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The calculations of elastic-plastic damage of non-weave geo-technological fabric for strengthening embankment

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ABSTRACT: For the special thin layer structure and good mechanics properties, non-weave geo-technological fabric is widely used for strengthening of the road drainage and reinforcement etc. However during the manufacture process, it has got initial damage and the resulting high porosity that will worsen the mechanics properties by acupuncture craft. So the Damage Mechanics theory is adopted to study its mechanics property. The method for calculation of elastic-plastic damage variables and evolution equation, Damage strain function equation, Damage constitutive equation and Damage coefficient under the one-axial tensile stress is given in present paper. The agreement between the numerical result and the experimental result is good.

1 INTRODUCTION

Damage mechanics is a new subject that focuses on the research of the micro-deficiency in the material and its effect on the mechanics properties during the further development, which is developed very fast in recent years. The definition of the damage is the strength decrease resulted from the micro-deficiency in the material. The final stage of the damage is the macro rupture of the material. The reasons for damage are listed as following: (1) Initial damage by its micro porosity or the manufacture process. (2) Elastic-plastic damage by large stress deformation under the still loads. (3) Damage by the circulation loads. (4) Creep damage by the constant load. (5) Multi-damages or manufacture damage.

The damage is not an independent physical phenomenon. It is the complicated one, and develops with the increase of tensile stress. When the increase of the tensile is negative (Unload), the damage will stop development. Non weave geo-technological fabric is a continuous medium made of fabric. Although acupuncture craft technology can increase its tensile strength, it also brings the damage during the process. And the damage can develop with the following load acting on it. In addition, there is no yielding stage in the strain-stress relation curve for the non-weave geo-technological fabric in the test. So it is possible for us to use the damage mechanics to calculate it. Also the non weave geo-technological fabric has a lot of advantage. In present paper, based on the test data under uniaxial stress for non weave geo-technological fabric, we present a method for calculating the elastic-plastic damage.

2 METHODS FOR CALCULATING ELASTIC-PLASTIC DAMAGE

2.1 *Damage variables and its evolution equations*

Basically non-weave geo-technological fabric is treated as the homogenous material, so its damage can be treated as homogenous. Under the assumption of the small change for elastic module during damage, the equation can be obtained from the balance equation and iso-effect stress assumption as following:

$$D = 1 - (E_i/E_o) \quad (1)$$

$$E_i = (1 - D)E_o \quad (2)$$

where E_o is initial elastic module, E_i is elastic module during the damage. It decreases with the increase of the load. (D can increase but is smaller than 1).

The figures for the tensile strain (kN/5 cm) and stress (%) relation curve under uni-axial load or circulation load are given in Figure1 and Figure 2 respectively.

(1) In Figure 1 and Figure 2, the curve is nonlinear. The curve of unload and that of load is not the same. Their mean slope is defined as damage elastic module E_i, which is smaller than the original one E_o.

(2) The elastic strain ε_2^e when unload is bigger

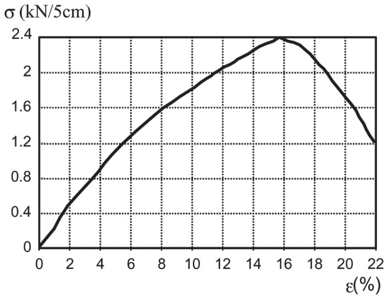

Figure 1. Uni-axial load tensile curve.

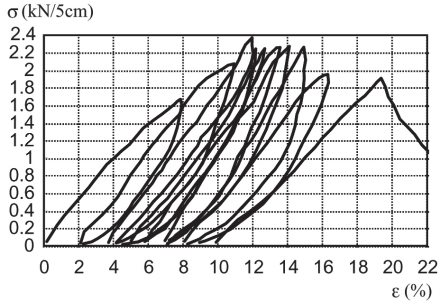

Figure 2. Circulation load tensile curve.

than the elastic strain ε_1^e by using of E_o. From this, we can see that E_i is changed to be smaller comparing with E_o when the damage is going on and ε_2^e is changed to bigger comparing with ε_1^e. There must have some relation. To illustrate the relation, Figure 3 is given.

In Figure 3, E_{si} is secant module of mono-load curve at A point. E_{ti} is tangent line module at A point. The relations in Figure 3 are listed as following:

$$\varepsilon = \varepsilon_1^e + \varepsilon_1^p = \varepsilon_2^e + \varepsilon_2^p \tag{3}$$

$$\sigma = E_0 \varepsilon_1^e = E_i \varepsilon_2^e = E_{si} \varepsilon \tag{4}$$

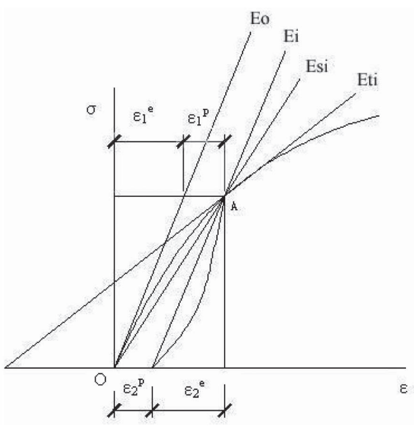

Figure 3. The relation of σ and ε.

Where: σ and ε are tensile stress and strain at A point. From Eq s (1), (3) and (4), we can obtain:

$$D = (E_o - E_i)/E_o = (\varepsilon_2^e - \varepsilon_1^e)/\varepsilon_2^e = (\varepsilon_1^p - \varepsilon_2^p)/\varepsilon_2^e \tag{5}$$

Damage variable is defined as:

$$\varepsilon_f = \varepsilon_1^p - \varepsilon_2^p = \varepsilon_2^e - \varepsilon_1^e \tag{6}$$

with $\varepsilon_2^e = \varepsilon_1^e + \varepsilon_f$ (7)

We can obtain

$$D = \varepsilon_f / \varepsilon_2^e \tag{8}$$

From the relations above, (a) when stress σ becomes larger, strain (ε_1^e and ε_1^p or ε_2^e and ε_2^p) will be larger. Only when damage strain (ε_f) appears and becomes larger, the changing value of ε_2^e is bigger than the changing value of ε_1^e. And E_i will be smaller than E_o and the damage variable (D) increases continuously. (b) Damage strain ε_f is in the un-recovery plastic strain, which is expressed in formula (6). From formula (7), we can see that ε_f results in the decrease of E_i, i.e, the effect of increase of D.

To compute the value of ε_f, we can obtain the following equations according to the curve of damage strain (ε_f) and relatively stress (σ/σ_u):

$$\varepsilon_f \times 10^2 = c \exp\,[d(\sigma/\sigma_u)] \tag{9}$$

where σ_u is peak stress (N/5 cm). The constant parameter c and d can be obtained by optimization. However, the correlated coefficient γ should meet the basic requirement.

From (1) and (4), we can obtain the following equations.

$$\sigma = (1 - D) = E_o / \varepsilon_2^e \tag{10}$$

2.2 *Calculation of elastic module*

From Figure 1 or Figure 3, we can obtain

$$\sigma = \varepsilon/(a + b\varepsilon) \tag{11}$$

where a and b are constant parameters.

$$E_{si} = \sigma/\varepsilon = 1/(a + b\varepsilon) \tag{12}$$

$$E_{ti} = d\sigma/d\varepsilon = (1 - \sigma b)^2/a = a/(a + b\varepsilon)^2 \tag{13}$$

From the above, we can see that when ε is closer to zero, $E_{ti} = 1/a$ is closer to E_o, that is:

$$E_o = 1/a = (E_{si})^2/E_{ti} \tag{14}$$

$$D = 1 - E_i/E_o = 1 - E_i E_{ti}/(E_{si})^2 \tag{15}$$

2.3 *Method for determining damage degree*

K is damage degree coefficient, and K is:

$$K = 1 - E_{ti}/E_o \tag{16}$$

At original point: $E_{ti} = E_o$ and $K = 0$. At peak point: $K_{ti} = 0$ and $K = 1$. So K varies from zero to one.

From equations (12) and (13), we can obtain

$$E_{ti}/E_o = (1 - \sigma b)^2 \quad (17)$$

$$\text{Or } E_{ti}/E_o = [a/(a + b\varepsilon)]^2 \quad (18)$$

Substituting into (17), we can get

$$K = 1 - (1 - \sigma b)^2 \quad (19)$$

$$\text{Or } K = 1 - [a/(a + b\varepsilon)]^2 \quad (20)$$

2.4 *Damage constitute equations*

From equations (3), (4) and (6), we have:

$$\varepsilon = \varepsilon_2^p + \sigma/[E_o(1 - D)] \quad (21)$$

The difference is plastic strain (ε_2^p) and the damage variable (D).

3 EXAMPLE

In some real engineering of road foundation, experiment was carried out on the non-weave geo-technological under the uni-load and uni-unloaded tensile stress. Curves are given in Figure 1 and Figure 2. From the Figures, we can have $a = 3.646 \times 10^{-5}$ and $b = 1.79 \times 10^{-4}$, and the correlated coefficient $\gamma = 0.998$, Also $c = 0.2$, $d = 3.44$, the correlated coefficient $\gamma = 0.97$ is obtained. Peak stress $\sigma_u = 2402.3$ (N/5 cm) and peak strain $\varepsilon_u = 16\%$ is used.

When $\varepsilon = 5\%$, $\sigma = 1103.6$ (N/5 cm) in Figure 1., we can have the following process:

From (14): $E_o = 27426$ (N/5 cm).

From (13): $E_{ti} = 17661.4$ (N/5 cm).

From (12): $E_{si} = 22021.6$ (N/5 cm).

From formula (4): $\varepsilon_1^e = 4\%$, and $\varepsilon_1^p = \varepsilon - \varepsilon_1^e = 5\% - 4\% = 1\%$.

From formula (9): $\varepsilon_f = 0.97\%$.

From formula (6): $\varepsilon_2^p = 0.03\%$, we can see it is much larger.

From formula (7): $\varepsilon_2^e = 4.97\%$.

From (8): $D = 0.2$.

Finally from (16) we can get the damage degree coefficient $K = 0.36$, which can not be ignored. When put $\sigma = 1103.6$ (N/5 cm) into formula (19), we can obtain the strain $\varepsilon = 0.0499 \approx 0.05$,which is the same as the experimental data that we carried out.

4 CONCLUSIONS

(1) In the computation of permitting tensile strength of the materials in real engineering, damage by initial manufacture process and larger strain is not considered. The present paper proposes a method of considering such damage, which can be a revalue references for the computations.

(2) The main reason for damage is the high porous net structure in non-weave geo-technological fabric. For further study, the method in the two papers in references can be used.

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