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The use of geosynthetics in pavement engineering

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ABSTRACT: The use of geosynthetics in pavement and rail track construction is reviewed with emphasis on their role as reinforcing elements. The design principles are discussed for use in granular and asphalt layers and practical design methods are outlined.

1 INTRODUCTION

The use of geosynthetics in pavement construction has developed significantly over the past twenty years. In the mid-1970's, manufacturers produced a range of geotextiles looking for civil engineering applications. The principal highway application was separation of granular material from soil, filtration, which is a related requirement, and a vague hope that reinforcement could also be mobilised. Today, the civil engineer is able to design the geosynthetic into the construction and has a far wider choice of properties and material types available in the market place.

Extensive research and development has improved understanding of the basic mechanisms involved in separation, filtration, drainage and reinforcement. This work has embraced geosynthetic inclusions in soil, granular materials and asphalt, either within or between the construction layers and to facilitate positive drainage from the pavement to side drains. While most emphasis has been on road applications, both haul roads and permanent construction, geosynthetics have also been applied to airport pavements and to rail track.

This address concentrates on the reinforcing function, since this is where the largest potential savings and improvements to performance can be achieved.

2 DESIGN PRINCIPLES

2.1 *Reinforcement*

Reinforcement of pavement construction materials is effected by reducing the tensile strain which would otherwise develop at critical positions in the construction. Fig. 1 shows four examples of this for granular and for asphalt layers. In Fig. 1(a) there is a tendency for horizontal tension to develop at the bottom of the granular layer in a haul road over soft ground. Restrictions to this tensile movement will both improve the load spreading ability of the granular layer and reduce the stress on the subgrade. A comparable situation in a permanent road will occur when construction traffic operates on the foundation. It will also arise when the asphalt layer has been constructed over the foundation, particularly if the latter has a low stiffness. In these circumstances, the repeated loading caused by traffic over a long period can cause fatigue cracking, which generally initiates where the tensile strain is highest, i.e. at the bottom of the layer.

Fig. 1(b) illustrates repeated traffic loading causing permanent shear stresses which result in flow of material away from the wheel track. This causes the formation of ruts. Once again, a comparable situation arises in asphalt layers. Improved performance will result if these permanent strains can be reduced.

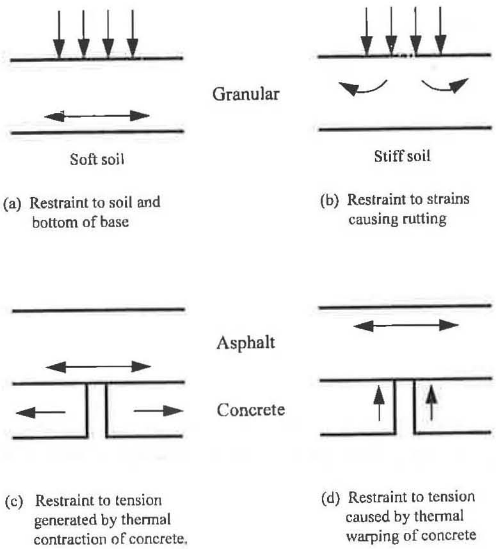

Fig 1. Various reinforcing concepts

The problem of reflection cracking of asphalt overlays above concrete pavements or asphalt layers over cement treated bases which crack, is illustrated in Figs. 1(c) and (d). High strains are induced in the asphalt layer when the concrete contracts due to a fall in temperature (Fig. 1,c) while the warping of concrete caused by a fall in air temperature after a hot day is considered to cause tension at the asphalt surface. The detailed mechanisms for the reflection cracking problem are still not fully understood, being more complex than those involved in the cases of Figs. 1(a) and (b).

An understanding of the basic mechanisms of pavements can, thus, indicate where critical strains develop under wheel loading and thermal loading. This suggests the most useful locations for tensile reinforcement. In Fig. 2, three scenarios are illustrated for haul roads or pavement foundations based on the principles in Fig. 1(a) and (b). In Fig. 3 the reinforcement of asphalt layers to reduce fatigue or reflection cracking and rutting is illustrated. For reflection cracking (Fig. 3,c), even if the crack cannot be entirely prevented from forming, some geosynthetics can provide a waterproofing layer above the underlying crack, which is helpful in extending pavement life.

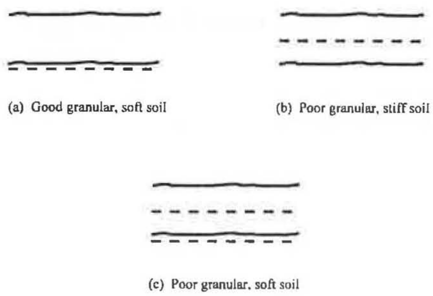

Fig 2. Geosynthetic reinforcement of haul roads or foundations to permanent roads

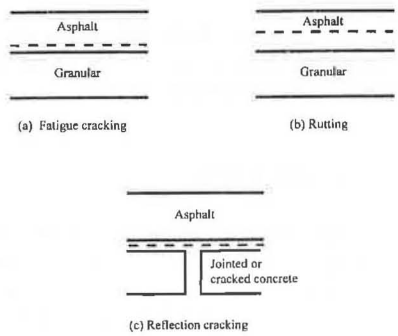

Fig 3. Applications of Geosynthetic reinforcement for asphalt layers

Applications to rail track are shown in Fig. 4. In all cases the reinforcing function would be based on the principles of Fig. 1(a). However, there may be a more important requirement to prevent contamination of the ballast by mobilising the separation function. In this case, positioning the geosynthetic above a sub-ballast layer (Fig. 4,b) is likely to give best performance. Fig. 4(d) shows how the geosynthetic may be used when replacing the top half of an old, contaminated layer of ballast with new material.

The environment in rail track is very harsh for geosynthetics. Laboratory and field tests summarised by Selig and Waters (1994) indicate that careful site investigation is needed when designing improvements to existing track so that the problems are properly understood and an appropriate geosynthetic inclusion can be included if required.

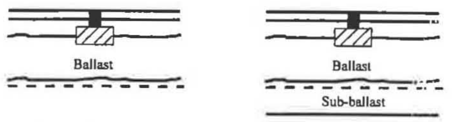

Fig 4. Rail track applications of Geosynthetic reinforcement

In order to mobile the reinforcing potential of a geosynthetic, it must have three critical properties; appropriate stiffness and strength and ability to interlock effectively with the host material. The strength requirement is obvious; since it must not fail in service. The stiffness requirement relates to the need for tensile strains to be minimised. The interlock with surrounding material is to ensure compatibility of strains. Clearly if the geosynthetic slips relative to the material it is reinforcing, then the effect is lost. This requirement leads to a need for the geosynthetic to be compatible with the host material. Early pilot scale pavement experiments by Brown et al (1982) showed that the use of a melt bonded non-woven geotextile between a standard crushed limestone base and a silty clay subgrade resulted in poorer performance than when no geotextile was used. Their results are summarised in Fig. 5 as transverse surface profiles with the full lines for the reinforced cases. The pore sizes of the geotextile were much smaller than the particle sizes of the limestone. The use of a stiffer geotextile in experiments G5, GT5 and G6, GT6, did not improve the situation.

Further experiments, reported by Chan et al (1989), showed that a stiff woven geotextile was less effective at reducing rutting than a less stiff geogrid. This demonstrated the importance of good interlock which was mobilised by the grid. Placement of the reinforcement near the top of the granular layer, when the subgrade was reasonably stiff, was more effective than the usual location at the interface with the soil.

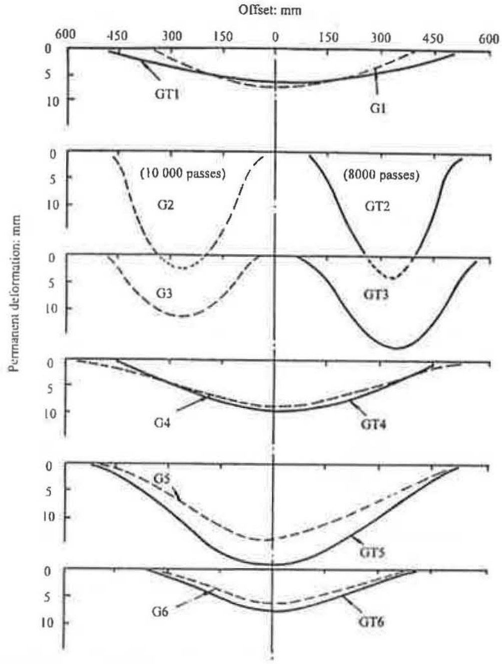

Fig 5. Transverse surface profiles after 60 000 wheel passes (after Brown et al, 1982)

For reinforced asphalt, the effectiveness of geogrids has been demonstrated by Brown et al (1985,a) and by Brunton and Caltabiano (1991) in laboratory testing. The ability of stiff grids to control crack propagation resulted in a tenfold increase in fatigue life for a standard asphaltic concrete as shown in Fig. 6. The number of load applications to reach a critical rut depth was increased by a factor of three when a grid was placed at a depth of 0.2 to 0.3 times the width of the wheel load contact patch.

The beam tests by Brunton and Caltabiano (1991) are summarised in Table 1. This shows relative lives based on reflection crack development for three potential treatments and their relative costs.

As noted above, the reinforcing mechanism for reflection cracking is not fully understood. Very high concentrated tensile strains can develop above cracks or joints in the concrete below. For the overlay to be protected from the effects of these high strains requires that the deformation across the crack be dissipated over a reasonable length of the overlay either side of the discontinuity. This

Table 1. Reflection cracking performance of overlays (after Brunton and Caltabiano, 1991)

Overlay	Relative lives	Relative costs
Standard asphaltic concrete	1	-
Polymer modified concrete	2.5	2.5
Geotextile reinforcement	5	1.0
Geogrid reinforcement	10	4.0

requires some controlled debonding for a limited distance and evidence of this was noted by Brown et al (1985,a) in their beam experiments. In practice, the installation method has to be carefully defined to ensure that the debonding does not become general as slip between the overlay and the existing road surface is clearly undesirable.

2.2 *Separation and filtration*

There is much evidence to suggest that a geotextile cannot prevent some clay particles from penetrating into an overlying granular layer under repeated loading. While small pore size is an obvious requirement, the ability to prevent local movement of granular particles, which may cause a pumping effect, is also desirable and this requires a grid rather than a fabric. The new composite materials involving a geotextile bonded to a grid and intended for asphalt applications, may offer a good solution, since they will provide reinforcement as well as separation. Whenever a small pore size geotextile or a geomembrane are used, careful consideration must be given to the possibility for pore water pressures building up in the subgrade. The filtration function of geotextiles is intended to prevent this but clogging by fine particles can reduce effectiveness in time. A build-up of pore pressure will reduce the effective stress in the soil leading to reduced strength and stiffness.

3 DESIGN METHODS

3.1 *Asphalt reinforcement*

No effective design method for practical use has yet been developed for overlays where reflection cracking is a possibility. The two conferences on reflection cracking held by RILEM (1989, 1993) have included papers on analysis and performance of trial sections, but not on design.

For the fatigue cracking and rutting failure mechanisms in conventional asphalt pavements, Brown et al (1985) used an extension of the mechanistic design method developed at Nottingham (Brunton et al, 1987) for unreinforced pavements. They were able to quantity the benefits of including a grid at the bottom of the asphalt layer and within the layer to deal with cracking and rutting respectively. Some typical results are shown in Fig. 7 for U.K. conditions and in Table 2 for three U.S. locations.

These design methods were based on an extension of fatigue life by a factor of ten and of life to a critical rut depth by a factor of three. Further work is currently in progress at Nottingham to improve the design methods for reinforced asphalt and to make their applications more general.

3.2 *Haul roads and pavement foundations*

A design method was developed at the University of Oxford by Houlsby et al (1989) and Milligan et al (1989) which was extended by Houlsby and Jewell (1990). The method considers monotonic loading of a granular layer over a soil and is based on the increase in bearing capacity made possible by reinforcement restraining horizontal movement at the interface. The system is shown in Fig. 8. The vertical stress on the subgrade (p_r) and tension in the reinforcement (T) are calculated for an assumed angle of load spreading, β, load contact pressure, p, and angle of shearing resistance for the granular layer (ϕ'). The clay subgrade is characterised by its undrained shear strength (c_u).

Design charts were developed by Houlsby and Jewell (1990) using a computer program. Fig. 9 shows an example of these charts which are based on the use of dimensionless parameters. The arrows indicate how the chart is used. Part (a) is entered

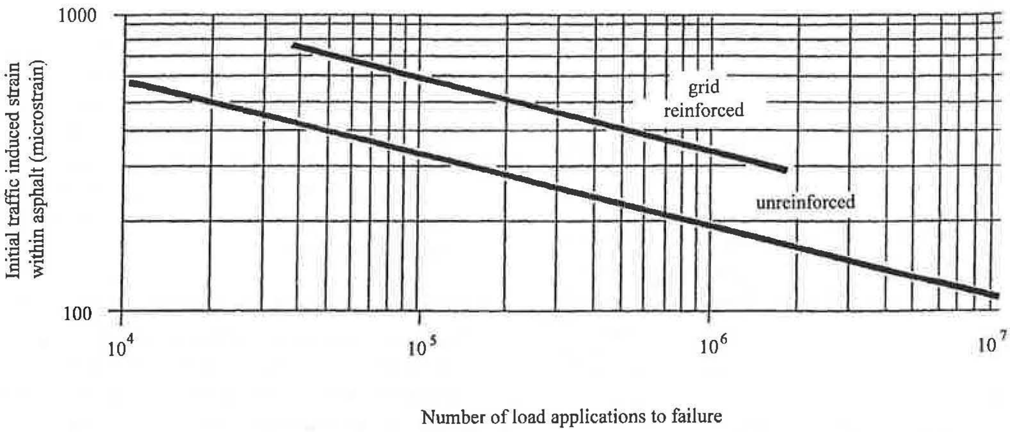

Fig 6. Fatigue strength of reinforced asphalt (after Brown et al, 1985a)

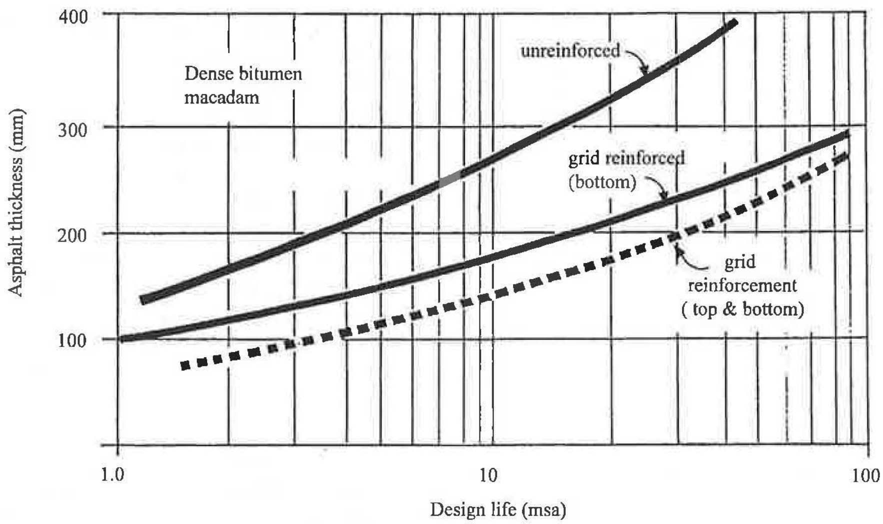

Fig 7. Effect of grid reinforcement on design thickness for UK (Afer Brown et al, 1985b)

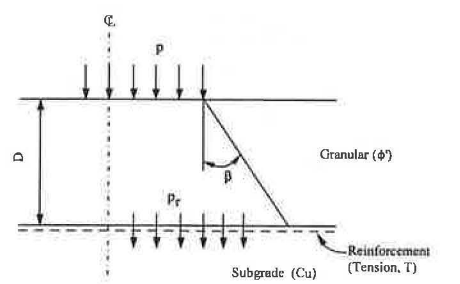

Fig 8. Oxford design method (After Houlsby and Jewell, 1990)

with the ratio of applied contact pressure (p) divided by undrained shear strength of the subgrade(c_u). Intersection with the reinforced load capacity line determines the thickness of the granular layer. Extrapolation to part (b) gives the tensile force required for the reinforcement, normalised with respect to the product of c_u and the radius of the loaded area (c). Part (a) of the diagram is also used to determine the thickness of an unreinforced granular layer through intersection with the line for the appropriate angle of shearing resistance. The details of this design example are summarised in Table 3.

Table 2. Summary of Potential Asphalt Saving Through Inclusion of Reinforcing Grid (after Brown et al, 1985,a)

Temperature Region	Design life (msa)	% saving in asphalt thickness	
		1 layer of grid at bottom	1 layer grid near top and 1 layer grid bottom
1	1	-	14
New York	10	16	29
	100	26	35
2	1	13	27
South	10	24	35
Carolina	100	29	31
3	1	11	24
Ottowa,	10	25	36
Illinois	100	30	31

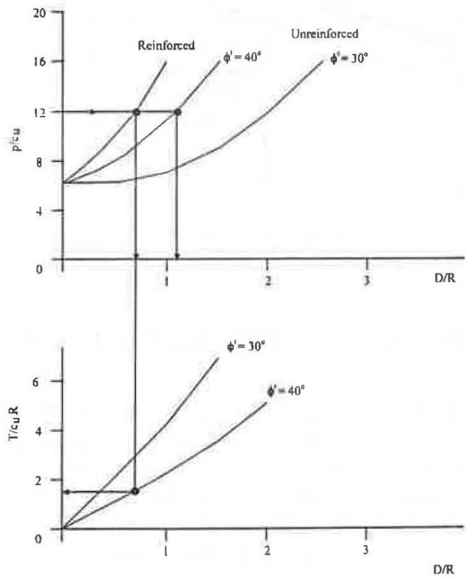

Fig 9. Design chart for unsurfaced pavement, $\beta = 35^\circ$, $c_u/\gamma R = 5$, (after Houlsby and Jewell, 1990)

This design method requires further development to take account of the effects caused by repeated loading. A method for unreinforced pavement foundations has been proposed based on extensive research into repeated loading of soils and granular materials. This work has been summarised by Brown (1996). A blending of these two approaches could provide a more appropriate method in the future.

Earlier design methods were based on use of the "tension membrane" effect (Fig. 10) which is unrealistic unless very large rut depths can be tolerated. The reason for this is that a large strain needs to be mobilised in the reinforcement to develop the necessary force and ensure a significant vertical component on which the reinforcing effect depends.

A useful review of design methods for reinforced haul roads has been presented by Little (1993). He conducted full-scale trials at the Bothkennar soft clay site in Scotland and carefully monitored the performance of sixteen test sections with and without reinforcement designed by various methods incorporating five different geosynthetics and a bamboo/geotextile combination. A summary of the experiments has been presented by Dawson et al (1994). The findings from these experiments were used to evaluate the design methods and to obtain an improved understanding of basic mechanisms. This was facilitated by the use of extensive insitu instrumentation.

Rut depth was taken as the basic design parameter. About 20% of the rutting was observed to take place within the granular layer rather than in

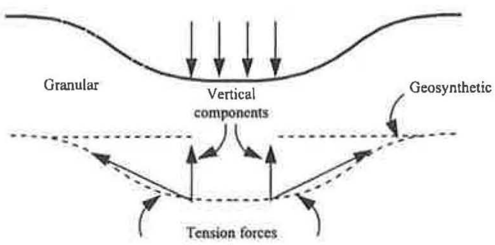

Fig 10. Tension-membrane principle

Table 3. Design example for unsurfaced pavement (after Houlsby and Jewell, 1990)

INPUT	
Wheel load (kN)	40
Load radius (m)	0.22
Contact pressure (kPa)	263
Undrained shear strength for clay (kPa)	22
Unit weight of subgrade (kN/m^3)	22
Angle of shearing resistance for granular layer (°)	40
Load spread angle (°)	35
OUTPUT	
Thickness of reinforced layer (in)	0.14
Tensile force in reinforcement (kN/m)	7.6
Thickness of unreinforced layer (in)	0.23

the subgrade. This was partly due to an increase in undrained shear strength of the subgrade surface from about 45 kPa to 80-100 kPa as a result of prolonged dry weather during and after construction. The concept of placing the reinforcement within the granular layer for situations like this appears sound.

The assumptions of the Oxford design method appeared reasonable while the tension membrane effect was only mobilised for a section which approached failure with a 200 mm rut. The other major finding was that the development of rutting involved a rapid initial phase followed by a linear increase with the number of load applications. This contrasts with the usual assumption of an exponential relationship between rut depth and wheel passes. The fourth power law did not appear to apply for the small number of different load magnitudes which were involved. The separation function of the geosynthetics was significant based on excavations made after trafficking.

4 CONCLUSIONS

1. Extensive use is now being made of a wide range of geosynthetics to improve pavement performance or to economise in design.

2. The principles of design to reinforce pavements with geosynthetics in asphalt or in the granular layer are being better understood.

3. The reflection cracking problem in asphalt overlays still requires further research before a reliable design method will evolve.

4. Rational design methods do exist for the reinforcement of haul roads and pavement foundations.

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