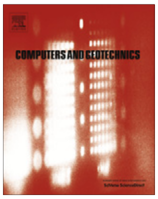
Computers and Geotechnics 48 (2013) 117–126

Contents lists available at SciVerse ScienceDirect

Computers and Geotechnics

journal homepage: www.elsevier.com/locate/compgeo



Finite element simulation of an embankment on soft clay – Case study

Jinchun Chai [a,*], Yutaka Igaya [b,1], Takenori Hino [c,2], John Carter [d,3]

[a] Department of Civil Engineering and Architecture, Graduate School of Science and Engineering, Saga University, Japan
[b] Prefectural Planning Head Office, Saga Prefectural Government, Japan
[c] Institute of Lowland and Marine Research, Saga University, Japan
[d] Faculty of Engineering and Built Environment, The University of Newcastle, NSW 2308, Australia

ARTICLE INFO

Article history:
Received 14 February 2012
Received in revised form 8 October 2012
Accepted 8 October 2012
Available online 12 December 2012

Keywords:
Soft ground
Finite element analysis
Embankment
Case history

ABSTRACT

Numerical simulations and field measurements of an embankment constructed on a deposit of soft Ariake clay in Saga, Japan are compared and discussed. The simulations were made both before (Class-A) and after (Class-C) the field data became known. It is shown that the Class-A prediction resulted in poor simulations of the measured settlement–time curves, mainly due to over-estimation of the magnitude of the yield stresses of the subsoils (i.e., the sizes of the yielding loci) and under-estimation of the compressibility, hydraulic conductivity and the slope (M) of the critical state line. It is demonstrated that: (a) appropriate site investigation, soil testing and interpretation of the test results are essential for accurate prediction of the behaviour of an earth structure constructed on soft clayey deposits; (b) when using a soil model developed within the framework of Critical State Soil Mechanics to make such predictions, M value should be directly determined from tests with an appropriate effective stress path; and (c) yield stresses of soft soil layers can be calibrated by comparing the predicted undrained shear strengths (S_u) with measured values, provided the effect of strain rate and/or strain softening on the value of S_u is properly considered. The results of this analysis indicate that Bjerrum's strain rate correction factor can be adopted as a first approximation of the correction factor applied to field or laboratory measured values of S_u.

1. Introduction

Comparing the predicted and field-measured behaviour of embankments constructed on soft clayey ground often provides a good check on the suitability of the constitutive model adopted for the clay soil, as well as the capacities of the numerical procedures used to make predictions of the embankment behaviour, providing of course that appropriate values have been adopted for the model parameters. The latter is a function of the quality of sampling, sample preparation, testing and overall characterisation of the soils at the site. There is a relatively rich literature in this particular field of geotechnical engineering (e.g., [30,22,4,6,9,12,15,20,16,21,18]).

The Modified Cam Clay (MCC) constitutive model [23] is one of the most widely used elastoplastic models for soft clayey soils because of its simplicity and its ability to predict yielding, strain soften as well as failure in soft clayey soils. However, MCC is an isotropic yielding model and it does not consider viscous behaviour such as creep of clayey soils. Elasto-viscoplastic (EVP) models (e.g., [31]) and anisotropic yielding elastoplastic models (e.g., [11]) have been developed to account for these complicating effects. However, there are still differing opinions as to which model provides the best prediction of the field response of clayey soils under embankment loading (e.g. [18,20]). In principle, a more sophisticated soil model should be able to represent better the mechanical behaviour of natural soft clayey soils, but the drawback in adopting them is that more sophisticated models require specification of more soil parameters, and in many cases in engineering practice there are insufficient test data to reliably define those parameters. Further, for some sophisticated soil models, some of the soil parameters can only be calibrated by fitting the model predictions to the test results, rather than being determined directly from those test results. On the other hand, the parameters of relatively simple soil models, such as the MCC model, which is acknowledged for being capable of capturing the most important mechanical features of soft clayey soil, can be easily and reliably defined. It is generally acknowledged that the use of some simple models can result in acceptable predictions of soil behaviour, at least from a practical

---

[*] Corresponding author. Tel.: +81 952 28 8580; fax: +81 952 28 8190.
E-mail addresses: chai@cc.saga-u.ac.jp (J. Chai), igaya-yutaka@pref.saga.lg.jp (Y. Igaya), hino@ilt.saga-u.ac.jp (T. Hino), John.Carter@newcastle.edu.au (J. Carter).
[1] Tel.: +81 952 66 0912; fax: +81 952 66 0956.
[2] Tel./fax: +81 952 28 8612.
[3] Tel.: +61 2 4921 6025.

http://dx.doi.org/10.1016/j.compgeo.2012.10.006

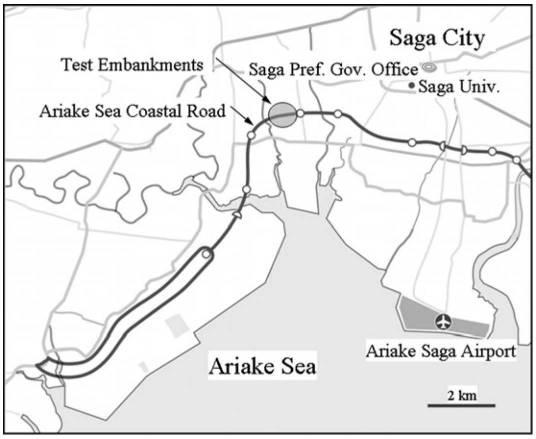


Fig. 1. Location of Ariake Sea Coastal Road and test embankment.

perspective. Whichever the case, obtaining accurate Class-A predictions [17] of the behaviour of embankments on soft clayey deposits still remains a difficult task.

As shown in Fig. 1, in Saga, Japan, a highway around the Ariake Sea has been planned and was under construction at the time of writing. For its entire length this highway is located over deposits of soft Ariake clay. In order to verify the correctness of the assumed design strength and deformation parameters of the soft deposit, as estimated from laboratory tests, a test embankment was built on the natural deposit and its performance was monitored for more than 3 years in terms of settlements, lateral displacements and excess pore water pressures. For this test embankment an internal Class-A prediction was made and documented before construction. After the field-measured data became known, these Class-A predictions were compared with the measurements and there were considerable discrepancies. The same case was then re-analyzed (Class-C prediction) using additional site investigation results and after applying a correction to the measurements of the undrained shear strength (S_u) of the subsoils. For all the analyses reported here, the soft Ariake clay was modelled by the MCC model.

In this paper the site conditions, history of the embankment construction and the measured data are reported and compared together with the results of the Class-A and Class-C predictions. The insights gained into predicting the behaviour of an embankment on soft ground are discussed.

2. Soil profile and embankment construction

In total, three (3) test embankments were constructed at the location indicated in Fig. 1, one on natural soft ground and two on the same type of soft ground after it had been improved by the installation of soil–cement columns formed by deep mixing [13]. The test embankment considered in this study is the one constructed on natural ground. As shown in Fig. 2, in and around the test site, six (6) boreholes (BH) were drilled in order to investigate the soil properties required for design of the road embankment. At the locations of BH-1, -3, -5 and -6, undisturbed soil samples were taken using a Japanese thin-wall sampler and laboratory index tests and consolidation and unconfined compression tests were conducted on these samples.

BH-1 to BH-5 were drilled and the corresponding laboratory tests were conducted before the test embankment was constructed, and the resulting data were available at the time the Class-A prediction was made. BH-6 was in the test site and was bored just before the commencement of embankment construction. The test data from this borehole were not available when the Class-A predictions were made. The soil profile and some physical properties obtained from BH-1, 3, 5 and 6 are summarized in Fig. 3. In this figure, W_p, W_L and W_n are plastic limit, liquid limit and natural water contents respectively, γ_t is the unit weight, and e_0 is the initial void ratio. Values of W_p and W_L are only for the samples from BH-6.

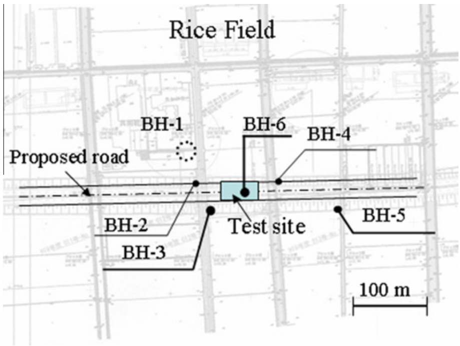


Fig. 2. Borehole locations in and around Test Site.

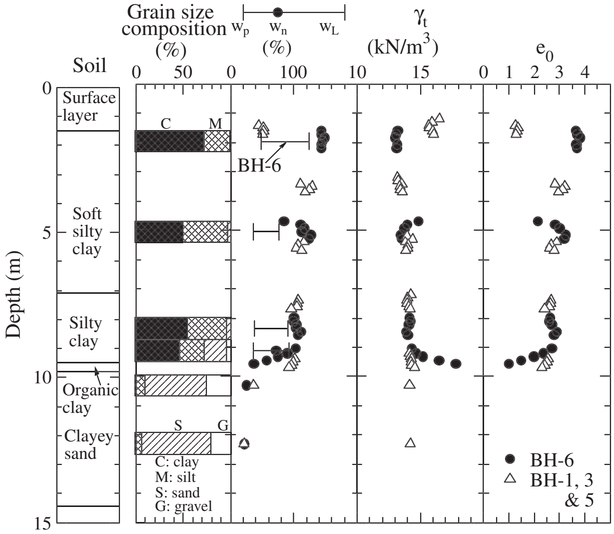


Fig. 3. Soil profile and some physical and mechanical properties at the Test Site.

It is noted that at this site there exists a surface layer about 1.5 m thick underlain by a thick soft silty clay layer (the Ariake clay) which is about 8.0 m thick. Below it is an organic clayey soil layer about 0.3 m thick, underlain by alternating clayey sand and sandy clay layers. The natural water content of the soft silty clay was generally more than 100% and larger than the corresponding liquid limit. The groundwater level was about 1.0 m below the ground surface.

For the undisturbed samples from BH-6, consolidated undrained triaxial compression tests with excess pore water pressure measurement were also conducted. The effective stress paths in a p'–q plot (p' is effective mean stress and q is deviator stress) of the triaxial test are given in Fig. 4. In the figure, σ'_1 and σ'_3 are effective stresses in the vertical and horizontal directions respectively. The e-$\log(\sigma'_v)$ curves (e is void ratio and σ'_v is vertical consolidation stress) from odometer test results for the samples from BH-6 are given in Appendix A.

For the test embankment constructed on natural ground the critical height was estimated to be about 3.0 m, and so it was decided that an embankment should be constructed with an initial