Geosynthetics Asia'97, 26–29 November, Bangalore, India

DEFORMATION OF NON-WOVEN FABRIC UNDER GROUND

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ABSTRACT

To examine the tensile strength of the non-woven fabric put under ground, tensile tests of the non-woven fabric that confined lateral deformation were conducted. As a result, the tensile strength which is produced by confining lateral contraction increased about 15% in comparison with the non-confined non-woven fabric. The rate of increase could be explained by the Poisson's ratios. These results are useful to estimate the design strength of non-woven fabrics. As the next step, when pull out force act on non-woven fabrics, tensile strength distributions that will produce on the non-woven fabric were analyzed by mechanical models and in this case experiments were also carried out. As a result, the trend of the tensile strength distributions by analyzing agreed approximately with experimental result. It can be expected that this analytical method is useful for estimating the deformations of reinforced soil structure.

1. INTRODUCTION

An unified view about the design strength of non-woven fabric has yet to be reached. To clarify this, a laboratory tensile test and analytic mechanics were performed. As a result, tensile strength which was confined the lateral face increased about 15% when compared with non confined non-woven fabric. The rate of increase could be explained by the Poisson's ratios.

However, the tensile strength was less than what was estimated by the slope failure test (Joint technical report 1987, 1988).

As the first step in solving this problem, a laboratory pull out test was carried out. The stress distribution produced on the non-woven fabric using a mechanical model was also examined. The trend of the tensile stress distribution by analyzing agreed approximately with the experimental results.

2. EXPERIMENTAL PROCEDURES

A spun-bonded (needle-punched) 100% polypropylene non-woven fabric was used in this experiment. Dimension of specimen used for tensile tests were 5 cm in length 5 cm in width and 3 mm in thickness. Density of non-woven fabric was 0.3 g/cm^3. Tensile tests, shown in Figure 1, were carried out at a strain rate of 2%/min.

As the next step, the pull out tests shown to Figure 2 were conducted. Dimensions of the specimen used for this experiment were 50 cm in length and 10 cm in width. Pull out rate was 1 mm/min. Furthermore, to examine the composite of sand and non-woven fabric, the deformation of sand near non-woven fabric was measured by using magnetic force and hole sensor (Figure 3).

Dimension of the hole sensors were 2 mm in length, 2 mm in width, and 1 mm in thickness.

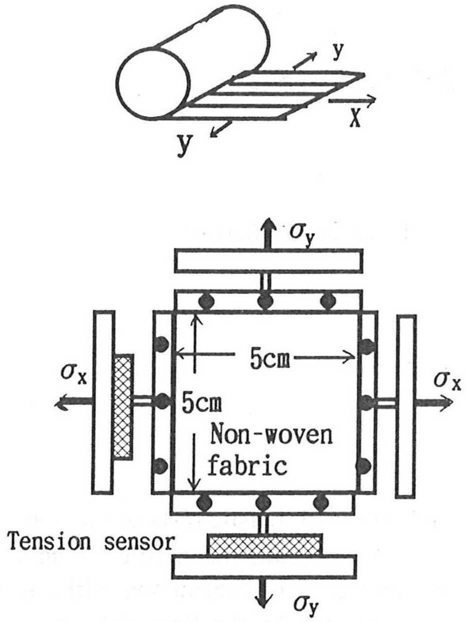

Figure 1: Tensile Testing Device

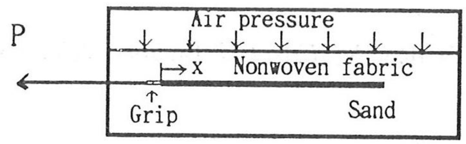

Figure 2: Arrangement of Equipment for Laboratory Pull Out Test

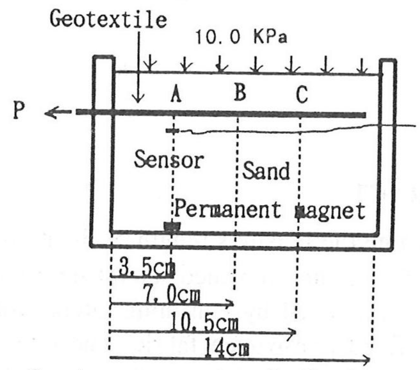

Figure 3: Arrangement of Equipment for Measuring Sand Deformation

3. TENSILE STRENGTH OF NON-WOVEN FABRIC WHICH WAS CONFINED BY LATERAL FACING

When pull out force acts on non-woven fabric laid under ground, the lateral contraction will not be developed because the lateral contraction was confined by the friction between the non-woven fabric and soil. It is generally accepted that the strength of the materials which was confined the sides increased when compared with non-confined materials. Therefore, tensile strength under the same condition is believed about the non-woven fabric laid under the ground too. Accordingly, concerning non-woven fabric, it is necessary to clarify tensile strength regarding condition mentioned above. Until now, similar studies have been carried out by researchers. However, these studies have not been performed as analytic purpose (Tatsuoka et al., 1985, Yamaoka et al., 1985 Miki et al., 1988).

A formula of stress-strain concerning anisotropic elastic materials is shown as follows (Stephen, 1980):

$$\varepsilon_x = \sigma_x \frac{1}{E_x} - \sigma_y \frac{\nu_y}{E_y} \quad \text{....} \quad (1)$$

$$\varepsilon_y = \sigma_y \frac{1}{E_y} - \sigma_x \frac{\nu_x}{E_x} \quad \text{....} \quad (2)$$

ε_x, ε_y: strain, σ_x, σ_y: stress

E_x, E_y: elastic coefficient

ν_x, ν_y : Poisson's ratio

The strain (ε_{xo}) which was confined lateral face and the strain (ε_x) which was unconfined were can be expressed as follows:

$$\varepsilon_x = \frac{1}{E_x}\sigma_y \quad \text{.... (3)}$$

$$\varepsilon_{x0} = \frac{\sigma_x}{E_x} - \frac{\nu_y}{E_y}\sigma_y \quad \text{.... (4)}$$

From Eq. (2), the relationship between the stress of lateral axis (Y axis) and tensile axis (X axis) for $\varepsilon_y = 0$ is expressed as follows:

$$\frac{\nu_x}{E_x}\sigma_x = \frac{1}{E_y}\sigma_y \quad \text{.... (5)}$$

Equation (4) is divided by Eq. (3) and when substituted Eq. (5) to it, this new equation can be expressed as follows:

$$\frac{\varepsilon_{xo}}{\varepsilon_x} = 1 - \nu_x\ \nu_y \quad \text{.... (6)}$$

Equation (6) express a strain ratio of non-woven fabric confined the lateral face to non-confined non-woven fabric. The strain rate is controlled by the Poisson's ratio. By putting the actual Poisson's ratio ($\nu_x = 0.5$, $\nu_y = 0.26$) of a non-woven fabric used for this experiment. Eq. (6) is capable of obtaining 0.875. As a consequence, non-woven fabric which was confined to the lateral face decrease by about a 13% in strain when compared with non-confined non-woven fabric. Tensile strength also increase 15% when compared with non-confined non-woven fabric.

This tensile strength agreed with experimental values which were obtained by tensile testing shown in Figure 1. However, this tensile strength was less than what was estimated by the slope failure test (Joint technical report, P.W.R.I. Ministry of Construction, 1987, 1988). As a result, it is indicated that it needs to be studied as a composite material of sand and non-woven fabric.

4. DEFORMATION OF SAND CONTACTING NON-WOVEN FABRIC

Concerning the deformation problem of non-woven fabric laid under the ground, there are deformations of non-woven itself and soil near the non-woven fabric. It is important to know the deformation of soil because it considers to affect the resistance force between sand and non-woven fabric that resist pull out force. However, it is very difficult to measured the deformation of soil near a non-woven fabric. There has been little research in this area. Then, we have carried out research using magnetic force and the hole sensor shown in Figure 3 that developed as new equipment, the deformation of soil measured by hole sensor. Figure 4 shows a result obtained by this method.

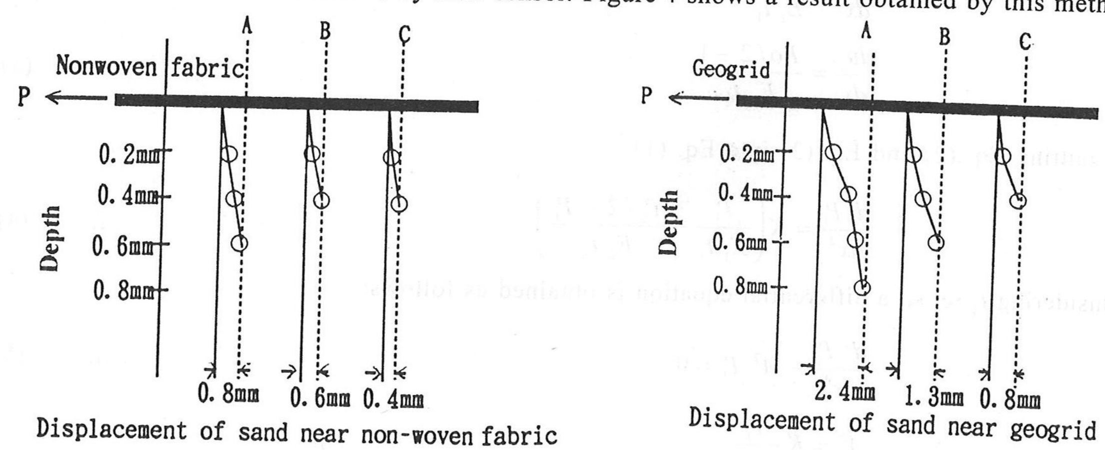

Figure 4: Deformation of Sand Near Geotextile

The soil used in this experiment is sand. As shown in this figure, it is indicated for the resistance to pull out force to have to consider as composite strength of sand and non-woven fabric.

5. MECHANICAL MODEL BETWEEN THE NON-WOVEN FABRIC AND SOIL

As the first step, to study the composition of sand and non-woven fabric, by a mechanical model as shown in Figure 5, the distribution of tensile stress on the non-woven fabric was estimated. The evident theory about non-woven fabric in particular has not been proved until now. Studies concerning geosynthetics deformation have been performed by Imaizumi (1995) and Takahasi (1996). However, their studies are different from mechanical model in this study because considering constant shear strength on geosynthetics.

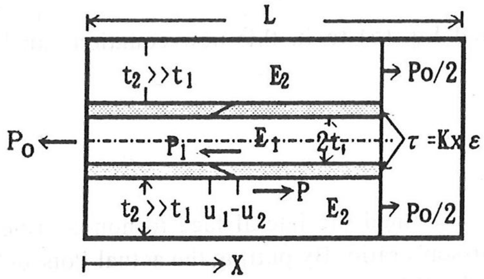

Figure 5: Mechanical Model for Analyzing Distribution of Tensile Strength

E : **Young's Modulus**
ε : **Strain**
P_0 : **Pull Out Force**
t : **Thickness**
L : **Plate Length**
K : **Coefficient**
τ : **Shear Strength**

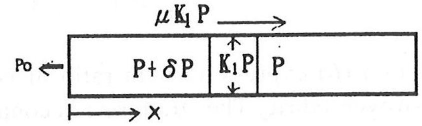

Figure 6: Mechanical Model for Analyzing Distribution of Tensile Strength

P_0 : **Pull Out Force**
P : **Tensile Strength**
μ : **Coefficient of Friction**
K_1 : **Coefficient**

From the equilibrium condition, the tensile strength is shown as follows (refer Figure 5):

$$\frac{d\tau}{dx} = K\left(\frac{du_1}{dx} - \frac{du_2}{dx}\right) \qquad \text{.... (1)}$$

From Hoek's law of elasticity

$$\frac{du_1}{dx} = \frac{P_1}{E_1\, t_1} \qquad \text{.... (2)}$$

$$\frac{du_2}{dx} = \frac{Po/2 - 1}{E_2\, t_2} \qquad \text{.... (3)}$$

By putting Eq. (2) and Eq. (3) into Eq. (1)

$$\frac{d^2 P_1}{dx^2} = K\left(\frac{P_1}{E_1\, t_1} - \frac{P_0/2 - P_1}{E_2\, t_2}\right) \qquad \text{.... (4)}$$

Considering $t_1 << t_2$, a differential equation is obtained as follows:

$$\frac{d^2 P_1}{dx^2} - A^2\, P_1 = 0 \qquad \text{.... (5)}$$

$$A^2 = K\frac{P_1}{E_1\, t_1}$$

Solving Eq. (5) with the boundary conditions of $P_1 = P_0$ at $X = 0$, $P_1 = 0$ at $X = L$

$$P_1 = \frac{P_0 / 2 \sinh AL\left(1 - X/L\right)}{\sinh(AL)} \qquad \cdots\cdots \qquad (6)$$

Considering both surfaces of non-woven fabric.

$$P = \frac{P_0 \sinh AL\left(1 - X/L\right)}{\sinh(AL)} \qquad \cdots\cdots \qquad (7)$$

P: tensile strength on plate

Equation (6) is able to evaluate the tensile strength distribution on the plate laid under the ground. A similar idea is also used single-lap adhesive joint by Kawata (1976). Furthermore, by other a mechanical model as shown Figure 6, we examine the distribution of tensile stress on the non-woven fabric. Differential equation is expressed as follows (refer Figure 6)

$$-dPt = 2K_1 \mu P dx \qquad \cdots\cdots \qquad (8)$$

solving with the boundary conditions of

$$X = 0 \quad P = P_0, \quad X = L \quad P = 0$$

$$P = P_0\, e^{-2k_1 \mu L (X/L)/t} \qquad \cdots\cdots \qquad (9)$$

P: tensile strength on plate

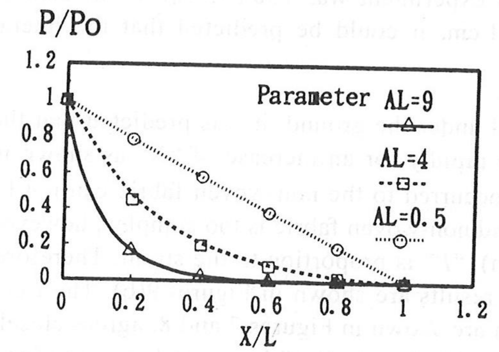

Figure 7: P/P_0 with X/L Shown in Terms of Parameters AL

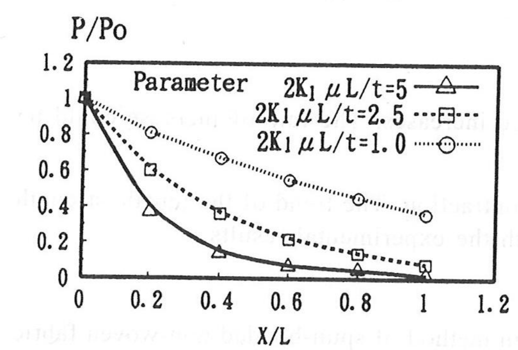

Figure 8: P/P_0 with X/L Shown in Terms of Parameters $2\mu K_1 L/t$

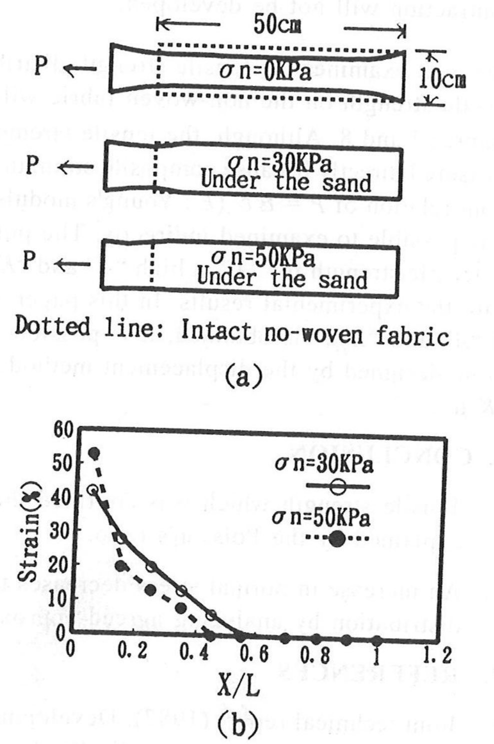

Figure 9: Deformation of Non-woven Fabric Under Sand.

Equation (8) is simple in compare with Eq. (6) because don't considering "E_l". At first, we examine Eq. (6). "P" with "x" are shown in Figure 7 in terms of parameter "AL". As parameter "AL" is large, an increase in "x" decreases rapidly "P/P_0". While "P/P_0" shown approximately constant slope for "x" as parameter "AL" is small.

From this result, it can be predicted that the tensile strength on non-woven fabric which "E_l" is much small than metal decrease rapidly for an increase in "x". Similar result has been obtained by laboratory test by Teachavorasinskun (1997). However, analytic mechanics has not been performed.

Next we examine Eq. (8) "P/P_0" with "x" is shown in Figure 8 in terms of parameter $2k_1 \mu L/t$. As seen in this figure, we can see similar trending to the result shown in Figure 7. To confirm these results shown in Figures 7 and 8, a laboratory pull out test of the non-woven fabric laid under the ground was carried out. The next chapter will show the results.

6. DEFORMATION OF NON-WOVEN FABRIC UNDER THE SAND

To examine the deformation of a non-woven fabric laid under the ground, a laboratory pull out test as shown in Figure 2 was carried out. A pull out displacement was about 10 cm. After a pull out force was carried out, the deformation of the non-woven fabric was measured.

The test results are shown in Figure 9(a) and (b). Figure 9(a) shows the lateral contraction of the non-woven fabric. As shown in this figure, an increase in normal stress decreases the lateral contraction.

From these results, it could be predicted that the lateral contraction will not be developed as the lateral contracted strength is equal to the friction on the upper and lower surfaces of non-woven fabric.

The lateral strength of non-woven fabric used for this experiment was 150 N/5 cm. If the sum of the friction on non-woven fabric is more than 50 N/1 cm, it could be predicted that the lateral contraction will not be developed.

The next examines the tensile strength distribution laid under the ground, it was predicted that the tensile strength on the non-woven fabric will decrease rapidly for an increase of "X" as shown in Figures 7 and 8. Although, the tensile strength which occurred to the non-woven fabric can not be measured directly because composite strength of sand and non-woven fabric is too complex, however, from relation of $P = E\varepsilon$ (E : Young's moduls, ε : strain). "P" is proportion to the strain. Therefore, it is possible to examined indirectly. The pull out test results are shown in Figures 9(b). The trend of tensile strength for "X" at high "A" and "$K_l\mu$" which are shown in Figures 7 and 8, agrees closely with the experimental results. In this paper, the values of "A" and "$K_l\mu$" have not been examined. If "A" and "$K_l\mu$" is obtained, it is possible for the reinforced structures by the non-woven fabric to be designed by the displacement method. Now, we are carrying out research to decide "A" and "$K_l\mu$".

6. CONCLUSION

1. Tensile strength which was confined the lateral face increases. The rate of increase could be explained by the Poisson's ratio.
2. An increase in normal stress decreases the lateral contraction. The trend of the tensile strength distribution by analyzing agreed approximately with the experimental results.

7. REFERENCES

1. Joint technical report (1987): Development of design method of spun-bonded non-woven fabric reinforced embankment, Public Works Research Institute, Ministry of Construction, pp79–97, Japan.

2. Joint Technical Report (1988): Stability analysis of embankments and earth retaining wall reinforced by spun bonded non-woven fabric, P.W.R.I. Ministry of Construction, pp77–103, Japan.
3. Stephen W. Tsai, H Thomas Hahn (1980): Introduction to composite materials, Technomic Publishing.
4. Tatsuoka F., Andou H., Iwasaki K., Nakamura K. (1985): Reinforcing of cohesive-soil-embankment with non-woven fabric. In: JSSMFE, Vol 33, No. 5, pp.15–20.
5. Tatsuoka F., Kondo K., Miki G., Haihara O., Hamada H., Sato G., (1983): Fundamental study on tensile-reinforcing of sand. In: JSSMFC, Vol. 31, No. 9, pp.11–19.
6. Yamaoka I., Tnaka S., Nisigata T., (1985): The methods and evaluation of geotextile. In: Proc. 30th Soil Engineering Symposium, JSSMFC, pp.87–92.
7. Miki H., Hayasi Y., Nagano Y., Yamada K., Nakano M., Takasago T., Takahasi S., Shido H. (1988): Investigation on Tensile Test Methods for Geotextiles, In: Proc. 3d. Geotextile Symposium, Japan chapter IGS, pp.92–98.
8. Teachavorasinskun S., Pongvithayapanu P. (1997): Effect of Load Transferring Mechanisms on the Analytical Results of the Reinforce Ground. In: Inter. Conf. on Ground Improvement Techniques, pp.561–566.
9. Imaizumi S., Takahasi S., Yokoyama Y., Nshigata T. (1995): Evaluation of pull-out behaviour of HDPE geomembrane embedded in sand, J. Geotech. Eng., JSCE, 1995-3 No. 551, 3-30, pp.155–162.
10. Takahashi, Imaizumi S., Yokoyama Y., Tsuboi M. (1996): Methodology of evaluating a frictional coefficient and a deformation modulus based on geosynthetics pull-out tests, j. Geotech. Eng., JSCE, 1996-3 No. 535, pp.3–34.
11. Kwada K. (1976): Shearing fracture of single-lap adhesive joint Trans. JSCM, vol. 2, No. 1, pp.26–29.