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The Axial Loading of Foundations Embedded in Frozen Soils

A.P.S. Selvadurai and J. Hu
Department of Civil Engineering and Applied Mechanics, McGill University, Montreal, Quebec, Canada

ABSTRACT

A finite element code which incorporates a unified creep model is used to examine several geotechnical problems where the structure-frozen soil interaction is influenced by the creep deformations of the frozen soil. The creep behaviour of a frozen soil has three characteristic stages involving primary, secondary and damage-dependent tertiary phenomena. The paper investigates the influences of the complete creep response of the frozen soil on embedded structures subjected to external loadings. The modelling is viewed as a methodology for identifying time-dependent peak loads that can be sustained by structures embedded in frozen ground.

INTRODUCTION

The creep response of frozen soils is influenced by the ice and unfrozen water within them. The structures founded on or embedded in frozen ground will therefore undergo creep movement. In general, the creep behaviour of a frozen soil has three characteristic stages involving primary, secondary and tertiary phenomena. These creep processes are also influenced by temperature and applied stress.

Several numerical simulations of structure-frozen soil interaction involving creep modelling can be found in the literature. Most creep models used in such analysis employ power laws, which are valid only for describing the primary or secondary creep stages (Ladanyi, 1972, 1981, 1985). Examples of these include the creep behaviour of frozen tunnel walls (Klein and Jessberger, 1979), penetrometer tests and vertically loaded cylindrical footings embedded in frozen soil (Puswewala and Rajapakse, 1990, 1991). Using the creep model proposed by Fish (1983), Puswewala and Rajapakse (1990) examined the creep curve of a pressuremeter test, a plate load test and laterally loaded rigid cores. However, the unified creep model proposed by Fish (1983) can only simulate primary and tertiary creep stages and the secondary stage cannot be included in the model.

This paper employs the finite element method to investigate the complete creep behaviour of structure-frozen soil interaction for the specific situation where the creep response is modelled by a unified creep model. The structures used in the simulations include an embedded cylindrical footing and a circular footing placed on the surface of frozen ground. The loadings can take the form of either an axial load, multi-step load or a quasi-static cyclic load.

CONSTITUTIVE MODELLING OF FROZEN SOIL

In the proposed unified creep model, three separate creep equations are used to characterize primary, secondary and tertiary stages of creep behaviour, and the criteria for transition from one stage to another are also introduced separately.

Primary Creep Stage

The primary creep is usually represented by a power law of the form:

$$\dot{\varepsilon}_{ij}^{cp} = \frac{3}{2} A C \sigma_e^{B-1} t^{C-1} s_{ij} \tag{1}$$

where the equivalent stress $\sigma_e = \sqrt{3/2 s_{ij} s_{ij}}$; $s_{ij} = \sigma_{ij} - 1/3\ \sigma_{kk}\ \delta_{ij}$ is the stress deviator tensor and A, B and C are temperature-dependent material parameters.

Secondary Creep Stage

The secondary creep stage is also described by a power law of the form:

$$\dot{\varepsilon}_{ij}^{cs} = \frac{3}{2} A_2 \sigma_e^{B_2 - 1} s_{ij} \tag{2}$$

where A_2, B_2 are temperature-dependent material parameters.

Primary creep parameters A, B, C and secondary creep parameters A_2, B_2, can be evaluated from the creep curves of a uniaxial constant-stress creep test by a graphical method. The details of these procedures are given by Andersland and Anderson (1978).

Tertiary Creep Stage

Tertiary creep is modelled using the phenomenological theory of creep damage mechanics. The theory of damage mechanics has been used to examine the stress-induced progressive deterioration of engineering materials such as concrete, ice and composites (Kachanov, 1986; Lemaitre and Chaboche, 1974; Boehler and Khan, 1991; Selvadurai and Au, 1991). Creep damage is defined as the time-dependent stress-induced accumulation and growth of microvoids within a material. In a phenomenological creep damage model, the strain rate acceleration in the tertiary stage and the process of creep rupture are explained by appeal to the degradation of the material. Consider a control area in a body whose original area is A_0. With the development of internal damage, the area diminishes as a result of the creation of voids. The area of voids induced by damage is defined by A_D (Fig. 1). A damage variable (ω) for a uniaxial stress state is such that:

$$\omega = \frac{A_D}{A_0} \tag{3}$$

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KEY WORDS: Creep, creep damage, frozen soil, embedded pile, surface foundation, finite element method.