

Behavior of a municipal landfill from field measurement data during a waste-disposal period

Yeon-Soo Jang · Yong-In Kim

Abstract The behavior of a municipal waste landfill on marine clay was analyzed from field measurement data. Instruments, e.g., a groundwater level sensor, piezometer, earth pressure gauge, settlement plates, inclinometer, etc., were installed and operated during the disposal period from October 1992 to November 2000. A database system was developed to manage the data from this landfill using Access (Microsoft) with Delphi programs. From the analyses, it was determined that the settlement of the landfill during the initial period of waste disposal was small because of the high leachate level in the landfill. As the level of waste became higher than the leachate level, the settlement of the landfill increased significantly due to the increasing effective pressure within the landfill. From a stability point of view, the critical time for the landfill in this study was the initial period of landfill disposal, which was caused by either the impact load of waste disposal or the time schedule of waste disposal, which was faster than the consolidation of foundation clay caused by the waste load.

Keywords Behavior and stability · Korea · Leachate level · Municipal waste landfill · Waste disposal

Introduction

Stability of landfills is an important issue from an environmental and structural point of view. When a barrier

system of the landfill fails, the peripheral subsurface environment can be severely contaminated by the leakage of leachate from the landfill. Landfill designers often provide various monitoring instruments to detect the instability of the landfill as well as the contamination of the peripheral environment. The usual measurements are the settlement of the waste and the subsurface system, groundwater level and its quality, and the amount of leachate and its quality.

Recently, database systems, which can interpret the data obtained from the monitoring instruments, have been actively developed and used for various areas (Oloufa and others 1994; KMOC 1997; Sadek and others 1999). In the case of landfills, data are often collected periodically during the operation of the landfill without the proper systems for analyzing the monitored data. Developing a database that can be applied to the landfill operation is critical for early detection of potential instability of the landfill and the contamination of the surrounding environment.

In this paper, a database system for managing the data from landfills was developed using the Access program of Microsoft with Delphi language. This system was used to analyze the data collected from a landfill in Korea, i.e. Kimpo No. 1 Landfill in the western part of Seoul, during landfill operations from October 1992 to August 2000 (EMC 1992–2000). The types of instruments installed in this landfill included a groundwater level sensor, piezometer, earth pressure gauge, settlement plate, and inclinometer. The inputs for the database were the status of the landfill and liner, the engineering properties of the foundation soil, and the field measurement data. These three inputs were linked together and the user could search the data easily and analyze the stability of the waste fill (Fig. 1). The changes in the leachate level and the earth pressure with respect to the height of disposed waste, the settlement characteristics, the horizontal displacement of the toe of the landfill slope, and the variation of surface index marks were analyzed and the critical factors obtained from the analysis are described.

Site condition

Kimpo No. 1 Landfill was constructed on marine clay in 1992 and operations started in 1993. Disposal of waste was completed in 2000. The total area of the landfill is about

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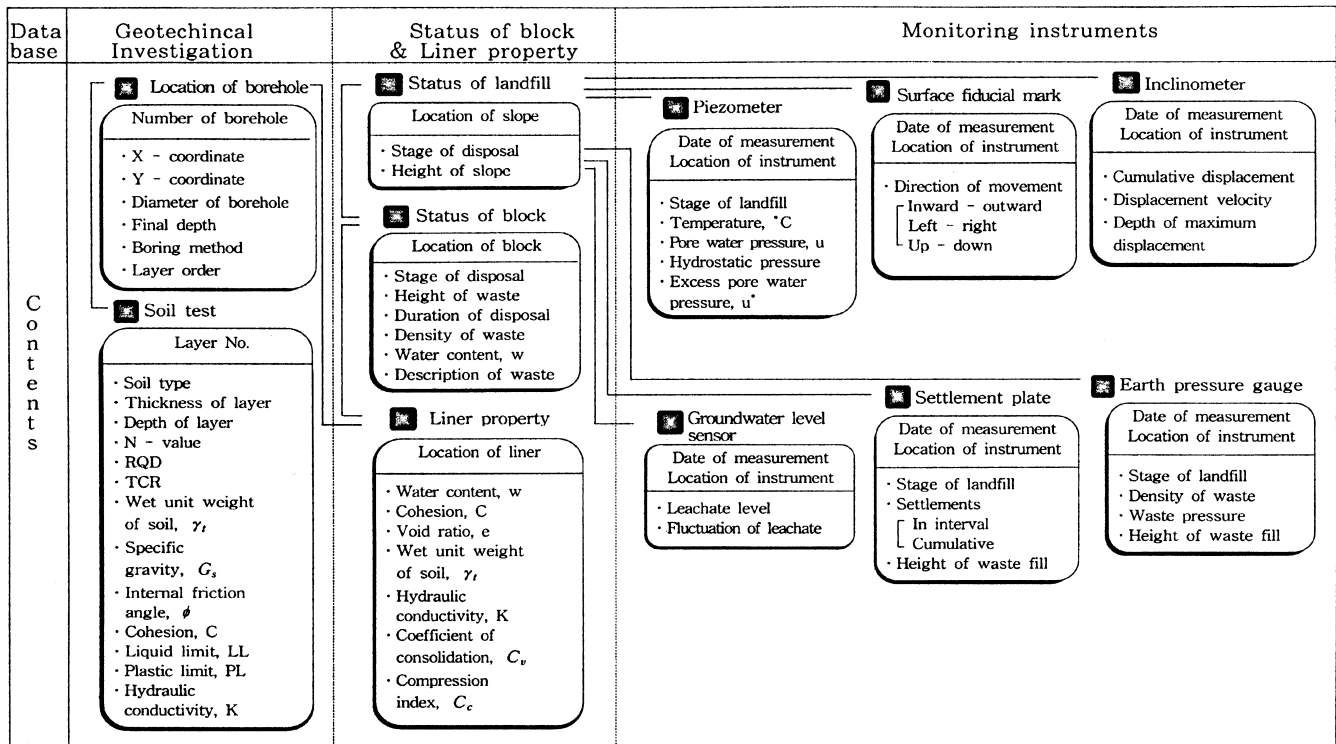


Fig. 1
Schematic diagram of the database of landfill

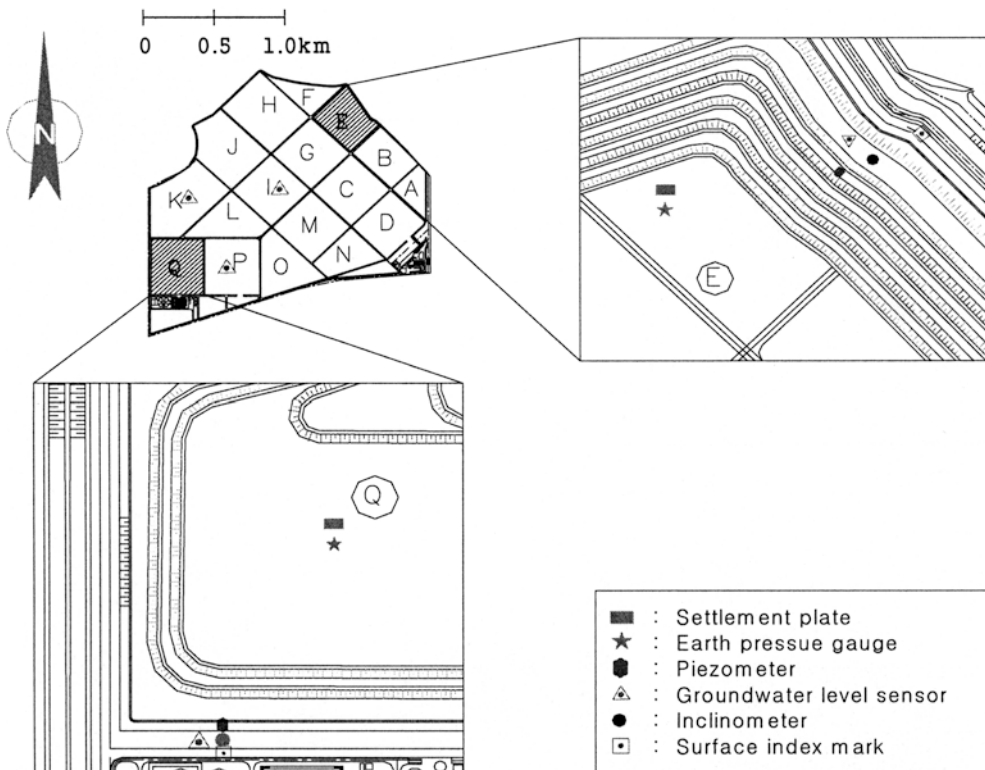


Fig. 2
Plan view of the landfill and the location of field monitoring instruments

2.5 km² and is constructed with 17 blocks of various sizes (Fig. 2). Each block is designed to dispose of 5-m thickness of waste in a stage-by-stage manner. The total

number of waste stages and the final height planned were 8 and 40 m, respectively (Jang 2000). The locations of the field monitoring instruments are shown in Figs. 2 and 3.

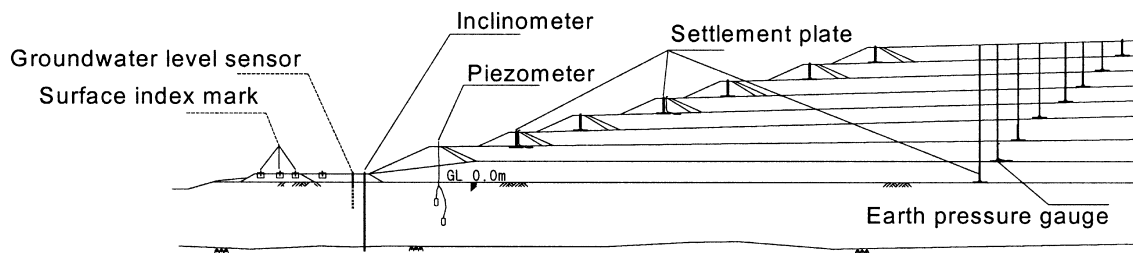


Fig. 3

Cross section of the landfill with the field monitoring instruments

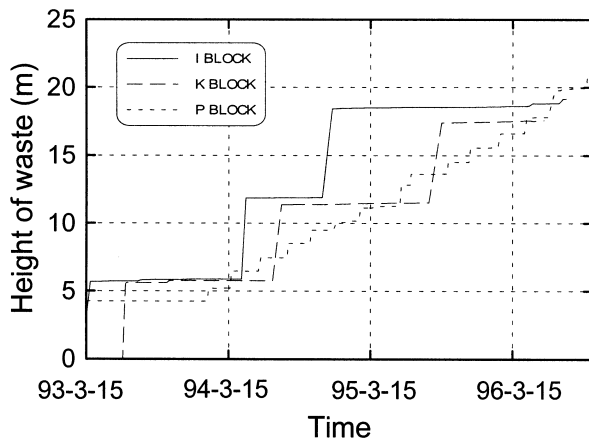


Fig. 4

Variation of the height of waste with respect to the time of waste disposal

Settlement plates with the earth pressure gauge to measure waste load were placed in the central part of the blocks and the leachate level sensor, piezometer, surface index mark, and the inclinometer were installed on the slope of the landfill.

The thickness of marine clay layer is 13 m in E block and 22 m in Q block. Marine sediments where the landfill is located were deposited less than 10,000 years ago. The surface of the marine sediments, before the waste was disposed of, was relatively flat with elevations ranging from EL1–4 m above sea level. The groundwater levels under the foundation soil of the landfill ranged from 2.5–1 m from the surface of EL 1–4 m (Dong Ah 1996).

Analyses of the behavior of the landfill

The characteristics of settlement, waste pressure on the foundation soil, and density of waste with respect to the increase with stage of waste disposal were analyzed. The leachate level within, and the slope of the landfill were analyzed using the data obtained from the leachate level sensor and the piezometer. The stability of the slope of the landfill was analyzed by the variation in the surface index mark and the inclinometer.

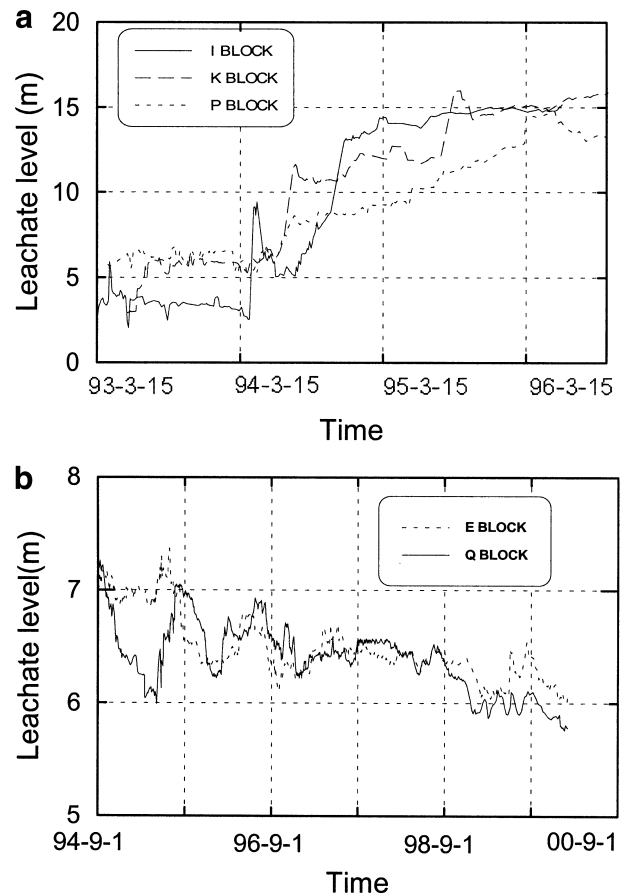


Fig. 5

Variation of the leachate level during the time of waste disposal for the center and the slope of the landfill: a center of the landfill; b slope of the landfill

Leachate level

The variation in the height of waste that was disposed of in a stage-by-stage fashion is shown in Fig. 4 for blocks I, K, and P, and the variation in leachate level during the time of waste disposal is shown in Fig. 5 for the center and the slope of the landfill.

It can be recognized that the leachate levels in blocks I, K, and P increased with an increase in waste height. Even though the waste height was increased stage-by-stage up to 40 m, the leachate level began initially from a height of 4 m and increased to 15 m by March 1996, after the fourth

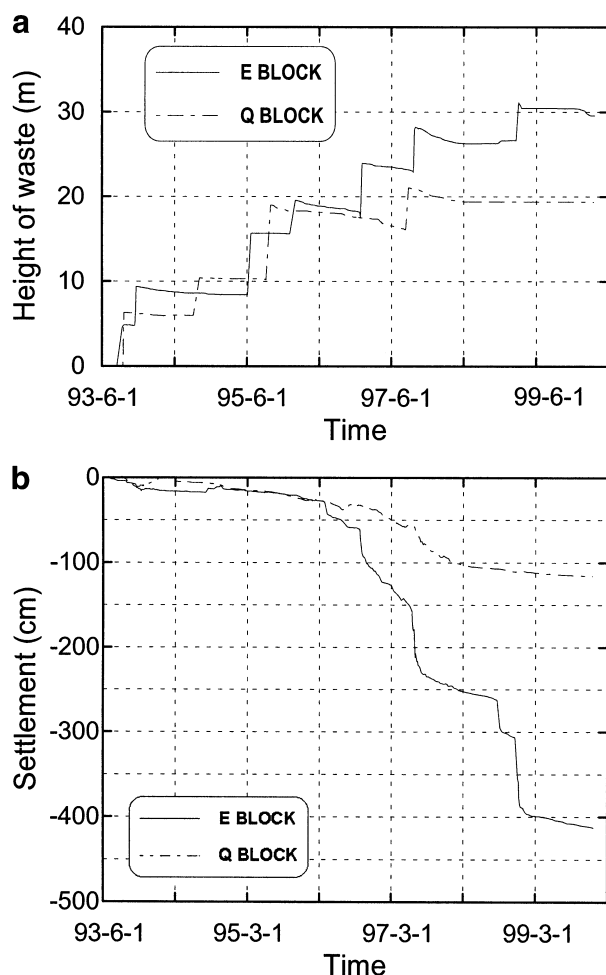


Fig. 6

Variation of waste height and settlement with respect to time of disposal: a height of waste; b settlement to time

stage of waste disposal was completed (Fig. 5a). Variations in leachate level near the slope of blocks E and Q are shown in Fig. 5b. It was found that the leachate level initially fluctuated between 6 and 7 m and gradually converged to approximately 6 m. The leachate level in the outer area of the landfill was lower than within the landfill area because this area formed the boundary of the landfill. Variation in leachate level in this area was small.

Settlement of marine sediment under the landfill

Settlement of marine sediment of blocks E and Q under the waste load was plotted with respect to the time of disposal, and is shown in Fig. 6. Disposal of waste was started in June 1993 for E block and September 1993 for Q block. Until June 1996, 3 years after the start of waste disposal, the height of the waste disposed was nearly 20 m at the fourth stage of disposal (Fig. 6a). Settlement of the subsurface under the landfill, which occurred in the same

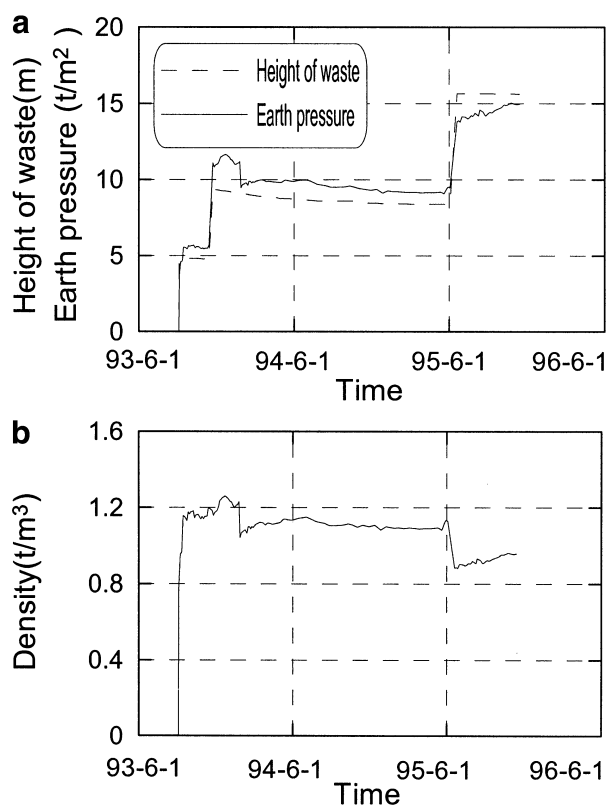


Fig. 7

Relation of pressure, density, and height of the waste with time of disposal (block E): a pressure and height of waste; b density of waste

period, was approximately 40 cm for both blocks. After June 1996, the settlement of the subsurface increased rapidly with the increase in waste load (Fig. 6b). The final settlements of the subsurface were 1 m for Q block and 4 m for E block, which closely correlated with the thickness of clay and the heights of the waste: 20 m for Q block and 30 m for E block.

The drastic increase in settlement after June 1996 seemed to be caused by an increase in effective stress from the waste load. As indicated in Figs. 4 and 5a, the leachate level was increased by up to 15 m with the increase in waste height at the central area of the block. The unit weight of the waste disposed of in the field was calculated to be approximately 0.9–1.2 t/m³ (Fig. 7b). The increase in leachate level at the initial four stages of waste disposal offset the waste load, and, therefore, the effective stress needed to develop settlement until the early period of 1996 was small.

Waste pressure and density with increase in waste height

The pressure of waste at each disposal stage was measured in E block using an earth pressure gauge, and the density of waste was calculated from the monitored waste pressure (Fig. 7a, b). Figure 7a illustrates that the pressure of waste increased in proportion to the height of waste. Waste

density was obtained by dividing the measured earth pressure by the height of waste.

Variation in the density of waste was negligible with the increase in height of waste and the time of waste disposal. The range in waste density was calculated to be 0.9–1.2 t/m³. The waste density is in the range of density of compacted waste as documented in the literature (Sharma and others 1990; Jang and Lee 2000).

Horizontal displacement from the inclinometer

As shown in Fig. 3, inclinometers were installed near the toe of the slope of the landfill with a groundwater level sensor. The horizontal displacement of the slope of the landfill was measured and compared with that of the surrounding ground where no movements were monitored. The threshold displacement velocity designed for the disposal of waste in the landfill was 20 mm/day. From the observed data, the displacement velocity, cumulative horizontal displacement, and the depth of maximum displacement are plotted in Fig. 8, with respect to the elapsed time for block E.

In the early days of waste disposal, the horizontal displacement velocity was in the range of 1 to 17 mm/day, although the measured velocities were below the threshold velocity of 20 mm/day (Fig. 8a). As waste disposal progressed, the range of monitored velocity decreased to 0–2 mm/day. This means that the critical period of the landfill, from a stability point of view, was the first year of waste disposal. Fluctuations in the monitored velocity seemed to be caused by the impact load of waste disposal and the vibration of waste trucks and bulldozers operating during waste disposal. The influence of this vibration decreased as the height of the disposed waste increased.

The rate of cumulative displacement of the waste slope was higher in the initial stage of disposal and the displacement converged to 18 cm at 3 years after the start of waste disposal (Fig. 8b). In Fig. 8c, the depth of maximum horizontal displacement that occurred is marked. It can be recognized that the maximum displacement occurred at a depth of 0 to 4 m at the initial stage of the waste disposal and converged to a depth of 2 m after March 1997.

Surface displacement from the surface index mark

Horizontal displacement of the surface under the slope was measured using a surface index mark to detect the upheaval of the ground near the toe of the slope, which is a sign of potential failure of the waste slope. Directions and the cumulative displacement of the mark in Q block are shown in Fig. 9a and b. In Fig. 9a, the upward movement

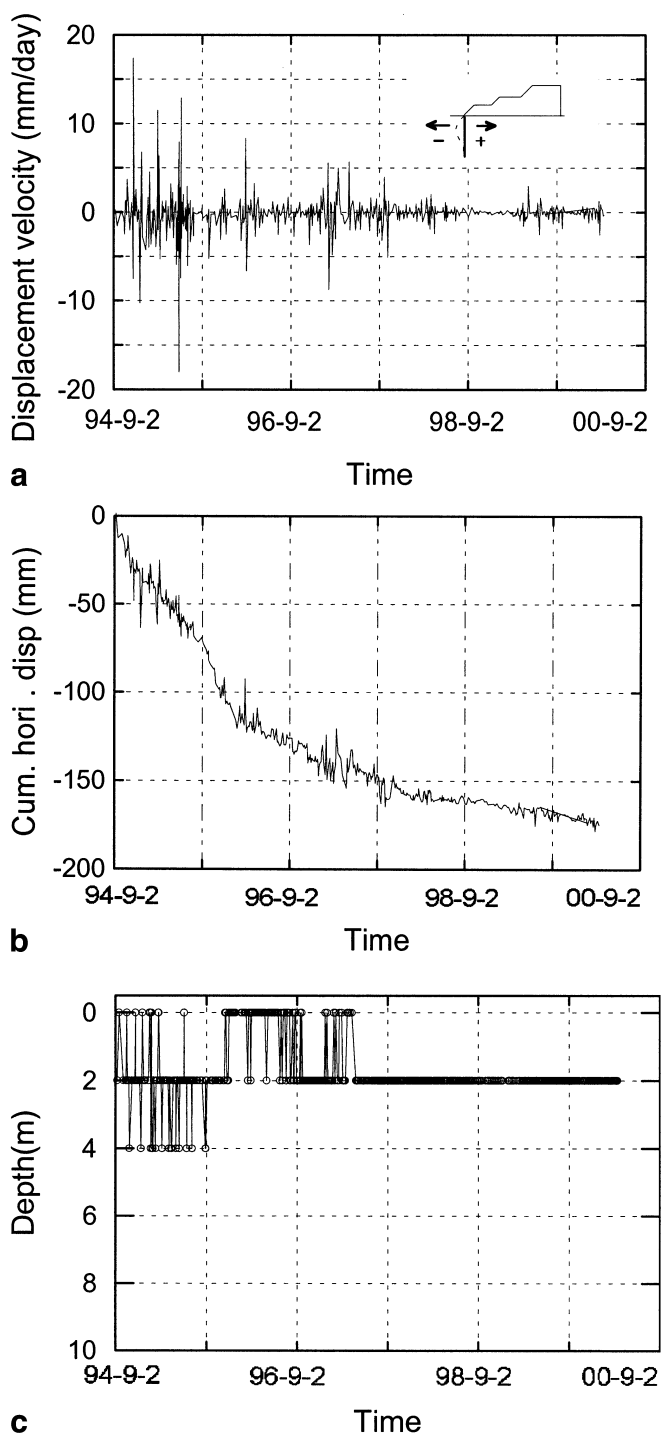


Fig. 8

Displacement, velocity, horizontal displacement, and depth of maximum displacement with respect to the time of disposal: a displacement velocity(mm/day); b cumulative horizontal displacement(mm); c depth of maximum horizontal displacement

of the surface and the outward movement of the slope are considered as positive.

Vertical surface movement, shown in Fig. 9b, indicates negative displacement, i.e., settlement, at the toe of the slope except for an early period in 1998. Settlement in this location was mostly due to the impact of vehicle loads.

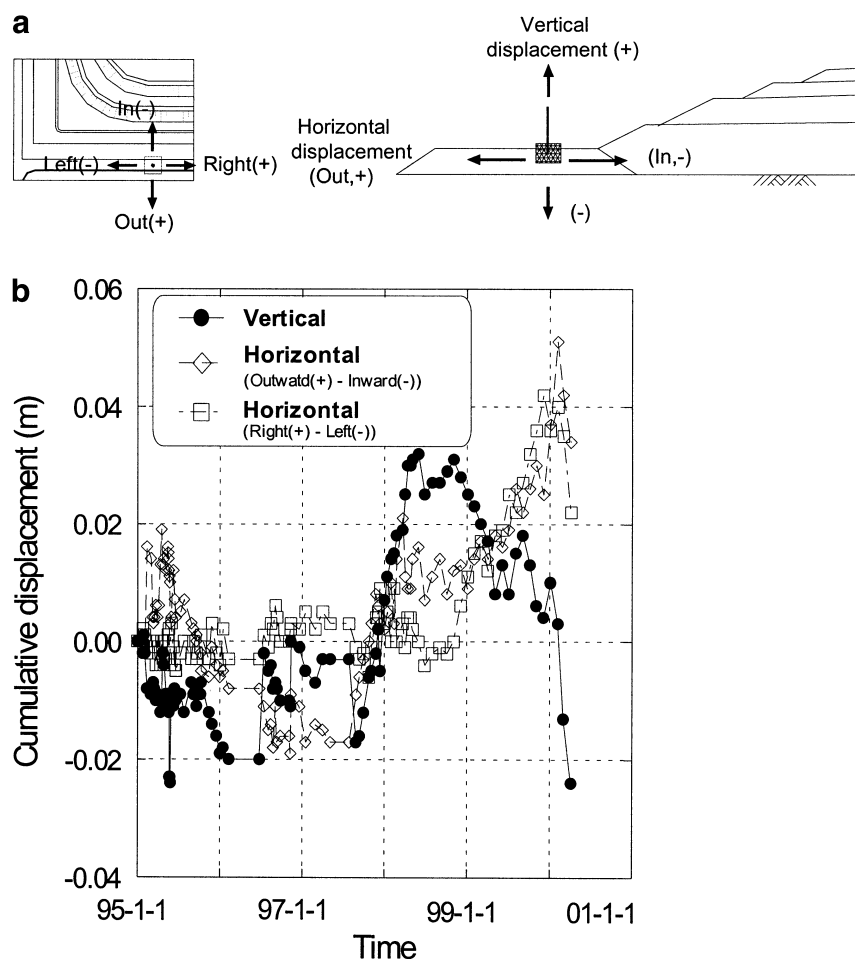


Fig. 9

Displacement of surface index mark with time of waste disposal: a direction sign of surface movement; b cumulative displacement

However, significant positive displacement, showing the upheaval of the toe of the slope, was recognized during the early period of 1998. This period was consistent with waste disposal stage 4. Outward movement of the mark was also noticed at the start of this year. This is the most critical time of stability for the slope in Q block, in which the thickness of marine clay under the landfill was significantly greater than that of the other blocks. After recognizing the potential instability of the waste slope from the measured surface displacement data of the surface index mark, the management officials, as well as the designers of the landfill, decided to quit disposal of waste in this block at the fourth stage. Since stopping waste disposal, the upheaval of ground movement, i.e., the positive vertical movement, began to decrease. The instability problem of the waste slope in Q block was resolved and the database system clearly indicated a stable condition of the waste slope.

Settlement of the marine clay due to disposed waste was continued until the closure of the landfill and the downward vertical movement of the surface is indicated in Fig. 4b. Horizontal movement, a diamond symbol in Fig. 9b, indicated a positive movement outwards. Outward movement continued until the operation of this landfill was almost finished during early 2000.

Conclusions

Data collected using field instruments in a municipal landfill were analyzed by the database systems developed and the following conclusions were obtained:

1. Leachate level in the landfill increased with the increase in waste height. As the waste height increased in stages, the leachate level increased initially from 4 to 15 m after the fourth stage of waste disposal was completed.
2. During the period of 3 years from the start of waste disposal, settlement was approximately 40 cm for both Q and E blocks. After this period, the settlement of the subsurface under the landfill increased rapidly with the increase in waste load. This was due to the increase in effective stress with waste load after the leachate level was increased to 15 m.
3. The pressure of waste at each disposal stage in E block was measured using an earth pressure gauge. The density of waste calculated from the monitored waste pressure was 0.9–1.2 t/m³. This waste density is in a similar range to the density of compacted waste as documented in the literature.
4. From a stability point of view, the critical time of seashore landfill was the initial period of waste disposal,

which was affected by either the impact load of the disposed waste or when there was faster waste disposal than consolidation of the foundation clay.

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