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CONTAMINANT TRANSPORT ANALYSIS OF A NATURAL MARINE CLAY LANDFILL LINER

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SYNOPSIS

The performance of the natural marine clay landfill liner is investigated by evaluating the effect of the consolidation due to the weight of the wastefill on the hydraulic conductivity of the liner and by analyzing the potential of the contaminant migration through the bottom liner of the peripheral embankment. The results show that the amount of seepage can be reduced significantly by reducing the hydraulic conductivity due to the consolidation of the clay liner as well as by installing the geomembrane on the slope of the embankments. The transport of leachates below the bottom of the embankment was negligible with the reduced hydraulic conductivity.

INTRODUCTION

In recent years, landfills have been built on seashores in the far-east because of the easy availability of the sites and the relatively far distance from human communities. Also natural clay soils on these seashores have been used as a natural bottom liner.

The purpose of this paper is to discuss the suitableness and adequacy of the containment systems built on seashores, by discussing a landfill located in the Kimpo reclamation site close to Inchon seashore, Korea (Fig. 1.a). The suitableness of the bottom lining is evaluated with regard to the hydraulic conductivity of the clay layer consolidated due to the weight of waste fill, and a contaminant transport analysis performed to evaluate the potential of leachate transport for polluting the sea water.

SITE DESCRIPTION

The site is located approximately 40 km west of Seoul. The area of the landfill is 244,500 m^2 with a height of 20 m. The period of landfilling operation was 2 years from Feb, 1990 to Dec., 1991. A plan of the site is shown in Fig. 1.b, and the soil profiles in two directions are plotted in Fig. 2.

The ground underlying the landfill is composed of silt, clay and weathered granitic materials. Soil types and their thicknesses are varing significantly from point to point.

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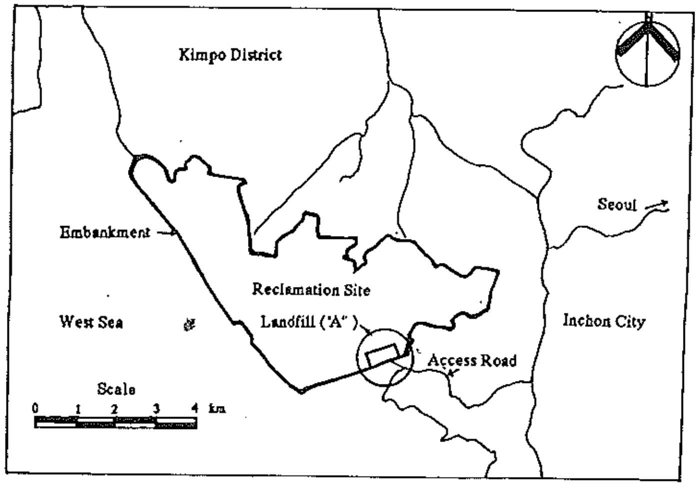
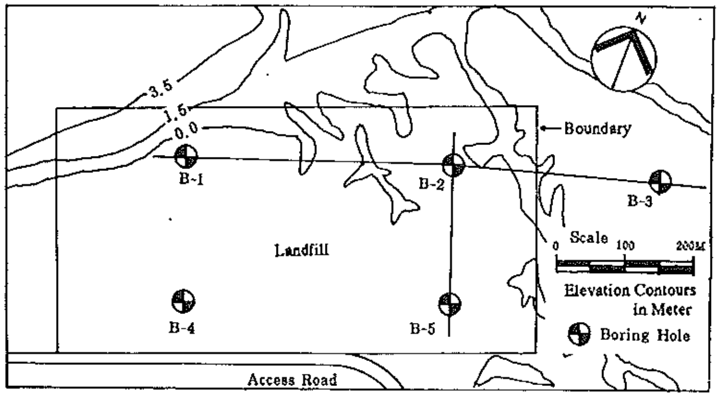


(a) Geographical location of the landfill



(b) Details of the landfill ("A") with the boring plan

Fig. 1 Geographical Location and the Boring Plan

The leachate collection facilities in the landfill are the semi-aerobic type, which includes natural ventilation and perforated poly-vinyl chloride (p.v.c.) pipes. The liner system is composed of a natural clay layer on the bottom and a high-density polyethylene (HDPE) geomembrane liner along the side of the containment embankment. The geomembrane liner is installed to prevent the leachate from passing through the side of these embankments, and also to prevent tidal water from seeping into the containment. The embankments are composed of granular soil with a slope

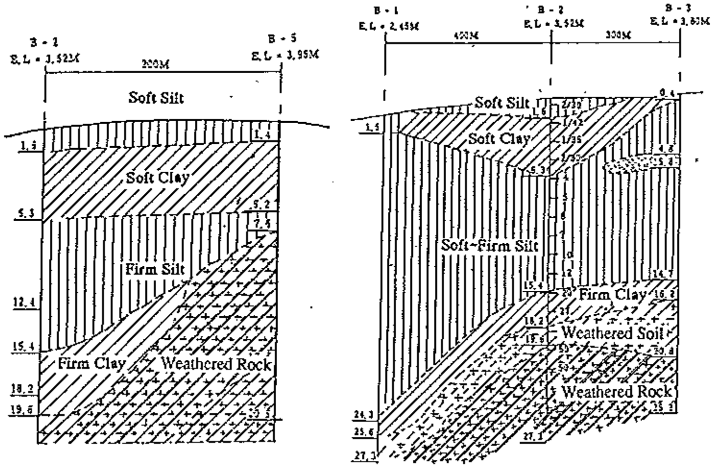
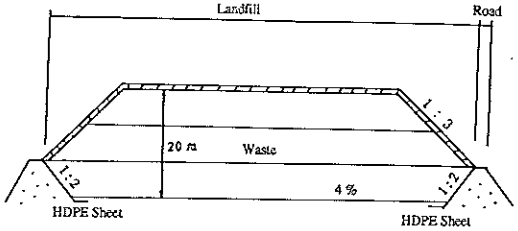
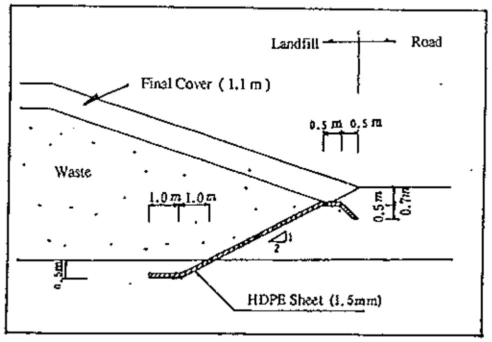


Fig. 2 Soil Profiles through Boring Holes in Two Directions



(a) Typical section



(b) Configuration of geomembrane sheet

Fig. 3 Typical Section of the Landfill and Configuration of HDPE Geomembrane

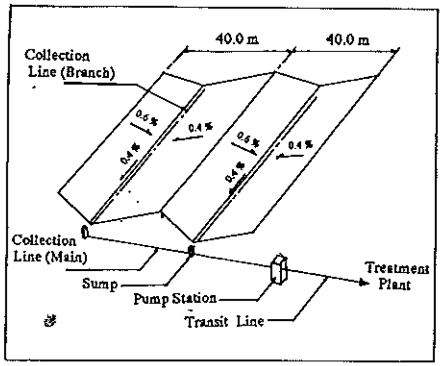


Fig. 4 Drainage Scheme in the Bottom of the Landfill

of 1 : 2, and the waste has a slope of 1 : 3. A typical section of the landfill, and the detail configuration of the geomembrane, are shown in Fig. 3. The gradient of the perforated drainage pipes in the ground is 0.2 percent in the transverse direction and 0.4 ~ 0.6 percent in the longitudinal direction (Fig. 4). The pipes lead to the leachate treatment system located at the south-west edge of the landfill.

GEOTECHNICAL CHARACTERISITICS OF THE SITE

Geotechnical characteristics of the materials which form the natural liner are given in Table 1. These values are similar to the properties of soils used to construct soil liners in other landfill sites as reported by Goldman et al. (1986).

Table 1 Physical and Engineering Characteristics of the Natural Marine Clay Liner.

Specific gravity	2.64 ~ 2.68
Unit weight (KN/m^3)	17.4 ~ 17.8
Void ratio	1.02 ~ 1.13
Soil classification (ASTM)	ML ~ CL
Percent passing No. 200 sieve	> 95
Percent of clay particles	20
Liquid limit (W_L)	33.4 ~ 41.5
Plasticity Index (I_p)	11.2 ~ 19.0
Cohesion (KN/m^2)	19.6 ~ 35.28
Friction angle (°)	2 ~ 6
SPT (N)	< 4
Compression index	0.235 avg.

Hydraulic conductivity of the liner material was evaluated from the grain size distribution and the laboratory varying head permeability test. The hydraulic conductivity from the grain size analysis is 10^{-6} cm/sec and that from the permeability test is in the range of $9.42 \times 10^{-7} \sim 1.25 \times 10^{-7}$ cm/sec.

ESTIMATION OF THE FLOW QUANTITIES OF THE CONTAINMENT SYSTEM

The containment embankments and the bottom liner must be impervious enough to prevent the leakage of leachate through them. Seepage quantities through the embankments were calculated using the Dupuit-Forchheimer equation shown below

$$Q = \frac{K}{2d}\left(H1^2 - H2^2\right) \qquad (1)$$

Where H1 and H2 are hydraulic heads at upstream and downstream of the embankment, d is the length of drainage path and K is the hydraulic conductivity. Seepage quantities under the bottom of embankments are calculated using flow net method.

Flow through the Embankment

Seepage quantities computed are shown in Table 2 for two conditions, i.e, with and without geomembranes. The hydraulic heads at the upstream and downstream of the embankments are assumed to be 5.5 and 0. m, respectively, and the length of the drainage path is 40 m. Hydraulic conductivity, $K = 10^{-6}$ cm/sec, obtained from the grain size analysis is used.

Table 2 Seepage Quantity through the Embankment.

Conditions		Flow rates (m^3/day m)	Method used for calculation
without geomembranes on the embankment	through the embankment	0.00163	Dupuit solution
	below the bottom of the embankment	0.00112	flow net
	total seepage quantity	0.00275	
with geomembranes on the embankment	below the bottom of the embankment	0.00098	flow net

About 64% of seepage quantity is reduced by installing geomembranes at upstream slope of the embankment.

Consolidaton Effect on Hydraulic Conductivity

Hydraulic conductivity of the bottom clay liner will be reduced due to the weight of wastes as the filling progresses. To analyze this phenomenon laboratory consolidation tests were carried out using undisturbed clay samples, and hydraulic conductivities were calculated from the relationship :

$$K = Mv\ \gamma w\ Cv \tag{2}$$

where Mv is the coefficient of volume compressibility, γw is the unit weight of water, and Cv is the coefficient of consolidation. Since the coefficient of volume compressibility in equation (2) is a function of surcharge load, the relationship between K and the surcharge load can be obtained and is plotted in Fig. 5. The results show that the hydraulic conductivity of the liner reduces from 10^{-6} cm/sec to 10^{-8} cm/sec with the increase of waste load.

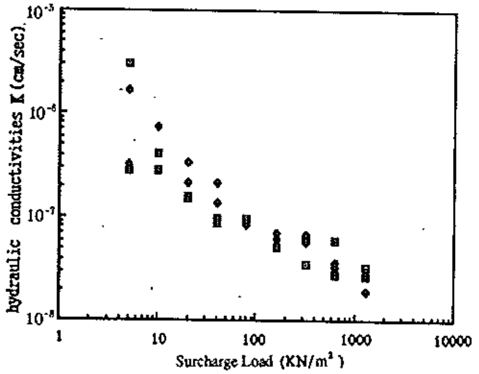


Fig. 5 Changes of Hydraulic Conductivity with Increasing Surcharge Load

Flow Quantities with Surcharge Load Effects

Flow quantities below the bottom of the embankment were computed again using the hydraulic conductivities obtained from Fig. 5 for various surcharge load conditions (Table 3). It was assumed that a geomembrane is installed on the embankment and flow net method was used to calculate the flow quantities.

Table 3 Hydraulic Conductivity and Flow Rate with Varying Surcharge Load.

Height of waste (m)	Surcharge load (KN/m^2)	K (cm/sec)	Flow rate (m^2/day m)
0	0	1.0×10^{-6}	9.8×10^{-4}
9	58.8	0.2×10^{-7}	3.6×10^{-4}
20	137.2	7.0×10^{-8}	6.8×10^{-5}

A significant reduction of flow rate resulted from the incrase in surcharge load. 93% reduction of the flow rate is achieved after the whole filling is completed.

PREDICTION OF LEACHATE TRANSPORT

Because of the inhomogeneities of the soil composing the bottom of the landfill, and the malfunction of the leachate collection facilities due to creep and clogging of the pipes, there may be a leak of contaminants to the peripheral system in the long term. The possible transport of the leachate below the bottom of the embankment was investigated by varying the hydraulic conductivity and hydraulic head. The sensitivity to the concentration of contaminants at the base and the downstream toe of the embankment was also analyzed.

Theory

The movement of leachates through a natural liner is governed by advection, hydrodynamic dispersion and diffusion, and can be represented by the following equation :

$$\mathrm{div}(D\,\mathrm{grad}\,C - C\overline{V}) = \frac{dC}{dt} \tag{3}$$

where grad C is the gradient of the concentration of leachates, $\overline{V}$ is the average linear velocity of the flow through the liner, D is the dispersion coefficient, and div represents the spatial gradient of the flux of leachates.

Dispersion coefficient is given by

$$D = D^* + \alpha\overline{V} \tag{4}$$

where D* is the effective molecular diffusion which represents the spreading of leachates through Brownian motion, α is dispersivity and $\alpha\overline{V}$ accounts for the spreading of leachates due to the microscopic mechanisms of flow through liners. Average linear velocity, $\bar{V}$, is obtained from the modified Darcy's law :

$$\bar{V} = \begin{Bmatrix} \bar{V}x \\ \bar{V}z \end{Bmatrix} = \frac{K}{n} \begin{Bmatrix} \dfrac{\partial h}{\partial x} \\ \dfrac{\partial h}{\partial z} \end{Bmatrix} \qquad (5)$$

in which $\bar{V}x$ and $\bar{V}z$ are the x and z components of a average linear velocity, n is porosity, h is the hydraulic head, and z is the thickness of the liner. A steady state hydraulic head distribution in the two-dimensional flow domain is obtained by solving the Laplace equation :

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial z^2} = 0 \qquad (6)$$

Equations (3) and (6) can be solved numerically and the Galerkin finite element method is employed in the analysis presented here (Jang et al., 1990).

Input Data

The hydraulic conductivities in the range of $10^{-7} \sim 10^{-5}$ cm/sec are used. The hydraulic conductivity 10^{-5} cm/sec which is greater than the values given previously is used here for the following reasons :

(1) The hydraulic conductivities used before are the results of laboratory test. The hydraulic conductivity obtained in the field often shows higher values than the laboratory K values. It is interesting to simulate numerically for an extreme condition and to study the possible consequences of the effect on the transport behavior.

(2) Although the averaged hydraulic conductivity is enough for obtaining the flow quantities, the role of the high K layers is important for the contaminant transport analysis, because the contaminant transport behavior is often controlled by the high K layers (Freeze and Cherry, 1979). Also, the foundation soils below the landfill are highly heterogeneous.

The hydraulic heads in the natural clay liner were assumed to be 4 m to 8 m. Since the effective diffusion coefficient does not show significant changes with different chemicals (Goodal and Quigley, 1977), it was assumed to be 6×10^{-10} m^2/sec. Dispersivity is 0.5 m and porosity is 0.3.

Problem Formulation

The problem intends to investigate the extent of leachate transport below the bottom of the embankment with varying hydraulic conductivity of foundation soils and hydraulic head in the waste fills. The points A and B in Fig. 6 were located in the center of the foundation of the embankment and at the toe of the downstream slope of the embankment.

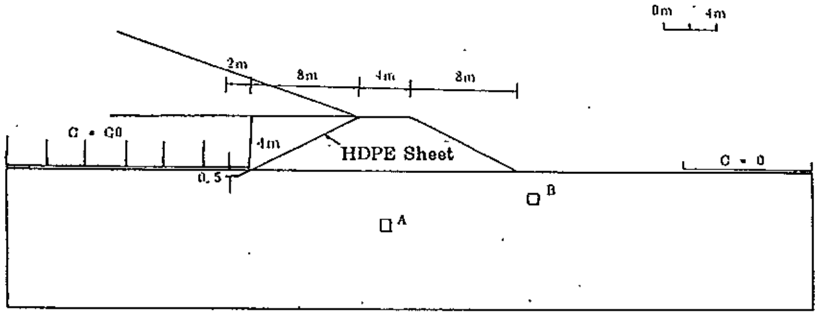


Fig. 6 Schematic Profile of the Landfill and the Embankment used for the Leachate Transport Analysis

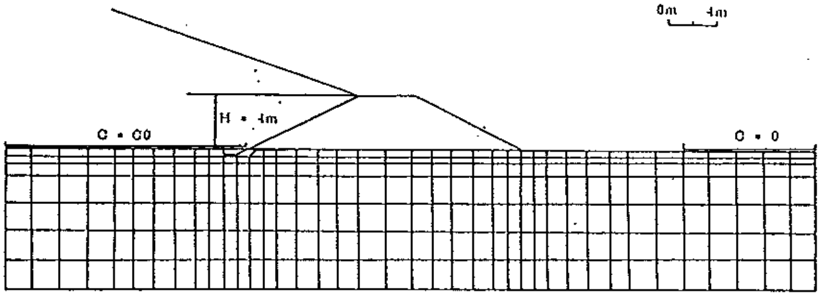


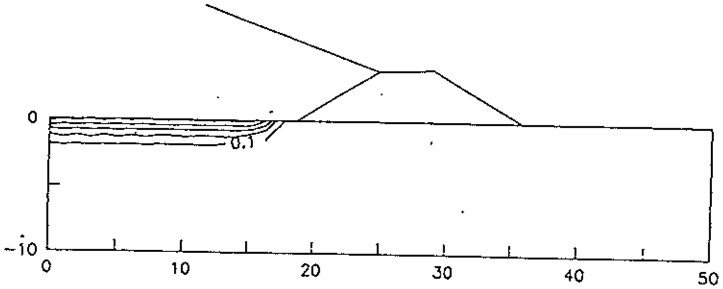
Fig. 7 Finite Element Mesh used for the Leachate Transport Analysis

These points were selected to investigate the influence of time and the varying hydraulic heads on the concentration of leachate at these points. The upstream slope of the embankment has the contamination source 1.0 and the surface water was located 20 m away from the toe of the downslope. The concentration of leachate in the surface water was assumed to be zero because the leachates are cleaned out due to the tidal flow of sea water.

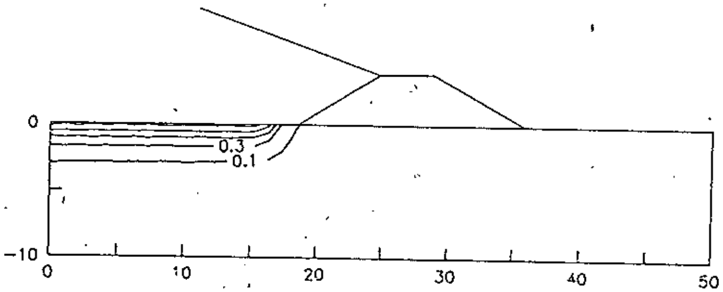
The following problems were considered :

(1) How far does the leachate travel beneath the embankment during 30 years with various hydraulic conductivities? (The hydraulic head is 4 m and the leachate is assumed to be non-reactive).

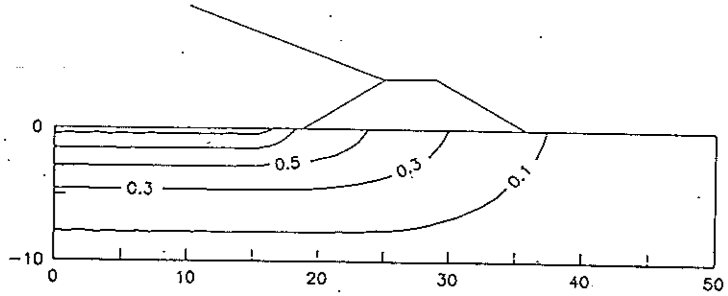
(2) How far does the leachate travel with varying hydraulic head? (The selected hydraulic conductivity value was 10^{-5} cm/sec)



(a)K = 10^{-7} cm/sec.



(b) K = 10^{-6} cm/sec.



(c) K = 10^{-5} cm/sec.

Fig. 8 Contours of Normalized Concentration (C/C_o) with Varying Hydraulic Conductivities (i.e. 10^{-7}, 10^{-6}, 10^{-5} cm/sec) after 30 Years

(3) Assuming the amount of leachate from the waste decreases with time, how does the concentration at point A vary with source duration = 5, 10 and 20 years?

(4) What variation of concentration at point A and B occurs with different hydraulic heads.

The finite element mesh used in this analysis is shown in Fig. 7.

Analysis of Results

The concentration contours of leachate which are normalized by the source concentration, Co, after 30 years leakage is shown in Fig. 8. With the hydraulic conductivity between $10^{-6} \sim 10^{-7}$ cm/sec, leachate travels $2 \sim 3$ m in the vertical direction and the travel distance of leachate in the horizontal direction beneath the embankment is negligible. This is because the influence of effective molecular diffusion on the transport of leachate is greater than that of the advection through the liner. When K is 10^{-5} cm/sec, the leachate travel about 20 m in the horizontal direction from the source during 30 years. For all three cases the geomembrane buried at the toe of the embankment cannot block the leachate movement significantly below the bottom of the embankment. If the layer with K greater than 10^{-6} cm/sec exist, the burial length of geomembrane should be extended to a greater depth or the pervious zone should be identified by detailed in-situ investigation and replaced by impervious clay in order to prevent the movement of leachate beneath the embankment to the peripheral environment.

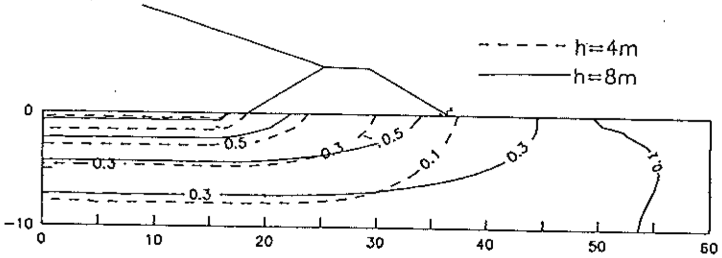


Fig. 9 Contours of Normalized Concentration (C/C_o) with Two Different Hydraulic Heads after 30 Years

Fig. 9 shows the contours of the concentration with two different hydraulic heads 4 and 8 m. Hydraulic conductivity is assumed to be 10^{-5} cm/sec. In the case of hydraulic head being 8 m, contaminants travel significantly. The concentration contour 0.1 in Fig. 9 reflects the influence of boundary conditions ($C/C_o = 0$) at the surface water. From these results it should be emphasized that uncertainty over the groundwater table in the waste landfill will have significant influence on the movement of leachate if K of the soils is high.

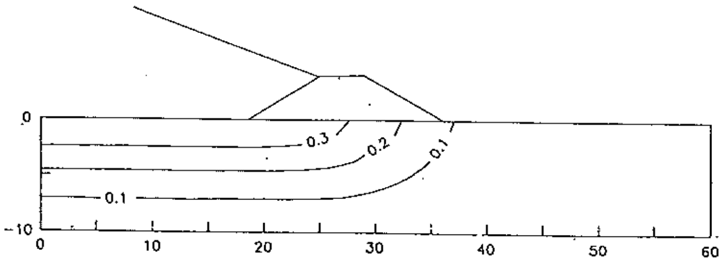


Fig. 10 Contours of Normalized Concentration (C/C_o) with the Duration of Contaminant source, 10 Years

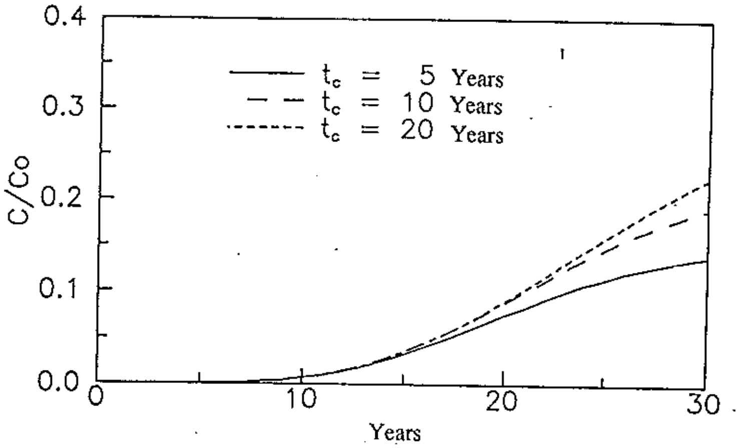


Fig. 11 Changes of Normalized Concentration at the Point Beneath the Embankment with the Duration of Contaminant Source, 5, 10, 20 Years

Fig. 10 shows the contours of concentration when the duration of leachate source is 10 years. Hydraulic conductivity is 10^{-5} cm/sec, hydraulic head at the source is 4 m and the period of leachate travel is 30 years. Concentration near the transient source has reduced to 0.3. However, the travel distance has not changed significantly.

Fig. 11 shows the variation of concentration at point A for source duration periods of 5, 10 and 20 years. Contaminants are detected 5 years after the close of waste fill and increased continuously throughout the remaining 25 years. It can also be seen that the concentration at the center of the foundation of the embankment is increased with the increase of duration of contaminant source.

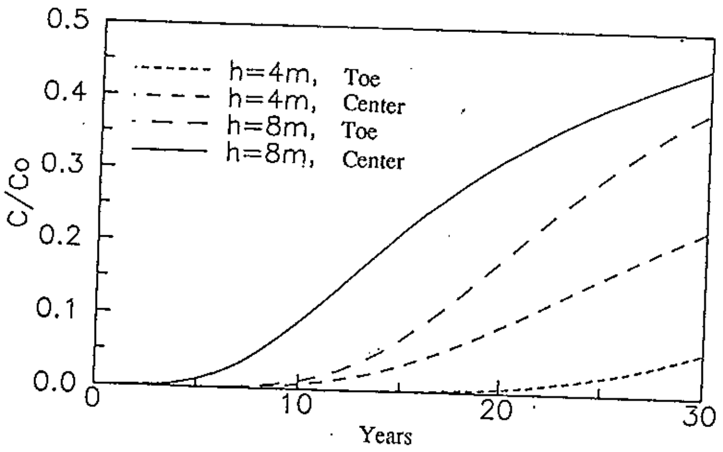


Fig. 12 Changes of Normalized Concentration at the Center and Toe of the Embankment with Respect to Two Hydraulic Heads

The changes of concentration at point A and B with varying hydraulic head 4 and 8 m are shown in Fig. 12. The concentration increases with respect to time at both points. The amount of increase is greater when the hydraulic head is higher. The concentration is lower and time takes longer to arrive at the point B located farther from the contaminant source.

CONCLUSIONS

The appropriateness of a seashore area as a landfill site is considered. The original clay layer on the seashore of the landfill site is used as the bottom liner and the geomembrane is installed only on the upstream slope of the peripheral embankments. The flow characteristics of the natural clay liner are analyzed for the different depths of waste. The leachate transport through the bottom of the embankments is investigated using a two-dimensional numerical transport model.

From the analysis of flow characteristics, it can be seen that a significant amount of seepage can be cut off using a geomembrane on the embankment. The reduction of hydraulic conductivity of the bottom clay layer to below 10^{-7} cm/sec, can be achieved due to the consolidation of the bottom liner.

Leachate transport analysis below the bottom of the embankments shows that the travel distance of contaminants is negligible if the hydraulic conductivity of the natural clay is lower than 10^{-6} cm/sec. When the hydraulic conductivity of the bottom liner is greater than 10^{-6} cm/sec, the advection of leachates controls the transport and significant movement has occurred below the bottom of the embankment.

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