STRUCTURAL DESIGN OF ROADS WITH STEEL REINFORCING NETTINGS

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Abstract

It is well-known that classically used multi-layer design models are unable to describe the local stress concentrations encountered around cracks or discontinuities in roads. Earlier finite element simulations of cracked road structures in which interlayer systems are described as continuous homogeneous layers are also found not to be satisfactory to describe the real reinforcement effects of grids and steel reinforcing nettings.

This paper describes the results of a structural design model which is based on a three-dimensional finite element analysis of a road structure containing a discontinuity or a crack and in which an exact modeling of the Bitufor® steel reinforcing netting is introduced, with its real geometry and mechanical characteristics.

The aim of this study was to compare the lifetime for crack initiation with the use of Bitufor® steel reinforcing nettings to that of a system without interface system and to determine the gain in asphalt layer thickness with the use of these systems. Only the crack initiation phase was taken into account so far. Two types of loading were considered : thermal movements and traffic.

The model has been applied for the simulation of asphalt overlays with steel reinforcing nettings on transversal cracks/joints in rigid pavements, in semi-rigid pavements and in flexible pavements and on longitudinal cracks in cement concrete structures. In the case of traffic loading, both the effect on the vertical differential displacements at slabs "slab rocking", as well as the effect on the bearing capacity were studied. Several overlay thicknesses were considered.

The efficiency of Bitufor® could be demonstrated for these different cases and design charts were developed, which can then be used for practical applications.

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1. Introduction

Over the past fifteen years Bitufor® steel reinforcing nettings have been used as a solution for a number of problem areas [1] :

- asphalt overlay on cracked rigid and semi-rigid pavements (reflective cracking),
- prevention of rutting,
- overlays in hilly areas (slippage problems),
- prevention of cracking related to frost action,
- prevention of cracking at road widening,
- asphalt overlays on peat roads and weak subbases,
- overlays for underdesigned asphalt roads,
- reinforced road bases.

The use of these reinforcing products is presumed to allow thinner road structures and longer life-cycles, which provides a cost-effective solution for rehabilitation and so a reduction in maintenance costs. However, at present very few guidelines are available for the structural design of reinforced overlays [2].

Most of the design models currently used, are based on elastic multilayer models. In these models each layer of the structure is considered as continuous and uniform. The presence of cracks and other discontinuities (such as joints) give rise to local stress concentrations, which induce problems of reflective cracking on overlaid cracked road structures. These effects cannot be taken into account in the standard models. Moreover, new technologies, such as Bitufor® steel reinforcing nettings, cannot be simply described as uniform and continuous layers.

The question therefore arises to develop design models able to describe road structures with cracks or other discontinuities, where non-conventional road materials, such as the Bitufor® reinforcement system are applied, and subjected to traffic as well as temperature loads.

The present paper discusses the results of a research project dealing with the development of such a structural design method.

2. Description of the structural design model

2.1 Modelling of the road structure

The design model is based on three-dimensional finite element analysis. Several simulation models of cracked road structures with Bitufor® steel reinforcing steel nettings were developed. They represent several road structures, several problem areas and several loading conditions. Table 1 gives an overview of the investigated cases.

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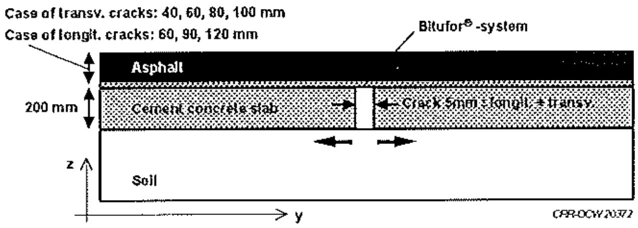

Fig.1 : Overview of the road structures considered for the simulation of overlays on cement concrete slabs (thermal movements).

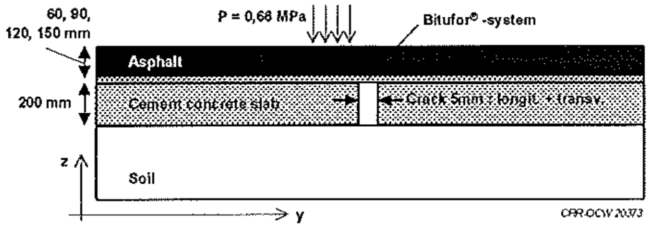

Fig.2 : Overview of the road structures considered for the simulation of overlays on cement concrete slabs (traffic).

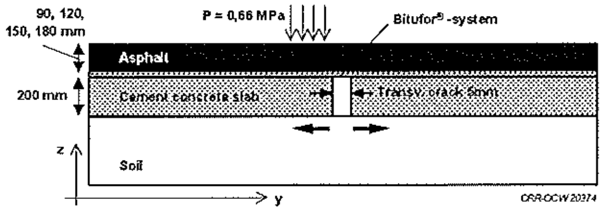

Fig.3 : Overview of the road structures considered for the simulation of overlays on lean concrete (thermal movements and traffic).

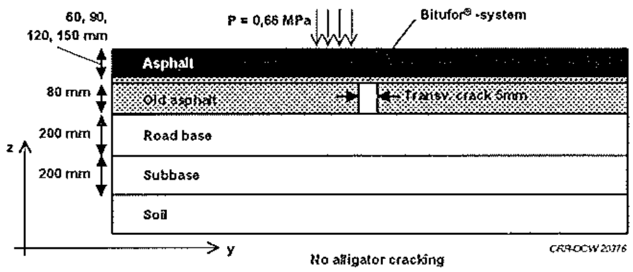

Fig.4 : Overview of the road structures considered for the simulation of overlays on flexible pavements (traffic).

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Table 1 : Overview of the investigated cases.

Cracked structure before overlaying	Thermal movements		Bearing capacity		Slab rocking	
	Transv. Cracks	Longit. cracks	Transv. Cracks	Longit. cracks	Transv. Cracks	Longit. cracks
Cement concrete	X	X	X	X	X	X
Lean concrete	X		X		X	
Flexible			X		X	

New in this finite element analysis is that the Bitufor®-system is modelled in a very realistic way as shown in fig.6 and is built up as a netting of simple steel threads, twisted steel threads and flat torsioned wires at regular intervals. The netting is embedded in a slurry seal as indicated in fig.7. The following assumptions were used :

- the system is considered linear elastic,
- temperature variations are accounted for by a "controlled" displacement at the bottom of the crack, as indicated in figure 1,
- traffic load is simulated by applying a constant vertical pressure of 0.66 MPa (the load is equivalent that of a single axle of 100 kN). The load is positioned asymmetrically in regard to the crack. As a result of that, large shear strains are induced. They give rise to relative vertical movements at the crack edges. This effect, also called slab rocking, is considered as most deteriorating for road structures. The effect of Bitufor® steel reinforcing nettings on slab rocking is studied, as well as that on the vertical deflections (bearing capacity),
- table 2 surveys the mechanical properties of all materials.

Table 2 : Material properties.

Material	Modulus E (MPa)	Poisson's ratio
New asphalt overlay	15.000	0.35
Old asphalt	10.000	0.35
Cement concrete	40.000	0.3
Lean concrete	20.000	0.35
Slurry	14.000	0.35
Steel	210.000	0.3
Granular road base	500	0.5
Sand subbase	200	0.5
Subgrade soil	40	0.5

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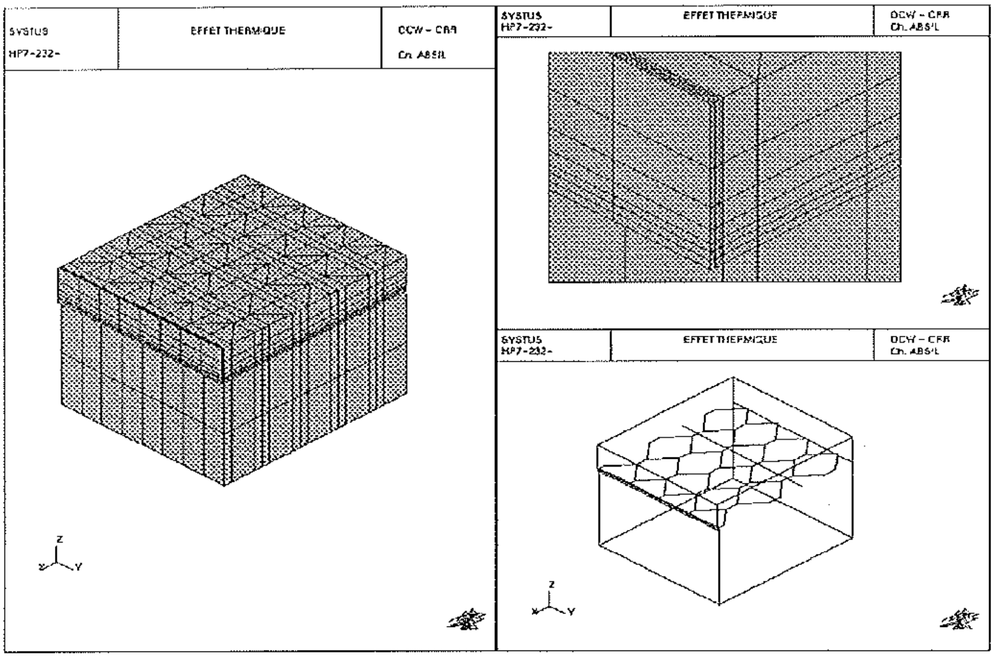

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Fig.6: Representation of the Bitufor® steel netting and its position in the slurry seal for the finite element model.

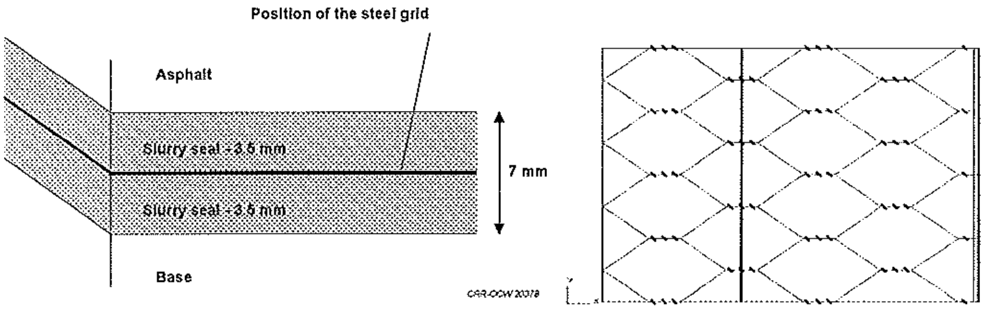

Fig.7 : Detail of the simulation model : steel netting as simulated with its position in the slurry seal.

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2.2 Evaluation criteria

Crack prevention systems, such as the Bitufor®-system, can be effective for both crack initiation and propagation. In the actual stage of this research project, only the crack initiation phase has been considered. For the evaluation of crack onset, use is made of the fatigue law, giving the relation between the number of load repetitions N (needed to initiate the crack) and the strain level ε which is involved:

$$N = (C / \varepsilon)^{-1/a} \qquad (1)$$

The type of strain ε depends on the phenomenon being studied : horizontal strains ε_{xx} in the case of horizontal thermal movements, shear strains ε_{zx} in the case of slab rocking. Numerical calculations based on the finite element method yield values for the strain in the asphalt overlay. Making use of equation (1), it is then possible to compare the relative gain in lifetime for crack initiation for a road structure with steel reinforcing nettings to that without interface system.

3. Results

Finite element calculations were performed on all road structures discussed in 2.1. Comparisons of lifetimes of different structures were made and it can be estimated how much can be saved on asphalt overlay thickness by using these steel reinforcing nettings. The aim is then to deduce design charts, which can be used in practical applications and which avoid to carry out this time-consuming finite element calculations for each particular road structure. As it is impossible to discuss all the results in this paper, we will focus on the case of overlaid cement concrete slabs. Further details and results on other structures can be found in [3, 4, 5, 6].

3.1. Thermally induced cracking

Fig.8 gives an example of the thermally induced horizontal strains ε_{xx} in the asphalt overlay above a transversal crack, with and without Bitufor®-system. It can be concluded that :

- very high deformations are present just above the crack tip when no Bitufor®-system is applied,
- these large strains are largely reduced with the use of the Bitufor®-system, preventing the onset of cracks in the overlay,
- the Bitufor®-system is most efficient in the direct vicinity of the cracks, this is also the most critical zone,
- close to the top of the overlay, both curves converge,
- the strains that develop in the slurry can be high and call for the use of elastomeric bitumen in the slurry.

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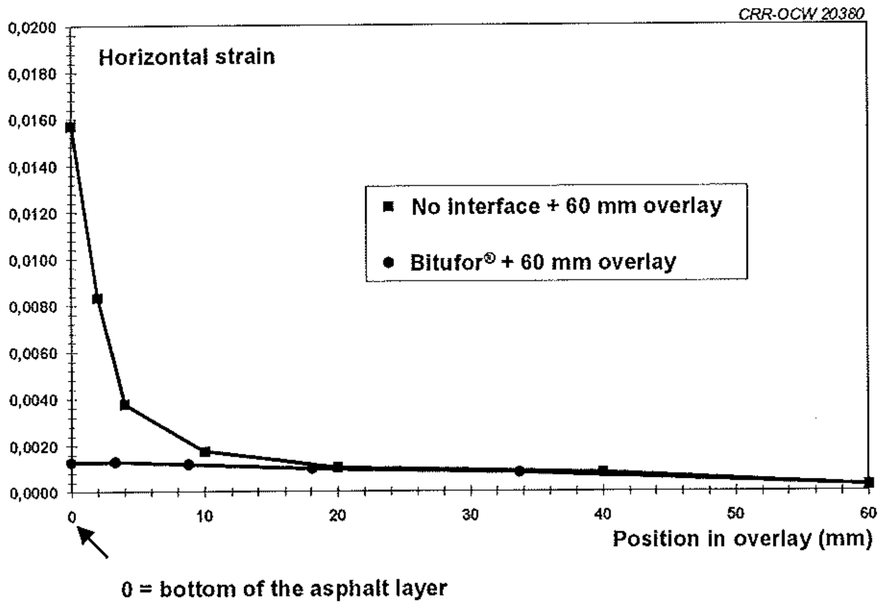

Fig.8: Horizontal thermally induced strains in the asphalt overlay, in the prolongation of a transversal crack: for a 60 mm overlay on cement concrete slabs, with and without Bitufor®-system.

In table 3, the difference in lifetime for crack initiation of a road structure with Bitufor® and without interface system are given for two different locations: 10 and 20 mm from the bottom of the overlay.

Table 3: Lifetime improvement factor with Bitufor® for crack initiation induced by temperature variations, for the structures represented in fig.1.

Relative lifetime with Bitufor® compared to that without interlayer				
Transversal cracks			Longitudinal cracks	
Overlay thickness (mm)	10 mm above bottom overlay	20 mm above bottom overlay	Overlay thickness (mm)	10 mm above bottom overlay
40	6.8	1.27	60	16
60	6.5	1.31	90	21
80	8.2	1.63	120	27
100	8.8	1.87		

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Table 3 clearly shows a considerable longer lifetime for the road structures with Bitufor®. As for the deformation, the lifetime improvement with Bitufor® is highest for positions that are nearest to the crack. Note that the beneficial effect of Bitufor® is larger for longitudinal cracks than for transversal cracks. This is related with the fact that for longitudinal cracks the flat torsioned wires are in a more favorable position with respect to the applied stress.

For crack initiation as a result of thermal movements we have found that a thin overlay with Bitufor can be as effective as a thick unreinforced overlay.

3.2. Reflective cracking induced by shear / slab rocking

In a similar way, from the shear strains giving rise to slab rocking, the relative lifetimes of the road structure with Bitufor® to these without Bitufor® could be estimated. They are represented in figure 9 and in table 4.

Table 4: Lifetime improvement factor and reduction in asphalt overlay thickness with Bitufor® for crack initiation induced by traffic (slab rocking for the structures represented in fig.2.

Overlay thickness (mm)	Lifetime gain with Bitufor®		Overlay thickness with Bitufor® (mm)	
	Transversal cracks	Longitudinal cracks	Transversal cracks	Longitudinal cracks
60	3	2.4	40 (1)	40 (1)
90	3.3	4.3	67	65
120	3.5	7.8	90	82
150	4.9	-	100	

(1) limited to 40 mm because of reasons of placement of the product.

From fig.9 it is possible to evaluate how much can be saved on asphalt thickness when using Bitufor®. This evaluation, also given in table 4, is based on the following equivalence principle : "Two structures are equivalent in crack initiation performance when they have the same relative lifetime". In view of this definition, design charts as given in fig. 10 can be deduced. The following conclusions can be drawn from fig.10 :

- the average gain in thickness with Bitufor® is of the order of 25% for transversal cracks and 30 % for longitudinal cracks (for slab rocking on cement concrete slabs),
- the greater the asphalt overlay thickness, the more the effect of Bitufor® will be beneficial. Applications on site confirm this statement [1, 7].

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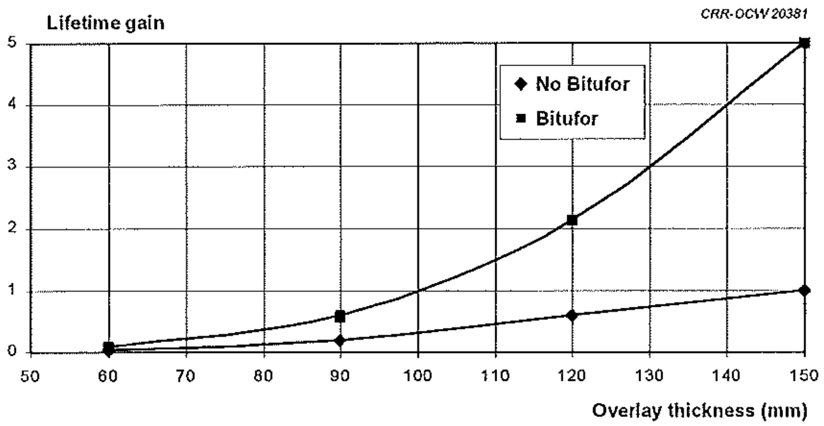

Fig. 9 : Relative lifetimes for crack initiation induced by slab rocking, with and without Bitufor®, compared to a structure with a 150 mm – overlay without Bitufor®.

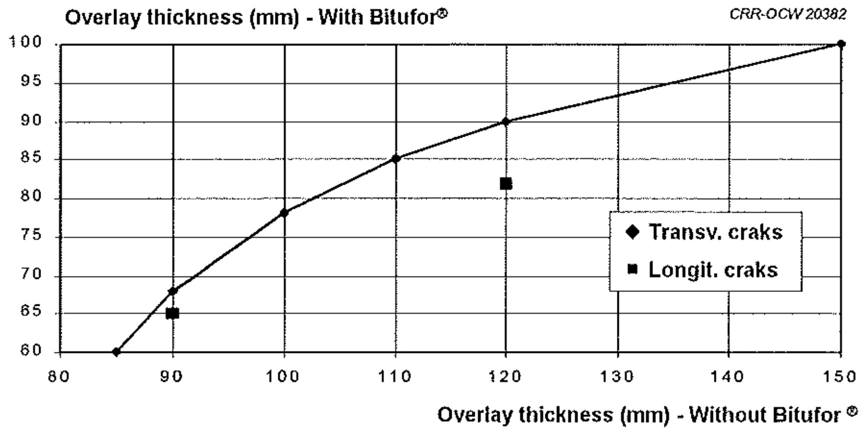

Fig.10 : Design chart to be used for overlaid cement concrete slabs with Bitufor® steel reinforcing nettings for the case of slab rocking.

3.3 Vertical deflections (bearing capacity)

We also studied the effect of Bitufor® on the bearing capacity. Especially, the area in the vicinity of the load and the crack was investigated. Deflection measurements performed on site indeed showed that Bitufor® is highly effective in this case [8]. It could be shown in the calculations that the transfer of loads is much more efficient when Bitufor® is present.

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In order to estimate the gain in asphalt thickness by the use of Bitufor®, the average deflection under the contact surface of the tyre was calculated and compared to that of a reference structure without Bitufor®. To be equivalent from the point of view of the deflections at a crack, two structures should have the same average deflection in the vicinity of the crack. Based on that principle, design charts could be deduced as are shown in fig. 11 for the case of cement concrete slabs. It can be concluded that :

- the gain in overlay thickness with Bitufor® varies between 10 and 30 % for the structures which were studied, depending on the overlay thickness,
- the role of Bitufor® is more significant when the thickness of the asphalt overlay increases.

We note that these conclusions are only valid for deflections under the load and for a contact area located at the edge of the crack/joint. The asphalt gain that was deduced should in no way be extrapolated to areas of the structure outside the cracked region. Here classical pavement design method should determine the necessary thickness of the pavement.

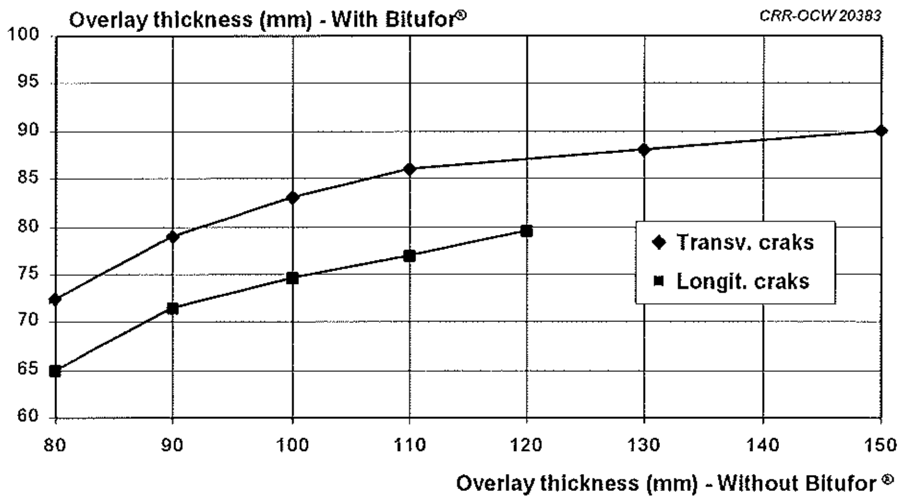

Fig.11 : Design chart based on vertical deflection performance for overlays in zones above cracks in cement concrete roads with Bitufor®.

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4. Conclusions

A structural design method aiming to account for different problem areas in the field of reflective cracking and able to describe the effects of the Bitufor® reinforcement system was developed. The design model is based on finite element analysis and consists in a realistic modelling of the steel reinforcing netting.

The effectiveness of the Bitufor® reinforcing system for crack prevention could be clearly demonstrated. Comparisons of lifetimes of different structures, with and without Bitufor®, were made and it was estimated how much can be saved on asphalt overlay thickness. Design charts could be developed, aiming to be used in practical applications. Future work is however necessary to confirm and to complete the actual study :

- Although deflection measurements, carried out on applications on site, seem to confirm the results of these calculations, more field validation is necessary, for different road structures.
- The results given in this document only concern the initiation of cracks in the asphalt overlay. They may not be extrapolated to the case of crack propagation.

We also note that the asphalt gain that was deduced in particular concerns cracked areas with severe stress concentrations and local deficiencies in bearing capacity. The results should therefore not be applied to areas of the structure outside the cracked region.

5. References

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