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An application of non woven fabrics to embankment of cohesive soil

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ABSTRACT: For recent years, geotextiles have been used to increase the stability of embankments and other earth works. The authors tried to apply non-woven fabrics to a fill slope of cohesive soil which is about 20 m in height and comfirmed that the following effects should be included in the design of relevant earth works; ① to accelerate consolidation so as to increase shearing strength of the embankment during construction. ② to reinforce the fill slope with tensile strength of non-woven fabrics. A conventional slip circular method was employed taking into account both effects as above mentioned in the stability analysis of the fill slope. Tensile strength of non-woven fabric used for the slope stability analysis could be obtained from a series of tensile tests which were devised to reduce influence of necking for test specimens.

1. INTRODUCTION

This paper deals with a fill slope for the improvement of Ashigara parking area of Tomei expressway as shown in Fig. 1. It is located about 80 km west of Tokyo. Fine-grained volcanic ash soil of which origin is Mt.Fuji is distributed widely in this area. This soil is identified as "loam" in Japan and has high water content Fig. 2 shows a typical cross section of the site of Ashigara parking area. There is a soft layer of volcanic ash soil "Flm" on the stiff layer of mud-flow "Fmf" and the embankment was planned to be filled by using excavated very soft loam material about 20 m height on the "Flm" layer. As shown in Fig. 2, the embanking site was limited in a narrow area due to the existing railway at the toe of this slope, and the minimum inclination of this slope should have been kept at 1 : 1.8. Therefore, this fill slope was considered to be less stable without any soil stabilization. In order to increase the slope stability, the authors employed non-woven fabrics to be placed horizontally in the embankment for an effective countermeasure.

There are not many examples of fabrics used like this. It may be worth describing an approach to use them for the reinforcement of inclined slope.

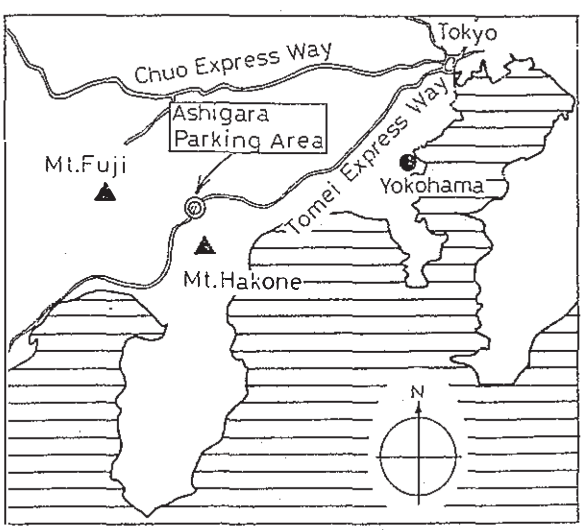


Fig. 1 Location of the Embankment

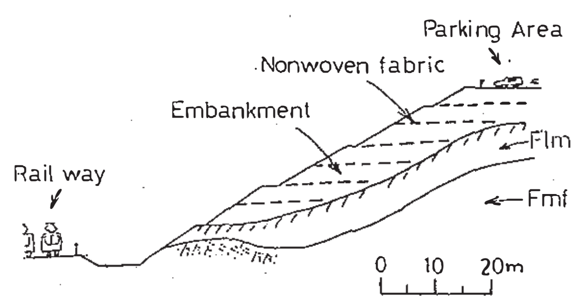


Fig. 2 A Typical Cross Section of the Embankment

2.CONCEPT OF REINFORCEMENT OF FILL SLOPE

Since water content and degree of saturation of "loam" are considerably high, self weight consolidation is occurred during and after the embankment. Therefore, the safety factor of slope can be smallest immediately after the embankment. It gradually becomes larger with the progress of consolidation and the incerase of shearing strength. In general horizontal drainage is provided in the embankment. The role of drainage is, among others, to dissipate excess pore water pressure of the embankment during construction and to drain water fed by the rain or ground after construction. For recent years, non-woven fabrics have been used for drainage in many cases (Yamanouchi, 1985). Comparing with other geotextiles such as polymer grid,non-woven fabrics generally have high permeability, low tensile strength and large strain at rupture. Therefore, the strength of non-woven fabrics has not been included in the design of fill slope in Japan. However, the recent study with model tests of reinforced embankment using non-woven fabrics manifested that the effect of reinforcement is very large(Tatsuoka et al., 1985). Non-woven fabrics may be used for reinforcement of a fill slope. Up to now, there has been no acceptable method to evaluate the strength of non-woven fabrics for the design of fill slope of cohesive soil.

3.STABILITY ANALYSIS OF FILL SLOPE

For this project, the authors employed a conventional slip ciecle method. It can include the effects of consolidation and reinforcement, i.e. tensile strength by non-woven fabrics for analyzing the stability of fill slope. The tensile strength of non-woven fabrics used for the analysis is given in the next section.

First, increase of strength by consolidation is considered. Initial and final effective stresses in the embankment may be defined as follows;

- P_0 -- effective stress immediately after compaction (which can be obtained from e~logp relationship)
- P_f -- effective stress after the completion of embanking (which can be obtained from overburden pressure)

The result of Cu-test of compacted loam is obtained as shown in Fig. 3. Accordingly, the shearing strength on the sliding surface of the fill slope at its completion is given by the following equation;

$$\tau = C_0 + \{P_0 + U(P_f - P_0)\}(C/P) \text{--(1)}$$

Where U is a degree of consolidation and (C/P) is a rate of strength increase. It can be assumed that P_0 is equal zero because P_0 is generally very small. Then, equation (1) can be reduced as follows

$$\tau = C_0 + U\ P_f\ (C/P) \text{ ------------(2)}$$

Where consolidation pressure is assumed to be effective overburden pressure of slice for simplification of calculation. Therefore strength increase of banked material due to consolidation can be taken into account in the stability analysis of fill slope. The shearing strength on slip circle is calculated from applied effective overburden pressure by using equation (2). It is possible to control the strength increase by changing the pitch of holizontal drains.

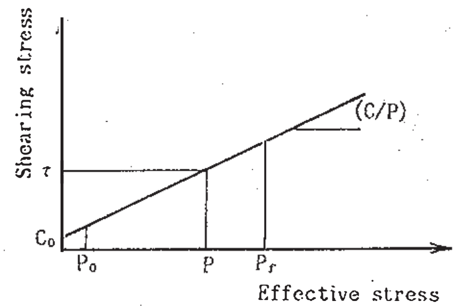


Fig. 3 $\sigma \sim \tau$ curve of CU-test

Next, the effect of reinforcement of non-woven fabrics is discussed hereunder. The effect of reinforcement can be modeled as shown in fig. 4 (a)~(c). Safety factor by slip circle method is given as below (Nagao et al., 1987).

$$Fs = \frac{Mr + \Delta Mr}{Md} = \frac{\sum R\ l\ \tau}{\sum R\ W \sin\phi} + \frac{\sum R\ (S\cos(\theta-\alpha) + S\sin(\theta-\alpha)\ U\ (C/P))}{\sum R\ W \sin\phi} \text{ -------- (3)}$$

Where the second term represents the increase of safety factor by reinforcement of geofabrics. Notations in the equation are as follows.

- τ : shearing strength
- U : degree of consolidation
- Fs : safety factor
- Mr : resisting moment
- ΔMr: added resisting moment by geofabrics
- Md : driving moment
- R : radius of slip circle
- l : width of a slice
- W : weight of a slice

θ : angle between horizontal plane and tangential plane of slip circle

α : angle between holizontal plane and plane of geotextile

S : mobilized tensile strength of geofabrics

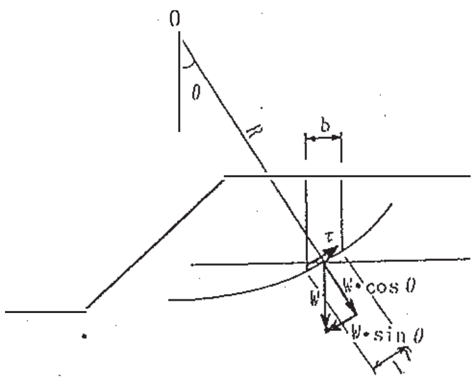
$$S \leqq Min[\ T,\ T_A\ ,T_R\ ]$$

where

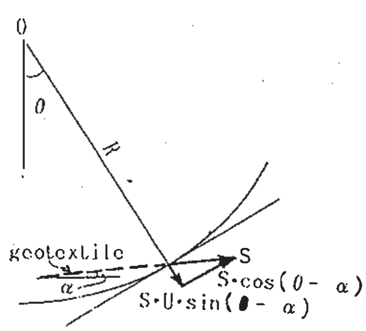
T :tensile strength of geofabrics(tf/m)

T_A :pull-out registance of geofabrics (tf/m)

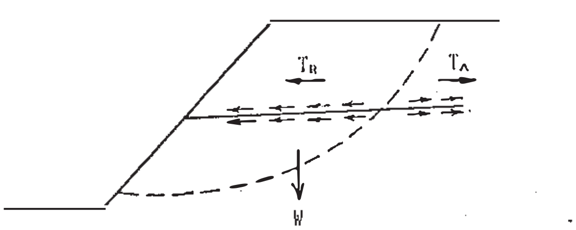
T_R :earth retaining ability(tf/m)



(a) Acting Stresses at a Slice



(b) Mobilized Tensile Strength of Geotextile on Slip Surface



(c) Tensile Stress Induced on Geotextile in Embankment

Fig.4 Geotextile Reinforced Embankment

4. TENSILE TEST OF NONWOVEN FABRICS

There are many kinds of non-woven fabrics and they are classified to several types by materials and manufacturing processes. It is generally recognized that permeability and tensile strength for each kind of fabrics are very different. A series of extention tests that were devised to decrease the effect of necking were carried out to obtain strengths of geotextils for design and to compare ones of various non-woven fabrics under the same test condition.

TEST METHODS

Tensile tests on non-woven fabrics have been, in many cases, carried out using relatively narrow strip. In such tensile tests, necking develops entirely (Veldhuijzen van Zanten et al., 1986). Using non-woven fabrics, the necking has been hardly occurred in reinforced soil layers. Some testing methods have been devised recently which can reduce the necking to a large extent. Among these, the authors carried out the cylindrical tensile test proposed by Tatsuoka et al.(1985) and the wide width tensile test.

a) The cylindrical tensile test

A specimen 15cm × 35cm in size was stitched cylindrically by using cotton thread and was set up in the apparatus. Then specimen was fixed on the pedestals by wire and metal strips. The actual tensile length of specimen between the upper and the lower pedestals was 4 cm. See Photo. 1.

b) The wide width tensile test

Since the cylindrical tensile test described above could not be applied at high level of loading, the wide width tensile test also was employed which could reduce the necking to a large extent using relatively wide strip(10cm × 30cm). The apparatus is shown in Photo. 2.

TEST PROGRAMA

A series of tensile tests were carried out using several kinds of non-woven fabrics. Materials and manufacturing processes are different. Table 1 shows the test program and summary of the test results. Though geofabrics are generally wet in the soil layers, tensile tests were carried out not only on dry specimens but also on wet ones which were kept in the water for 24 hours for comparison. In Table 1, materials A to G were tested with the cylindrical apparatus, F to I with the wide width apparatus.

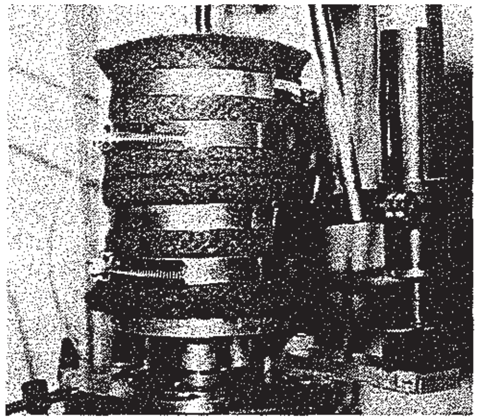


Photo. 1 Cylindrical Tensile Test

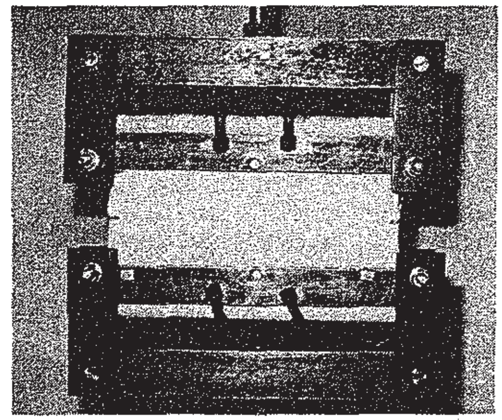


Photo. 2 Wide Width Tensile Test

TEST RESULTS

Fig. 5 shows load-elongation curves of the cylindrical tensile tests, and results of the wide width tests are given in Fig. 6. Since a kind of adhesive agent was used for bondage of fabrics in manufacturing process of specimen A, C, E, test results of the dry specimens were different from those of the wet specimens in strength and strain. The test results of other specimens showed similar values in the dry and the wet conditions except specimen A, C and E. Since specimen H and I had reinforcing members inside, their stiffness coefficients were initially very large. Nevertheless, after the reinforcing members were broken, their strengths were decreased a lot. Comparing test results of specimen G and I of which fabric materials were the same, both load-elongation curves became close after the reinforcing members had been broken. Fig. 7 shows the comparison results of cylindrical tests and wide width tests. In the cylindrical tests, peak strengths of F and G were not obtained though load-elongation curves were similar to the results of wide width tests. Therefore it can be concluded that the wide width tests which have enough large width/length ratio can give the same accuracy as the cylindrical tests. Although the range of the tensile strength of non-woven fabrics was very wide at this time, it is found that the strain at ruptuer is very large as common characteristic. Because failure strain of soil is not so large comparing with that of non-woven fabrics, peak strength of geofabrics can not be mobilized in soil layers. Consequently, the strength of geofabrics at failure strain of soil is recommended as the design value.

Table-1 Test Program and Summary of Test Results

	specimen		manufacturing process	thickness (mm)	weight (kgf/m)	tensile strength (kgf/cm) cylindrical dry	cylindrical wet	wide width dry	wide width wet
	A	Polyester	Chemically bonded	3	0.26	5.47	3.23		
	B	Polyolefin	Spun bonded	10	0.70	13.49	12.57		
	C	Palm fiber	Chemically bonded	10	0.55	5.51	2.67		
	D	Polyester	Spun bonded	10	1.00	3.03	3.63		
	E	Polyester	Chemically bonded	10	0.41	4.47	3.99		
	F	Polyester	Needle punched	3.5	0.40	*2 –	–	40.00	38.27
	G	Polypropylene	Spun bonded	4	0.42	–	–	24.39	26.24
*1	H	Polypropylene	Spun bonded	3	0.26			20.19	20.93
	I	Polypropylene	Spun bonded	4	0.40			24.40	23.59

*1 : H & I have reinforcing member inside

*2 : The peak strength of F & G could not be reached by cylindrical tensile test

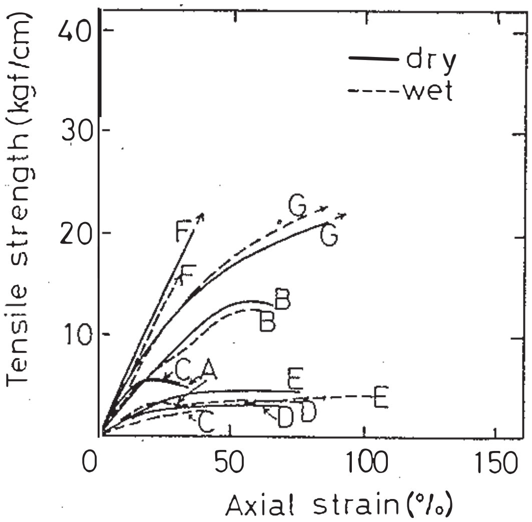


Fig. 5 Test Result of Cylindrical Tensile Test

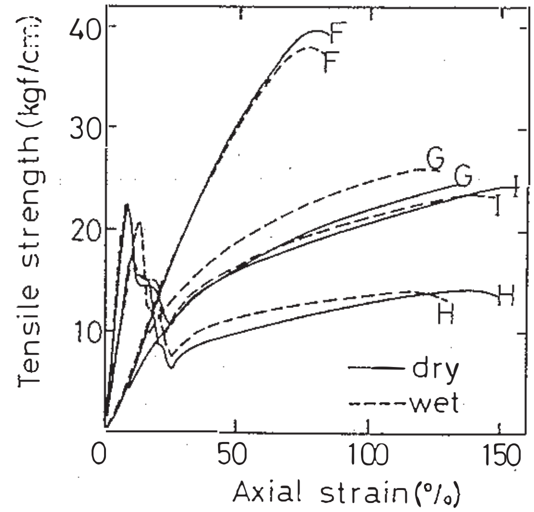


Fig. 6 Test Result of Wide Width Tensile Test

5. APPLICATION TO AN ACTUAL DESIGN

A stability analysis was carried out to examine the effect of reinforcement of non-woven fabrics using equation (3) described in the foregoing section. Fig. 8 shows an example of cross section of the embankment of Ashigara parking area. This embankment will be banked up in two years. The cross section and the banking material cannot be changed because of the restrictions as mentioned previously. The problem for this embankment, therefore, is how to keep the safety factor under the given local conditions; the soil is rather soft and slope inclination is fixed. Two kinds of countermeasures are considered. One is to replace soft soil "loam" with gravel in the toe area of the fill slope. Another is to increase the safety factor by using non-woven fabrics. The embankment material is local soil, "loam". Table-2 shows the properties of the soils used in

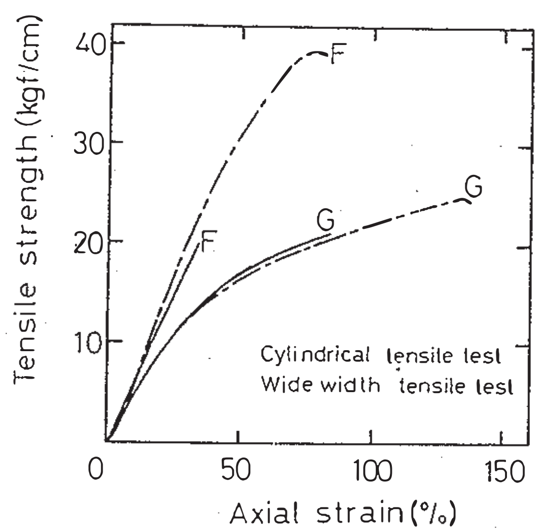


Fig.7 Results of Cylindrical Tensile Test and Wide Width Tensile Test

Table-2 Properties of the soils

Material	Unit Weight t/m³	Strength Parameters	
Embankment	1.42	Co=1.2 t/m²	C/P=0.3
Flm	1.60	Co=1.6	C/P=0.4
Gravel	1.90	Cd=0.5	ϕ_d = 35°

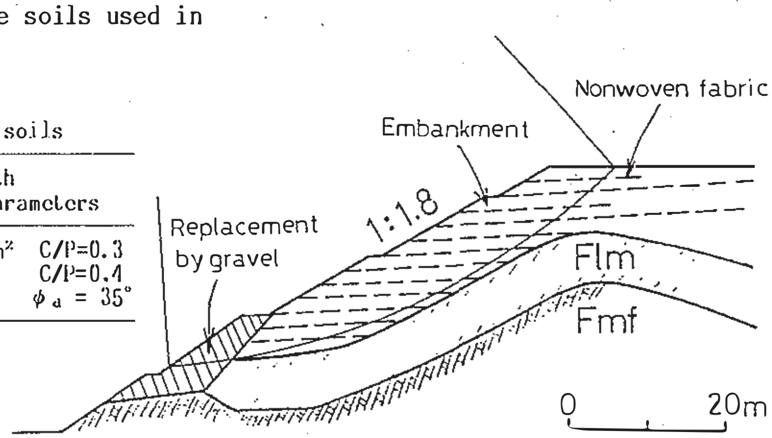


Fig. 8 An Example of Cross Section

the stability analysis. The strength of non-woven fabrics T was determined to be 0.6 t/m from Fig. 6, which is the strength of specimen H, I at 15% strain. (The failure strain of compacted "loam" was assumed to be 15%.) For this case, the effect of reinforcement of non-woven fabrics for safety factor was about 0.05. The embankment is under construction at present settlement, deformation, and pore water pressure are being measured. The authors will report on comparison of measuring results and estimated ones made in this report elsewhere.

6. CONCLUSIONS

① The authers used non-woven fabrics, 1.67m long, to a fill slope of 1 : 1.8 inclination and 20 m in height, then reinforcement effect of non-woven fabrics for slope stability was estimated to increase safety factor about 0.05.

② Since it was found that the effect of reinforcement by non-woven fabrics had significant influence to slope stability, it is supposed that the effect of reinforcement should be included in the design of cohesive-soil-embankments employing non-woven fabrics.

③ The strength of non-woven fabrics used in the design has to be determined by the tensile tests that can reduce the necking such as cylindrical tensile test or wide width tensile test.

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