay layer is 82m. Further, inside of the double SPSP cutoff wall (the diameter of each steel pipe sheet pile is 1m) is filled up with sandstone. The gap (20m) between the SPSP on the landfill site and the waste reclaimed region is filled up with pre-mixed processed soil (sandy soil). Here, in Fig.5, the waterproof sheet and steel sheet pile are present, but in the cross section subject to the analysis, the water cutoff sheet and steel sheet pile were not used. Thus, the analysis was done by considering the hazardous side. On the other hand, even in the case when steel sheet pile (of hydraulic conductivity 1×10^{-6}cm/s) is provided, pre-analysis has been done, which shows that although there is an effect on leakage time, the overall leakage behavior is not affected much.

In coastal landfill sites, leakage of toxic substances into the waste can be suppressed by the ability of the water cutoff function of the SPSP cutoff wall. For evaluating this, the waste layer was considered as the source of pollution and the possibility of the leakage of toxic substances was evaluated. Concentration of toxic substance C = 100 was considered as a fixed condition and initial concentration for the other layers was considered as C = 0. Further, the condition of the environment was considered as an unknown concentration and the analysis was carried out by considering the possibility of in and out flow. Now, in the coastal landfill site, usually the water level is managed so that the difference in the inner and outer water level does not exceed 2m. And therefore, the total water head was considered to be of H = 0m from the extreme left to the extreme right end of the upper end of the sea water and that from the extreme left to the extreme right end of the upper end of the waste was considered as the fixed value of H = 2m and, as for the environmental condition, the water head was supposed to be unknown. The analysis was carried out by using stationary percolation flow. For the analysis, it was assumed that the basic composition of each layer would not change.

Material properties given to each component layer were the hydraulic conductivity (horizontal direction), the hydraulic conductivity (vertical direction), effective gap, vertical dispersion length, horizontal dispersion length, molecular diffusion coefficient and delay coefficient. Table1 shows the values of the properties used as material properties in this analysis. The values of material properties mentioned in Table1 were determined by referring to Kamon et al. (2001) and Inazumi et al. (2008).

Table 1 Assumed properties of each layer in the analysis

Materials	Hydraulic conductivity (Horizontal direction) k_H (cm/s)	Hydraulic conductivity (Vertical direction) k_V (cm/s)	Effective porosity θ	Longitudinal dispersion α_L (cm)	Transverse dispersion α_T (cm)	Molecule diffusion coefficient D_m (cm^2/s)	Retardiation factor R_d
SPSP	1×10^{-7}	1×10^{-7}	0.1	10	0.1	1×10^{-5}	1
Clay	7×10^{-7}	5×10^{-7}	0.65	10	1	1×10^{-5}	2
Sand	1×10^{-3}	1×10^{-3}	0.4	10	1	1×10^{-5}	1
SCP	1×10^{-6}	6×10^{-4}	0.45	10	1	1×10^{-5}	1
Filling sand	1×10^{-2}	1×10^{-2}	0.4	10	1	1×10^{-5}	1
Pre-mixing	1×10^{-6}	1×10^{-6}	0.4	10	1	1×10^{-5}	1
Waste	1×10^{-0}	1×10^{-0}	1.0	10	1	1×10^{-5}	1
Seawater	1×10^{-0}	1×10^{-0}	1.0	10	1	1×10^{-5}	1
Disturbed area (Clay)	1×10^{-1},1×10^{-3} 1×10^{-5},1×10^{-6}	1×10^{-1},1×10^{-3} 1×10^{-5},1×10^{-6}	0.65	10	1	1×10^{-5}	2
Disturbed area (Sand)	1×10^{-1}	1×10^{-1}	0.4	10	1	1×10^{-5}	1
Disturbed area (SCP)	1×10^{-1},1×10^{-3}	1×10^{-1},1×10^{-3}	0.45	10	1	1×10^{-5}	1
Soil cement	1×10^{-6}	1×10^{-6}	0.65	10	1	1×10^{-5}	2

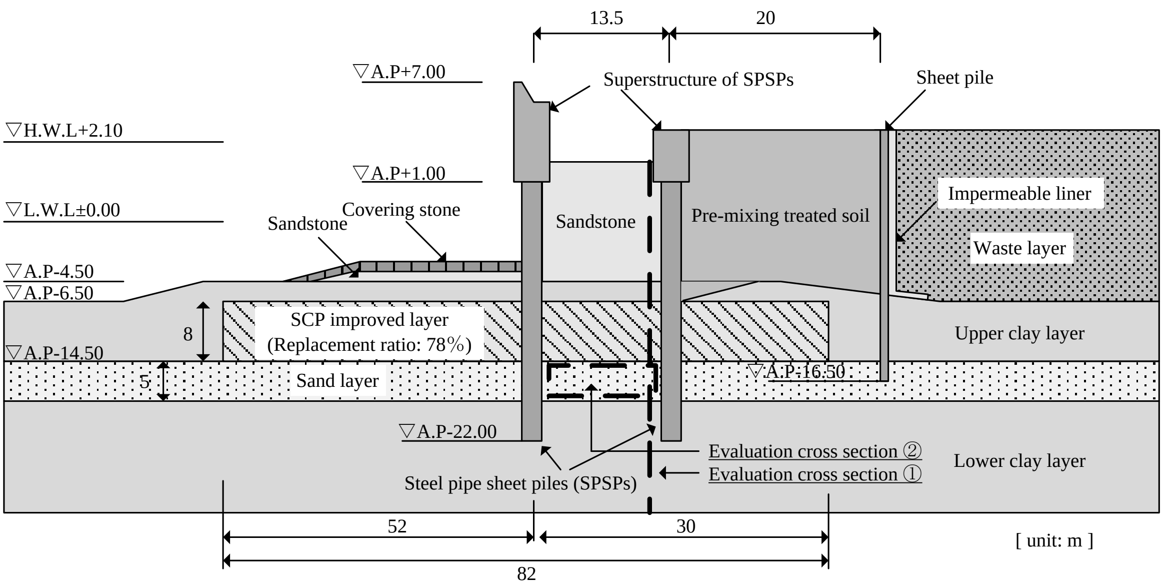


Fig. 5 Basic cross section of coastal landfill site having SPSP cutoff wall for the analysis

The percolating concentration of toxic substances total depth at the linear left of the SPSPs on the landfill-side (evaluation cross section ① in Fig.5) was noticed and it was discussed on the basis of the leakage concentration ratio with that at the place in question per unit length, as against the concentration of the waste layer taken as C = 100, for evaluating the water cutoff performance of toxic substances in the SPSPs cutoff wall. For studying the effect of the given conditions on the leakage route in more detail, the concentration ratio of toxic substances in the medium sand layer (evaluation cross section ② in Fig.5) present in the double SPSPs cutoff wall to the concentration of the waste layer taken as C = 100 is discussed. Further, as the toxic substances move due to shifting of flow (percolation) and dispersion, the analysis results show a concentration obtained from a combination of shifting (percolation) of flow and dispersion.

Effect of disturbance of the ground around the cutoff wall

The effect of the formation of a disturbed area around the SPSPs cutoff wall on the leakage behavior of toxic substances in the coastal landfill site is studied.

As shown in Fig.6, the evaluation of leakage properties of the toxic material from the waste is carried out when the disturbed area is generated in the upper deposition clay layer, medium sand layer and lower deposition clay layer (Case-1), and only in the lower deposition clay layer (Case-2). Further, as regards the width of the disturbed area, it was set to 10cm and 20cm in this analysis, based on the report that when an 80cm steel pipe post is driven in by a vibro-hammer, the properties of the base ground are maintained in a sideways region of more than 20cm from the periphery of the post (Japan Vibro-hammer Association 2003).

Figure 7 shows the concentration ratio of toxic substances in the total depth on the left of SPSP of the waste side, as against a concentration C = 100 of the waste layer in the disturbed area generated in the upper deposition clay layer, medium sand layer and lower deposition clay layer (Case-1), and only in the lower deposition clay layer (Case-2) (width of disturbed area: 20cm, hydraulic conductivity of disturbed area in upper and lower deposition clay layer: 1×10^{-3}cm/s and hydraulic conductivity of disturbed area in the medium sand layer: 1×10^{-1}cm/s). From this, there does not seem to be a large difference in the concentration of toxic substances passing through SPSPs on the waste side due to the presence of the disturbed area in the upper deposition clay layer and medium sand layer. This may be attributed to the effect of the hydraulic conductivity in the SCP improved layer. Thus, since the hydraulic conductivity of the SCP improved layer is higher in a vertical direction that in a horizontal direction, the toxic substances getting into the SCP improved layer move predominantly in a vertical direction. Due to this, the leaching water containing the toxic substances may be soaked into the medium sand layer by passing through the SCP improved layer in a vertical direction before reaching the disturbed area in the upper deposition clay layer. Further, since the toxic substances soaked into the medium sand layer move into the lower deposition clay layer, the formation of the disturbed area at the interface of the lower deposition clay layer and the SPSP becomes an important factor for the leakage of toxic substances. Here, Fig.8 shows the relation of the concentration ratio in the medium sand layer in the SPSP cutoff wall as against the concentration of the waste C = 100 and the width of the disturbed area and hydraulic conductivity of the disturbed area. The difference in concentration of toxic substances contained in the medium sand layer in the SPSP cutoff wall corresponds to the hydraulic conductivity and width of the disturbed area. Especially, the hydraulic conductivity of the disturbed area influences the concentration of toxic substances leaking into the medium sand layer in the SPSP cutoff wall and, when the hydraulic conductivity of the disturbed area changes in the range from 1×10^{-6} to 1×10^{-3}cm/s, the concentration of leaking toxic substances increases to about 30 times.

The leakage of toxic substances due to the formation of the disturbed area in the peripheral ground due to the installation of an SPSP cutoff wall takes place from the waste layer through the SCP improved layer, medium sand layer, disturbed area in the lower deposition clay layer and SPSP and, its presence was significant in the leakage route in the medium sand layer in the SPSP cutoff wall. Further, the hydraulic conductivity preserved by the disturbed area in the lower deposition clay layer predominantly influences the quantity of leakage in the leakage route mentioned above. Thus, for constructing the SPSP cutoff wall, it is important to maintain the adhesion between the SPSP and the peripheral ground. The method of installing the SPSP by improvement of the ground in the periphery of the SPSP by the soil cement (SC improvement) method has been developed here. The method of installing SPSP by improvement of the ground by the soil cement method can be considered to be effective in preventing disturbance of the ground in the periphery of the SPSP.

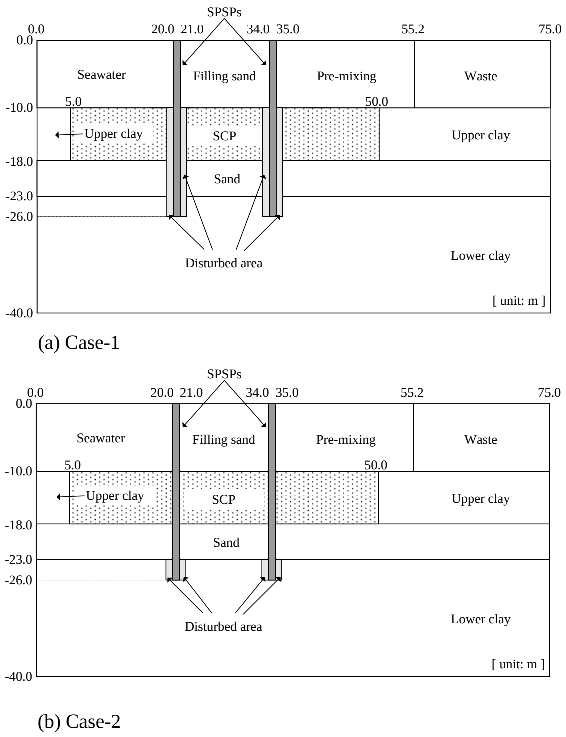


Fig. 6 Structural profile used in the analysis assuming formation of disturbed area

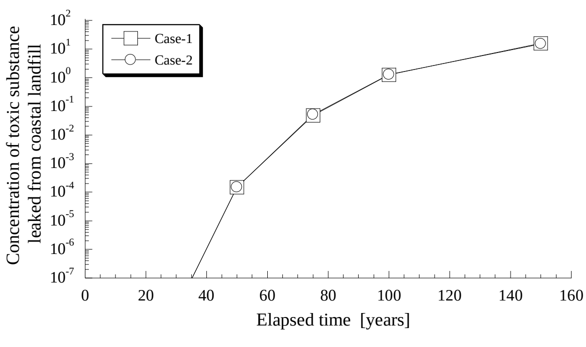


Fig. 7 Relationship between leaked concentration of toxic substance and formation of disturbed area

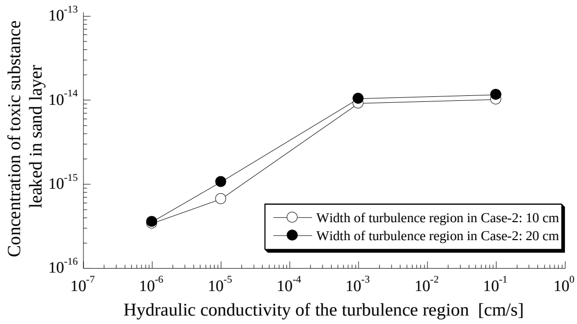


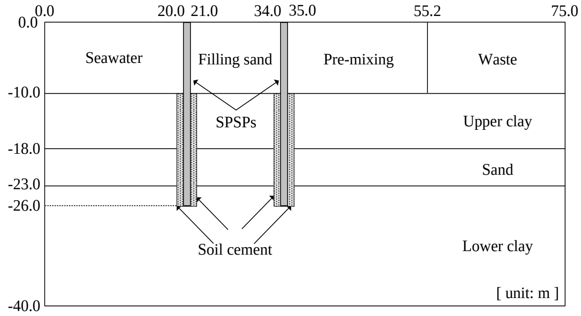
Fig. 8 Relationship between leaked concentration of toxic substance and hydraulic conductivity of disturbed area

Effect of SC and SCP improvement methods

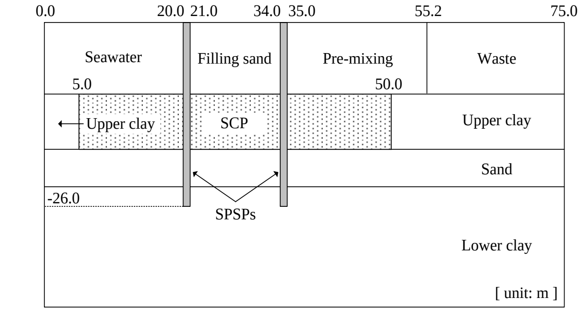
In this analysis, the effect of the SPSP cutoff wall constructed by using the SC improvement method on the behavior of the leakage of toxic substances in the entire coastal landfill site has been studied. Thus, in the analysis, in the cross section shown in Fig.9, evaluation of the leakage properties of the toxic substances from the waste in the case of the installation of an SPSP cutoff wall by the SC improvement method (Case-SP) and that in the case of the installation of an SPSP cutoff wall by using the sand compaction pile method (SCP improvement method) for increasing the mechanical stability of the steel sheet pile (Case-SCP) was done. Here, in Case-SC, the diameter of soil cement was set to 140cm for a steel pipe of a diameter of 100cm.

Figure 10 shows the concentration ratio at the left of the total depth of the SPSP on the waste side in the case of Case-SC and Case-SCP, as against C = 100 of the waste. By using the SC improvement method, the leakage concentration of the toxic substances passing through the SPSP on the waste side can be suppressed by more than 1 order of magnitude as compared to that in the case of the SCP method. This is because in an SPSP cutoff wall using the SCP method and in a coastal landfill site, the upper deposition clay layer gets replaced by the SCP improved layer and therefore, the water cutoff property of the upper deposition clay layer (as the bottom cutoff ground) is lost. Thus, the installation of the SPSP by using the SC improvement method is more effective for screening as compared to the SCP method, which is usually used. It can also contribute in the streamlined increase in the waste reclamation capacity.

Figure 11 shows the concentration ratio of the toxic substances when the depth of the improvement in the SC improvement method is changed at the left of the total depth of the SPSP on the waste side as against C = 100 of the waste. This shows that when the SC improvement is done up to the upper deposition clay layer, it is very effective in improving the effect of the suppression of leakage of the toxic substances as compared to that carried out only up to the medium sand layer depth. As can be seen from Fig.3, the reason for this is that, when the SC improvement is carried out only up to the depth of the medium sand layer situated at the bottom of the upper deposition clay layer, there is a possibility of leakage of the leaching from the waste to the interface of the SPSP and the upper deposition clay layer.



(a) SPSP cutoff wall constructed by using SC improvement method (Case-SC)



(b) SPSP cutoff wall constructed by using SCP improvement method (Case-SCP)

Fig. 9 Structural profile used in the analysis assuming installation by SC or SCP improvement method

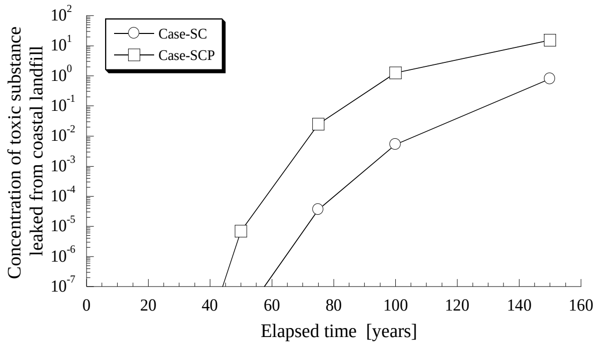


Fig. 10 Relationship between leaked concentration of toxic substance and difference in improvement methods

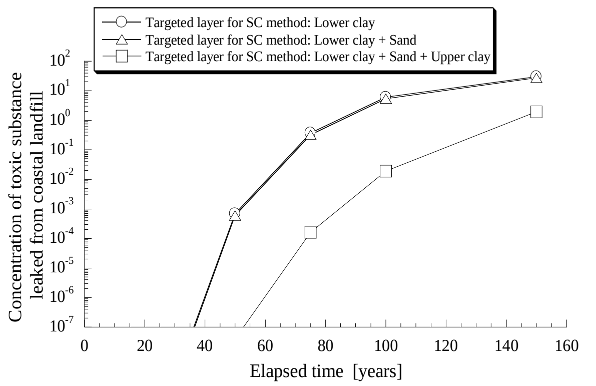


Fig. 11 Relationship between leaked concentration of toxic substance and depth of improvement using SC method

As a result, the function of the upper deposition clay layer (as the bottom cutoff ground) is lost. Thus, for getting a better contribution from the SC improvement method to the improvement of the cutoff function of the SPSP cutoff wall, it is important that the base ground below the upper deposition clay layer (which is also the bottom water cutoff) is improved by using soil cement. This is explained in section 2 above, and it can be dealt with by shortening the length of the sheet pile (of the SPSP post to be erected), according to the thickness of the upper deposition clay layer and its supporting strength.

CONCLUSIONS

In this study, the disturbance of the ground around the installation of the SPSP cutoff wall at the coastal landfill has been noticed and the evaluation of the effect of the formation of the disturbed area at the periphery of the steel pipe sheet pile cutoff wall on the cutoff function of the toxic material at the coastal landfill as a whole is done. Further, the possibility of the SC improvement method (which is supposed to keep the adhesion between the SPSP and peripheral ground) is compared with the SCP method which is one of the methods already in use, for the improvement of the ground.

The results are as follows:

1. The formation of a disturbed area in the peripheral ground of the constructed SPSP cutoff wall causes the formation of the leakage route in the medium sand layer of the vertical cutoff wall because the leaching water containing toxic substances passes through the waste layer, SCP improved layer, medium sand layer and vertical cutoff wall. This causes the formation of the disturbed area in the medium sand layer in the vertical cutoff wall. Moreover, the hydraulic conductivity which maintains the disturbed area formed in the lower deposition clay layer greatly influences the quantity of leakage in the leakage route of toxic substances mentioned above.
2. In the SPSP cutoff wall installed by using the SCP method and the coastal landfill site, as the result of the replacement of the upper deposition clay layer by the SCP improved layer, the function of the upper deposition clay layer as the bottom cutoff base ground has deteriorated. Thus, the improvement of the bottom cutoff base ground by the SCP method influences the shifting of the leakage of toxic substances to the vertical cutoff wall in accordance with the hydraulic conductivity and the width of the improved layer.
3. The installation of the SPSP by using the SC improvement method is effective in suppressing leakage of the toxic substances. Further, since the improvement takes place from inside of the upper deposition clay layer to the end of the SPSP in the SC improvement method, the SC improvement method contributes to the improvement of the cutoff performance of the SPSP cutoff wall.

REFERENCES

INAZUMI, S., KIMURA, M. and KAMON, M. (2008). Environmental designs for vertical cutoff walls in coastal landfill sites, Geotechnical Engineering Journal, Vol. 38, (Accepted for Publication).

JAPAN VIBRO-HAMMER ASSOCIATION (2003). Handbook for design and construction by vibro-hammer methods, Japan vibro-hammer association, (in Japanese).

KAMON, M. and INUI, T. (2002). Geotechnical problems and solutions of controlled waste disposal sites, JSCE *Journal of Geotechnical Engineering*, No. 701/III-58, pp. 1-15, (in Japanese).

KAMON, M., KATSUMI, T., ENDO, K., ITOH, K. and DOI, A. (2001). Evaluation of the performance of coastal waste landfill with sheet pile containment system, *Proceedings of the 5th Japan National Symposium on Environmental Geotechnology*, pp. 279-284, (in Japanese).

KIMURA, M., TOO, A.J.K., ISOBE, K. and NISHIYAMA, Y. (2002). New construction method for offshore bulkhead waste disposal facilities using steel pipe sheet piles, *Proceedings of the 2nd Japan-Korea Joint Seminar on Geoenvironmental Engineering*, pp. 33-36.

NISHIGAKI, M., HISHIYA, T., HASHIMOTO, N. and KOHNO, I. (1995). The numerical method for saturated-unsaturated fluid density dependent groundwater flow with mass transport, JSCE *Journal of Geotechnical Engineering*, No. 501/III-30, pp. 135-144, (in Japanese).

SHIMIZU, K. (2003). The latest geotechnical problems in waste landfill, Tsuchi-to-Kiso (Japanese Geotechnical Society), Vol. 51, No. 58, pp.1-4, (in Japanese).

WATERFRONT VITALIZATION AND ENVIRONMENT RESEARCH CENTER (2002). *Design, Construction and Management Manual for Managed Type Waste Reclamation*, Waterfront Vitalization and Environment Research Center, (in Japanese).