Lessons learned from 20 years experience of geosynthetic reinforcement on pavement foundations

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ABSTRACT: Research into the mechanisms by which geogrid materials influence the performance of the granular layers of pavements began at the University of Oxford in 1979. The initial work involved model scale testing and indicated that some features of the reinforcing mechanism were more important than others to the performance of the pavement. The stiffness and form of the reinforcement were concluded to be particularly important, as was control of strain in the soft subgrade. Full scale testing with “static cyclic” rather than “rolling” load applications followed at the University of Waterloo in Canada. The valuable work by Giroud also highlighted the influence of membrane action and this was adopted by the geosynthetics industry worldwide. Further work at TRL in the UK on both pilot and full scale trafficked construction confirmed the influence of the reinforcement. Analytical work by Milligan et al looked again at the control of strain being the predominant mechanism and produced new proposals for reinforced pavement design. The US Corps of Engineers, Webster and Kinney, highlighted suggested important reinforcement properties and further work by Collin, Vanggaard, University of Newcastle continues this investigation.

1 OVERVIEW

Researchers have been examining the performance of geosynthetic materials in the granular layers of pavements for over 20 years and many have tried to identify important properties and mechanisms that influence the performance of the pavement. The early work was carried out at model scale in the laboratory and there was then a gradual progression through larger laboratory work, full scale pilot study and up to full scale trafficked pavements.

All these methods have different advantages and different problems which need to be recognized but they have all shown a consistency in the identification of the mechanisms that are important. The separation and filtration functions provided by correctly specified geotextiles are very important in particular circumstances.

2 MODEL SCALE

Research work by Milligan at the University of Oxford on the model testing of geogrid reinforcement of granular layers began in the early 1980’s using a monotonic loading through a load bar onto the granular layer. Figure 1

Figure 1

This work, some of which was reported by Milligan (1984) used saturated kaolin clay to model the subgrade and Leighton Buzzard sand as the granular layer. Foam rubber had been used to model the soft subgrade in earlier work.

At the time, the researchers put forward a number of conclusions, the importance of which were perhaps not sufficiently recognized at the time. Their suggestions for the basic requirements of a reinforcing geosynthetic have been shown to be valid by subsequent work from 1980 to the present day.

The main conclusions were that a reinforcing geosynthetic requires:-

1) Stiffness, rather than just strength so that the application of a load induces relatively small strain.

2) Interlock, so that the aggregate particles are, in themselves, restrained at the interface between the subbase and the subgrade.

This restraint not only reduced the shear stresses imposed on the soft subgrade soils in this work but also stiffened the granular layer so that the vertical stresses were imposed over a wider area of the subgrade thus reducing the actual pressure and hence deformation. Figure 2.

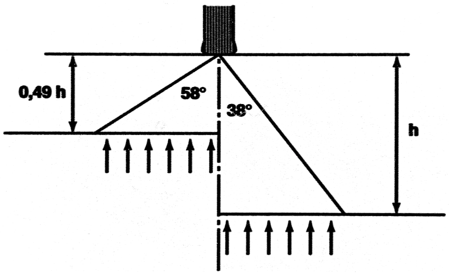


Figure 2.

The effect of membrane action was also considered in this work but the magnitude of the deformations that are required in order to mobilize tensile resistance were not seen as being compatible with serviceability criteria for normal road pavements.

3 ANALYTICAL APPROACH

Giroud et al. (1984) derived an analytical approach to the design of reinforced unpaved roads by building on the work that had been done on unreinforced, unpaved roads. An extensive program of trafficking trials by the US Corps. of Engineers produced the data from which Giroud & Noiray (1981) derived the equation which has been adapted in different forms to relate the unreinforced thickness of an unpaved road to the subgrade CBR and the number of passes of an 80kN standard axle.

$$h = \frac{0.19 \log N}{(CBR)^{0.63}}$$

It was appreciated by Giroud et al. that there were differences between the effect of geotextiles and geogrids in granular layers although some features of the geotextile design method that he had produced in 1981 could be transferred over. The major differences that had to be accommodated were in the interaction between the granular material and the geosynthetic. The interlocking of the aggregate particles into the grid apertures producing “confinement” and the modified vertical load distribution were the features which resulted in the revision of the equations.

Giroud was able to adjust the basic equations to allow for a wider load distribution angle through the reinforced subbase and also to account for the lateral restraint and confinement of the subgrade soil by the combined action of the subbase aggregate and the reinforcement. The results of this work were that a reduction in thickness of the subbase layer could be calculated with approximately half of the reduction coming form the improved load distribution and half from confinement of the subgrade. The effect of the tensioned membrane comes into play if the traffic is channelised. If traffic is more random then the membrane action cannot be mobilized.

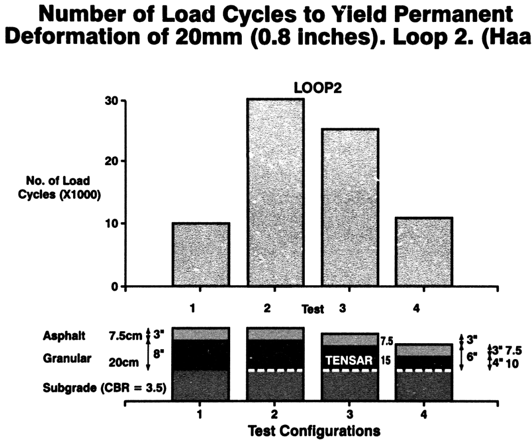
4 FULL SCALE LABORATORY TESTING

The testing regime developed and reported by Haas (1987) moved closer to a realistic trafficking situation with a large rectangular box containing the subgrade and road construction. Loads, equivalent to the twin wheel load at the end of a standard 80kN axle, were applied through a 300mm diameter plate at a frequency of 8 cycles per second. The plan dimensions of the box were 4.5m x 1.8m ensuring that any edge effects from the side of the box were small and insignificant.

Haas used a very fine grained beach sand for the subgrade with an almost uniform grain size. By adjusting the moisture content of this sand the subgrade support value (CBR) could be achieved quite accurately and uniformly.

The testing was carried out at subgrade CBR values ranging from 8% to 0.5 – 1% with consistent results. The presence of the geogrid:-

1) reduced the permanent deformation
2) allowed the sections incorporating the geogrid to carry 3 times the traffic for the same deformation (rut).
3) enabled the thickness of the unreinforced section to be reduced by up to 50% for the same performance.



Number of Load Cycles to Yield Permanent Deformation of 20mm (0.8 inches). Loop 2. (Haas)

Figure 3.

The mechanism of interlock between the aggregate particles in the subbase was seen as the fundamental mechanism that enabled the reinforcement benefits of the grid to be mobilized at strain levels which were not detrimental to the pavement serviceability.

Haas used the results of this practical work to provide the background to his proposals for a design method based on the AASHTO Guide for Design of Pavement Structures (1986). The equivalency relationship between reinforced and unreinforced granular layers was established to enable the increased structural contribution of the reinforced granular layers to be calculated with appropriate layer equivalency values.

5 PILOT SCALE TESTING

Testing at TRRL by Chaddock (1988) consisted of full size traffic loading of an unpaved road constructed in a 17m long, 5m wide pit. This followed the gradual progression of research through from model testing up to full size. A soft clay subgrade and a subbase layer were placed and compacted on the natural sandy clay and the resultant pavement was trafficked by a wagon loaded to impose an 80kN rear axle. This was increased to 130kN towards the end of the tests.

The subbase layer varied in thickness along the length of the test and one half of the pavement, i.e. one wheel track, was reinforced with a layer of geogrid.

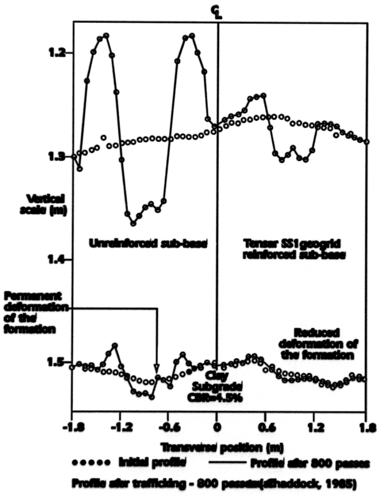


Figure 4.

Again the confinement of the aggregate and resistance to deformation at the subbase / subgrade interface showed how the wider load distribution mobilized by the interlocking mechanism restricted the pressures, and hence deformation of the subgrade.
Figure 4.

The construction equipment used to place and compact the materials was, of necessity, smaller than that which would be used on a normal road construction site and some of the results reflected the different procedures.

Full scale testing in a more realistic environment would avoid these discrepancies but gain other problems of control and consistency of both the construction and the environment.

6 DESIGN

Milligan et al (1989) proposed a new approach to the design of unpaved roads which was based on the original laboratory work done by Milligan & Love. This work moved away from the concept of a tensioned membrane and the wider load distribution angle and examined the outward shear stresses applied to the soft subgrade soils. The presence of the outward shear stresses reduces the effective bearing capacity of the soft subgrade. The analysis therefore required the reinforcement to carry the load that would neutralize these outward shear forces and allow the subgrade to mobilize it’s full bearing capacity.

This more fundamental examination of the reinforcing mechanisms required the reinforcement to have certain criteria of:-

1) tensile stiffness and
2) interaction with the granular subbase.

Again these important characteristics are identified as being critical to the performance of reinforcement in a road subbase.

7 FULL SCALE FIELD TESTING

An important and comprehensive piece of work by Webster (1992) at the US Corps of Engineers Waterways Experimental Station provided a large amount of information to be added into the database of knowledge on this subject.

The purpose of this independent research program was to investigate the use of geosynthetic reinforcement of the base (subbase) layers of flexible pavements for light aircraft. The study was split into two parts, the first being a literature review of the subject and the second being a full scale test program based on the findings of that literature review.

The results of the first part were that while geotextiles provided a separation and filtration function they did not provide a reinforcing function and therefore the actual testing would be carried out using a range of available geogrid materials. The loading was imposed by a single 130kN wheel load to simulate the load from a light aircraft undercarriage.

A typical set of results is shown in Figure 5 with rut depth plotted against the number of passes of the wheel. The test lanes covered a number of different alternatives in terms of:-

1) depth of subbase
2) position of the reinforcement layer in the pavement
3) the type of reinforcement.

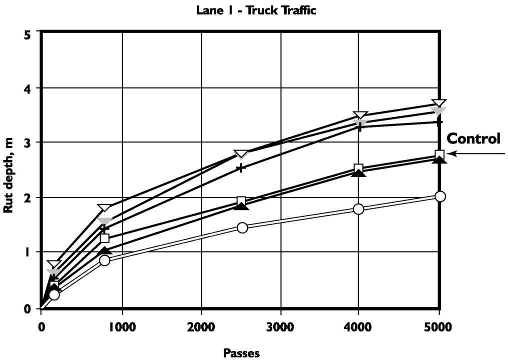
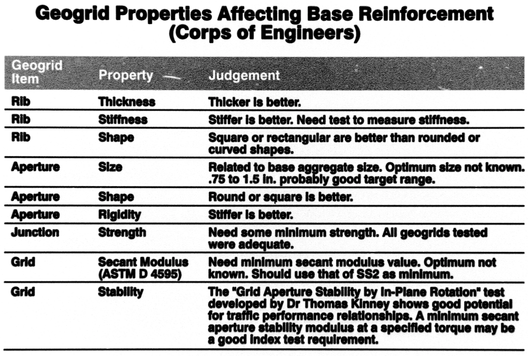


Figure 5.

The results of the trafficking program showed that not all geogrids produced the same results and that there were substantial differences in performance under these conditions. This discovery prompted the author to try to identify the important properties of a geogrid that provide the optimum reinforcement effects.

This was a very important step in the development of this subject as the important properties were very closely linked to the properties suggested and, to some extent, forgotten in detail, from work carried out by Milligan et al 8 years previously. Figure 6.



Geogrid Properties Affecting Base Reinforcement (Corps of Engineers)

Geogrid Item	Property	Judgement
Rib	Thickness	Thicker is better.
Rib	Stiffness	Stiffer is better. Need test to measure stiffness.
Rib	Shape	Square or rectangular are better than rounded or curved shapes.
Aperture	Size	Related to base aggregate size. Optimum size not known. .75 to 1.5 in. probably good target range.
Aperture	Shape	Round or square is better.
Aperture	Rigidity	Stiffer is better.
Junction	Strength	Need some minimum strength. All geogrids tested were adequate.
Grid	Secant Modulus (ASTM D 4595)	Need minimum secant modulus value. Optimum not known. Should use that of SS2 as minimum.
Grid	Stability	The "Grid Aperture Stability by In-Plane Rotation" test developed by Dr Thomas Kinney shows good potential for traffic performance relationships. A minimum secant aperture stability modulus at a specified torque may be a good index test requirement.

Figure 6.

These suggested properties focus around two main aspects of the grid performance:-

1) the shape and stability of the grid components and apertures to ensure effective interlocking with the aggregate particles.
2) the tensile stiffness/modulus at the imposed load regime to provide restraint to the interlocked particles.

The list of properties in Figure 6 provides a very good basis from which to continue the investigation into subbase reinforcement. The properties have been derived from observation of the performance of the test sections and some have been examined further in isolation.

This closer examination of particular properties is a very important step in our understanding but care should be taken not to put too much emphasis on one particular property at the expense of other factors. The ideal reinforcement is, no doubt, a geogrid material that can satisfy all the suggested parameters, and perhaps some more characteristics that have not yet been identified.

8 GEOGRID APERTURE ROTATIONAL STABILITY

One of the properties identified by the Webster work was the stability of the aperture against rotational forces in the same plane as the geogrid. Kinney et al (1995) developed a test that examined this particular property and used the data from the Waterways Experimental Station testing to investigate any possible correlations between the improvement in trafficking capacity and the rotational stability of the grids. Figure 7

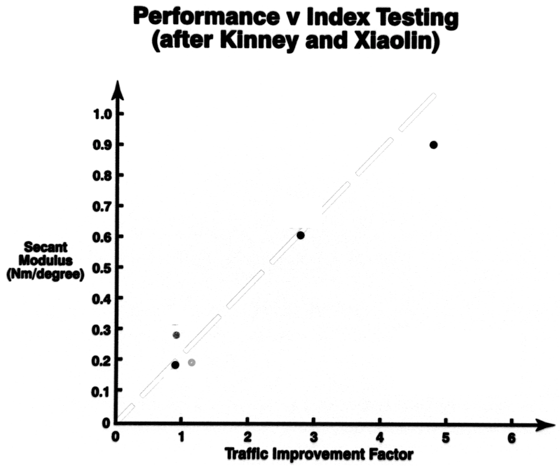


Figure 7.

The results of this testing showed a very good correlation between the performance of the geogrids and the aperture stability and the conclusions of the authors was that this was a promising result. It would be reasonable to conclude that good rotational stability is an important feature to have in a geogrid reinforcement of subbases although, of course, it must be combined with other important features.

9 FURTHER FULL SCALE TESTING

Full scale testing within a laboratory environment continued with work by Collin et al (1996) and Knapton et al. (1996) on both paved and unpaved road construction.

A test area at the University of Alaska was used by Collin et al to confirm the benefits of stiff biaxial geogrids in the base (subbase) layers of flexible pavements. Two versions of the same family of geogrids were used in this research and the results fitted well with the results of Waterways Experimental station.

The loading wheel in this project was much more typical of road traffic at 20kN with the conclusions that a flexible pavement reinforced with a stiff biaxial could withstand up to 10 times the amount of traffic compared with the unreinforced construction in optimum conditions. In general a conservative assessment of the increase was between 2 and 4 times. This magnitude of increase can make a substantial difference to maintenance costs.

This work provides additional evidence as to the benefits that can be gained by using geogrid reinforcement and extends our knowledge of monitored construction.

Considerations of the unpaved situation were examined at the University of Newcastle upon Tyne, UK, using the Newcastle University Rolling Load Facility, NUROLF. This facility allows a pavement construction to be trafficked by a wheel load corresponding to an axle load of up to 140kN. Knapton et al constructed a test section which comprised an unreinforced control section and two further reinforced sections in the 9m long x 2m wide pit. The reinforcement used in these sections were different generations of similar biaxial grid material. The results of this work showed that the reduction in pavement deformation of the reinforced sections compared with the unreinforced sections was approximately 70% and that both geogrids used performed in a similar way. Figure 8

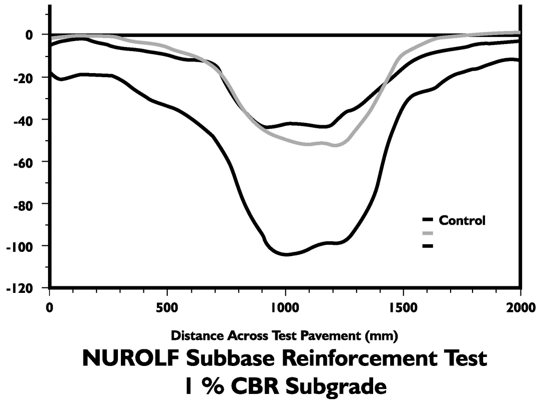


Figure 8.

10 MODULUS TESTING

All the testing reported in this paper follows the general approach used in the UK and US whereas mainland Europe uses a modulus approach to road design and application. The design does not go through the stage of assessing the unbound layers for their ability to carry the construction traffic but seeks a prescribed modulus on top of the unbound pavement layers to provide the required level of support to the bound pavement layers above.

Vanggaard (1999) carried out plate load testing on a number of different locations in Denmark with different geogrid materials. The purpose of the testing was to:-

1) Compare the Danish and German methods of assessing the E (Modulus) value.
2) Assess the influence of the choice of geosynthetic on the behaviour of the subgrade soil.
3) Assess the influence of the choice of geosynthetic on the behaviour of the subbase layer.

The results of Vanggaard’s work showed good comparison between the Danish and German Modulus evaluation methods and also gave a reasonable correlation to the work by Webster. This correlation between the performance of different types of geogrid in terms of modulus mobilized on the surface of the reinforced unbound layer and trafficking under a heavy wheel load gives confidence that the mainland European, the UK and the US approaches to the design of the unbound layers of pavements give similar results.

Again we see the ability of the geogrid to proved restraint to the granular aggregate by interlock with the stiffness to restrict the strain under the loading conditions being the important functions. This again ties back to the initial research at Oxford where these features were recognized by the researchers as being critical for good performance.

11 FULL SCALE LIVE ROAD TRIALS

Huntingdon et al (2000) reported the results from an experimental pavement in Wyoming, US, which has taken the whole subject a step further in terms of verification of the performance of geogrid reinforced pavements.

The comparison in this case was an unreinforced base layer 430mm thick and a base layer 280mm thick reinforced with one layer of Tensar BX1100. The design of the reinforced layer followed the recommendations of the Haas work in terms of geogrid position.

The rut development during the first 3 years of this experimental section was the same in both the 430mm unreinforced section and the 280mm reinforced section with no other signs of distress or deterioration. The conclusions, therefore, are reported that 280mm of crushed base reinforced with geogrid can replace 430mm of conventional crushed base.

12 FURTHER WORK

The large amount of work that has been carried out on the reinforcement of granular pavement layers is much more than has been reported here. Millions of square metres of biaxial geogrids have been installed all around the world and are performing their function effectively and efficiently.

The work on developing a database of information on live pavements in terms of deflection data, condition data etc. must continue to provide the basis of our understanding of the mechanisms.

Analytical work on the mechanism of interlock is also an essential step forward to further our understanding. To date the numerical modeling of this mechanism has not been able to accurately describe the small details of grid form combined with the strength and stiffness characteristics when embedded in granular soil. The important characteristics suggested by Webster are small details that need to be modeled and then combined to allow true analysis of the system. Treating the geogrid as a sheet with interface characteristics with the granular soils can not provide the detailed examination that is required.

Laboratory scale testing to try to identify the influence of different characteristics is also important in providing data for numerical modeling work. Targeting particular aspects of the reinforcing mechanism and devising tests which give a greater understanding is where laboratory scale research can link into this fundamental understanding.

13 CONCLUSIONS

The wealth of research work and practical experience that has been gained in the reinforcement of the granular layers of pavements over the last 20 years has shown how effective stiff biaxial geogrids are in that function.

The particular features that a geogrid requires to produce these benefits were suggested in the early stages of the research but a more detailed examination of these features was not recognized as being necessary. The materials were performing satisfactorily without any need to identify the intuitive mechanisms any more accurately.

The characteristics identified by Milligan et al are still the most important to enable efficient reinforcement of the unbound layers within the serviceability limits of a pavement construction.

A geogrid placed below or within the granular layer of pavements should therefore:-

1) interlock with the aggregate particles
2) have high tensile stiffness under the loading conditions

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