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# A coastal waste disposal site on permeable ground in the Inland Sea of Japan

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ABSTRACT: This paper describes the highlights of analysis, design and construction of a coastal waste disposal site with area of 5 ha and the planned disposal volume of 330,000 $m^3$ that was constructed on permeable ground as the first case under the current legal requirements in Japan. For the barrier system of the site, a double geomembrane geosynthetic liner system was adopted for both side and bottom liners. The liners were required to be structurally stable against uplifting forces caused by ocean wave and tide with large range in the Inland Sea. Then the steel slag was used as geomaterials for both protection layers to function as the overburden to resist the uplift forces. In structural design of the barrier system, the design external forces of the pressure due to ocean waves and the hydraulic pressure due to tide were evaluated by centrifuge model tests and numerical analyses. In construction of the multi-layer geosynthetic liner, the following effective procedures were adopted: a) assembling to a jointed sheet by adhesive, b) enlargement works of sheet units as wide and long as possible in the processing yard, and c) submergence and placement of the jointed sheet for side and bottom liner entirely jointed by lap welding in the site.

## 1 INTRODUCTION

The municipal and industrial solid wastes from major urban districts in Japan have been mostly disposed to the coastal waste disposal sites due to the advantageous geological and geographical conditions and the limitations related to location for inland landfill sites. They are usually located on the thick marine clay layer as a natural impermeable layer, and their seawalls enclose the site with barrier systems intended to limit contaminant migration. When they are constructed on permeable ground, the current regulation in Japan requires barrier systems in both side and bottom of the site. Then, the barrier systems are required to have performance with high reliability and durability under severe marine conditions.

This paper describes an engineering and construction project of a coastal waste disposal site located on permeable ground as the first case under the current legal requirements in Japan. The disposal site with the area of 5 ha was planned to construct in a part on the seaside of a new reclaimed land in the Inland Sea of Japan. Fig. 1 shows the aerial view of the completed disposal site. The industrial solid waste ash with the volume of 330,000$m^3$ was planned to be disposed in 8 years. For the barrier system, a double geomembrane geosynthetic liner system was adopted at this site. The highlights of analysis, design and construction of the barrier system are described in the paper.

Figure 1. Aerial view of the costal waste disposal site

## 2 ACTIONS OF WAVE AND TIDE

The features of geotechnical and marine conditions at the site were a) highly permeable foundation ground consisting of gravels, b) high ocean waves in winter, and c) large fluctuation of tidal level.

Fig.2 shows the actions of the ocean wave and tide on the side and bottom liners. It is considered that the water pressure due to ocean waves

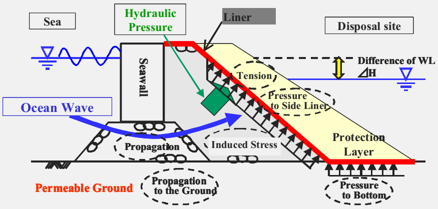

Figure 2. Actions of ocean wave and tide on the liner

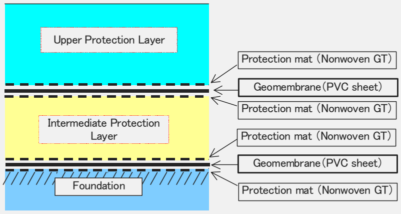

Figure 5. Structure of barrier system

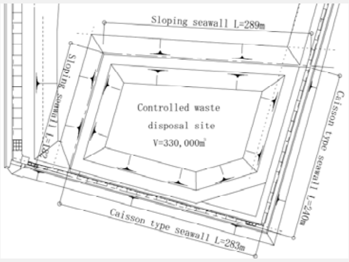

Figure 3. Plan of the coastal waste disposal site

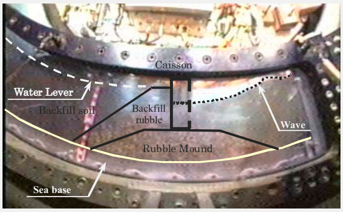

Figure 6. Hydraulic model test by drum type centrifuge

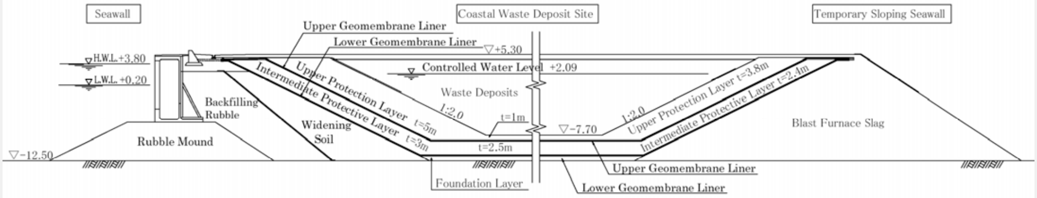

Figure 4. Cross section of the coastal waste disposal site

propagating through the seawall applies on the side liner behind the seawall during the periods from construction to closure of the disposal site. Also, after completion of the barrier system, the difference of water levels between the sea and the disposal site along with fluctuation of tidal level causes the hydraulic pressure that applies to the liner (WAVE 2000).

Under such conditions as described above the liners were required to be structurally stable against uplifting forces caused by ocean wave and tide. Then the use of geomaterials for protection layers was considered to be appropriate so that the protection layers of the liner system could effectively resist the uplift forces as overburden on the liners. However, the difficult problems arising in structural design were to evaluate quantitatively a) the attenuation of the wave pressure in the seawall and the ground; and b) actions of wave and tide applying to the bottom liner.

## 3 ANALYSIS AND DESIGN

### 3.1 *Structure of barrier system*

Figs.3 and 4 show the plan and the cross section of the disposal site, respectively. The caisson type seawalls were constructed on the seaside and the sloping seawalls made of steel slag were constructed as temporary seawall in the disposal site.

The marine conditions for design were as follows; the design wave height $H_D$=5.6m and period T=5.8sec, the design depth h=14.5m, and the tidal range of 3.6m (H.W.L.-L.W.L.). The foundation ground consisted of mostly alluvial sandy gravel layer of more than 15m thick without any continuously distributed clay layer beneath the disposal site. The hydraulic conductivity of the sandy gravel layer was estimated to be in the range of k=1.0E-1 to 1.0E-3 cm/s.

The structure of the barrier system is shown in Fig.5. Polyvinyl chloride (PVC) sheet of 3mm thickness was used for geomembrane, and polyester nonwoven geotextile with mass per unit area of 550 g/m$^2$ was used for protection mats that sandwiched the geomembrane. Steel slag was used as geomaterials for both intermediate and upper protection layers as a whole to function as the overburden to resist the uplift forces. The side and bottom liners have basically similar structures.

### 3.2 *Pressure due to ocean waves*

In design the thickness of protection layers was one of the major subjects since it may affect the planned disposal volume and the construction cost. Due to lack of past research works available in the project, the design external forces were evaluated by laboratory model tests and numerical analyses.

So as to clarify the phenomenon that may be related with the wave-ground-structure interaction, hydraulic model tests by using a drum type centrifuge apparatus were conducted (Baba et al. 2002). Fig.6 shows the side view of the centrifuge model for a caisson type seawall with a liner installed along the slope of backfill. That was suffered from wave actions by using the wave generation apparatus.

In addition the dynamic response analysis was conducted by elasto-plastic finite element method on the ground-structure system to simulate the results of centrifuge model test. In the analysis the water pressure induced by the ocean wave attacking to the seawall was used as input that was obtained from the numerical simulation of the hydraulic tests by CADMAS-SURF (CDIT 2001).

It seemed that by the numerical analysis the attenuation of the wave pressure and the effects of permeable ground could be reasonably evaluated for design. Fig. 7 shows a typical result on distribution of water pressure obtained from the numerical analysis. Based on the numerical results, the pressure by wave applying to the side liner was evaluated to be approximately 35% of the uplift pressure at the toe of the caisson.

### 3.3 *Hydraulic pressure due to tide*

The hydraulic pressure due to tide was evaluated by two-dimensional transient state seepage flow analysis that prescribed the tide fluctuation as boundary conditions of the seawalls of the disposal site (Kotake et al. 2003).

The phase lag in propagation of water pressure and the decay with respect to the distance from the seawall were clearly seen from the time history of pressure head at the liner obtained from the analysis. Fig.8 shows the maximum uplift pressures applied to the side and bottom liners that were evaluated in relation to the distance along the section. It is seen that the uplift pressures are strongly affected by the hydraulic conductivity of the foundation ground.

### 3.4 *Slope stability on side liner*

It was considered that the side liner would suffer from shear force caused by the self-weight of the mass of geomaterials in the slope during the periods from construction to completion of landfill. In this respect, interactive shear strength and displacement between geosynthetics and geomaterials are important factors to assess the stability of the multi-liner systems. In the present project nonlinear elasto-plastic finite element analyses were conducted to simulate the interaction behaviors of a geosynthetic multi-linear system installed in a slope, considering the actual construction procedures with incremental analysis method. The interface properties and tensile stiffness and strength of the geosynthetics used in the present barrier system were examined based on the numerical results (Kotake et al. 2002, 2005).

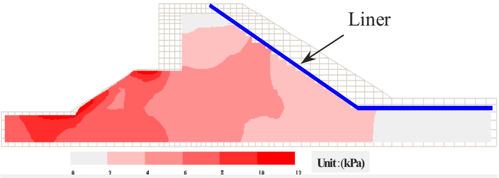

Figure 7. A typical result on distribution of water pressure obtained from numerical analysis

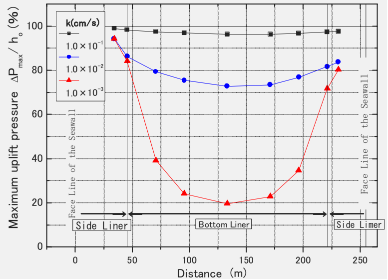

Figure 8. Maximum uplift pressures applied to the liners

## 4 CONSTRUCTION

The effective construction methods adopted in the field were; a) assembling to a jointed sheet by adhesive, b) enlargement works of sheet units as wide and long as possible and c) submergence of the entirely jointed sheet for side and bottom liners.

### 4.1 *Enlargement works of sheet units*

Enlargement works of sheet units were conducted according to the following procedures:

a) Geomembrane sheet and upper and lower protection mats were assembled and jointed to a united form by using the adhesive in the factory, and rolls of the three-layer jointed sheets were carried to the construction site.

b) A very large unit of 40m in width and 50 to 60m in length was made of 21 rolls of the jointed sheet of 2m in width at the processing yard. The edge of the sheets were welded by using self-propelled welding machines with a lap width of 100mm in the order of the lower mat, the geomembrane sheet and the upper mat.

c) All of the welded parts of geomembrane were inspected by either pressurizing or decompression. The completed part of the large unit was equipped with buoys, and directly drawn out from the quay

Figure 9. An enlarged sheet unit extended to the sea

Figure 10. Enlarged sheet units floating in the site

Figure 11. Discharging slag by FCS

wall to the sea by using winches that were arranged on the barge floating in front of the yard (Fig.9).

d) The large sheet was towed into the disposal site from the opening of seawall under construction. Inside the disposal site each edge of the adjacent two floating sheet units was carried up to the deck of smaller barges and jointed by lap welding to become a more enlarged sheet. The welding procedure was similar to the one conducted in the processing yard. Finally all the geomembrane sheets for the side and bottom liners were jointed entirely while floating on the sea (Fig.10).

### 4.2 *Installation of the jointed sheet*

Installation of the jointed sheets was conducted according the following procedures:

a) The upper edge of the sheet for side slope was pulled up and fixed at the top of the slope. The floating sheet was submerged to the sea base by cutting the buoys successively while keeping the sheet in tension.

b) Large sandbags filled with steel slag were placed immediately to avoid the submerged sheet from floating due to the effects of wave and tide. Then, the slag for protection layers were discharged on the liner by using the floating conveyer system (FCS) equipped with GPS positioning that may give less impact forces to the geomembrane sheet to avoid the damage (Fig.11). The uneven surface of the slag layer under the sea was leveled by using vessels equipped with blades.

The performance of the barrier system was examined by monitoring the water level measured by water pressure gauges both inside and outside of the disposal site.

## 5 CONCLUSIONS

The construction project was successfully completed under the unprecedented design and construction conditions, and the disposal site has been in service without any serious problems. This project has verified that the barrier system with double geomembrane liners can be constructed even in the coastal site.

## ACKNOWLEDGEMENTS

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