Steel Reinforced Asphalt Layers
- Investigations and Experiences in Germany –

B. Lechner
Chair and Institute of Road, Railway and Airfield construction, Munich University of Technology, Munich, Germany

ABSTRACT: Due to the increase of heavy traffic loading and expenses for road maintenance and rehabilitation a continuous research and development work in the field of innovative pavement and material designs is needed. Aims of reinforcement structures used in asphalt roads are prolongation of service life by increasing bearing capacity and delaying plastic deformations or cracking respectively. Within the 4th EU-framework the REFLEX-project "Reinforcement of flexible road structures with steel fabrics to prolong service life", was focusing on benefits and further developments of reinforced asphalt layers using steel fabrics. Dependent on the load and environmental conditions within Europe the research group was focusing on bearing capacity and on resistance against thermal cracking (including frost heave) reflective cracking, plastic deformations and flow rutting. This paper shows the German investigations, results and experiences focusing on flow rutting and bearing capacity:
- Design of reinforced pavements supported by theoretical models (Multi-layer-theory, FEM) to check the performance of net structures.
- Interaction between asphalt and reinforcement structures (bond) as well as performance of reinforced layers by lab tests.
- Monitoring of the behaviour of steel reinforcements during the placing of the asphalt and establishment of recommendations for the design and the construction of such pavements. Measurements performed during the paving process show the sensitivity of this technology (especially for the usage against flow rutting) given by the fundamental material properties of asphalt and steel.
- Monitoring of test sections (especially bus-stops) and road sections.

Key words: Reinforced asphalt, paving, flow rutting

1. INTRODUCTION

The service life of asphalt pavements is determined by the traffic loading and the climatic impacts. The respective loading conditions are taken into account by the European road community using individual and therefore differential pavement design solutions. The competition on the market boosts continuous developments concerning the reduction of expected life cycle costs (LCC).

The pavement designs are as manifold as the pavement distresses and respective distress developments, which are the limitations of the service life of asphalt pavements as well as the starting points for improvements. One approach to increase the stableness and bearing capacity is given by the usage of steel nets which are originally used within reinforced concrete structures.

Within the last two decades experiences on steel reinforced asphalt pavements for road and airfield construction have been born in the Nordic countries. But the special climatic conditions in that region must be taken into account, which would cause uneconomic solutions in case complete frost resistant road superstructures are required. Great and uneven frost heave movements are causing wide diverged cracks at the surface, which have been reduced or have been shifted towards the intersection to the shoulder in case of using steel reinforced asphalt layers (REFLEX 2002).

First experiences based on that technology have been collected in Germany within short test sections, but focusing on the reduction or avoidance of flow rutting effects. Several trial sections on bus-stops had been installed, which are in the responsibility of the Munich road administration (Rubner 1998). To reach further development and acceptance of this concept of using additional steel reinforcement structures for the construction of new asphalt pavements as well as for road-maintenance the research project REFLEX „Reinforcement of flexible road structures with steel fabrics to prolong service life" had been forwarded by the European Commission within the 4th frame work program.

2. THE "REFLEX-PROJECT" (REFLEX 2002)

The REFLEX project has been carried out under the management of the Swedish National Road and Transport Research Institute (VTI) between 1999 and 2002. Following institutions took part: FUNDIA ARMERING AB (FUNBY), SE; Finnish National Road Administration, FI; Technical Research Centre of Finland; FI; Institut für Stahlbetonbewehrung e.V. together with Munich University of Technology TUM-BvL, DE; Ferriere Nord SpA together with Autovie Venete SpA, IT.

Within the consortium different tasks concerning the possible usage of steel reinforced asphalt pavements had been identified and had been worked in the frame of theoretical investigations, laboratory tests up to full scale tests and the implementation of trial roads. The investigations focus on the implementation of steel reinforcements into asphalt as well as into unbound layers (unbound granular material – UGM):

- Increase of bearing capacity or reduction of required thickness of asphalt layers
- Increasing the resistance against distresses caused by frost impact
  - Frost heave cracking
  - Thermal cracking
- Increasing the resistance against reflective cracking
- Avoidance or reduction of flow rutting effects
- Avoidance or reduction of distresses caused by differential settlements (e.g. in case of road widening measures)

The following explanations focus on the usage of steel net reinforcement within bituminous bound layers.

2.1 Results and experiences given by existing trail sections

Since the 80th several trail sections had been installed using steel net reinforced asphalt pavements and monitored in Sweden and Finland especially despite the problems of frost heave cracking. Measurements have been done concerning crack development, flow rutting and bearing capacity.

Within the frame of maintenance measures a first bus-stop in the city of Munich has been equipped at the end of 1996 with a steel net reinforced asphalt pavement in a length of about

40m: 6,5 cm gap-graded SMA 0/11 S including the steel net on 8 cm asphalt binder 0/22 S and 18 cm asphalt base course 0/32 CS.

The steel mesh in a length of 6,45m, width 2,95m and a bar-diameter of 5 mm had been designed especially for this measure. Mesh size was 50 mm x 50 mm within the area of the running wheels and 100 mm x 100 mm for the "unloaded" sections, which caused a bar assembly in three layers. To assure a sufficient depth of coverage of the steel mesh (total height of net is about 15 mm) the thickness of the surface layer was increased to 6,5 cm.

In face of the net length and the positioning of the net within the surface layer the installation and paving procedure has been done without any problems. Within more than 8 years not any negative concomitants have been observed, which might be connected anyway to the additional installation of steel nets.

In 1999 to 2001 measurements concerning the depth control of the reinforcement, removal of drilling cores and repeated profile measurements to control the flow rutting development have been performed. The bus-stop is being frequented by about 140 line-operating busses per day. A scanning device usually used for steel reinforcement structures within conventional concrete structures has been calibrated on steel reinforced asphalt test specimen and has been used to control randomly the in-situ distance between asphalt surface and top edge of the steel nets. A mean value of 53 mm of coverage has been determined in which the minimum value was 30mm. These results had been verified by the core samples, which additionally are showing a sufficient embedment of the steel mesh within the SMA 0/11 S. Only small voids have been visible at the cross-over points of the longitudinal and transversal steel bars of the net. First measurements of the transversal profiles during summer of 2000 result in a maximum depth caused by flow rutting of 7mm, which was increased up to 9mm as shown by the repetition measurement at the beginning of 2002.

2.2 Laboratory investigations concerning flow rutting

The interaction and load transfer between asphalt and steel net has been researched within different test series (pull-out tests; shear tests). Of course the most important parameter is given by the mesh size, but surface structure of the steel bars is getting an increased influence during deep temperature conditions. Because of the time and temperature dependent visco-elastic material properties of asphalt the description of the bond behaviour between steel and asphalt demonstrates a very complex issue and therefore a wide field for further and detailed investigations. But basic knowledge was essential for theoretical investigations and modelling work.

To evaluate the influence given by additionally implemented steel net reinforcing structures in respect of flow rutting effects at asphalt pavements comparative test series with reinforced and unreinforced asphalt test specimens had been performed using the wheel tracking test set-up of the institute for road, railway and airfield construction of the Munich University of Technology (TUM). Asphalt pavement structures according to the German catalogue RStO (FGSV 2001) had been selected and have been built in situ by common paving procedures and machinery in a length of at least 50 m. The test specimens with the dimensions of 75cm x 140cm have been cut off these test sections and were fixed in the wheel tracking devise resting on a resilient mat to simulate support conditions given in situ by a modulus of subgrade reaction according to E_{v2} = 120 N/mm². Both asphalt sections (reinforced and unreinforced) have been loaded simultaneously each by one track wheel in longitudinal direction whereas fixed temperature gradients within the asphalt pavements were given to simulate summer conditions by controlled heating of the surface. Within a first test series following parameters have been investigated: influence of the surface (plain, ribbed) of steel bars with diameter 6mm, mesh size and location (depth) of the reinforcement within the upper part of the asphalt pavement.

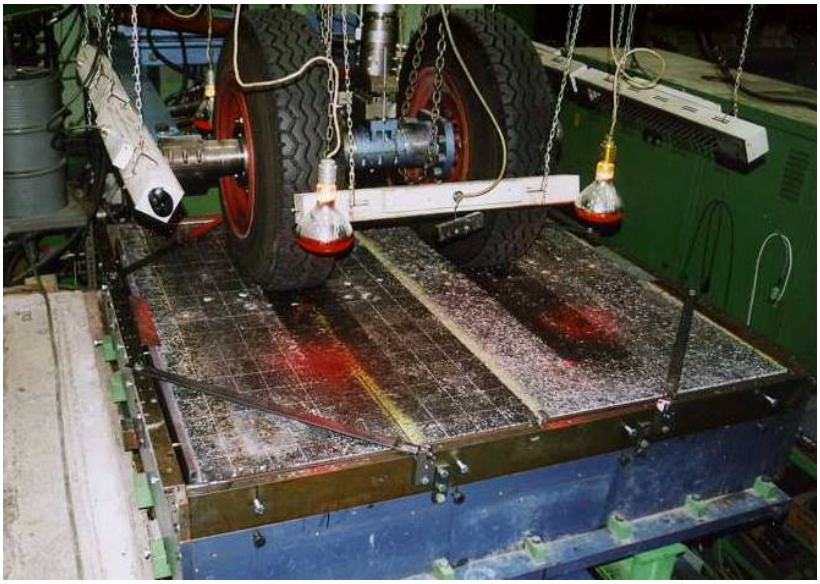

Figure 1: Wheel tracking test set-up (TUM laboratory)

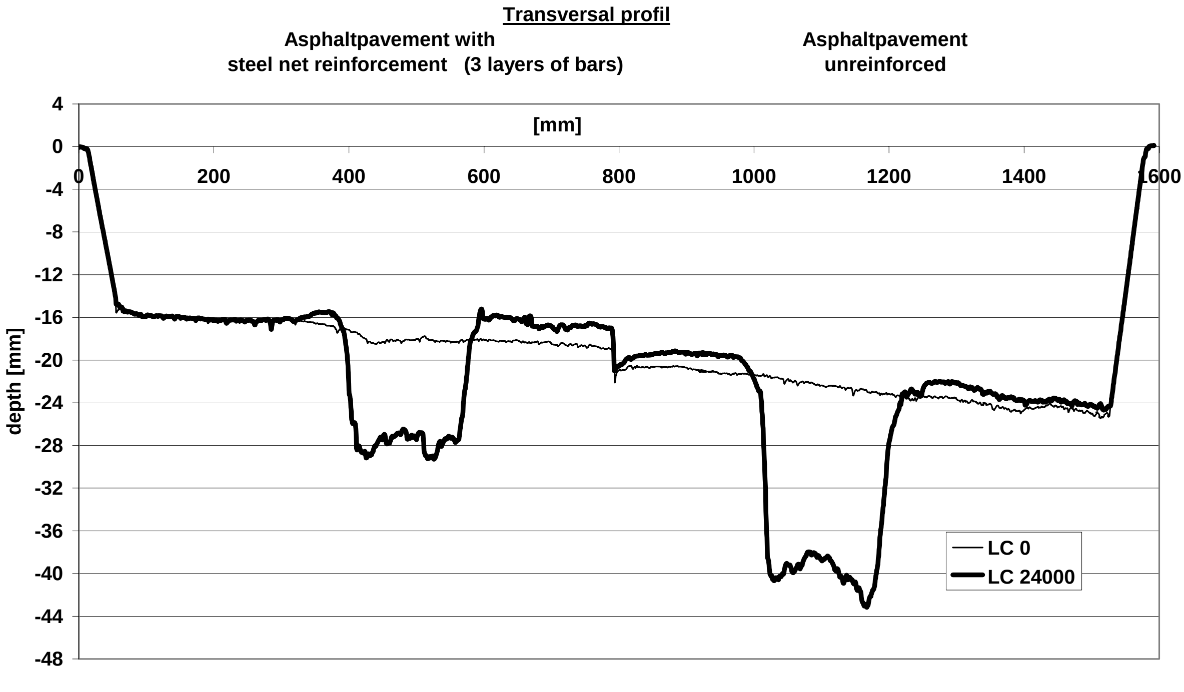

Figure 2: Wheel tracking test: Transversal surface profile showing surface deformations of reinforced and unreinforced test specimen up to 24.000 load cycles (LC).

In particular the tests demonstrate the effectiveness of steel net reinforcing structures within asphalt pavements even under unfavourable circumstances. The maximum depth measured within the rut compared with the level of the original surface was significantly reduced (up to 30%) for the reinforced asphalt test specimen compared to the unreinforced ones. On the other hand the presence of reinforcement caused increased bulges beside the rut during the stage of volume constant material movements whereas the positive effect according the total rut depth (effective depth of water) was reduced.

The conclusions born by these test series has been used as input for new steel net designs like three layered nets (so called “3D”- nets), nets with cranked longitudinal bars to realise a one layer net, diagonal meshes etc. These structures have been evaluated by comparative testing within a second test series.

Beside the improvements concerning the performance of these net structures general problems have been observed especially connected to the bond between the asphalt layers, which underlined the importance of requirements concerning the minimum acceptable mesh size, the maximum net dimensions (length) and the installation procedures and conditions. It must be assumed that increase of layer-stiffness by additional steel reinforcement within the upper part of the pavement will increase the loading of the bond conditions towards the supporting (unreinforced) layer. This interface has been already stressed in a special way during the paving process (see 2.4 “installation tests”).

2.3 Theoretical investigations and modelling

The most popular modelling tools for theoretical investigations on asphalt pavements are based on the elastic multi-layer theory, which requires isotropic and homogenous layer conditions. Therefore this model tool is first of all not suitable for the description of special structures like reinforcements. By a first approach the reinforced layer can be defined by a layer of substitute extensional stiffness (E·A).

Appropriate three-dimensional FE-models are able to describe the bearing and deformation behaviour of reinforced asphalt pavements in a sufficient approximation or to determine the above mentioned substitute extensional stiffness. Following assumptions have been used: linear elastic material behaviour, quadratic cross section of steel bars, bar crossings within one level and full friction between steel and asphalt elements.

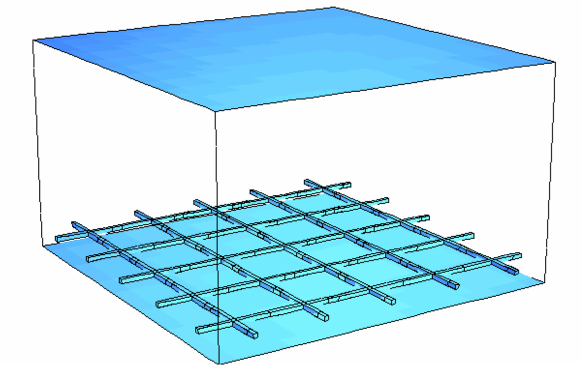

Figure 3: REFLEX - FE-model with steel net at the bottom of the base course.
1/4 slab for single wheel load (Neßlauer 2002).

To examine the influence of the steel net, the reinforced system was compared with the un-reinforced one. It must be taken into account that because of the assumption of full friction the steel elements transmit high stresses to the adjoining asphalt elements. Therefore the stresses of the asphalt elements next to the steel elements are relatively high. This effect must be taken into account for the evaluation (Neßlauer 2003).

Because of the visco-elastic and visco-plastic behaviour permanent deformations in the asphalt layers are induced. Some pavement design models try to calculate the rutting rate of a pavement system, but until now no generally accepted method to calculate rut depth has been developed.

The multi-layer theory program BISAR (Shell 1998) is able to calculate the values and vectors of stress and strain tensors, the principal stresses and strains and the corresponding principal directions, the maximum shear stresses and strains and displacements in x-, y- and z-directions. Therefore the stress tensor and the deformation tensor (D) can be determined.

Laboratory tests showed that after a certain time of post-compaction there is no change of volume during rutting. Therefore the part of the deformation tensor which describes a deformation with constant volume has to be determined. By splitting off the hydrostatical part from the deformation tensor one gets the deformation deviator D'. This deviator describes the modification of the shape at constant volume. These thoughts have been adopted by an extension of the BISAR-program which is splitting off the hydrostatical part from the deformation tensor and is calculating horizontal and vertical deformations (Hilmer 1984).

For reinforced asphalt pavements the reinforcement was substituted by an equivalent layer.

Under constant volume conditions and vertical loading a deflection beneath the load will appear, but heaves beside the load contact area. It has to be differed between the relative and the absolute rut depth. Relative rut depth means the difference between the profile of the cross section before loading and the rut depth at the time of measuring. Absolute rut depth means the sum of the heave beside the load and the deflection under the load.

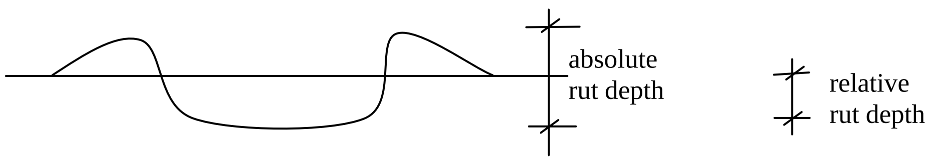

Figure 4: Definition of "absolute rut depth"

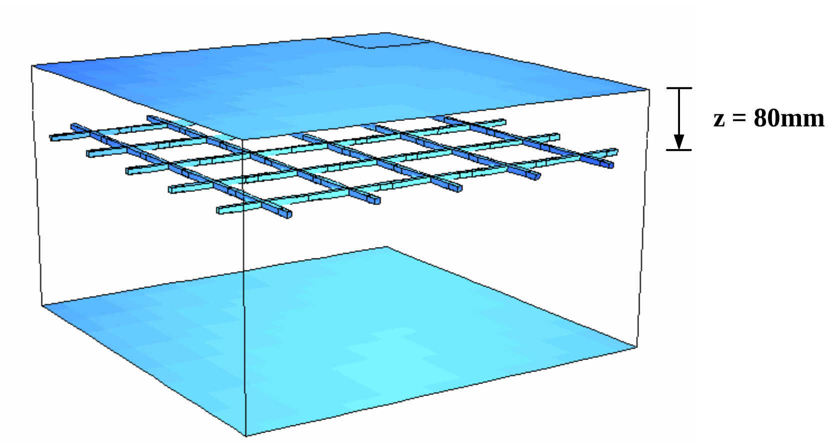

Figure 5: FE - model with reinforcement at z = 80mm to investigate flow rutting effects (Neßlauer 2002).

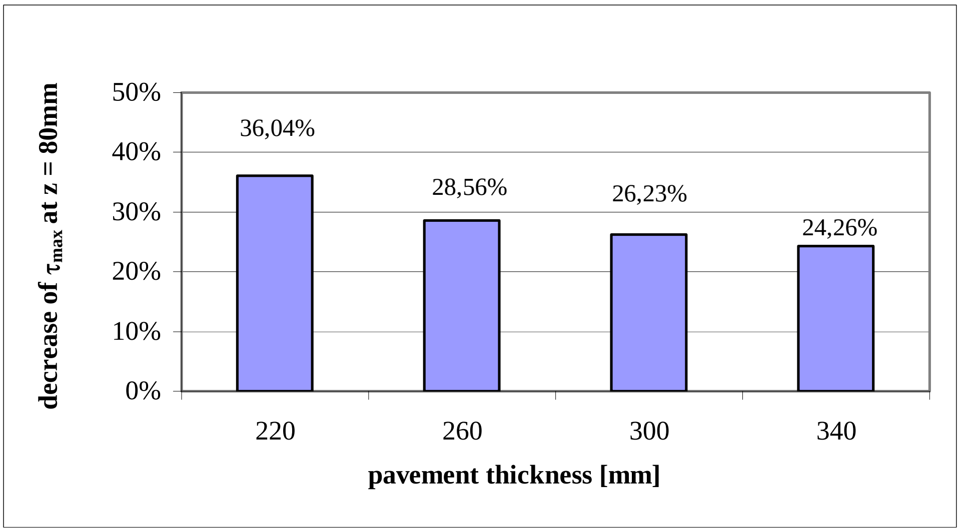

Figure 6: Example showing the decrease of max. shear stresses within asphalt (τ_{max}) at depth (z) =80mm regarding different pavement thicknesses compared with the unreinforced structure; steel net reinforcement placed at z = 80mm (Neßlauer 2002).

The results of the modelling work concerning flow rutting as well as bearing capacity have been checked by experimental investigations showing good correlations. In accordance with the flow rutting test series an additional steel net reinforcement within the binder course (respective depth of about 6 cm to 8 cm) showed the highest increase concerning the resistance against flow rutting.

2.4 Installation tests

By theoretical and practical investigations performed on steel net reinforced asphalt specimen criteria for further optimisation of this concept can be worked out and evaluated. But crucial for the potential usability of a steel net reinforced asphalt pavement is first of all the faultless installation. By the combination of steel and asphalt, which are two materials showing strong differential properties, especially the control of steel strain caused by high temperature changes during placing the asphalt is a challenge.

Because of the mechanical and thermal loading of the steel nets stresses, strains, horizontal displacements and vertical deformations will occur during the paving process, which will affect the bond conditions between the layers and between steel reinforcement and asphalt as well as the compaction of the mixture itself. Overlapping of unfavourable conditions and mistaken parameters will make the installation impossible!

The loading conditions and the behaviour of steel nets during the paving procedure have been investigated by field tests. Limitations according to the available length of the test section (about 60m) required restrictions according to the numbers of parameters to be investigated.

- Paver with caterpillar traction, which is unfavourable compared to wheel traction.
- Final compaction using smooth-wheeled rollers or pneumatic/smooth-wheeled rollers
- Thickness of reinforced layers: 4 cm, 6 cm and 8 cm
- Aggregates of the mixture: 0/11S and 0/16 S; different mixture temperatures
- Mesh size 100mm x 100mm and diameters of the steel bars 5mm and 6 mm

The actual conditions during time of installation in November 2001 are characterized as really unfavourable. The air temperature was close to or below the allowable lower limit valid for the installation of conventional (unreinforced) asphalt according to the ZTV Asphalt-StB

01 (FGSV 2001). Additionally a great net length of 3,70m and high temperature of the mixture close to the allowable upper limit have been chosen to achieve a combination of unfavourable conditions.

To enable measurements for documentation and analysis during and after paving the asphalt mixture some steel nets had been equipped with measurement devices to record longitudinal movements, strains and temperature changes. The results have been used among others as input for the list of design and installation recommendations described in chapter 3.

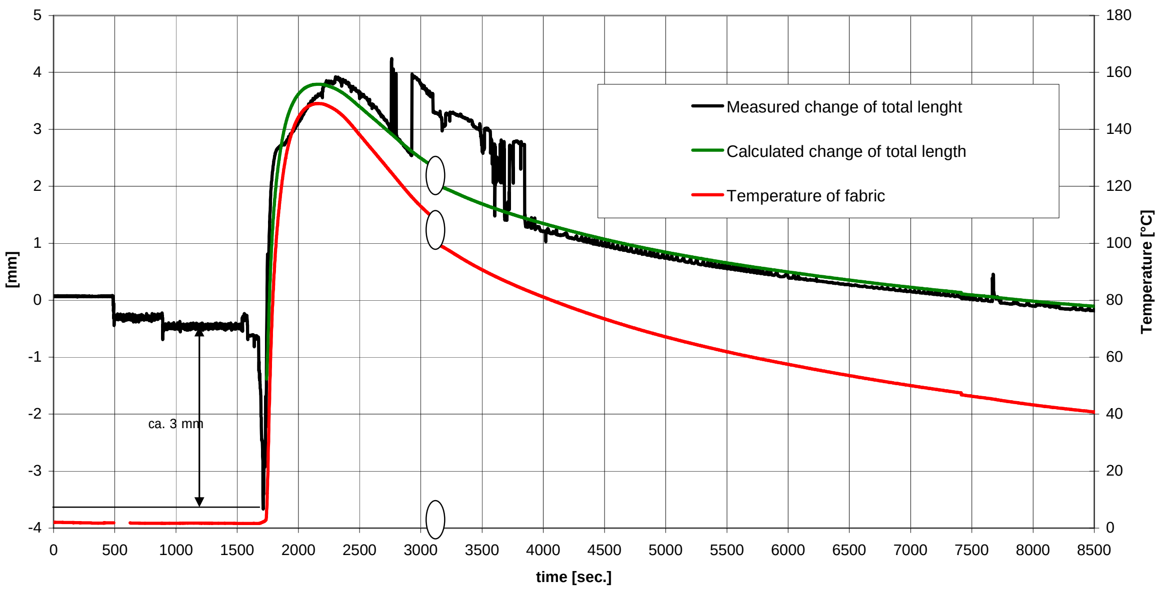

Figure 7: Changes of the total length (black line) of the 3,7m long steel net (5mm bars) during delivery and paving of the surface layer. Green line is showing the theoretical change of length based on the measured temperature development (red line).

2.5 Construction of trial roads

One section of the county road K 80 near Trier was foreseen to be rehabilitated based on the existing pavement. Improvement of the alignment was planned to do by one-way or two-way widening measures (minimum radius of the existing road was 117 m). The old pavement is contaminated by pitch containing binders. This material should remain in the existing pavement covered by a steel reinforced asphalt overlay including the road widening sections to reduce costs and construction time of this county road which is partly bordering a water protection zone. The test section in a total length of 3140m has been built in summer 2001, whereas 2300m are equipped with an additional steel net reinforcement and an unreinforced section in a total length of 840 had been installed for comparison reasons. The pavement design was as follows:

- 4 cm wearing course 0/11 S
- 4 cm binder course 0/16
- steel net reinforcement (see below)
- 10 cm asphalt base course 0/32 C
- Profile clearing on the old (existing) pavement

Steel net reinforcement:

- Bar diameter 6,0 mm (BST 500 M)
- Quadratic meshes 100mm (Weight of net: 56,3 kG/unit)
- Length (acc. to road axis) of net: 2,3m
- Overlap about 0,3 m
- Width of net: 5,9 m

In total 1170 steel nets have been installed.

A first trial to pave the 4 cm thick binder course covering the steel net reinforcement by a 6m wide paver equipped with caterpillar traction was not successful. After exchanging this machine by the originally foreseen 3m wide wheel tracked paver not any major problems occurred.

Drilling cores which have been taken within the regular quality control procedure showed actuated bond. Below the knots (crossings of longitudinal and transversal bars) small cavities have been identified particularly. During about 3 ½ years of service life not any unfavourable changes or distresses have been observed which might be connected with the additional usage of steel nets.

3. STATE OF THE ART AND RECOMMENDATIONS

Based on the positive experiences by the usage of steel net reinforced asphalt, which have been especially collected in the Nordic countries according to their great frost heave movements, this idea has been started to be discussed in Europe focusing on other possibilities of usage.

Benefits can be detected by theoretical investigations and experimental measurements especially concerning the usage of additional steel net reinforcements within the upper area of asphalt pavements (flow rutting effects; reflective cracking …). Positive effects born by additional steel nets within the lower area of asphalt pavements (increase of bearing capacity) can be calculated. But evidence concerning the in-situ change of bearing capacity was not possible up to now based on Falling Weight-Deflection-Measurements (FWD) performed in Sweden and Italy whereas the location of the reinforcement within the investigated asphalt pavements must be taken into account.

The advantages of additional steel net reinforcement are only utilisable in case the installation process succeeds. This is especially directed towards the planned location of reinforcement within the upper area of asphalt pavements. Based on the existing experiences following recommendations can be given to obtain a safe and controlled installation process (coverage, bond) of steel net reinforced asphalt layers (bar diameter 5 mm or 6 mm):

- Because of the deformation behaviour of steel nets an installation within the surface layer will be very problematic intension (guarantee of vertical cover!). Based on wide theoretical investigations the position of an additional reinforcement will be best within the binder course (depth of 6 cm to 8 cm, respectively) in case of aiming the reduction of flow rutting effects.
- For any other layer the thickness should be at least 4 cm plus thickness of the steel-net itself. Mesh size (net bar spacing) should be at least 5 times the maximum aggregate size.
- Steel net and underlay must show an adequate evenness (profile clearance might be needed)
- Limitation of net length (maximum of about 2,5m recommended)
- Nets must be placed longitudinal bars up and edges have to overlap (about 270 mm recommended). In direction of the later paving the cantilevered longitudinal bars have to be placed on the transversal bars of the following net. Sufficient space (about 30 mm recommended) between the end of the longitudinal bar and the next transversal bar of the following net must be given to enable free longitudinal movements of the net during paving. Longitudinal bars at the overlap will bend downwards when loaded by the running trucks.
- Within small radii cutting of the nets to reach radial overlapping joints is needed.
- Net width must be according to the required lane or road width to avoid longitudinal joints.
- Nets must not be fixed on the underlay (but beginning of the first net, if needed).

- Tack coating should be done according to the specifications for unreinforced layers. Spraying by two different angles is advantageous, but an increase of the total amount may cause de-bonding between the layers!
- Installation of nets and paving should be done during dry, warm weather conditions. Low temperature of the mixture within the acceptable range (compaction) is preferable according to the expected steel net strains.
- Usage of wheel tracked pavers; paving width of more than 3 m require additional loading of the nets beside the paver.
- Horizontal forces caused by braking, accelerating or turning must be limited. Delivering trucks must not be pushed by the paver as usually, to avoid concentration of traction forces.
- Usage of additional reinforcement cause additional compaction work needed to reach sufficient integration of the steel nets and bond between the layers. Compaction with additional kneading work (pneumatic wheeled roller) is showing better results. Minimum temperature of the base layer (dry surface required) should be significant higher for paving reinforced layers than the conditions required for unreinforced layers.

An experienced paving team will reach about the same paving capacity as usual!

REFERENCES

FGSV - Forschungsgesellschaft für Straßen- und Verkehrswesen. 2001. *Zusätzliche Technische Vertragsbedingungen und Richtlinien für den Bau von Fahrbahndecken aus Asphalt, ZTV Asphalt-StB 01.* FGSV Verlag GmbH, Köln.

FGSV - Forschungsgesellschaft für Straßen- und Verkehrswesen. 2001. *Richtlinien für die Standardisierung des Oberbaues von Verkehrsflächen RStO 01*, FGSV Verlag GmbH, Köln.

Hilmer, A. 1984. *Einfluss der Radlasten und Reifeninnendrücke auf die Spurrinnenbildung an Asphaltstraßen.* Mitteilungen des Prüfamtes für Bau von Landverkehrswegen der Technischen Universität München, Heft 43.

Neßlauer, S. 2002. *Reinforcement of Flexible Pavements – Design of Finite Element Models.* Proceedings of the 6th International Conference on the Bearing Capacity of Roads and Airfields, Lisbon, Portugal, 24-26 June 2002.

Neßlauer, S. 2003. *Untersuchungen zum Verformungs- und Tragverhalten bewehrter Asphaltstrassen*. Mitteilungen des Prüfamtes für Bau von Landverkehrswegen der Technischen Universität München, Heft 78.

Reinforcement of Flexible Road Structures with Steel Fabrics to Prolong Service Life (REFLEX). 2002. *Final report.* http://www.vti.se/reflex/ >(Feb. 2004).

Rubner, G. 1998. *Bewehren von Asphaltdecken*. VSVI-Seminarvortrag am 5. Febr. 1998; München.

Shell International Oil Products B.V. 1998. *Handbuch BISAR 3.0.*