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No. 18 of 19

Geosynthetics in Asphalt Pavements

by

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Lecture Outline

- The pavement design problem
- Reinforcement
- Design methods
- Fatigue/failure
- Construction requirements
- Background research

The Pavement Design Problem

•Pavements need to carry large numbers of moving wheel loads over many years; designs are typically for a 20 year life.

•Pavement failure is defined in terms of decreasing serviceability caused by the development of cracks and ruts.

•Wheel loads have to be spread through the construction to ensure that no component, from the soil to the surfacing, is over-stressed.

•Analytical methods are increasingly being used to do these calculations.

•In the past and in much current practice, pavement design is empirical.

•Proper use of geosynthetics in a cost-effective manner requires the scientific approach based on the use of analysis and the results of relevant research.

Asphalt Pavement Mechanics

- Failure mechanisms
- New roads
- Maintenance of existing roads

•As an introduction to asphalt pavement engineering, the next section will deal with an understanding of failure mechanisms.

•In developed countries, most highway engineering is concerned with maintenance rather than new construction.

•Both topics will be covered since they are interconnected

Failure Mechanisms

- Fatigue cracking
- Rutting
- Importance of repeated loading

•Fatigue cracking of asphalt and cement treated materials involves tensile failure at stress or strain levels below the static strength of the material.

•Hence, failure depends on the number of wheel load applications, which can be many millions for major highways.

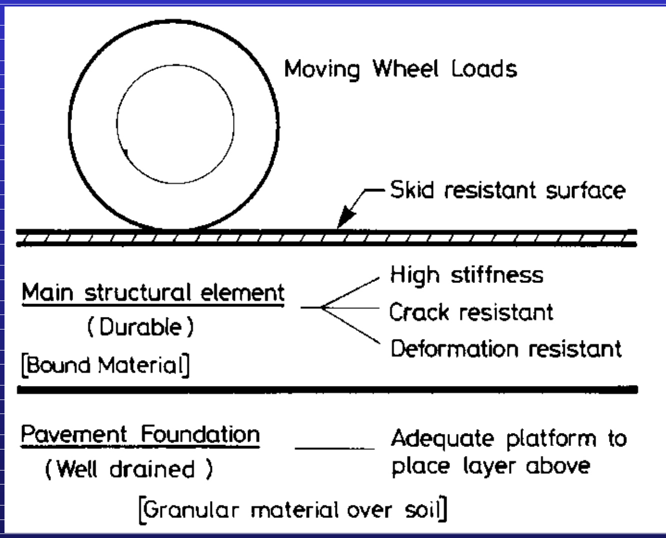
•Cracking is a structural failure and the effectiveness of the asphalt layer in distributing wheel loads to protect the lower layers decreases as cracking develops.

•Rutting results in reduced serviceability through ponding of water and constitutes a danger to traffic.

•It is also a function of the number of wheel loads and is worse when temperatures are high because of the visco-elastic nature of asphalt.

•Each of these failure mechanisms will be described in what follows.

Design Requirements for Asphalt Pavements



•Before dealing with the individual failure modes, it is appropriate to summarise the design requirements for an asphalt pavement.

•The surfacing is essentially cosmetic and provides skid resistance and, sometimes, waterproofing.

•The dense asphaltic materials provide the main structural layer which must have the properties shown.

•Composite construction can be used in which the lower part of this layer is made from cement treated material. This generates shrinkage cracks which can ‘reflect’ through the asphalt and measures are needed to deal with this problem. Geosynthetics can be applied.

•The term ‘durability’ has a special meaning in asphalt technology; it refers to resistance to effects of the environment, principally air and water, which can cause ageing and stripping of binder from aggregate respectively.

•The pavement foundation has to carry construction traffic in the short term (a small number of high stress applications) and provide good support in the long term (a large number of low stress applications).

Typical Fatigue Cracking

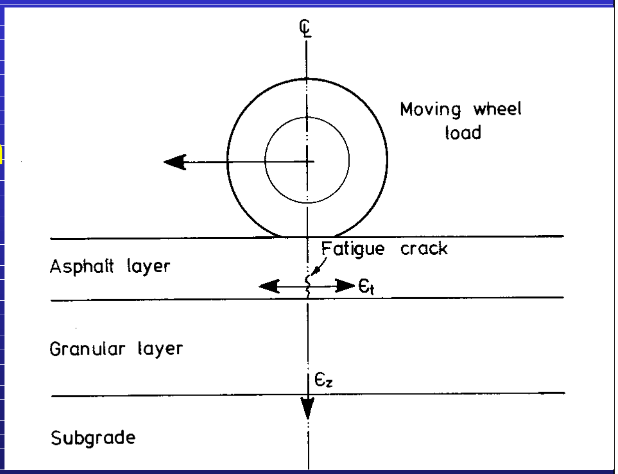
•Fatigue cracking develops in the wheel tracks as a result of repeated traffic loading.

•It initiates where the tensile strain is highest. This is at the bottom the layer for most situations but surface initiated cracking is common in heavy duty pavements with stiff foundations.

•The cracks weaken the asphalt layer and, when they have propagated through the layer, water can enter and weaken the lower layers of the pavement.

Fatigue Cracking Principles

- Crack initiation depends on tensile strain
- Crack propagation depends on tensile stress
- Interaction of asphalt layer and foundation



•The tensile strain is a function of the thickness and stiffness of the asphalt layer and of the stiffness of the foundation.

•Once initiated, the propagation of the crack depends on the tensile stress.

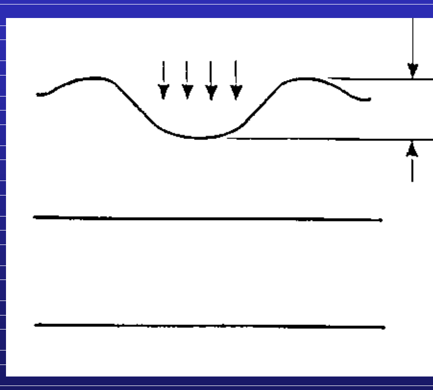
•Typically, the life of the layer is made up of a relatively short crack initiation phase and a relatively long crack propagation phase.

•Mechanistic design methods typically use linear elastic theory to compute the tensile strain and relate this to the fatigue life including an empirical allowance for crack propagation time.

•The vertical strain at the top of the subgrade is used to assist with design against rutting.

Rutting Mechanism for Asphalt Layer

- Permanent shear strains near surface
- High temperatures
- Heavy wheel loads
- High traffic volume



•This type of rutting is caused by the accumulation of permanent (irrecoverable) shear strains which are highest below the edge of the wheel load and some 50 to 100 mm below the surface.

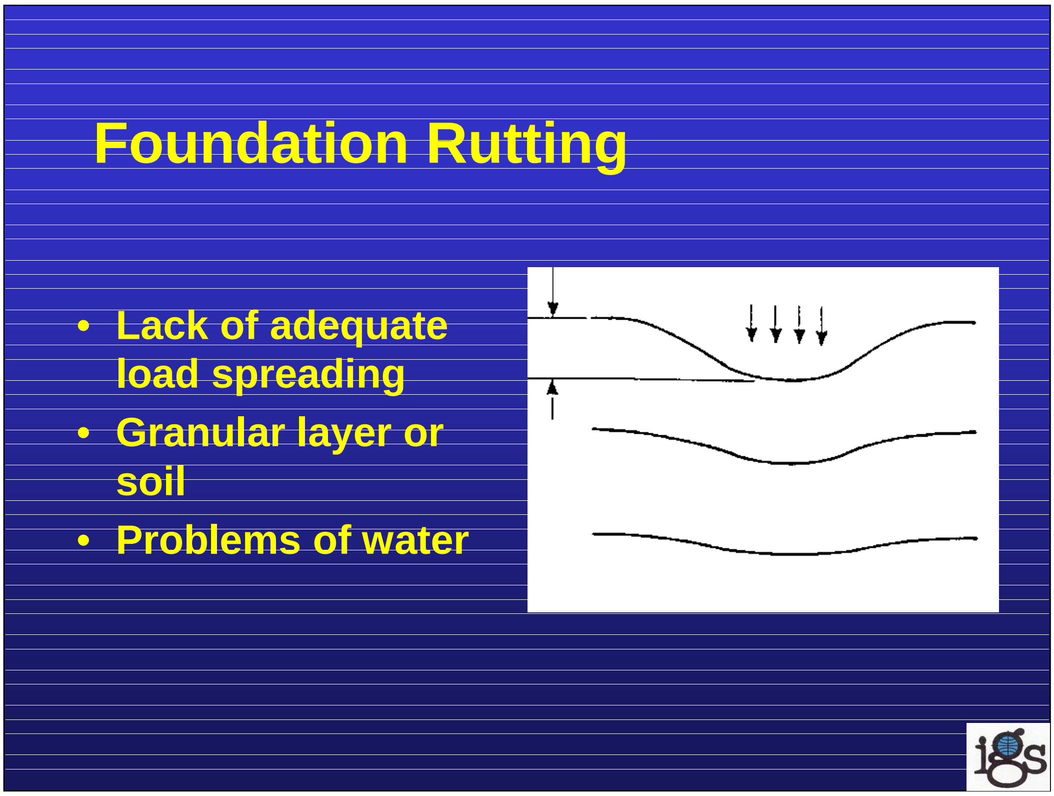
•The characteristic ‘hump’ at the sides of the rut typifies this form of rutting, which is caused by inadequate mixture design for the conditions.

•The worst conditions for this type of rutting are identified on the slide.

Typical Wheel-track Rutting

•This is a typical example of rutting in the asphalt near the surface.

•The dual wheel loads applied by most heavy vehicles are reflected in the shape of the ruts.



•Ruts which are wider and do not display the side 'humps' are caused by permanent strains developing lower down in the construction.

•This is a result of over-stressing of the granular layer and/or the subgrade.

•It is aggravated by the presence of water, which weakens the resistance of these materials to deformation.

Roles for Geosynthetics

- Separation/Filtration
- Reinforcement

•Geosynthetics can be used in various ways to mitigate the distress mechanisms which develop in pavements.

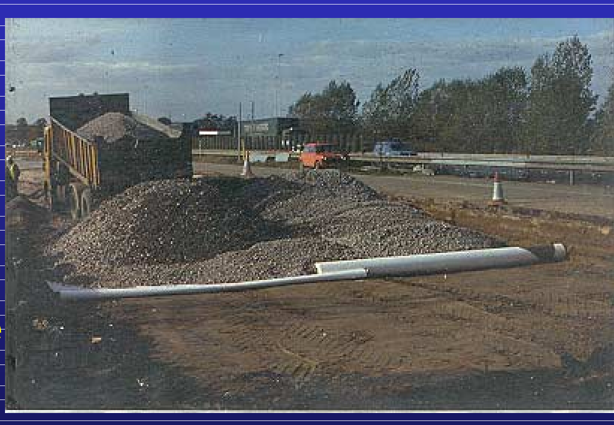
•The two principal roles are **separation/filtration**, to prevent cohesive soil contaminating granular material, and **reinforcement** to control the development of strains which can cause failure.

•Reinforcement can be used in the foundation and in the asphalt.

•It can also be used for new construction or for overlays applied to strengthen existing pavements.

Separation & Filtration

- Interface between soil & aggregate
- Prevent contamination
- Avoid build-up of pore pressure



•This was the first application of geosynthetics to pavements.

•The geosynthetic is applied between the soil and the granular layer.

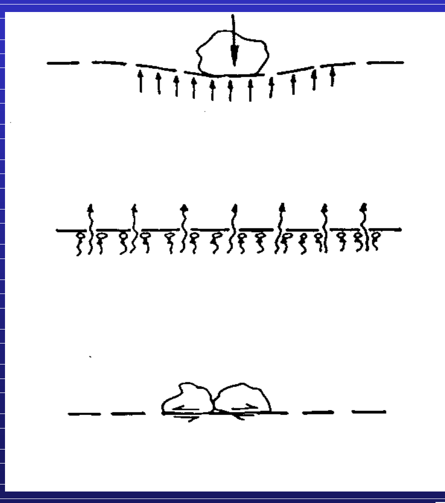
•It can be used simply as a construction expedient for wet sites.

•It can also be applied for long-term separation to maintain the structural integrity of the granular layer. The presence of clay particles reduces the stiffness and deformation resistance of granular material and makes them more susceptible to deterioration by water.

•It is important that separators allow pore water pressure in the soil to dissipate, otherwise serious weakening can occur. Hence, the filtration role of the geosynthetic must be combined with that of separation.

Mechanism of Separation

- Appropriate pore size for geosynthetic
- Advantages of interlock
- Construction expedient or long term effect



•Research has shown that geotextiles may not completely prevent the passage of clay particles in the long term, though they will probably reduce it.

•The pore size of the fabric is critical; too small and filtration will be prevented; too large and separation will not be effective.

•Geogrids can lock the granular particles together and prevent repeated strains on the soil that can cause slurry to form and pumping of the slurry up into the granular layer.

•Ideally the siffness of a grid combined with the small pore size of a fabric may provide the ideal combination.

Reinforcement

- Only deals with potential failure mechanisms
- No effect on transient strains
- No reduction in surface deflection
- Reduction in permanent strain level
- Restriction to crack propagation

•Important to realise that reinforcement in pavements is intended to prevent or to impede the development of those strains which are likely to lead to failure.

•Consequently, the inclusion of a reinforcement will not result in lower transient strains or deflections. Thus surface delection measurements, for instance, will not be reduced by the presence of a reinforcing element.

•Geosynthetic reinforcement is analogous to steel reinforcement in concrete pavement slabs, which is intended to control, rather than to eliminate cracking.

•To be effective, geosynthetic reinforcement must be positioned in the pavement as close as possible to the location of the critical strain which it is intended to control.

Foundation Reinforcement

- Reduce rutting from construction traffic
- Haul roads or foundations to permanent roads

•The reinforcement of foundations for permanent roads can follow the same general principles as for unsurfaced haul roads.

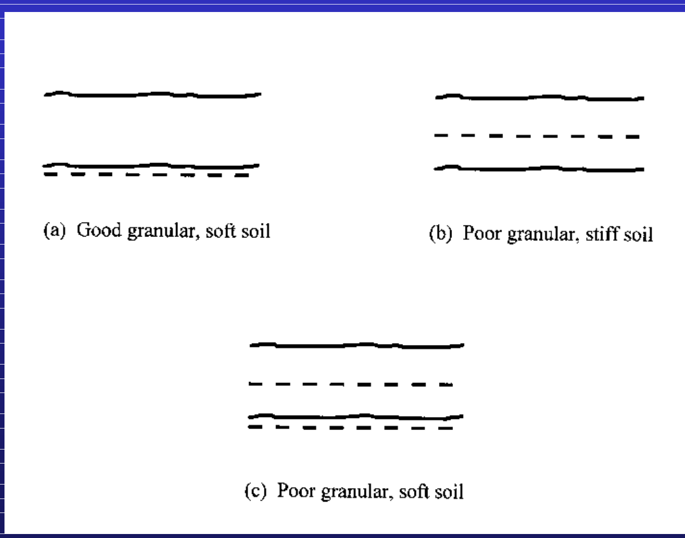
•The critical requirement is that large rutting should be prevented. The permissible rut depth may be up to 75mm for an unsurfaced haul road but somewhat less (up to 50 mm) for a permanent road foundation.

•The foundation of a permanent road has to be designed to carry the high loads imposed by construction traffic. This will involve, at least, asphalt delivery lorries, pavers and the stresses imposed by compaction equipment operating on the asphalt layers above. For concrete pavements, use of a paving train may mean that the foundation is more protected. In other situations, the foundation may be used as a haul road fopr access to other parts of the site.

Sub-base Rutting from Construction traffic

•This slide illustrates the type of rutting which can occur during an asphalt paving operation and is caused by the delivery lorries backing up to the paver.

Locations for Reinforcement of Foundations



•Rutting in an unsurfaced road subjected to wheel loading can develop through accumulation or vertical permanent strains either in the granular layer, the subgrade or both.

•The three figures show the best location for the reinforcement for each case.

•In case (a), the objective is to increase the bearing capacity of the soft subgrade by restricting lateral movement at its surface.

•In case (b), the objective is to restrict the permanent strain development in the granular layer and this is best achieved by placing the reinforcement at approximately mid-depth unless the layer is very thick when it should be at a depth of about 150 mm.

•Case (c) caters for both the above situations.

Design Methods

- Oxford/Jewell analytical method
- Based on increase of subgrade bearing capacity
- Charts available
- Geosynthetic at bottom of granular layer

•An analytical design method has been developed for reinforced haul roads based on work at Oxford University, extended by Jewell.

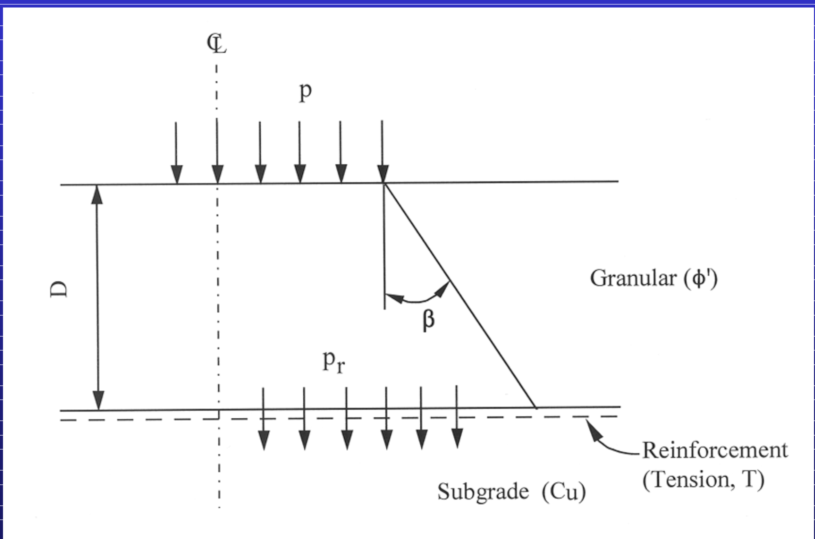
•It is based on increasing the bearing capacity of the subgrade by limiting lateral deformation at the surface of the subgrade.

•This is achieved by placing the reinforcement at the granular fill/subgrade interface.

•Details of the method are contained in the CIRIA publication by Jewell entitled ?

•An outline is presented in what follows since the method can be applied to the foundations of permanent roads. The CIRIA publication should be consulted for full details.

Oxford/Jewell Design Principle



•This slide identifies most of the key parameters required for the design calculations.

•A value for the angle of load spreading has to be assumed; a typical value is ?

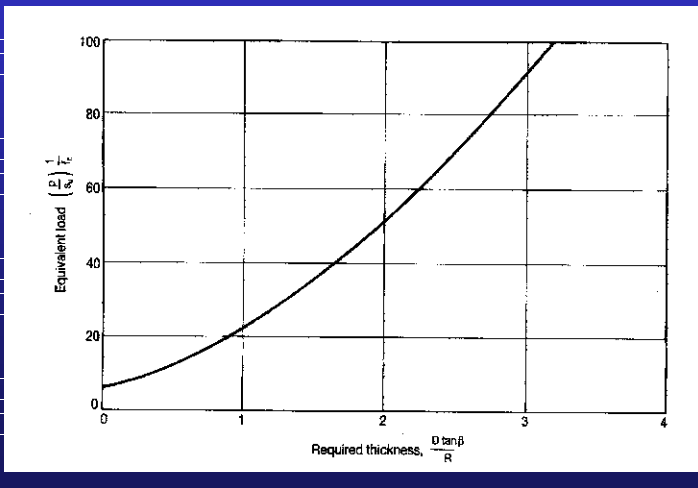
Oxford/Jewell Method

- Input parameters
  - Undrained shear strength and unit weight of subgrade
  - Applied contact pressure & wheel load
  - Shear strength of granular material
  - Load spreading angle
  - No of load applications
- Output
  - Layer thickness; reinforced & unreinforced
  - Tensile force in geosynthetic

•The design parameters and the output are identified here.

•Designs for the reinforced and unreinforced cases can be carried out for comparison and to assess the economics of the reinforced case.

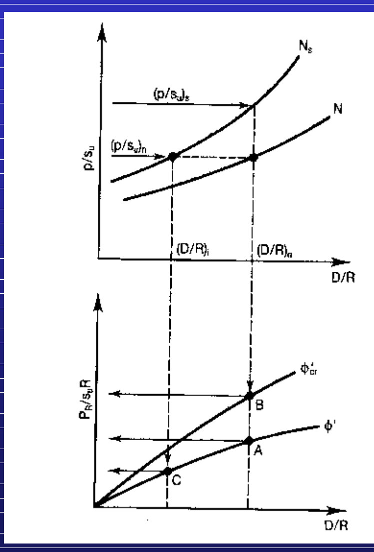
Design Chart 1 for Unpaved Roads (After Jewell)



•This chart, like the others to follow, is in non-dimensional units.

•The required thickness is related to the equivalent load, which incorporates a term to allow for repeated loading, since the original analysis was for the monotonic loading case.

Design Chart 2 for Unpaved roads (after Jewell)



Asphalt Reinforcement

- Increase in fatigue life
- Reduction in rutting
- New construction
- Strengthening overlays
- Generally requires stiff geogrids

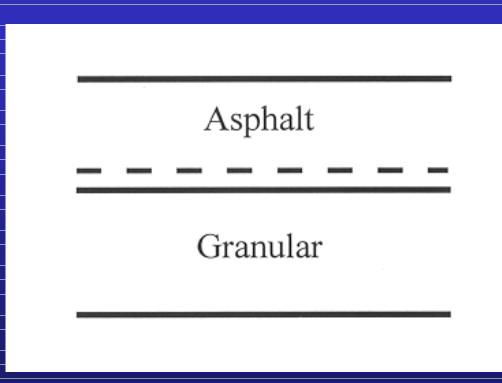
•Reinforcement of asphalt layers can be used to inhibit fatigue cracking in new construction or reflection cracking in overlays over cracked or jointed construction which is usually in concrete or other cement treated materials.

•It can also be deployed to reduce rutting in either form of construction.

•To be most effective, stiff geogrids are the best option for asphalt reinforcement but certain geotextiles can have some effect on slowing down reflection cracking and provide a waterproofing layer below an overlay when cracking does develop.

Fatigue Cracking

- Locate where tensile stress/strain is maximum
- Restricts crack growth

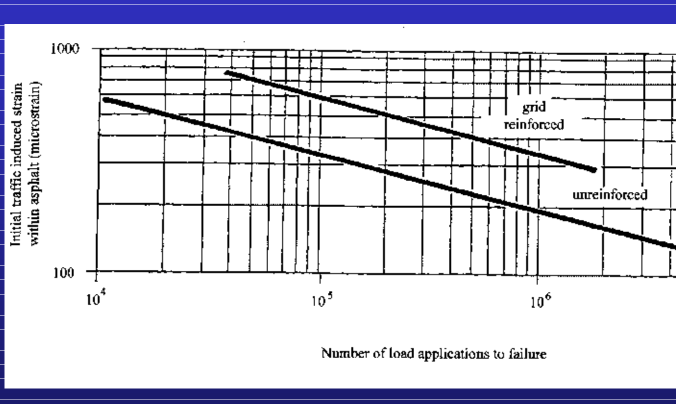


•For inhibiting the growth of classical fatigue cracking in the main asphalt layer of a pavement, the geogrid shopuld be placed near the bottom of the layer where the tensile stress and strain is a maximum.

•The presence of the grid may not delay the initiation of cracks but will inhibit crack propogation under repeated loading through control of the local tensile strains.

Design for Fatigue Cracking

- Fatigue life increased by 10 times
- Grid located at bottom of layer
- Use in mechanistic design method



•Research at the University of Nottingham has shown that the relationship between the maximum tensile strain and the number of cycles to produce failure through cracking is modified by the presence of a high tensile polymeric grid.

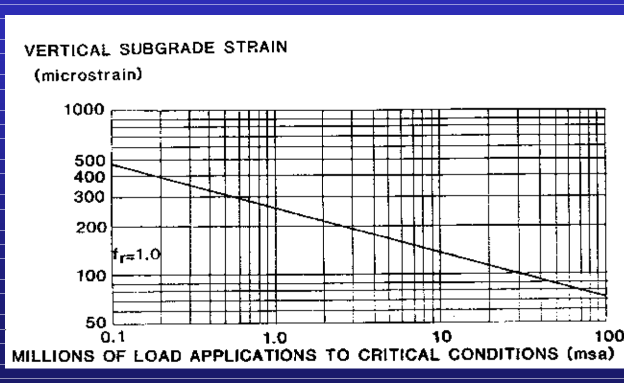
•This modification results in the life, at a particular strain level, being increased by a factor of 10. This is a result of longer crack propagation time.

•The lives plotted here include crack initiation and propagation phases.

•This relationship provides the basis for designing a reinforced asphalt layer using the mechanistic approach.

Approximate Design for Rutting

- Life for given strain level increased by factor of three
- Use with mechanistic design method
- Grid in top half of layer



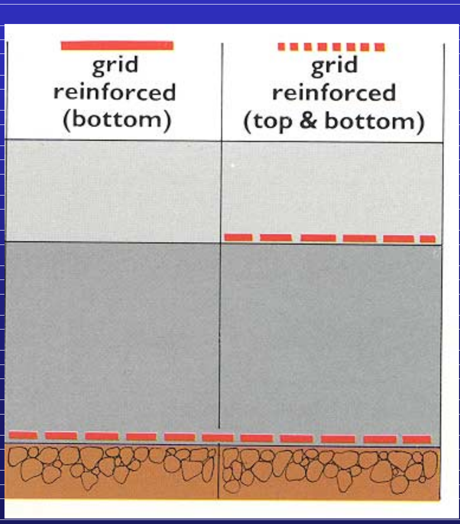
•The basis for design to limit the development of serious rutting is the use of this relationship between the vertical compressive strain at the top of the subgrade and the number of load applications.

•This is a semi-empirical relationship derived from the back-analysis of pavements with known performance.

•Research at Nottingham showed that the provision of a reinforcing element in the asphalt layer can increase life to a critical rut depth by a factor of three.

•Consequently, an approximate approach to design is to shift the relationship in this figure to the left by this factor so that, at a particular strain, the life is increased by a factor of three.

Grid Locations for Asphalt reinforcement

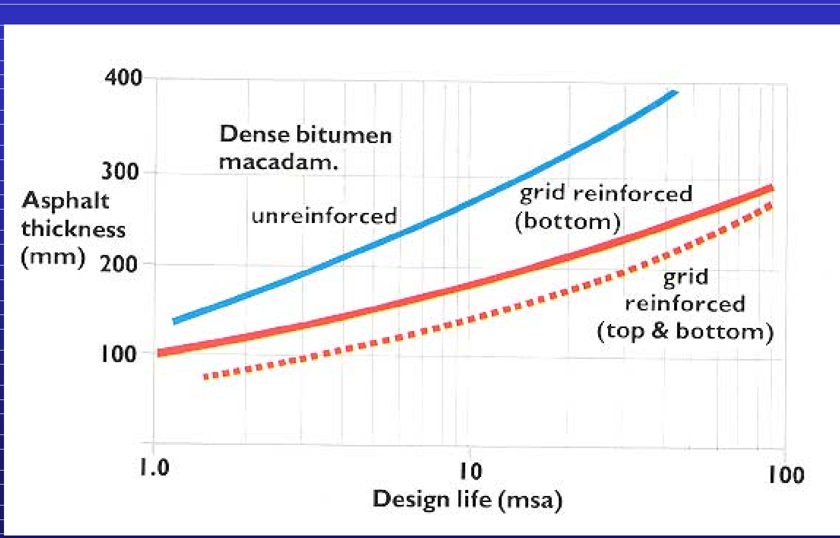


•This slide shows the preferred locations for geogrid reinforcement of asphalt.

•One layer at the bottom of the asphalt deals with fatigue cracking, while the additional layer nearer the surface will be effective for rutting.

•These mechanisms have been demonstrated in research at Nottingham using the Pavement Test Facility.

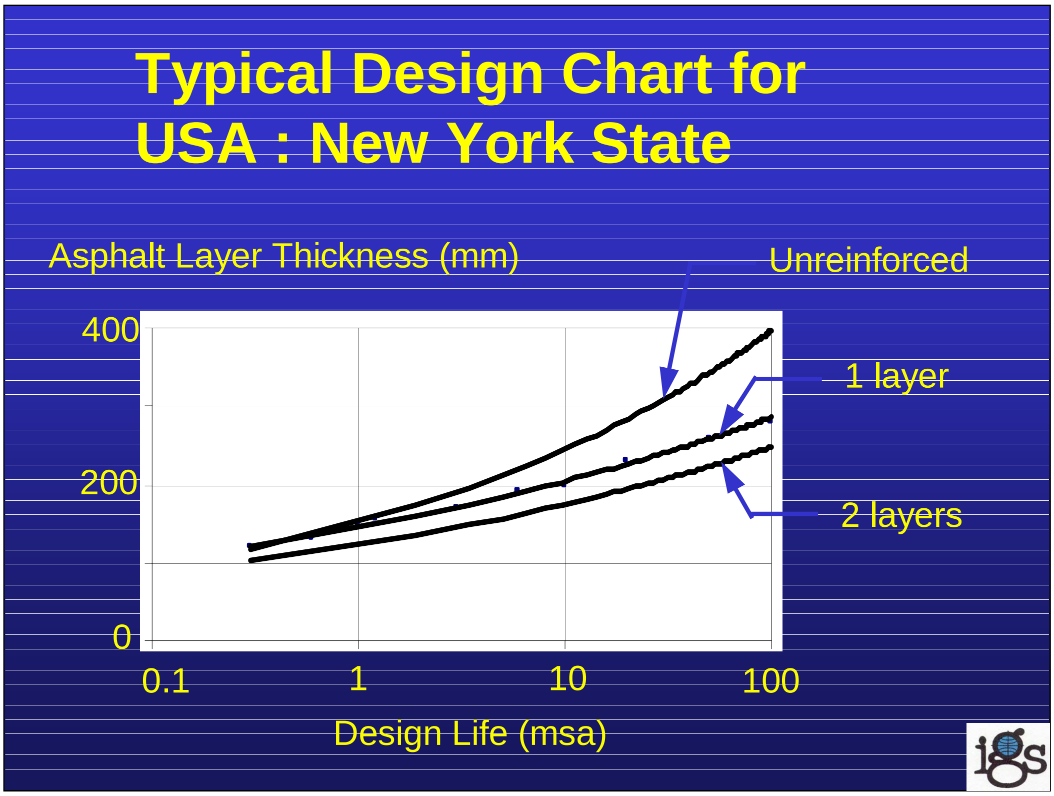
Typical Design Chart for UK conditions



•This chart shows asphalt layer thicknesses required for particular design lives in terms of millions of standard axles.

•It shows three situations: Unreinforced, Singly reinforced for fatigue cracking and Doubly reinforced for both cracking and rutting.

•Similar relationships can be determined for other environmental situations and with different types of asphalt mixture by using the basic relationships presented earlier between the critical strains and the number of load applications that are appropriate for the location under consideration.



•This slide provides an example of design curves for a different location, namely New York State.

•The principles used to develop this chart were the same as for the UK with due consideration given to the different environmental conditions involved.

Reinforcement of Asphalt Overlays

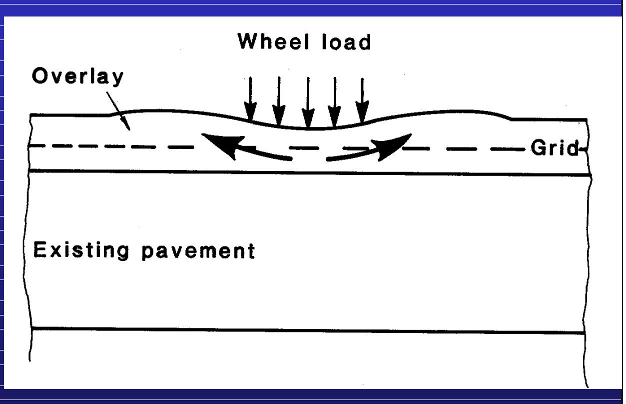
- Rutting
- Reflection cracking
- Composite construction

•As noted earlier, reinforcement of asphalt overlays can assist with reducing the development of reflection cracking and rutting in that layer.

•For composite construction, in which the lower road base is built of a cement treated layer and the top is of asphalt, reinforcement at the interface between the two can assist with reducing the development of reflection cracks initiated by the effects of shrinkage during curing and thermal effects resulting from temperature changes.

Rutting in Overlays

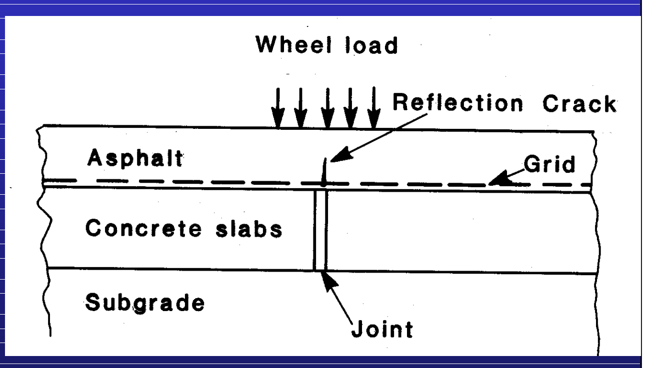
- Locate where strains are largest; mid-depth
- Increase in life to critical rut of three times
- Requires stiff geogrid



•This slide sets out the principles for reinforcing asphalt overlays to reduce rutting.

Reflection Cracking

- Locate near to existing discontinuity
- Mechanistic design method still evolving
- Stiff geogrid best
- Geotextile can waterproof



•This slide sets out the principles for reinforcing an overlay to reduce reflection cracking.

Parameters for Reflection Crack Reinforcement

- Stiffness of geogrid
- Shear strength of interface
- Location and installation of geogrid

•The most popular application of geogrids in asphalt paving has been for dealing with the reflection cracking problem in overlays.

•Research is still in progress on the development of a mechanistic design method for reinforced overlays which takes into account all the relevant parameters.

•This slide identifies the key factors.

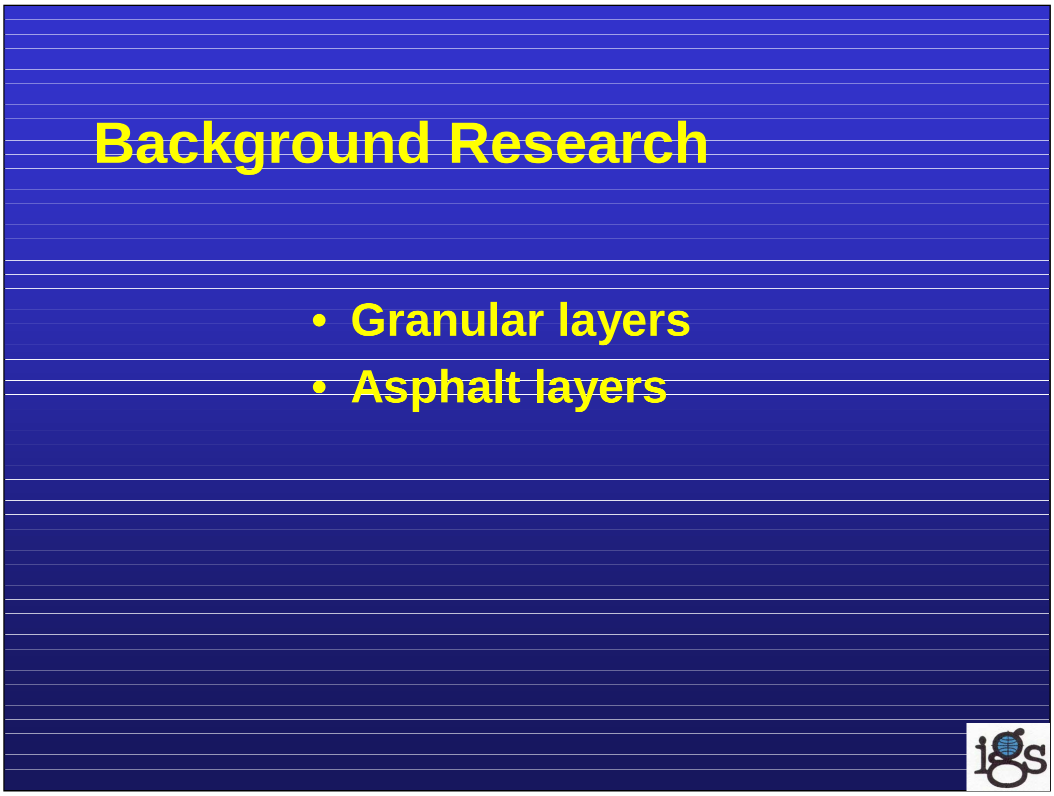
•The interface shear strength is important since any serious reduction in the continuity between layers either side of the reinforcement will reduce the structural integrity of the pavement. A balance has to be reached between the provision of crack inhibiting reinforcement and the need for an adequate shear strength, since there will usually be some reduction in the latter.

•The need for high quality construction must be emphasised for the benefits of reinforcement are to be achieved.

Construction Requirements

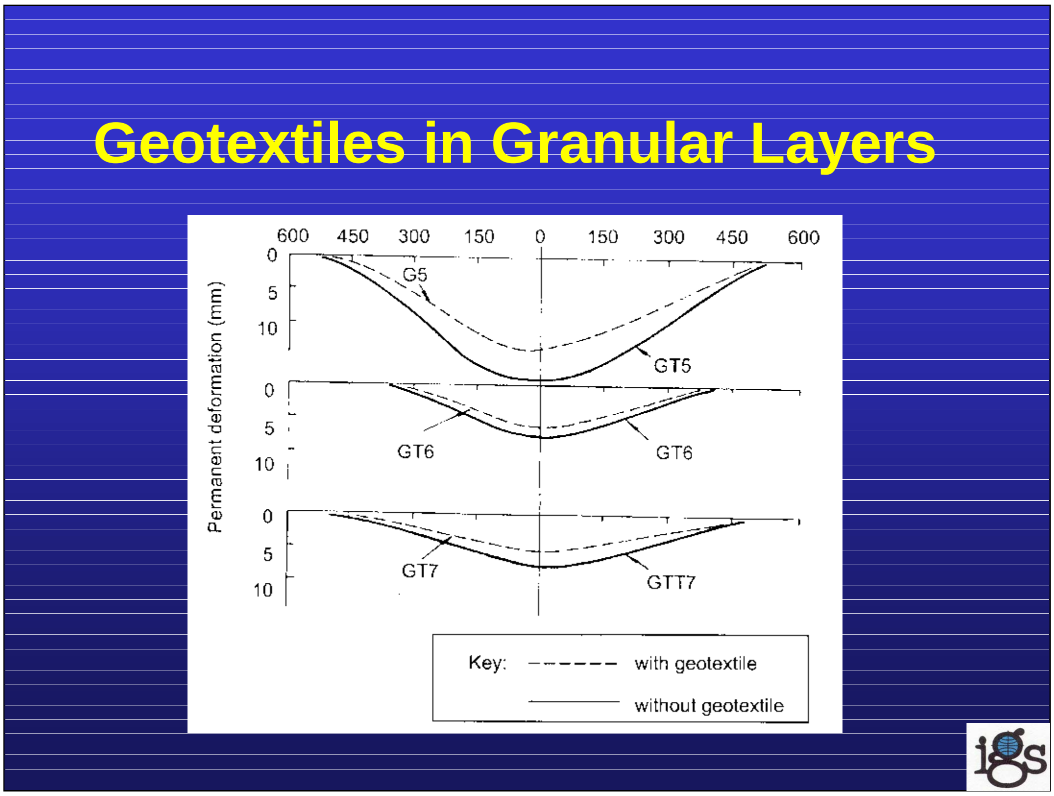
- Good site practice
- Geosynthetic must be firmly fixed and correctly located
- Attention to interface conditions
- Resistance to damage from hot asphalt

•This slide sets out some of the key features to be observed in construction of reinforced asphalt.



•This design-oriented presentation has referred to research that has provided quantitative information for design.

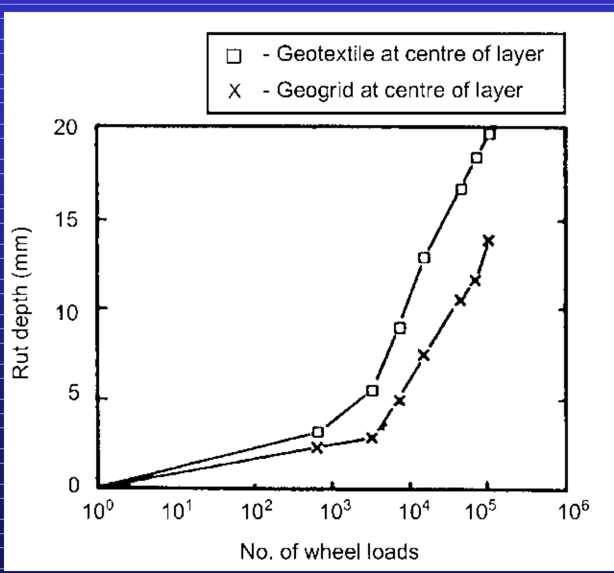
•The next section presents some of these key findings as background information.



•Early wheel-tracking tests at the University of Nottingham in the Pavement Test Facility showed that the use of a low stiffness geotextile below a granular base actually caused larger rut depths to develop than for the equivalent unreinforced sections.

•This was considered to arise because of the low stiffness of the geotextiles and the lack of adequate interlock or friction between the inclusion and the materials on either side of it.

Importance of Interlock

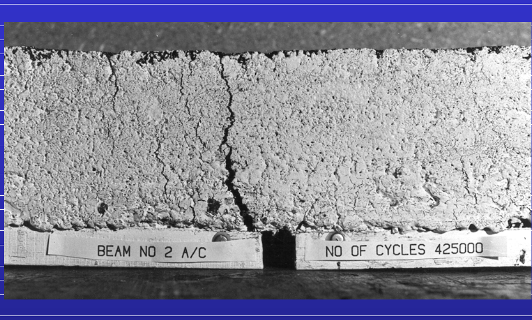


•Further results from the Nottingham research demonstrate the importance of interlock between the geosynthetic and the material in which it is installed.

•This slide shows that a stiff woven geotextile is less effective than a geogrid of lower stiffness in reucing rutting.

•In both cases, the reinforcement was placed at the centre of a ?? mm layer of crushed rock below a ?mm asphalt surface.

Reflection Cracking Reduction



•These two photographs contrast the response of a reinforced and an unreinforced beam of asphalt subjected to repeated loading in an environment designed to simulate reflection cracking in overlays.

Reflection Cracking Comparisons

(Caltabiano & Brunton, 1991)

Overlay	Relative Life	Relative Cost
Standard Asphalt	1.0	-
Polymer modified asphalt	2.5	2.5
Geotextile	5.0	1.0
Geogrid	10.0	4.0

•Tests which compared three reflection crack treatments in the beam testing arrangement shown on the previous slide provided the results summarised here.

•An indication of the relative costs of the treatments is also given.

•Both the geosynthetics were more effective than the polymer modified asphalt.

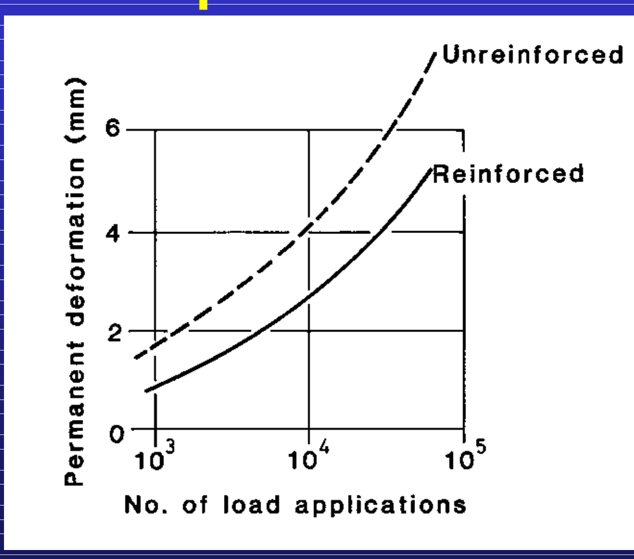
Rutting of Asphalt

(Brown et al,1985)

•This photograph shows a pair of slabs following wheel tracking at Nottingham.

•The lower rut depth in the right hand slab, which was reinforced, is readily apparent.

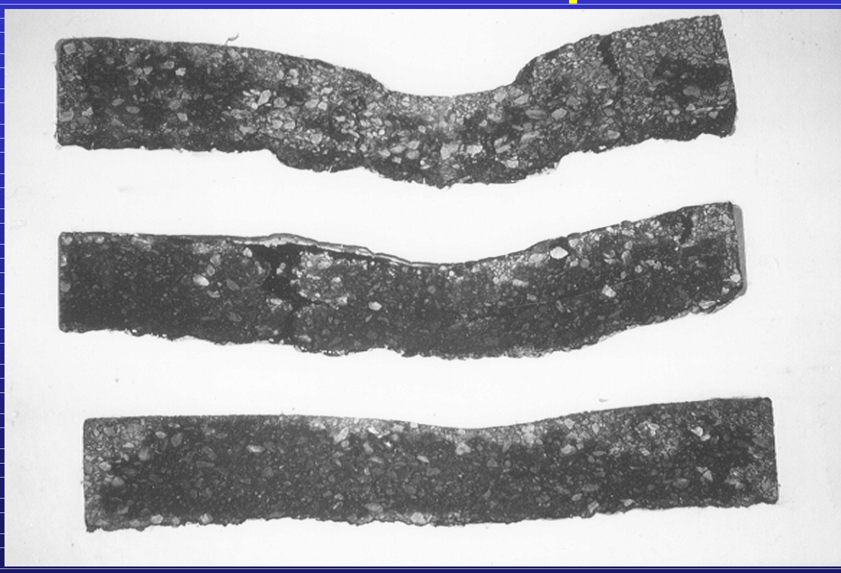
Rutting from Wheel Tracking Tests on Asphalt Slabs



•Relationships between the accumulation of permanent deformation, which causes rutting, and the number of load applications such as tjis were obtained from extensive wheel tracking tests at Nottingham.

•The factor of three recommended for design came from these test results.

Reinforcement of Asphalt



•These three cross sections of asphalt were cut from across the wheel tracks of test sections subjected to repeated wheel loading in the Nottingham Pavement Test Facility.

•The top section was unreinforced and exhibits cracking and rutting both in the layer itself but mainly from the layers below.

•The middle section had reinforcement at mid-depth and it can be seen that the rutting was entirely from the layers below. Hence, the reinforcement had prevented permanent deformations from developing in the asphalt itself.

•The third section was reinforced at its base to prevent fatigue cracking, which it has done. This also allowed the structural integrity of the layer to be preserved so that lower stresses were transferred to the foundation, which resulted in lower permanent deformation. Some permanent deformation did develop in the asphalt layer since the reinforcement was at the base and unable to reinforce for this mechanism.