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On modelling visco-elastic behaviour of reinforced soil

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ABSTRACT: A simple model of an elastic soil reinforced with visco-elastic material is proposed. Mechanical macro-properties of such a composite are derived from respective properties of constituents and their geometrical arrangement. Both macro- and micro-behaviour of reinforced soil are studied mainly from the viewpoint of redistribution of intrinsic stresses due to the creep. Discussion of results obtained is presented.

1 INTRODUCTION

Artificially made materials, particularly those based on polymers, display rheological properties which influence long-term behaviour of soil structures reinforced with them. Such phenomena as creep or stress relaxation in the reinforcement may lead to the regrouping of intrinsic stress state within a reinforced soil structure which, in turn, may lead to some unexpected behaviour, like a loss of overall stability, etc. It is then of great importance to know how to predict long-term behaviour of earth structures reinforced with materials displaying rheological properties.

Geotextiles are relatively new materials and we do not know much about their properties after many years of exploitation as the soil reinforcement. Importance of the problem was recognized a few years ago and respective research had been taken up. Papers of Leflaive(1988), Minster (1986), Kabir(1988), Jailloux and Segrestin (1988), Bush(1990), Greenwood(1990), Miki at al (1990), Matichard et al (1990) and many others, represent variety of related problems, as ageing, long-term strength, creep, etc.

In this paper an attempt has been made to construct the most simple continuum model of the soil reinforced with viscoelastic material and to predict its long-term behaviour on the basis of mechanical properties of the constituents, their geometrical arrangement and volume fractions. It is hoped that the theoretical attempt proposed will increase our understanding of reinforced soil mechanics.

2 ASSUMPTIONS AND BASIC FORMULAS

The macro-behaviour of reinforced soil is described in terms of the mechanical properties of the soil and the reinforcement and of their volume fractions. The description is based on the continuum theory of composites proposed by Sawicki (1983a,b), with some modifications.

The reinforced soil is treated as a macroscopically homogeneous composite, the behaviour of which is described using macroscopic quantities, such as macrostress $\boldsymbol{\sigma}$ and macrostrain $\boldsymbol{\epsilon}$. These quantities are defined as respective averages over the representative elementary volume of the composite. There appear also microscopic quantities, such as microstresses $\boldsymbol{\sigma}^{\alpha}$ and microstrains $\boldsymbol{\epsilon}^{\alpha}$, which are the averages over the volumes of respective constituents.

The soil is elastic and obeys the Hooke's law, which may be written in the following incremental form:

$$d\epsilon_x^s = \frac{1}{E_s}\left[d\sigma_x^s - \nu_s(d\sigma_y^s + d\sigma_z^s)\right], \tag{1}$$

$$d\epsilon_y^s = \frac{1}{E_s}\left[d\sigma_y^s - \nu_s(d\sigma_x^s + d\sigma_z^s)\right], \tag{2}$$

$$d\epsilon_z^s = \frac{1}{E_s}\left[d\sigma_z^s - \nu_s(d\sigma_x^s + d\sigma_y^s)\right], \tag{3}$$

$$d\epsilon_{xz}^s = \frac{1}{2G_s} d\sigma_{xz}^s, \tag{4}$$

where the superscript "s" distinguishes respective microstrains and microstresses in the soil, E_s and ν_s denote the soil Young's modulus and Poisson's ratio respectively, G_s is the shear modulus. An assumption about the soil elasticity is the first approximation, which allows for a relatively simple analysis of our problem.

In the plane strain conditions Eqs.(1)–(3) take the following form:

$$d\epsilon_y^s = 0, \tag{5}$$

$$d\epsilon_x^s = \frac{1+\nu_s}{E_s}\left[(1-\nu_s)d\sigma_x^s - \nu_s d\sigma_z^s\right], \tag{6}$$

$$d\epsilon_z^s = \frac{1+\nu_s}{E_s}\left[-\nu_s d\sigma_x^s + (1-\nu_s)d\sigma_z^s\right]. \tag{7}$$

The reinforcement is assumed to work only in the x direction (fixed system of co-ordinates). One dimensional creep experiments, cf. Kabir (1988), Miki at al(1990), Matichard et al (1990), Greenwood (1990), provide some information about the creep behaviour of various geotextiles. Creep curves (strain v. time at constant stress) are in general non-linear, but the behaviour of some geotextiles may be approximated by straight lines, similar to that shown in Fig.1.

Geotextile's deformation consists of two parts:

$$\epsilon_x^r = \epsilon_x^{r,el} + \epsilon_x^{r,t}, \tag{8}$$

where $\epsilon_x^{r,el}$ is an instantaneous elastic strain and $\epsilon_x^{r,t}$ is the time dependent strain.

The behaviour presented in Fig.1 can be described by the following formulas:

$$\epsilon_x^{r,el} = \frac{1}{E_r}\sigma_x^r, \tag{9}$$

$$\epsilon_x^{r,t} = At, \tag{10}$$

where E_r is an elastic modulus of geotextile and $A = A(\sigma_x^r)$ denotes some function of the microstress σ_x^r in geotextile. Differentiation of Eq.(10) with respect to time gives:

$$\frac{d\epsilon_x^{r,t}}{dt} = A + \frac{dA}{dt}t. \tag{11}$$

In the case of $\sigma_x^r = \text{const}$ (creep under constant stress) Eq.(11) reduces to the following form:

$$\frac{d\epsilon_x^{r,t}}{dt} = A. \tag{12}$$

Assuming

$$A = \frac{1}{\eta}\sigma_x^r, \tag{13}$$

where η denotes viscosity, we have obtained the Maxwell's rheological model for geotextile. Further analysis will be restricted to that model of geotextile, but a general philosophy of approach presented remains valid for other rheological models.

For more complex loading conditions, i.e. when $\sigma_x^r = \sigma_x^r(t)$, Eq.(11) takes the form:

$$\frac{d\epsilon_x^{r,t}}{dt} = \frac{1}{\eta}\sigma_x^r + \left(\frac{1}{E_r} + \frac{1}{\eta}t\right)\frac{d\sigma_x^r}{dt}, \tag{14}$$

describing microstrain changes in the geotextile due to the creep.

The geotextile, used as the soil reinforcement, collaborates with the surrounding granular material. The aim of present communication is to predict the macroscopic behaviour of reinforced soil assuming that the soil behaves elastically and the reinforcement displays viscoelastic properties.

3 VOLUMETRIC DEFORMATION

It is assumed that the overall deformation, except that in the reinforcement direction, is the same as that of the pure soil. It is a rational assumption, showing only the basic feature of the

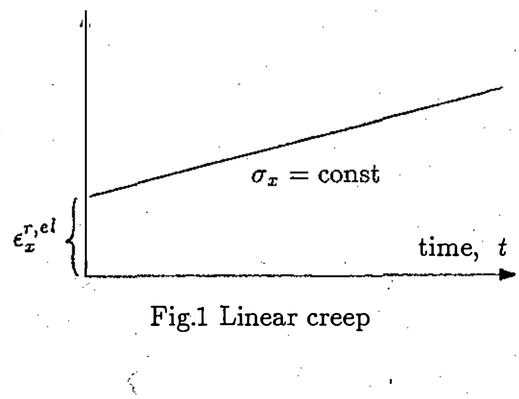

Fig.1 Linear creep

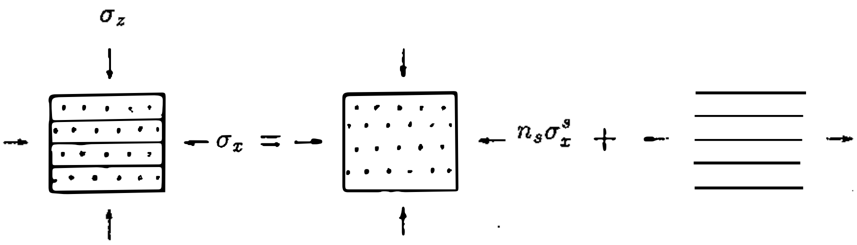

Fig.2 Macro- and microstresses in reinforced soil

macroscopic behaviour of reinforced soil. The assumption about no relative motion between the soil and the reinforcement leads to the following relations:

$$\epsilon_x = \epsilon_x^r = \epsilon_x^s, \tag{15}$$

or

$$\frac{d\epsilon_x}{dt} = \frac{d\epsilon_x^r}{dt} = \frac{d\epsilon_x^s}{dt}, \tag{16}$$

where a superscript distinguishes the microstrains in the soil (s) and the reinforcement (r) respectively.

Substitution of Eqs.(6) and (14) into (16) leads to the following formula:

$$\frac{1+\nu_s}{E_s}\left[(1-\nu_s)\frac{d\sigma_x^s}{dt} - \nu_s\frac{d\sigma_z^s}{dt}\right] = \\ = \frac{1}{\eta}\sigma_x^r + \left(\frac{1}{E_r} + \frac{1}{\eta}t\right)\frac{d\sigma_x^r}{dt}. \tag{17}$$

The following relations between micro- and macrostresses hold, cf. Sawicki at al (1988):

$$\sigma_x = n_s\sigma_x^s + n_r\sigma_x^r, \tag{18}$$

$$\frac{d\sigma_x}{dt} = n_s\frac{d\sigma_x^s}{dt} + \frac{d\sigma_x^r}{dt}, \tag{19}$$

where n_s and n_r denote volume fractions of the soil and the reinforcement respectively (there is $n_s + n_r = 1$). The other two normal stresses in both constituents are equal to each other because of equilibrium conditions:

$$\sigma_z^s = \sigma_z^r = \sigma_z, \qquad \sigma_y^s = \sigma_y^r = \sigma_y. \tag{20}$$

Eqs.(17)-(20) allow for the determination of the longitudinal microstress in the reinforcement as function of the macrostresses σ_x and σ_z. After simple algebraic manipulations the following differential equation is obtained:

$$A_1(t)\frac{d\sigma_x^r}{dt} + \frac{1}{\eta}\sigma_x^r = A_2\frac{d\sigma_x}{dt} - A_3\frac{d\sigma_z}{dt}. \tag{21}$$

where:

$$A_1(t) = \frac{1}{\eta}t + a, \qquad a = \frac{1}{E_r} + \frac{n_r(1-\nu_s^2)}{n_sE_s},$$

$$A_2 = \frac{1-\nu_s^2}{n_sE_s}, \qquad A_3 = \frac{\nu_s(1+\nu_s)}{E_s}.$$

If the macrostress histories are known, then the right hand side of Eq.(21) is also known, and the microstress in the reinforcement can be determined by solving the differential equation (21).

4 MICROSTRESS RELAXATION IN THE REINFORCEMENT

Consider a special case of the volumetric deformation in which the macrostresses σ_x and σ_z are constant, Fig.2. The solution of Eq.(21) can be easily obtained by separation of variables:

$$\sigma_x^r = S_0\frac{1}{1+t/(a\eta)}, \tag{22}$$

where:

$$S_0 = \frac{1}{\frac{E_s}{E_r} + \frac{n_r(1-\nu_s^2)}{n_s}}\left[\frac{1-\nu_s^2}{n_s}\sigma_x - \nu_s(1+\nu_s)\sigma_z\right] \tag{23}$$

is an initial (instantaneous) microstress in the reinforcement.

Eq.(22) displays an interesting feature of the reinforced soil behaviour, namely the microstress relaxation in the reinforcement. In the limit there is:

$$\lim_{t\to\infty}\sigma_x^r = 0, \tag{24}$$

which means that the microstress in the visco-elastic reinforcement gradually decreases down to zero. According to Eq.(18), the lateral microstress in the soil also changes, and in the limit there is:

$$\lim_{t\to\infty} \sigma_x^s = \frac{1}{n_s}\sigma_x \cong \sigma_x. \qquad (25)$$

The macroscopic stress-strain relations have the following form:

$$\epsilon_x = \frac{1-\nu_s^2}{n_s E_s}\sigma_x - \frac{\nu_s(1+\nu_s)}{E_s}\sigma_z - \\ - \frac{n_r(1-\nu_s^2)S_0}{n_s E_s}\frac{1}{1+t/(a\eta)}, \qquad (26)$$

$$\epsilon_z = -\frac{\nu_s(1+\nu_s)}{n_s E_s}\sigma_x + \frac{1-\nu_s^2}{E_s}\sigma_z + , \\ + \frac{n_r\nu_s(1+\nu_s)S_0}{n_s E_s}\frac{1}{1+t/(a\eta)}. \qquad (27)$$

5 DISCUSSION

The main conclusion which follows from the results presented is that the soil reinforced with visco-elastic material may not work, after a long period of time, as a classical reinforced soil. Because of the microstress relaxation phenomenon in the visco-elastic reinforcement the regrouping of intrinsic stresses (microstresses) takes place. In the limit, the microstress in the reinforcement drops to zero, which means that such a reinforcement does not play its main role.

The macroscopic stress-strain relations (26) and (27) show that the reinforced soil will behave macroscopically as a soil without reinforcement after a long time.

The results presented in this paper have been obtained in a theoretical way by applying the formalism of composites' mechanics. Such an approach has been successful in some other reinforced soil mechanics problems, cf. Sawicki (1983a), Sawicki at al (1988).

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