A Comparison of Four Elastic Visco-Plastic Models for Soft Clay

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Abstract. The time-dependent settlement of soft clays following application of surface loading may be modelled using elastic visco-plastic constitutive models to describe the soil behaviour. For applied loadings that increase the stresses to around the in-situ yield stress, the predicted behaviour is strongly influenced by the associated breakdown of clay structure and the way in which this is modelled. Four elastic visco-plastic models have been compared and all calculate the creep rate in fundamentally the same manner by comparison to the state at the same effective stress on a reference isotache.

1 Introduction

The prediction of long-term settlements of embankments foundations and fills on soft clays requires a good understanding of the time dependant behaviour of the clay. While a complex finite element analysis may sometimes be necessary, it will often be more appropriate to undertake a one-dimensional analysis of the centre-line conditions. The study reported here explores the implications of the different assumptions made within four constitutive models as the clay is stressed towards and beyond the yield stress, and its structure is gradually damaged.

2 A Simple Isotache Model

In the 1-D elastic visco-plastic (EVP) models used in the present study the incremental total strain $\partial\varepsilon$ resulting from a change of vertical effective stress $\partial\sigma'$ is the sum of the incremental elastic strain $\partial\varepsilon^{e}$ and the incremental creep strain $\partial\varepsilon^{tp}$.

In stress-strain-strain rate models the creep strain rate is defined by the relationship of the current soil state to that on a reference isotache at the same effective stress. Under constant effective stress the creep or secondary compression strain ε^{tp} at time t is assumed to increase linearly with logarithmic time as given by equation (1):

$$\varepsilon^{tp} = \varepsilon_{ref} + C.\ln\left(\frac{t}{t_{ref}}\right) \tag{1}$$

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where C is a coefficient of secondary compression, and ε_{ref} and t_{ref} define a reference state. In incremental form equation (1) may be expressed as:

$$\dot{\varepsilon}^{tp} = \frac{C}{t} \quad \text{and thus} \quad \dot{\varepsilon}^{tp}_{ref} = \frac{C}{t_{ref}} \tag{2}$$

The creep strain to the current state from the reference state (equation 1) may then be expressed as:

$$\varepsilon^{tp} = \varepsilon_{ref} + C.\ln\left(\frac{\dot{\varepsilon}^{tp}_{ref}}{\dot{\varepsilon}^{tp}}\right) \tag{3}$$

Many of the EVP models described in the literature use a relationship in the form of equation (1) to evaluate the creep rate by reference to a linear isotache but this presents the analyst with the inherent difficulty of deciding the reference time. Use of the logarithmic creep relationship in the form of equation (3) avoids this difficulty. Four EVP models were used in the present study:

1. A 1-D 'equivalent time' creep model for unstructured clay (Yin & Graham 1996, Nash & Ryde 2001) denoted Model 3;
2. The Plaxis Soft Soil Creep model for unstructured clay (Vermeer & Neher 1999) denoted SSC;
3. Model 3-d accounting for an initial structure (Nash 2010);
4. The University of Chalmers time resistance creep model accounting for an initial structure (Claesson 2003) denoted Chalmers model.

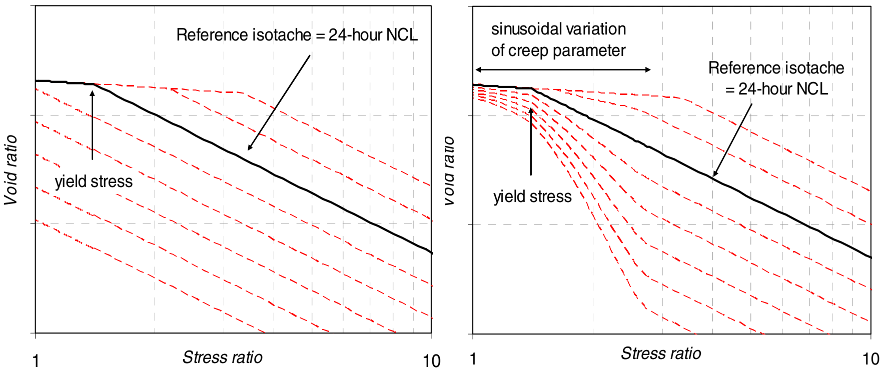

Fig. 1. General isotache shapes for EVP models a) without structure and b) with initial soil structure

The Soft Soil Creep model is run within Plaxis; the others have been implemented into the finite difference framework Briscon (Nash & Ryde 2001). All are similar to the simple isotache model described above. The first pair of models do not model destructuration of the clay and use a set of parallel isotaches that are linear on a plot of void ratio or engineering strain vs logσ'_v. However this is not a requirement for an EVP analysis and the other pair of models that incorporate destructuration of the clay use curved isotaches as illustrated in Figure 1.

3 Full-Scale Test Predictions

A benchmarking study proposed by the Norwegian Geotechnical Institute, was reported at an international workshop on creep of soft soils held in 2009. Six research groups undertook various creep predictions (Jostad and Degago 2010) for a simplified geometry comprising 10m of sand overlying 30m of soft compressible clay. Variables specified included the applied stress at ground level, initial OCR and drainage conditions. A single oedometer test was provided from which soil parameters were to be determined. The Bristol prediction was described by Nash (2010), but the exercise was recently extended to explore the performance of several EVP models, and to highlight the implications of modelling initial soil structure. Two situations were considered:

1. An initial OCR of 1.4 in the clay, with 0kPa applied stress (creep only).
2. An initial OCR of 1.4 in the clay, with 90kPa applied stress.

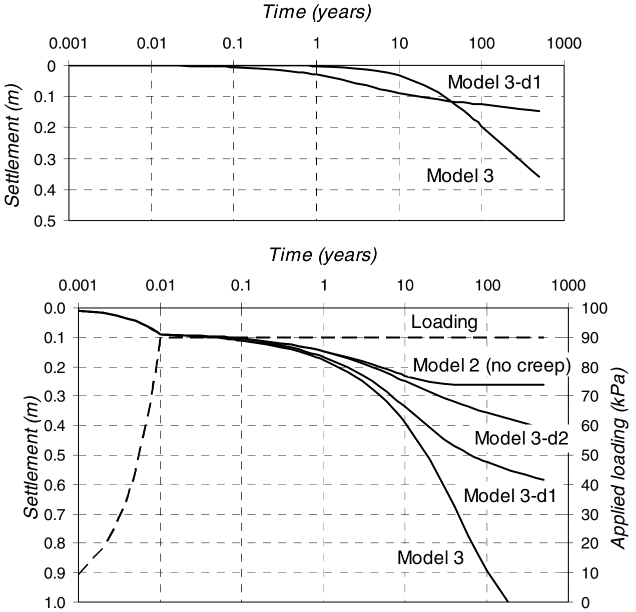

Fig. 2. Predicted settlement vs time for a) no load and b) 90 kPa for OCR=1.4 1-D analyses were undertaken that involved creep for 500 years. Each pair of models for *unstructured* and *structured* clay predicted very similar results, confirming that each accounts for creep in a similar manner. Some time-settlement plots are shown in Figure 2 for zero and 90 kPa applied load.

With no applied load (case 1) settlements up to 0.4m were predicted, with the final creep rate for the *unstructured* clay greater than that of *structured* clay. These large settlements seem implausible and result from high creep rates in the initial state. When equivalent age of the clay was increased from 1 day (in model 3 and 3-d1) to 10000 years (model 3-d2) the settlement was negligible. Under 90 kPa applied loading (case 2), models accounting for initial structure predicted circa 50% of the settlement predicted by the structured models, highlighting the importance of representing the initial material structure. Further details are given by (Nash and Brown 2012).

4 Conclusions

Four 1-D elastic visco-plastic models have been studied; despite differences in terminology, they are all similar to the simple isotache model described above. Modelling the gradually changing creep behaviour as clay structure is broken down in the over-consolidated state and around the yield stress has a significant effect on strain predictions for over-consolidated material. While a two or three dimensional analysis with a more complex constitutive model may sometimes be necessary, this will often present difficulties in defining representative soil parameters. It may often be appropriate to undertake a one-dimensional analysis of the centre-line conditions like those illustrated here, taking care to use a model such as the two reported above that incorporate the gradual destructuration of the clay.

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