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Research Paper

Modelling the behaviour of the Ballina test embankment

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ABSTRACT

As part of the Australian Research Council Centre of Excellence for Geotechnical Science and Engineering (CGSE) research program, an instrumented embankment was constructed on soft ground with and without the use of prefabricated vertical drains at Ballina in northern New South Wales (NSW, Australia). To better understand the behaviour and to help build a more robust geotechnical model for the Ballina site, a comprehensive characterisation study was carried out on the subsurface soil. This paper presents the results of a back analysis on the test embankment with wick drains at Ballina, in which the soft clay layers have been modelled using Modified Cam Clay. A 2D plane strain finite element model in ABAQUS was used to predict instrumentation recordings for a 3 year period. The results of the back analysis suggest that the Modified Cam Clay model is able to predict the behaviour of the embankment but care is needed in parameter selection to account for anisotropy, destructuration and most significantly, time dependent behaviour. The complex evolution of soil properties during wick drain installation and consolidation also created difficulties in confidently describing individual soil parameters.

1. Introduction

Deeply incised valleys on the East Australian coast contain geologically recent sediments with significant deposits of soft clayey sediments. These sediments have, and continue, to represent major challenges for road and other infrastructure developments along Australia's coastal fringe. To advance the understanding of soft soil behaviour, the Australian Research Council Centre of Excellence for Geotechnical Science and Engineering (CGSE) has established a National Soft Soil Field Testing Facility (NFTF) near Ballina, NSW for which an extensive site investigation including a wide range of in-situ and laboratory tests has been conducted (Kelly et al. [1]).

One of the activities involving the NFTF was a prediction exercise, in which the authors participated, associated with the construction of an instrumented embankment. The test embankment occupies 6.5 ha of land that was previously used to farm sugar cane. A thin alluvial layer overlies about 9 m of soft clay, a sand layer and then a further clay layer. The design geometry of the embankment consists of a working platform, approximately 95 m long by 25 m wide by 0.6 m thick, a sand drainage layer, approximately 0.4 m thick, and an embankment, 80 m long by 15 m wide by 2 m. The batters were sloped at nominally 1.5H:1V. Layers of geotextile were placed at ground level, above and below the sand drainage layer. Vertical drains were also installed on a nominally 1.2 m square grid. The spacing of individual drains were noted to have been locally increased by 100 mm to 200 mm to reduce the risk of damage to buried instrumentation. More details on the construction and instrumentation of the embankment can be found in an accompanying paper [2].

Our approach to the initial prediction exercise was to use the commercial FE package ABAQUS and the Modified Cam Clay (MCC) model available within ABAQUS to perform a plane strain, fully coupled finite element analysis to predict the behaviour of the soft clay. A set of model parameters were selected based on existing laboratory and *in situ* data provided by CSGE, supplemented by additional tests performed by the authors. In selecting values of parameters for our initial prediction we also attempted to make allowance for the limitations of MCC, which include its inability to account for anisotropy, destructuration and time dependent behaviour. While there are models that include these aspects, their implementation into readily available numerical codes and their application to large scale construction projects has been relatively limited. Nevertheless, we expected that MCC would provide reasonable predictions because of the stress paths imposed by the embankment loading and the relatively modest embankment height of approximately 3 m.

Our Class A prediction of the embankment settlement after 3 years was approximately 20% too low, an outcome we largely

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attributed to the uncertainty in how to allow for creep. In this paper we discuss the process we have used to modify the parameters to provide better fits to the measured data, and discuss some of the challenges associated with the prediction of infrastructure performance on soft soils more broadly.

2. Geotechnical model

2.1. Soil characterisation

2.1.1. Laboratory and in situ testing

The laboratory characterisation of the Ballina Clay from the NFTF has been described in detail by Pineda et al. [3]. The paper details the use of large-diameter fixed piston samples and non-destructive methods to assess and select samples for laboratory testing to provide both quality and reliability in test results. The results of some soil properties required to develop a geotechnical model are shown in Fig. 1. Further, an analysis of both *in situ* and laboratory testing of the Ballina field testing facility has been performed by Kelly et al. [1]. The *in situ* data, particularly the CPTs, were used to determine soil stratigraphy, confirm the uniformity of the layers and to provide parameters for soil layers where laboratory test data were limited.

2.1.2. Identification of the yield locus

One of the important inputs for an analysis using MCC is the size of the initial yield locus, represented by p'_o where the yield locus intersects the p′ axis. Values for p'_o were estimated from the vertical yield stresses in CRS consolidation tests (Pineda et al., [3]) by assuming that yield occurred on the MCC yield locus, the critical state parameter, M = 1.462 (ϕ' = 36°) and $K_o = 1 - \sin \phi'$. The value of M was estimated from triaxial tests reported by Pineda et al. [3] and additional tests performed by the authors. The estimated p'_o data are shown in Fig. 2(a) together with the isotropic yield stress profiles used in the initial prediction and in the back analysis.

In addition to the data provided by CGSE, a number of drained stress path triaxial tests were completed at the University of Sydney. The samples were taken from the core Incl/MEX5 in the range of 7–8.5 m depth. All triaxial specimens were either 38 mm or 54 mm in diameter with 2:1 height:diameter ratio. These tests were carried out in a temperature controlled room using an in-house computer controlled triaxial test system. In order to identify the yield locus of Ballina clay, each triaxial test consisted of at least 3 stages: (a) saturation, (b) isotropic consolidation and (c) stress path controlled drained shearing. Specimens were subjected to an isotropic confining stress of 10 kPa and allowed to drain to atmosphere and then a stress controlled saturation ramp was applied until the cell pressure and back-water-pressure reached 510 kPa and 500 kPa, respectively. The specimens were then isotropically consolidated to different effective stresses before drained shearing at either constant mean effective stress or constant effective confining stress. All the stress path controlled tests were run at a sufficiently low strain rate (approximately 0.025%/hr) to minimise the build-up of pore pressure and were continued until failure. Yield points, determined from a marked change in the slope of the stress-strain response, are plotted in Fig. 2(b).

As seen in Fig. 2(b), an anisotropic yield locus was discovered for the subsoil, typical of other soft soils reported in the literature. A MCC yield locus is indicated on Fig. 2(b) passing through the point corresponding to the assumed K_o of 0.41. It can be seen that this locus lies well outside the actual yield surface except in the vicinity of K_o compression loading. Preliminary analyses showed that stress paths beneath the centre and toe of the embankment should be intercepting the yield locus in the region indicated on Fig. 2(b), and that the MCC yield locus based on the 1-D consolidation test data would tend to overestimate the yield stresses in this region. As a result a lower p'_o profile, shown in Fig. 2(a), has been adopted. This results in the yield locus shown in Fig. 2(b) being used for the back analysis at a depth of 8 m. It may be noted that at this depth the isotropic yield stress is reduced by a factor of 0.71. A slightly lower yield stress was adopted in the back analysis than the initial prediction, especially in the upper four metres, to better reflect the measured yield stresses and settlement profile.

2.2. Subsurface profile and geotechnical parameters

The geotechnical models adopted for both the initial prediction and the back analysis of the Ballina test embankment are summarised in Table 1. A Poisson's ratio of 0.3 was adopted for all soil layers. The values adopted in the model are based on the laboratory and *in situ* results provided by the CGSE and a number of tri-

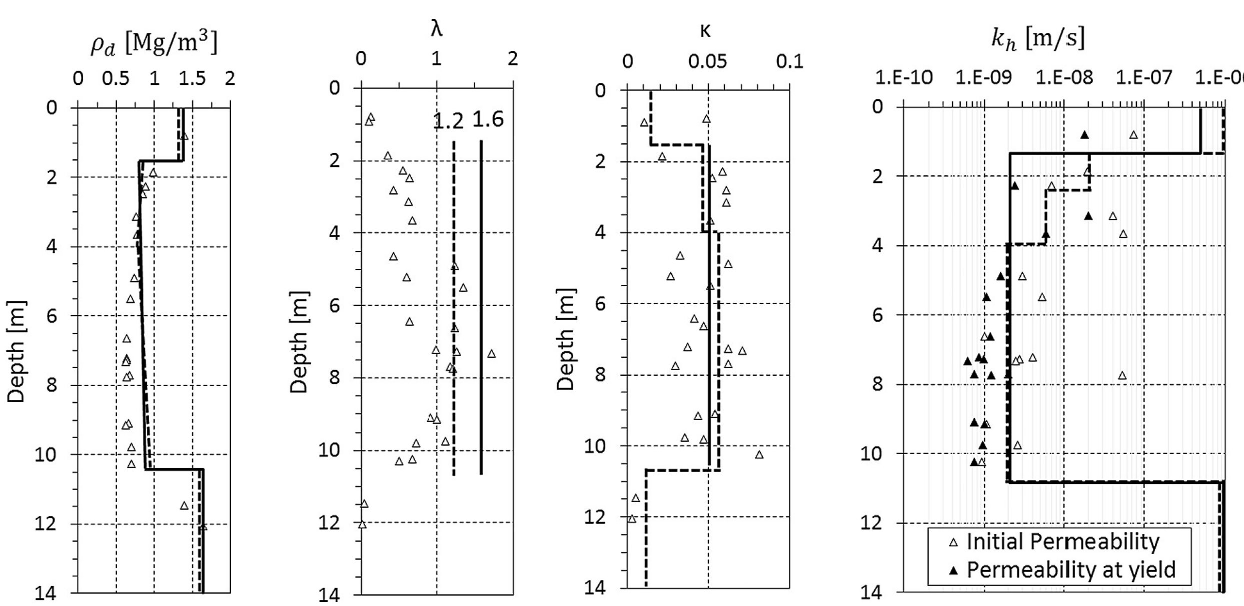

Fig. 1. Simulated and experimental indices for (a) density, (b) normal compression index (lambda), (c) recompression index (kappa), and, (d) permeability.