On a new rheological model for soils

Sur un nouveau modèle rhéologique pour les sols

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SYNOPSIS: A unic rheological model is proposed to describe soil behaviour under different loading conditions. The model simulates the stress history of the soil and visualises its influence on soil behaviour and strength. Decay and collapse of soil structure during loading are simulated. The model can accommodate the consolidation model of Terzaghi to account for drainage conditions of the soil during loading.

INTRODUCTION

Soils exhibit complex and non standard behaviour under external loads. This is because of the complexity of their structure and the numerous factors which govern their behaviour. Among these factors,stress history and permeability are the central part.

In solving a soil mechanics problem we always start by building up a rheological model which relates between physical quantities such as stress strain and time in a given loading condition. Several theoritical and empirical models describing different soil behaviours are proposed and used (Coulomb 1776), (Biot 1956), (Terzaghi 1943) and (Roscoe 1968). None of the proposed models can describe every feature of soil behaviour. The principal reason is the problem of a proper coupling of the different parameters governing the soil behaviour. This is why we use different models to solve different soil problems even though we are dealing with the same soil.

In an attempt to properly couple the principals of these parameters for a better simulation of the mechanical behaviour of soil, a new rheological model is built up and proposed in this paper.

THE PROPOSED MODEL

The model we are proposing is composed of springs, sliding blocs and a dashpot assembled according to the configuration given by figure 1. The model uses an element similar to that of KEPES where the friction mobilised by the sliding bloc is proportional to its displacement. In fact, the spring element S3 can be initially preloaded; when point C in the model moves toward point D, the spring S3 is consequently unloaded and the friction resistance T1 mobilised by the sliding bloc B1 decreases until it vanishes. We assume that the sliding bloc B1 doesn't resist traction and hence no tensile load can take place in the spring element S3.

BEHAVIOUR OF THE MODEL

The response of the model to different loading conditions is very much affected by the behaviour of its part wedged by points C and D. In fact, while point C moves toward point D, the sliding resistance T2 mobilised by bloc B2 decreases from an initial maximal value, due to the contribution of the initial load F3 and the load V, until it reaches a minimal value that is due only to load V.

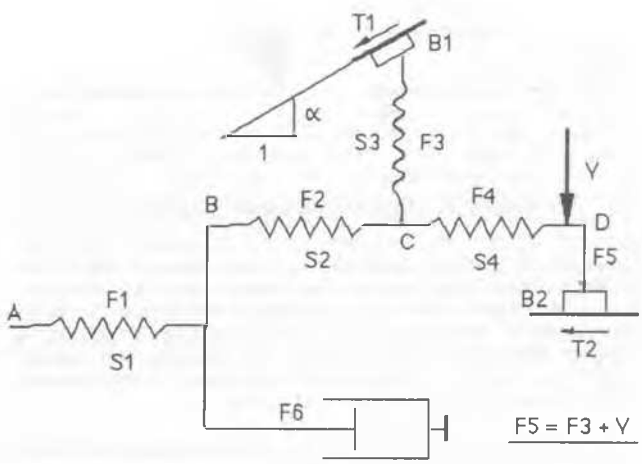

Figure 1. Model description

In recognizing that the load F4 in the spring element S4 can not exceed the sliding resistance T2 mobilised by bloc B2, and that the load needed to displace point C toward D is the sum of the resistance mobilised by the sliding bloc B1 and the load F4 in spring element S4, the part of the model wedged by points B and D may exhibit the nine different load-displacement patterns given by figures 2 a,b and c.In some cases, depending on the springs constants of the model, a drop of load at point B (in F2) may occure when point C moves toward D. This happens when the constant of spring element S2 is equal or less than that of the equivalent spring of the part of the model wedged by points C and D. Five additional load-displacement patterns corresponding to these cases are obtained and given by figures 2 d-e.

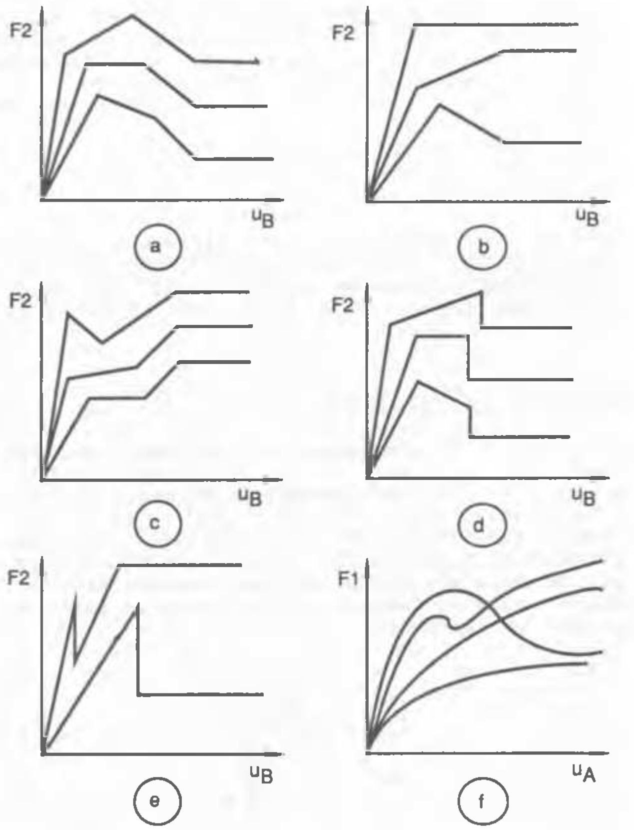

Figure 2. Load-displacement patterns

Figures 2 a-b-c visualise the decay of the material and the resulting load transfer within its structure during loading. Figures 2 d-e visualise a collapse of the material structure during loading. These forms of damage are well known in solid mechanics (Duncan and Chang 1970),(Hoeg 1972) and (Desai 1974).

The behaviour of the whole model can be now easily known for different loading conditions. In case of a given constant displacement rate loading, we will obtain a large variety of load-displacement curves similar to those given by figures 2 a-b-c-d-e but smooth. The most common patterns are those given by figure 2-f.

In creep loading, when a sustained load is applied at point A, many patterns of displacement-time response can be obtained. To each curve of fig.2 (a through e) a set of displacement-time curves can be associated where each curve within a set is associated with a given load. Some of these displacement-time patterns are shown by fig.3 where one can recognize the primary, the secondary and the tertiary creep stages on the first set and the hesitating creep in the second set.

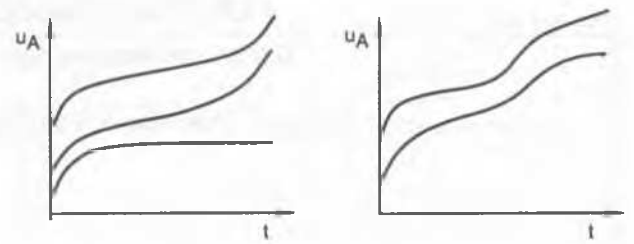

Figure 3. Displacement-time patterns in creep loading

From the different curves associated with the different loading conditions, we can relate the KEPES element used in the proposed model to the "memory" of the material or its stress-history. Hence, it is not imopssible to have the slope α of the inclined sliding plane in figure 1 related to the Over Consolidation Ratio (OCR) of the soil as follows :

$$\alpha = 1 - \frac{1}{OCR}$$

α could also be related to the dilatancy properties of the material. It will take a negative value for contracting materials, positive value for dilatant materials, and zero for incompressible materials.

The load V applied on the sliding bloc B2 may be related to the actual effective pressure σ' in the soil as :

$$V = \sigma'$$

and the initial load F3 in spring element S3 may be related to the preconsolidation pressure σ_C' and the actual effective pressure σ' in the soil as :

$$F3 = \sigma_C' - \sigma'$$

Hence the slope α of the inclined sliding plane, the initial load F3 in the spring element S3 and the applied load V on the sliding bloc B2 are related to each other.

SOIL STRENGTH

By defining the strength as the peak load value obtained on a load-displacement curve given by the model, and using the above definitions adopted for some parameters of the model, we can obtain the well known failure envelope relating the strength of the soil to the consolidation pressure. In fact, if the soil is over consolidated, i.e., the slope α (fig. 1) is positive,the initial load F3 in the spring element S3 will be automatically positive (compression). Therefore the model exhibits a strength even though the applied load V on the sliding bloc B2 is equal to zero. On the other hand, if the soil is normally consolidated, i.e., the slope α and the initial load F3 in the spring element S3 are equal to zero, and if the preconsolidation pressure is also equal to zero the model will be reduced to the Maxwell one indicating a fluide state of the material with no strength. As the material consolidates, i.e., load V in the model increases, the strength of the model will build up. The curves representing the variation of the strength obtained by the model as a function of the applied load V on the sliding bloc B2 are similar to those commonly obtained for soils with the distinction of the normally consolidated state from the over consolidated state (Fig. 4).

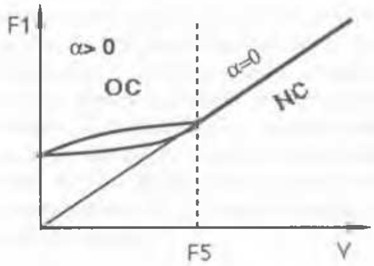

Figure 4.Failure envelope obtained from the model

DRAINED AND UNDRAINED BEHAVIOUR

It is commonly known that the behaviour and the strength properties of saturated clays and silts are greately affected by the drainage conditions, the rate of loading and the stress history. This is because of the very low permeability and the compressibility of these soils.

When an element of these soils undergoes a shear deformation, it generally exhibits a tendancy to change in volume. When loading is very slow, the element can exchange water with its environment with no pore water pressure change. On the orther hand, when loading is very quick, there will be not enough time for the soil element to exchange water and hence the pore water pressure will increase or decrease depending on the tendancy of the soil element to decrease or to increase in volume. These tendancies depend essentially on the stress history of the soil. This property is simulated by properly inserting into our model the famous consolidation model of Terzaghi according to the configuration given by figure 5.

"Absolute" undrained conditions are simulated by closing the valve of Terzaghi model. If the valve is left open during loading, exchange of water will take place in Terzaghi model and the water pressure will change. The rate of flow and the change in water pressure in Terzaghi model will depend on the rate of loading.

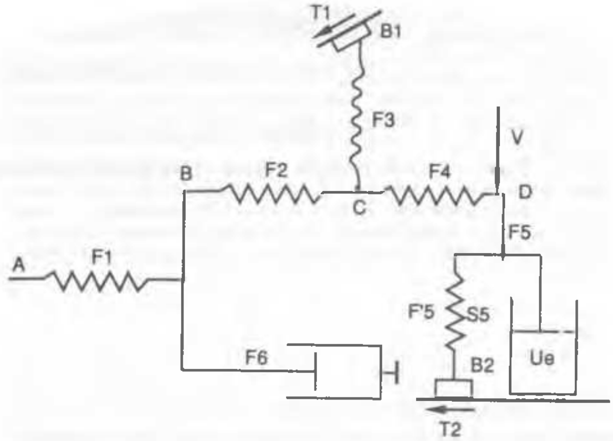

Figure 5. Drainage condition simulation

While the exchange of water proceeds, the length of spring S5 which belongs to Terzaghi model changes causing consequently a change in the sliding resistance T2 available from the sliding bloc B2. The resulting behaviour of the model is realistic and in a good agreement with that of real soils. In fact for example, for an over consolidated soil, the model (with $\alpha > 0$) gives a drained strength lower than the undrained strength. For normally consolidated loose soil (simulated by taking negative α in the model), the drained strength is higher than the undrained one.

CONCLUSION

Many features of soil behaviour are simulated by a unic model that can take into account, with realistic coupling, the stress-history of the soil, its dilatancy properties and the drainage condition during loading. We do not pretend to exactly describe soil behaviour, because the different mechanisms involved in the behaviour of real soils are much more complicated than those in the proposed model. We simply aim, in proposing this model, to allow a better and easier physical description of the significant features of soil behaviour.

ACKNOWLEDGEMENT

The author is very grateful to the research team of the civil engineering department of ENIT for their valuable comments during the preparation of this work.

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