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In situ study of road reinforced by geotextiles

Etude experimentale de chaussée renforcé par géotextile

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SYNOPSIS: A provisional road was built on soft subsoil for full scale testing of reinforcement by means of non-woven geotextiles. The subbase has one or two layers of fill material with or without geotextiles separating the layers. The results from an extensive series of plate tests have been analysed and a simple method of calculating the reinforcement effect is proposed.

INTRODUCTION

In the last fifteen years geotextiles have been an important facility in road construction, most intensively used in unpaved roads situated on soft subsoils, and to-day there is a wide range of woven or non-woven geotextiles available on the market. They are normally used to prevent the subbase layers from mixing with the subsoil. They are supposed to permit better compaction of fill materials and in rainy periods they function as drains. The users in the field have also observed improvement of the bearing capacity of provisional roads by trial and error, but this is not satisfactorily demonstrated in experiments.

Experiments can be carried out in different ways:

i. Small scale plate loading tests in special test boxes in the laboratory. The subsoil can be any soft material such as remoulded clay or even bark. The advantage is that it is quite easy to control every important parameter and to perform the tests under controlled circumstances. But it is difficult to fulfil model laws to avoid boundary effects and to use undisturbed subsoil. Gourc et al. (1982) reported plate loading tests with static and cyclic loading (number of loadings $N \leq 1000$). Kinney (1982) reported similar tests with $N \leq 100 - 150$.

ii. Plate loading tests with diameters of 30-50 cm, mentioned as full scale tests, have been reported by Sørlie (1977), Resl and Werner (1986).

iii. Wheel loading tests under laboratory conditions. It seems to be the best way to perform tests in the laboratory, but it is rather cumbersome and special equipment must be used to measure what happens when a wheel passes by. Potter and Currer (1981) and Laier and Bräu (1986) has reported tests with 100 – 1000 wheel passes.

iv. In situ full scale tests carried out on a site with optimal soil conditions. The advantages are obvious: Now the conditions are realistic and the soil is undisturbed. But it is difficult to control the water content in the subbase, and the undrained shear strength of the subsoil alters in the test area. Capillary forces increase the bearing capacity of the subbase. This paper deals with that type of testing.

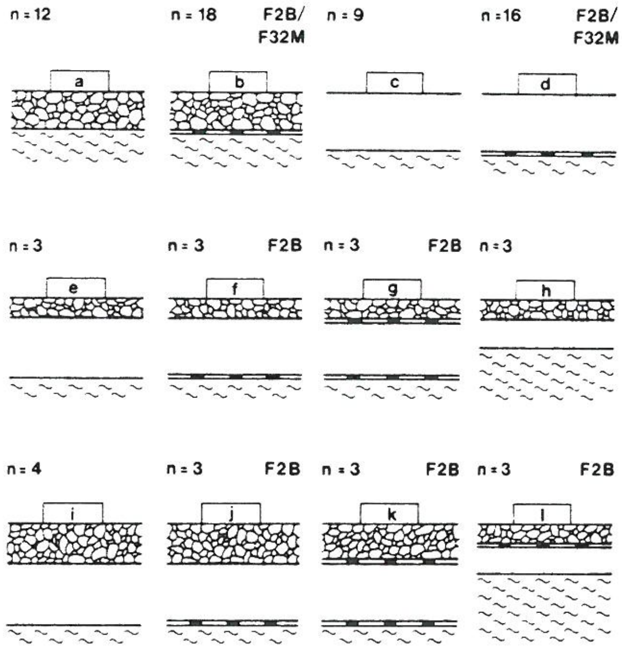

Figure 1. In situ plate loading tests. The total number of tests is $n = 83$. 49 tests are performed on fill reinforced with Fibertex F2B or F32M.

v. Observations on real unpaved roads. The measuring device should be stable for a long period.

IN SITU PLATE LOADING TESTS

A provisional, unpaved road was built on soft subgrade especially for full scale study on the effect of reinforcement when non-woven geotextiles are used. The road was divided into sections with varying constructions as shown in Fig. 1. Fig. 1 also shows the numbers of tests and the use of two types of geotextiles, either F2B or F32M. The total test number seems to be rather big. But it is necessary to estimate the most appropriate values of soil parameters and to repeat each test for statistical reasons.

The subbase was built up of one or two layers of granular material and for each new construction a control area without reinforcement was established. In fact 39 tests were performed as control tests. The reinforcement effect on the bearing capacity of the road and on the creation of ruts during many reloadings could be verified simply by comparing the behaviour of tests in control areas and reinforced areas.

Most of the tests were static plate loading tests with circular plates (diameter of 10, 20, and 30 cm). The traffic load was simulated by alternating loads in 29 tests. Two stress levels for maximum load were applied, corresponding to about 50 per cent and 80 per cent respectively of the static bearing capacity. The number of reloadings was 10 or 30 only. The number is too small, but it gives some information on the dynamic behaviour of the structures.

MATERIAL PROPERTIES

Two different types of fill material were used in the embankment: A sand ($U = 3$) compacted to a void ratio $e = 0.37 - 0.46$ and a sand gravel $U = 10$ compacted to a void ratio $e = 0.21 - 0.27$.

The strength parameters c' and ϕ' depends on the water content in situ and the ground water level. Based on in situ plate loading tests with small circular plates ($D = 10\,cm$) the strength parameters are estimated to be:

Sand: $\phi' = 31 - 37°$; $c' = 8kPa$
Sandy gravel: $\phi' = 38 - 45°$; $c' = 8kPa$

The cohesion c' is caused by capillary forces and is for both fill materials 8 kPa, according to a ground water level 0.5 – 1 m below ground surface.

The subsoil consisted of a postglacial, marine deposit of organic clay. It was originally supposed to be very soft, but the undrained shear strength appeared to be c_u = 50 kPa . The geotextiles used in the experiments were non-woven Fibertex F2B and F32M with needlepunched polypropylen fibres. Therefore, it is very important to measure the mechanical properties in a tensile test, where lateral deformations of the geotextile is prevented.

Fig. 2 shows results from tests with tension P in the transverse direction. The maximum tensile force P_{max} and the tensile stiffness K_{50} corresponding to $\frac{1}{2}P_{max}$ are

Fibertex F32M: $P_{max} = 11kN/m$: $K_{50} = 20kN/m$
Fibertex F2B: $P_{max} = 10kN/m$; $K_{50} = 30kN/m.$

These low strength geotextiles are rather cheap and the use in reinforced road embankment makes up a realistic alternative to a normal road embankment.

The two types have almost the same tensile strength but different tensile stiffness. The tests show that the difference is very important for the reinforcing effect of the geotextile although it is 50% only.

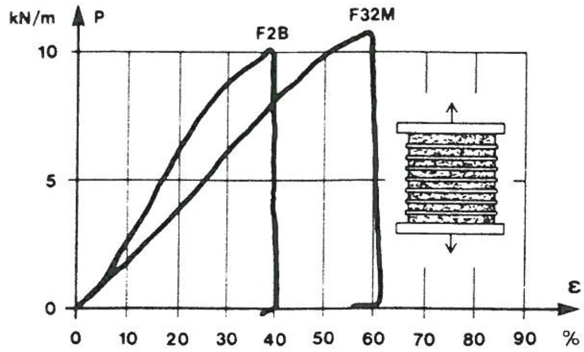

Figure 2. Tension — elongation curves for Fibertex geotextiles.

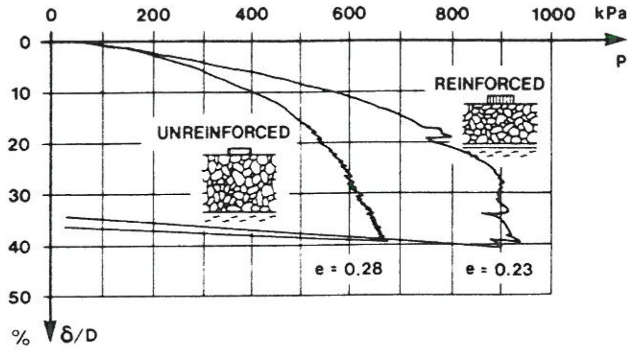

Figure 3. Static plate loading tests ($D = 10\ cm$) from test group a and b. (see also Fig. 1)

COMPARING TWO TESTS

The possible reinforcement effect from the use of a geotextile situated between subbase and subsoil may be observed by comparing a test from group a and b. Fig. 3 shows such two tests and the relative reinforcement should then be about 40%. Or should it ?

Two facts make this first attempt difficult. The figur shows that the plate carrying the heaviest load is situated on the strongest subbase ($e = 0.23$ instead of 0.28), but the thickness H of the subbase is small ($H = 16cm$ instead of $23cm$.) The corrections for void ratio and subbase thickness can be determined by comparing all the 12 tests in group a. After correction the reinforcement factor does not differ significantly from unity.

Note that the relative settlement corresponding to ultimate bearing capacity is about 30 to 40 per cent. For practical reasons all loads corresponding to a relative settlement of 40 per cent are taken as ultimate loads.

REINFORCEMENT RATIO

The reinforcement effect from the geotextiles can be expressed by the ratio between the bearing capacity with and without geotextile. But all tests should first be corrected for differences in thickness of subbase layers and compaction degree (void ratio) of the fill materials. The

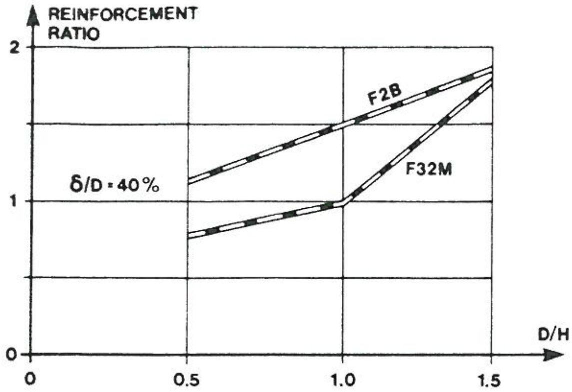

Figure 4. Reinforcement ratio measured on a gravel subbase of a thickness T of 20 *cm*.

corrections require quite a number of tests to give a conclusive and significant result.

The tests in group a and b demonstrate a reinforcement for a gravel subbase of a thickness of 20 cm, as shown in Fig. 4. The ratio increases with the diameter of the loaded area, but the influence from the two types of geotextile is very different. The most flexible geotextile F32M has even a negative influence on the bearing capacity for small plates, probably because some scale effects take place.

The tests in group c and d demonstrated that no significant reinforcement took place, when the subbase consisted of sand, probably because the sand material was too weak compared with the subsoil.

The reinforcement ratio in two layer subbases reinforced by one or two geotextiles is tested in group e - l. Since the number of tests are rather small, the corrections are difficult, and the results characterized by many sources of error. The conclusion of these tests is that the geotextiles reinforce two layers subbase, but it seems to be a bad idea to use thin layers separated by geotextiles.

ANALYSES OF TEST RESULTS

The theory of plasticity can be used in a very simple way to analyse the possibility of reinforcement. First the bearing capacities b of the subsoil itself and the subbase itself are calculated by using the usual formulas:

$$\text{Subsoil:} \quad b = (\pi + 2)\, c_u\, s_c + q$$
$$\text{Subbase:} \quad b = \tfrac{1}{2}\gamma\, B\, N_\gamma\, s_\gamma + q\, N_q\, s_q + c'\, N_c\, s_c$$

where N_γ, N_q and N_c are bearing capacity factors. s_γ, s_q and s_c are shape factors.

Fig. 5 shows bearing capacities of a subbase consisting of sandy gravel. The bearing capacity of the subsoil depends on c_u, which is constant, but that of the subbase itself depends on the diameter of the plate. At small diameters the failure takes place in the subbase only and a geotextile placed between subbase and subsoil has no effect. At big diameters the influence of the subbase

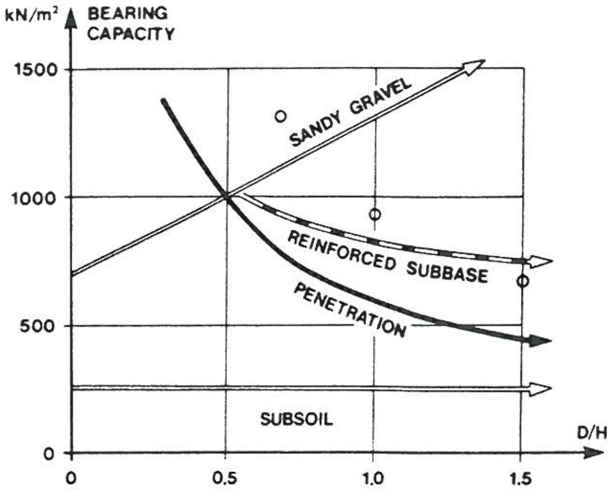

Figure 5. Bearing capacity analysed by plate loading tests. Results of proposed calculation method are shown by circles. Test groups a and b.

vanishes. A normal traffic load corresponds to diameters between these two extremities and failure takes place by penetration of the subbase. The subbase is then assumed to distribute the load. The loaded, circular area on the subsoil has a diameter D^* of

$$D^* = (1 + 2\alpha H/D)D$$

where H is the thickness of the subbase. The load distribution factor α can be estimated from test results, especially in group a. α depends on the ratio β between the bearing capacity of subbase and subsoil:

$$\alpha = 0.07\beta$$

The ultimate bearing capacity of an unpaved, non-reinforced road can be taken as the smallest of the two bearing capacities. If D/H is close to the intersection point the possibility of reinforcement is rather small because the failure mechanism changes.

For bigger values of D/H the possibility of reinforcement is increasing as demonstrated in Figs. 4 and 5. For small settlements the membran theory could possibly be used to determine the reinforcement effect (Gourc et al. 1982) combined with a design method based on the theory of elasticity (Giroud and Noiray 1981).

However, it is possible to use the theory of plasticity too and it seems reasonable since the settlements exceed 40 per cent. Penetration of a layer takes place when a subbase of a pyramid is pressed vertically into the subbase (Fig. 6). The failure mechanism in the subbase is neglected but the effective strength of the soil influences β and α. If a geotextile is situated in the surface between the two soil layers, the tensile forces T_A in the geotextile follows the direction of the movement. T_A is vertical!

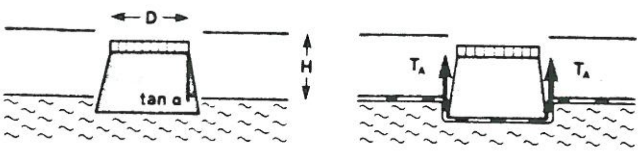

Figure 6. Approximative failure modes in the subbase by penetration and by reinforcement.

The bearing capacity by reinforcements is calculated using vertical tensile forces and unchanged α-values, and the results shown in Fig. 5 by circles. For $D/H \geq 0.5$ this method gives a very high value indicating the change in failure mechanism.

The same method can be used to analyse tests on a sandy subbase. The sand shows to be weak compared with the subsoil. The intersection point then corresponds to $D/H > 1 - 1.5$. The load distribution factor is very small too. Therefore no reinforcement effect is measured.

The proposed method shows that the reinforcement effect of geotextiles depends on the compaction of the fill material in the subbase and on the undrained strength of the subsoil. A weak subsoil gives the best opportunity to reinforce the unpaved road.

Example: Calculation of reinforcement.

Subbase : Sandy gravel	$H =$	20	cm
Diameter of loaded area	$D =$	30	cm
Geotextile F2B	$P_{max} =$	10	kN/m
Bearing capacity of sandy gravel :		1600	kPa
Bearing capacity of subsoil :		250	kPa
Bearing capacity ratio :	$\beta =$	6.4	
Load distribution factor	$\alpha =$	0.45	
Tensile force	$T_A = \pi D^* \cdot P_{max} =$	15	kN
Reinforcement		210	kPa

SETTLEMENTS

The proposed method of estimating the ultimate bearing capacity must be followed by some consideration on the plastic settlements in the structure, because development of deep wheel tracks prevent use of the road. To study this problem plate tests with alternating loads have been carried out. A simple formula for the increment of the depth of the wheel track per load $\Delta\delta/D$ could be

$$\Delta\delta/D = \alpha M + \beta M(1 - M)$$

The degree of mobilization M is used in tests with and without geotextiles. α depends on the grain size of the fill material in contact with the geotextile. The tests show $\alpha = 0.4$ for sandy gravel, but $\alpha = 0$ for pure sand. β depends on the number N of alternating loads. The number $N = 10$, which gives $\beta = 0.2$, is too small for practical use. But the result indicates that the design value of M should be less than 0.5. An appropriate value of M could then be 0.33.

CONCLUSION

The reinforcement effect of non-woven geotextiles on the bearing capacity of an unpaved road has been tested in an extensive in situ test series.

Analysis of test results demonstrates that a very simple way of estimating the static, ultimate bearing capacity pf the road can be used (see the example and Fig. 5 and 6).

Analysis of tests with alternating load demonstrates that only less than one third to half the ultimate bearing capacity should be allowed in order to prevent deep wheel tracks.

Analysis of tests on two layer subbases demonstrates that when thin layers ($H < 20$ cm) of fill material are separated by geotextiles, the reinforcement effect is small and uncertain.

These conclusions are based only on the mentioned test series and ought to be studied further before used in practice.

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