REINFORCEMENT WITH DOUBLE TWIST STEEL WIRE MESH: MODELING AND LABORATORY EXPERIENCES TO EVALUATE THE DESIGN LIFE IMPROVEMENT OF ASPHALT PAVEMENTS

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ABSTRACT

One of the oldest interface systems used in flexible pavement is steel reinforcement. The idea that appeared in early 1950s was based on the general concept that hot-mix asphalt is strong in compression and weak in tension, then reinforcement could be used to provide the needed resistance to tensile stress. However, it appears that steel reinforcement was abandoned in the early 1970s after tremendous difficulties were encountered in its installation. The idea reappeared in the early 1990s with a new class of steel reinforcement products in Europe: many of the problems encountered earlier appeared to have been solved and satisfactory experiences with the new class of steel reinforcement were reported.

The double twist steel mesh was initially introduced to intercept the reflected cracks generated by jointed concrete pavements. Wider use of the product and further research have found the steel mesh being used more widely and for a greater number of applications, as the steel mesh is able to absorb the stresses induced by a reflected crack generated by a jointed crack; to intercept the shear plane to provide rut resistance and to reduce the peak tensile stress and strain under load. Configuration of the current steel wire mesh reinforcement consists of a double-twist, hexagonal mesh transversally reinforced at regular intervals with steel wires inserted in the double twist.

Several research groups have been investigating the effectiveness of the reinforcement both by laboratory tests and numerical modelling, with a variety of finite element models adopted to characterize the reinforced pavements, as they cannot be analysed using multi-layer elastic theory.

The paper presents an overview of the main results obtained from worldwide researches on pavements reinforced with steel mesh reinforcements: the large amount of collected data in different working conditions and the comparison between the results of laboratory and field tests, have proven that steel mesh reinforcements can be designed to effectively enhance the working life of the pavement structure by a significant factor, whose actual value depends on the overlay thickness and the pavement structural capacity.

Keywords: steel reinforcement, interface system, life improvement

1. INTRODUCTION

Modern road planning and management must guarantee a running of the road network that is as safe, comfortable and environmentally friendly with the best utilization of financial resources. Against this, the growth of heavy traffic determines an increase in the amount of distress inflicted on road pavement.

This increase in performance required from the road network and in particular from the pavement, has inspired researches towards the study of new materials and technological solutions that can guarantee efficiency and durability, such as the use of interface systems. Starting from the early 1930s, Beckham and Mills suggested the use of cotton fibres as an interlayer system in flexible pavement in North and South Carolina (Beckham et al. 1935). Today, the use of degradable materials such as cotton fibres may not be the best alternative for reinforcement, but the concept is still valid.

One of the oldest interface systems used in flexible pavement is steel reinforcement. The idea that appeared in the early 1950s was based on the general concept that if HMA is strong in compression and weak in tension, then reinforcement could be used to provide needed resistance to tensile stress. At that time, the idea may have been taken from the very successful steel-reinforced Portland cement concrete (PCC). Several experiences with welded steel wire reinforcement in the period between 1950 and 1970 to reduce reflection cracking were made in USA, where different problems related mainly to installation were reported: expansion and contraction of the mesh caused transverse cracks at mesh splices due to insufficient overlap between the rolls; buckling of the steel mesh, due to the movement of the paving equipment; possibility of resulting low densities of upper HMA layers. The mesh was also reported to rust, neck, and break at cracks. Even with these problems, welded steel mesh was found to be effective in retarding reflective cracks, but its use was nevertheless abandoned in the early 1970s. The idea reappeared in the early 1980s with a new class of steel reinforcement products in Europe (Belgium, Italy and the Netherlands): many of the problems encountered earlier appeared to have been solved, and satisfactory experiences with the new class of steel reinforcement were reported.

2. THE DOUBLE TWIST WIRE MESH REINFORCEMENT

Road Mesh is manufactured from double twisted steel wire mesh with transverse reinforcing rods evenly spaced throughout at approximately 16 cm centres, as depicted in table 1 and figure 1. The hexagonal mesh size is 80 by 100 mm (nominal) as defined in EN 10223-3, the wire is protected against corrosion by a zinc coating complying with EN 10244-2 Class A. The mesh thickness varies between the 2.4 mm wire diameter up to 9.2 mm where the transverse rod passes through the double twist. The varying height of the product strands, and distance between them, ensures that the asphalt can encapsulate the wire, without developing a weak shear zone at the product interface.

Table 1: Mechanical characteristics of Road Mesh

Wire diameter (mm)	Transverse rod (mm)	Tensile strength MD/XD (kN/m)
2.4	4.4	39/50

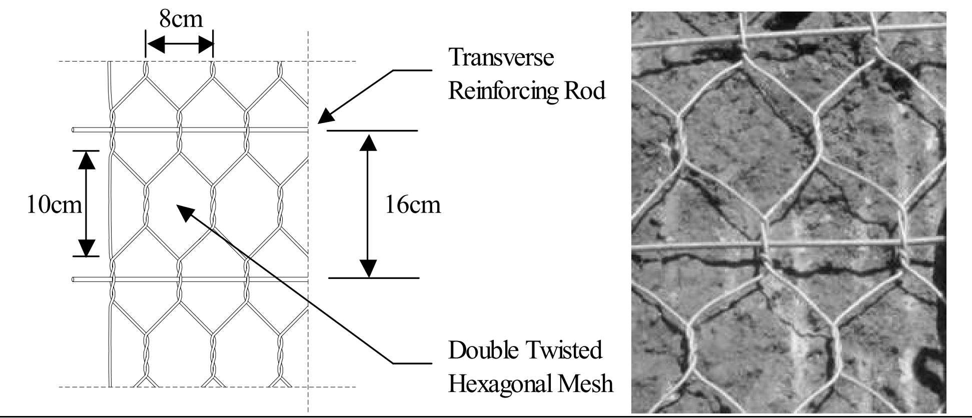

Fig. 1: Geometrical characteristics of the Road Mesh

3. ROAD MESH APPLICATIONS

Road Mesh was initially introduced to intercept the reflected cracks generated by jointed concrete pavements. Wider use of the product and further research have found the steel mesh being used more widely and for a greater number of solutions.

The steel mesh is best suited to be used for the following applications:

- Fatigue cracking and overlays: if a new pavement or if a new overlay is installed over a fatigued/cracked pavement, cracks will propagate to the surface after a very short traffic period. Road Mesh is introduced to extend the life of the overlay by absorbing the horizontal tensile stresses resulting from the existing cracks and by traffic loads.

- Road widening: when roads need to be widened, differential settlement cracks occur at the junction between the old and new pavement structures. Road Mesh is introduced to bridge the junction to absorb the crack stresses caused by the differential settlement: the effective interlock with the asphalt aggregate matrix ensures the optimum contribution of the reinforcement; a minimum of 1 m either side of the joint is required.

- Surface rutting: under repeated heavy vehicle traffic, the asphalt surfacing is exposed to repeated shear forces which result in shear slip circles and ultimately leads to shoving. Road Mesh is installed at the base of the overlay, for a layer thickness more than 60 mm, thus intersecting the shear slip circle and ultimately reduces the surface rutting.

4. LABORATORY AND FIELD EXPERIENCES

The key objective of this chapter is to review the existing worldwide experiences on the application of the steel mesh reinforcement in HMA pavements: summaries of the most notable investigations follow hereafter.

4.1 Nottingham University (UK)

The research (Brown et al., 2001) investigated the effectiveness of different interlayer systems (geogrid, steel reinforcement and fibreglass grid) in preventing the reflection of cracks in HMA overlays with both physical tests and numerical modelling. A repeated load shear test was first used to evaluate the interface shear strength and stiffness for unreinforced and reinforced samples. Results of this study indicated that only steel reinforcement provides interface shear stiffness comparable to the unreinforced case; both geogrid and glass fibre caused a significant reduction in the interface shear stiffness.

A set of four-point bending 400x200x120 mm test was performed to establish the contribution of reinforcement to the fatigue life of HMA: the reinforcement was placed 30 mm above the base, and support was provided by two rubber layers placed over a steel base. Furthermore, pilot-scale pavement tests enabled the model to be checked under realistic conditions: the pavement consisted of two layers of asphalt with reinforcement between them, overlying individual concrete slabs with air gaps between them that acted as wide cracks, inducing reflection cracking in the overlying asphalt. The test results have shown that steel reinforcement improves the fatigue life by a factor up to 3, well above the other materials performance (Fig. 2).

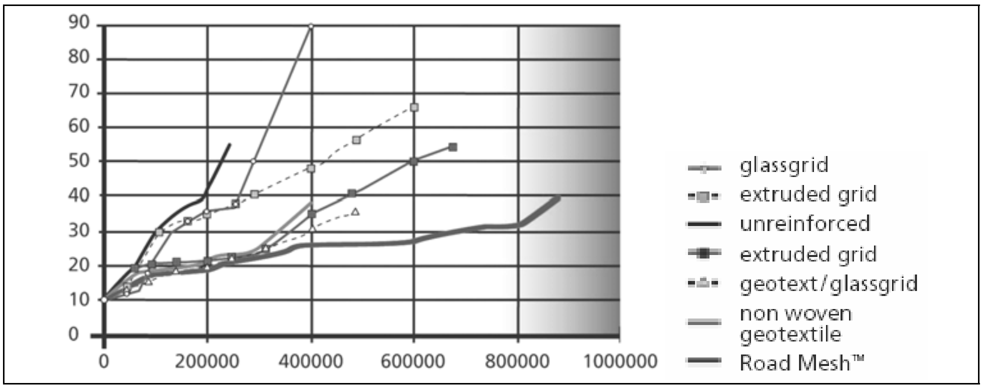

Fig. 2: Crack growth (mm) vs. load application (cycles) for the different reinforcing materials

4.1.1 Finite element modelling with CAPA 2-D

The CAPA analysis was restricted to the modelling of the semi-continuous beam test and to the pilot scale trafficking pavement, as the code is not user friendly and its use can be very time-consuming. The CAPA modelling in the first case enabled the stress conditions in the test to be satisfactorily understood and allowed confidence in the tests and also in the use of the relatively simple simulative models. The second case was considered essential to provide further validation of the program OLCRACK, a method of analysis which, though approximate, is able to give sufficiently accurate prediction for design (Thom N. H., 2000)

The pavement considered was a 60 mm thick asphalt overlay, overlying 110 mm of existing asphalt including a crack, 200 mm of sub-base and 3300 mm of subgrade; only the bottom-up cracking case was considered. Interface stiffnesses were taken above and below the reinforcing elements themselves. In the analyses carried out, no account was taken of the effect of different strand spacings or of strand diameter. The only other variable which was considered was the stiffness of the reinforcement, therefore it was not easy to model individual reinforcement types exactly.

It has been found that CAPA gives similar predictions to the simplified Olcrack method for unreinforced pavements; significant differences have been found for reinforced pavements, but that is a consequence of differences in modelling the reinforcement not the asphalt.

4.2 Cagliari University (I): finite element modelling with ANSYS

The research (Coni and Bianco, 2000) investigated the crack propagation process in the presence of steel reinforcement based on a finite element (ANSYS) model, simulating a pavement structure consisting of an HMA layer (30 mm), a base course (40 mm), a base layer (100 mm), a subbase layer (200 mm) and a subgrade soil. An elastoplastic behaviour was assumed for all materials (except steel reinforcement, which was assumed linear elastic), and friction was considered at all interfaces. Both static and dynamic analyses (modal and harmonic analyses) were considered in this study.

Results of the static analysis indicated that steel reinforcement causes a reduction in the surface vertical deflection and tensile stress in the reinforced layer, but has no influence on vertical stress components. The study of the superstructure also encompassed analysing the resulting tensile strains in relation to the deflections, stresses and strains under the axle loads at the interfaces of the different layers. The introduction of a pavement reinforcement into the superstructure is most significant when the pavement structure and the modules of the layers are inadequate; the horizontal tension is reduced by 18% at the interface base-foundation and 26% between the base and the bound layers.

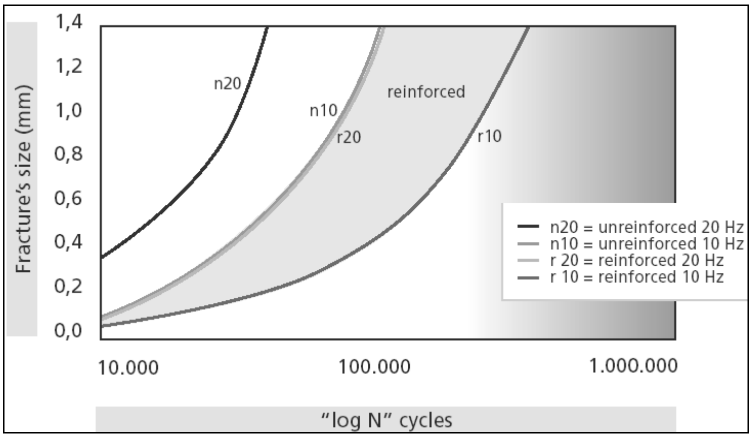

Fig. 3: Crack growth vs. load application at different load frequencies

Results of the dynamic analysis showed that steel reinforcement reduces the stress and strain level in the pavement structure, especially when resonance frequency occurs, at which point the stress and strain levels become very high. Further simulations have been carried out to evaluate the crack opening versus load frequencies, showing that the reinforcement protects from the crack initiation and its further propagation. Fig. 3 shows the crack development as a function of the load cycles at different frequencies (10 and 20 Hz): by making reference to a crack 1 mm deep, the reinforcement increases the pavement life by a factor variable between 3 and 12 (at 20 Hz and 10 Hz respectively).

4.3 Smart Road – Virginia Tech. (USA)

The Smart Road allowed testing of various hypotheses on pavement material performance and characteristics: pavement materials have been tested under different environmental conditions using the All Weather Testing facility (Mostafa E., Al-Qadi I., 2004). The flexible pavement portion of the Smart Road included 12 sections 100 m long, closely monitored through a complex array of sensors located beneath the roadway and embedded during construction, providing data of the pavement performance under real loading conditions and allowing for the monitoring of pavement performance under actual vehicular loading and environmental conditions.

The steel mesh was installed at 14 cm depth on top of a surface mix base layer and underneath a base mix layer to investigate its capability as a reinforcing system in overlays. All instruments were embedded in the pavement section during construction and included pressure cells, thermocouples and specially made HMA strain gages.

4.3.1 Finite element modelling with Abaqus

ABAQUS 5.8 was used in the modelling process; the dimensions of the modelled portion were 560 mm x 38000 mm. These dimensions were selected to reduce any edge-effect errors, while keeping the elements' sizes within acceptable limits (modelling constraints). Due to the symmetry in loading and geometry, only half the pavement was considered (Fig 4). The generated mesh was designed to give an optimal accuracy, with small elements around load and large elements far from it. All layers were simulated with the same shape to preserve the continuity of nodes between consecutive layers.

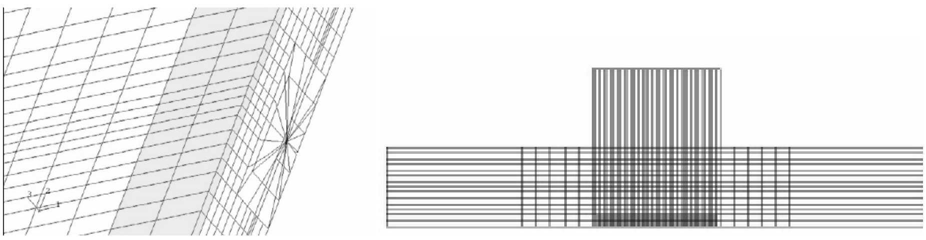

Fig. 4: Layout of the FE model developed at Virginia Tech.

A visco-elastic constitutive model was selected to simulate the behaviour of HMA. The steel reinforcement was simulated as a non-homogeneous layer with accurately simulated openings and a regular steel stiffness (E=200 kN/mm^2), the results of the developed FE models were compared with actual stress and strain measurements at the

Smart Road. Pavement responses to vehicular loading were compared at three temperatures (5, 25, and 40°C) and at a speed of 8 km/h, showing a good agreement between the results of the FE models and the response of the pressure cell, thus allowing the developed FE models to be used to evaluate the steel reinforcement's effectiveness.

4.3.2 Results

To quantify the contribution of steel reinforcement to the early stages of a pavement's service life a classical fatigue law (Arizona DOT) was adopted:

$$N = 9.33\ 10^{-7}\ \varepsilon_t^{-3.84}$$

Where:

N = Number of cycles for crack initiation;

ε_t = tensile strain at the bottom of the HMA layers.

Figure 5 shows the percentage increase in the number of cycles for the crack to propagate to 12.7 mm from the overlay surface, which is due to steel reinforcement. In general, the percentage improvement ranged from 40 to 120 percent depending on the stiffness of the overlay and the existing pavement structure.

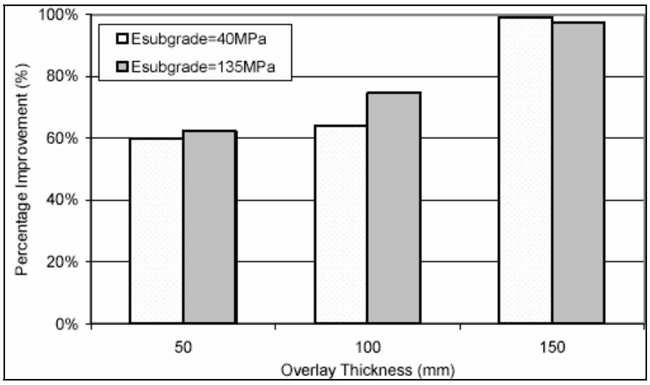

Fig. 5: Percentage improvement in fatigue response due to steel reinforcement

4.4 Catania University (I)

The research (Cafiso, Di Graziano, 2001), focused on the capacity of non-destructive pavement measurement techniques to quantify the increase in terms of resistance to deformation given to flexible reinforced pavements by steel mesh, was carried out elaborating data coming from a survey conducted with Falling Weight Deflectometer (FWD) and Ground Penetrating Radar (GPR) on an experimental section 250 m long on a national road (SS 121) in West Sicily.

4.4.1 Finite element modelling with Supersap

The pavement structure was modelled through the SUPERSAP code, comparing the stress and strain behaviour of the HMA with and without reinforcement; the modelled portion was 5940x5845x3040 mm. Two different installation depths of the reinforcement have been analysed at 8 and 15 cm, in order to match the experimental setup on the SS 121.

The initial validation of the pavement FE model without reinforcement has been carried out on the basis of the results obtained from the same pavement structure analysed according to the elastic multilayer theory. Furthermore, thicknesses and characteristics of the different layers have been assumed on the basis of the values obtained from GPR and FWD on the experimental stretch. The mechanical characteristics of the 3 layer model materials (HMA, Subbase and Subgrade) have been obtained by the back-calculation carried out through the ELMOD4 program on the deflection basins measured on the experimental stretch after installation.

The analysis of the strain distribution (Fig. 6) have shown that for the reinforcement at 8 cm depth the horizontal strain ε_{xx} is reduced by 23% at the reinforcement level and by 9% for the reinforcement at 15 cm depth.

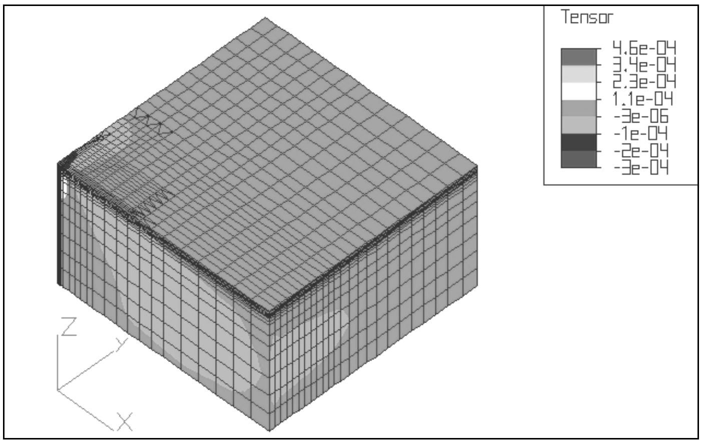

Fig. 6: Modelled strains for Road Mesh at 15 cm depth at Catania University

To quantify the contribution of steel reinforcement to the early stages of a pavement's service life, a classical fatigue law (Asphalt Institute) was adopted, similarly to the method adopted in par. 4.3:

$$N = 0.0796\ \varepsilon_t^{-3.291}\ E^{-0.854}$$

where

N = number of cycles for crack initiation;

ε_t = tensile strain in the HMA at the reinforcement level;

E = elastic modulus of HMA.

The presence of Road Mesh provides a service life increase variable between 36 % and 52 % (reinforcement at 15 and 8 cm depth respectively).

4.5 Parma University (I)

This research (Montepara, Tebaldi and Costa 2005) is focused on the evaluation of a steel mesh reinforced pavement through numerical modelling, laboratory and field tests. The mechanical performances were evaluated in laboratory and in situ by means of an experimental section equipped on purpose; the laboratory tests were performed using two experimental test setups specifically designed for avoiding size effect problems.

The experimental stretch consisted of two sections realized with the same pavement reinforced (at 8 cm depth) and unreinforced; both sections were monitored by strain gages placed with the mesh between binder and base layers; the sections were regularly monitored by means of an equipped vehicle able to highlight the cracks on the surface.

4.5.1 Finite element modelling with Abaqus

The model was developed using the program ABAQUS 6.4; three-dimensional 8-node brick elements were used for the asphalt layers, the steel reinforcement was modelled using 3D beam elements; the modelled portion was 500x500x230 mm (Fig. 7). The comparison between the stress levels of both the reinforced and unreinforced specimens obtained from the FEM analysis and those obtained from laboratory tests shows a very good agreement.

The model allowed the estimation of the stress trends within the specimens and a comprehensive understanding of the steel mesh working: the reinforcement system supports the load differences and also constrains the stress on the lower surface. By observing the restriction of the stress areas close to the bars, the FEM analysis implies another important result: the bars play the highest contribution to limit the strain, while the netting plays more the role of connection and load distribution.

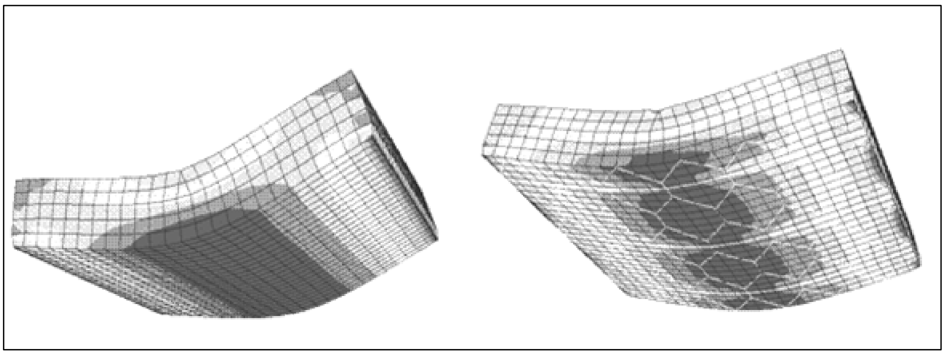

Fig. 7: Unreinforced and reinforced modelled pavements at Parma University

4.5.2 Field tests

The experimental work investigated the efficiency of the reinforcement in the pavement rehabilitation two years after installation: the deformations induced by the vehicular loads on the reinforced section are at the higher temperatures about 46% and at the low-medium temperatures about 30% lower than the unreinforced ones. This leads to the statement that steel reinforcement in a surface position increases the fatigue life of the asphalt pavement. The visual analysis of surface cracks confirms this thesis: the mobile mapping analysis of pavement surface shows a significant difference in the reinforced pavement, with a reduction of surface cracking of 65%.

4.6 Palermo University (I)

Rutting in flexible road surfaces is mainly caused by the accumulation of plastic deformations, as a consequence of the action of heavy loads on the road surface. In some cases, such as cross roads or bus stops, the tangential actions caused by wheels can determine effects that are more severe than vertical ones; this is also due to the incapacity of the bituminous conglomerates to elastically respond to such stresses.

In this research an elasto-plastic FE model (ANSYS) of a flexible road surface structure subjected to the action of heavy vehicles during the braking and accelerating phase was analysed (Tesoriere and Ticali, 2004). Different possible condition of work have been studied for the paving, comparing the shear stress distribution between a traditional unreinforced paving and one reinforced with steel mesh placed at the interface between binder and wearing course at 5 cm depth.

4.6.1 Finite element modelling with ANSYS

A pavement structure subjected to the tangential actions due to vehicles braking and accelerating has been modelled through the ANSYS code. The modelled volume is 640x640x830 mm and consists of a wearing course layer (50 mm), a binder layer (80 mm), a base layer (200 mm), a subbase layer (500 mm) and a subgrade soil (fig. 8). The modelling has highlighted that accelerations or decelerations of a heavy load on a flexible pavement may create a plasticizing tensional state, especially when high temperatures are present. The steel mesh reinforcement at the binder/wearing course interlayer allows for a sensitive reduction of tractive forces in the AC layers: positioning steel mesh below the wearing course reduced stresses in the bituminous agglomerate layers by at least 50%.

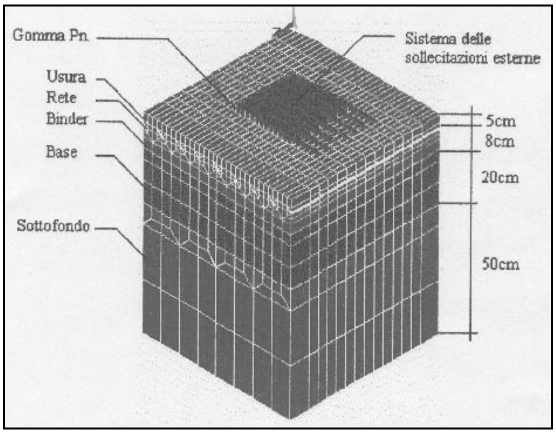

Fig. 8: Modelled reinforced pavement at the Palermo University

4.6.2 Field tests at 2 bus stops

This finding encouraged the continuation of the study with a practical test involving the installation of steel mesh reinforcement in a real pavement at two bus stops in Palermo, where the problem was particularly severe. The two trial sites were setup during the reconstruction works of the wearing course and were fitted with test instrumentation consisting of two strain gauges positioned lengthways and crossways to the direction of movement. Measurements were taken with the strain gauges while a bus travelling at 50 km/h braked at the bus stop, accelerated away from the stop or just passed through the stop.

Comparison of the micro-strain test values for the traditional and the reinforced road paving confirmed the contribution made by the reinforcement to reducing the strains in the asphalt concrete layers. These reductions are particularly significant on the transversal axis to the vehicle's direction of travel, varying from 70 to 80% in the case of braking and accelerating; lengthways to the direction of movement, the mesh produced reductions between 20 and 40%.

In cases where the bus travelled through the stop, the strain gauges measured an equal contribution of the mesh in the two directions, reductions lengthways and crossways were never less than 40%, demonstrating the capacity of the mesh reinforcement to spread loads in the two directions. Results from finite element analysis and test measurements taken during field trials are in perfect agreement and indicate that reinforced road paving can considerably reduce the plasticization caused by these tangential strains, thus considerably increasing the working life of the road surface.

5. CONCLUSIONS

The performances of Road Mesh in asphalt pavements have been thoroughly investigated in the last 10 years through a number of research projects carried out by Universities around the world, finalised to develop an empirical design methodology for reinforced pavements, validate FEM numerical results with tests and field data and eventually evaluate the working life enhancement of a reinforced pavement.

Table 2 shows an overview of the main parameters adopted by researchers for FE modelling.

Table 2: Details of the adopted FE models

University	FE code	Materials Behaviour (1)	Modelled portion (mm)
Nottingham	Capa-2D	VE	400x200x90
Cagliari	Ansys	EP	960x960x770
Virginia Tech.	Abaqus 5.8	VE	560x38000
Catania	Supersap	E	5940x5845x3040
Parma	Abaqus 6.4	VE	500x500x230
Palermo	Ansys	EP	640x830x640

(1) VE=viscoelastic, EP=elastoplastic, E=elastic

The main results of the researches are:

- Nottingham: the fatigue life of a reinforced pavement improves by a factor up to 3
- Cagliari: the reinforcement increases the pavement life by a factor between 3 and 12
- Virginia Tech.: the crack initiation factor is improved by a factor between 1.15 and 3.6
- Catania: the crack initiation factor improvement varies between 1.36 and 1.52
- Parma: the surface cracking is reduced of 65%
- Palermo: stresses due to shear actions (rutting) are reduced by 50%

The large amount of data collected from the worldwide research experiences, have proven that the double twist steel wire mesh, originally developed to inhibit reflective cracking in the asphalt layers, can be designed to effectively enhance the working life of the whole pavement.

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