CONSOLIDATION MODELS CONSISTING OF AN ASSEMBLY OF VISCOSOUS ELEMENTS OR A CAVITY CHANNEL NETWORK

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SYNOPSIS

A cavity channel network consisting of many cavities with different compresibility interconnected by channels with different conductivity can serve as a model for a consolidating soil in both the primary and the secondary periods of consolidation.

The abundance of the constituting elements is introduced as a continuous frequency function using the spring dashpot assembly as a model because it produces similar effects. It is shown how this frequency function can be determined from test results.

INTRODUCTION

In his book *Grondmechanica*, Keverling Buisman (1940) describes his observation that soils show time settlement effects which differ from the original Terzaghi theory of consolidation and which are especially pronounced in the secondary period. This discovery was mentioned in his paper to the 1939 Conference, but in his book and other publications (1938) he develops in more detail the possible causes and the consequence of this phenomenon. Since, however, all this was written in Dutch and never translated, some of his ideas which formed the basis of the present considerations are reproduced here.

Buisman called the secondary settlement the 'secular effect', from the Latin 'seculum' which means century. He coined the word 'secular' to point out to engineers that settlement could continue to develop after excess pore pressure had disappeared, and could continue to do so for a long time, perhaps centuries.

Because his work is only thirty years old a centennial verification is not available. However, for practical purposes his suggestion to extrapolate the settlement time curve as a straight line, when settlement is plotted on a linear scale and time on a logarithmic scale, gives an estimate which was verified to be reasonable in many instances. He called the corresponding settlement time relation the logarithmic time law and gave it the mathematical form

\[ \zeta = \phi h (e_s + \alpha \log t) \]

where \( \zeta \) is the settlement, \( \phi \) the effective stress increase by loading, \( h \) the layer thickness, \( e_s \) and \( \alpha \) the settlement parameters, and \( t \) is the time in days after loading.

It was his opinion that the soil skeleton follows such a time settlement law, starting from the moment when an effective stress increase is created. Therefore the secular settlement also operates during the primary period of consolidation when excess pore pressures still prevent the effective stress from carrying the total load. Keverling Buisman suggested as a first approximation to use Terzaghi's theory for the determination of excess pore pressure and the effective stresses as a function of time. From these he calculated the settlement as produced by the gradually increasing effective stresses by adopting the validity of a superposition principle. He assumed that the response to unit step loading always conforms to equation (1).

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His analysis to include this secular settlement within the framework of the hydrodynamic theory of consolidation was only a crude approximation, because at that time the powerful method of integral transforms was not available for the solution of consolidation problems. The importance of his analysis, however, is in the introduction of a time retarded soil skeleton in both primary and secondary periods of consolidation.

To give credit to Keeverling Buisman, the word 'secular' could be reserved for those effects and mechanisms which delay settlement both in the primary and secondary periods of consolidation, and are responsible for deviations in time-settlement behaviour from Terzaghi's linear theory. In this Paper 'secular' is used in this sense.

Another important aspect of consolidation which he examines in his book is the explicit description of two mechanisms that could be responsible for the time-delayed reaction of the soil skeleton. One secular mechanism could be the viscous character of the pore water bound by the particles, the other mentioned is the size difference of the pores which have to transmit the expelled water in order to allow settlement to occur.

Both these mechanisms will be shown in this Paper to lead to the deviations from Terzaghi's theory which are frequently observed in tests after the excess pore pressure has reduced to zero. It will be seen that the pore system with different channel widths is to be preferred as a model to the viscous soil skeleton, for the former will allow the data to be fitted to the theory over a wider time range than is possible with the latter.

Taylor and Merchant (1940) introduced secular effects in their consolidation theory. As Barden (1965) has pointed out they obtained results which are representative for spring dashpot systems, but they did not specify the mechanism in terms of a rheological model.

Tan (1957) substituted a specific spring dashpot system for the grain contacts in order to introduce a secular effect according to Keeverling Buisman's viscous secular mechanism. Tan (1957) and Gibson and Lo (1961) give solutions for discrete values of the relaxation properties of the spring dashpot combination. By taking three kinds of elements with enough difference in the relaxation time, Schiffman, Ladd and Chen (1964) obtained for the secondary period a time settlement curve, which on a semilogarithmic scale has an undulating shape with three successive waves. Barden (1965) introduced the non-linear behaviour of the viscous soil skeleton and using a power law for the relation between shear stress and shear strain rate he obtained a secondary time settlement curve. By plotting the difference between the final value of settlement and the settlement at an intermediate time, a power time law is obtained, which differs from the power time law used in this Paper.

These workers have therefore developed mathematically the first mechanism proposed by Keeverling Buisman. The viscous character of the soil skeleton has been incorporated in the consolidation process and exact solutions have been obtained. It may be worth mentioning that the cases considered by Schiffman obey differential equations of so complicated a character that only electronic computers can solve them.

In this Paper the notion of a viscous grain skeleton represented by elements containing springs and dashpots is reconsidered. Instead of introducing a limited number of discrete parameters for the elements as was done in the previous work, the treatment will be concerned with a distribution of element parameters which is continuous and stochastic. This means that the properties of the individual elements vary randomly and that by their abundance it is possible to represent the frequency of occurrence of their parameters by a continuous function.

Besides the introduction of a continuous frequency function, the object of this study is to determine the form of this frequency function for a particular soil by analysing its settlement time response to loading. Actually this is the inverse analysis of the previous investigators, who determined settlement time response for a given element distribution. The motive for such an inverse procedure is the opportunity it offers us to study soil structure on a microscale.