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A piezocone dissipation test interpretation method for hydraulic conductivity of soft clays

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Abstract

An alternative approach is developed in order to estimate the hydraulic conductivity of soft fine grained soils, based on numerical simulation of the full penetration and dissipation process for piezocones. Unlike previous methods of analysis, the process of penetration and dissipation has been explicitly simulated, thus eliminating several of the simplifications inherent in existing interpretation methods such as geometric approximations, predefined stress fields or neglecting material compressibility. The presented method is not established upon a particular set of data leading to limited applicability, but is rather developed using a more general approach and can be extended to other datasets if intended. Given the time to 50% consolidation and a number of influencing soil parameters, a single estimate of the soil horizontal permeability can be obtained via a single-run piezocone sounding using pore pressure measurements taken at the shoulder filter element (u_2) located immediately behind the cone.

The proposed interpretation method embodies many of the key parameters (namely the soil shear strength, soil rigidity, and soil confining stresses) likely to influence the soil behaviour and thus the parameter to be interpreted. Numerical analyses demonstrated that the rate of dissipation increases as the soil rigidity or the soil confining pressure increases, which is a consequence of higher excess pore pressure gradient at higher depths or at larger rigidities. The method, which involves a new excess pore pressure normalisation technique, is applicable to both monotonic and dilative dissipation data. The proposed interpretation method is compared to a series of experimental data including two recent field tests. Although the method was calibrated against only a select few cases, its applicability to a wide range of clayey soils was verified.

Keywords: Piezocone dissipation test interpretation; Numerical modelling; Large deformations; Modified Cam clay; Soil permeability estimation

1. Introduction

Piezocone dissipation test data are currently interpreted using either empirical and semi-empirical correlating equations and charts, derived from recorded field measurements and laboratory test results (Parez and Fauriel, 1988; Robertson et al., 1992; Tavenas et al., 1982), or are evaluated through associating the collected dissipation data with some analytical (unique) normalised dissipation curves (Baligh and Levadoux, 1986; Gupta and Davidson, 1986; Senneset et al., 1982; Teh, 1987; Teh and Houlsby, 1988, 1991; Torstensson, 1977; Chung et al., 2014) which in general, are introduced by breaking down the complex problem to a simpler one, e.g., cavity expansion (Baligh and Levadoux, 1986; Torstensson, 1977) and strain path (Baligh,

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1985), and meanwhile neglect issues like material compressibility and proper stress path due to cone penetration (Teh and Houlsby, 1988, 1991). More importantly, all these categories in interpretation methods are only applicable to monotonically decreasing dissipation curves. For dilative or 'non-standard' dissipation curves (see Fig. 1), these methods cannot be directly applied. For tests with dilative dissipation data, analytical (Burns and Mayne, 1998) and semi-analytical methods (Sully and Campanella, 1994) have been proposed.

Nonlinear finite element methods less-frequently have been used to develop new methods of estimation and interpretation. Only during the last decade have numerical methods been incorporated in piezocone penetration tests and in dissipation tests, and to either develop new methods of interpretation (Silva et al., 2006; Voyiadjis and Song, 2003) or improve existing methods (Chai et al., 2012). The multi-penetration rate interpretation method developed by Silva et al. (2006) and the 'dual-point' excess pore pressure measurement method by Voyiadjis and Song (2003) are principally derived from the numerical modelling of penetration problems. These methods, however, require multiple piezocone penetrations with various rates or dual-sensor simultaneous pore pressure measurements during piezocone sounding and are hence of limited practical use. In addition, the above-mentioned interpretation methods obtain a range of values for the interpreted parameter and require some geotechnical judgement to come to a conclusion. Chai et al. (2012) takes advantage of a numerical model to modify the time component for cases of dissipation data with dilative response. Their analysis, however, embraces uncoupled radial consolidation analysis and relies upon the analytical method of Teh and Houlsby (1991) to obtain an estimate of the horizontal coefficient of consolidation.

In this paper, both piezocone penetration and dissipation tests are directly modelled using large deformation finite element analysis, where the most significant features of the problem, namely, the material, geometry and boundary nonlinearities as well as coupling between displacements and pore pressure are taken into account. Subsequently, a new method for interpreting dissipation data is presented in which a dissipation time of interest is linked to the soil permeability value. Modification factors are proposed in order to neutralise the effect of influencing soil parameters on the dissipation data. The soil permeability is eventually valuated by implementing the so-called modified dissipation time into a time – permeability linkage which is derived using the numerical modelling of the piezocone dissipation test. This new interpretation method is intentionally kept simple, by adopting simple modification factors to account for the effects of important soil parameters. This approach will help facilitate the use of the proposed interpretation method in engineering practice. The approach undertaken in this study does not rely robustly on specific experimental data or analytical approximations, but is rather established upon a general numerical model with minimum simplifications/assumptions, which provides higher accuracy. This method proposes a single-run piezocone sounding with single pore pressure measurement at the cone shoulder element (u_2) which is of more practical convenience. It also obtains a single-value estimation of the soil permeability, instead of a range of values. The finite element model and the new interpretation method are compared against existing data in the literature as well as two recent field measurements.

1.1. Dissipation data normalisations

Dissipation data require some type of normalisation in order to examine the changes in the dissipation response with respect to the changes in the soil parameters or testing conditions. These normalisations apply to either the excess pore pressure component or the time component, or in some cases, to both.

1.1.1. Normalisation of excess pore pressure

A common normalisation method for excess pore pressure is based on the initial value of excess pore pressure measured at the filter elements (Teh and Houlsby, 1991; Torstensson, 1977) in the form of

$$U = \frac{u_t - u_0}{u_i - u_0} = \frac{\Delta u_t}{\Delta u_i} \tag{1}$$

where u_0 is the initial hydrostatic pore pressure; u_i is the pore pressure at the beginning of the dissipation; and u_t is the pore pressure at time t. Other normalisation methods have also been introduced (Gupta and Davidson, 1986; Senneset et al., 1982; Teh, 1987), but are not widely used in practice.

As illustrated in Fig. 1, the dissipation response is not necessarily monotonic and the initial excess pore pressure at the u_2 position is not necessarily the maximum value. Dilative dissipation behaviour is observed when the pore pressure measurement is carried out via porous elements behind the cone. Dilative dissipation data can be attributed to a number of factors, the more recognised ones being the confined dilation due to shearing of the soil adjacent to the shaft body for overconsolidated clays, the redistribution of the initial excess pore pressure after a halt in penetration, the unloading stress path that any soil element experiences when travelling from the cone face to the cone shoulder, and the partial saturation of

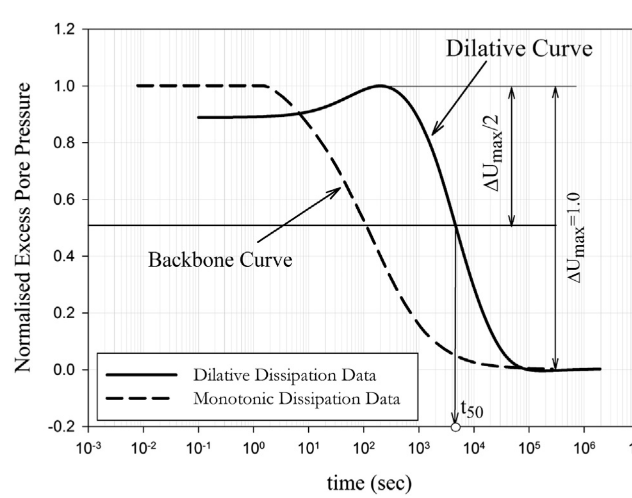

Fig. 1. Typical piezocone dissipation test – monotonic vs. dilative dissipation response (u_2 position).