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Research Paper

2D and 3D analyses of an embankment on clay improved by soil–cement columns

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ABSTRACT

The behaviour of a test embankment constructed on a soft clayey deposit in Saga, Japan, was simulated by both three-dimensional (3D) and two-dimensional (2D) finite element analyses (FEA). Floating soil–cement columns had been installed in the clay prior to construction of the embankment. Comparing the results of 3D and 2D FEA indicates that 2D analysis predicts incorrect results in terms of the lateral displacement and bending moment in the columns under the toe of the embankment. In the 2D analysis, the rows of columns were modelled by continuous walls, which partially block the interaction between the soil layers and the columns and influence the simulated lateral displacement and bending moment in the column. It has been postulated that compaction of fill material during the construction process has a significant influence on both the magnitude and pattern of the lateral displacement of the column under the toe of the embankment. Pragmatically, this influence can be indirectly simulated by reducing the stiffness and increasing Poisson's ratio of the embankment fill material. Finally, both the measured and FEA results indicate that the columns not only reduced the total settlement but also accelerated the settlement rate of the deposit under the embankment loading, due to the much higher stiffness of the column material.

1. Introduction

Deep cement mixing, normally forming soil–cement columns in the ground, is a widely used soft ground improvement method, especially for the cases where ground deformation is a crucial control item (e.g., [3,4,20]). To reduce construction cost and minimize the possible impact on the ground environment, improving the soft clayey deposit by installing floating columns has been applied to several field projects [23,8,7,11]. The behaviour of a floating column -improved deposit will be different from one improved by the installation of fully penetrating soil–cement columns. Near the base of a floating column, there will be differential settlement between the column and the surrounding soils [20], and there may also be more lateral displacement of the deposit under an embankment load. However, the behaviour of a floating column-improved subsoil under embankment loading is not well understood and has not yet been comprehensively investigated.

When analyzing the behaviour of embankments on soft clayey deposits by the finite element method (FEM), usually plane strain models are adopted, and in the case of a column (including pile)-improved deposit, the columns are usually modelled as continuous walls [12,19,10]. Interaction between the foundation columns and the soft soil is actually a three dimensional (3D) problem and when analyzing it with a two-dimensional (2D) model some shortcomings will be inevitable, such as: (a) any relative horizontal movement between the columns and soil cannot be simulated; (b) interaction between soil layers may not be correctly simulated; and (c) equivalent values of the bending rigidity EI (where E is Young's modulus and I is the second moment of area) and equivalent values of the axial rigidity EA (where A is the cross sectional area) of the column section cannot be satisfied simultaneously for most cases. For floating column-improved soft deposits, no systematic study has investigated comprehensively how accurate 2D

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analysis is when compared with 3D analysis, and which option, either equal values of *EI* or *EA*, should be adopted in 2D analysis.

In this paper, a test embankment constructed on a clayey layer improved by the installation of floating soil–cement columns is described. Details of both 2D (plane strain) and 3D finite element analyses (FEA) of the embankment are then presented. Using field measured and FEA results, the behaviour of the floating column-improved deposit under embankment loading is investigated and discussed, and comments are made on the most suitable numerical modelling method.

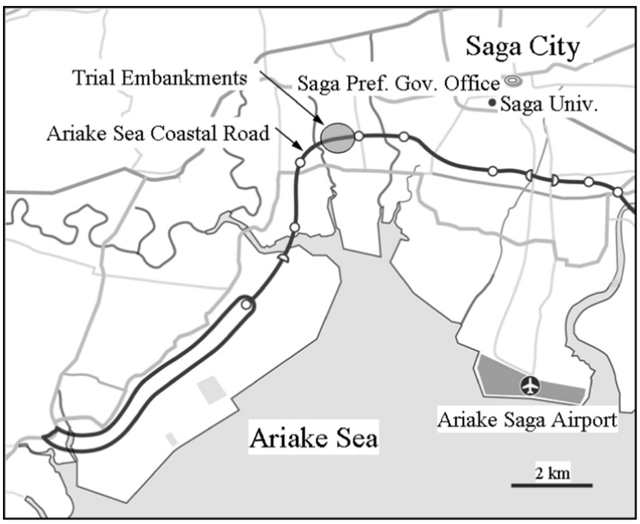

Fig. 1. Site of trial embankments (after [13]).

2. Test embankment

As shown in Fig. 1 (after [13]), a highway around a section of the Ariake Sea, Japan, was planned and construction commenced in 2010 for the section in Saga Prefecture. This road was designed as an access controlled freeway with an embankment height of 5.0–8.0 m for most sections of the road. A deposit of soft Ariake clay exists along the route of the highway, virtually from the ground surface to depths between 10 and 30 m. This deposit is characterized by high compressibility and low strength [17,11]. Below this soft clay layer there is an aquifer (a sand layer). The design for this project required that: (1) the residual settlement of the embankment and road surface should be less than 0.3 m after the completion of construction; (2) the vertical and horizontal displacements along the property boundary of the road should be less than ±50 mm; and (3) the road construction should have no effect on the groundwater quality. In order to satisfy these requirements, one of the construction methods selected involved ground improvement resulting from the installation of floating soil–cement columns. In this case it was anticipated that the mechanical properties of most of the soft clay layer would be improved by the presence of these columns, while leaving an intact clay sublayer (without improvement) below the tips of the columns and immediately above the aquifer. It was expected that this clay layer would serve as a barrier to prevent hazardous chemicals from the cement treatment entering and possibly contaminating the groundwater. To verify the performance of the proposed method a test embankment was constructed. The location of the trial embankment is indicated in Fig. 1.

The soil profile and some engineering properties of the soil strata at the test site are summarized in Fig. 2 (data from [1]). At this site there exists a surface crust about 1.5 m thick underlain

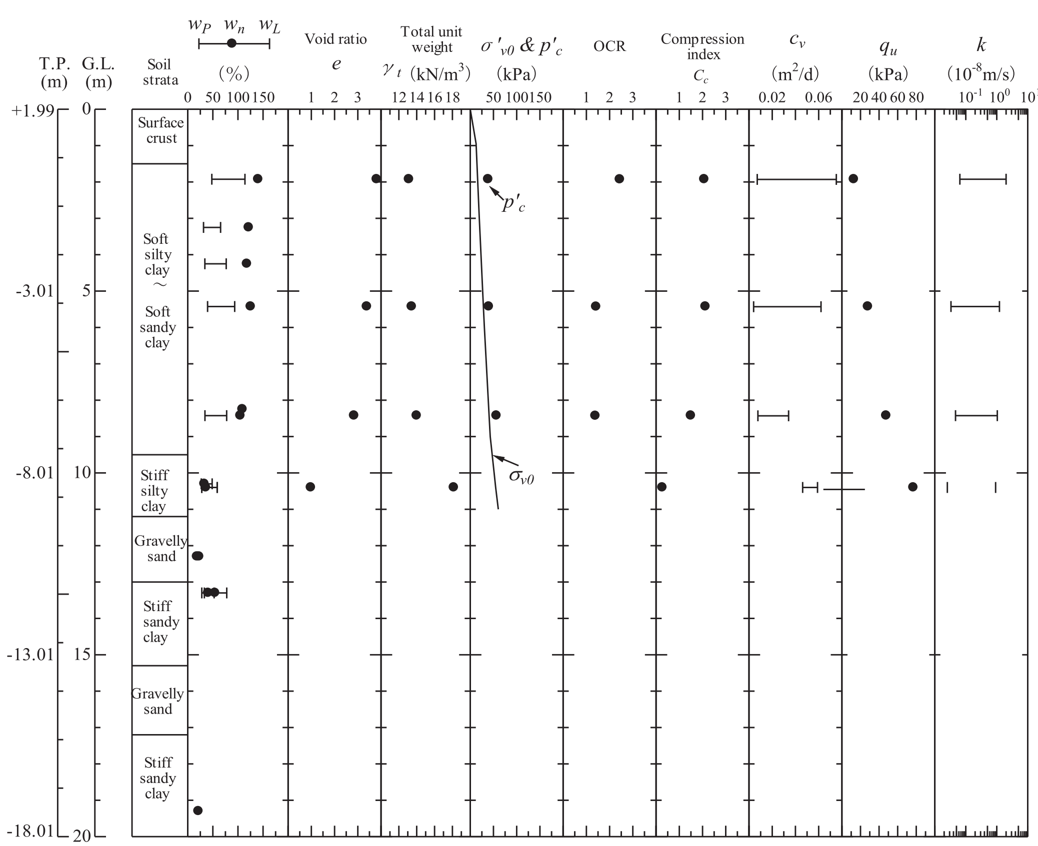

Fig. 2. Soil profile and some engineering properties of soils at the test site.