On design principles of reinforced pavement structures - the COST 348 REIPAS action

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ABSTRACT: The paper is summarizing the development work for reinforcement of pavements and structures in the COST 348 REIPAS Action. Design approaches developed either for the utilization of geosynthetic reinforcement materials or for the utilization of steel grids are referred. The basic common principles of reinforcing practice is inserting or laying the steel or geosynthetics mesh below or underneath the pavement either during the maintenance or reconstruction of existing roads or construction of new sections. The COST 348 action is taking a step towards practicable guidelines for the structural design and execution of reinforced pavements and road sub-bases and to reach a consensus on the methods to determine relevant material parameters essential for analysing or predicting the behaviour of the reinforced structures.

KEY WORDS: Pavement, reinforcement, design.

1 INTRODUCTION

Geosynthetic reinforcement has been used in road pavements in Europe for more than 40 years, steel reinforcement in asphalt pavements nearly two decades. Utilisation of reinforcing elements in road pavements has generally the purpose to prohibit reflective cracking, to prolong the service life of pavements and thus to reduce maintenance costs and further more to increase resistance of the road structure against frost heave or differential settlements. The beneficial effects in terms of reduced construction costs and /or enhanced service lifetime have been verified both in research projects and in field experiences. Reinforcing materials may be used both in the unbound granular base and in the asphalt overlay. The European COST REIPAS research project (COST-348, 2002) has been initiated to look into the use of reinforcement of pavements with steel meshes and geosynthetics. Based on the preliminary results from the COST REIPAS project an overview is given on typical applications and solutions, on the experiences gained and also on ongoing work in Europe for research and development. The terminology used in this paper is based on the recommendations from COST REIPAS (COST-348 WG1, 2004) and is shown in Figure 1.

Various solutions to place reinforcement between pavement layers or to modify the mechanical characteristics of pavement layers are presently available. The materials applied in the different technologies vary from steel grids, plastic grids and meshes to woven and non-woven geotextiles.

Reinforcement of pavements has several advantages, both economical, environmental and for traffic safety. The method is presumed to allow thinner road structures and longer life cycles, which lead to a saving in natural resources due to prolonged service intervals. Integration of reinforcing materials provides a cost-effective solution for rehabilitation and so a reduction in maintenance costs.

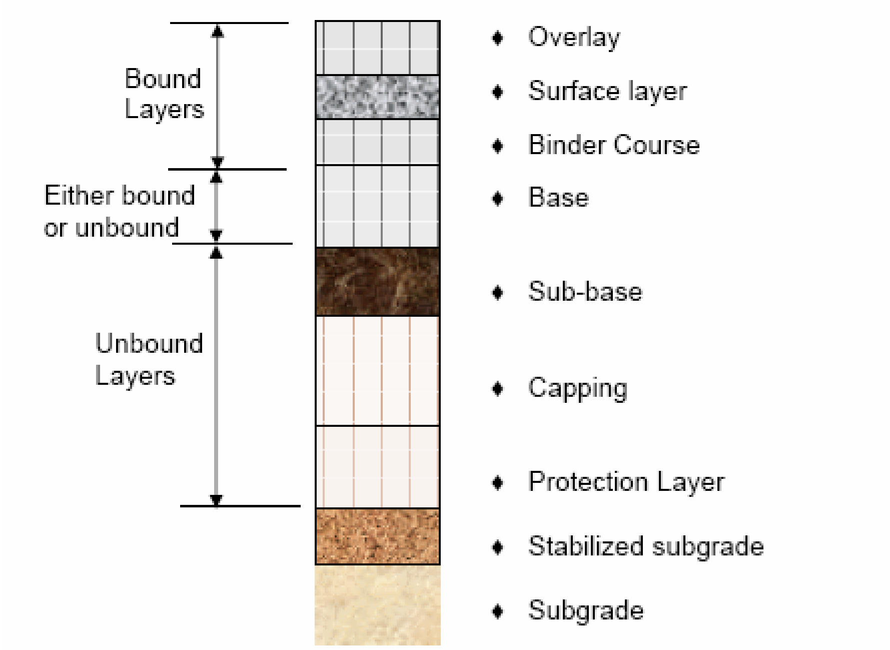

Figure 1 Terminology of pavement structure used in the COST REIPAS project.

2 FUNCTIONS AND BENEFITS

The committee work in the COST REIPAS project compiled in the beginning the existing knowledge through a set of questionnaires amongst the experts in the participating countries. These resulted in descriptions of the damage cases for which reinforcement products are relevant and in an overview of assessment methods and in addition in a review of previous and ongoing research on the subject of reinforcement of pavements. It is seen essential also to integrate the experience gained outside Europe, both in industrialised and developing countries. Further more the benefits that have been gained up to date by reinforcing of pavements and road bases are identified and the goals that should be set for the future development are formulated. The purpose of using reinforcement thus is to

- -increase pavement fatigue life,
- -minimize differential and total settlement,
- -reduce rutting – surface and subgrade,
- -prohibit or limit reflective cracking,
- -increase resistance to cracking due to frost heave,
- -reduce natural mineral usage,
- -reduce maintenance costs,
- -increase bearing capacity,
- -enable bridging over voids,
- -enable economic construction platforms.

The way reinforcement is used is to a large extent dependent on local conditions. Foundation, moisture, temperature and traffic conditions, types of granular materials, types of overlay, precipitation etc., all are influencing the structural solutions, the types of reinforcement to be used and what effects can be achieved.

3 APPLICATIONS

3.1 Unbound layers

Geosynthetics used in the unbound layers for reinforcement are polymer geogrids, geotextiles and geocomposites. In addition steel grids and meshes are used for some functions. The reinforcement is installed under and sometimes within the unbound base, subbase, capping and stabilized subgrade layers of a pavement. A summary of the functions, location of the reinforcement and type of reinforcement are presented in Table 1 (COST-348 WG1, 2004).

Table 1 Function, location and type of reinforcement in unbound layers

Function	Base Course	Subbase Course	Capping Layer	Stabilised Subgrade
Avoidance of Rutting	Polymer grids Steel fabrics Composite polymer grids/geotextiles.	Polymer grids Composite polymer grids/geotextiles. Geotextiles	Polymer grids Composite polymer grids/geotextiles. Geotextiles	Polymer grids Composite polymer grids/geotextiles. Geotextiles
Increase of Bearing Capacity	Polymer grids Steel fabrics Composite polymer grids/geotextiles. Geotextiles	Polymer grids Steel fabrics Composite polymer grids/geotextiles. Geotextiles	Polymer grids Composite polymer grids/geotextiles. Geotextiles	Polymer grids Composite polymer grids/geotextiles. Geotextiles
Avoidance of Cracking due to Frost Heave	Steel fabrics Polymer grids	Steel fabrics Polymer grids		
Avoidance of Reflective Cracking in areas of road widening	Polymer grids Steel fabrics Composite polymer grids/geotextiles. Geotextiles	Polymer grids Steel fabrics Composite polymer grids/geotextiles. Geotextiles	Polymer grids Steel fabrics Composite polymer grids/geotextiles. Geotextiles	
Avoidance of Fatigue Cracking	Polymer grids Steel fabrics Composite polymer grids/geotextiles. Geotextiles	Polymer grids Steel fabrics Composite polymer grids/geotextiles. Geotextiles	Polymer grids Composite polymer grids/geotextiles. Geotextiles	
Control of Subgrade Deformation		Polymer grids Composite polymer grids/geotextiles.	Polymer grids Composite polymer grids/geotextiles.	Polymer grids Composite polymer grids/geotextiles.
Bridging over Voids		Polymer grids Steel fabrics Composite polymer grids/geotextiles. Geotextiles	Polymer grids Steel fabrics Composite polymer grids/geotextiles. Geotextiles	Polymer grids Steel fabrics Composite polymer grids/geotextiles. Geotextiles
Construction Platform	Not normally a base layer	Polymer grids Composite polymer grids/geotextiles. Geotextiles	Polymer grids Composite polymer grids/geotextiles. Geotextiles	Polymer grids Composite polymer grids/geotextiles. Geotextiles

The reinforcement can be used both for construction of new roads and for rehabilitation and upgrading of existing roads. When used in new roads the most common function is to effectively increase the bearing capacity of the soft subsoil by distributing the traffic wheel loads over a wider area with the reinforcement commonly placed directly on the subgrade.

The beneficial effects are related to a reduced pressure being applied to the soft subsoil and hence less deformation during the construction period and less deformation (differential settlements and rutting) during the service lifetime. Generally the beneficial effects of the reinforcement are increasing with decreasing subgrade strength and increasing traffic loads. In cases with very soft subsoil, typically soft clay of peat, there is occasionally used a multilayer solution with reinforcement at the subgrade combined with a second or third layer up in the road structure. Also in areas prone to subsidence, e.g. old mining areas, reinforced structures are commonly used for bridging of voids.

Typically in areas susceptible to frost the old gravel roads have frost susceptible material and have very low bearing capacity in the thawing period. Before installation of the new pavement structure it is common to use a separating geotextile and a grid or mesh reinforcement on top of the old road before the new base layer and an asphalt overlay is installed. The function of the reinforcement in such cases is to reduce the deformation of the old road structure to avoid extensive rutting and possible damage on the new road structure.

A wide range of materials are included in and under the unbound layers and they have many different functions and effects. Whilst all reinforcing materials provide some benefit to the pavement it is not possible to define the benefit from standard laboratory testing. A first step to a classification has been developed in the Netherlands by CROW (CROW Publicatie 157, 2002) with the publication of the chart presented in Figure 2

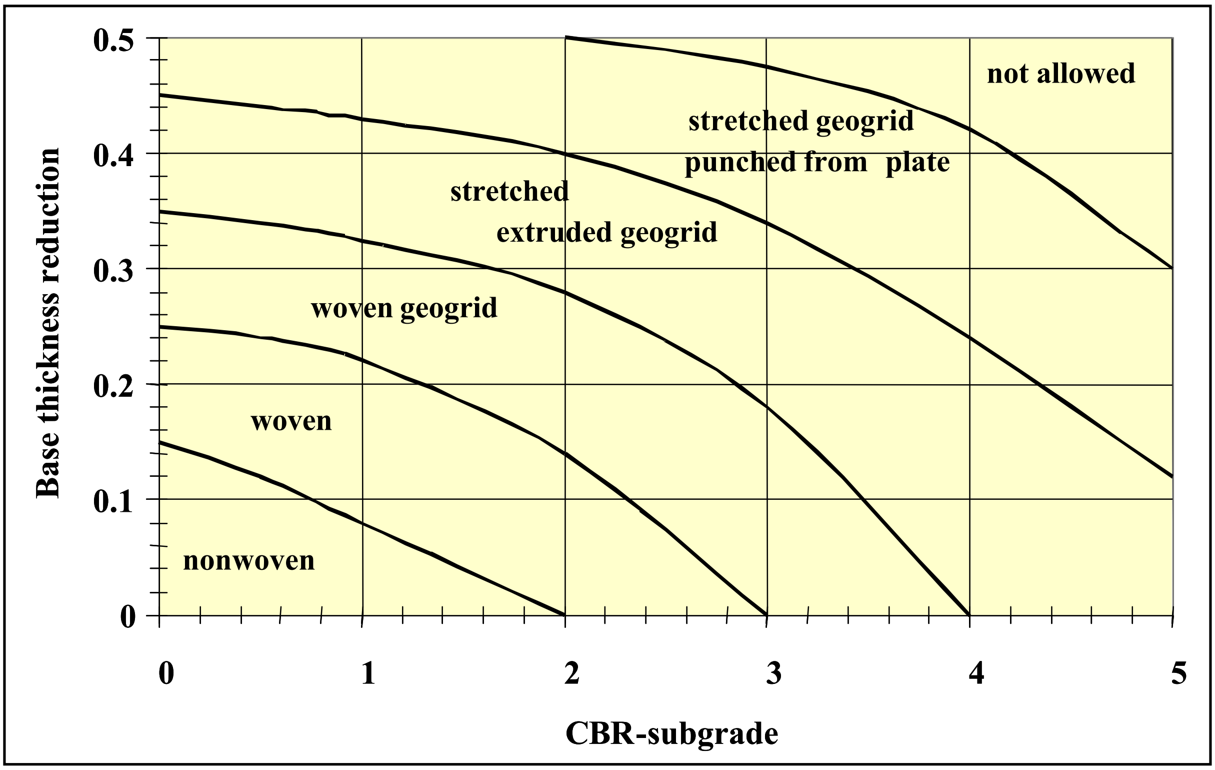

Fig. 2 Example of classification chart for selection of geosynthetic reinforcement

3.2 Bound layers

The reinforcement of the bound layers utilises a wider range of materials and addresses a number of problems. The types of reinforcement materials are geotextiles, grids, glass grids and geocomposites, but also steel meshes and grids. The use of reinforcement in bound layers is most commonly related to road rehabilitation and may both be for upgrading and installation of asphalt overlays on existing gravel surfaced roads or for repaving of existing paved roads with cracked overlay.

A summary of functions, the location and type of reinforcement used is presented in Table 2.

Table 2 Function, location and type of reinforcement in bound layers /2/

Function	Base Course	Binder Course	Surface Layer	Overlay
Avoidance of Rutting		Steel fabrics	Steel fabrics Polymer grids	Steel fabrics Polymer grids
Increase of, and protection of, Bearing Capacity	Steel fabrics Paving fabrics	Steel fabrics Paving fabrics	Paving fabrics	
Avoidance of Cracking due to Frost Heave	Steel fabrics	Steel fabrics	Steel fabrics	
Avoidance of Reflective Cracking	Steel fabrics Glass grids Polymer grids Paving fabrics	Steel fabrics Glass grids Polymer grids Paving fabrics	Steel fabrics Glass grids Polymer grids Paving fabrics	Steel fabrics Glass grids Polymer grids Paving fabrics
Avoidance of Fatigue Cracking	Steel fabrics Glass grids Polymer grids Paving fabrics	Steel fabrics Glass grids Polymer grids Paving fabrics	Steel fabrics Glass grids Polymer grids Paving fabrics	Steel fabrics Glass grids Polymer grids Paving fabrics
Control of Differential Settlement	Steel meshes Polymer grids Paving fabrics Glass grids	Steel meshes Polymer grids Paving fabrics Glass grids	Steel meshes Polymer grids Paving fabrics Glass grids	

In applications to avoid frost heave cracking special types of steel meshes are designed for applications which have > 5 m width. In Table 3 recommended dimensions from Finland are given for different road classes. As the classification of roads varies between countries, these values are indicative.

Table 3. Steel meshes as applied to different road classes

Road / lane width m	Bar ϕ - spacing length dir. mm	Bar ϕ - spacing transv. dir. mm	Length of mesh m
12.5 / 7	8 - 100	6 - 150	13.00
10.5 / 7.5	8 - 150	6 - 200	11.00
10.0 / 7	8 - 150	6 - 200	10.50
8.0 / 7	7 - 100	5 - 150	8.50
7.0/ 6	7 - 150	5 - 200	7.50
7.0	7 - 150	5 - 200	7.50
6.0	6 - 100	5 - 150	6.50
5.5	6 - 100	5 - 200	6.00
4.0	6 - 150	5 - 200	4.50

4 FUNCTION MECHANISMS AND DESIGN

4.1 Unbound

The design and performance of granular base layers in road structures is probably 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. Until today a lot of experience has been gained on material properties, on the effect of loads and on the structural behaviour.

The design of road structures includes a large variety of parameters, traffic loads, temperature, precipitation, subgrade, drainage, and type of material in the pavement. Accordingly numerical models to describe the behaviour 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.

The possible mechanisms how reinforcement functions in unbound granular base layers is outlined by A. de Bondt in reference (COST-348 WG4, 2004) for

-increasing the resistance against elastic deformations by increasing the horizontal stress level in the structure

-increasing the load bearing capacity of the pavement structure by distributing the load onto a larger area of the underlying soil

-reducing the mobilization of the subsoil by reducing the shear stress transferred to the subgrade

-increasing the resistance to permanent deformation of the granular material itself by restraining horizontal movements of the granular particles (confinement).

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 a 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 stiffness of the granular layer

-effect on the damage transfer function of the granular layer

-effect of reduced mobilisation of the subgrade

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.

4.2 Overlay

In case of asphalt overlay reinforcement is applied for new construction as well as for maintenance of old cracked overlays and in some cases to avoid reflective cracking over an old concrete overlay (see de Bondt, A.H., 1999). Cracking can be caused by three different mechanisms:

-traffic loads,

-temperature variations over time,

-uneven soil movements (settlements, frost heave).

Two different function mechanisms are identified for the use of reinforcement in overlays:

-reduction of tensile strain in the asphalt by mobilization of tensile stress in the reinforcement,

-stress revealing interlayer to avoid transfer of tensile strain to underlying layers (geosynthetic materials).

Since the beneficial effect of the reinforcement highly dependent on the type of cracking mechanism, it is impossible to give general guidelines for design based on laboratory experiments. A design model or design guideline to be used for reinforcement in overlays has to take into account:

-dominating cracking mechanism,
-traffic characteristics,
-temperature variations,
-properties of the pavement,
-properties of the granular materials,
-conditions for existing pavement (in case of repaving),
-material properties for reinforcement,
-interaction reinforcement and surrounding overlay material (asphalt),
-construction equipment and procedures.

Currently it seems that no model or method exists which takes all this factors in account in a consistent way. Similar as for reinforcement in granular bases therefore design is to a large extent based on experience ("this worked well last time") and is also product sp ecific.

From the questionnaire performed amongst the COST-REIPAS project members it is clear that only a small number of design models and procedures are available, of which no one meets all the requirements which are mentioned above. Also the design of maintenance treatments for cracked pavements, in which no reinforcement is included, has not got the necessary attention in the road construction community in the past. In almost all cases the selection of e.g. the mixture properties and the thickness of an asphaltic overlay is based on empirical knowledge. This implies that relatively new options (such as e.g. geosynthetic and steel reinforcement) need a very long waiting period before they can be judged, which is unacceptable from an econom ical point of view

The following models and procedures are currently used in practise and are described more in detail in (COST-348 WG4, 2004). These are known as Arcdeso, Bitufor, REFLEX and University of Nottingham.

4.3 Verification of effects

A number of field trials has been performed to evaluate the effect of reinforcement and also experience is available to a great extent. However only a limited number has been documented such that they can be used as reference.

As a part of the COST-REIPAS project also the methods used to verify the effects from reinforcement in pavements were investigated. The investigation included both verification o f properties as basis for design and verification by testing in the field. There is an obvious lack of suitable short term methods which really reflect the beneficial effect of rein forcement.

5 EXAMPLES OF EMPIRICAL DESIGN PROCEDURES IN USE

5.1 Danish Road Design Procedure

The Danish road design manual offers two possibilities to integrate geosynthetic reinforcement:

a) a catalog for the selection of typical secondary pavements, chosen when the examination of the subsoil conditions is not sufficient,

b) a diagram for more subtle balancing of cost-effective material conditions, traffic loads and the actual sub soil.

According to the diagram method, the E-value (stiffness) of the subsoil has to be determined by means of triaxial experiments in a laboratory or by field experiments as e.g. the CBR-test (and making use of the well-known equation E in MPa is roughly 10 times the CBR in %). The extent and accuracy of the subsoil investigations must match the importance of the project, as the road will never be better than the quality of these investigations.

Geosynthetic reinforcement is introduced in the design procedure as follows: for E-value of the subsoil higher than 30 MPa the design chart is used without modifications. If the E-value is less than 30 MPa the implication of using a geotextile allows the E-value to be multiplied by 1.8 and the increased value for the soil support can then be inserted into the design chart. The factor 1.8 originates from monitoring trial sections in the USA and is valid when typical non-woven fabrics are utilized (Steward, Williamson, and Mohney, 1977).

5.2 REFLEX Design Model

REFLEX is the acronym for the BRITE/EURAM III research project “Reinforcement of Flexible Road Structures with Steel Fabrics to Prolong Service Life” carried out within the EC 4th Framework Program 1999 - 2002. The final report of the eight task groups is available via the web address http://www.vti.se/reflex/.

For the integration of a steel reinforcement in the design the multi-layer linear pavement structure modelling approach is used. The steel net reinforcement is included into the model as an additional layer within the pavement. As the reinforcement is described as one layer of the model, there are only three variables that can be changed so as to reproduce the effect of reinforcement on the resilient (elastic) deformation response of the pavement structure. These three variables include:

- the stiffness of the layer that represents the reinforcement
- the thickness of the layer that represents the reinforcement
- the interface properties of the layer as it is interacting with the layers above/below.

The basic idea of the “Equivalent Layer”-concept is to substitute the reinforcement with a layer of finite thickness of some tens of millimetres and to give that layer some sort of average properties of the steel and the surrounding material.

5.3 MSU/SINTEF Design Method

A comprehensive research project GeoRePave has been executed by MSU (Montana State University, USA) and SINTEF (Trondheim, Norway), see (Perkins S.W,. et al., 2004). The objective of this project was to develop design methods for reinforced unbound base course layers in roads and 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 may 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).

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 dimensioned. 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 method is planned to be implemented in the NCHRP 1-37A Design Guide (NCHRP, 2003). The design and analysis steps will then be automated and hidden to the user. The end user will only see the following requirements in addition to those contained in the NCHRP 1-37A Design Guide to design reinforced pavements:

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

6 CONCLUSIONS

Pavement reinforcement with geosynthetics has been used for more than 40 years, steel reinforcement for more than 2 decades in Europe. We believe that use of 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.

Currently general road design is to a large extent based on semi empirical methods and this complicates the inclusion of new materials and methods. A number of research projects has been carried out in order to develop models and methods and this experience is updated in the recent COST-REIPAS action.

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