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Behaviour of high airport embankment with geotextile horizontal drain

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ABSTRACT: The fill of Noto Airport is constructed rapidly to a height of 55 meters, and its embankment material is high water content clay. Geotextile horizontal drain is installed in the fill to accelerate consolidation. To establish a reasonable method to analyze a behavior of the fill installed the horizontal drain, an applicability of the elasto-visco-plastic FEM is examined in this paper. The result of the simulation is agreed with observed deformation and stress behavior, but horizontal deformation measured is smaller than estimated by FEM. It probably shows that a reinforced effect by friction between the soil and the geotexitile, not modeled in FEM, is produced in fact. The effect of the geocomposite drains embedded in the embankment is discussed mainly in this paper. Propositions of the paper as well as the author's views of the practical implications of the results.

1 INTRODUCTIONS

Soft cohesive soil with high natural water content is being used for the embankment material of a large-scale airport embankment. Horizontal geotextile drains were embedded in the embankment to dissipate the excess pore water pressure. Settlement, lateral displacement, pore water pressure, and earth pressure within the embankment were measured during the construction. An elasto visco-plastic consolidation FEM analysis was carried out to reproduce this process. The numerical results were generally consistent with the measurements but discrepancy was found in the lateral displacement of the embankment during its construction; the actual lateral displacement was significantly suppressed. The effec t of the geocomposite drains embedded in the embankment is discussed mainly in this paper. Propositions of the paper as well as the author's views of the practical implications of the results.

2 THE OUTLINE OF NOTO AIRPORT AND THE BEHAVIOR OF TEST EMBANKMENT

The construction of Noto Airport is being carried out at a quick pace. The large-scale embankment involving a total volume of

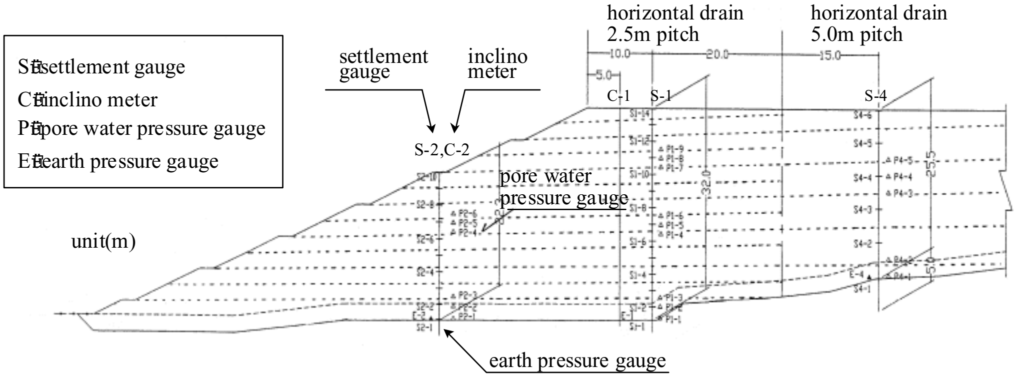


Figure 1. Outline of the test embankment and arrangement of monitoring gauges

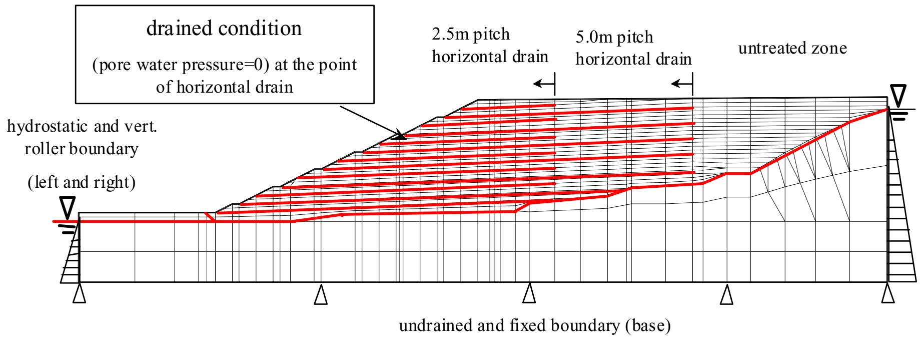


Figure 2. Mesh diagram and boundary conditions for FEM analysis

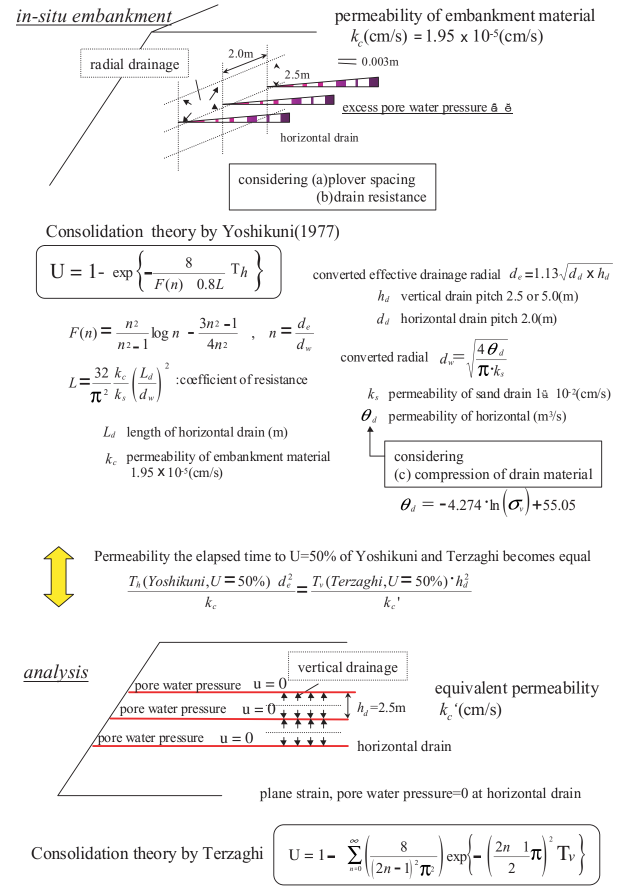


Figure 3. Idea for determinating the equivalent permeability coefficient

16,000,000 m^3 and a maximum embankment height of 55 m should be completed within three years. Because soft cohesive soil with high natural water content (30-80%) was used as an embankment material, the embankment was constructed while accelerating the consolidation of the soil zone by using horizontal geotextile drains. In the first design stage, the consolidation properties of the embankment containing the drains were evaluated by using the consolidation theory of Barron (Barron, 1948), and the stability of the embankment was analyzed by the circular slip method. It was estimated that the required safety factor could be achieved by arranging the drains embedded at 5-m intervals vertically and 2-m intervals horizontally. Because a number of design-related uncertainties including the effect of the drains remained unsolved, a large-scale test embankment (Figure 1) was constructed before the start of the actual construction work in order to investigate the stability, stress-deformation behavior, and the drainage effect of horizontal drain by taking several in-situ measurements. An elasto-visco-plastic consolidation FEM analysis was also carried out to compare the measured and numerical results and to monitor the stability of the embankment.

3 NUMERICAL MODEL

Because the embankment material consists mainly of a high-water-content clay, a two-dimensional elasto-visco-plastic soil/water coupled FEM analysis incorporating the constitutive model (Sekiguchi & Ohta, 1977) was carried out. A cross section of the test embankment and the arrangement of instruments are shown in Figure 1. The mesh diagram and the boundary conditions used for the analysis are shown in Figure 2. To reproduce the construction, embankment elements were sequentially added according to the actual construction schedule. Excess pore water pressure generated by the equivalent nodal force corresponding to the embankment load is dissipated toward the horizontal drains. Modelling the horizontal geotextile drains is not so easy. Because each drain has a thickness of only about 3 mm, expressing it as an element in the numerical mesh is not practical. It was therefore assumed that the drains only have the capability of drainage, and complete drain condition (with no pore water pressure) was assumed at each node of horizontal drain as a hydraulic boundary condition (Figure 2). However, the effect of the drains may be overestimated when complete drainage is assumed because of the following reasons:

(a) Although ideal drain surfaces are assumed to extend in the depth of embedded drain in the two-dimensional plane strain analysis, the drains are actually arranged at 2-m intervals horizontally perpendicular to the profile of the embankment.
(b) Consolidation is delayed because of the finite permeability of the drains (drain resistance effect (Yoshikuni, 1979)).
(c) The permeability of actual drains is reduced by clogging and the decrease of drainage area by overlying earth pressure.

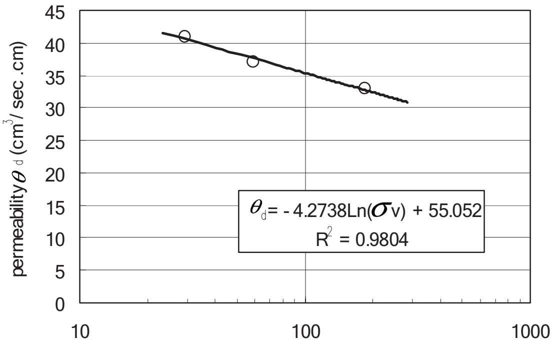


Figure 4. Dependence of permeability on the overburden pressure

To avoid the overestimation of the drainage ability of the horizontal drain, a smaller-than-real permeability coefficient (equivalent coefficient) was adopted in consideration of the above (a) through (c) for the soil between the drains.

The idea for determinating the permeability coefficient in consideration of the above (a) to (c) is shown in Figure 3. The flow of water in the embankment was assumed to follow the consolidation theory of Yoshikuni (Yoshikuni, 1979), which can account for the in-situ staggered arrangement of the drains and the effect of drain resistance. The flow of water in the numerical cross section was assumed to be mainly one-dimensional vertical flows toward the drains following the consolidation theory of Terzaghi. The permeability coefficient of the soil between the drains in the analysis was set to a value that gives the same time, t_{50}, to achieve an average consolidation degree of 50% in both theories. The permeability of each horizontal drain, $_d$, in Yoshikuni's consolidation equation was evaluated in consideration of its dependence on the overburden pressure, based on the empirical formula shown in Figure 4. The permeabilities of different portions and at different depth within the embankment were evaluated in accordance with the process of construction. This allows numerical description of such phenomena as the decrease of permeability at deeper portions of the embankment due to drain resistance and the overlying earth pressure. The decrease of permeability due to clogging was not taken into account because no significant effect was found in a laboratory clogging test for the period of about 120 days.

Physical parameters were specified based on the results of laboratory tests (consolidation, long-term consolidation, and CU tests) and field permeability tests on the embankment material.

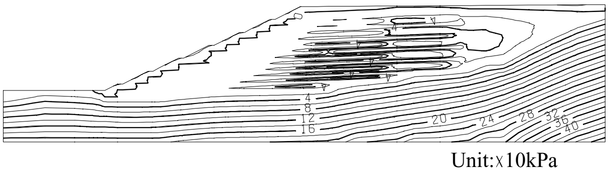


Figure 5(a). Numerically-deduced contour of pore water pressure

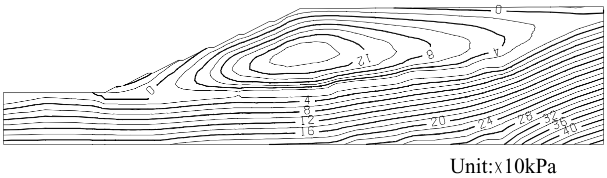


Figure 5(b). Numerically-deduced contour of pore water pressure (case without drains)

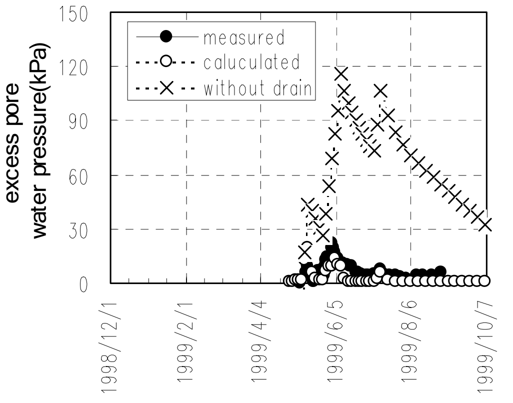


Figure 6. Comparison of the numerical and measured results of pore water pressure between drains

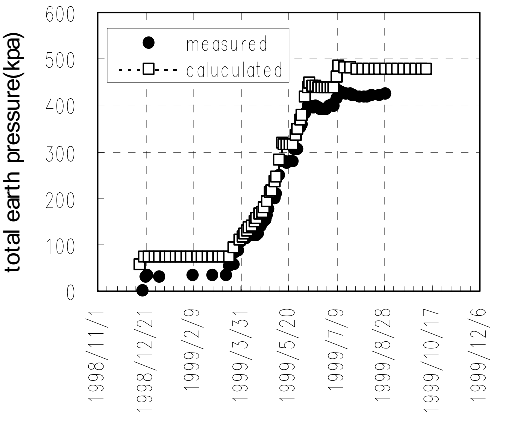


Figure 7. Comparison of the numerical and measured results of earth pressure

4 COMPARISON OF MEASURED AND NUMERICAL RESULTS

Figure 5(a) shows the numerically-deduced contours of pore water pressure in the embankment at the time of its completion. The pore water pressure of the soil between the drains is high at the deeper portions of the embankment, where embankment load is big and drain resistance highest. Figure 5(b) shows a case without horizontal geotextile drains; high pore pressure occurs at the center of embankment. The numerical results indicate that the embankment could not have been constructed without the drains. Figure 6 compares in time sequence the numerical results of pore water pressure with values measured between the drains; numerical results without the drains are also shown for comparison. The generally good agreement between the measured and numerical results in the figure indicates that the equivalent permeability coefficient previously described was almost appropriate. Figure 7 compares the measured and numerical results of vertical earth pressure (total stress). The numerical results well reproduces the increase of earth pressure with the progress of construction. Figure 8 shows good agreement between the numerical results of embankment settlement and the values measured with differential settlement gauges (cross-arm).

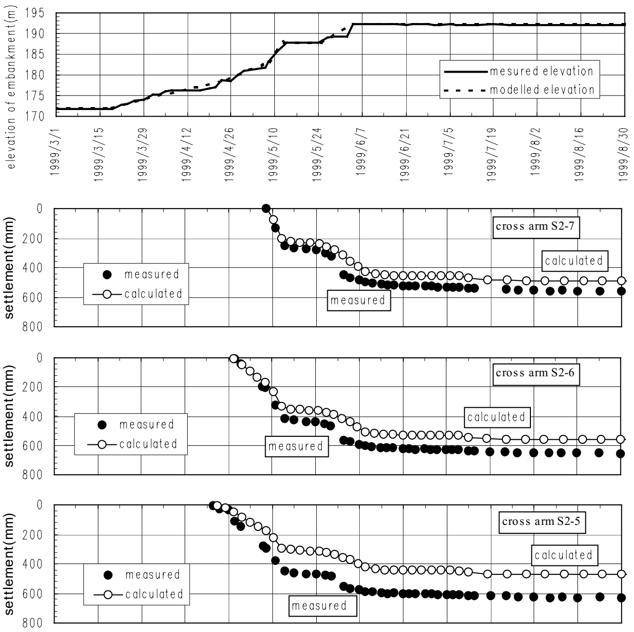


Figure 8. Comparison of the numerical and measured results of settlement

5 RESULTS AND DISCUSSION ON THE COMPARISON OF THE LATERAL DISPLCEMENT OF THE EMBANKMENT

Figure 9 shows, in comparison with numerical results, the relationship between the settlement and the lateral displacement of the slope (displacement vectors) measured with survey piles installed at the top of the slope. The numerical results show that the top of the slope deforms nearly along the slope of embankment (1 :2). However, a similar trend was observed only in the beginning stage of construction and then deformations occurred with little horizontal displacement actually. Figure 10 compares the horizontal displacement measured with the inclinometers and numerical results. The numerical values are greater than the measured ones by a factor of two or more as for the measurement with survey piles.

The drains used for the test embankment have nearly the same structure as a recently developed geocomposite, a composite geotextile where a non-textile fabric is adhered to both sides of a textile fabric having high strength and stiffness. The geocomposite is said to have the functionality of both drainage and reinforcement. Miyata et al. carried out geocomposite pulling tests in the embankment material used for Noto Airport and in Kanto Loam (Miyata, 2000). They showed that the embankment material, containing some amount of sand and gravel, was a material exhibiting positive dilatancy during shearing, exerting strong confining force during the pulling of the geocomposite. As a result, the embankment material was much more resistant

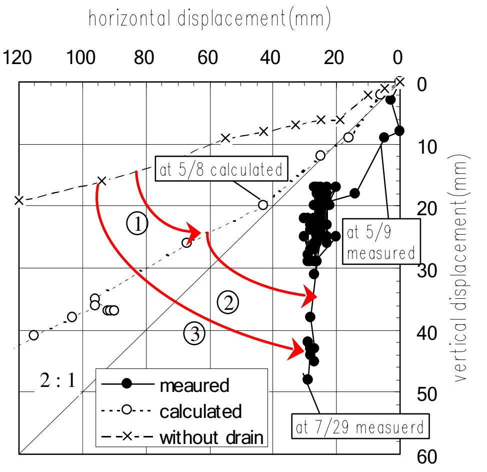


Figure 9. Comparison of the numerical and measured results of displacement vectors with survey piles on the top of slope

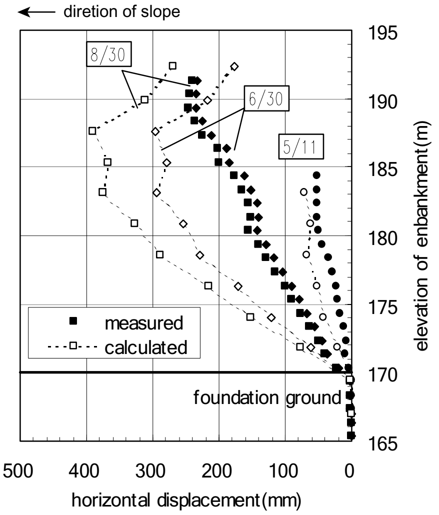


Figure 10. Comparison of the numerical and measured results of horizontal displacement with inclinometer

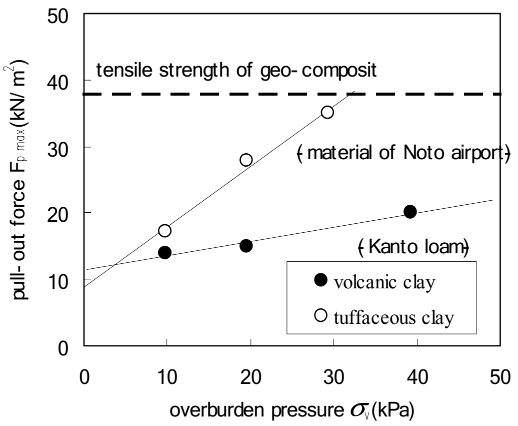
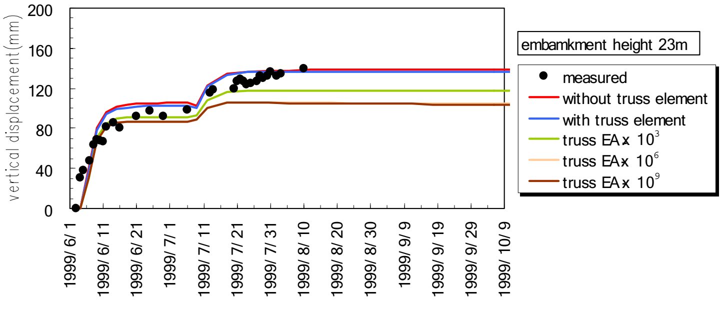
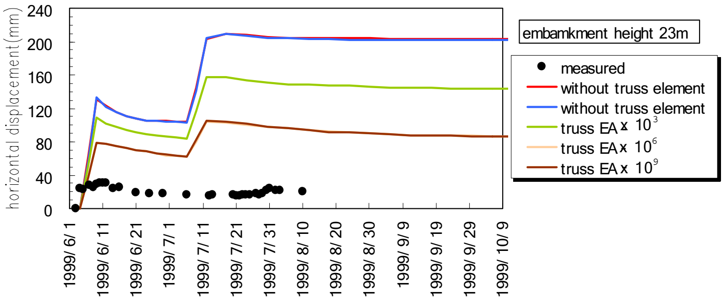


Figure 11. Results of geocomposite pulling tests (Miyata et al., 2000)

against pulling than Kanto Loam (Figure 11). The test results indicate that tensile resistance associated with strong confinement occurred between the drain materials and the surrounding soils suppressing the lateral displacement of the embankment. The numerical results of a case without drains are also plotted (denoted by X) in Figure 9, which provides displacement vector



(a) vertical displacement



(b) horizontal displacement

Figure 12. Calculation of displacement at the top of slope using truss elements

diagrams for the top of the slope. This case is compared with the effect of drainage (case 1), the reinforcement effect of friction (case 2), and the combined effect of drainage and reinforcement introduced by the horizontal geotextile drains (case 3 = case 1 + case 2).

The effect of the tensile resistance of the geotextile was analyzed in the model of Figure 2 by placing truss elements at all the nodes of horizontal drain. Figure 12 shows in time sequence the vertical and horizontal displacements. The measured values of vertical displacement generally agree with the numerical results. The measured values of horizontal displacement, on the other hand, are well suppressed compared to the numerical results from the beginning stage of construction. A few cases of using truss elements are also plotted in Figure 12. No significant effect on the numerical results was found when realistic property values were used for the truss elements. The stiffness of the truss elements was then increased by up to nine orders of magnitude on trial. Horizontal displacement decreases without much changes in vertical displacement as the stiffness is increased, but it is hard to discuss quantitatively the effect of the truss elements on the actual suppression of horizontal displacement. As experimentally shown by Miyata et al. (Miyata, 2000), there appears to be an unclarified mechanism of very strong resistance exerted in combination by the geotextile and the surrounding soil.

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