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Behavior of a high airport embankment with horizontal drains

Tatta, N. & Ito, S.
Maedakosen Co., Ltd., Japan

Kawauchi, M. & Matsumura, T.
Shizuoka Prefecture Government, Japan

Nakamura, Y.
Nippon Koei Co., Ltd., Japan

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ABSTRACT: Land development is underway at Shizuoka Airport. The development involves the construction of a high embankment of a total fill quantity of 26 million m^3 with a maximum height of 75 m. Not all of the locally available embankment materials are of high quality. High-water-content materials also need to be employed. Then, it has been planned to stabilize the embankment by encouraging the consolidation of embankment materials and increasing drainage capacity using horizontal drains. Numerous uncertain factors are, however, related to the effectiveness of horizontal drains. A test embankment was therefore constructed and the behavior of the embankment and the effectiveness of drains were investigated through field observation. An FEM analysis was also made of the test embankment. The effectiveness of drains were analyzed and the results were compared with the field observations.

1 INTRODUCTION

Shizuoka Airport, located in the Midwest of Shizuoka Prefecture, is under construction for opening in March 2009. At present, land development is underway. A high embankment with a total amount of materials of 26 million m^3 and a maximum height of 75 m will be constructed. Embankment materials will be acquired at the site to have balanced cut and fill quantities at the project site. Not all of the embankment materials are, however, of high quality. High-water-content materials also need to be used. It has therefore been planned to stabilize the embankment and facilitate construction by encouraging the consolidation of embankment materials and increasing the drainage capacity using horizontal drains (Figure 1). Numerous uncertain factors are, however, related to the effectiveness of horizontal drains. A test embankment was therefore constructed and the behavior of the embankment and the effectiveness of horizontal drains were investigated through field observation. The test embankment was also checked by an FEM analysis and the calculations obtained by the FEM analysis were compared with the measurements for the test embankment to examine the effects of horizontal drains on the embankment.

A test embankment with a maximum height of 45 m was constructed. Figure 2 shows a general view of the test embankment. Horizontal drains were laid at spacing of 5.0 m vertically and 2.0 m horizontally.

Figure 1. Construction conditions.

Figure 2. A general view of the test embankment.

The behavior of the embankment was monitored during field observation using settlement gauges, inclinometers, earth pressure gauges and water pressure gauges. Figure 3 shows a profile of the test embankment.

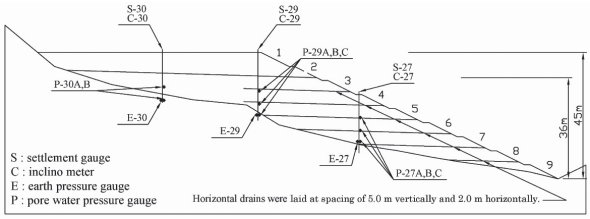


Figure 3. A profile of the test embankment.

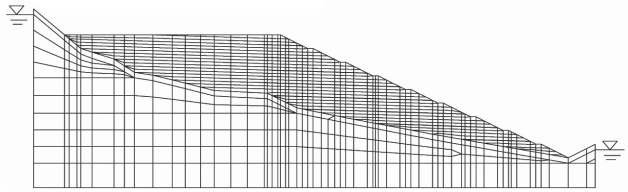


Figure 4. FEM model.

2 OUTLINE OF ANALYSIS

The profile of test embankment was modeled for FEM analysis (Figure 4). The actual steps for constructing the test embankment with a height of 36 m above the toe of the slope for four months were accurately reproduced in FEM analysis (Figure 5). Earth-water coupled two-dimensional analysis was made using the Sekiguchi-Ohta model to represent the constitution of embankment material. To examine drainage capacity, drainage conditions were provided at the nodes on the model corresponding to the locations of drains and the coefficient of permeability was modified to make the drainage in the soil in the two-dimensional model equivalent to three-dimensional drainage at the site (drains were installed at vertical and horizontal spacing of 5.0 and 2.0 m, respectively) [2], [3]. In relation to the two-dimensional model, drains have been reported to be effective not only for providing drainage capacity but also for increasing tensile strength [1]. In the analysis in this study, calculations were made in the case where the effectiveness of the drains in the model only for increasing drainage capacity was considered and in the case where assumed stiffness was applied to the horizontal drains on the model to consider the effectiveness for increasing tensile strength as well. Calculations were also obtained in the case with no drains. These calculations were compared with the field observations. For the stiffness of horizontal drains, a value earlier estimated to represent the effectiveness for increasing tensile strength was used [4]. For details of the analysis method, refer to the references.

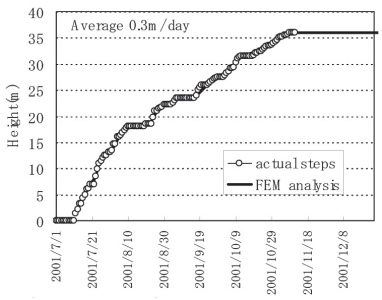


Figure 5. Construction steps.

3 RESULTS OF ANALYSIS

Differential settlement and vertical earth pressure were measured and horizontal displacement was obtained using inclinometers during field observation. The measurements were compared with the calculations. Results are shown in Figures 6 through 8. The figures show the analysis results in three different cases: (a) case with no drains, (b) case where only the effects on drainage capacity was considered and (c) case where the effects on both drainage capacity and tensile strength (with stiffness additionally applied) were considered.

From the tests, it was observed that both closed- and open-ended piles show increasing resistance as the driving depth increases. In terms of resistance magnitudes, the shaft resistances of closed-ended piles are much higher than the shaft resistances of open-ended piles at all settlements.

(1) Results of analysis in the case where only the effects on drainage capacity was considered

The readings of differential settlement gauges (Figure 6) indicate that the effects on drainage capacity were represented nearly satisfactorily. The inclinometer readings (Figure 7), however, fell short of reflecting measured horizontal displacements. Measurements

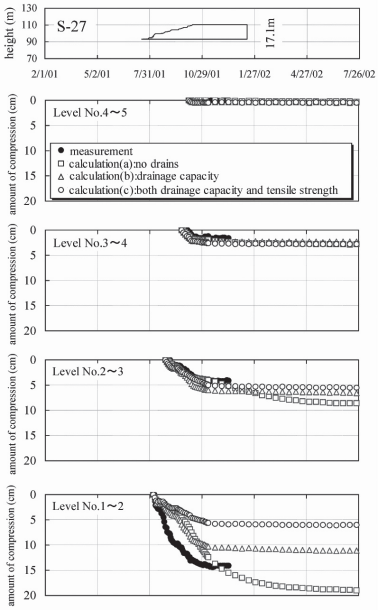


Figure 6. The differential settlement gauge.

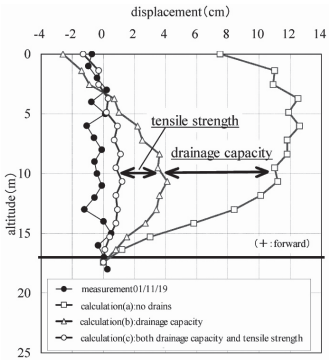


Figure 7. The inclinometer.

were smaller than calculations. The measurements obtained by earth pressure gauges were smaller in some locations than the analysis results for earth pressure, which was equivalent to overburden pressure (Figure 8). This is ascribable to the effects of drains on tensile strength that were not considered in analysis.

(2) Results of analysis in the case where the effects of drains on tensile strength was also considered (with stiffness additionally applied)

Based on the results described in (1) above, calculations were made in the case where assumed stiffness was applied to drains (to consider the effects on tensile strength). For the stiffness, E = 2.34 × 1010 kN/m^2 (106 times the actual value) and I = 100 m^4 were adopted that were estimated for similar drains used at another airport [4]. The calculations are shown in Figures 6 through 8. Measurements were accurately represented in all of the figures. The analysis, however, underestimated the measurements obtained by differential settlement gauges in some locations.

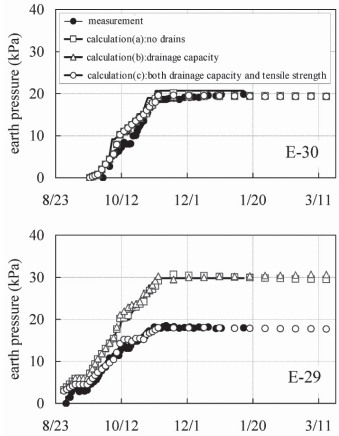


Figure 8. The earth pressure gauge.

4 EFFECTIVENESS OF HORIZONTAL DRAINS FOR REINFORCEMENT

Figure 9 shows contours of pore water pressure and local safety factor in cases with and without horizontal drains. The figure shows the results where only the effects on drainage capacity were considered in analysis. It is evident that the drains quickly dissipates pore water pressure in the embankment and thus increases the stability of the embankment. Figure 10 shows the state of compaction at the site with or without drains. The results of analysis considering only the effects on drainage capacity are sufficient for showing the stability of the embankment. Judging from the fact that horizontal displacement was reduced in the field, greater stability may have been provided to the embankment than that owing to the effects on drainage capacity. (Drains were effective also for increasing tensile strength.)

5 CLOSING REMARK

As a result of comparison of measurements with analysis results, it was found that horizontal drains greatly increased the stability of the embankment.

Phenomena observed at another airport were also found in the test embankment. The effectiveness of drains for reducing horizontal displacement was therefore found not to be unique to the site. The

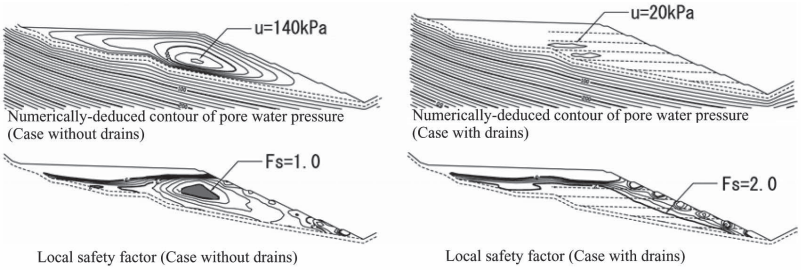
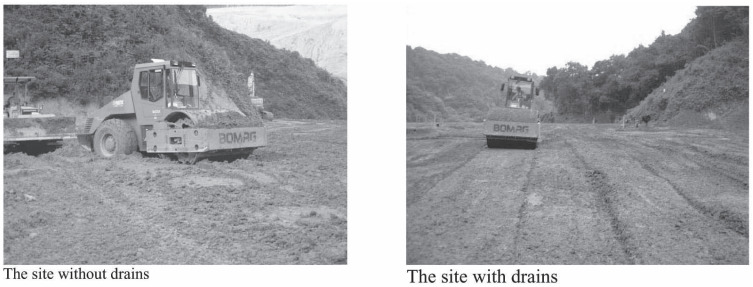


Figure 9. The contours of Numerically-deduced (only the effects on drainage capacity were considered in analysis.



The site without drains

The site with drains

Figure 10. The state of compaction.

stiffness estimated at another airport was applicable to the site without any modification. Thus, it was found that the horizontal drains employed at the site were effective for increasing not only drainage capacity but also tensile strength to the level higher than that owing to the stiffness of drains. Apparent stiffness may have been provided to increase the tensile strength not solely by the horizontal drains but through the interaction between the drains and surrounding embankment materials. The method of analysis used in this study, however, can express the effectiveness for increasing tensile strength simply by inputting assumed figures during calculation, but cannot logically represent actual phenomena. Only the possibility of horizontal drains providing effects on tensile strength was expressed.

Clarifying phenomena logically and incorporating the effectiveness for increasing tensile strength have been left for the future.

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