STRUCTURAL DESIGN OF FLEXIBLE PAVEMENTS USING STEEL NETTING AS BASE REINFORCEMENT

D. Léonard[1], A. Vanelstraete[2], S. Parewyck[3]

ABSTRACT

This paper deals with the structural design of flexible pavements reinforced by steel nettings. The purpose is to estimate the gain in base material obtained by using such systems. Most of the current pavement design methods are modelling the reinforcing system as a continuous layer. This approach is leading to cost-ineffective solutions. To overcome these present limitations, a three-dimensional (3D) finite element modelling (FEM) approach is suggested. The application of 3D-FEM allows simulation of the real shape of steel reinforcing nettings.

To cover as many practical cases as possible, various pavements are considered, defined by various base thicknesses and soil bearing capacities. Structures with and without base reinforcement system are compared in terms of asphalt fatigue, rutting, and deflection performance. These comparisons make it possible to draw several design charts for various asphalt thicknesses and soil bearing capacities. Such design charts will avoid time-consuming computations with 3D-FEM applications and provide project engineers with more cost-effective solutions.

KEY WORDS

Flexible pavement, steel reinforcing nettings, 3D-FEM simulation, design charts, cost-effective design.

1. INTRODUCTION

Over the two last decades many types of reinforcing system have been used in pavements. Some of these interface systems are meant to delay or prevent reflective cracking through a new overlay laid over an old cracked pavement, while others serve as base reinforcements. Much research effort has been put in the development of new theories to better understand the main parameters and to better predict the performance of reinforced pavements.
In the past, the BRRC [1,2] tried to gain a better insight into the effect of many types of interface system, either by laboratory tests or test sections on site or by numerical modelling. In this context, recently the effectiveness of the use of steel reinforcing nettings embedded in

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an elastomer-bitumen (called Bitufor®) in controlling reflective cracking and the role of steel nettings (called Mesh Track®) as base reinforcements have been investigated. The simulation of Bitufor® in reducing reflective cracking was described in a previous paper [3].

Concerning the effect of Mesh Track® in the road base, the present philosophy is based mainly on empirical studies and multilayer programmes (for example ELSYM5 or BISAR). In these, the road is modelled with uniform and homogeneous layers. These models cannot simulate the exact geometries of reinforcements. Using these design methodologies results in overly conservative solutions that are not cost-effective.

Hence the need to develop a new improved model capable of estimating the real behaviour of a road reinforced with Mesh Track®.

This paper will present the results of such a study carried out with Mesh Track® in the road base.

2. DESCRIPTION OF THE DESIGN METHODOLOGY

The research work described in this paper focuses on the evaluation of the gain, in terms of base thickness, provided by the use of Mesh Track® to reinforce the base of a flexible pavement (asphalt on unbound material). In this research, structures are assumed to be subjected only to traffic loading.

The originality of this work consists in using 3D finite element simulation to account for the particular shape of Mesh Track®.

The finite element computations are carried out on structures with different geometries. The goal is to cover as many practical cases as possible. Moreover, pavements with Mesh Track® and without any reinforcement are modelled to allow comparisons. From the results of these computations, design charts are built. The objectives of these design charts are to avoid time-consuming computations with 3D finite element simulations and to provide potential users with an efficient tool to quantify the base thickness that can be saved by using Mesh Track®.

Two types of Mesh Track®, differing in stiffness, are studied. The stiffer is called Mesh Track® 1, the other one being Mesh Track® 2. Their geometries are summarised in table 1.

Table 1 Main characteristics of Mesh Track® 1 and 2

Mesh	Section (mm^2)		Inertia (mm^4)	
	Type 1	Type 2	Type 1	Type 2
Single wire	4.71	3.8	1.8	1.2
Twisted double wire	9.42	7.6	3.6	2.3
Flat torsioned wire	21	13	35.1	13.4

The main part of this study is carried out on Mesh Track® 1.

2.1 Geometries of pavement structures

The road pavements considered consist of an asphalt surfacing, a crushed stone base and a 200-mm sandy subbase. The Mesh Track® reinforcing system is placed between the base and the subbase. A standard cross section is represented in figure 1.

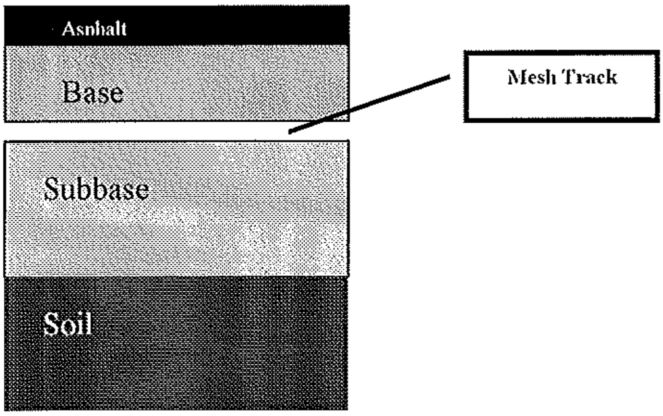

Figure 1 Schematic cross section of the modelled structures

The different pavement geometries simulated with the finite element method are summarised in table 2.

Table 2 Geometries of the different structures

Name of structure	Asphalt thickness (mm)	Road base thickness (mm)	Subbase thickness (mm)	Subgrade soil modulus (MPa)
A100-B150-E10	100	150	200	10
A100-B250-E10	100	250	200	10
A100-B400-E10	100	400	200	10
A100-B600-E10	100	600	200	10
A200-B150-E10	200	150	200	10
A200-B250-E10	200	250	200	10
A200-B400-E10	200	400	200	10
A200-B600-E10	200	600	200	10
A100-B150-E80	100	150	200	80
A100-B250-E80	100	250	200	80
A100-B400-E80	100	400	200	80
A100-B600-E80	100	600	200	80
A200-B150-E80	200	150	200	80
A200-B250-E80	200	250	200	80
A200-B400-E80	200	400	200	80
A200-B600-E80	200	600	200	80

Note AX-BY-EZ denotes a structure with an asphalt surfacing X mm thick, a road base Y mm thick, and a subgrade soil having a Young's modulus of Z MPa.

No simulations with Mesh Track® are performed when the base is 600 mm thick. In a similar way, no calculations without Mesh Track® are made when the base thickness is as small as 150 mm.

2.2. Structure modelling

The different road structures listed in table 2 were simulated by 3D finite element programme SYSTUS+ of FRAMASOFT. SYSTUS is a finite element software which was initially developed for the nuclear power plant construction industry. Now, this interactive design-computation graphic system is widely used through many industries: welding simulation, crash test simulation, fracture mechanics, etc. [4]

To simulate the behaviour of the steel net within the structure, the following assumptions were made:

1. All the materials in the structures have a linear elastic behaviour characterised by a constant Young's modulus and Poisson's ratio.
2. All the layers are continuous: neither cracks nor joints are considered.
3. The load is accounted for by a 50-kN force applied on top of the asphalt surfacing, with a constant pressure of 0.7MPa (100-kN axle load).
4. Table 3 surveys the mechanical properties of the materials.

Table 3 Mechanical properties of materials

Material	**E (MPa)**	**μ**
Asphalt	15000	0.35
Base	500	0.5
Subbase	200	0.5
Soil	10 or 80	0.5
Steel	210000	0.3

New in these 3D finite element simulations is that the Mesh Track® steel reinforcing netting is modelled with its real shape formed by simple steel threads, twisted steel threads and flat torsioned wires at regular intervals (figure 2).

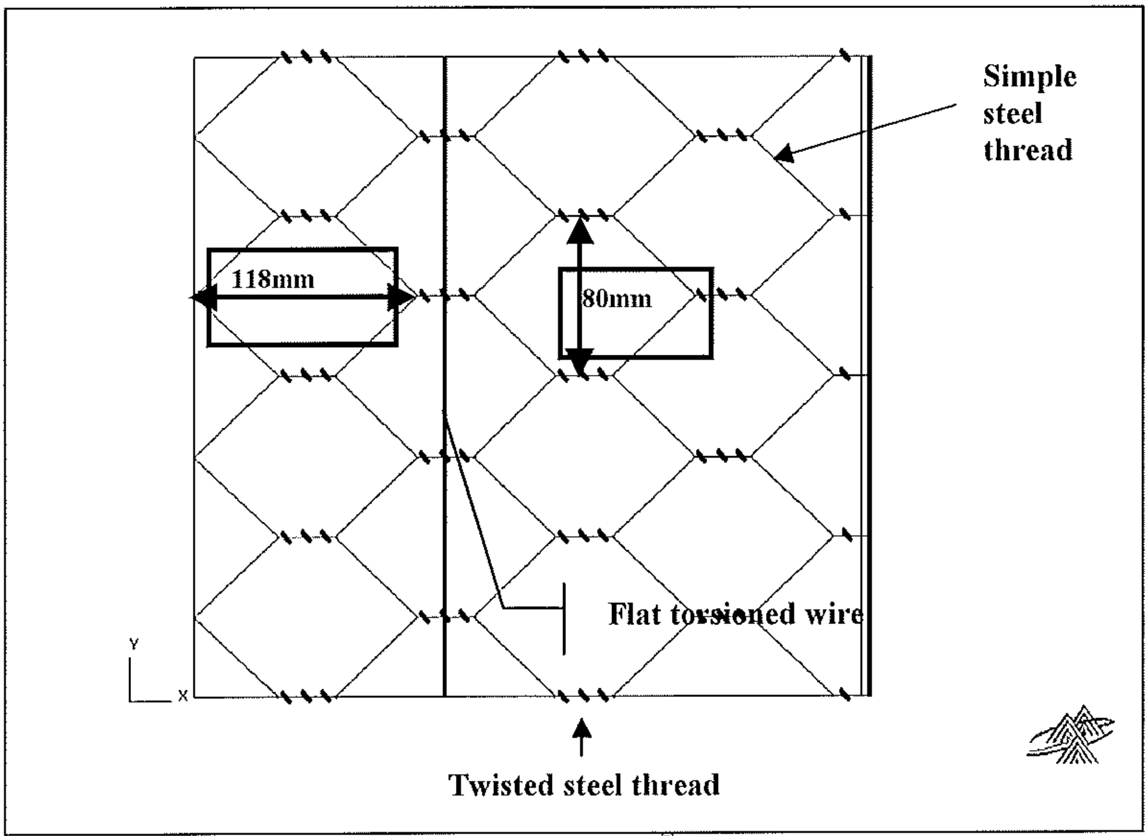

Figure 2 Mesh Track® geometry

All the threads of the net (simple, twisted and flat-torsioned wires) are modelled with 1-D beam elements. These various kinds of threads are defined in the same way. This means that, within the simulation of the geometry, there is no distinction between these three types of wires. However, the values of cross-section area and inertia for each beam are depending on the type of thread (table 1).

Concerning the bonding condition between the Mesh Track® and the surrounding granular material, full bond is assumed. Indeed, thanks to the high aggregate interlock level provided by the high rigidity of each mesh of the net, it can be considered that no relative displacements between the mesh and the unbound material are taking place.

Figure 3 shows the finite element model of structure A100-B400-E10 as an example. It can be noted that the real shape of the Mesh Track is taken into account. Wheel load is also indicated.

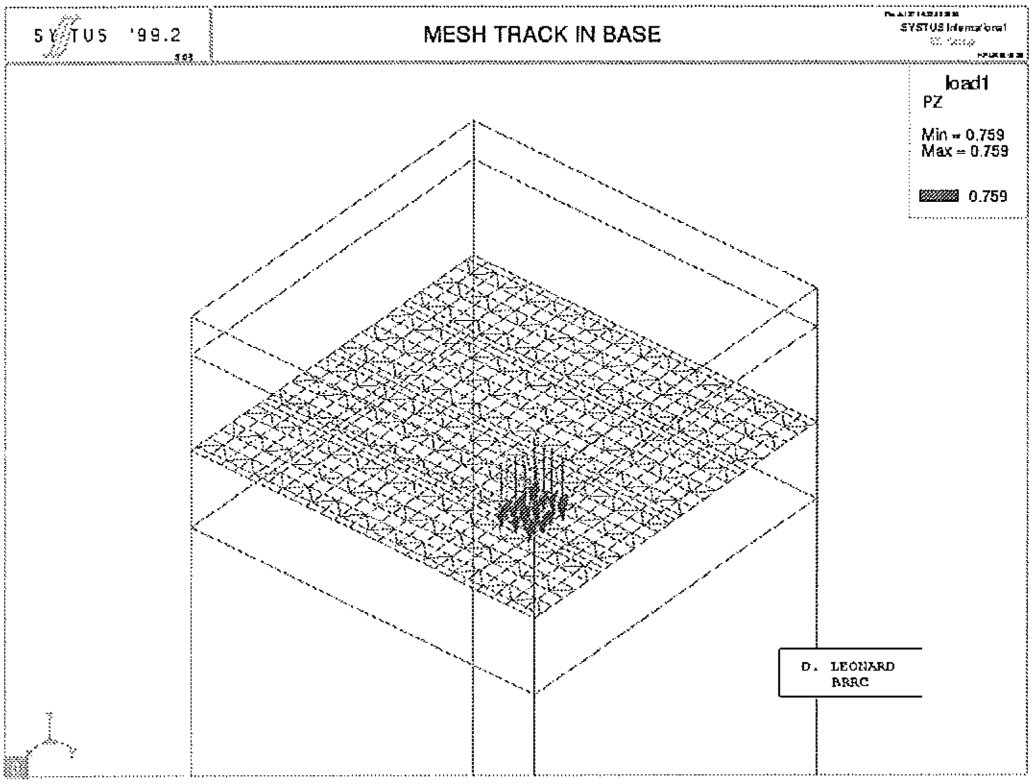

Figure 3 Representation of the Mesh Track® steel netting and its position in the structure

3. ANALYSIS OF THE RESULTS

Finite element calculations were performed on all the structures described in 2.1. Displacements and strain fields were calculated at Gaussian points and subsequently extrapolated to nodes in the mesh. To translate these results into the final performance of the various road structures, several parameters are considered and described in the next few paragraphs. From the final performance prediction, the gain provided by the Mesh Track® steel reinforcing netting in terms of base thickness can be estimated and design charts can be developed.

3.1. Evaluation criteria

Three performance criteria are used to compare the structures reinforced with Mesh Track® and the pavements without any reinforcement: fatigue at the bottom of the asphalt layer, structural rutting, and vertical displacement at the top of the asphalt surfacing. The first two criteria are commonly used in current pavement design method[4], while the third one is the

[4] In Europe, more than 60% of the pavement design methods are based on mechanistic-empirical theory. These approaches are calculating stresses and strains in the structures. Afterwards, these values are related to the final performance by use of empirical laws.

parameter often measured to describe the bearing capacity of pavements (Benkelman beam measurement, Falling Weight Deflectometer, etc).

The finite element results used to predict the final performance described hereafter are represented in the diagram of figure 4.

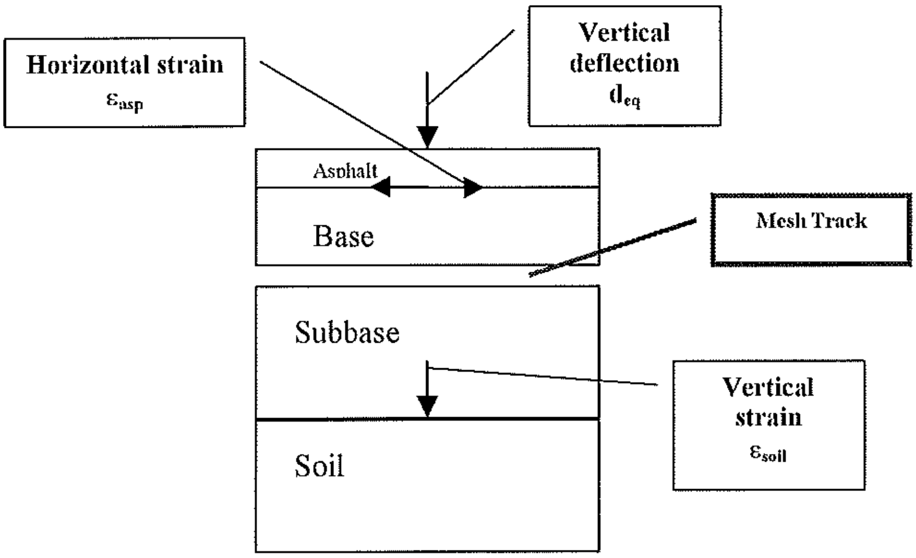

Figure 4 Diagrammatic representation of the finite element results used for performance prediction

3.1.1 Fatigue of asphalt

To investigate fatigue at the bottom of asphalt layers, current pavement design methods often relate the elastic strain at the bottom of the asphalt layer (ε_{asp}) to a number of loading cycles (N) that can be allowed according to a fatigue law [5]:

$$N = \left(\frac{\varepsilon_{asp}}{C}\right)^{-\frac{1}{a}} \tag{1}$$

where:
- a is the slope of the fatigue law (of the order of 0.2);
- C is the intercept of the fatigue line (of the order of 10^{-3}).
- ε_{asp} is the strain at the bottom of the asphalt layer
- N is the corresponding allowable number of wheel passes

The loading type implies that ε_{asp} (figure 4) corresponds to a bending strain computed from the 3D finite element simulation.

With this law and according to parameters estimated from BRRC laboratory tests, it is possible to define an equivalence factor, $C_{r,fat}$, expressing the ratio between the fatigue strength of any given structure and a reference structure:

$$C_{r,fat} = \frac{N}{N_{ref}} = \left[\frac{\varepsilon_{ref}}{\varepsilon_{asp}}\right]^{4,76} \tag{2}$$

where: N is the allowable number of cycles for any given structure, corresponding to ε_{asp}.
ref is a subscript denoting quantities calculated for a randomly chosen reference structure.
ε_{ref} is the elastic horizontal strain at the bottom of the asphalt layer of the reference structure.
N_{ref} is the allowable number of loading cycles for the reference structure corresponding to ε_{ref}.

Using this factor, it is then possible to compare the fatigue performance of the various pavements investigated.

3.1.2 Structural rutting

Structural rutting corresponds to the plastic deformation occurring within the granular sublayers. In current design methods, it is admitted that structural rutting is mainly due to the development of irreversible deformation in the subgrade soil. That is why vertical elastic strain at the top of the soil is limited to reduce structural rutting. As for fatigue prediction, evaluation laws exist to determine the number (N) of load applications that can be allowed to produce a given elastic strain (ε_{soil}) (figure 4) at the top of the subgrade. The law used by BRRC can be written as [6]:

$$\mathrm{N} = \left[\frac{0.011}{\varepsilon_{soil}}\right]^{4.23} \tag{3}$$

where : N is the allowable number of wheel passes;
ε_{soil} is the vertical elastic strain at the top of the soil.

Using the BRRC law, it is possible to define the equivalence factor, $C_{r,rut}$, that allows comparison of the different structures:

$$C_{r,rut} = \frac{N}{N_{ref}} = \left[\frac{\varepsilon_{ref}}{\varepsilon_{soil}}\right]^{4.23} \tag{4}$$

where: N is the allowable number of cycles for any given structure, corresponding to ε_{soil}.
ref denotes quantities calculated for a randomly chosen reference structure.
ε_{ref} is the vertical elastic strain at the top of the soil for the chosen reference structure
N_{ref} is the allowable number of loading cycles corresponding to ε_{ref}.

For the first two performance criteria, structure A200-B600-E80 (pavement with 200 mm of asphalt surfacing and a 600-mm base laid without any reinforcement on a high-quality subgrade having a modulus of 80 MPa) was taken as reference.

3.1.3 Vertical deflections

The third criterion used to investigate the effect of Mesh Track® on vertical deflections is the maximum deflection under the wheel load (d_{eq}) (figure 4).
Assuming that two structures are equivalent if their maximum deflections are equal, it is possible to compare various pavements.

3.2 Results with Mesh Track® 1

Some of the results obtained by the application of these criteria are discussed hereafter to highlight the major findings from the finite element simulation.

3.2.1 Fatigue of the asphalt layers

Using the criterion for comparing fatigue performance, equivalence factor, $C_{r,fat}$, can be calculated for the various road structures. For example, the trend of $C_{r,fat}$ with road base thickness is plotted in figure 5 in case of a low-bearing subgrade (E modulus = 10 MPa).

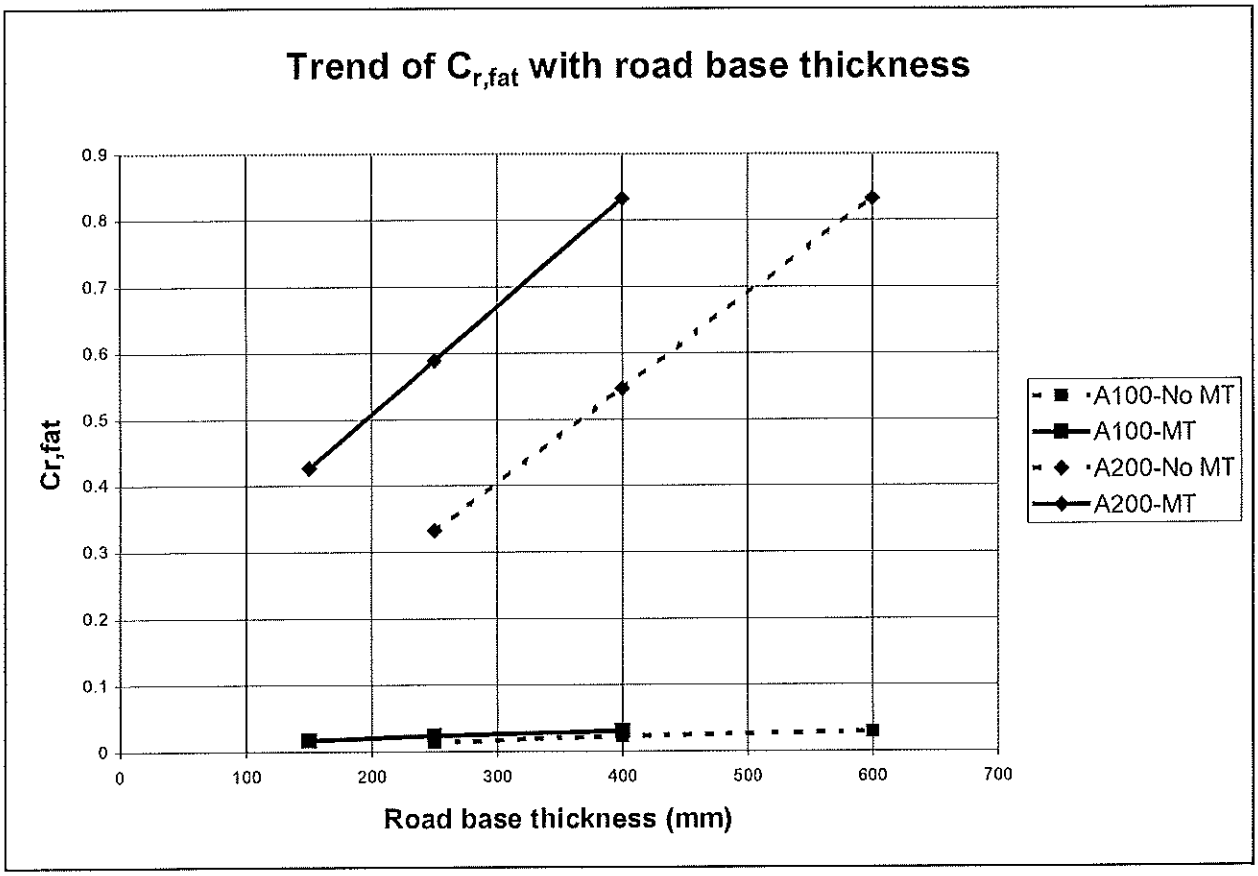

Figure 5 Trend of factor $C_{r,fat}$ with road base thickness (fatigue criterion) in case of a poor quality subgrade soil

As defined above, two structures are equivalent in fatigue performance when their respective $C_{r,fat}$ factors are equal.

From figure 5, it can be concluded that no structure with a 100-mm asphalt surfacing can compete in fatigue performance with a pavement constructed with 200 mm of asphalt, regardless of whether it contains Mesh Track® 1 or not and whatever the thickness of the road base in the range considered here.

From figure 5, it is also possible to evaluate how much can be saved on base thickness by using Mesh Track® 1, knowing that two structures are equivalent if they have the same equivalence factor, $C_{r,fat}$. Assuming this, various design charts can be derived according to subgrade soil quality (E modulus) and asphalt thickness.

The design chart corresponding to a 100-mm asphalt surfacing and a poor quality subgrade is plotted in figure 6.

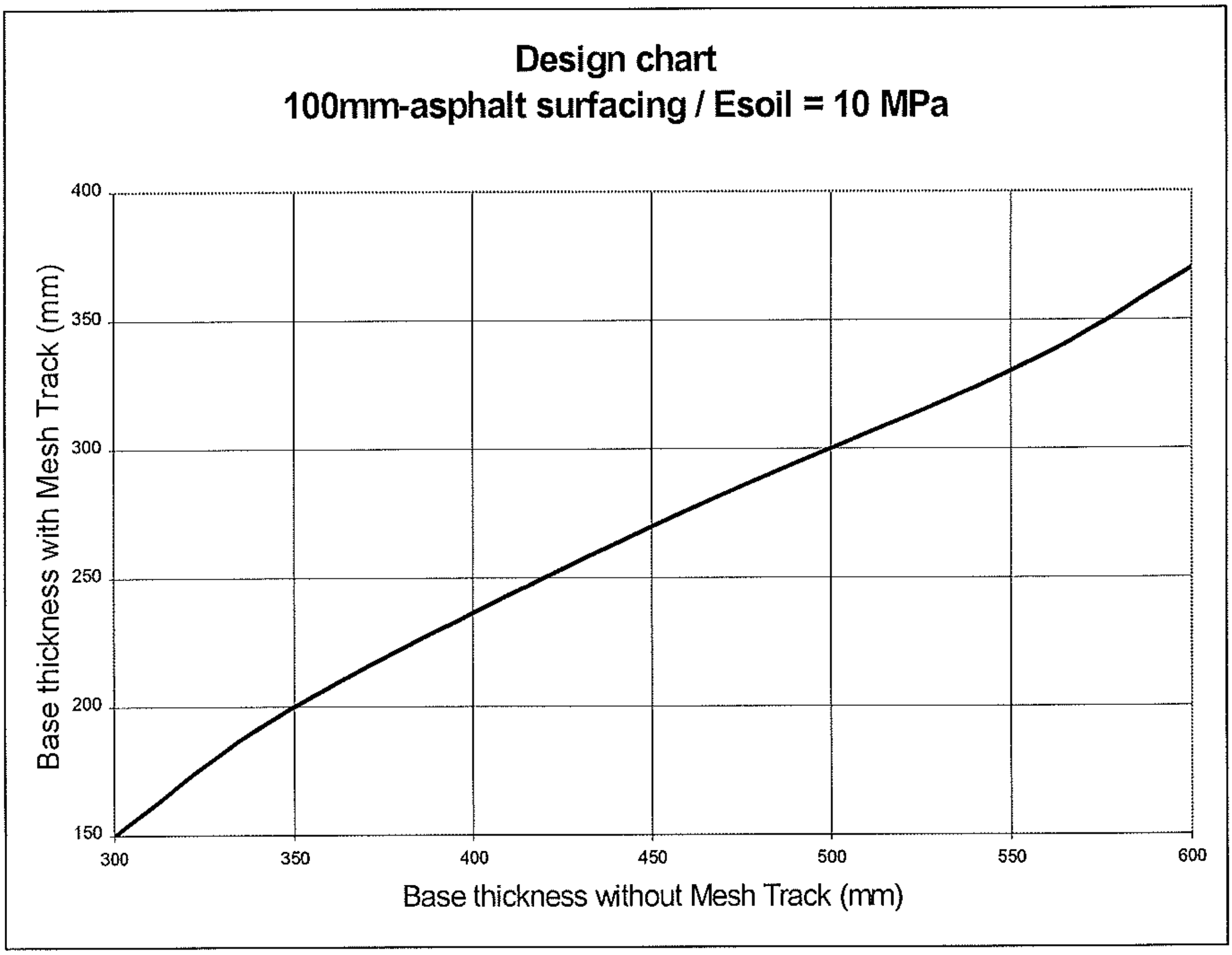

Figure 6 Road base thickness design chart (fatigue criterion) for pavements with a 100-mm asphalt surfacing constructed on poor quality subgrades (E modulus = 10 MPa)

The various design charts established for fatigue performance are available in a research report [7]. They show that the relative gain in base thickness obtained by the use of Mesh Track® 1 varies between 18 and 57 %.

3.2.2 Structural rutting

In a similar way, the equivalence factor for structural rutting, $C_{r,rut}$, can be estimated from vertical strain at the top of the subgade soil.

Knowing that two structures are equivalent in structural rutting performance if their $C_{r,rut}$ factors are equal, design charts depending on the subgrade soil and on asphalt thickness can be plotted. As an example, the design chart corresponding to a pavement laid on a poor quality subgrade and overlaid with a 100-mm asphalt surfacing is shown in figure 7.

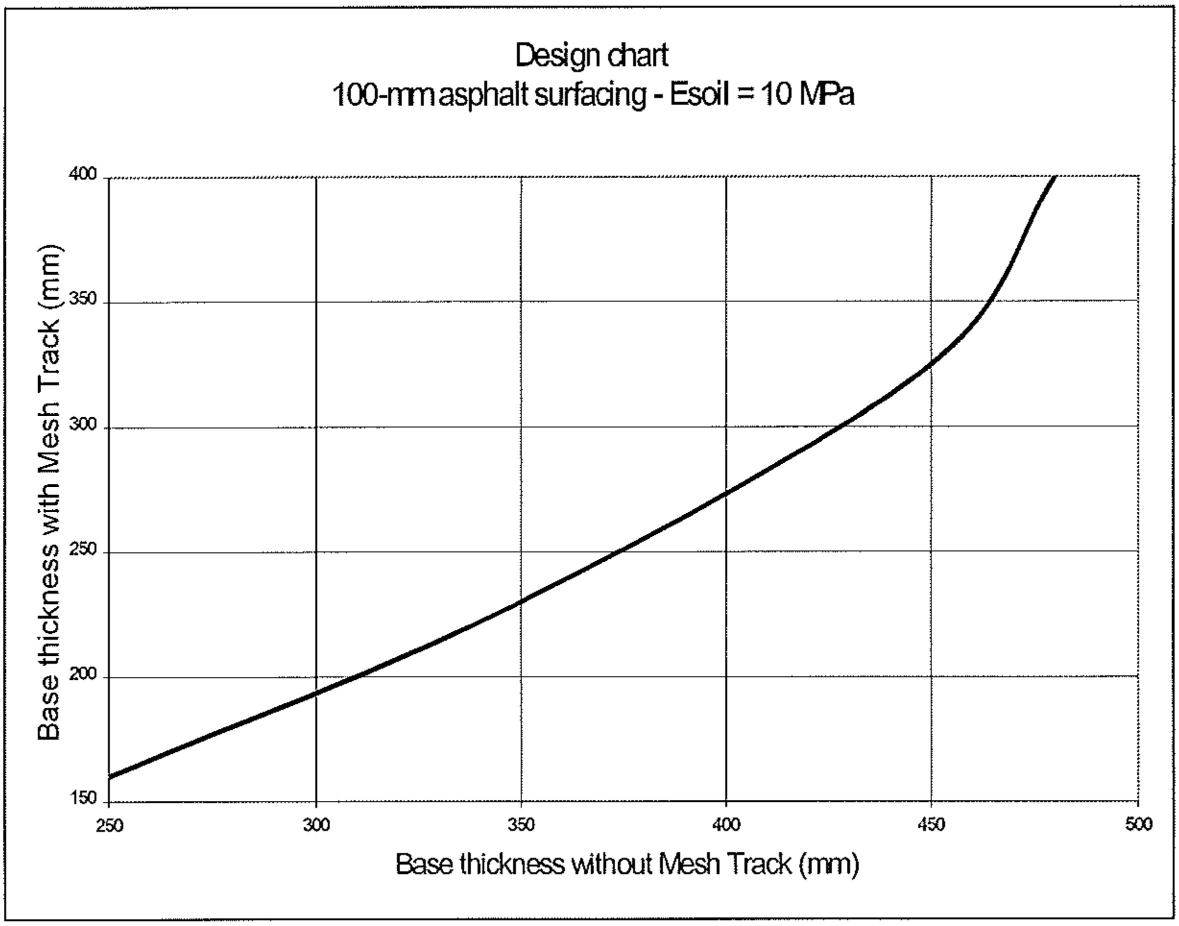

Figure 7 Road base thickness design chart (structural rutting) for pavements with a 100-mm asphalt surfacing constructed on low-bearing subgrades (E modulus = 10 MPa)

Other design charts are available [7]. Analysing these charts, it can be concluded that the relative gain in road base thickness obtained with the use of Mesh Track® 1 varies between 25 and 57 % and that the average relative gain reaches 42 %.

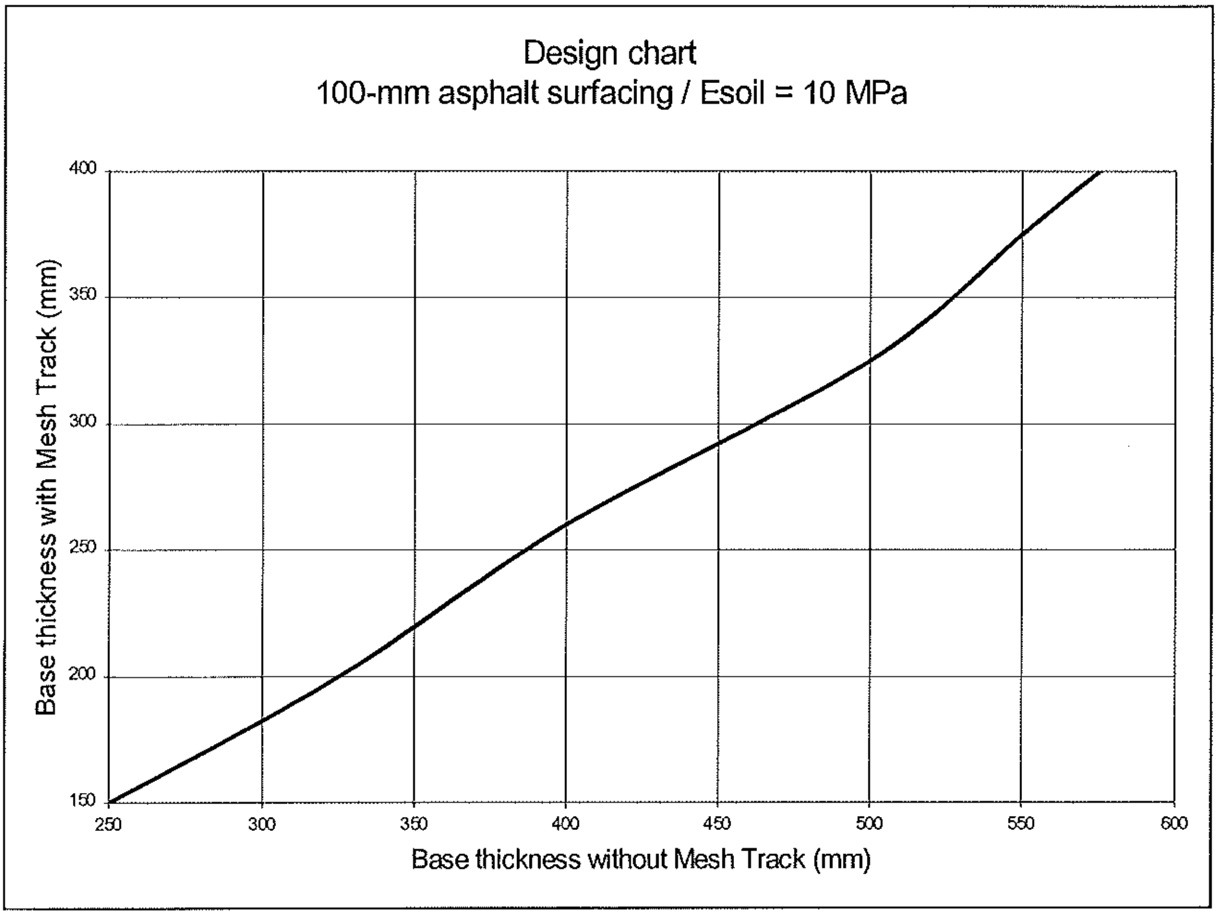

Figure 8 – Road base thickness design chart (deflection criterion) for pavements with a 100-mm asphalt surfacing constructed on low-bearing subgrades

3.2.3 Vertical deflection

In order to estimate the gain in road base thickness when using Mesh Track® 1, the deflection under the contact surface of a tyre was calculated. To be equivalent from the point of view of deflection, two structures must have the same maximum deflection. Based on this principle, design charts can be developed as shown in figure 8 for the case of a pavement with a 100-mm asphalt surfacing constructed on a low-bearing subgrade (E modulus = 10 MPa). Other design charts are available [7].

Finally, analysing the design charts for fatigue, rutting and deflections, it can be concluded that the relative gain in road base thickness when using Mesh Track® 1 varies between 25 and 60 % and that the average relative gain reaches 40 %.

3.3 Results with Mesh Track® 2

Results obtained from the simulation of structures with a road base reinforced by Mesh Track® 2 are described in [7]. The main conclusion is that considerable savings in base thickness are also possible with the use of Mesh Tack 2. As it is not as stiff as Mesh Track® 1, savings in base thickness are about 10 % smaller than with Mesh Track® 1.

4. CONCLUSIONS

A structural design method aiming at quantifying the effect of the Mesh Track® 1 and Mesh Track® 2 as base reinforcement systems has been developed. Use was made of finite element calculations of road structures in which the steel nettings were simulated with their actual geometries and shapes. The purpose was to estimate the gain in terms of road base thickness with the use of Mesh Track® 1 and 2.

To cover a wide variety of situations, the choice of structures defined in table 2 of this report was led by the following principles:

- two extreme values of asphalt surfacing thickness,
- four road base thicknesses, in the range from 150 mm to 600 mm,
- two qualities of subgrade soil characterized by two widely different modulus values.

The effectiveness of Mesh Track® 1 and 2 in reducing fatigue, rutting and deflections was clearly demonstrated. A set of design charts was developed that can help project engineers in designing pavements with a Mesh Track® 1-reinforced road base.

From the results, it appears that in many cases the steel reinforcing netting allows a gain in road base thickness that amounts to 40 % of the original value.

Finally, the influence of the type of Mesh Track® was investigated. From the results obtained on a few structures, it appears that the design charts referred to above remain valid for pavements reinforced with Mesh Track® 2 provided the road base thicknesses designed with these charts are increased by 10 %.

However, further work is needed to improve the finite element models and also to check the results against field measurements.

Finally, the method developed above utilises the flexibility of the 3D finite element method and, moreover, has produced design charts that can be used directly in practice.

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