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A Full-Scale Experiment on Granular and Bituminous Road Pavements Laid on Fabrics

Expérience à grande échelle avec couches de forme granulaires et bitumineux sur textiles

Granular pavements of two thicknesses were laid on each of five fabrics over a clay subgrade, with two control sections. One fabric section and one control were overlaid with dense bitumen macadam. Surface deformations, strains in all layers and vertical stress in the subgrade were measured under wheel loads up to 5300 kg. Fabric had no effect on the performance of the macadam-surfaced pavement. In the granular pavements permeable fabrics caused reductions of permanent surface deformation and permanent subgrade strain. Transient subgrade strain was only reduced in the transverse direction. Fabrics were torn at surface deformations of 90 - 110 mm. Permanent transverse tensile strain of 1 - 2% developed in the fabrics under the wheel ruts.

Au dessus d'un sol support argileux, on a construit des couches de forme granulaires de deux epaisseurs sur chacun de cinq textiles différents. On a construit aussi deux éléments experimentals de contrôle. On a couvert de macadam de bitume un des éléments avec textile et un des éléments de contrôle. On a mesuré les déformations de surface, les déformations de tous les matériaux et les contraintes verticals dans le sol support, à cause de circulation de charge maximum 5300 kg. Le textile n'a changé pas du tout le fonctionnement de l'élément couvert de bitume. Les textiles perméables ont réduit les déformations permanents de la surface et du sol support des éléments granulaires. Ils ont réduit le déformation dynamique du sol support, main seulement dans le direction transversale. Les textiles se sont déchirés lorsque la surface de la route s'était déplacée par 90 - 110 mm vertical. Sous les lignes de circulation des roues les textiles ont supporté des tensions transversales permanentes de 1 - 2%.

INTRODUCTION AND PREVIOUS WORK

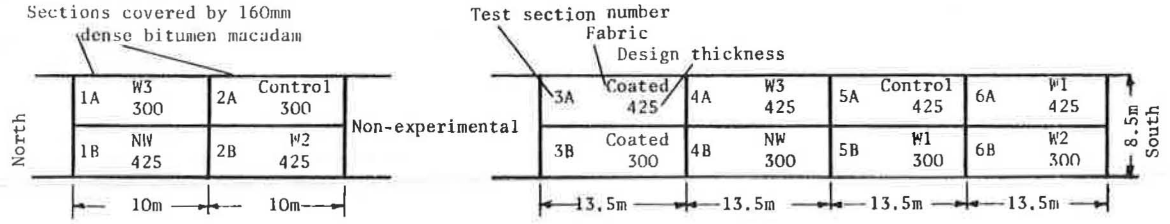
A full-scale experiment was planned to investigate the effects of inclusion of fabric at the subgrade/sub-base interface in granular and bituminous-surfaced pavements. In previous experiments (1,2,3) on granular pavements laid on clays with CBR's from 0.7 to 12%, the permanent surface deformation had been reduced by the presence of fabrics and meshes of differing properties, but only one experiment had sought any understanding of the mechanism of improvement. This was a pilot full-scale experiment by the Transport and Road Research Laboratory in 1977.(3) The pavement was contained within a rigid tank and thus restrained against overall lateral spread. The permanent vertical strain under the wheel-path, both in the subgrade and in the bottom of the sub-base, was reduced significantly by the presence of a melt-bonded fabric. Transient vertical strain in the subgrade was not altered but transient horizontal strains, both longitudinal and transverse, were reduced significantly.

DESCRIPTION OF EXPERIMENT

Site. An experimental road was constructed on a level site at Sandleheath in Hampshire. The subgrade was London Clay, with mean properties as follows:

Liquid limit	51%
Plastic limit	23%
Natural moisture content	28%

Depth below formation (mm)	CBR % (measured with cone penetrometer by Black's method) (4)
0	0.7
75	2.4
150	2.8
225	3.0
300	3.5



1. Layout plan

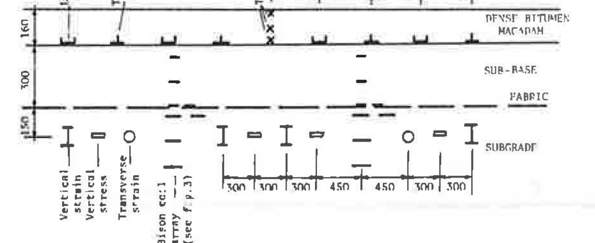
Table 1. Fabrics

Fabric designation	Description	Direction of tests	Ultimate[3] strength kN/m width	Extension[3] at failure %	Supplier
W1[1]	Woven polypropylene tape 96 x 44 per 10 cm	Longitudinal (warp) Transverse (weft)	19.0 13.3	19.0 11.2	Synthetic Fabrics (Scotland) Ltd
W2[1]	Woven polypropylene tape 59 x 37 per 10 cm	Longitudinal (warp) Transverse (weft)	56.6 38.6	13.7 9.2	Low Brothers & Co
W3[1]	Woven multi-filament polyester 112 x 106 per 10 cm	Longitudinal (warp) Transverse (weft)	82.8 84.4	14.7 14.8	ICI Fibres Ltd
Coated[1]	Neoprene-coated nylon balanced weave	Longitudinal Transverse	60.4 42.8	25.0 23.0	MVEE
NW[2]	Melt-bonded polypropylene/ polyethylene	Random	8.1	50.5	ICI Fibres Ltd

NOTES
1. Tested by standard strip tests
2. Tested by ICI plane strain method
3. All test results are means of four

Table 2. Instrumentation.

Test Section No	Design thickness (mm)	Fabric	Measurements
1A	300	W3	Transient stress & strain in the soil, permanent strain in the soil and in the fabric, transient strain and temperature in dense bitumen macadam.
2A	300	None	Transient stress & strain in the soil, permanent strain in the soil, transient strain and temperature in dense bitumen macadam.
4A	425	W3	Transient stress in soil, transient & permanent strain in soil, fabric and granular layer.
5A	425	None	Transient stress in soil, transient & permanent strain in soil and granular layer.
6A	425	W1	Transient & permanent strain in soil, fabric & granular layer. (Bison gauges only in this section)



2. Typical layout of instruments. Longitudinal section along wheel path.

<u>Materials and Construction</u>. The experiment included three woven fabrics of different properties, one non-woven and one impermeable coated fabric. Details of the fabrics are given in Table 1.

Two thicknesses of granular material were used, designed to be 300mm and 425mm after compaction. The material was crushed granite conforming to the Department of Transport (DTp) Type 1 sub-base specification.(5) The 300mm thickness was obtained by spreading in a single layer and compacting by Vibroll tandem vibrating roller to comply with the DTp Specification, Clause 802.(5) For the 425mm thickness a second layer was spread and compacted with the same scheme of passes. The mean dry density achieved was 2.17 Mg/m³ and mean moisture content 5.39%.

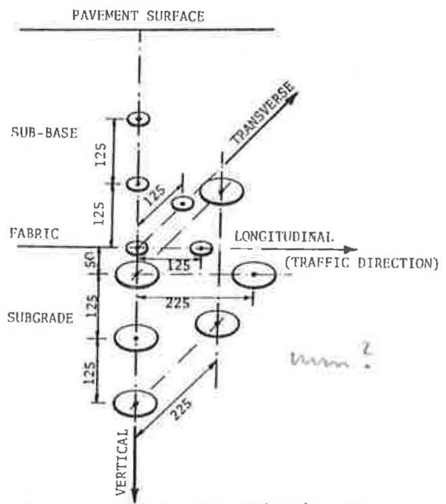
Two of the 300mm thick sections were overlaid with dense bitumen macadam basecourse (5) to a nominal thickness of 160mm. Compaction was by an 8 tonne, three-wheeled, steel-tyred roller to the DTp specification.

<u>Layout and Measurements</u>. A plan of the experiment is shown in Fig 1. Each fabric was used in two test sections, one of 300mm design thickness and the other of 425mm, and there was one control section of each thickness, containing no fabric. The two 300mm sections overlaid with dense bitumen macadam were the control and the W3 fabric section; they were overlaid after very brief trafficking. Instruments for measurement of stress, strain and temperature were installed in five sections, as listed in Table 2 and shown in Fig 2 and Fig 3. The vertical surface deformation was measured at intervals of 300mm across four cross-sections in each pavement throughout the experiment.

<u>Trafficking</u>. For early trafficking on the sub-base, two-axle lorries with dual rear wheels were used. Axle loads were increased in steps to a maximum of 9940kg. For final trafficking, these lorries were replaced by a three-axle dump-truck with single wheels and coarse cross-country tyres on both rear axles, with a maximum axle load of 9460kg.

The line of travel was varied randomly within a 800mm wide path for each wheel, but when stresses and strains were being measured wheels were driven in the middle of the wheel path directly over the gauges.

As the sequence of traffic varied betweeen test sections, a unified scale of trafficking was adopted, the unit of the scale being one pass of the 9940kg axle. This is the scale of 'equivalent axles' used in the results given below. The equivalence factor for every other axle was the ratio of the mean transient vertical strain measured at 150mm depth in the subgrade of sections 4A and 5A



3. Typical array of inductive (Bison) coils.

under the axle to the mean strain measured under the 9940kg axle. This procedure took into account the axle load and the effect of the different tyres and wheel systems.

The dense bituminous macadam sections were trafficked by the two-axle lorry with dual wheels initially carrying a rear axle load of 9940kg. Because no measurable change in road behaviour was recorded after 4600 vehicle passes, the rear axle load was increased to 13600kg and a further 7700 passes were applied.

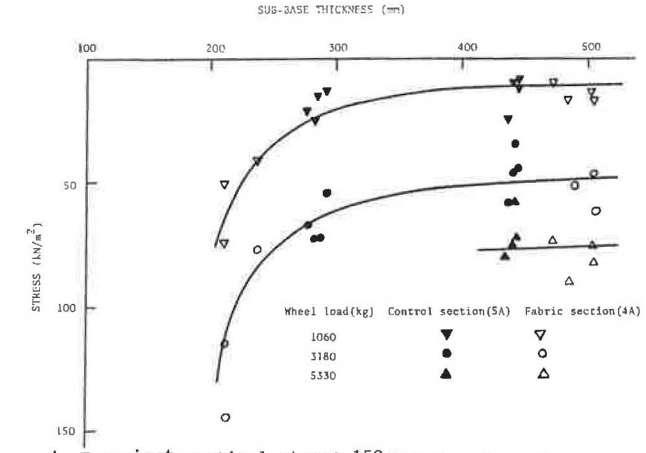
RESULTS

The stresses, strains and deformations described below were measured during and at the end of trafficking. With two exceptions it was possible to discontinue traffic on each granular pavement as soon as it failed.

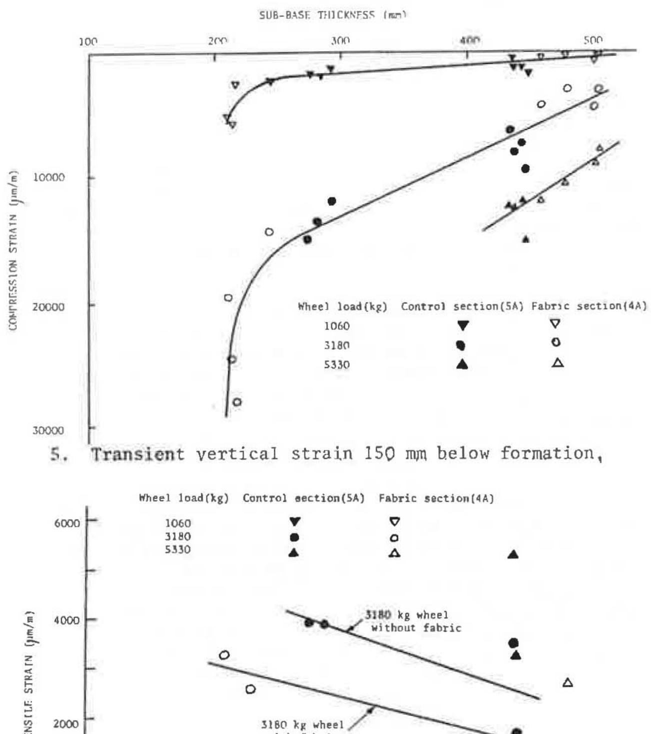
The results from individual stress and strain gauges and from the four cross-sections where surface deformation was measured are referenced by their distances in m from the north end of the experimental section.

Transient Stress and Strain. Many thousands of readings of transient stress and strain were made on the TRRL stress and strain gauges under all vehicle axles. In general, after each increase of axle load, the peak values of vertical stress, vertical strain and transverse strain increased with vehicle passes until constant levels were achieved. The number of vehicle passes to reach these new levels, however, varied from about twenty to several hundred. The peak values obtained in the four instrumented sections (before overlaying sections 1A and 2A with dense bitumen macadam), are plotted against the pavement thickness at each gauge in Figs 4, 5 and 6. It can be seen that thickness has a greater influence on both vertical stress and strain than the presence of fabric and no influence of fabric can be inferred. Figure 6, however, shows that the heavier wheel loads generate considerably less transverse strain in the sections with fabric.

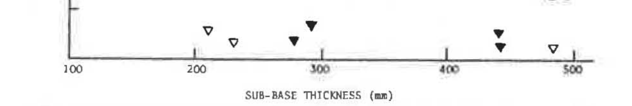
Similar measurements were made on the dense bitumen macadam sections (1A and 2A) and these showed also that the presence of fabric made no difference to the transient vertical stress and strain in the soil and to the transverse and longitudinal strains at the bottom of the bituminous macadam. There was, however some evidence to suggest that the transient transverse strain in the soil was reduced slightly under the fabric.



4. Transient vertical stress 150mm below formation.



5. Transient vertical strain 150 mm below formation.



6. Transient transverse strain 150 mm below formation.

A good general indicator of structural condition is the transient deflection (6) under a slowly moving lorry wheel. Deflections were measured frequently at eight positions on sections 1A and 2A and were found not to be affected by the fabric.

Permanent Strain. The most marked effect of fabric in the unsurfaced sections was the reduction of transverse strain at the subgrade/sub-base interface (Fig 7) and at

50mm below it (Fig 8). In Figure 8 the curve for 6A (3.0m) represents a location where the fabric survived untorn to the end of trafficking and 6A (6.0m) a point where large tears occurred during trafficking. The strain at 6A (6.0m) increased continuously throughout the trafficking, as in control section 5A, but the pattern at 6A (3.0m) of a reducing rate of increase of strain was similar to that observed in section 4A with strong fabric. It is inferred that the presence of either fabric, W1 or W3, caused a large reduction of transverse strain so long as it remained untorn.

Similar differences were observed at 150mm below the interface in sections 4A and 5A where the transverse strains were approximately 1.5% and 7% respectively at the end of trafficking.

In the two sections overlaid with dense bitumen macadam the permanent transverse strain in the soil was less than 0.02% at the two measurement locations in the section with fabric and at one location in the control section. The other gauge in the control section had a thinner cover of bituminous material and indicated a strain of 0.2%.

The permanent vertical strains in the subgrade of section 5A were also greater than in section 4A but the curves for 5A were tending, at the end of trafficking, towards constant values, unlike the transverse strain curves for 5A (Fig 8). After considering variations in sub-base thickness and other factors,(6) it was concluded that in unsurfaced pavements the presence of untorn fabric causes a substantial reduction in permanent vertical strain in the subgrade to at least 150mm below the interface. This effect was not found in test section 6A at (6.0m) where the fabric was torn.

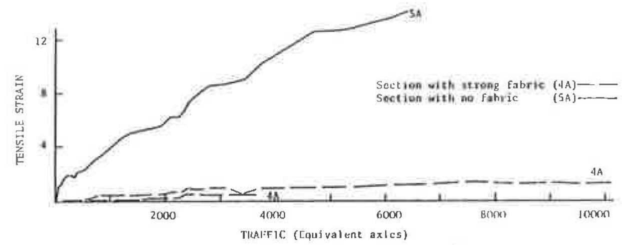
The measurements of permanent strain at a single array of coils are not subject to the effects of variation in pavement thickness or material properties and they thus provide a reliable picture of the distribution of strain in the cross-section. The permanent strains in the cross-section through the wheel path at each array of Bison coils when the vertical surface deformation was 50mm are plotted in Fig 9. The strains in the subgrade were smaller at the arrays with untorn fabric, viz. the arrays in unit 4A and at 6A (3.0m). It is inferred that subgrade deformation at these arrays was distributed through a larger area of the cross-section than at the other three arrays, since the maximum surface displacement was the same at all six positions. This occurred however without reducing the peak values of transient vertical stress and strain (Figs 4 and 5). Even at surface deformations of only 30mm there was a pronounced difference of permanent strains between sections with and without fabric, although not so large a difference as at 50mm (Fig 9).

The wider spread of permanent strain in the cross-section coincides with longer life of the pavements. The number of equivalent axles taken to reach a surface deformation of 50mm at each of the Bison arrays was:

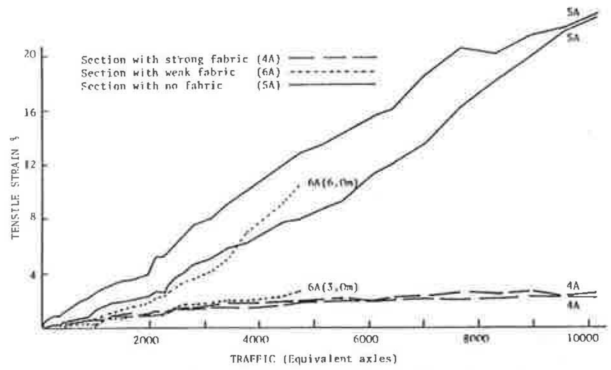
Section 4A,	both arrays	1875	equivalent axles
Section 5A	(4.0m)	1460	" "
	(5.8m)	1180	" "
Section 6A	(3.0m)(fabric untorn)	1830	" "
	(6.0m)(fabric torn)	1180	" "

Section 6A suffered much more rapid deformation than 4A after passing 50mm deformation. At that stage, according to concepts discussed in the next section of the paper, it was failing.

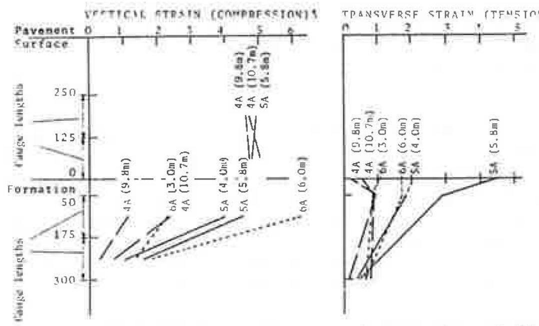
In the sections covered with dense bitumen macadam the permanent vertical strains in the soil were not influenced by the presence of fabric but they did depend on the thickness of the bituminous macadam. At the end of trafficking the permanent strain was only 0.2% under 160mm of dense bitumen macadam.



7. Permanent transverse strain at formation.



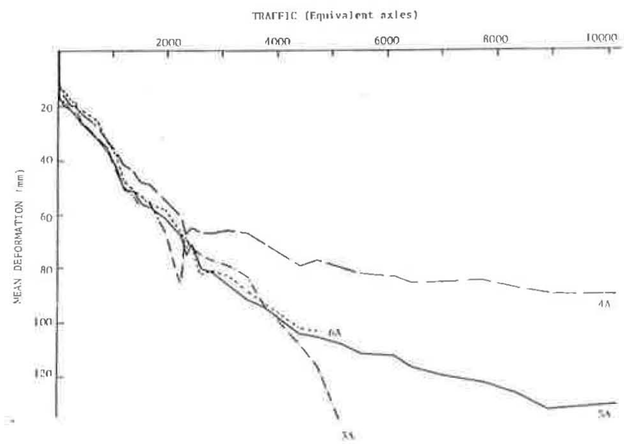
8. Permanent transverse strain 50mm below formation.



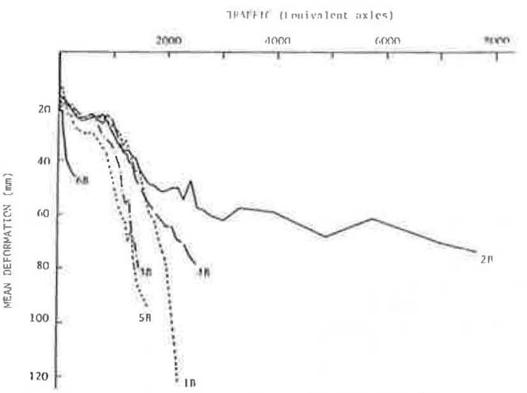
9. Permanent strains at surface deformation of 50mm.

Permanent Surface Deformation and Pavement Failures. The development of mean surface deformation measured in the outside wheel paths of all the unsurfaced sections are plotted in Figs 10 and 11. Curves of decreasing slope represent pavements adequate for the wheel loads in use, while curves of constant or increasing slope represent failing pavements. It is clear that all the B sections except 2B failed after the passage of moderate numbers of equivalent axles. Sections 3A and 6A also suffered failure in the outside wheel paths, although the mean deformation curve for 6A does not show it. (The final failures in all sections were concentrated in short lengths, with local deformations more rapid than is shown by the mean curves). The trigger to failure in most of the B sections was the start of trafficking by the three-axle dump-truck, with its maximum axle load similar to the previous lorry but on single wheels with coarse-treaded tyres.

The permanent deformation of the dense bitumen macadam



10. Mean surface deformations of A sections.



11. Mean surface deformation of B sections.

sections depended on the thickness of the bituminous layer and was not reduced by the fabric. For a thickness of 160mm of dense bitumen macadam the surface deformation was 7mm at the end of trafficking.

On completion of trafficking two trenches were dug across each section. One at the cross-section showing maximum deformation and the other where deformation was a minimum. At many places the fabrics were found to be torn in the wheel paths. At all of these, the deformation at the end of trafficking was increasing rapidly, in the way identified in Figs 10 and 11 as a failure mode; but at several locations where the deformation curve was in the failure mode the fabric was not torn, showing that failure may begin before the fabric tears. General observations suggested that this was the case in all the sections that failed.

Although torn fabric was found at one place where the vertical surface deformation was only 55mm, the general evidence was that in sections with sub-base thickness less than 400mm the weaker fabrics were torn if the surface deformation exceeded 90mm, but in sections of thickness 400-470mm they were only torn if the deformation exceeded 110mm.

The influence of the properties of the fabrics on the deformation curves had to be isolated carefully from effects of differing sub-base thicknesses, subgrade properties, etc.(7) The most important observation was that neither of the strong permeable fabrics (W2 and W3) was torn except in the premature failure of section 6B, caused by excessive local subgrade weakness and a thin granular layer. Sections of adequate thickness with these fabrics (2B and 4A) did not fail and underwent less deformation than the control section (5A) which also survived to the end of trafficking without failure. Weaker permeable fabrics were torn during failure of their overlying pavements. The failure of 6A (containing fabric W1) before 5A is attributed to its weaker subgrade, but is evidence that such fabric will not prevent failure of a pavement inadequate for the ruling conditions of subgrade and traffic.

Sections 3A and 3B containing the coated fabric, which was also of high strength but impermeable and of smooth surface, underwent deformations similar to those of comparable sections with weak fabrics. This was attributed to slip between the fabric and the clay as the excavations made on completion of trafficking showed the contact to be wet and slippery. Vane shear tests indicated a sharp reduction of strength at the surface of the subgrade. In contrast, the subgrade strength in the wheel paths directly under permeable fabrics almost doubled during trafficking.(7)

12. View of fabric in trench across section 4A.

The deformation of some of the unsurfaced pavements varied with the distance of the wheel path from the unrestrained pavement edge. Comparisons between the development of deformation near the edge and near the centre of the road showed that the rate of deformation was increased if the middle of the wheel path was less than 1.4m from the edge of the running surface.

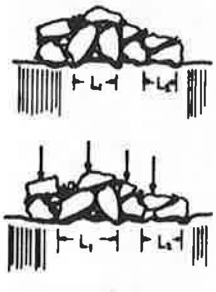
Final Condition of Fabric and Sub-base. The separation of the sub-base from the subgrade was effectively maintained by all the fabrics, only a slight coloration from the subgrade showing in the bottom of the sub-base over permeable fabrics. In the control section the sub-base and subgrade were intermixed to a depth of about 50mm over the whole section.

In most of the trenches across the pavements the fabrics, if not already torn, were stretched taut across the wheel paths. Elsewhere, both between the wheel paths and outside them, wrinkles were observed parallel to the wheel paths but at varying distances from them (Fig 12). The deformation of the subgrade/sub-base interface in the wheel paths was enough only to stretch the fabric by about 1 or 2%, but the strain necessary to cause rupture of any of the fabrics would be more than 10%. The largest permanent tensile strain measured in an untorn fabric was also less than 2% (see Fig 7). An explanation of these observations is offered in the discussion below.

When the sections overlaid with dense bitumen macadam were excavated, fabric W3 on section 1A was untorn. Moreover no measurable deformation had occurred at the top of the soil and hence no stretching of the fabric was observed.

DISCUSSION

The formation of a rut in the granular pavements under repeated loading involves incremental plastic deformations in both sub-base and subgrade. Deformation of the sub-base proceeds by non-reversible rearrangements of particles, in which the relative movement of individual particles may exceed the average strain measured over a greater length. Figure 13 shows how general deformation of the sub-base can induce large strains in small areas of fabric. The lengths labelled L1 and L2 are both strained much more than the average measured over a typical gauge length because the large particles bite into the fabric and move it with them. If the local strain in the fabric rises to the rupture strain, a tear is initiated; the existence of the tear reduces horizontal restraint on the sub-base, and under repeated loading allows greater deformation and progressive extension of the tear.



1. Initial stable arrangement of sub-base particles.
2. Downward load forces particles into a new arrangement. When the load is removed the particles will remain in the new arrangement. Because the particles bite into the fabric there has been a large percentage extension of the lengths L_1 and L_2.

13. Local extension of fabric by sub-base deformation.

In observations of the movements of cracks during trafficking it appeared that portions of the sub-base bounded by cracks might be rocking on the subgrade as rigid bodies. It is suggested that in this rocking motion fabric can be fed gradually away from the wheel paths to form the longitudinal wrinkles seen on either side in the excavations.

The wrinkles between the wheel paths showed that the fabric was not in tension and this, on a saturated clay subgrade, is contrary to an important assumption of Giroud and Noiray's design method.(8) Some measurements of subgrade strain made just outside the wheel paths in this experiment, suggest that the angle of effective load distribution within the granular layer is smaller than Giroud and Noiray assumed. In addition this experiment has shown that permanent tensile strain can exist in fabric across a rut, a feature not allowed for in Giroud and Noiray's assumptions. This applies a transverse prestress to the loaded area, which must be beneficial. How large the permanent strain can become without risk of rupture remains to be determined. The tensile strain and prestress will occur more readily in pavements where traffic is confined to relatively narrow wheel paths.

CONCLUSIONS

In granular pavements the presence of a permeable fabric reduces the rate of surface deformation provided that the fabric is not torn. The fabric reduces permanent vertical strains in the granular layer and in the soil although transient vertical stress and strain in the soil are not changed. Transient and permanent horizontal strains in the soil are reduced by the presence of fabric.

The structural behaviour of the pavements containing bituminous bound layers was not improved by the presence of fabric.

All the fabrics used were effective as separating layers between the clay subgrade and well graded sub-base material.

ACKNOWLEDGEMENTS

The work described in this paper forms part of the programme of research of the Construction Industry Research and Information Association and the Transport and Road Research Laboratory and the paper is published by permission of the Directors. The Military Vehicle and Engineering Establishment provided the site for the experiment, both organisations are grateful for their assistance. The research was sponsored by the following UK organisations; Construction Industry Research and Information Association, Department of Transport, ICI Fibres Limited, Lambeg Industrial Research Association and Ministry of Defence.

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