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NUMERICAL SIMULATION OF AN EMBANKMENT APPLYING THE MIT-E3 MODEL

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Summary. *This paper begins with a brief description of the constitutive MIT-E3 model. The model is used to simulate an embankment built on a deposit composed "Boston Blue Clay". The numerical results are compared with de field data in terms of vertical displacements, horizontal displacements and increments of pore pressures. Finally, the numerical results are analysed in terms of the yield area, contours of vertical and horizontal effective stress increments and contours of shear stress increments.*

1 INTRODUCTION

Most of the models used to simulate the behaviour of clay soils accept that they are governed by elastoplastic and isotropic models, presupposing isotropic hardening and associated flow rules. They also take the conditions relative to the critical state as a failure criterion. The overconsolidated state is generally governed by an elastic behaviour nearly always linear, and so these models do not associate the volumetric and distortional behaviour within the yield surface.

The MIT-E3 model overcomes some of these limitations, making it possible to simulate the chief characteristics of the behaviour of clays. The work reveals some of the MIT-E3 model's potentials, using a finite element program developed in the FCTUC [2].

2 MIT-E3 MODEL

2.1 Modelling normally consolidated behaviour

The behaviour of normally consolidated soil is described by means of an elastoplastic model. This can reproduce the anisotropic behaviour under "K_0" conditions, its evolution under subsequent loading, and also the softening phenomenon observed experimentally for certain strain modes.

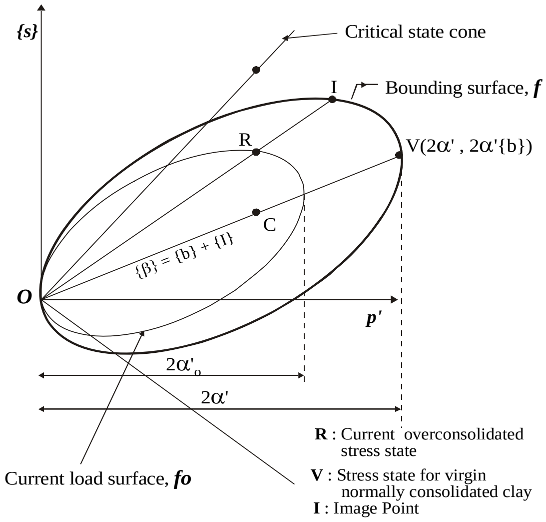


Figure 1: Yield, failure and loading surfaces for the MIT-E3 model (based on [3]).

The elastoplastic model consists of an elastic component and a plastic component. The elastic component is calculated by means of the generalized Hooke's law, while the plastic component is found using the incremental theory of plasticity. This requires the definition of a yield function, hardening rules, a failure criterion and a function of plastic potential. The yield function takes the form of an ellipsoid, initially oriented in the consolidation direction (Fig. 1), where α' is the variable controlling the size of the yield surface, *p'* is the effective average normal stress, $\{s_i\}$ is the desviatoric stress tensor and $\{b_i\}$ the tensor that describes orientation of the yield surface.

The evolution of the yield surface with the plastic flow is controlled by two hardening rules that describe the change in size and yield surface orientation. The failure criterion coincides with the critical state criterion, and is defined by a conical surface whose vertex is located at the origin (Fig. 1). The model uses a non-associated flow rule that allows the K_0 and critical state conditions to be satisfied.

2.2 Modelling overconsolidated behaviour

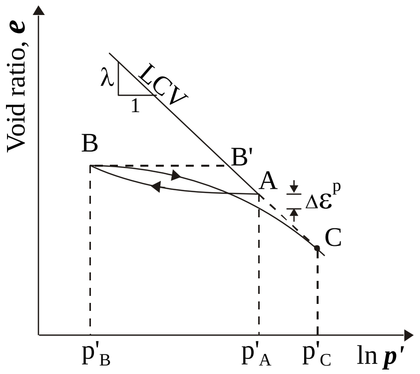


Figure 2 : Modelling an unloading-reloading cycle by the MIT-E3 model.

In order to simulate the behaviour of overconsolidated clays, the MIT-E3 incorporates the perfect hysteretic model and the bounding surface plasticity. The first simulates the elastic nonlinear behaviour of an overconsolidated clay in an unloading-reloading cycle (Fig. 2) by gradually altering stiffness. The second model is used to simulate the development of plastic strains in overconsolidated clays. This permits coupling between the volumetric and distortional behaviour, and a smooth transition between the overconsolidated and the normally consolidated state.

3 SIMULATION OF THE BEHAVIOUR OF AN EMBANKMENT

Figure 3 shows the finite element mesh used to study embankment I-95 [2], which was composed of 203 square elements with 8 nodes and 676 nodal points.

The foundation soil is composed of three layers: peat, silty sands and Boston Blue Clay (BBC). The peat layer is replaced by an elastic granular material with E'= 10 MPa. An elastic law is assumed for the embankment material, with E' varying between 5.7 MPa and 78 MPa. The silty sand layer is simulated by the Modified Cam Clay model where λ = 0,025, κ = 0,005, M = 1,5 and $e_{\lambda o}$ = 2,50. The OCR for BBC decrease with depth, from 4.5 to 1.0, with its behaviour being reproduced by the MIT-E3 model, with the parameters: $K_{o(nc)}$ = 0,50; $\phi'_{(TC)}$ = 26,54º ; $\phi'_{(TE)}$ =39,52º ; c = 0,866 ; ψ_o = 100; λ = 0,147 ; κ_o = 0,001 – 0,006; υ' = 0,30 ; C = 22 ; n = 1,6 ; w = 0,07 ; St = 4,5 ; γ = 0,5 ; h = 0,2 ; $e_{\lambda o}$ = 3,56.

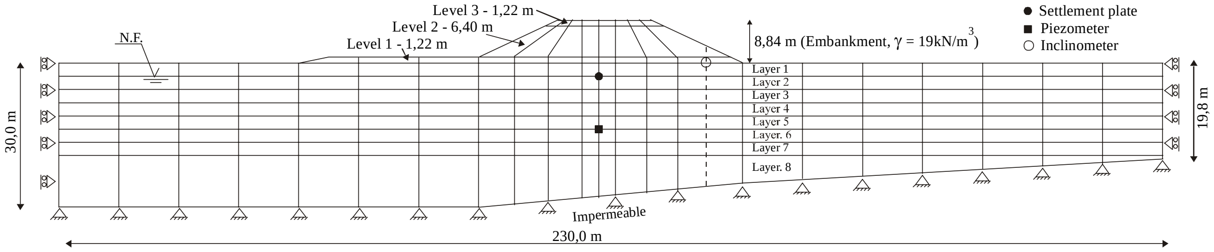


Figure 3 : Soil profile and finite element mesh for I-95 embankment (based on [1]).

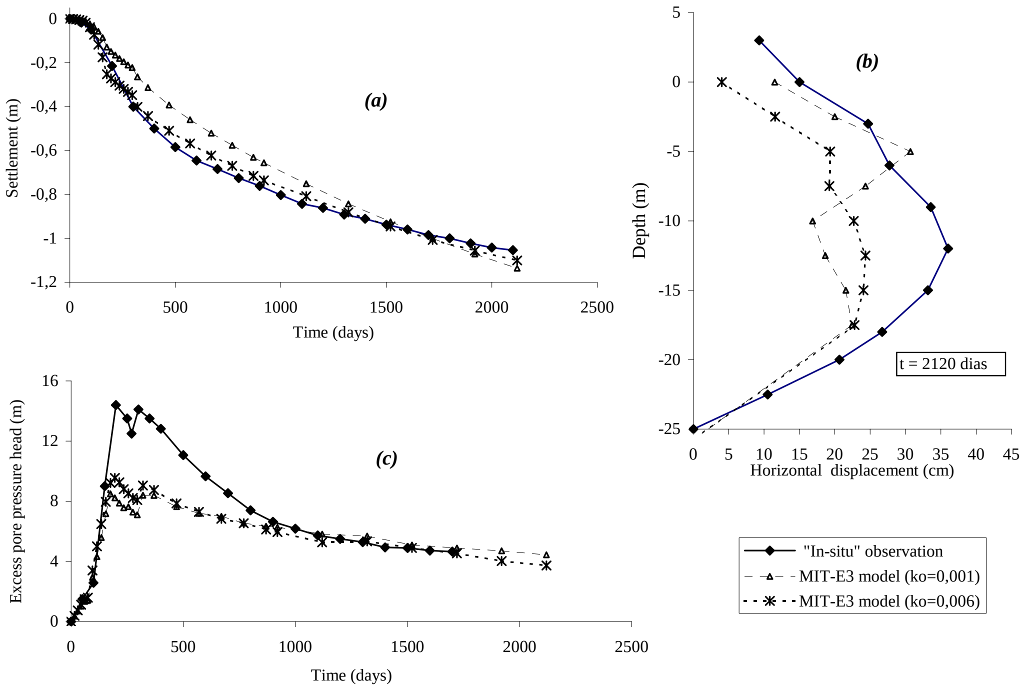


Figure 4 : Comparison between field data and numerical analysis. (a) Curve settlement-time (node 31). (b) Horizontal displacement of inclinometer (t=2120 days). (c) Excess pore pressure head-time (node 363).

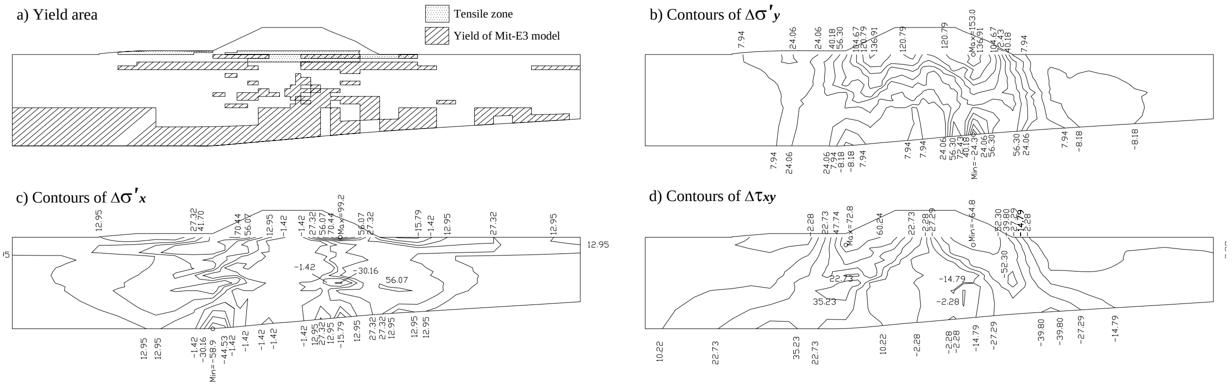
In Figure 4 the values measured *in situ* are compared with the numerical results. Figure 4a shows that the MIT-E3 model (where κ_o=0.006) provides a good simulation of the settlement time evolution. As κ_o is reduced, a more linearized time-settlement curve is achieved, because of the greater initial stiffness.

In Figure 4b it can be seen that, where κ_o=0.006, we get a diagram of horizontal displacements that are parabolic in shape, which qualitatively reproduce the *in situ* results. In fact, the analysis where κ_o=0,001 gave a better simulation of the actual behaviour at the top and the bottom of the BBC layer, even though it showed a clear inflection in the central area, due to the change in stiffness between the surface layers and the BBC.

Analysing the size of the yield zones (Figure 5a), the natural concentration of yield zones in the deeper layers can be seen. This is because they are less overconsolidated, and the yielding extends up to the layers nearer the surface in the form of a cone, whose vertex coincides with the centre of the embankment, since this naturally corresponds to increased vertical effective stress increments (Fig. 5b).

The $\Delta\sigma'_X$ diagrams (Figure 5c) reveal a progressive concentration of the horizontal effective stress increments close to the foot of the slope, which is related to the emergence of an inflection in the diagram of the horizontal strains.

Figure 5d shows the natural concentration of shear stresses under the foot of the embankment slope.


a) Yield area

b) Contours of $\Delta\sigma'_y$

c) Contours of $\Delta\sigma'_x$

d) Contours of $\Delta\tau_{xy}$

Figure 5 : Numerical analysis with MIT-E3 model (κ_o=0,006). Yield area, contours of vertical and horizontal effective stress increments and contours of shear stress increments.

4 CONCLUSIONS

This work has provided a brief description of the chief characteristics of the MIT-E3 model. The application of this model to simulate the behaviour of an embankment revealed behaviour close to that observed *in situ*. This study also made it possible to understand the considerable influence of initial stiffness on the development of vertical strains.

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