Geosynthetic reinforcement for road pavements in cold climate

A. Watn
WatnConsult AS/SINTEF, Norway (arnstein.watn@watnconsult.no)

Inge Hoff
Norwegian University of Science and Technology, Norway (inge.hoff@ntnu.no)

C.Recker
SINTEF, Norway (christian.recker@sintef.no),

ABSTRACT: Geosynthetics have been used for reinforcement in roads in the Nordic countries for more than 50 years. Roads in these countries have relatively low traffic volume and the main deterioration mechanisms are related to soft subsoil, high water content and frost actions. The geosynthetics are used to improve bearing capacity and reduce deformations. The solutions are based on an evaluation of deterioration mechanisms and the design is to a large extent based on experiences from the field. Geosynthetics are commonly used in the sub-base or base layer to improve the resistance to deformation in rehabilitation and upgrading of existing roads. However, despite positive effects are verified through experiences, no technically sound design model is existing. To a large extent design is based on producer specific empirically based design recommendations. This means that comparison between different solutions with reinforced base layers and comparison with more conventional solutions are very difficult. This is a major obstacle to the implementation of geosynthetic reinforcement into conventional road design procedures and means that the use of reinforcement in the base layer only to a limited extent has been taken into account in general recommendations for road design. The paper presents some results from research projects and experiences from the field. It also presents a basis for developing a design model for reinforcement in granular materials and recommendations related to the use of geosynthetic reinforcement in granular materials in road pavements.

Keywords: pavement, design, reinforcement

1 INTRODUCTION

Geosynthetics have been used in road pavement construction in Nordic countries for more than 50 years. The main use has traditionally been as separation between fine graded materials in the sub-soil and the more coarse graded materials in the sub-base layers. This is now very commonly used in most road construction works and a system for certification and specification of geotextiles for this purposewas developed (Alfheim &Sørlie). The system, NorGeoSpec has been further developed in a Nordic co-operation projectis now used in Finland, Sweden, Norway, Iceland and Estonia. The system has now been extended to other functions and applications and the aim is to develop a complete system for specification and certification covering most functions and applications for geosynthetics for civil and environmental engineering purposes (Moe et al).

Another successful use of geosynthetics is as reinforcement to build on very weak soils like peat. Often it is necessary to build temporary roads for construction purposes and it would be unpractical and expensive to remove the weak soil which often would be the alternative to using geosynthetic reinforcement. Use of reinforcement in asphalt layers has shown very mixed results. In some rehabilitation projects this method has prevented reflective cracking, but other projects were less successful.

This paper focus on use of geosyntethic reinforcement in unbound base or sub-base layers.

Geosynthetic reinforcement in sub-base, base or asphalt layers are commonly used for rehabilitation and upgrading of low volume roads. The effects and the solutions in terms of structural solution and type of products are more controversial and we do not have enough high quality field tests or theoretical understanding to conclude on when and how geosynthetics should be used. To be able to establish recommendations for design and construction it is necessary to try to improve the understanding of the function and develop usable design tools.

2 DISTRESS MECHANIMS

For high volume roads most of the damages are related to the top asphalt layer. Base and sub-base layers are normally build thick enough to prevent damages from frost heave and loss of bearing capacity

2.1 *Low volume roads*

Some typical damages and related causes are shown in Table 1.

Table 1. Typical damages and causes

	Frost heave/spring thaw	Narrow roads	Thin base/sub-base	Temperature changes
Rutting	X		x	
Cracks	X	x		x
Edge damages	X	x		
Uneveness	X		x	
Asphalt durability				x

For most low-volume roads in areas with seasonal frost damages related to frost heave and spring thaw weakening is the most common cause of deterioration. These roads will normally not be build thick enough to prevent frost to penetrate into frost susceptible materials in the sub-soil. Uneven frost heave will reduce comfort for road user and often cause cracks to develop – typically in the center of the road in longitudinal direction. In addition to the direct problems caused by frost-heave we observe a lot of damage in the spring thaw. Water from ice-lences will melt and be trapped by impermeable, still frozen, layers below. Granular base and sub-base materials will then become over-saturated and loose most of the bearing capacity. This effect is most dramatically seen on gravel roads where you do not have asphalt to cover the problems (Figure 1)

Figure 1 Cracking from edge deformations (left), frost heave (middle) and, spring thaw (right)

Another common problems are cracks close to the edge of the road. The low-volume roads are quite often rather narrow with little or no shoulder. Heavy vehicles are forced to drive with the outer wheel very close to the edge to avoid oncoming traffic. In addition to the obvious safety problems this leads to cracks and deformations along the edge of the road (Figure 1).

Rehabilitation of these low volume roads is a challenging task and unfortunately many of the observed damages are caused by rehabilitation strategies that does not solve the real problem (e.g. frost heave) but rather tries to solve the symptoms (e.g. asphalt cracks). This is partly due to lack of information/understanding of the real problems but also from political pressure that wants to rehabilitate as many meters of roads as possible for a limited budget. Obviously, this gives very short time before the problems returns and is not cost efficient. The most typical damages that could be caused by faulty rehabilitation are:

- Reflective cracking (frost heave, low-temperature, cracks close to edge)
- Problems from widening of the road – often cracks between new and old structure
- Uneveness from low bearing capacity
- Rutting caused by layers below the asphalt.

3 FUNCTIONAL MECHANISMS FOR GEOSYNTHETICS IN ROAD PAVEMENTS

3.1 *Reinforcement function mechanisms in granular layers*

The design and performance of granular base layers in road structures is probably one of the oldest topics in civil engineering. Also the use of reinforcement for stabilization of the granular bases of the road is a very well known technique from ancient times using different types of reinforcement. A lot of experience has been gained on material properties, on the effect of loads and on the structural behavior. However, a sound scientifically based model for modelling the reinforcement function and evaluating the effects is still not existing.

The design of road structures includes a large variety of parameters, traffic loads, temperature, precipitation, subgrade, drainage, and type of material in the pavement. Numerical models to describe the behavior and theoretical design get complex and the inclusion of reinforcement does not simplify the task! Thus design of reinforced granular bases is to a large extent based on experience and numerical models are trying to replicate what has been observed in the field.

For flexible pavements the linear elastic multi-layer mechanistic-empirical approach is widely used. In this approach the strain at the bottom of the overlay, the vertical stress on top of the granular base and the compressive strain at the top of the soil are the critical parameters. These parameter are partly chosen because they could be calculated fairly accurate using linear elastic models. Other important parameters, like the horizontal stress, is not calculated in a reliable way using this method. More realistic non-linear models and use of a more advanced tool for calculation of stress and strains like the Finite Element Method would improve the possibility for accurate prediction of performance.

The possible mechanisms of reinforcement functions in unbound granular base layers are outlined by a working group in the European COST Action cooperation (de Bondt et al):

a) -increasing the resistance against elastic deformations by increasing the horizontal stress level in the structure
b) -increasing the load bearing capacity of the pavement structure by distributing the load onto a larger area of the underlying soil
c) -reducing the mobilization of the subsoil by reducing the shear stress transferred to the subgrade
d) -increasing the resistance to permanent deformation of the granular material itself by restraining horizontal movements of the granular particles (confinement).

Of these mechanisms only d) seems to be documented through laboratory and field observations. Mechanism a), b) and c) all are related to increased elastic stiffness of the reinforced material. Several laboratory or field tests have shown no increase or very small increase in elastic stiffness by the inclusion of geosynthetic reinforcement.

To avoid fatigue cracking of the asphalt top layer it is important to limit the elastic deformation of the structure to about 0.5 mm. The actual limit will depend on the asphalt stiffness (binder type). Even if this is a small deformation the allowable permanent deformation per axle load is several order of magnitudes smaller. If this is more than a few nm the accumulated deformations will result in fast development of rutting.

The modelling both should take into account the effect of the elastic deformations of the pavement and effect on the resistance against the plastic (permanent) deformations. Generally the effect of reinforcement in the granular bases is mostly related to the resistance against plastic deformations and to a less extent influences the elastic properties.

In practice, when a pavement designer is interested in using reinforcement in a granular base layer he/she has to estimate the main effect of the function mechanisms. This means that modelling of the effect of the reinforcement has to take into account:

- effect on the damage transfer function of the granular layer
- effect on stiffness of the granular layer (small)
- effect of reduced mobilisation of the subgrade (small)

Since the effect of a given reinforcement is highly dependent on the local conditions (traffic load, subgrade, materials, and degree of flexure of the pavement) no general rules/guidelines for modelling of the effect are found. To a large extent design is based on producer specific empirically based design recommendations. However, this commonly means that comparison between different solutions with reinforced base layers and comparison with more conventional solutions is very difficult. This also means that the use of reinforcement in the base layer only to a limited extent has been taken into account in general recommendations for road design.

Currently general road design is to a large extent based on empirical or semi-empirical methods and this complicates the inclusion of new materials and methods. Pavement reinforcement with geosynthetics has been used for more than 50 years, steel reinforcement for more than 2 decades in Europe. Reinforcement in road pavements has a promising potential and the beneficial effects of the reinforcement may both reduce construction costs and enhance the road performance. However, despite the large amount of research projects and a large number of successful projects in the field with good experience, pavement reinforcement is still not recognised as a solution at the same level with conventional methods. This is to a large extent due to the lack of technically sound models for the function mechanisms of the reinforcement and proper non product related design models.

3.2 *Reinforcement in granular layers-a design approach*

A comprehensive research project GeoRePave has been executed in a co-operation project between MSU (Montana State University, USA) and SINTEF (Trondheim, Norway) (Eiksund et al) (Perkins et al) The objective of this project was to develop design methods for reinforced unbound base course layers in roads. The project included the development of numerical material models and numerical modelling methods for road foundations. This research project has resulted in a proposed design procedure.

The motivation for including reinforcement in unbound base course materials is to reduce the construction and maintenances cost of the road. The latter should be evaluated in terms of life cycle cost. The life cycle cost can be split into:

- construction costs including materials
- maintenance costs over the road lifetime
- environmental impact from the use of construction materials

The cost reduction due to the use of reinforcement could theoretically be evaluated in terms of reduced required thickness of the unbound layer or increased number of traffic passes before maximum allowable deformation of the road is exceeded. This may be expressed with so-called benefit ratio's:

- Traffic Benefit Ratio (TBR): ratio of allowable traffic passes for a reinforced base course.
- Base Course reduction Ratio (BCR): ratio for the reinforced base thickness

If the TBR ratio is applied, the reduction in maintenance costs in the future must be larger than the cost for purchasing and installing the reinforcement. The life cycle cost may however be the easiest to determine on basis of the BCR, since this compares designs for the same traffic load (same number of passes before the design criteria on allowable traffic is reached). However reduction of base course thickness is problematic. This will lead to increased frost penetration with possible damage. Provided that the influence of elastic stiffness of the road structure from geosynthetic is very limited, reduction of base layer thickness, also will increase the mobilisation of the subgrade with potential increases permanent deformation. Accordingly it is recommended to use the geosynthetic reinforcement to increase the service lifetime and not to reduce the base course thickness.

To be comparable with the unreinforced design, the design method for reinforced base courses must include parts of the experience and empirical relations derived from field tests. It is therefore a difficult task to compare the design of reinforced and unreinforced pavements in engineering terms. Design of reinforced pavements has thus to be performed in relation to conventional road design. Starting from a 2D-axial symmetric Finite Element Model the unreinforced structure is designed. The effect of compaction, traffic load and reinforcement on the horizontal and shear stresses is calculated stepwise. Due to its complexity, this procedure needs to be incorporated into a software/design package in order to be used on a routine basis in practice. The research in the GeoRePave project has provided the outline of the methods and is published on the web address http://www.coe.montana.edu/wti/wti/display.php?id=89.

The proposed design models includes the following requirements and test methods:
a) material properties for the reinforcement. Stiffness in MD and CMD direction, Poisson's ratio and in plane shear-modulus.
b) interface properties between reinforcement and the base aggregate.
c) identification of shear stress growth functions for the reinforcement-aggregate interface.
The following test methods will be required to measure the reinforcement and interaction properties:
a) stiffness - wide with tensile test
b) Poisson's ratio – biaxial tensile tests
c) in plane shear modulus – a fully appropriate test method does not exist
d) cyclic pullout tests to define interaction properties
e) cyclic loading model tests on a reinforced pavement structure
f) cyclic triaxial tests on base course material to define permanent deformation properties.

In practice a usable design tool will have to limit the number of input variables that can be determined by standardized test methods or default values.

On request from the Norwegian road authorities a proposal for guidelines for the use of geosynthetic reinforcement in road structures was prepared (Øiseth & Hoff). The guidelines includes an overview of typical road pavement deterioration mechanisms, evaluation of possible effects of geosynthetic reinforcement, recommendation on the use of different types of reinforcement and structural solution. The guidelines also includes recommendation on installation and quality control of the installed products.

4 EXPERIENCES FROM THE FIELD

A number of test sections have been built to investigate the effects of geosynthetic reinforcement both in granular unbound layers and in overlays. Most of the test projects have in common that the evaluation of effects of the geogrid is difficult to evaluate as it is difficult to distinguish between the effect of the geogrid compared to other effects such as drainage os.

4.1 *Test section Vågan, Norway*

Error! Reference source not found. shows an example from a test project with a grid reinforcement in the granular bearing layer of a low volume road in Vesterålen in Norway in 1984 (Myre, J) A common problem in these areas is strengthening and paving of gravel roads on soft subsoil. In this case the old road was located in an area of peat subsoil with thicknesses up to 3m. The road had insufficient bearing capacity during the thawing period and was also subjected to extensive differential settlements. The strengthening of the road was done by using geogrid reinforcement directly on the old road and then placing a bearing layer with a thickness up to 1 m on top of the grid before the asphalt overlay was installed.

Measurements after the rehabilitation indicated that the reinforcement increased the bearing capacity of the subsoil and reduced differential settlements. The road has now been in use for more than 30 years since the rehabilitation was completed. Generally the experience has been good but repaving due to cracking of the asphalt overlay has been carried out including geosynthetic reinforcement in the asphalt overlay.

Figure 2 Installation of geogrid for road construction on peat in Myre, Vestrålen in Norway (1984). Foto SINTEF. (J. Myre)

4.2 *Test section at Hitra, Norway*

The project was performed to investigate the effect of geosynthetic reinforcement for rehabilitation of an old gravel road on very soft subsoil subjected to settlements and low bearing capacity in the thawing period. The aim of the rehabilitation was to improve the bearing capacity of the road to avoid restrictions on the axle load during the thawing period and to restrict the deformations of the surface to avoid cracking of the asphalt pavement. The structural layout was designed by the municipality of Hitra with assistance from the local road authorities. SINTEF was responsible for following up the road structure with measurements of elastic stiffness and rutting and with the evaluation of the results (Watn & Øiseth). The structural layout of the solution is presented in Figure 3.

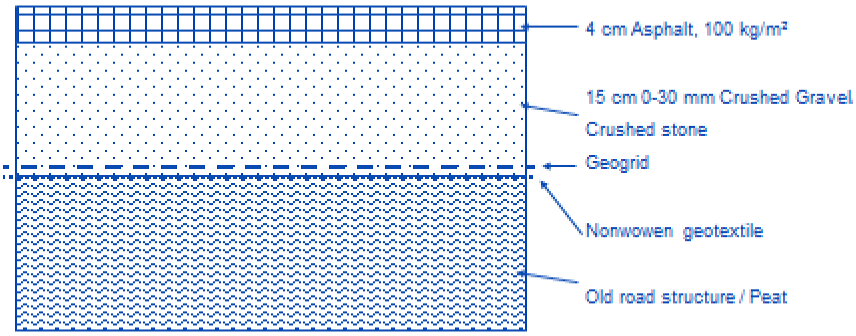

Figure 3 Structural layout of test road at Hitra (Watn & Øiseth)

The rehabilitation was performed in section over a period of several years and different types of geogrid reinforcement were used. Pictures from the installation of the reinforcement and after installation of the asphalt pavement are shown in *Figure 4*.

Figure 4 Road rehabilitation, Hitra Norway (Watn & Øiseth)

The evaluation of the results indicated that the rehabilitation works had been successful as no substantial rutting or cracking of the asphalt overlay has been observed on any of the test sections, *Figure 5*5.

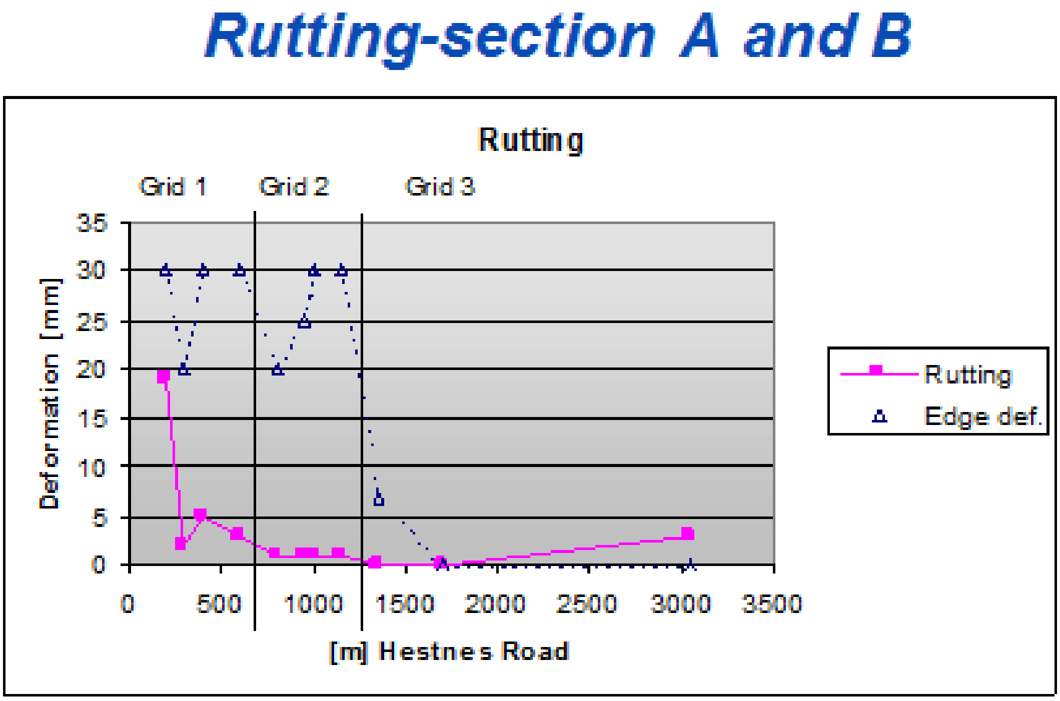

Figure 5 Rutting measurements, Hestnesveien, Hitra, Norway

Falling Weight Deflectometer (FWD),
Figure , show the effect on elastic properties while the beneficial effect of the reinforcement generally was related to the plastic deformations. The FWD test confirms that very little effect could be found on the elastic stiffness.

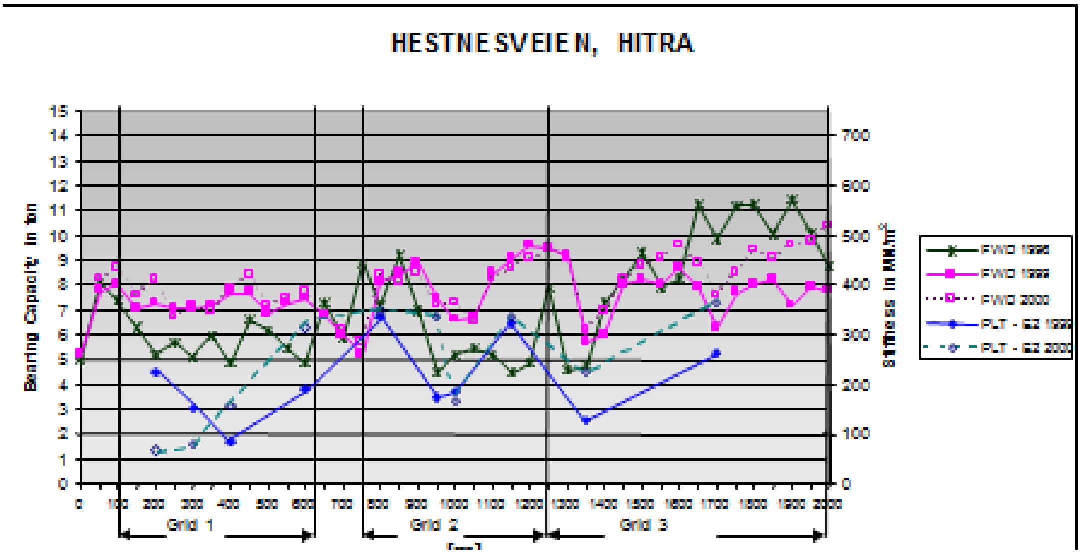

Figure 6 Falling weight deflectometer measurements, Hestnesveien, Hitra, Norway

4.3 *Test road, Finland*

An interestingly different use of geogrid reinforcement has been reported by Johansson and Nilsson (Johanson & Nilson), where welded steel was successfully used beneath a wearing course to prevent cracking due to frost heave of the pavement.

HVS full-scale accelerated pavement tests were also performed to examine the effect of a geo-textile on the performance of a rehabilitated steep-sloped pavement structure (Korkiala-Tanttu et al. 2003). The reinforced structures had around 25 - 50 % smaller rut depths than unrein-forced reference structures. This corresponds to the lengthening of the service life by at least 50 %. The tests showed also that steel grid delayed fatigue to some extent.

4.4 *Other field experiences*

The execution of the work is regardless application, type of geosynthetic reinforcement and installation conditions crucial for the result. There are numerous examples of damage and failures due to improper installation and execution of the works. Typically traffic directly on the geosyntheteic may cause damage and hence result in poor performance during the service lifetime. The cover of the geosynthetic should be at least 300 mm before any construction traffic, *Figure 7*.

Figure 7 Traffic by heavy construction traffic after installation of bearing layer on top of reinforcement

Also there are examples of damage on the geosynthetic due to installation in low temperatures, *Figure 8*.

Figure 8 Damage on geogrid from installation at low temperature (Foto Trafikverket, Sweden)

The physical behaviour and possible damage on geosynthetic reinforcement under cold conditions has to be evaluated as a part of a design procedure.

When installing geosynthetic reinforcement in asphalt overlays it is important to ensure proper bond between the geosynthetic layers and the asphalt and also to have a minimum of asphalt cover over the reinforcement to avoid possible delamination caused by e.g breaking of heavy vehicles, *Figure 9*.

Figure 9 Deformations of asphalt overlay due to debonding with geosynthetic reinforcement

5 CONCLUSIONS

Geosynthetics have been used in road structures in the Nordic countries for more than 50 years. Most of the damages seen on low volume road are caused by climatic problems during the winter, with frost heave and reduced bearing capacity during the spring thaw. The over-saturation of the unbound materials also occur in the base layer with enough fines for a paved road.

Since more than 30 years also geosynthetic reinforcement has been used to improve the bearing capacity and reduce surface deformations in roads. The main purpose of the geosynthetic reinforcement is to reduce cracking and to improve the bearing capacity on weak soils and reduce unevenness of the road.

The geosynthetic reinforcement is used quite frequently and have proven to work well in many cases. Based on the experiences from the field and state of practice the follow application seem most promising for the use of geosynthetic reinforcement in the granular materials in road pavements:
-upgrading and rehabilitation of low volume roads
-road widening and strengthening of road edge
-to facilitate use of sub-standard materials in road structures
-in combination with frost insulation materials
-access roads and temporary roads on soft subsoil

However, there is still no scientifically based design model existing to evaluate the function mechanisms of the reinforcement, neither as part of the granular material nor in the asphalt pavement. Also there is no commonly accepted design model that can be used as a design tool using commonly accepted criteria and properties.

It is necessary to develop a fundamental understanding of the functional mechanisms of the reinforcement to be able to evaluate the effect of geosynthetic reinforcement. The design model has to be linked to the corresponding deterioration mechanisms to provide a neutral design tool and to compare different products and solutions. Based on this understanding a non-product related design tool has to be developed using properties based on commonly accepted standardized test methods. This will also help to avoid use of reinforcement where it is not necessary of beneficial.

6 REFERENCES

Alfheim, Sørlie (1977). “Testing and classification of fabrics for application in road con-tructions”, International conference on the use of fabric in geotechnics, Paris, Vol 2, pp 33-338.

Cost Action 348 (2002): Memorandum of understanding for the implementation of a Eu-ropean Concerted Research Action Designated as COST Action 348 "Reinforcement of pavements with steel meshes and Geosynthetics.

Moe, H.L., Watn, A., Aaboe, R., Berntsen, G. & Myhre, Ø. 2008. Norgeospec 2002 - A Nordic System for Specification and Control of Geotextiles in Roads and Other Trafficked Areas. Proceedings of the Fourth European Geosynthetics Conference, Edinburgh, Scotland.

Eiksund, G.R., Hoff, I. & Perkins, S.W. 2004. Cyclic Triaxial Tests on Reinforced Base Course Material. Proceedings of the Conference EuroGeo 2004, Munich, Germany, pp. 619-624.

Perkins, S.W., Christopher, B.R., Cuelho, E.V., Eiksund, G.R., Schwartz, C.S. & Svanø, G. 2009.
A Mechanistic-Empirical Model for Base-Reinforced Flexible Pavements. International Journal of
Pavement Engineering, Vol. 10(2), pp. 101-114.

Øiseth, E. & Hoff, I. 2006. Use of reinforcement in roads. Proposal for guidelines. SINTEF report 502562-2006

Myhre, J. (1985): Strengthening of a road on peat using Tensar geogrid and Terram Geotextile. SINTEF report STF61 F85011.

Watn A and Øiseth E (2000): Geosynthetic Reinforcement in Roads – test Road at Hitra, Sør-Trøndelag, Norway. SINTEF report STF22 F00604.

Johansson, S., & Nilsson, L.E. 1998. Steel fabrics as reinforcement in road construction. Proc. 5th Int. Conf. Bearing Capacity of Roads and Airfields, Trondheim, Vol. 3, pp. 1513-1522.