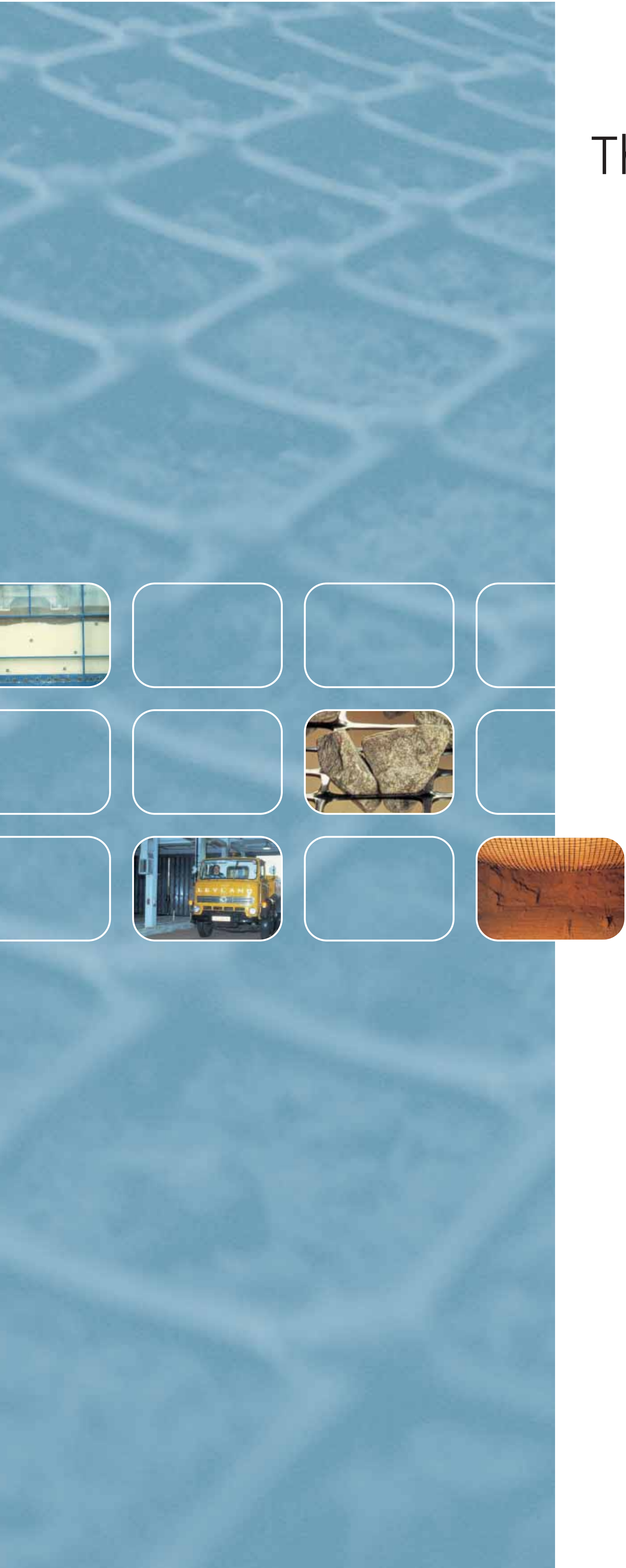


The Properties and Performance of Tensar Biaxial Geogrids

The essential guide to the
properties and performance of
Tensar Biaxial Geogrids
when used in constructing:

Road pavements
Trafficked areas
Foundations
Load transfer platforms

Tensar
international

Tensar. The value engineered solution

In Tensar you'll find a partner with the experience and flexibility to respond to your project requirements. From design to completion, we'll make sure you always benefit from a practical, cost-effective solution to your specific need.

Introduction to this guide

This is your essential guide to the properties and performance of Tensar biaxial geogrids when reinforcing unbound aggregates. The major topics of importance are: interlock, load spread and pavement performance. Each topic is discussed, and information presented from actual testing or trials. The important features are highlighted. At the end of the guide is a comprehensive list of properties of the Tensar SS biaxial geogrids.

Brief history of Tensar Biaxial Geogrids

In the 1970s Netlon extruded meshes were successfully introduced into civil engineering as a technique for stabilising soils. In the 1980s Tensar biaxial geogrids were developed from these early ideas, specifically for reinforcing unbound aggregates. They have been used extensively in the construction of road pavements, trafficked areas, foundations and load transfer platforms. During the last 20 years a huge number of projects have been completed successfully using Tensar SS geogrids, in a wide variety of conditions and climates.

FEATURES

- High quality durable polymers
- Unique interlock mechanism between geogrid and aggregate
- High angle of load spread through reinforced granular layers
- Improved pavement performance
- Confidence from extensive third party trials and records of performance

The performance of Tensar Biaxial Geogrid in granular material

It works!

The simplest way to see how well Tensar biaxial geogrid reinforces granular material is to use it over a wet, soft subgrade, where previous attempts with unreinforced material have resulted in deep rutting and failure, as shown in Figure 1. A practical demonstration of this is shown in Figure 2, overleaf, which summarises the results from a trial carried out to investigate the benefit of Tensar geogrid in a working platform for very heavy cranes over a soft clay subgrade.

The section using Tensar SS2 gave satisfactory results, even after many passes of the 300t test crane. Initially, the crane passed along the same track path, then moved from side to side along multiple paths. The ruts were then filled in, and the trial continued along a single track path. In the comparative section, a woven polypropylene geotextile was used, and the settlement on the first pass was 350mm. On the basis of this trial Tensar SS2 was chosen for the platform.

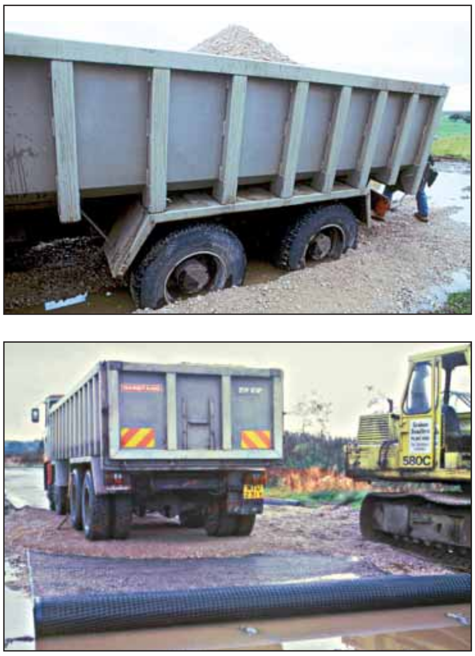


Figure 1: Simple practical demonstration of the benefits of Tensar biaxial geogrid.

Figure 2a: Crane used in trial.

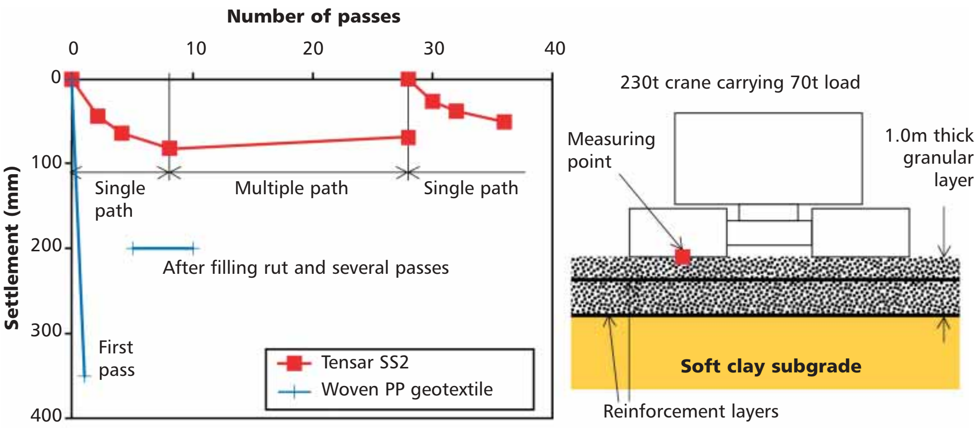


Figure 2b: Comparative trafficking trial of heavy crane over reinforced granular platform.

Interlock

Tensar biaxial geogrids work, as demonstrated above. This is because they interlock very efficiently with granular materials. When granular material is compacted over these grids, it partially penetrates and projects through the apertures to create a strong and positive interlock. The interlocking mechanism is similar to the effect of a snooker ball rack.

The snooker ball rack confines the balls above due to its high stiffness and the strength at the corners (junctions). Also, to confine the snooker balls effectively, the rack has high, flat sides. If cyclic load is applied to the top ball, there will be negligible settlement. However, if the rack is very flexible, or the corners are weak, then cyclic load will cause the stack of balls to settle. A further important feature of this analogy is that the rack stabilises the snooker balls above without relying on support from neighbouring racks. Thus interlock is localised.

The apertures of Tensar biaxial geogrids are very much like the snooker rack. The Tensar manufacturing process produces a unique grid structure, consisting of full strength junctions and stiff ribs, which present a square, thick leading edge to the aggregate for effective mechanical interlock. Interlock helps prevent dilation of aggregate particles, so that a very high effective angle of shearing resistance is mobilised. Vertical load applied through aggregate particles above the grid can generate tensile resistance in the ribs with very small deflection. The combination of these features ensures that, in Tensar geogrid reinforced granular layers:

- Tensile load in the grid is generated at very small deflections of an applied vertical load
- Reinforcement benefit can be generated within the loaded area

These features are demonstrated below using a number of practical tests and trials.

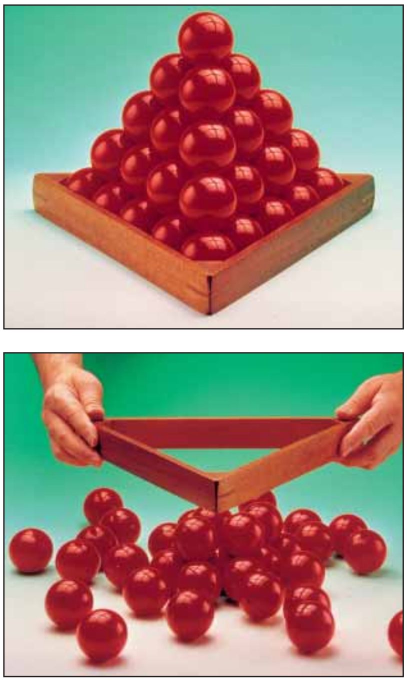


Figure 3: The snooker ball analogy.

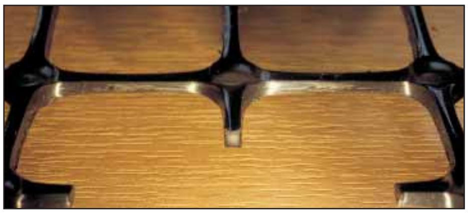


Figure 4a: The importance of the shape of Tensar biaxial geogrid ribs.

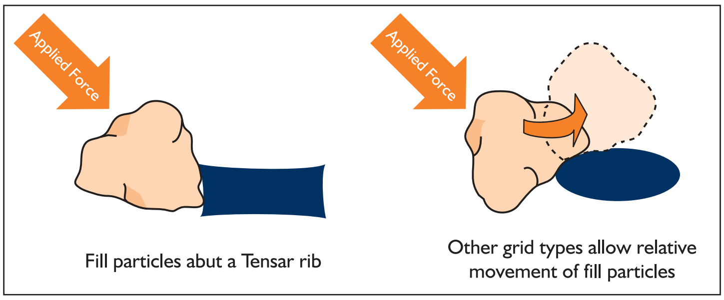


Figure 4b: The unique cross sectional shape of Tensar ribs provides bearing points for fill particles unlike other grid types with thinner or more rounded profiles.

Comparison with geotextiles

Provided that they are sufficiently robust to resist damage, both woven and non-woven geotextiles can improve pavement performance by providing a separation function. They can prevent contamination of the granular fill by intermixing with the subgrade soil. The only mechanism which allows geotextiles to offer a structural contribution to a road pavement or trafficked area is as a tensioned membrane under the wheel paths. For this mechanism to work effectively, the geotextile must be anchored outside the wheel path and then deform sufficiently so that it can carry tension.

For the tensioned membrane mechanism to develop adequately, the following should occur:

- Relatively deep ruts should form to permit the membrane to develop
- The geotextile should be anchored outside the rutted area and load transferred by friction
- The ruts should be maintained, implying that fixed wheel paths must be followed
- Formation of the ruts will deform and remould the subgrade soils
- The ruts can act as invisible sumps, providing a water source to soften the subgrade
- Performance above the ruts will differ from performance between the ruts

Based on these points, the only types of application likely to benefit from the tensioned membrane approach will be roads where fixed wheel paths are followed, and large rut depths are acceptable, for example narrow unsurfaced haul roads. It is unlikely that the required conditions can be met in the construction of permanent pavements.

As shown on Figure 5, the interlock mechanism of Tensar geogrids is distinctly different to the tensioned membrane. By interlocking with the particles, Tensar geogrids confine the aggregate layer and prevent lateral displacement. Load is distributed from the wheel to the subgrade within the loaded area. Unless the formation and maintenance of deep ruts is acceptable, geotextiles can only act as a separator. The two materials are not directly interchangeable without design review and amendment.

As part of a literature review of the use of geosynthetics in pavements, Webster (1) described a pavement trafficking trial, which compared four geotextiles and a geogrid with a control section. The results are summarised on Figure 6, which shows rut depth versus the number of passes of a 5t military truck over an unsurfaced granular pavement consisting of six different sections as shown.

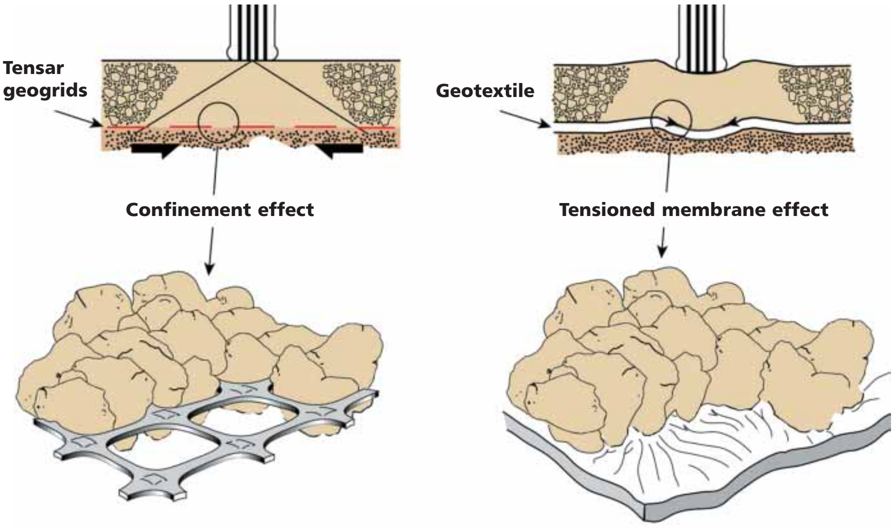


Figure 5: Confinement versus membrane effect.

These results show that all four geotextiles perform either worse than or similar to the control, whereas the geogrid is significantly better. The histogram shows the number of passes to form a 50mm rut, and also indicates the strength of each product tested. It is important to note that the strongest geotextile (strength is reported as a grab strength of 4450N which is equivalent to a tensile strength of about 90kN/m) gave the poorest performance. This probably occurred because the geotextile created a sliding surface, encouraging the aggregate to displace laterally. The geogrid, (tensile performance data reported as 8.4kN/m at 5% strain is similar to the longitudinal behaviour of Tensar SS1 which had a strength of 12.5 kN/m), is able to interlock with the aggregate and confine it. This greatly decreases lateral spread of the aggregate, thereby reducing rut depth.

Webster (1) presented a literature review of 104 papers and publications, as part of the preparation for a major aircraft pavement trafficking trial (described later in this document) to be carried out by the US Army Corps of Engineers (USACE). One of the conclusions from this review was:

If geotextiles are included in the structure no structural support should be attributed to the geotextiles.

On the basis of this study, and the many trials and tests reviewed, geotextiles were omitted from the USACE aircraft pavement trial.

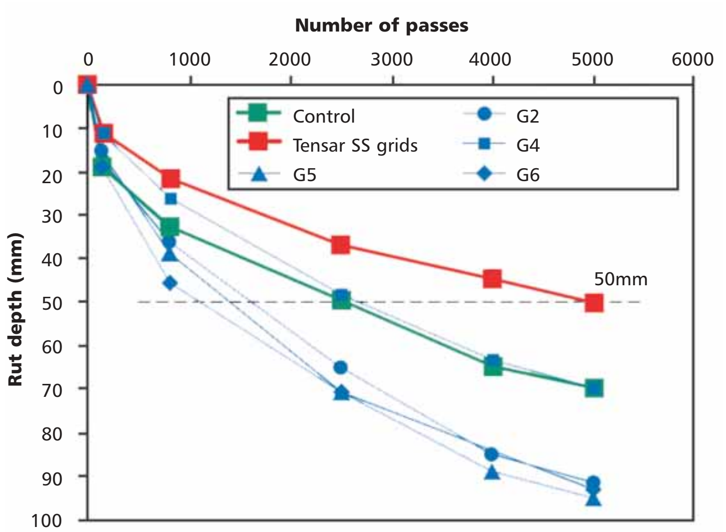
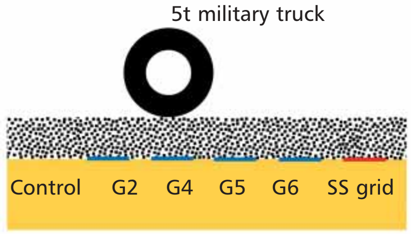
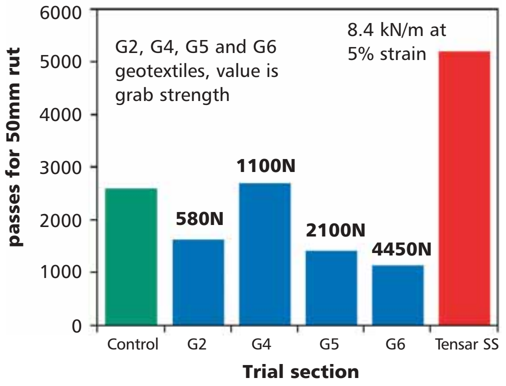


Figure 6: Comparison of geotextile and geogrid in USACE trafficking trial.





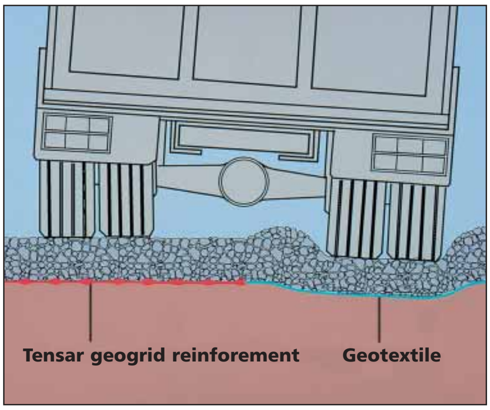


Figure 7: Geotextiles and Tensar geogrids perform differently.

Tensar biaxial geogrids interlock efficiently with aggregates – geotextiles cannot.

Twenty years of research, tests and trials

Over the last 20 years, a large number of tests and trials have been carried out by independent organisations, to investigate the performance of aggregate layers reinforced with Tensar biaxial geogrids. These tests and trials provide a huge body of high quality data which gives the basis for methods to design aggregate layers reinforced with Tensar geogrids, and is unrivalled by other geosynthetic materials. They can be divided into the following main categories:

- Static load tests
- Cyclic load tests
- Trafficking trials
- Other tests

Some of these tests and trials, and their results, are described in the following sections.

Static load tests

Oxford University tests (early 1980s) – improving bearing capacity and load spread

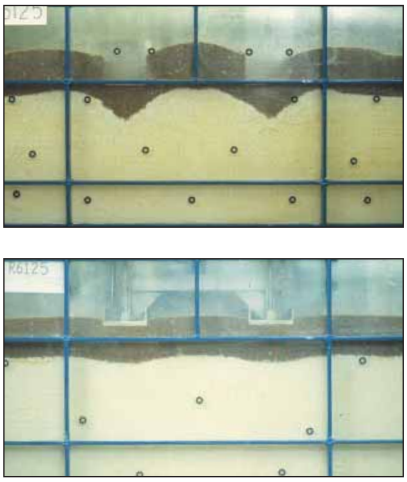


Figure 8: The University of Oxford, UK model footing experiments, without (top) and with (bottom) reinforcement at similar loads showing different behaviour.

Model footing experiments were carried out by the University of Oxford, UK (2), to investigate the benefit of reinforcing a granular layer over soft clay. Two of the experiments are shown on Figure 8, and some of the load versus settlement graphs are shown on Figure 9.

The experiments consistently demonstrated that an improvement in bearing capacity of around 40% was achieved in the reinforced cases. Reinforcement was also found to change the failure mechanism. The gravel layer was confined by interlocking with the reinforcement, which then resisted tensile strains at its base. This prevented gravel particles from moving laterally away from the loaded area, which can be seen in the unreinforced test on Figure 8 (upper) as a reduction in gravel thickness below the foundation. In addition, failure planes were driven deeper into the soft clay in the reinforced tests.

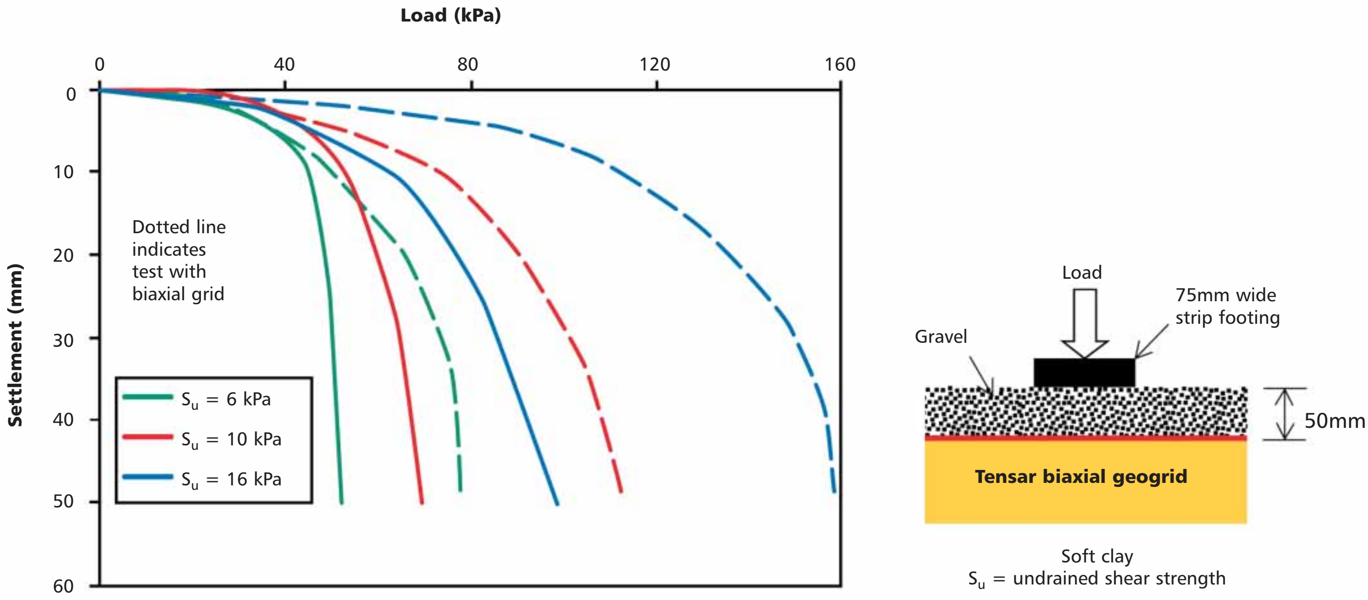


Figure 9: Some results from the Oxford University model footing experiments.

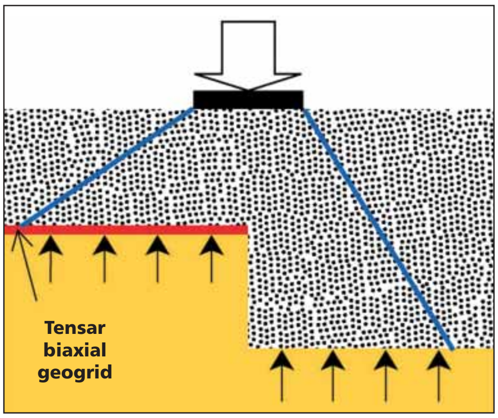


Figure 10: Load spread improvement.

Earlier work for Oxford University had provided some of the earliest insights into geogrid performance (3). The effect on angle of load spread was evaluated and data indicated a mean angle increasing from 38° in the unreinforced case to more than 50° with grid. This simple approach indicates that granular layer thickness may be reduced by around 50% to give a similar stress on the subgrade, see Figure 10.

Guido model foundation tests (1987) - optimising geogrid layout

In 1987, Guido et al (4) reported the results of larger model footing experiments, intended mainly to look at the effect of multi-layers of Tensar geogrid beneath foundations. In this case the test medium was sand, and no soft layer was present. The parameters varied in the tests are shown in Figure 11, and were: geogrid width (b), vertical geogrid spacing (Δz), depth to the top layer (u) and number of layers (N). Figure 11 also shows the effect of varying the geogrid width (b). It can be seen that there is only a small increase in bearing capacity for widths greater than 2.5B. This provides justification for one of the important observations given above, namely, that reinforcement benefit by interlock is generated within the loaded area. It is not necessary to anchor grid well beyond the loaded area to get maximum benefit.

Further tests by Guido et al demonstrated that maximum reinforcing benefit is achieved when:

- The depth to the upper geogrid layer is less than 0.25B
- Vertical spacing of geogrid layers is 0.25B or less
- 2 or 3 geogrid layers are used (but more than this does not give further improvement)

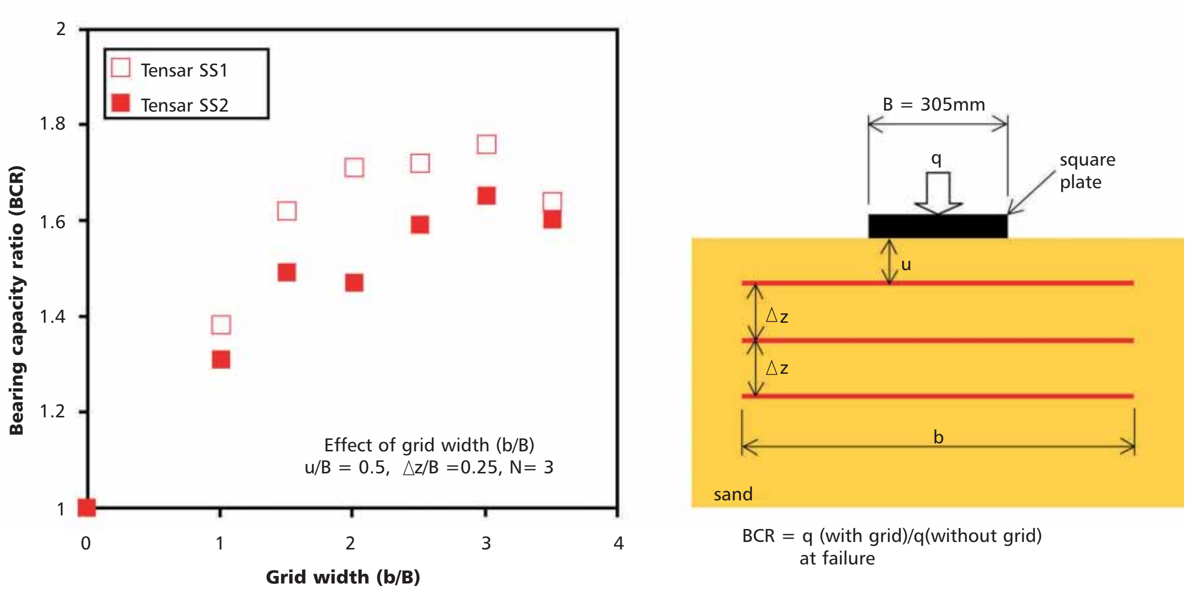


Figure 11: Model footing experiments reported by Guido et al (4).

Full scale foundation tests by FHWA (1997) - confirming Guido work

More recently, full scale foundation tests have been carried out by FHWA in the USA. These are reported by Adams and Collin (5). Square foundations up to 0.91m wide were tested using sand as the subsoil. Figure 12 shows the results from three of the tests, looking at the effect of geogrid width. It can be seen that a single layer of reinforcement gives around 50% increase in bearing capacity, but that the narrow geogrid layer (Test TL146) and the much wider geogrid layer (Test TL186) give the same performance. This conclusion is almost identical to that from Guido et al, again supporting the observation that the reinforcement effect provided by the interlock mechanism is localised. Other conclusions concerning the optimum depth to the upper geogrid layer, the spacing and number of geogrid layers are all similar to those of Guido et al.

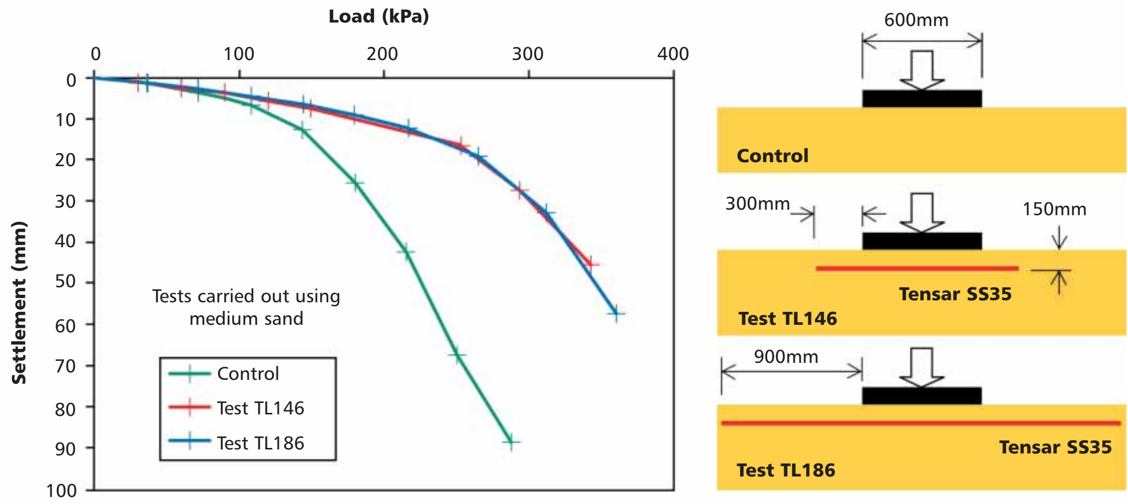


Figure 12: Full scale foundation tests carried out by FHWA.

Design recommendations for foundations and load transfer platforms have been developed from static load test results.

Cyclic load tests

The static loading tests described above provide useful insight into the mechanisms and benefits when reinforcing granular layers with Tensar biaxial geogrids. The conclusions have been used to develop design recommendations for applications such as reinforced foundations and load transfer platforms. However, for pavement design, loads are generally well below static failure load, but they are repeated many times. In order to model better the effect of traffic loading on a reinforced granular layer, cyclic loading tests have been carried out in which a relatively low intensity load is repeated many times.

University of Waterloo cyclic load tests (mid 1980s) - improving pavement performance

Research carried out at the University of Waterloo, Canada, in the mid 1980s, was reported by Haas et al (6). This consisted of a series of laboratory cyclic loading tests on full scale pavement sections.
The pavement sections were constructed with an asphalt layer over a granular base layer. The subgrade strength (in terms of % CBR) was varied in the numerous experiments carried out. Each set of tests was referred to as a “loop”.
A test load of 40 kN was applied through a circular 300mm diameter steel plate, representing one side of a standard 80 kN design axle.

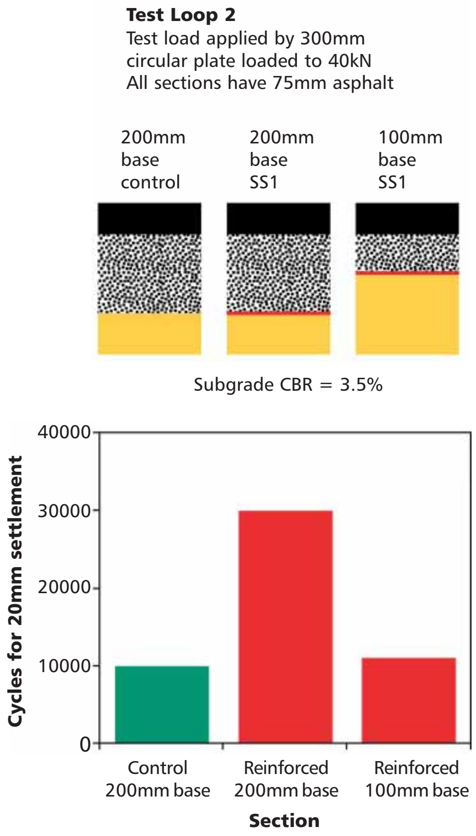
The results from Loop 2 are shown in Figure 13. In this case CBR = 3.5%, and the graph shows the settlement of the plate versus the number of load cycles. Comparison of the three sections shows that:

- Reinforcement of the 200mm base has increased the number of load applications by a factor of three to reach a given settlement
- 100mm of reinforced base gives the same performance as the 200mm control

A total of six loops were tested with CBR ranging from 0.5 to 8%, together with a range of pavement thicknesses and reinforcement layouts. From this research it was concluded that:

The introduction of a Tensar geogrid allowed a three times increase in the number of load applications.

The work carried out at the University of Waterloo was used to develop a design method for granular road base reinforced with Tensar biaxial geogrid, based on the AASHTO pavement design manual. The pavement is designed by the conventional AASHTO procedure, then the granular base thickness is reduced by 33% to give the same design life. This design method (often referred to as the “one-third rule”) has been used since the mid 1980s, and has been extended to sub-base design as well as other forms of trafficked area. It is applicable over a wide range of CBR values. Large numbers of road pavements have been designed in this way, and measured performance in two cases is reported later in this document.



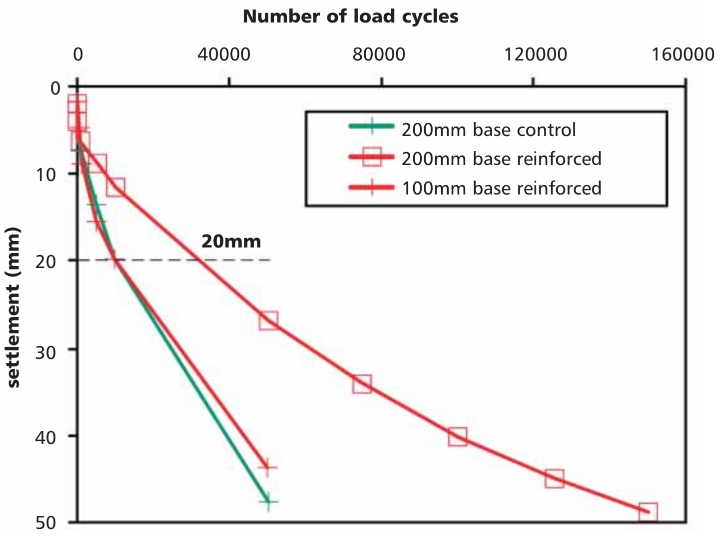


Figure 13: Cyclic plate tests carried out by University of Waterloo.

Trafficking trials

Cyclic load tests provide useful information on the performance of Tensar geogrid reinforced pavements. However, the nature of the load does not correctly model the effect of a wheel passing over the pavement surface. This can only be done using trafficking trials, and several such trials have been carried out to investigate the performance of Tensar biaxial geogrids in full scale pavements. Trafficking trials are all carried out in a similar fashion. A pavement is constructed, generally with several different sections representing the conditions to be investigated, including a control section. A wheel of known load is then run over the section, and the development of the rut and other deformations are observed and recorded.

TRL pavement trials (mid 1980s) - investigating rut profiles

Figure 14 shows some of the results from trafficking trials carried out by UK's Transport and Road Research Laboratory (TRRL - now known as TRL). The trials were carried out both in the test facility and in the field. The test facility work again identified the reinforcing effect of Tensar biaxial geogrids, and the report (7) stated:

When geogrid reinforcement is used, a given sub-base thickness can carry about 3.5 times more traffic.

The graph on Figure 14 shows a cross section of one of the test sections after 800 axle passes. The unreinforced control section has a deep rut at the surface, and a rut can also be seen at the top of subgrade. On the reinforced section, the surface rut is about half the depth, and there is negligible rutting at the top of subgrade. Similar behaviour was observed for CBR's of 0.4% and 1.6%. These results substantiate some of the earlier observations concerning granular layers reinforced with Tensar biaxial geogrids:

- Interaction by interlock is mobilised with minimal deformation of the geogrid
- Tensile strains and deformation in the subgrade are minimised
- Interlock confines the aggregate and minimises lateral displacement
- Rut depth for similar pavement life is reduced

This is quite different to the tensioned membrane mechanism, which requires large deformations both of the geosynthetic and at the subgrade surface. Furthermore, the tensioned membrane does not confine the aggregate, and can help to encourage lateral displacement of aggregate particles.

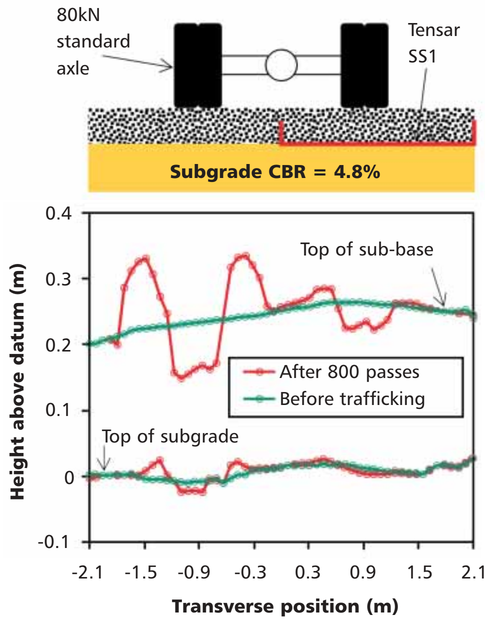


Figure 14: Trafficking trials at TRRL.

USACE pavement trials (early 1990s) - comparing geogrid types

Webster (8) reported the results of a major trafficking trial carried out in the early 1990s, aimed specifically at light aircraft pavements. The test load consisted of a single 130 kN wheel, and the test pavement was finished with 50mm of asphalt. Different base thicknesses were investigated, and the subgrade consisted of clay with CBR of 3% and 8%. The results from one section of this trial are summarised in Figure 15.

One purpose of the USACE trial was to compare the performance of different forms of geogrid and mesh (see Figure 15). It can be seen that the various geogrids and meshes tested give greatly different performance. A study of these results and the products tested, identified grid properties which affect the reinforcement mechanism (Table 1). These included the rib's shape, thickness and stiffness, and the aperture's size, shape, rigidity and stability. It should be noted that grid tensile strength (ie. rupture load at large strain) was not found to be relevant to a grid's performance. This property is not used when designing with Tensar biaxial grids. The study also determined that the prevailing mode of failure of the pavement was lateral movement of the base aggregate away from the applied wheel loads. This movement was prevented by the Tensar grids.

The report stated:

By interlocking with the base layer aggregate, geogrids reduce permanent lateral displacement, which accumulate with traffic passes.

The grids also effectively separated the aggregate base from the subgrade, in spite of their relatively large apertures, without the use of a separation fabric. The major conclusion of the work was that:

The performance of the various geogrid products tested ranged from no improvement up to 40 percent reduction in total pavement thickness requirement. The relatively rigid sheet-type geogrid (Tensar SS2) performed the best of all products tested. The lighter weight version of this product performed second best. However, one other sheet-type product and one woven-type product with good strength properties failed to provide any measurable performance improvement. The remaining woven-type products provided marginal performance improvement.

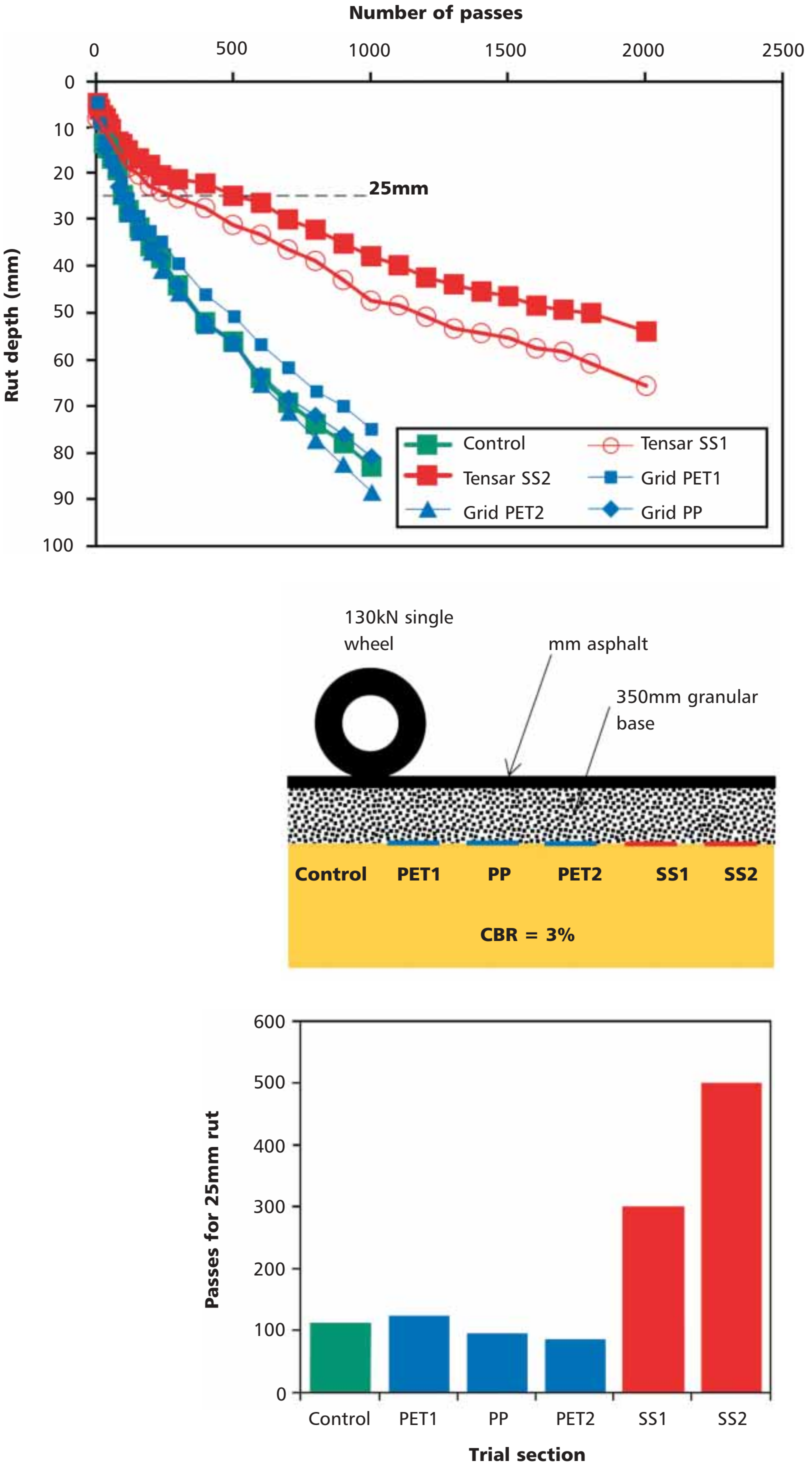


Figure 15: Pavement trial carried out by USACE comparing different grids.

Table 1 Geogrid properties affecting base reinforcement

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. 0.75 to 1.5 inches (20-40mm) 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 relationship. A minimum secant aperture stability modulus at a specified torque may be a good index test requirement.

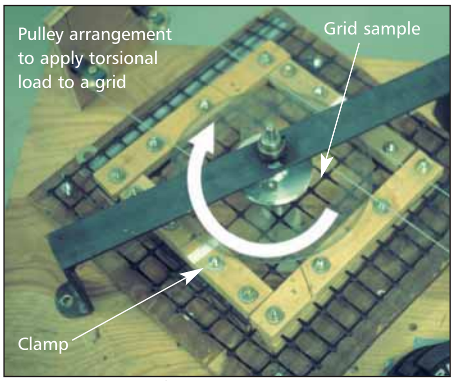


Figure 16: Apparatus for in-plane torsional rigidity test.

Mechanical properties of geogrid considered relevant to base reinforcement established in the USACE trial (8) listed in Table 1, include aperture stability. This is measured using a torsional test carried out in the plane of the geogrid, which was developed by Kinney & Xiaolin (9). The apparatus is shown in Figure 16, and the moment applied to the test specimen imitates the torsional loading applied to a section of grid in a pavement due to a passing wheel. Testing has established that a product required to provide the geosynthetic function of reinforcement in ground stabilisation should have high in-plane stiffness, in addition to the ability to interlock effectively with aggregate particles. To quote from Kinney & Xiaolin:

the aperture rigidity modulus is a measure of material property which is significant to the geogrid performance in base reinforcement applications.

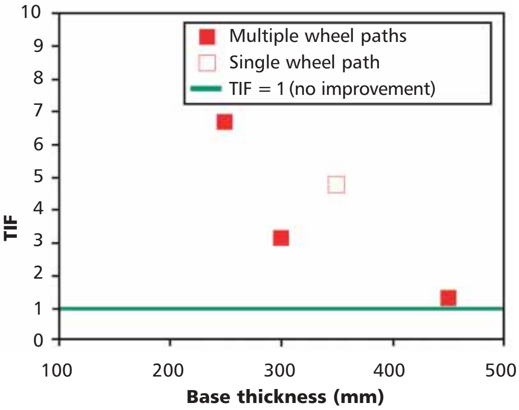


Figure 17: Traffic improvement factors for Tensar SS2 from USACE trial.

The USACE report introduces the concept of Traffic Improvement Factors (TIF). For any specific pavement, TIF is defined as:

$$\text{TIF} = \frac{\text{Number of passes with geogrid}}{\text{Number of passes without geogrid}}$$

where the number of passes is defined for a specific failure or serviceability criterion.

For the USACE trial, TIF for a rut depth of 25mm for Tensar SS2 is plotted against base thickness in Figure 17. This shows that for base thickness less than 400mm, TIF is around 5, but as the base becomes thicker TIF reduces.

Newcastle pavement trials (1996) - further comparative testing

A more recent trafficking trial has been carried out at the Newcastle University, UK (10). In this case, the pavement was unsurfaced. The results on Figure 18 show similar trends to the previous trials and tests. After 52,000 wheel passes, the sections with other forms of geogrid (coated woven polyester and extruded PP) have similar rut depth to the unreinforced control. Rut depth for Tensar SS2 is about half that of the control, which is similar to the behaviour observed in both the TRRL and USACE trials. This trial included Tensar SS30, which has superseded SS2, and it can be seen that both Tensar grids give a similar performance.

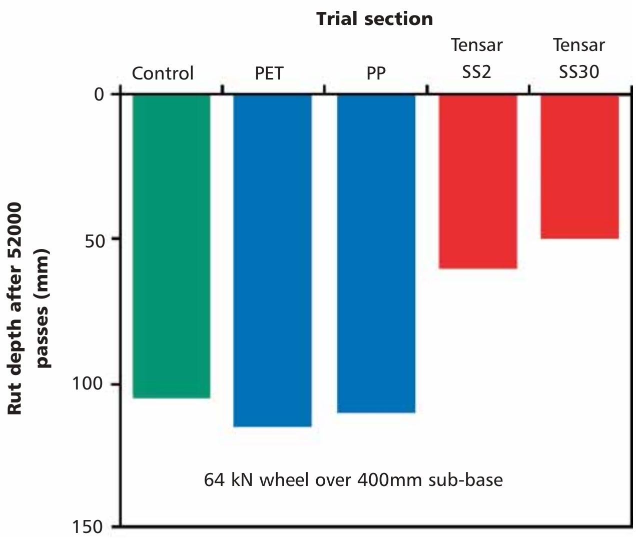


Figure 18: The Newcastle University trafficking trials.

TRL pavement trials (2000) - relating performance in pavements to geosynthetic stiffness

In 2000, TRL carried out a further pavement trial, incorporating a variety of geosynthetic materials (11). The pavement consisted of 320mm of sub-base over a clay subgrade with CBR = 1.5%. The pavement was trafficked by a 40 kN double tyred wheel along a fixed path, representing one end of a standard design axle. Figure 19 shows rut depth versus number of passes for five of the sections tested. Four of these sections include a 40 kN/m biaxial geosynthetic product at the subgrade level. Table 2 summarises TIF (for a 40mm rut depth) for these four products, and also gives their stiffness (in terms of load at 2% strain from tensile tests).

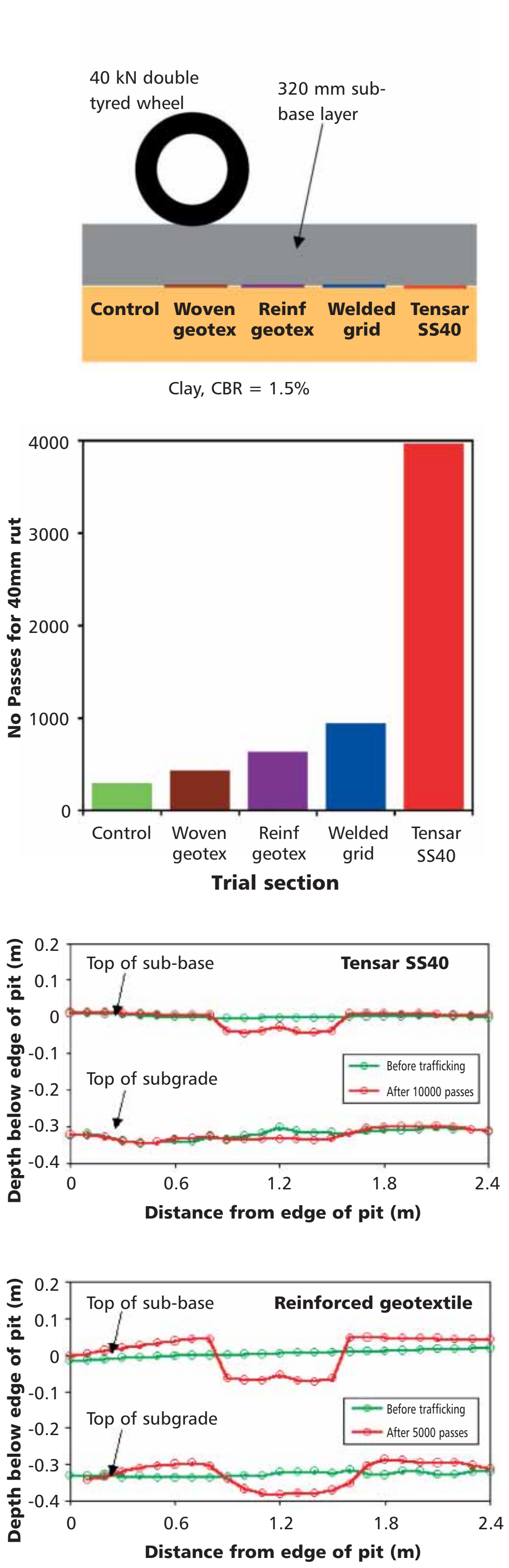


Figure 19: Comparative pavement trial carried out by TRL.

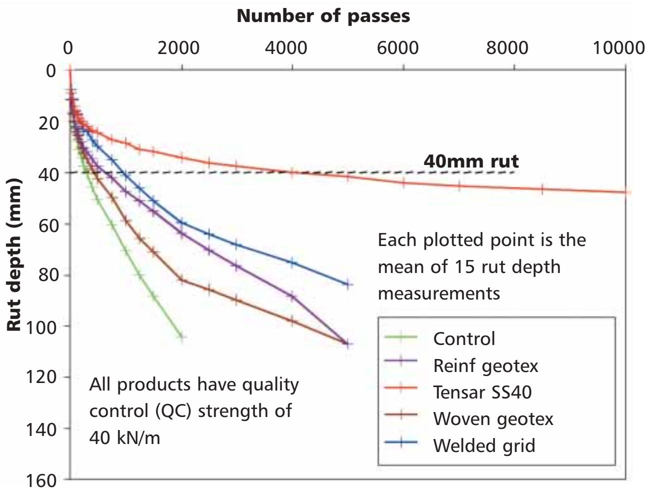


Table 2: Summary of TIF for 40 kN/m products in TRL trial related to stiffness

Product	TIF	Load at 2% strain (kN/m)	Comments
Woven PP geotexile	1.5	14.0	must rely on tensioned membrane
Reinforced geotexile	2.1	26.0	must rely on tensioned membrane
Welded grid	3.2	15.0	limited interlock possible
Tensar SS40	13.5	14.0	efficient interlock

The woven geotextile has similar stiffness to Tensar SS40, yet provides negligible reinforcing benefit. The reinforced geotextile (a composite consisting of a non-woven geotextile reinforced with high modulus aramid fibres) has twice the stiffness of Tensar SS40, but provides very little improvement in performance compared to the control section. The lower part of Figure 19 shows rut profiles measured in this section, compared with Tensar SS40. After 5000 passes, not only is there deep rutting and heave in the sub-base surface, but also in the subgrade surface below. For Tensar SS40 after 10,000 passes, there is a smaller rut, negligible heave and little deformation of the subgrade surface. The welded grid consists of very thin polyester strips welded to form a grid shape, with similar stiffness to Tensar SS40. The thin strips do not interlock effectively with the aggregate and the improvement in pavement performance is less than 25% of that provided by Tensar SS40. This comparison has similar conclusions to many others, and again emphasises that the most important feature of a geogrid to reinforce a road pavement effectively is its ability to interlock with the aggregate particles.

Design recommendations for road pavements and trafficked areas have been developed from cyclic load tests and trafficking trials.

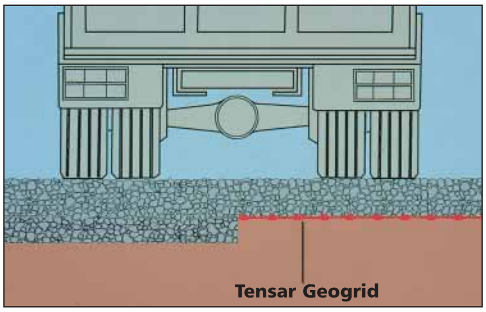


Figure 20: Concept of pavement design with Tensar biaxial geogrid - reduced pavement thickness for similar performance.

Plate loading tests

Plate tests reported by Vanggaard (1999) - investigating layer modulus

The results from plate loading tests are commonly used as input parameters for pavement design. Vanggaard (12) reports the results of plate loading tests carried out to investigate pavement modulus at a number of sites in Denmark. In each case, the subgrade modulus (E_m) is measured, then the modulus on top of the granular sub-base (E_{v2}). The test arrangement and results are summarised on Figure 21. The relationship between E_m and E_{v2} is a measure of the increase in vertical stiffness created by the sub-base. Figure 21 shows the results for the control sections (without any geosynthetic), and sections reinforced with Tensar SS30. The vertical difference between the two lines is a measure of the improvement in vertical stiffness of the sub-base by reinforcing it with Tensar SS30. Figure 21 includes some results from woven coated polyester grids, which show considerably less improvement.

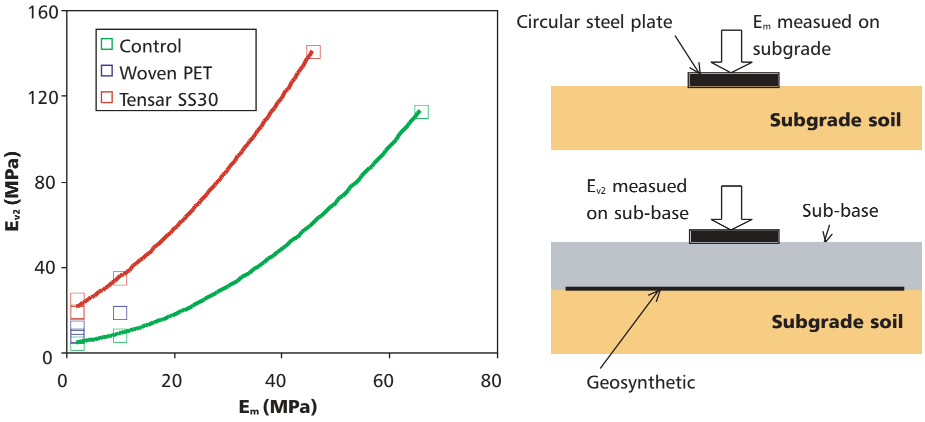


Figure 21: The arrangement and results from plate tests to establish pavement modulus.

Plate loading tests reported by Seiler (1995) - investigating layer modulus

During upgrading of a section of the Berlin to Munich railway line in Germany, plate load tests were carried out to determine the benefit of reinforcing the sub-base with Tensar biaxial geogrid (13). In the test section the subgrade was very weak with CBR around 0.5 to 1.0% (modulus 7 to 15 MPa). Figure 22 summarises the results of plate loading tests on the sub-base. Sub-base thicknesses of 400 and 600mm were tested. Using a single layer of Tensar SS2 at the base of the layer resulted in approximately 100% increase in modulus. These results are similar to those reported by Vanggaard, and are important because many pavement design methods use modulus as the principal design parameter of the granular layers. This testing demonstrates that including Tensar geogrid in a granular layer effectively increases its modulus by a factor of 2 or more.

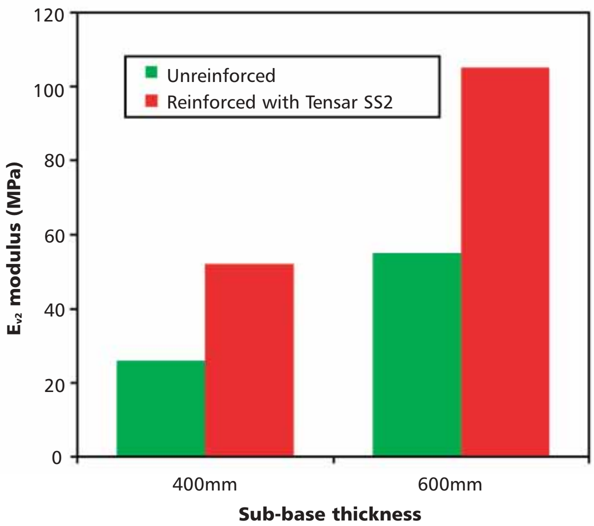


Figure 22: Effect of using Tensar SS2 on sub-base modulus.

Void trial - The ultimate demonstration of interlock

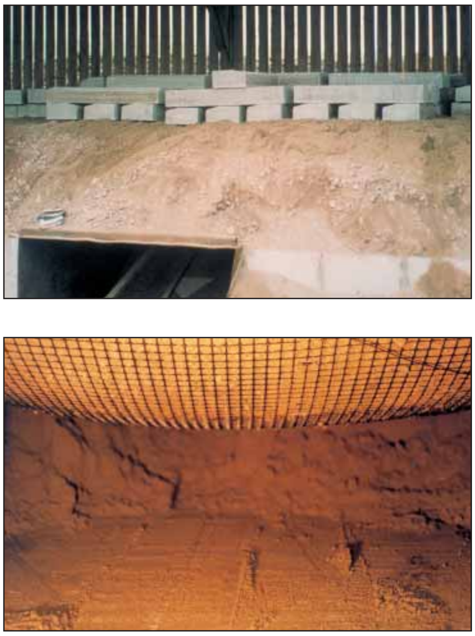


Figure 23: Views of the void trial before (top) removing support and inside void.

The University of Wales (14) carried out a special trial to investigate using Tensar biaxial geogrid reinforced pavements to span across voids. The aim of this trial was to see if pavements reinforced in this way could provide an early warning system of a void appearing unexpectedly beneath a road, for example, in areas of old mine workings. The requirement was that the void would create a depression in the road sufficiently deep to be detected easily, but able to survive long enough for remedial measures to be taken safely.

The arrangement of the trial is shown on Figure 24. A 3m diameter void was formed in between blockwork walls, then filled with sand. A pavement consisting of 0.6m of granular sub-base was placed above the sand-filled void, reinforced with 2 layers of Tensar SS35 geogrid. Two layers of kerbstones were placed on top of the sub-base to give 5 kPa surcharge (Figure 23). The sand fill was then removed to create the void. The underside of the lower geogrid layer after formation of the void can be seen on Figure 23 (lower). The geogrid was monitored with strain gauges at various distances from the centre of the void and the results for the lowest layer are shown in Figure 24. It is important to note that the geogrid was not fixed or anchored to the top of the blockwork wall – it was just resting on top.

The results from this trial are remarkable for a number of reasons:

- Strain reached a maximum of 4% after completion of void formation, and increased very little until 72 hours were reached, when the trial was demolished
- Tensioned membrane theory predicts that load in a membrane used in this way should be well above the breaking load of the geogrid – it clearly was not
- Membrane theory and creep properties of the PP geogrid would suggest that grid strain should increase rapidly with time – this did not happen
- Strain (and therefore load) measured in the geogrid at the two points resting on top of the blockwork wall (1.75m and 2.25m on Figure 24) is zero, indicating that the support mechanism does not rely on friction between the grid and the top of the blockwork wall

This trial shows how effective interlock is in creating a stiffened granular mattress, and how superior it is to a tensioned membrane. As a tensioned membrane, the granular pavement should have collapsed very quickly. However, the sub-base/geogrid composite created a 0.6m thick gravel mattress spanning 3m at strains well below failure. This unique composite action can be utilised in all applications where granular layers are reinforced with Tensar biaxial geogrids.

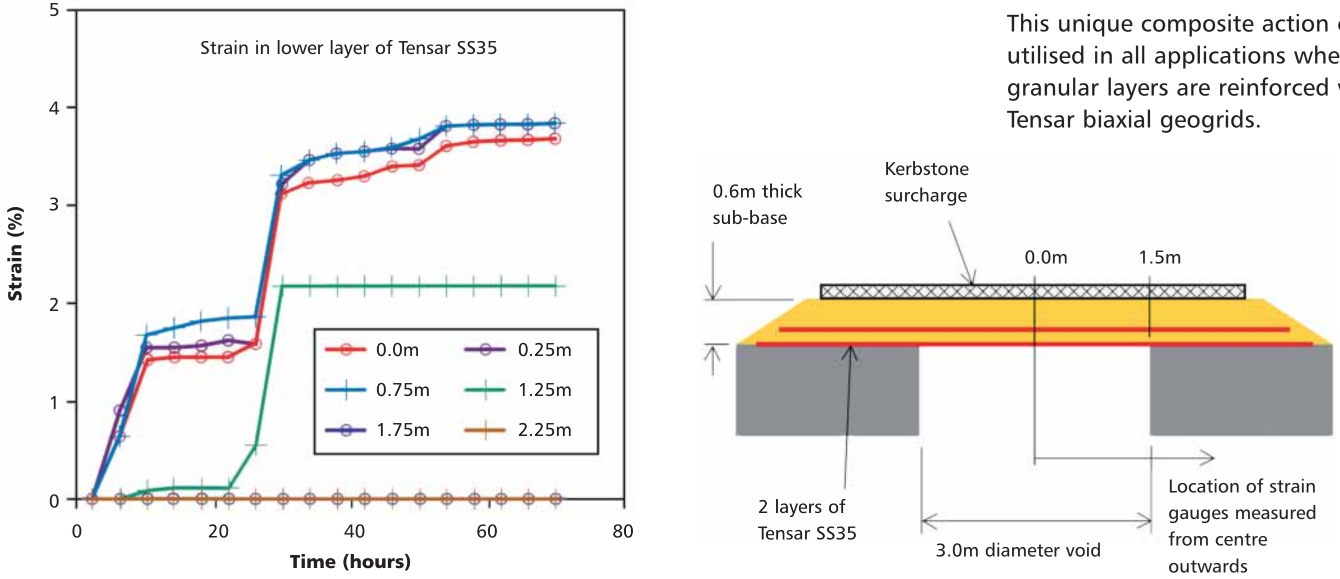


Figure 24: Void trial carried out by The University of Wales.

Performance in service

Glenlogan Park Estate, Queensland - confirming the "one-third rule"

A pavement was built in 1997 as part of a housing development in South Queensland, Australia. A section of the pavement was built using Tensar SS30 placed at the subgrade level, but with the granular layers designed using a one-third reduction in thickness. Both six months and two years after construction, Benkleman Beam (BB) deflection tests were carried out on the reinforced and unreinforced sections of pavement. Both series of tests gave consistent results, demonstrating that the thinner reinforced section of pavement deflected consistently less than the thicker unreinforced pavement.

In November 2000 further performance testing was carried out using the falling weight deflectometer or FWD (15).

The deflection results are shown on the upper graph of Figure 25, and they show a similar trend to the Benkleman Beam tests, namely consistent results with deflection of the thinner reinforced pavement significantly less than the thicker unreinforced pavement. FWD tests can be analysed to interpret layer modulus in the pavement. This is shown for the sub-base layer on the lower graph of Figure 25. The results are consistent, and show that the modulus of the thinner reinforced sub-base is on average more than double that of the thicker unreinforced sub-base. This observation is almost identical to the results from plate loading tests described earlier in this guide.

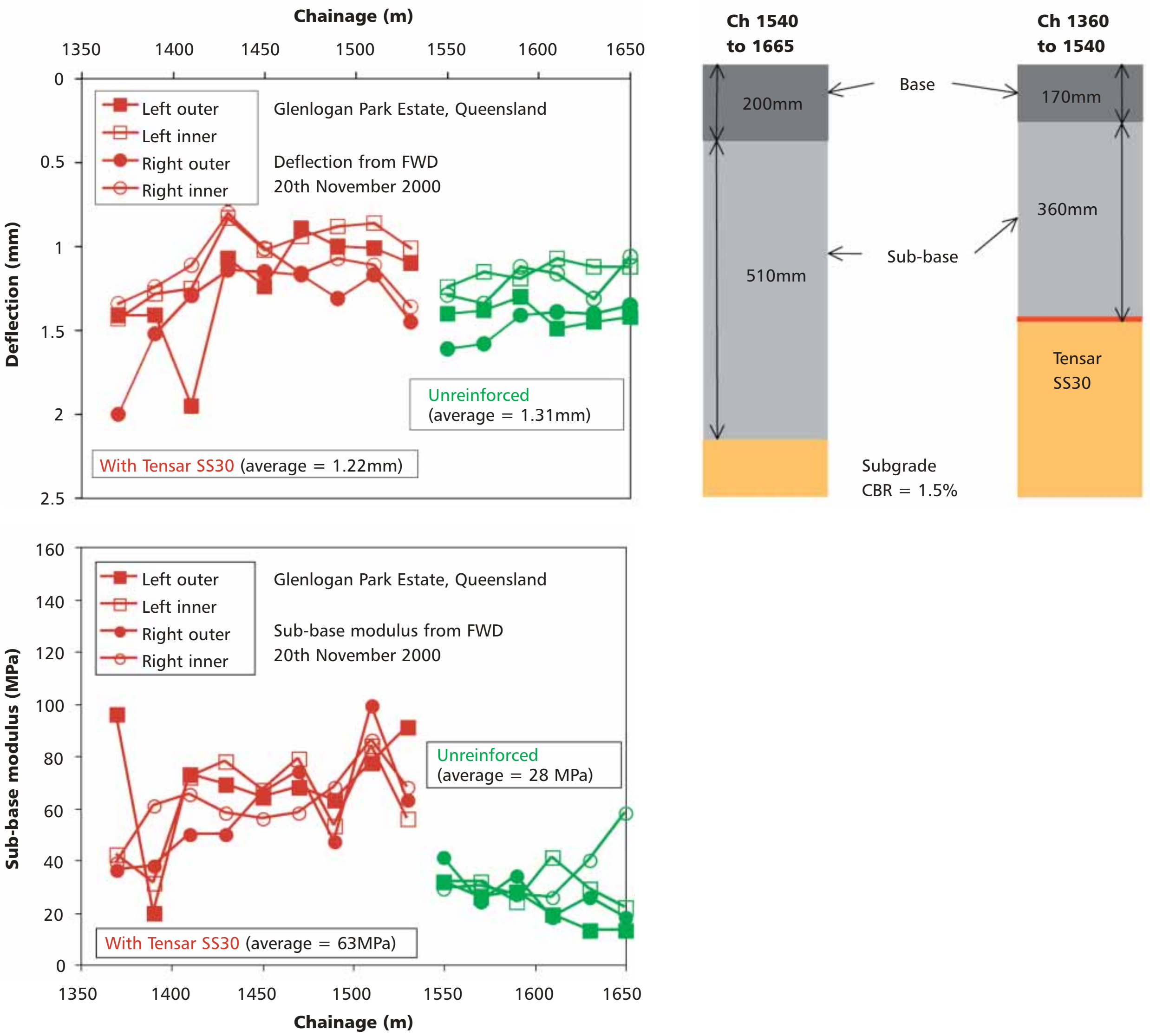


Figure 25: Comparison of reinforced and unreinforced pavements in Australia.

Wyoming, USA - confirming the "one third rule"

Huntington and Ksaibati (16) describe a pavement built in 1995 to evaluate the performance of biaxial geogrid. A control section was built adjacent to a section reinforced with Tensar SS1 geogrid (described by its US designation of BX1100 in the paper), and with a one-third reduction in granular base thickness.

After three years service in 1998, the sections were checked using a Falling Weight Deflectometer (FWD), and by measuring rut depth. The results are summarised on Figure 26, which shows that both sections have almost identical characteristics.

Both trials described above confirm the "one-third rule", namely that a Tensar geogrid reinforced pavement with a 33% reduction in granular thickness gives similar or better performance when compared to the thicker unreinforced control section.

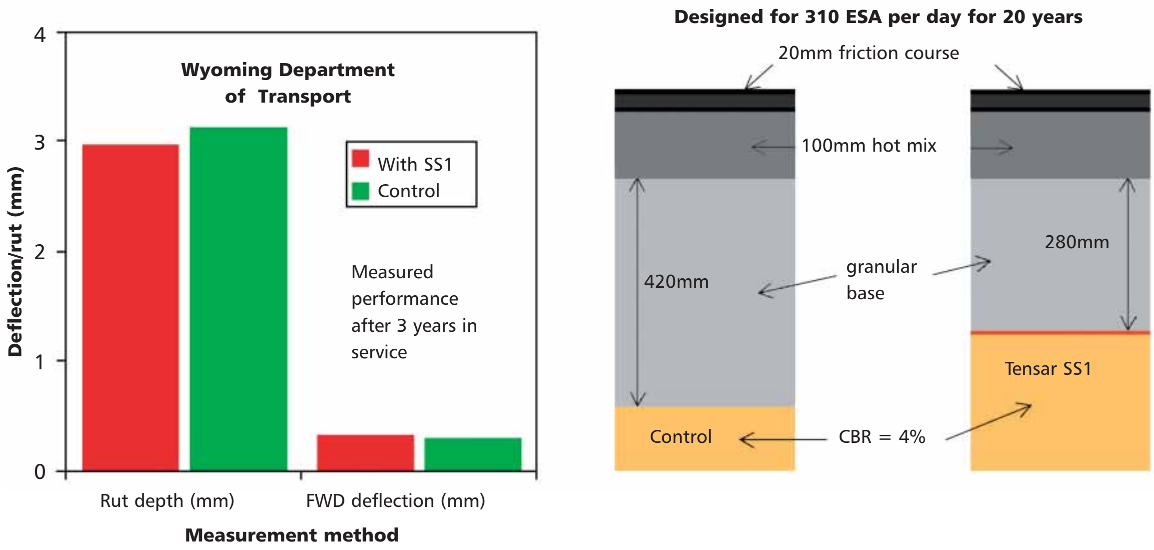


Figure 26: Comparison of reinforced and unreinforced pavements in USA.

Manufacturing process

Tensar biaxial geogrids are manufactured from carefully selected grades of polypropylene (PP). A long service life is required in most civil engineering applications and the grade of PP used in Tensar geogrids combines the optimum values of strength, stiffness, toughness and durability.

Biaxial geogrids are made by extruding a sheet of PP to very precise tolerances, punching an accurate pattern of holes, then stretching the sheet under controlled temperature, firstly in the longitudinal direction, then in the transverse direction. This process creates a geogrid with square or almost square apertures, called a biaxial grid because it is stretched in two orthogonal directions.

The polymer's long chain molecules are orientated in the direction of stretching resulting in a dramatic increase in both strength and stiffness. This orientation passes through both the narrower ribs and the thicker nodes, and is unique to the patented Tensar manufacturing process.

The resulting product is a monolithic grid with square edged ribs and integral junctions which possess both geometrical and molecular symmetry; critical for consistency in manufacture and efficient load transfer in service. Aperture sizes have been carefully chosen to match with typical gradings of pavement aggregates.

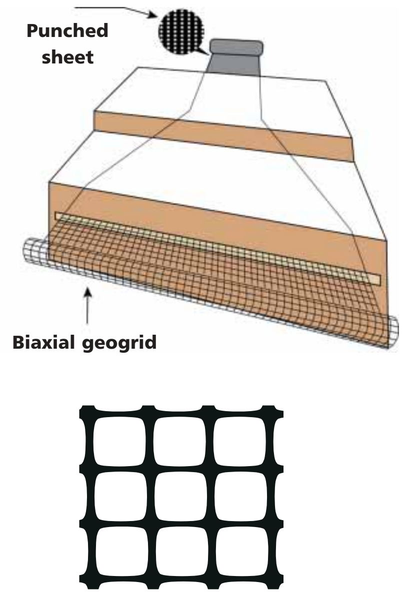


Figure 27: The Tensar manufacturing process and the stretched biaxial geogrid.

Quality control testing

For Tensar biaxial geogrids, quality control (QC) tensile testing is carried out using the method specified in International Standard ISO 10319. This requires a specimen width of at least 200mm. Strain rate is 20% per minute and test temperature is 20°C.

A typical test from an ISO 10319 QC test is shown on Figure 28. These tests are carried out at prescribed intervals according to the certified quality control procedures. The specified QC strength per metre width is the 95% lower confidence limit determined in accordance with ISO 2602-1980.

Tensar geogrids are manufactured under tightly controlled conditions. The quality assurance procedures covering design and application and the manufacturing process have been certified by the British Standards Institution as a Registered Firm in accordance with BS EN ISO 9001.

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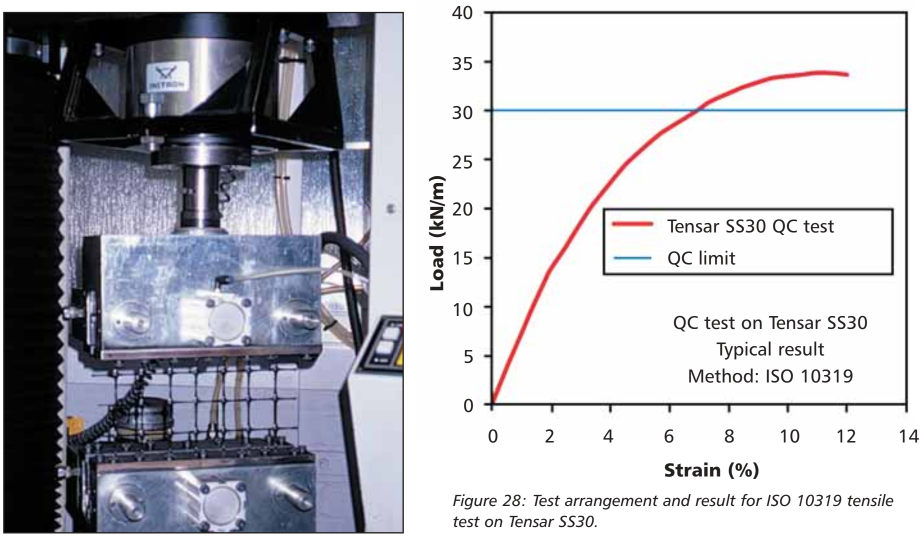


Figure 28: Test arrangement and result for ISO 10319 tensile test on Tensar SS30.

Durability and UV resistance

Tensar biaxial geogrids are extremely durable (17). They are not affected by hydrolysis, and are resistant to attack by aqueous solutions of salts, acids and alkalis. They have no solvents at ambient temperature. PP is not a nutrient medium for micro-organisms and is, therefore, not affected by them. In addition, the tough monolithic form of Tensar biaxial geogrids gives them a high degree of resistance to installation damage.

Ultra-violet light (UV) can damage unprotected polymers very rapidly, by breaking down the polymer chains. Tensar biaxial geogrids are manufactured with a minimum of 2% well dispersed carbon black, which gives a very high degree of protection by preventing UV from penetrating beyond a thin layer at the surface. This excellent UV resistance means that no special wrapping or covering is required during handling, and there is no need to specify minimum duration before cover is established if the grids are to be exposed during construction.

Tensar SS geogrid specifications

Property	Units	Tensar geogrid					
		SS20	SS30	SS40	SS2	SSLA20	SSLA30
Polymer (1)		PP	PP	PP	PP	PP	PP
Minimum carbon black (2)	%	2	2	2	2	2	2
Roll width	m	4.0 & 3.8	4.0 & 3.8	4.0 & 3.8	4.0	3.8	3.8
Roll length	m	50	50	30	50	50	50
Unit weight	kg/m^2	0.22	0.33	0.53	0.29	0.22	0.33
Roll weight	kg	46 & 44	67 & 64	65 & 62	60	43	65
Dimensions							
A_L	mm	39	39	33	28	65	65
A_T	mm	39	39	33	40	65	65
W_{LR}	mm	2.2	2.3	2.2	3.0	4.0	4.0
W_{TR}	mm	2.4	2.8	2.5	3.0	4.0	4.0
t_J	mm	4.1	5.0	5.8	3.8	4.4	7.0
t_{LR}	mm	1.1	2.2	2.2	1.2	0.8	1.7
t_{TR}	mm	0.8	1.3	1.4	0.9	0.8	1.5
Rib shape		Rectangular with square edges					
Quality Control Strength (longitudinal)							
T_{ult}(3)	kN/m	20.0	30.0	40.0	17.5	20.0	30.0
Load at 2% strain (3)	kN/m	7.0	10.5	14.0	7.0	7.0	11.0
Load at 5% strain (3)	kN/m	14.0	21.0	28.0	14.0	14.0	22.0
Approx strain at T_{ult}	%	11.0	11.0	11.0	12.0	10.0	9.0
Quality Control Strength (transverse)							
T_{ult} (3)	kN/m	20.0	30.0	40.0	31.5	20.0	30.0
Load at 2% strain (3)	kN/m	7.0	10.5	14.0	12.0	8.0	12.0
Load at 5% strain (3)	kN/m	14.0	21.0	28.0	23.0	15.0	25.0
Approx strain at T_{ult}	%	10.0	10.0	10.0	10.0	10.0	9.0
Junction strength as % of QC strength (4)							
Minimum junction strength	%	95	95	95	90	95	95

(1) PP denotes polypropylene.

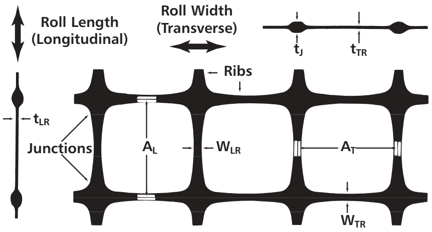
(2) Carbon black inhibits attack by UV light. Determined in accordance with BS 2782:Part 4: Method 452B:1993.

(3) Determined in accordance with BS EN ISO 10319:1996 and as a lower 95% confidence limit in accordance with ISO 2602:1980 (BS 2846:Part 2:1981).

(4) Determined in accordance with GRI GG2-87 and expressed as a percentage of the quality control strength.

(5) Tensar SS geogrids are inert to all chemicals naturally found in soils and have no solvents at ambient temperature. They are not susceptible to hydrolysis and are resistant to aqueous solutions of salts, acids and alkalis and are non-biodegradable.

(6) All quoted dimensions and values are typical unless stated otherwise.



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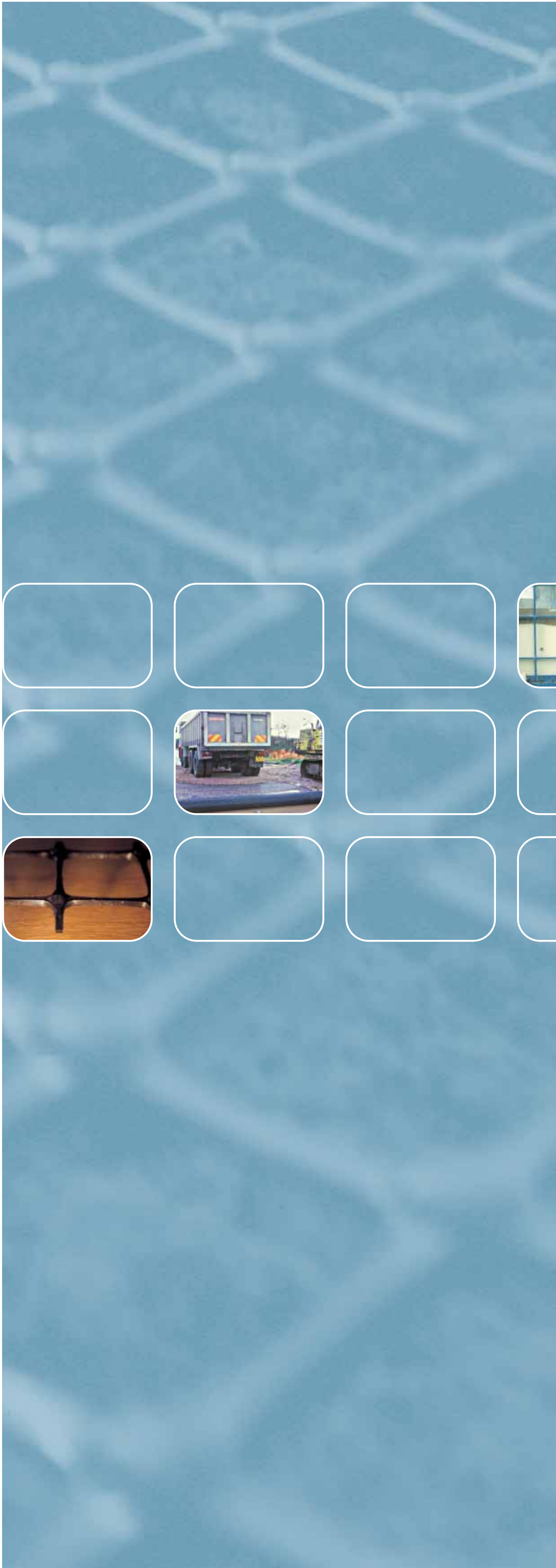
Contact Tensar International or your local distributor to receive further literature covering Tensar products and applications.

Also available on request are product specifications, installation guides and specification notes.

The complete range of Tensar literature consists of:

- **Tensar Geosynthetics in Civil Engineering** A guide to the products and their applications
- **Erosion** Controlling erosion on soil and rock slopes
- **Steep Slopes** Constructing embankments with steep slopes
- **Asphalt Pavements** Reinforcing asphalt layers in roads and trafficked areas
- **Ground Stabilisation** Reinforcing unbound layers in roads and trafficked areas
- **Retaining Walls** Constructing retaining walls in reinforced soil
- **Foundations over Piles** Constructing over weak ground without settlement
- **Basal Reinforcement** Constructing embankments over weak ground
- **Railways** Reinforcing ballast under railway track



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