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Creep-like delayed failure of clayey ground after the end of embankment construction

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INTRODUCTION

In the classical conceptual description of embankment behavior in normally or lightly overconsolidated clays, the embankment is said to be safe (or stable) if it is safe at the end of rapid construction. In contrast, there has been cases of failures even after the embankment construction is ended. In such a case, the embankment is apparently stable just after the construction, however, instability develops with elapse of time and embankment may experience total failure at a later stage. In this paper we discuss the occurrence of such a delayed failure in normally consolidated clay foundation through results of the soil-water coupled elasto-plastic finite deformation computation.

INITIAL STRESS CONDITION AND THE NUMERICAL PROCEDURE

A fully saturated homogeneous clay foundation of weightless soil with the surcharge load of 60kN/m^2 was assumed. The analytical domain was 10m in height and 25m in width and the loaded area was 5m. Fig. 1 illustrates the boundary conditions, in which top and bottom were assumed to be permeable, and the initial stress distribution. The earth pressure at rest (K_0) was assumed to be 1.0. The material parameters used are given in Table 1. The soil was assumed to follow the subloading surface Cam-clay model. The embankment construction procedure was simulated by applying equivalent nodal loads at different loading rates.

DELAYED FAILURE AFTER THE END OF EMBANKMENT CONSTRUCTION

Fig. 2 shows the computed load~deformation curves for different loading rates. The settlement marked in the figure was the surface settlement at the embankment center. For all the loading rates shown, except the extremely slow rate of 0.02kN/m^2/day, there exist limiting loads that the foundation can sustain. When the embankment loading is stopped at a load level little before the maximum load in the load~deformation curve, e.g. at the load level of 123.16kN/m^2 (for loading rate = 2.0kN/m^2/day) the foundation exhibited failure after 8.6 days (Figs. 3 and 4). when the load application is stopped at a low magnitude of load (compared with the maximum load, e.g. 120.0kN/m^2), the embankment is stable and only the consolidation process proceeds afterwards. As illustrated in Fig. 4, when embankment construction is stopped at a point proximity to the maximum load, e.g. 123.16kN/m^2 in this case, the embankment is apparently stable until sudden failure at 8.6 days. The velocity field at the instant of failure is shown in Fig. 5. The mechanism of such a delayed failure can be described through the Figs. 6 and 7 in which the specific volume change and the excess pore water pressure distributions are plotted respectively. In fact, for clarity these plots are made not for the total values but for the increments after the embankment loading has been stopped. Figs. 6a and 7a represent the condition at 2.5 days after the end of loading and figs. 6b and 7b represent the condition at failure. Since the applied embankment load at this loading rate was sufficient enough to make stress states of a considerable area of the foundation to be at critical state at the end of load application and subsequently leading to softening with swelling, the excess pore pressure isochrones, initially having a higher magnitude at the centerline, start to expand towards the swelling region in the middle. This behavior of course gives a negative stiffness as a whole. As a matter of fact the instability develops within the foundation gradually until the sudden outright failure. It is important to be noted here that until the failure the embankment under goes deformation at an almost constant rate similar to the non failure case (Fig. 4). However, with no prior warning, at 8.6 days it suddenly departs from non failure case.

CONCLUSIONS

1. When embankment loading is stopped at a point near the maximum load in the load~deformation curve, with the elapse of time the foundation exhibits failure
2. If the load level at the end of construction is comparatively low, only the consolidation process proceeds.

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Consolidation, creep, embankment, failure, finite deformation,
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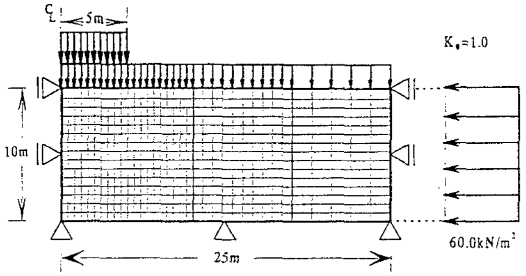

Fig. 1 Boundary conditions & initial stresses

Compression index λ	0.131
Swelling index κ	0.016
Critical state parameter M	1.53
Poisson's ratio ν	0.30
Initial specific volume v_0	2.038
Initial mean pressure p'_0 (kN/m²)	60.0
Permeability k (m/day)	3.2×10^{-5}

Table 1 Material Parameters

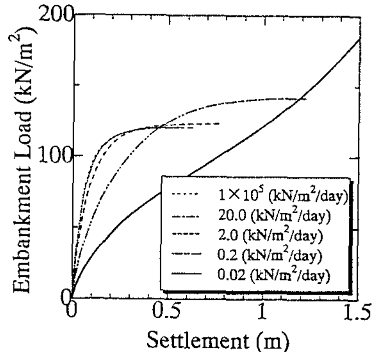

Fig. 2 Load~deformation behavior

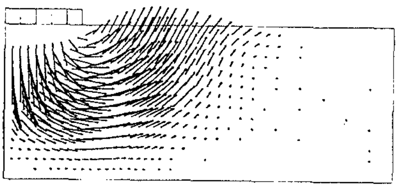
Fig. 5 Velocity field at failure

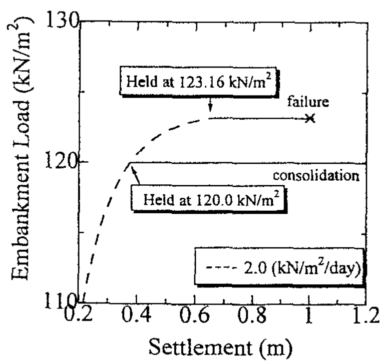

Fig. 3 Load~deformation behavior (after construction ended)

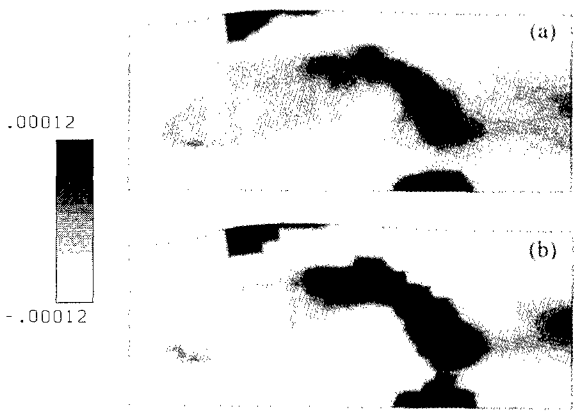

Fig. 6 Specific volume change (after construction ended)

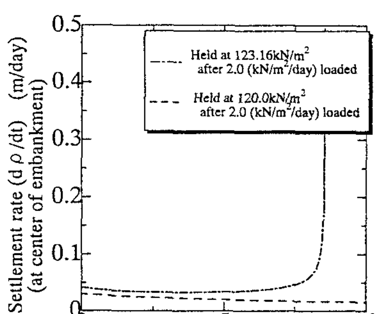

Fig. 4 Settlement rate~time relationship (after construction ended)

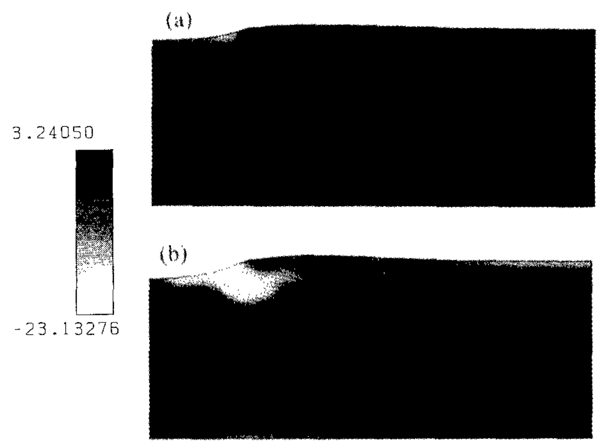

Fig. 7 Excess pore water pressure (after construction ended)