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Mechanical Influence of a Large-scale Excavation on the Adjacent Embankment

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ABSTRACT: A large sewage disposal plant was constructed on a very soft ground in Hikone. Since the site was close to a railway embankment, it was a great concern whether the construction work of sewage disposal plant would have undesirable influence on the railway embankment. Therefore, the deformation of railway embankment was carefully simulated using finite element techniques relating to the progress of the plant construction. The ground deformation due to the plant construction is discussed and the protection methods employed to prevent the deformation of adjacent railway embankment are examined throughout a series of F. E. analyses in this paper.

1 INTRODUCTION

In Japan, spaces for construction activities are extremely limited. Therefore many new structures are constructed under undesirable ground conditions, i.e., a very soft ground, a high-ground water level and so on. A large sewage disposal plant was constructed on a very soft ground, located at the lakeside of Lake Biwa. Since the site was very close to a railway embankment, it was a great concern whether the construction work of sewage disposal plant would have undesirable influence on the railway embankment. A very soft peat layer thickly covers the site. The plant construction was accompanied by the excavation work in the very soft peat layer. The open-cut method using the retaining wall made from the soil mixed with cement was employed. Any deformation of adjacent railway embankment due to the excavation work may interfere the safety of the train operation. Then, the deformation of railway embankment accompanied by the progress of the plant construction was carefully simulated using finite element techniques. Particularly, the following two factors were paid attention to, one was the influence due to lowering the ground water level with the plant construction and another was the stress release associated with the excavation work. Three kinds of finite element analyses were carried out; that is, the two-dimensional cross-section seepage analysis, the quasi three-dimensional seepage analysis and the soil/water elasto-viscoplastic deformation analysis. The ground deformation due to the plant construction and the protection methods employed to prevent the deformation of adjacent railway embankment are examined through a series of finite element analyses in this paper.

2 DESCRIPTION OF THE SITE

Figure 1 shows the plant of this site, in which the analyzed area is indicated by hatching. Four tanks are planed to construct, a primary sedimentation, bioreactor tank, final setting basin and rapid sand filter. The construction area (the third block) is about 8,500m^2 and total construction area is about 641,000m^2. A depth of tanks is about 3.0-6.0m and a large excavation work is needed in the construction of all tanks.

The railway embankment locates near the construction area. The distance between the

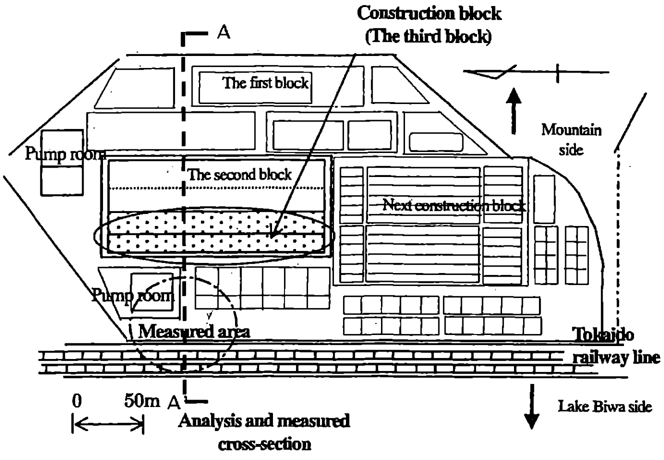


Figure 1 Plan view

railway embankment and the plants is only 80m, so that we worried about the deformation of railway embankment under the construction of plants.

The ground at the site consists of soft materials. A geological history of the site is as follows. The area had been the bottom of Lake Biwa many thousand years ago. Old Tokaido Line of railway was constructed about 100 years ago. The line was on the embankment. New Tokaido Line for high speed train operation was constructed by the embankment in the same way of the old line and the old railway embankment was abandoned in 1956. Figure 2 shows a geological profile at the site. Peat is seen from the surface of ground to a depth of about 10m. Between about 10m and about 13m in depth, a sandy clay layer exists. But, generally, the ground at the site is very soft. Particularly there exist very soft layers in which SPT blow count is almost equal to be zero. The largest deformation will occur in the very soft layers in the construction yard. Figure 3 shows the soil properties. The unit volume weight of the peat is 10.5-11.3 (kN/m^3); void ratios are 4 to 6 and the water contents vary from 200 to 400 (%) as summarized in the Table 1. Although the permeability of peat is usually anisotropic, the vertical and horizontal coefficients of permeability of the peat at this site are almost identical The groundwater level is about 0.4m beneath the ground surface.

3 SAFETY ESTIMATION OF RAILWAY EMBANKMENT

We carried out some numerical analyses (F. E. M.) to examine the mechanical behaviors of railway embankment relating to the construction of plant and to evaluate a safety of train operation. Judgment of safety was made based on the displacement of embankment. Figure 4 shows a flow chart of the monitoring system employed. We numerically predicted the displacement of railway embankment caused by groundwater withdrawal and stress relaxation, and checked whether it was less than the allowable limit specified by the Japan Railway Maintenance Rules. If the value of calculated displacement exceeds the allowable limit, some measures to protect the deformation of embankment have to be considered.

Table 1 Soil property

Parameter	Test value
Unit volume weight (kN/m^3)	10.5-11.3
Void ratio	4.0-6.0
Water content (%)	200-400
Unconfined compression test (kN/m^2)	1.4-1.7

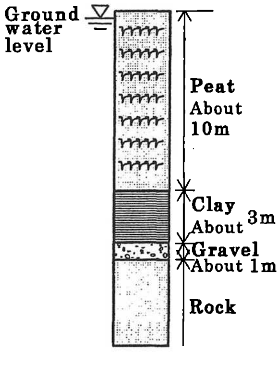


Figure 2 Geological profile

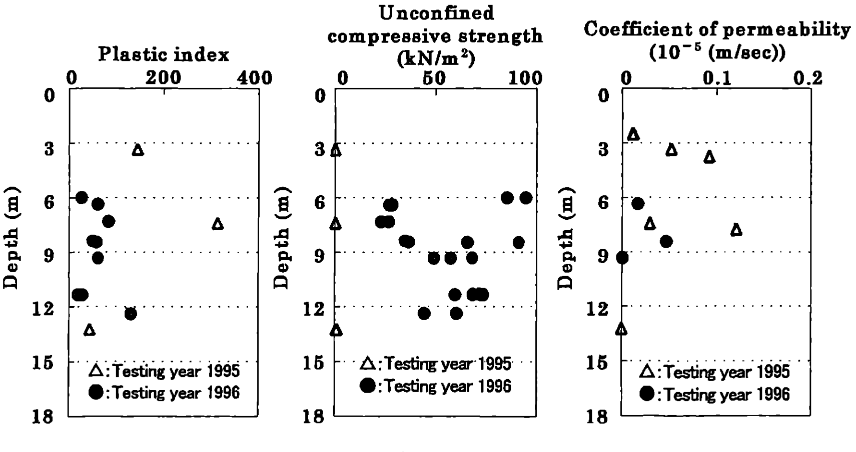


Figure 3 Soil properties

The construction sequence is shown in Figure 5. The vacuum consolidation method was employed to ensure the acceleration of consolidation resulting in increasing strengths of soils. After it, the excavation work began.

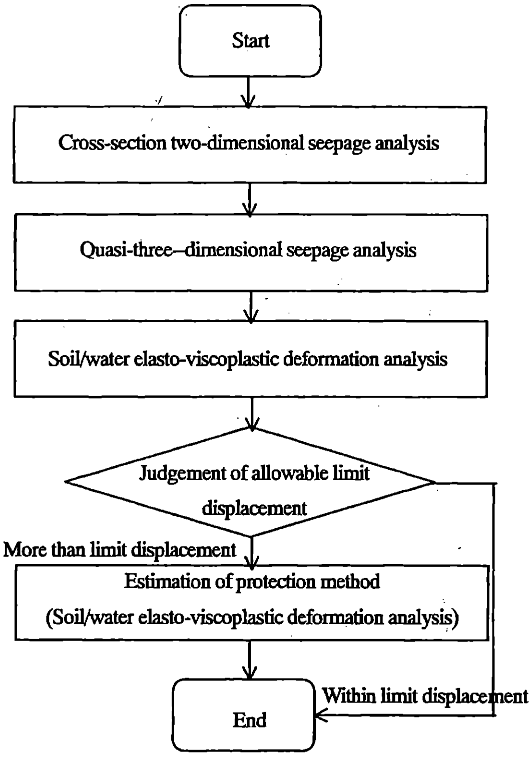


Figure 4 Flow chart of the watching system

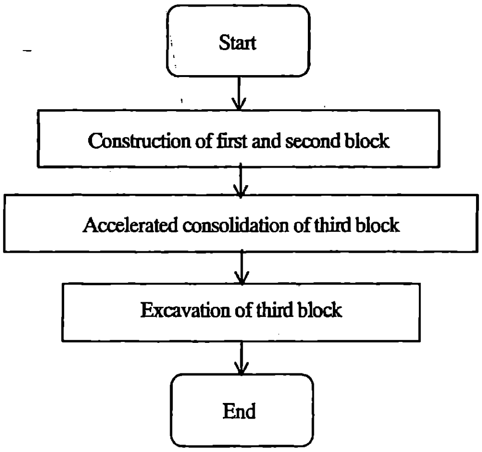
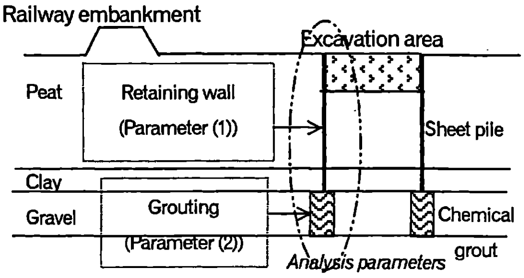


Figure 5 Construction flow

3.1 *Ground water withdrawal with excavation*

The groundwater withdrawal would strongly influence and cause the deformation of embankment. Therefore a protection method that prevents lowering the groundwater lever was required. The amount of groundwater withdrawal was estimated by cross-section two-dimensional and quasi-three-dimensional seepage analyses.

The cross-section two-dimensional analysis can consider the depthwise distribution of soil properties, so as to estimate the realistic depthwise water flow. The objects of this analysis are to evaluate the impervious effect of walls which is planned to penetrate a clay layer existing in the middle of the ground. Since the seepage analysis carried out was two-dimensionally for the cross-sectional plane, A-A' in Figure 1, it was anticipated that the withdrawal of the groundwater level would be somewhat excessively estimated. Figure 6 explains the cases analyzed. Results of the cross-section two-dimensional analysis are summarized in Figure 7 and 8. Estimated groundwater withdrawals based on a difference of wall property are summarized in Figure 7 (case 1 and 2). Walls considered in the analysis are a sheet pile wall (permeability, $k=1.16x10^{-7}(m/s)$) and a soil cement mixing wall ($k=3.20x10^{-9}(m/s)$), in which the coefficient of permeability of the sheet pile was estimated based



Case 1: Sheet pile (Parameter (1), not use grouting)

Case 2: Soil cement mixing wall (Parameter (1), not use grouting)

Case 3: Soil cement mixing wall and chemical grout (Parameter (1) and (2))

Figure 6 Seepage analysis model

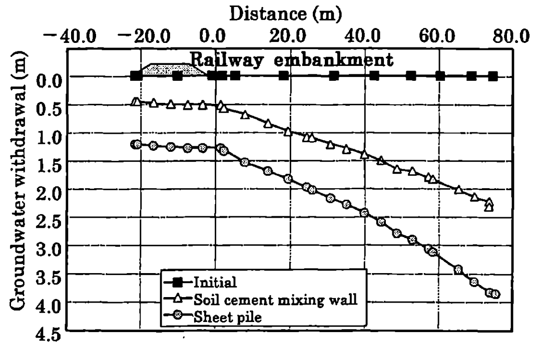


Figure 7 Result of the cross-section 2D analysis (Wall-style)

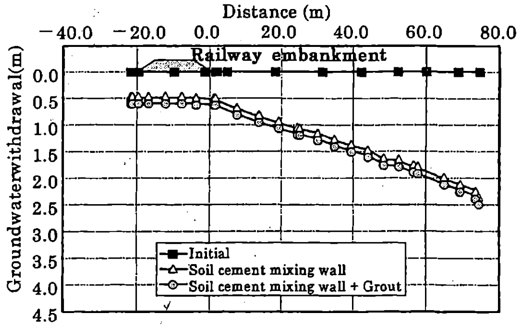


Figure 8 Result of the cross-section 2D analysis (Wall-length)

on a series of model tests carried out by Yamamura et. al. (1964) and the coefficient of permeability of the soil cement mixing wall was determined from the pump-up test at the site. Table 2 shows the coefficient of permeability of all materials used in the seepage analysis. Figure 8 shows the wall depth (Case 2 and 3). Two lines of groundwater withdrawals in the figures almost correspond. Then it was concluded that the installation of 15m deep wall would be sufficient for the required condition.

The quasi-three-dimensional seepage analysis can estimate the amount of water flow in the horizontal and vertical directions. As for the vertical direction, the averaged property of all soil layers in depth was used in calculation. So, the result from this analysis would not give very realistic value, but the total groundwater level can be expected as overall value close to the reality. Figure 9 shows the analysis model. Figure 10 shows the model of the protection method. The result of quasi-three-dimensional seepage analysis is summarized in Figure 11. The objective of analysis is to evaluate alternative protection methods. The computed results are presented in Figure 11. The soil cement mixing wall is effective to keep the groundwater level unchanged beneath the embankment. Thus, the quasi-three dimensional seepage analysis suggests that lowering of ground water level under the railway embankment can be restrained if the impervious walls are constructed under the toe of railway embankment. Then it was decided that the soil cement mixing walls were chosen as the retaining walls in the site.

Table 2 Coefficient of permeability of all materials used to seepage analysis

	Material	Coefficient of permeability (m/sec)
soil	Peat	4.10×10^{-7}
	Clay	4.40×10^{-10}
	Gravel	1.00×10^{-4}
wall	Soil cement mixing wall	3.20×10^{-9}
	Sheet pile	1.16×10^{-7}
	Grout	1.00×10^{-7}

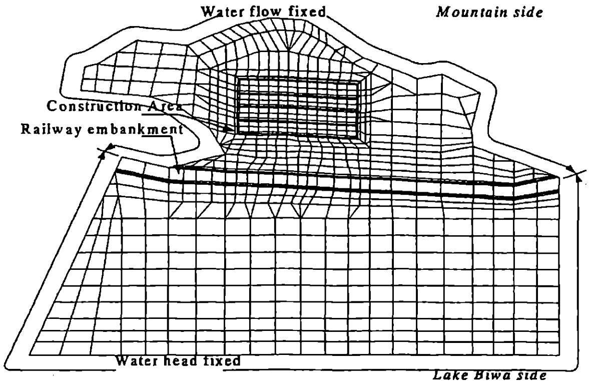


Figure 9 Model of quasi-three-dimensional analysis

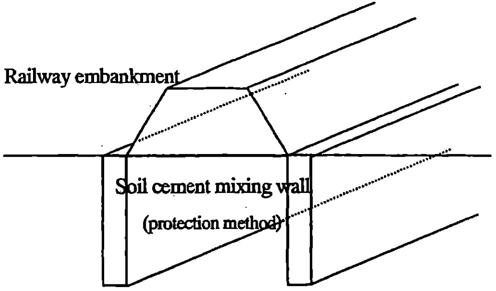


Figure 10 Protection method

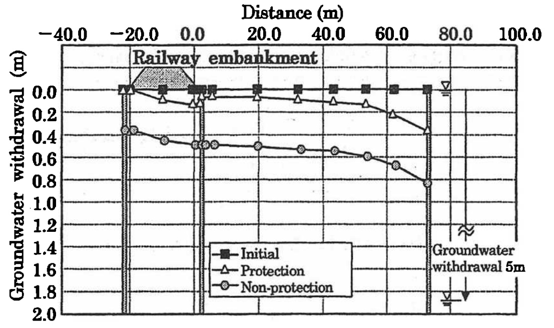


Figure 11 Result of quasi-three-dimensional seepage analysis

3.2 *Deformation of railway embankment*

If the predicted deformation exceeds the allowance limit prescribed, we have to make some judgment for further operation of construction. Then, a prediction tool is required. In this paper, the deformation analysis based on a soil/water coupling is employed in which the Sekiguchi-Ohta model is incorporated. This program was soil/water coupled elasto-viscoplastic finite element code developed by Iizuka and Ohta (1987). The modeling of the site and boundary conditions are shown in Figure 12. Input parameters were determined from the procedure using an unconfined compressive strength proposed by Ohta et. al. (1988).

At first, we carried out the analysis of deformation for the past record, that is, the construction in 1956 of new railway embankment was simulated. Then, the calibration work for input parameters needed in the analysis was made by comparing the computed settlement with the monitored one as shown in Figure 13. The computed settlement well agreed with the monitored one. This agreement encourages the further prediction of the ground deformation due to the excavation work at the site. Then, the excavation work in this site was simulated. The analysis followed the actual construction sequence. Two cases were computed.

(1) The soil cement mixing walls installed under the toe of new railway embankment in order to prevent lowering of ground water level under the embankment were considered in the computation.
(2) The soil cement mixing walls were not considered.

The numerical simulation was carried out in accordance with the actual construction sequence at the first, second and third blocks. In the analysis, the acceleration of consolidation at the site by the vacuum consolidation method was taken into consideration. Figure 14 indicates the computed displacement at the shoulder of embankment in the mountain side. The effect of soil cement mixing wall can be realized from the figure. The settlements exceeding 60mm were estimated in the case without the walls. On the contrary, the settlements remain within only 15mm when the soil cement mixing walls were considered. However, it can be seen that the horizontal displacements happen to be almost the same in two cases. It seems that the soil cement mixing walls does not work to reduce the horizontal deformation of the embankment, that is, the prevention of lowering of the ground water level does not contribute the reduction of horizontal displacements. At this site, the soil cement mixing walls were constructed before the excavation work for the disposal sewage plant.

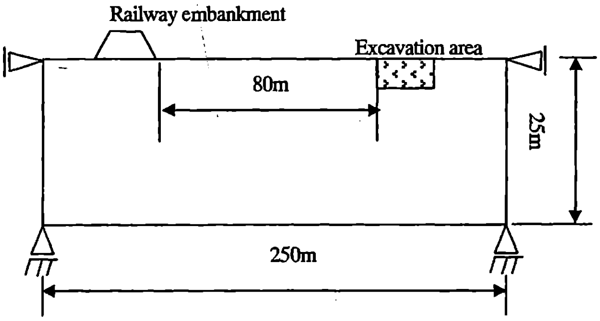


Figure 12 Analysis model

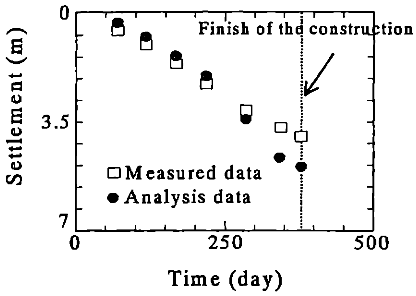


Figure 13 Settlement of new Tokaido line

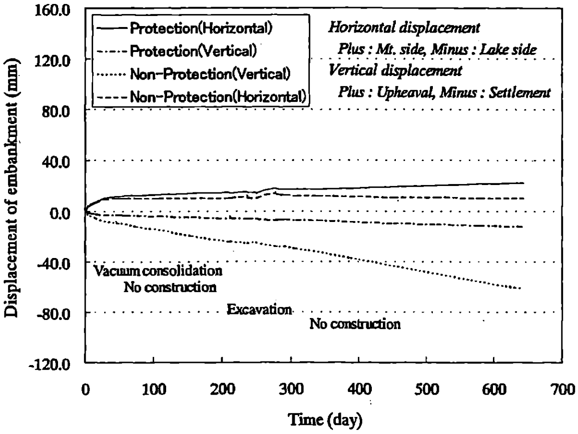


Figure 14 Displacement of top of embankment

4 CONSTRUCTION

To ensure the safety during construction, a measurement control was carried out during the excavation work. Figure 15 shows the locations of measurement implements installed/placed on the ground. The contents of monitoring were as follows, (A) deformation measured by the optical three-dimensional survey, (B) horizontal deformation by clinometers, (C) settlement by the settlement gauge, and (D) groundwater level by automatic recording water-level gauges. The deformation of the railway embankment measured by displacement stakes of H1 and H2, which were

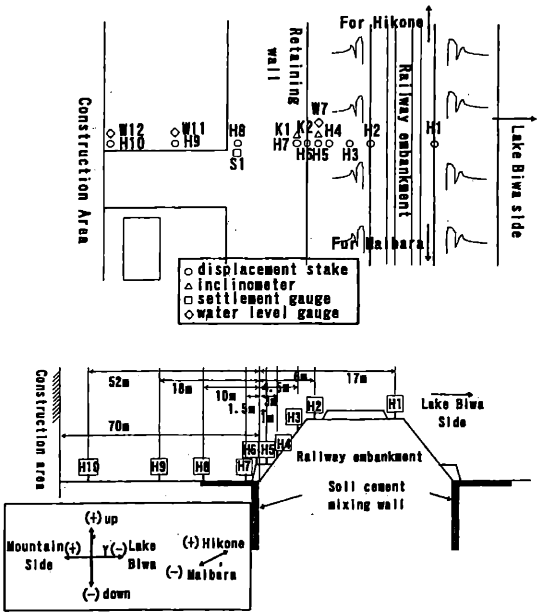


Figure 15 Location of measurement implements

installed to make use of judgment for the safe train operation.

Monitored results are summarized in Figure 16. numerically predicted results are also plotted in the figure. During the vacuum consolidation and the excavation work, the settlements remain within about 2mm. It is confirmed that the excavation work did not have any influence on the deformation near the railway track.

The horizontal displacement in the direction toward Lake Biwa side also remains in the small range from 1 to 5mm. It was judged that the excavation work did not cause any significant displacement around the railway track as well.

5 CONCLUSION

A large scaled excavation work was carried out near the main railway line. In this paper, reported is a series of analyses to ensure the safety not only of excavation work itself but also of train operation of the railway line. Three kinds of numerical techniques were employed, mainly in order to predict the change of ground water level relating to the excavation work and deformation of the railway embankment which exists adjacent to the excavation site. The retaining walls in the ground to prevent undesirable influence on the railway embankment were designed based on the results obtained from numerical analyses. And also, the safety management based on the monitoring the deformation during the excavation work is introduced.

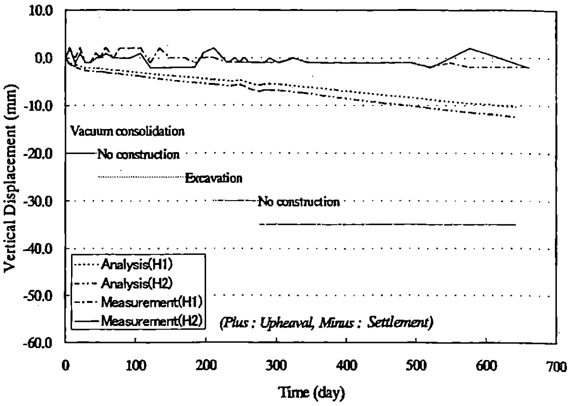


Figure 16 (a) Vertical displacement

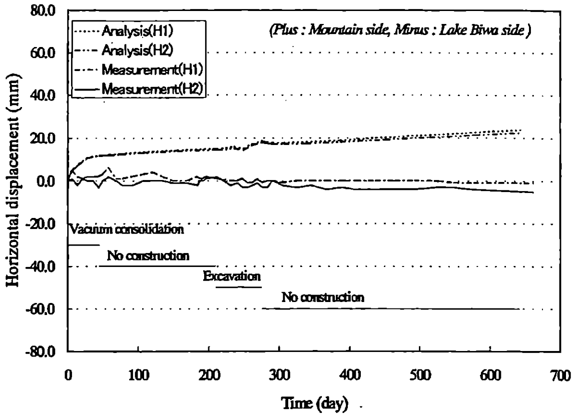


Figure 16 (b) Horizontal displacement

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