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Numerical Modelling of Soft Soils

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Summary

Several different models have been used in FEM analysis in order to simulate the behaviour of soft soils foundations. This paper presents the formulation of the Melanie Model, and also their application in a case study, allowing to compare the results of FEM analysis with field observations of a multi-stage embankment construction. The results show that the Melanie Model gives quite reliable predictions of the ground settlements under the studied embankment.

Introduction

Several regions of Europe, including Portugal, are partially covered with extensive soft soils deposits that for many years have been avoided as foundation for structures, especially for technical reasons. However, in recent years, the expansion of population and industrial centres, the constraints imposed on new transportation routes and the locations claimed by constructions related to environmental control and protection, vigorously stimulated the investigation on the behaviour of soft deposits.

This paper presents some of the intensive investigation carried at the Baixo Mondego alluvial deposit, involving road embankments instrumentation and observation, deposit characterisation and numerical simulations of the foundation behaviour [1] and [2].

Melanie Model

The Melanie Model, a critical state model, considers a yield locus that, represented on the (s'- t) plane, possesses an elliptical shape. As shown in Figure 1, the yield locus has the principal axis lined up with the k_0 line and is described [3] by:

$$F(s',t,K) = A^2 \times \left(s' \times \cos\theta + t \times sin\theta - \frac{K}{AC} \right)^2 + \\ + B^2 \times \left(t \times \cos\theta - s' \times sin\theta \right)^2 - \frac{K^2}{C^2} = 0 \qquad (1)$$

Where,

$$A = 2 \times (\sin\theta + \cos\theta) \qquad (2)$$

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$$B = -\frac{\mathrm{A}^2 \times \cos\theta}{C \times sin^2\theta}\left(C \times \cos\theta - \frac{2}{\mathrm{A}}\right) \tag{3}$$

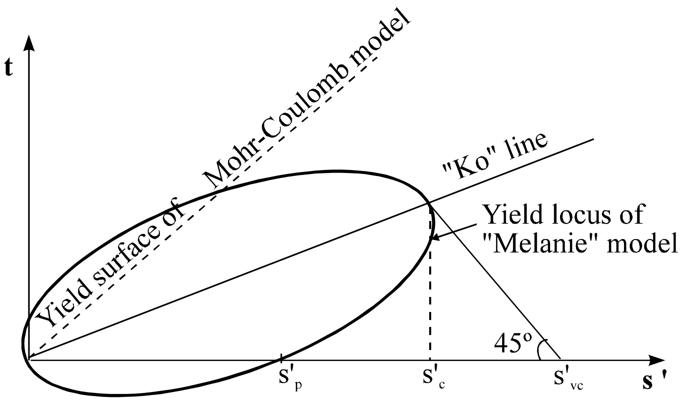

Figure 1. Yield locus according to Melanie Model

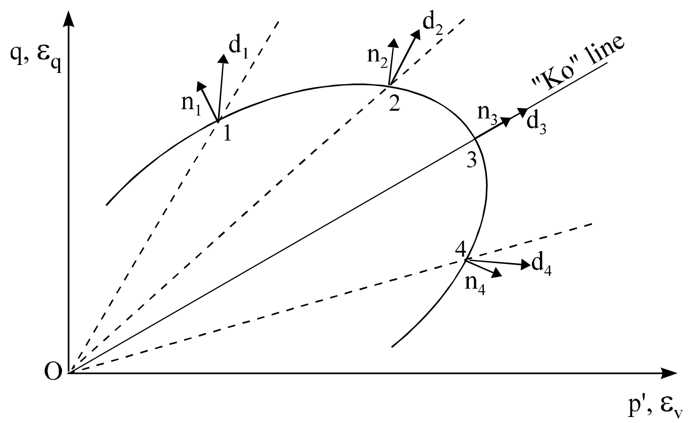

Figure 2. Direction of the vectors of plastic strains as defined by the Melanie model

$$\mathrm{C}= 0.6, \qquad \theta = \mathrm{arctg}\left[\frac{1-\mathrm{Ko}_{(\mathrm{n.c.})}}{1+\mathrm{Ko}_{(\mathrm{n.c.})}}\right] \tag{4}$$

and K is the hardening parameter required by the model, which [2] defined, for one-dimensional consolidation, as:

$$K = \frac{\mathrm{s'_c}}{2 \times \cos\theta} A \times C \tag{5}$$

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The Melanie Model considers a non-associated flow rule, as illustrated in Figure 2, being the direction of the vector of plastic strains (d_i) defined by the bi-secting-line between the normal to the ellipse (n_i) and the line joining the origin and the yielding point (i).

The Melanie Model does not exactly match the experimental observations [3], so that, as shown in Figure 1, it was coupled with the "Mohr-Coulomb" model, thus limiting the hardening of the yielding surfaces.

Case Study

During and after the construction of the multi-stage embankments of the section of the IP3 main road, S.[ta] Eulália - Figueira da Foz, partially built over the soft alluvial organic soils of Baixo Mondego, several instrumented profiles were observed. This paper presents the analysis of the settlements measured at the profile located at the km 9+237.5, where the geological and instrumentation characteristics are those illustrated in Figure 3. The settlements observed at the 3 settlement marks (M_i) were compared with those resulting from FEM analysis using the Mel model and considering the soil properties obtained from field and laboratorial tests.

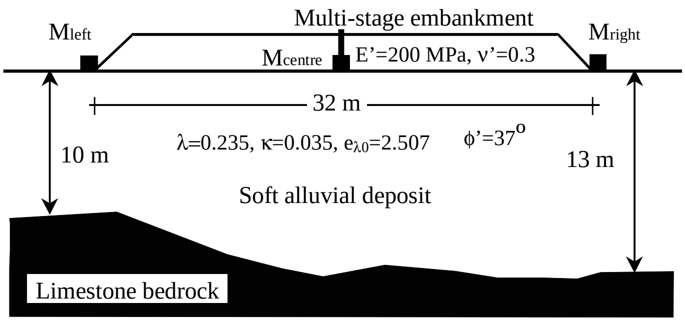

Figure 3. Geological and instrumentation of the studied section

Geological and Geotechnical Characterisation of the Foundation

During the last few years, several research programs have been dedicated to the characterisation of the soft soils of Baixo Mondego. The deposit, formed at the alluvial plains of river Mondego and its tributaries during the last 20,000 years, presents a variable thickness of plastic, organic and predominantly silty soil laying over a limestone bedrock. Its local organic content and OCR mostly determine the properties of the soft layer, fairly uniform in composition. The OCR, decreasing in depth, is mostly due to desiccation and water-table fluctuations imposed by agricultural needs [1].

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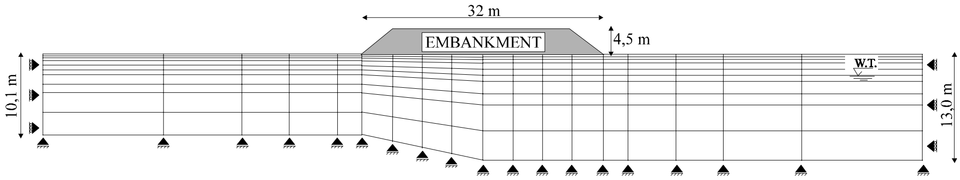

Figure 4. Finite elements grid used for the numerical analysis

Laboratorial and field tests were intensively performed at an investigation site near the studied profile. According to the deposit characteristics and some local field tests executed, it was admitted that the soil at the studied profile would present properties similar to those observed at the experimental site. Apart from the soil's granular composition, it is worth noting the erratic but quite high values of natural water content, void ratio, plasticity and compressibility, the low unit weight, the significant presence of organic matter, and the variation of OCR in depth, typical from the occurrence of a desiccated crust [1].

Characteristics of the Numerical Modelling

The discretisation of the problem for the numerical modelling was made by squared elements with 8 nodal points. For the foundation, hybrid elements were required in order to calculate all the nodal displacements (quadratic variation) and the pore pressure at 4 nodal points (linear variation).

The FEM analysis employed the grid shown in Figure 4, including 198 elements and 653 nodal points, and the boundary conditions for the problem were defined as:

- displacements and drainage restricted at the bottom of the soft layer;

- horizontal displacements and drainage restricted at the left and right vertical limits of the grid;

- free drainage at the top of the soft layer.

The water level was admitted to exist at 1.75 m depth. The characteristics of the layers used for the numerical calculation were mainly deduced from the results of the geotechnical characterisation undertaken at the experimental site. The K_0 values employed resulted from an experimental investigation [1], suggesting that they could be estimated, independently of the OCR, by:

$$K_0 = 0.4 \times OCR^{0.4} \tag{6}$$

In order to consider a convenient value for the permeability of the deposit, the values for the coefficient of permeability were obtained from back-analysis, using the Asaoka method [4]. This proved to be the only solution to model the deposit permeability, especially because vertical drains had been used to reduce the

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consolidation time of the foundation. It was also estimated a permeability ratio (k_h/k_v) of 3 and, to account for the stress increase, the initial values for k were replaced after 310 days for those corresponding to the normally consolidated soil.

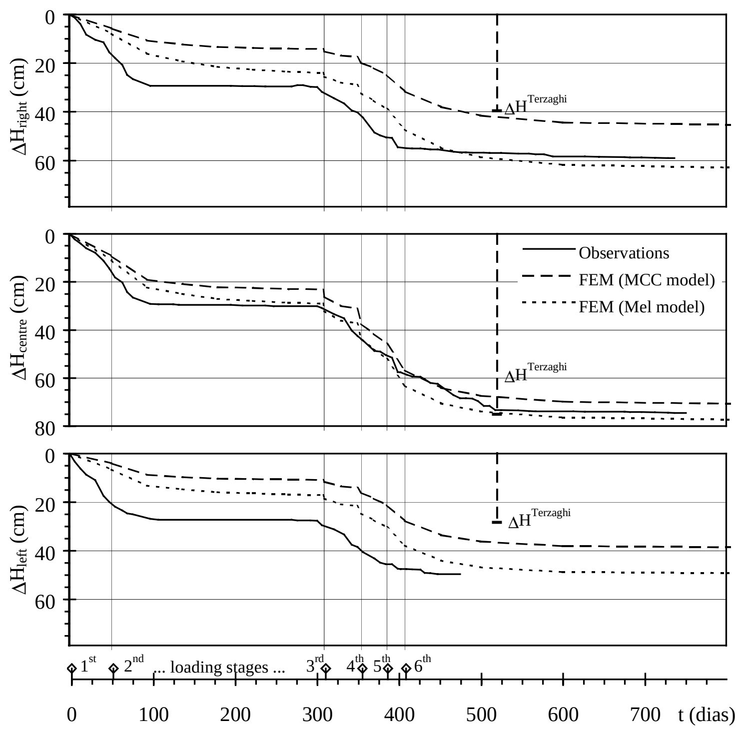

Figure 5. Comparison between the settlements observed and predicted.

The elastic modulus of the foundation was calculated for each Gauss point by the equation [5]:

$$E' = \frac{3 \times (1 + e_0) \times (1 - 2 \times \nu')}{\kappa} \times p'_0 \tag{7}$$

The embankment was supposed to behave elastically. Its construction was simulated by the insertion of new elements, corresponding each new line of elements to a new layer of the embankment.

The numerical simulations, using the Mel model, were performed by a FEM program developed at the University of Coimbra, capable of running elastoplastic analysis of consolidation problems.

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Results of the FEM Analysis

The purpose of this work was to compare the settlements observed at the 3 settlement marks [2], placed in the middle and both sides of the embankment, with those calculated from the FEM analysis using the two selected soil models. Figure 5 presents the observed and predicted settlements increase with time, at those selected points.

The central mark, Figure 3, M_{centre} the numerical predictions are close to the observed settlements. At M_{right} and M_{left} marks, the calculations clearly underestimates the settlements observed during the first loading phase, though final settlements predictions are quite correct, [2].

Conclusions

The results obtained suggest that, as stated by [3] FEM analysis performed with the Melanie model give good settlement predictions for embankments built on soft soils. At the studied problem, the analysis using the MCC model systematically underestimates settlements, probably as a result of the unrealistic isotropic shape assumed for the yield locus, [2].

Acknowledgements

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