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Embankment construction from marginal material

Construction de remblais avec des matériaux de mauvaise qualité

La construction de routes et de pistes de chantiers exige fréquemment l'édification de remblais. Pour des raisons de facilité et d'économie, on essaie d'utiliser la terre trouvée sur place. Pourtant certains matériaux allant de la tourbe aux sols "Black cotton" sont impropres à une réutilisation en remblais. Dans le but d'élargir la gamme des sols utilisables, on a étudié les améliorations apportées par l'incorporation de géotextiles dans un sol de remblai pour augmenter sa résistance. Après avoir passé en revue ces différentes améliorations, on présente le programme d'essais qui en a résulté sur toute une variété de géotextiles. Ce programme comprenait des essais de perméabilité, des essais de résistance et des essais de frottement sol-géotextile. En outre on présente les résultats de deux nouveaux appareils d'essais. La boîte octogonale de cisaillement est faite pour étudier l'influence de l'inclinaison du géotextile par rapport au plan de rupture du sol, avec des angles variant de 0° à 180° par intervalles de 15°. L'appareil d'essais de chargements répétés a pour but de simuler les conditions créées par les surcharges des roues sur la chaussée, afin d'étudier le comportement d'un géotextile placé sur la couche de fondation.
Différents géotextiles ont été ainsi testés et permettent la construction d'un remblai avec un mauvais sol.

INTRODUCTION

During recent years considerable interest has been shown in two types of soil inclusion - low elongation, high modulus strips laid within soils, and high-elongation low-modulus membranes placed on top of soils. Use of the former allows the satisfactory construction of self-supporting vertical earth retaining structures (Vidal, 1969, Price,1975), whilst experience has shown that the latter perform efficiently as separating layers to prevent punching of, for example, highway paving materials into poor soils (McGown & Ozelton, 1973). However, both types of inclusion, if correctly specified and used, appear to have the potential to reinforce soils (eg McGown et al, 1978).

Embankments for roads or railways exist in between the vertical soil mass of "reinforced earth" and the fabric-assisted subgrade. Hence either type of inclusion mentioned above would be suitable for stabilizing earth embankments. Ideally the material should also be cheap, easy to place, and be chemically inert in the soil. With these in mind it was thought that suitable inclusion materials could come from a range of relatively low-priced, low elongation high modulus woven mats manufactured from polypropylene.

THE EMBANKMENT PROBLEM

In order to keep construction costs of an embankment to a minimum it would be beneficial to be able to do the following with the aid of fabric inclusions:

a. Use low-grade fill from adjacent cuttings to form the embankment.

b. Construct the embankment on poor foundation soils without the use of expensive measures such as piles.

c. Steepen the embankment side slopes to minimize land acquisition.

If these objectives are to be achieved, certain design problems such as side-slope stability and settlement will become more critical than at present. It is therefore necessary to study closely the zones of possible failure so that the potential means by which fabrics may assist with these problems can be determined. With reference to fig.1, which is a schematic of a road embankment containing fabric inclusions, the following points are thought to be relevant.* Items

**In Northern Ireland, where this research is being carried out both the fill and the foundation material will frequently be formed from glacial till with a plasticity index of about 20%.*

1-3 are concerned with reinforcement and adhesion of fabrics in soil, and items 4-6 with permeability, consolidation, and filtration.

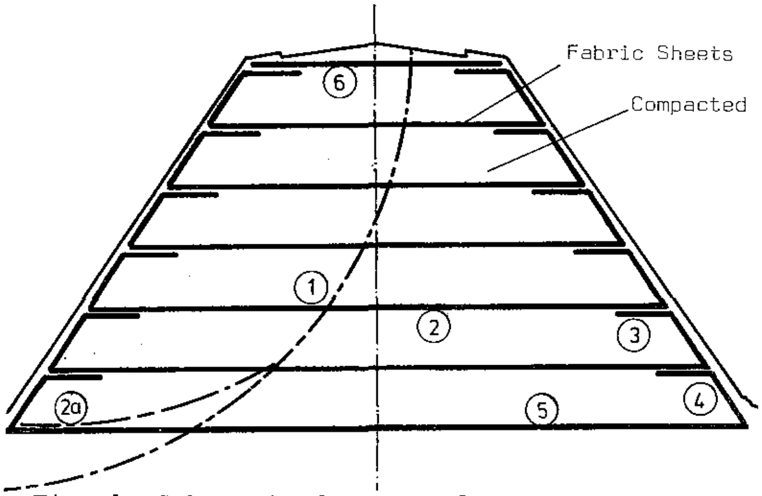

Fig. 1 Schematic diagram of road embankment.

Item 1. The classical mode of failure of an embankment side slope is due to a rotational shear. It would appear that one obvious way to combat this is to lay sheets of high-strength fabric across the potential surface of failure to act in a similar way as shear reinforcing bars in a concrete structure.

Item 2. If a shearing failure is to be prevented in the manner described above the interception material not only must be of sufficient strength to resist rupture, but must also be anchored to the soil adjacent to the zone of failure. There is also the possibility that the presence of an inclusion could assist in the formation of a shear surface (Item 2A). Hence a requirement exists to study the adhesion properties of fabrics in contact with soil.

Item 3. It is clear that at the sides of a steep embankment there will be a tendency for the soil to move laterally, tending to tear one layer of fabric away from the other. In order to resist this, without providing an artificial bond between the two layers, there must be adequate friction between the fabric materials.

Item 4. Consolidation of the soil mass will take place both during and after construction, forcing water out of the structure. The fabric layers must in no way impede the free movement of water, therefore the cross-plane permeability of the fabric sheets must be high. Cross-plane permeability herein refers to permeability perpendicular to the fabric sheets.

Item 5. Ideally, the consolidation noted under item 4 should occur sufficiently quickly for final embankment levels to be adjusted during, or soon after, the period of construction. It would be hoped, therefore, that the fabric layer would act as a drainage path for pore water. This would be particularly important with the use of low grade fill material. In order that the fabric can perform this job it should have high in-plane permeability relative to the soil surrounding it.

Item 6. A road pavement constructed on top of the embankment may well have a granular sub-base with a specified grading to yield a stable material. If for any reason the subgrade immediately below this layer becomes wholly or partially saturated, there is a possibility of the migration of fines from the soil into the granular layer under the pumping action of passing wheel loads. It would therefore be advantageous if a fabric could be used to prevent this effect.

LABORATORY INVESTIGATIONS

Reinforcement and Adhesion

As implied in the introduction most of the fabrics tested have been low elongation woven polypropylene fabrics. For comparison purposes various other materials have been tested, ranging from non-woven materials at one end of the scale to woven polyesters at the other.

Table 1 lists the results of simple strip tensile tests, carried out at the Lambeg Industrial Research Association (LIRA) to determine the relative strengths of the materials. It can be seen that the stress-strain moduli of the woven polypropylene fabrics are, in general, high. (It should be noted that for the woven fabrics tested the modulus used provides a fair representation of the stress-strain curve.)

However such figures take no account of the behaviour of the fabrics while embedded in soil. Furthermore, it is clear from fig. 1 that the plane of incipient shear failure may assume a number of different angles relative to the plane of fabric. In order to study this the octagonal shear box was developed. This is illustrated in fig. 2 with

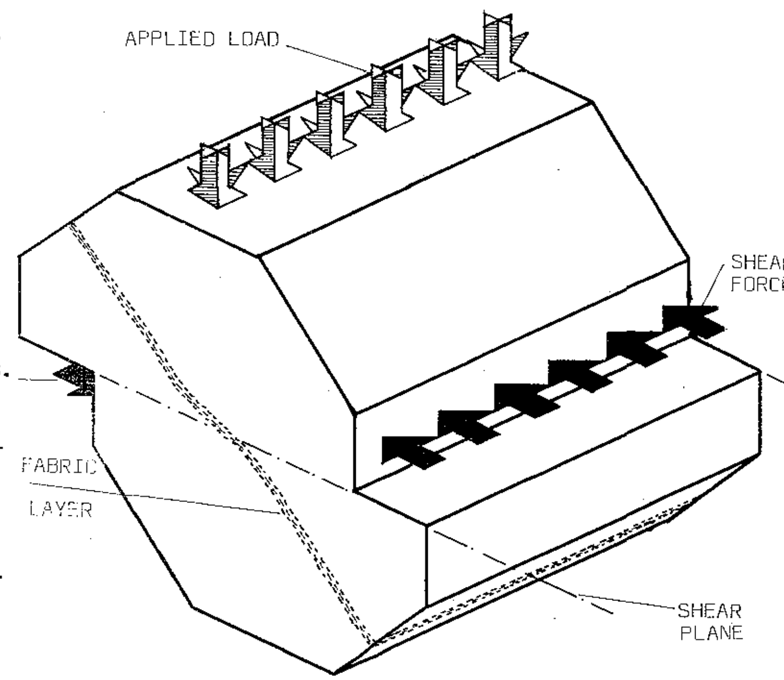

Fig. 2 Octagonal shear-box test.

the fabric plane inclined at θ=135° to the shear plane, although it is possible to vary θ between 0° and 180° in 15° intervals. At θ=0 and 180° the fabric and shear planes are coincident and the test simply becomes a measure of the adhesion between soil and fabric.

The clay specimens were prepared so as to simulate a typical embankment mass, that is, they were compacted at optimum moisture content to at least 95% relative compaction. Normal loads applied to the specimen were selected to represent typical overburden pressures. Several control tests were run without any fabric inclusions, and these were followed with tests in which various lightweight fabric inclusions were tried. In each test, the soil-fabric specimen was sheared at a deformation rate of 0,5mm/min which was chosen to approximate to 'undrained' field conditions. Fig. 3 shows the variation of shearing resistance with deformation for a

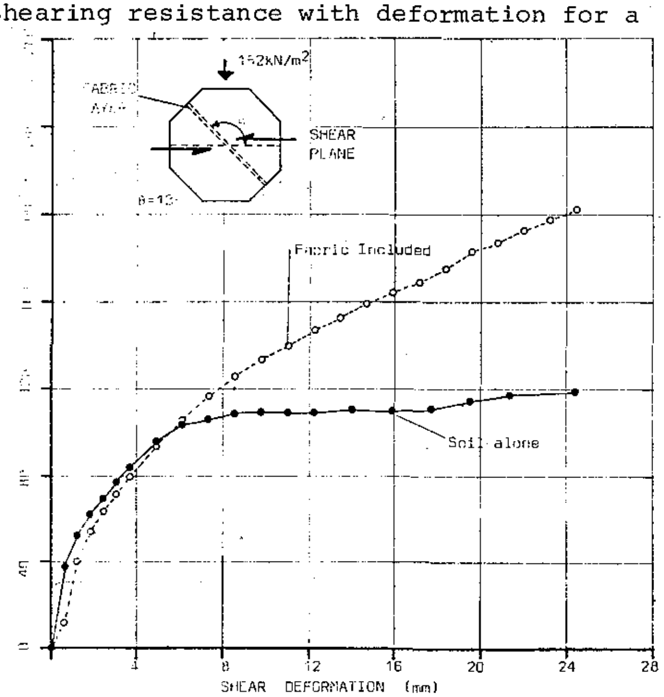

Fig. 3 Typical results from octagonal shear-box.

fabric-soil specimen (θ=135°) and for a soil control specimen.

The shearing resistance (τ_f) of any combination of fabric and angle θ is typically expressed as a ratio of the shearing resistance (τ_s) of the soil alone tested under identical conditions. In practice, of course, it is impossible to reproduce identical soil samples. Therefore a datum soil shearing resistance (τ_s) was chosen and the values of τ_f adjusted to conform to this by means of an experimental relationship between the shearing resistance of the soil for any given angle θ and its initial moisture content and density. (DuBois, 1978).

The ratios τ_f/τ_s, so obtained, are shown as a function of θ for small (5mm) and large (15mm) shear deformations respectively in figs. 4 and 5. The solid lines indicate the boundaries of the range of values obtained

Fabric Type		Tensile strength kN/m	Modulus at rupture kN/m	Extension at rupture (%)	Weight gm/m²
Woven Polypropylene tape	warp	17-89	95-1504	6-18	100 to 300
	weft	11-55	147-1850	3 - 8	
Woven as above but with needled nylon fleece	warp	6 or 8	66 or 94	9	-
	weft	8or10	87or117	9	
Non-woven spun-bonded		9-11	19-52	30-50	100 to 250

NOTE: Woven Fabrics

warps: 15-24 per inch @ up to 3000 den
wefts: 6-14 per inch @ up to 3250 den

Table 1 Typical Fabrics used in the Tests.

for woven fabrics, and the dashed lines indicate those obtained for non-woven fabrics†.

Five general facts are evident from figures 4 and 5:

a. The fabric has little, if any, beneficial effect when in a compressive mode (i.e. 0°<θ<90°).

b. The fabric has a reinforcing effect when in a tensile mode (i.e. 90°<θ<180°).

c. A reduction in shearing resistance is obtained when the plane of the fabric coincides with the shear plane.

d. The greater the shear deformation, the greater the reinforcing effect.

e. Both woven and non-woven fabrics exhibit similar behaviour, although the largest reinforcing effects were provided by woven fabrics.

The first three conclusions appear to confirm for a cohesive soil the similar findings obtained elsewhere for cohesionless soils (McGown & Andrawes, 1977, McGown et al, 1978).

It is possible to investigate the improvements in factor of safety against rotational shear failure using the type of information given in figs. 4 & 5. If fig. 1 is studied it can be seen that the shear plane intersects horizontal fabric layers at angles for which fabric inclusions have a reinforcing effect.

However, as shown in fig. 1 (item 2A) there is a possibility that the presence of fabric inclusions in earth embankments will alter the geometry of the incipient shearing surface in such a way that the factor of safety becomes reduced. The finding (fig. 5, θ=0° or 180°) that the adhesion between fabric and soil is lower then the strength of the soil is particularly relevant in this respect.

†*A small number of woven fabrics with needled fleeces have been tested. Except where otherwise stated data obtained from these fabrics is included with the non-wovens.*

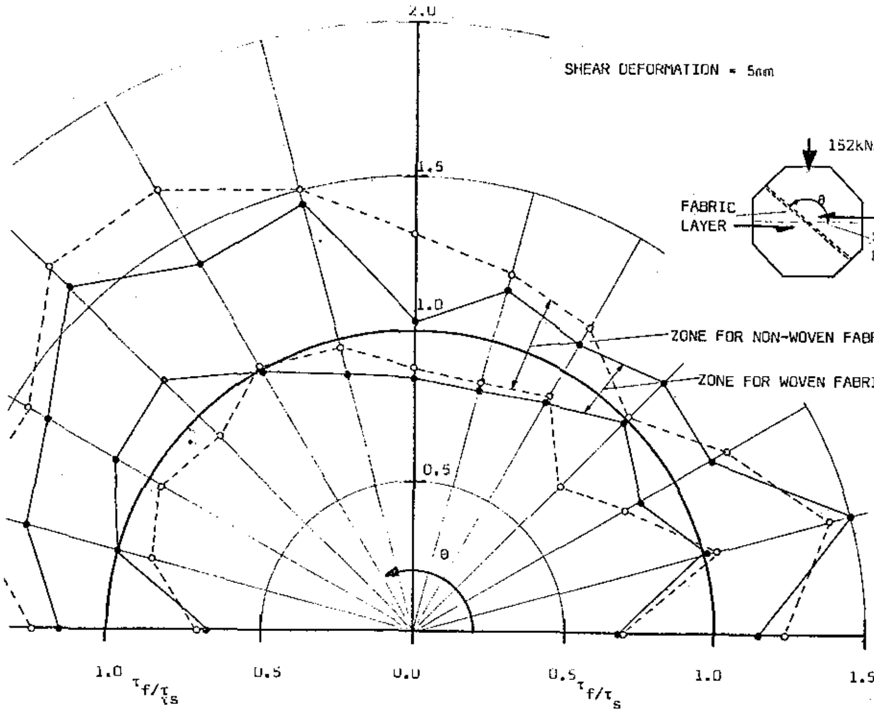

Fig. 4 Polar plot of octagonal shear-box results.

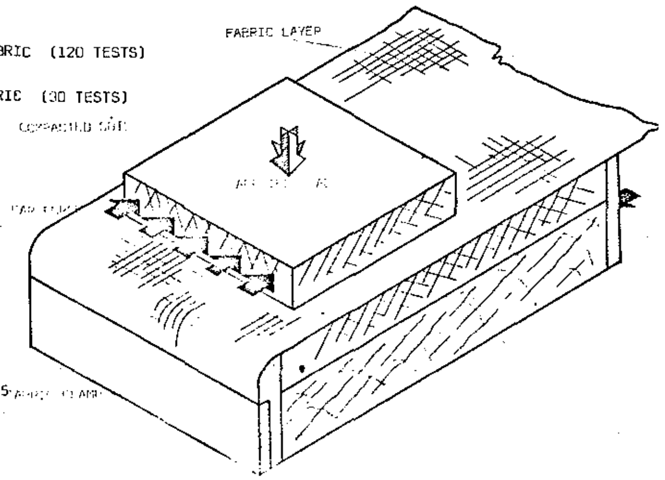

Fig. 6 Soil fabric adhesion test.

Clay-fabric adhesion was studied using the shear type equipment illustrated in fig. 6, which was designed to allow clay to adhere to both fabric faces during shear. The results shown for θ=0° and 180° on figs. 4 & 5 were obtained using this equipment.

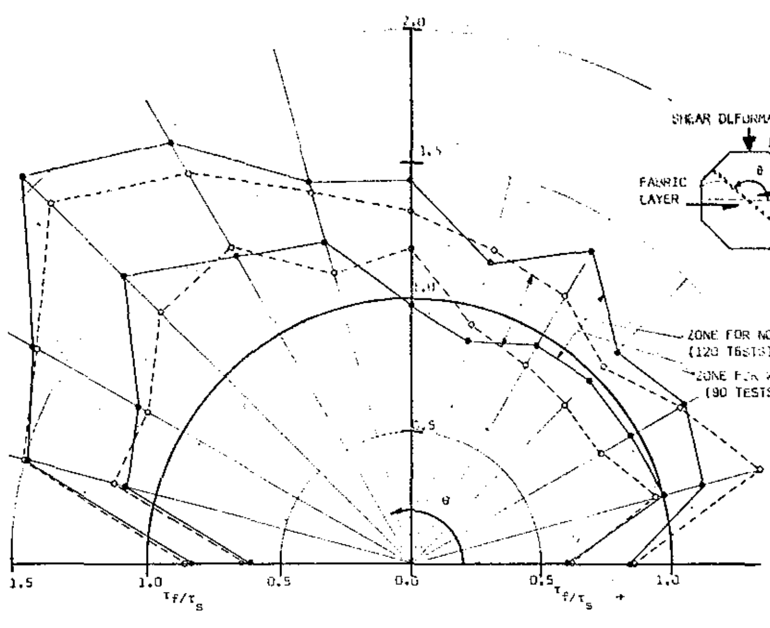

Fig. 5 Polar plot of octagonal shear-box results

Shearing resistance, corrected for variations in soil from test to test, for both woven and non-woven inclusions are shown versus shear deformation in fig. 7. The result from a soil control test is also shown for comparison.

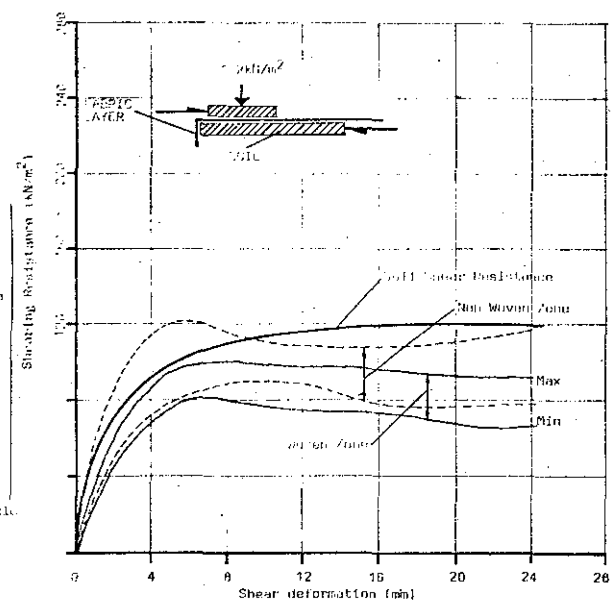

Fig. 7 Soil-fabric adhesion test results.

The non-woven materials developed their resistance to deformation at an earlier stage than the wovens, and in general adhered better to the clay. However the latter fabrics also performed well. An important finding is that the soil/fabric adhesion for wovens is much higher when the warp tapes run at right angles to the direction of movement than at any other angle. This, together with the observation of tested samples (Plate 1) has shown that the warp tapes, with their greater deviation from the plane of the fabric tend to 'bite' into the adjacent soil and develop a passive earth pressure type of resistance to further motion. The earlier shear-box investigations also pointed to these conclusions and suggested that the tensile modulus of the warp tapes is an important factor governing soil-fabric adhesion. At present, research is continuing into this topic with the aim of establishing the basic mechanisms of adhesion between fabric and clay.

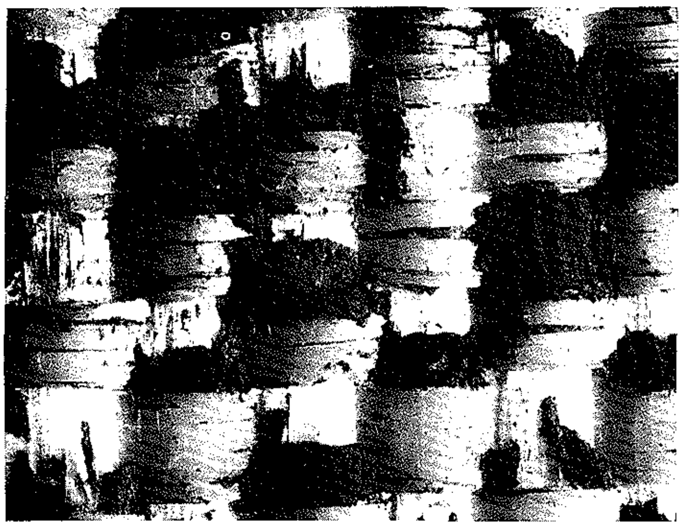

Plate 1 Soil/warp tape interaction.

The need for adequate friction between one fabric sheet and another is also clear (fig. 1, item 3). Shear box tests were used to clarify this problem. Two samples of the same fabric were glued to wooden blocks and placed in contact in the shear plane. Representative results, Table 2, clearly show that there is a requirement for the fabric to be laid such that both sets of warp tapes are at right angles to the direction of motion. This is because the largest values of friction coefficient arise due to the interlocking of the warp tapes.

DIRECTION OF SHEAR		COEFFICIENT OF FRICTION = Peak Shear Stress / Normal Stress
TOP	BOTTOM	
weft	weft	0.82
warp	weft	0.47
45°	weft	0.32
warp	warp	0.32

Table 2 Fabric to Fabric Friction.

Permeability, Consolidation and Filtration

The necessity for the fabric to provide easy passage of porewater through the soil mass results in the requirement for the fabric to have a high permeability and yet retain the soil (fig. 1, item 4). Previous work had demonstrated that the non-woven fabrics under consideration could fulfill this function under steady-state conditions.

A number of tests on both woven and non-woven fabrics were conducted in a constant head permeameter under varying normal pressures. The test set-up was similar to that used by Bourdillon (1976). The major conclusion derived from the tests is that the cross-plane permeability for non-wovens and wovens are very similar, and all are adequate for use in embankments.

The in-plane permeability of the fabric sheets is important when considering the rate of consolidation of an embankment because of their potential to act as drainage blankets. However, the in-plane permeability of the fabric in isolation will bear little relation to that obtained when it is embedded in a fine-grained soil which may well penetrate the fabric structure and close potential drainage paths. (Bell, Snaith & DuBois 1978).

For this reason direct tests on soil-fabric specimens were devised to study qualitatively the effect of fabric inclusions on consolidation. Triaxial consolidation equipment used for anisotropic consolidation of clay was used. Each cylindrical sample of compacted clay 100mm tall x 50mm diameter was manufactured with three fabric discs inserted in horizontal planes so as to divide the sample into four equal parts.

The samples, which included some containing no fabrics as controls, were then covered with standard filter-paper drains. The remainder of the preparation was as for a routine triaxial test. All of the prepared samples were allowed to stand for 24 hours with the drainage leads open to allow porewater pressure changes caused by compaction to reach equilibrium. After this, consolidation was begun. Each test was run using successive cell (or lateral) pressures of 25, 50 and 100kN/m^2. Axial pressures were adjusted after each increment to keep the lateral strains to a very small value. Thus consolidation approximated to 'Ko' conditions, and the influence on the test results of the lateral strain restraint provided by the fabric disc inclusions was therefore minimized.

Typical results are shown in Table 3 for a control sample along with two samples con-

FABRIC TYPE IN CLAY	CONSOLIDATION PRESSURES (kN/m^2)		Time for 100% consolidation (mins) (Log fitting method)
	σ_{1c}	σ_{3c}	
No Fabric (Control)	89.3	50	330
Non-Woven	88.0	50	250
Woven with Double Fleece	89.2	50	270

Table 3 Typical Consolidation Test Results

taining the better drainage fabrics - a non-woven and a woven with a needle-punched fleece on both faces. It can be seen that these fabrics have only marginally improved the rate of consolidation of the particular clay tested, especially when the possible experimental errors are considered.

As stated previously, the stability of a granular sub-base material resting on a soil may be impaired if it becomes contaminated by clay-sized particles migrating vertically from a cohesive subgrade. This phenomenon has been investigated, and is reported elsewhere (Snaith & Bell, 1978).

A number of different fabrics were tested. Within the somewhat limited confines of the test series undertaken it appeared that the woven polypropylene fabric with a double needled fleece behaved in a most satisfactory manner (Table 4). However, it should be added that testing will have to be extended to cover increased testing times and different subgrade and sub-base materials before firm conclusions can be made.

Filter Type	Woven/ Non-Woven	Depression of fabric (Δh) mm		Decrease in Dry Weight of Subgrade %
		@ 6 hours	@ 24 hours	
Control - no filter	-	7	9	4
Light Weight	Non-Woven	-	8	2.0
Light Weight with Sand Layer	Non-Woven	7	10	0
Thick	Non-Woven	7	8	0
Light Weight	Woven	-	5	0.25
Light Weight, double fleeced	Woven	2	5	0

Table 4 Summary of Results obtained in Dynamic Loading Trials.

DISCUSSION

The laboratory studies have attempted to examine the prime questions which arise from the concept of stabilizing earth embankments with cheap, lightweight fabrics. Most of these adhere adequately with clay, although the behaviour of the non-woven and fleeced fabrics is better than the wovens. A laboratory examination of the reinforcing effect of fabrics has been encouraging. All of the fabrics show sufficiently high cross-plane permeability to allow movement of water throughout the embankment. It is doubtful if fabrics can hasten consolidation or prevent fines contamination of sub-bases.

These shortcomings may be overcome by the manufacture of specialist fabrics designed for a particular job. However, such fabrics are likely to be expensive and narrow in their application. A good compromise, presently available, which possesses many of the advantages of both wovens and non-wovens is embodied in a woven fabric with a double needled fleece.

Care should be taken before extrapolating from the existing laboratory results. Although a number of encouraging field applications have been reported (eg Int.Conf. on Use of Fabrics in Geotechnics, Paris, 1977), there is a lack of information on failures of full-scale fabric-stabilized embankments. Thus the work reported herein has been done without a detailed knowledge of the failure mechanisms of fabric-stabilized embankments.

It has therefore been proposed that an embankment 12m tall should be constructed so that the effect of fabric inclusions can be assessed, and the construction problems examined on site.

It is envisaged that different fabrics will be used in adjacent sections of the embankment so that a comparison can be made. The double needled fleece polypropylene woven fabric will be used as it represents a good compromise and was manufactured in response to the laboratory work.

Currently, the design of the embankment and its instrumentation is being considered. Strains in the inclusions are to be measured using small inductive probes attached to the fabric. Larger probes working on the same principle are to be used to measure fill deformations. Similar probes developed at QUB have already been successfully used in a recent motorway reconstruction. Consideration is also being given to the measurement of stress in the embankment soils. Finally, porewater pressures are to be measured using conventional piezometers, and settlements are to be monitored using surveying techniques.

CONCLUSIONS

The indications are that there will be a design advantage in using lightweight fabrics in road or railway embankments. No clear preference for either woven or non-woven types has emerged. Perhaps the best compromise material available is a woven fabric with fleece on both faces. Further laboratory testing is required to show which soil-fabric combinations are most effective for embankments. However, the validity of these tests is to be evaluated by well-instrumented field trials.

ACKNOWLEDGEMENTS

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