DEFORMATION OF ROAD FOUNDATIONS WITH GEOGRID REINFORCEMENT

by B C J Chaddock

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ABSTRACT
The deformation under traffic of crushed rock sub-bases over clay subgrades has been investigated; the experiments included an investigation of the effectiveness of a reinforcing geogrid between the sub-base and the subgrade. Sections with and without reinforcement were trafficked simultaneously by a rigid two-axle lorry with its rear axle loaded to about 80 kN and the number of vehicle passes to cause 40 mm deformation at the sub-base surface was related to the sub-base thickness, subgrade strength and the use of geogrid. Transverse trenching revealed the accumulated deformation in the sub-base and subgrade. The results were compared with existing designs for foundation layers and the performance of the reinforcement was examined over a wide range of test conditions.

1 INTRODUCTION
During construction of a road pavement the foundation is used as a haul road for traffic delivering foundation and road-base material. The performance of a foundation under this traffic will depend on the mechanical properties of the subgrade and imported granular material, the thickness of the granular layer and the effectiveness of any reinforcement.

Previous studies by Potter and Currer (1981) and Ruddock, Potter and McAvoy (1982a) of unpaved experimental roads on clay subgrades showed that improved performance under traffic could be achieved by placing a strong fabric at the interface between subgrade and granular material. The fabric acted as a separator and, provided it did not tear, the sections with fabric carried more traffic before a given deformation at the aggregate surface was reached. Although a geogrid might not be expected to be as good a separator as a fabric, it should be more effective than a fabric in reducing lateral movement and consequent thinning of sub-base beneath the wheelpath provided there is greater granular interlock within the sub-base as a result of stones being forced into the apertures of the grid. According to Milligan and Love (1984), a grid between clay and aggregate largely prevented loss of aggregate from immediately beneath a monotonically loaded footing in the laboratory.

This report summarises the results of a series of three experiments designed to observe the performance under traffic of unbound crushed rock sub-bases built on clay subgrades ranging in strength from very soft to stiff. The experiments concentrated on measuring the effect of subgrade strength, sub-base thickness and the effectiveness of a reinforcing geogrid. The results are assessed in terms of existing designs for foundation layers and the effects of differences between the test conditions in the pilot-scale trials and normal construction practice are discussed.

2 CONSTRUCTION OF TRIALS
Each experiment consisted of a sub-base of varying thickness laid on a clay subgrade. Geogrid was laid between the sub-base and the subgrade over half the width of the experiment as shown in Figure 1. The subgrade was contained in a concrete pit 17 m long by 5 m wide and consisted of imported clay soils overlying the naturally occurring sandy clay soil (Bagshot Beds). Starting with a stiff Gault clay, three subgrades of successively lower strength were prepared in separate trials. For the two stronger subgrades, the clay was weakened by wetting and rotovation and compacted in three layers each approximately 175 mm thick to the Department of Transport Specification for Road and Bridge Works (1976). For the weakest subgrade, the clay was too weak to allow the operation of normal construction plant and was wetted, mixed and compacted in bulk with an excavator bucket to a depth just over 0.5 m. The excavator was also used to prepare a reasonably smooth and level formation.

Fig. 1 Typical layout of experiment
Subgrade properties are recorded in Table 1. The mean California Bearing Ratio (CBR) values were determined from measurements through the top 300 mm of subgrade in the wheel-paths with a penetrometer calibrated against in-situ CBR tests.
A polymer grid reinforcement manufactured by Netlon Ltd and designated Tensar SS1 Geogrid was used in all the trials for consistency. It is produced in 4 m wide rolls and has the mesh dimensions shown in Figure 2. Netlon (1984) advise that it should be laid directly on the subgrade over its full width and that adjacent strips should be overlapped by at least 0.3 m with the overlaps being secured to the soil by staples. However in this series of experiments the geogrid was laid across only half the width of the subgrade beneath one dual-wheel of the rear axle of the trafficking vehicle to allow a sub-base with reinforcement to be compared with an adjacent unreinforced sub-base. The longitudinal edges of the geogrid were turned vertically upwards between 150 mm and 200 mm to simulate the anchorage that would have been obtained from a greater spread of reinforcement; for the same reason the geogrid covered about 3 m of the concrete apron at each end of the pit.

The sub-base was a crushed limestone with a grading that is shown in Figure 3 to conform broadly with the Department of Transport Specification for Highway Works (1986) for Type 1 sub-base. The effect of sub-base thickness on the performance of the trial sections under traffic was investigated by constructing each sub-base in the form of a truncated wedge. The construction of the sub-bases is outlined in Table 2 and shown in Plates 1 and 2.
TABLE 2

Sub-base compaction

<table>
<thead>
<tr>
<th>Subgrade strength classification</th>
<th>Method of delivery to subgrade and sub-base</th>
<th>Nominal finished thickness</th>
<th>Compaction by vibrating roller</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiff</td>
<td>Dumped by off-site plant</td>
<td>150 mm layer + 0 to 125 mm wedge</td>
<td>2400 mass/roll width (kg/m)</td>
</tr>
<tr>
<td>Soft/firm</td>
<td>Tipped by dump trucks running on metal tracks on sub-base</td>
<td>200 mm layer + 0 to 200 mm wedge</td>
<td>2400</td>
</tr>
<tr>
<td>Very soft</td>
<td>Dumped by off-site plant</td>
<td>110 mm layers + 0 to 110 mm wedges</td>
<td>700 on two rolls</td>
</tr>
</tbody>
</table>

*[excluding deadweight rolling]*

Plate 2 Sub-base construction on geogrid on soft/firm subgrade

The sub-base was compacted according to the Department of Transport Specification for Highway Works (1986) except for the lowest layer on the weakest subgrade, which deformed too much under the roller. In this case, a dual drum pedestrian roller could not be operated with vibration on the unreinforced section but two passes were applied to the reinforced section; the geogrid apparently provided a better working platform for the construction of the subsequent layer. The compacted sub-base thickness in the wheel-paths for the three experiments is shown in Figure 4. The dry densities of the completed sub-bases were measured with a density gauge operated in the transmission mode. For depths equal to about half the maximum nominal thickness of each trial, the dry density of the upper sub-base was not significantly affected by subgrade strength or the inclusion of geogrid.

![Fig. 4 Initial thickness of sub-base](image)

3 PERFORMANCE UNDER TRAFFIC

A rigid two-axle lorry fitted with dual rear wheels was used to traffic the experiments, simultaneously loading the reinforced and unreinforced sections as shown in Figure 1 and Plate 3. Care was taken to minimize lateral variation in the wheel-paths from pass to pass. Most passes were with the rear axle loaded to about 80 kN, or one standard axle, but later trafficking was carried out with the rear axle load increased to about 130 kN as indicated in Table 3.


Table 3 Loading sequence

<table>
<thead>
<tr>
<th>Subgrade strength classification</th>
<th>Number of lorry passes</th>
<th>Axle loads (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiff</td>
<td>0 to 800</td>
<td>32.5</td>
</tr>
<tr>
<td></td>
<td>901 to 1200</td>
<td>38.5</td>
</tr>
<tr>
<td>Soft/firm</td>
<td>0 to 900</td>
<td>33.0</td>
</tr>
<tr>
<td></td>
<td>901 to 1200</td>
<td>38.5</td>
</tr>
<tr>
<td>Very soft</td>
<td>0 to 1050</td>
<td>32.7</td>
</tr>
<tr>
<td></td>
<td>1051 to 1300</td>
<td>39.1</td>
</tr>
</tbody>
</table>

Plate 3 Trafficking the trial sections

At intervals the lorry was stopped and the height of the sub-base surface relative to a datum was measured in the wheel-paths and at some locations across the full width of the experiment. As the deformation in the wheel-paths of the thinner part of an experiment became excessive, the ruts were filled with sub-base material and sometimes bridged by metal plates to allow trafficking of the rest of the experiment to continue.

3.1 REAR AXLE LOADED TO ONE STANDARD AXLE

The development of deformation of the sub-base surface in the wheel-paths is shown for different thicknesses of sub-base on the soft/firm subgrade in Figure 5. The thinnest areas failed rapidly but other regions showed evidence of strain hardening with the deformation caused by a single pass of the lorry decreasing as the trafficking proceeded.

3.2 INTERPRETATION OF RESULTS

The number of passes of the lorry to cause 40 mm deformation in the wheel-paths was obtained from each of these records, sometimes by extrapolation, and is plotted against initial sub-base thickness in Figure 6. This level of deformation was chosen because Powell, Potter, Mayhew and Nunn (1984) suggested that it is the maximum that can be tolerated if the sub-base surface is to be reshaped and recompacted efficiently and serious rutting is to be avoided in the subgrade. Figure 6 shows that an increase in the sub-base thickness on a soil of constant strength allows more traffic to be carried before the deformation at the surface of the sub-base reaches 40 mm. Thicker sub-bases are required on weaker subgrades if they are to deform at the same rate under traffic. Clearly the geogrid reinforced the foundation on the stronger subgrades, but there was minimal reinforcement of the foundation on the very soft subgrade.

Fig. 5 Deformation of trial sections on soft/firm subgrade

Neg. no. R801/84/10
constructed and on completion of trafficking by the lorry. The deformed profile of the formation was exposed by digging a trench through the granular material in the surviving part of each experiment. The profiles are compared in Figure 7.

Shear deformation of the subgrade and sub-base is evident especially in the unreinforced sections; soil and granular material have moved from beneath the wheel-path and caused adjacent material to heave. The weaker the subgrade, the greater was the proportion of the displacement of the sub-base surface due to deformation of the subgrade or, put another way, the smaller the migration of sub-base from the wheel-path. For the two stronger subgrades, the geogrid was at the surface of the subgrade over most of its surface revealed by the trenches. Stones penetrated through the apertures of the geogrid into the subgrade and overall the geogrid effectively separated the subgrade and sub-base. But for the very soft subgrade, most of the geogrid had a substantial covering of clay that must have pushed through the apertures at the time of construction and during trafficking. Interlock of the sub-base and geogrid appeared minimal at these locations.

Figures 6 and 7 show the deformation of the sub-base and the subgrade to be smaller in the reinforced regions but in order to make a quantitative comparison that allowed for differences in sub-base thickness and quality and subgrade strength, a statistical analysis was made of the data shown in Figure 6. Results from the reinforced region on the very soft subgrade were not included in the analysis because it was judged that the experimental design and construction procedures had produced little interlock between the sub-base and geogrid. Also omitted were results from those parts of the experiments that either failed too quickly to be of practical interest or too slowly to be tested within a reasonable time by trafficking. A multiple regression technique was used to establish a relationship between the number of lorry passes to cause 40 mm deformation at the sub-base surface, $N_{40}$, the thickness, $H$, of the sub-base in metres, and the
CBR of the subgrade in per cent. The relationship obtained was:

$$N_{40} = 2.6 \times 10^{-3} CBR^{-3} e^{8R}$$

where $R$ is set to 0 or 1.3 depending on whether the sub-base is unreinforced or reinforced.

Eighty two per cent of the variance of the data is explained by this relationship and the accuracy of fit to the data is illustrated in Figure 6. The relationship gives reasonable agreement with the data extrapolated up to twice the maximum number of lorry passes actually applied.

The quantitative effect of the major factors on the traffic to cause 40 mm deformation at the sub-base surface can be seen by varying one factor at a time in the relationship. For example, increasing the sub-base thickness by 25 per cent from 0.20 m to 0.25 m allows about 4 times more traffic to be carried, whereas a section of subgrade, whose CBR value is twice that of an adjacent section, supports 8 times the traffic. Also, when geogrid reinforcement is used a given sub-base thickness can carry about 3.5 times more traffic. Alternatively the reinforced sub-base will carry the same traffic if its thickness is 50 mm less than the corresponding unreinforced sub-base.

The multiple regression line predicted for a reinforced foundation on the very soft soil is shown in Figure 6 and is based on the average behaviour of the structures founded on the two stronger soils. In practice, there was little reinforcement of this structure. This behaviour was also observed in some of the tests carried out by Milligan, Fannin and Farrar (1986) and is contrary to the findings of other of their tests. They investigated the load bearing capacity under static loading of a similar structure that incorporated Tensar SS2 Geogrid. Where there was little structural reinforcement, clay was found to have extruded through the apertures of the grid and there was little evidence of the grid interlocking with particles of aggregate. However, they found that the geogrid was considerably more effective when it was placed within the aggregate at a position about one third of the thickness of the layer above its base. Although it is uncertain whether this improvement was due to better interlock between geogrid and aggregate or the closer proximity of the geogrid to the loaded surface, it suggests that there might have been improved performance of the reinforced sub-base on the very soft soil in these trials if some of the sub-base had been placed on the clay prior to laying the geogrid. In practice it would appear difficult to carry out construction in this way with a thin granular layer under the geogrid and extension of the multiple regression to the very soft soil must be regarded as speculative.

4 SUB-BASE DESIGN

Following trafficking with the lorry loaded to approximately one standard axle on the rear axle, a more heavily loaded lorry trafficked the trials founded on the two weaker subgrades. The rate of deformation of the foundation with lorry passes increased rapidly when the load carried by the lorry
was increased, as shown in Figure 5. The few results obtained agreed reasonably well with the fourth power damage law widely applied to bituminous bound pavements.

The relative damage factor, in standard axles, of the lorry used in the experiments was calculated by applying the fourth power law to both axles of the lorry using the work of Ruddock et al (1982b) to account for the increased damaging power of single wheels compared with dual wheels carrying the same load. The sum of the contributions of the individual axles of the test lorry was 1.2 standard axles when the lorry carried the lighter load.

In Figure 8 the multiple regression relationship derived from these trafficking trials and the relative damage factor for the test vehicle were used to produce curves showing how the traffic in standard axles, that might be expected to produce 40 mm surface deformation, depends on the thickness of sub-base material and the subgrade strength for both unreinforced and reinforced sub-bases. A curve has not been included for a reinforced sub-base over a subgrade of CBR one per cent because, although the trial on the subgrade of CBR 1.5 per cent showed the geogrid reinforcing the sub-base, there was little interlock between the aggregate and the geogrid and as a consequence no significant reinforcement of the sub-base in the trial on the subgrade of CBR 0.4 per cent.

In practice, there is a greater need to produce a platform on which to construct the foundation and construction plant operates on the uncompacted sub-base, delivering and spreading the sub-base. For geogrid on weak subgrades, thicker granular layers are placed on the subgrade and additional deadweight rolling is usual, using heavier vibrating rollers operating in the non-vibrating mode prior to applying vibration. These construction methods may have been instrumental in providing the aggregate interlock observed by Netlon in unpublished field trials founded on subgrades of CBR less than one trafficking trials carried out in the USA and modified by Powell et al (1984) for UK materials and deformation criteria. These curves are compared over the range of subgrade strengths common to both studies. For the stronger subgrades the present work indicates rather greater thicknesses of sub-base than those found by Powell et al but the differences are probably due to different experimental conditions and are no more than might be expected for the highly variable materials used in road foundations.

5 PRACTICAL CONSIDERATIONS

The pilot-scale trials enabled closer control of the major variables than in normal construction work and removed weather as a variable. However the design and construction procedures adopted during the trials differ in some respects from those occurring in practice because of the difference in scale of the operations. In the trials, the geogrid was laid across only half the width of the subgrade beneath one dual-wheel of the rear axle of the trafficking vehicle and the methods of construction reduced disturbance to the formation by minimizing or eliminating the movement of construction plant on the previously placed loose sub-base.

In practice, there is a greater need to produce a platform on which to construct the foundation and construction plant operates on the uncompacted sub-base, delivering and spreading the sub-base. For geogrid on weak subgrades, thicker granular layers are placed on the subgrade and additional deadweight rolling is usual, using heavier vibrating rollers operating in the non-vibrating mode prior to applying vibration. These construction methods may have been instrumental in providing the aggregate interlock observed by Netlon in unpublished field trials founded on subgrades of CBR less than one
per cent. The development of interlock on very soft subgrades could be accomplished with more certainty if practical procedures were developed for placing thin layers of granular material on these subgrades prior to laying the geogrid.

The trials were limited in that one sub-base source and one type of geogrid only were studied; the effect of strength and stiffness of geogrid would need to be studied to optimize its use in pavement foundations. Also, for the thick granular layers that are required to carry construction traffic over weak subgrades, multiple layers of geogrid reinforcement should be investigated.

6 CONCLUSIONS

For unreinforced foundations consisting of Department of Transport Type 1 crushed rock sub-bases on clay subgrades, the present results were in good agreement with the curves recommended by Powell et al (1984) when the subgrade CBR was 2 per cent but, for soils of CBR 5 per cent, thicker sub-bases were indicated in the present work. Overall the variability is no more than might be expected for the highly variable materials used in pavement foundations.

For the same thickness of Type 1 crushed rock sub-base on a subgrade of CBR value between about 1.5 and 5.0 per cent, the inclusion of Tensar SS1 Geogrid between the sub-base and subgrade allowed about 3.5 times more traffic to be carried before the deformation at the surface of the sub-base reached 40 mm. Alternatively, the same performance under traffic would be obtained if the reinforced sub-base was about 50 mm thinner than the corresponding unreinforced structure.

With the foundation design and construction method used on the subgrade of CBR value about 0.4 per cent, little reinforcement of the sub-base occurred; it appeared that extrusion of the clay through the apertures of the geogrid largely prevented the grid interlocking with particles of aggregate. There is a limited amount of experimental evidence that suggests it might have been more effective with different construction procedures or if some sub-base material had been placed on the subgrade prior to laying the geogrid but this form of construction was not investigated in the trials and might be difficult in practice.

7 ACKNOWLEDGEMENTS

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8 REFERENCES


