# Study of a Rehabilitation Method with a Pavement Reinforcement System for Low Volume Roads

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ABSTRACT: This paper presents the first results of an experimental study aimed at evaluating the effectiveness of a rehabilitation method for low volume roads. The method suggests the usage of a steel reinforcing netting in order to improve the performance. It consist in reconstructing the surface layer placing a steel reinforcement in the interface between the new binder layer and the existing base course. This reinforcing method aims at making a road possibly support a sudden increase of number and load of vehicles quickly and with a modest maintenance. The research considered the problem from three points of view: real scale, by constructing and monitoring an experimental section; reduced scale, with laboratory tests reproducing the situations recorded in the experimental section; a finite element modeling using all the so gathered results. The findings show that although the steel netting is placed in the top layers of the pavement, it is still able to improve its resistance and its strain energy absorption ability consequent to the vehicles transit.

KEY WORDS: Pavement reinforcement, steel net, low volume road, maintenance.

## 1 INTRODUCTION

In its definition, a local road must assure comfortable driving to a limited number of users. Therefore, the plan and construction guidelines need only to fix a long-lasting, easy and fast to maintain and not too expensive solution.

The terms of the problem can change completely, if, for several contingent reasons, what was thought and constructed as local road experiences suddenly increase in its traffic volume and loads. A typical example is when a new road or railroad infrastructure needs to be constructed in the open countryside or close to important means of communication. The consequent problem is how to quickly improve the overlay bearing capacity. In fact, the situation requires immediate solutions without closing the road to traffic for a long period.

This work studies the possibility to solve the problem by using a steel reinforcing system for flexible road pavements. In particular, the solution under analysis provides the placement of a double twisted steel wire mesh in the interface between the base course and the binder layer 8 cm below the pavement surface. Therefore, the reinforcing netting may be placed during superficial maintenance, that is to say in case of overlay works.

In order to evaluate the effectiveness of this solution, experimental sections have been constructed and instrumented, laboratory tests have been performed and the results have been combined with a finite element modeling.

## 2 OBJECTIVES

This research aims at evaluating the effectiveness of the rehabilitation by placing a steel netting in the interface between the existing base course and the new binder layer during rehabilitation works (wearing course + binder layer). The netting, with a double twisted, hexagonal mesh not bigger than 8 and 10 cm, was sewn with a wire (2.4 mm diameter) and reinforced with bars (4.4 mm diameter) placed regularly at 16 cm one from the next one. The research analyzed the effect of the work on the pavement as regards with the increase in strength and in load distribution, by comparing the performance of reinforced and unreinforced cases.

The study developed in the following steps:

- construction of an instrumented experimental section for real scale observation;
- laboratory study, based on the results of the experimental section;
- numeric modeling of the pavement with and without steel reinforcement;
- analysis of the results and first evaluations about the effect the steel reinforcement has on flexible road pavement performance.

## 3 EXPERIMENTAL SECTION

The research assumed as template the real scale pavement-reinforcement. The reasons were two: to understand correctly the phenomenon and to use the results as base for the laboratory testing. Therefore, two consecutive road sections have been constructed with a pavement with 3 cm of wearing course, 5 cm of binder layer and 15 cm of base course. The steel reinforcement has been placed in the base/binder layer interface of one of the two sections.

The netting has been then placed about 8 cm below the pavement surface: depth equivalent to the pavement thickness usually milled and reconstructed in ordinary maintenance works.

In order to monitor vehicular loading, temperature and deformations in both sections, the survey provided the placement of:

- 2 loading cells 10 cm deep, on the trajectories of vehicles, so to obtain their weight measuring;
- 3 thermocouples to measure the temperature of the pavement layers at different depths;
- 16 strain gauges 100 mm long, placed orthogonal and longitudinal to the driving direction;
- 6 strain gauges 0.6 mm long, placed on the reinforcing mesh and 4 on the bracing bars.

The measuring instruments have been set to monitor the effects of the rehabilitation works (new surface layer plus netting) on the base course, which is what “left” from the already existing pavement structure.

The collection of data have been systematic and is still going on, monitoring the effect of temperature and environmental condition changes.

The first results obtained from the back analysis of these data is the size of the phenomena.

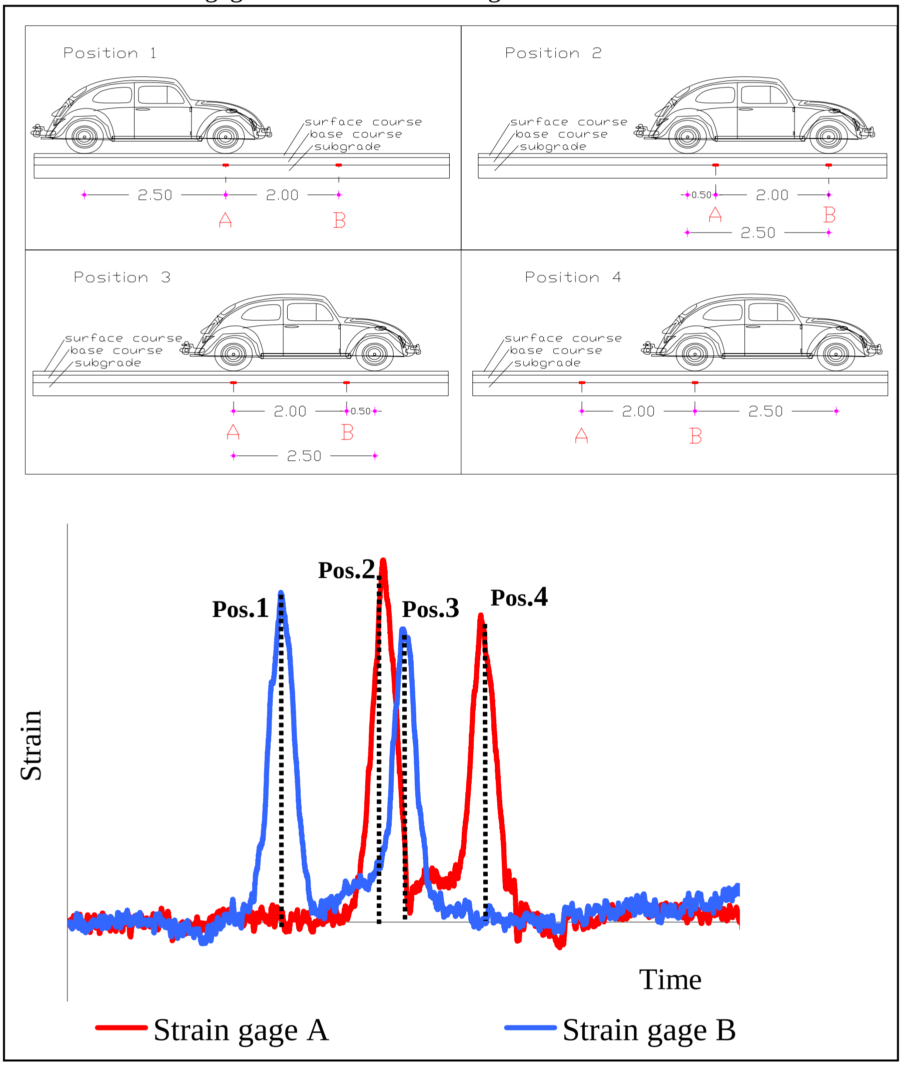
Considering the reading of the couples of strain gauges aligned on the same driving direction, when a vehicle drives on Figure 1:

- When the forward tire is on the first strain gage, sgA in Figure 1, the second strain gauge, sgB in Figure 1, does not show any deformation (position 1 in Figure 1)
- When the forward tire is on sgB and the back tire is closer than 50 cm to sgA, sgA does not show any deformation.

It was deduced that, in case of applied load, the effect of the netting reinforced pavement is limited to a 50 cm wide area.

10 months after the opening to traffic of the experimental section, and the start of the data surveying, the most frequent temperature relieved was about 25°C. Other two temperature, 9°and 45°C, was relieved with a significantly frequency but without the necessary repeatability to allow the generalizations of the respective pavement conditions. Vice versa relevant number of 25°C data permits to remark that the net induce a strain reduction, measured at the base-binder layer interface, equal to 25÷30%.

FIGURE 1 - Strain gages measurements during the transit of a vehicle




## 4 LABORATORY ANALYSIS

The laboratory study aimed at reproducing on reduced scale what really happens in the flexible road pavement structure with a steel netting. Real scale observations helped deducing the maximal size of the mesh and of the area affected by the netting when supporting a load. Hence, the proper laboratory sample was thought to be a square of a side length 50 cm. The samples resulted then as thick as the ones used in real road works. To prepare the samples, a proper compactor has been set (Figure 2), which was able to thicker the mixture as the roller would compact it during road construction works. This equipment is made up of a cylindrical horizontally pivoted steel cap upon which a 3 ton maximal load hydraulic press is placed. Below the press, a mobile basement is placed with the formwork containing the material. The formwork moves and the pivoted element applies a given pressure, so to reproduce the same forth-and-back movement the compacting roller exercises on the course. Two series of samples, with and without netting, have been prepared following this procedure. The first series was 23 cm thick (Figure 3) and reproduces the situation of the testing base: a 15 cm thick first layer with a material similar to a base course and a 8 cm thick second material similar to the “surface layer”. The second series was 8 cm thick (Figure 4) and reproduces only the surface layer. In this case, greater importance was given in distinguishing the first 5cm thick layer of material similar to the binder layer from a 3 cm thick second material similar to a wearing course. Some of the blocks of the first series have been instrumented, as in the testing field, by positioning strain gauges both on the mixture and the netting in the interface between base/binder layer. The experimental phase provided a first series of displacement control tests (compression tests, Figure 5, and 3-point bending tests, Figure 6), in order to determine the maximal resistance of the pavement blocks. A second series of test (only compressive tests), force control tests, aimed at evaluating the material deformations in the interface between base and binder layer. Both test series were conducted at 25°C temperature, according to the temperature surveyed in the experimental section. A second phase of laboratory analysis will made as soon as the in situ data collected will give other reference temperature. In the compressive tests, a layer of neoprene has been placed between the sample and the supporting plate, in order to simulate the possible deformation of the sub grade. The experimental measuring of the deformation module of the neoprene when the thickness changes helped determining the thickness of the layer necessary to obtain the same deformation module that might be obtained carrying out a plate-bearing test on the pavement sub grade during road construction works.

FIGURE 2-Heavy compactor

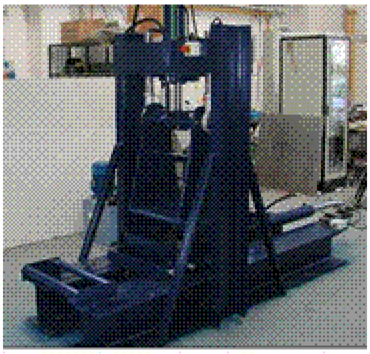


FIGURE 3 - 23cm-thick specimen, wit the strain gauges setup

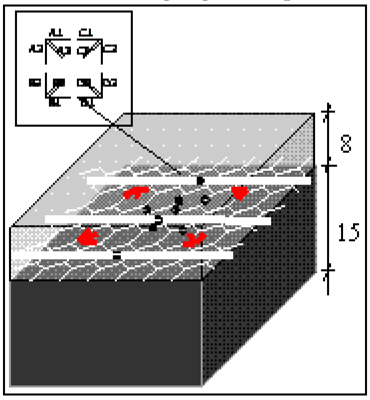



FIGURE 4 - 8cm-thick specimen

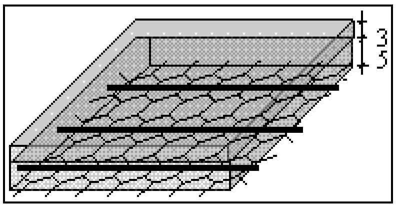



FIGURE 5-Central compression test with 23cm-thick specimen

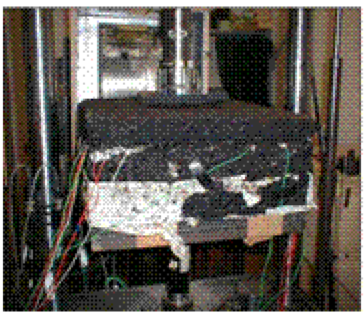


FIGURE 6 - 8cm-thick specimen 3-point bending test

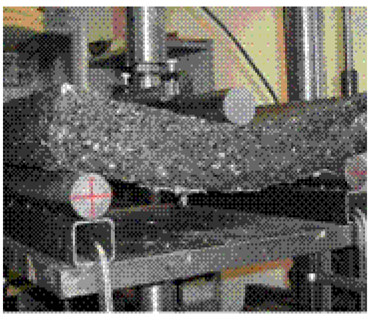
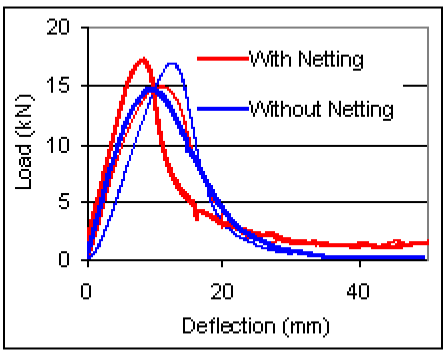


FIGURE 7 - Load/deflection curve in the 23cm-thick specimen 3-point bending test



4.1 Displacement control test

3-point bending tests have been carried out on 8 and 23 cm thick samples, with and without netting, realized applying a vertical load in the middle section at 50.8 mm/min according with the test for the tensile strength determination. The results of failure tests (Figure 7) on 23cm-thick sample, show that the samples with and without netting provide the same maximal resistance and that a few different appear in the post-fracture resistance where the specimens with netting are able to furnish high post-fracture resistance.
The results of failure tests on the wearing and binder layers (8-cm thick samples) surface show that the netting is able to furnish high post-fracture resistance even without affecting the maximal resistance. Besides, the presence of the netting allows the layer to absorb much more fracture energy (65.66 J with net and 35.92 without net) Moreover, the sample with the netting shows an asymptotic behavior in the post-fracture phase. On the contrary, the sample without the netting keeps on losing resistance ability failing.

FIGURE 8 - Load/deflection curve in the 8cm-thick specimen 3-point bending test

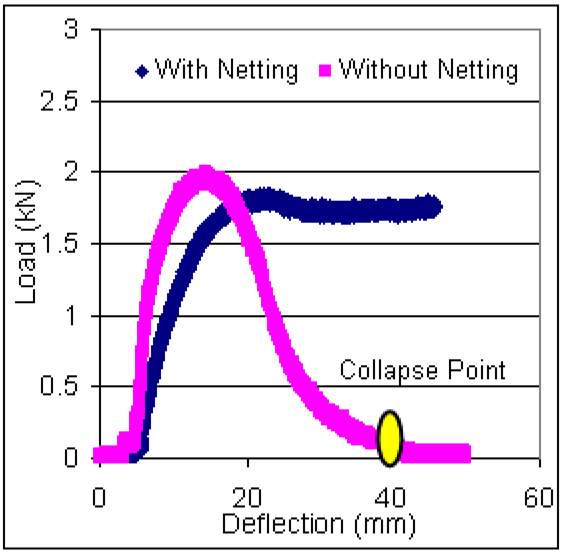
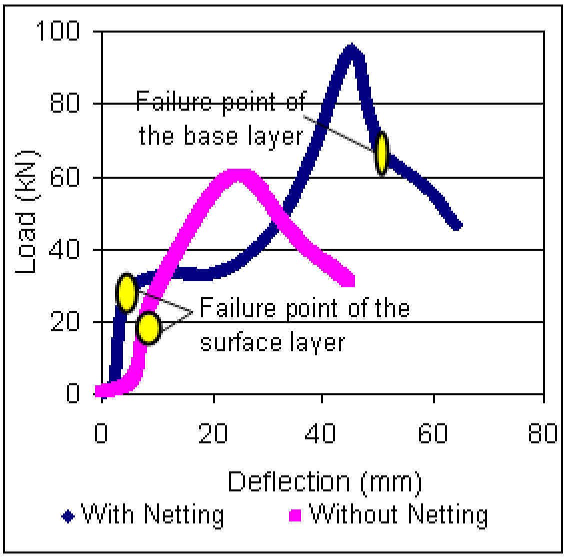



FIGURE 9 - Load/deflection curve in the central compression test




It is evident in Figure 8, where the discontinuity corresponding to the deflection at 40 mm shows that the material collapses losing instantly its resistance ability. The same energy absorption ability, observed in the fracture tests on the surface layers with the netting, can also be found in the fracture tests on the whole pavement (23 cm thick samples) (Figure 9): also in this case, irrespectively to the maximal resistance reached, the presence of the netting is able to furnish post-fracture strength. Comparing the surface layer to the whole pavement block, the entity of the post-fracture strength, that can be defined as residual strength, is noticed to have substantially the same value; it must be underlined that also in case of fracture of the whole pavement, the netting improves the energy absorption ability of the surface layer. The netting ability to preserve the surface layer can be also noticed at the end of the test (Figure 10 and Figure 11): with the netting, the 8 cm thick sample results deformed, but not destroyed. The same occurs in the 23 cm thick samples. The netting kept the binder and base course cohesive also after fracture. After the bending tests on 23 cm thick samples, some compressive tests (central compressive test) have been performed, applying the load on a circular area, with a 10 cm diameter, in the middle section of the sample, according to the tensile strength test. As the results of Figure 12 show, when such stress occurs, the reinforcing netting is very helpful both to the surface layer and the whole pavement. In the sample with no netting, excluding a slight decrease in rigidity in the fracture point of the surface layer, the behavior of the pavement is overall homogenous: all layers resist until they reach the maximal resistance and then collapse at the same time. In the sample with the reinforcing netting, the pavement keeps cohesive, but the layers work separately: first the surface layer exhausts its resistance (already significantly improved thanks to the netting), then, the still substantially untouched resistance of the base course plays its role. This fracture mechanism leads to a high improvement of the pavement resistance: the fracture load increases by about 60 kN to about 95 kN. The two different failure modalities can be attributed to the net: it leads a separation between the layers without a cohesion decrease (this is the same property used in the reflective cracking prevention). Besides, it is also able to make the material right below the loading area work together with the adjacent material, increasing the plate behavior of the pavement.

FIGURE 10-8cm-thick specimen with net after failure

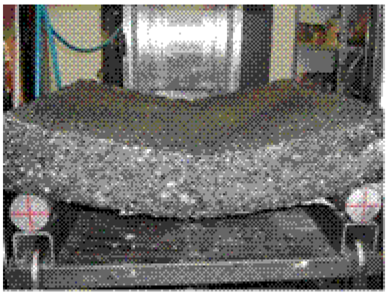
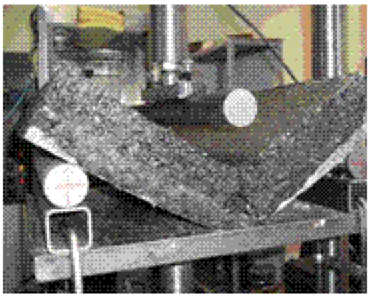


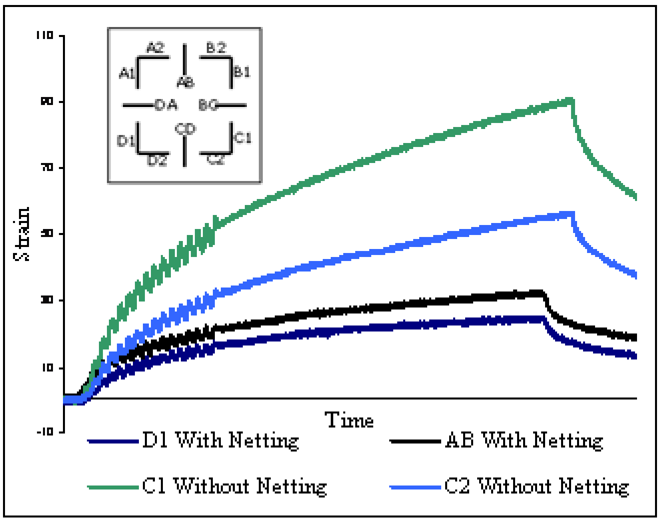
FIGURE 11-8cm-thick specimen without net after failure



## 4.2 Force control tests

Some force control compressive tests have been carried out on 23 cm thick samples, set up as the displacement control tests, in order to reproduce a stress similar to what the real pavement needs supporting. The scope was to individuate the fracture behavior of the pavement with a netting, to be used as reference for finite element modeling. The loading application modalities have been here deduced analyzing the first results of the experimental section (Figure 12).

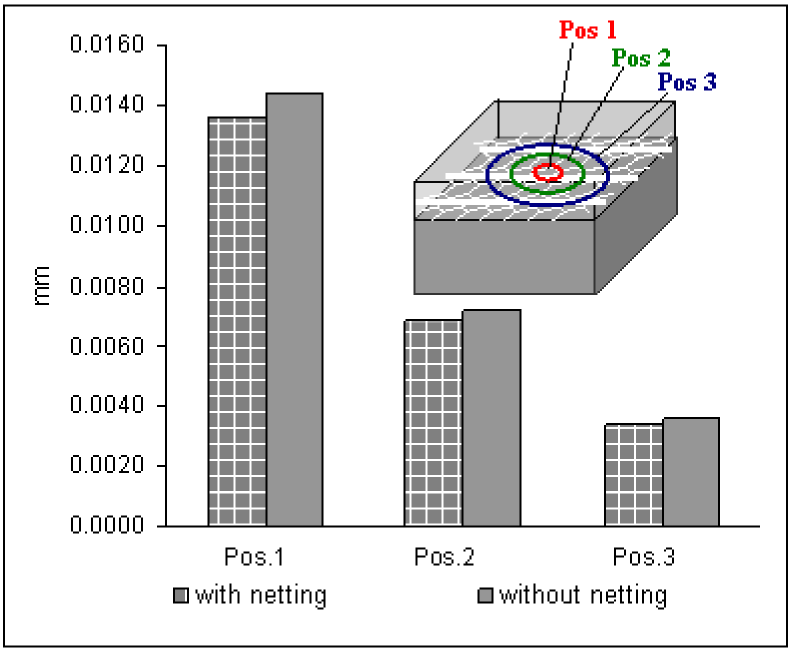
FIGURE 12 - Load control central compressive test



5 NUMERIC MODELLING

The third aspect the research deals with is the numeric modelling of the problem. Basing on the results of the laboratory tests, a finite element model has been elaborated, using ABAQUS. The three-dimensional model reproduced both the situation actually occurring during the tests, where the layers of different material have been modeled assuming as vinculum some elements able to simulate the real limit of the material during the road works, and the pavement blocks built in laboratory.
The various materials have been numerically simulated using three-dimensional elements named *Brick*. Netting has been schematized composing circular section *Beam* elements.
The materials were assumed having a elastic plastic behavior introducing a cohesion coefficient C of 3MPa.
The mechanical characteristics of materials for the numerical modelling of 3 point bending test (23cm-thick specimens) and of central compression test (8cm-thick specimens) at the temperature of 25°C follow:
Base Course: 2.24 kg/dm3 density, 1600 MPa elastic module and 0.35 Poisson coefficient, friction angle 43°
Binder Layer: 2.34 kg/dm3 density, 1800 MPa elastic module and 0.35 Poisson coefficient, friction angle 43°
Netting: 200000MPa elastic module.
Both type of tests have been numerically simulated in displacement control with the same load application law of the SHRP Indirect Tension Test (5.08 mm/min).
The values of the deformations have been particularly analyzed when occurring in correspondence to the load axe in the interface between base and binder layer and in points related to the positions of the strain gauges in the blocks built in laboratory.
The results of the modelling are illustrated in the histogram of Figure 13.

Figure 13-FEM deflection values with and without net




This modeling leads to results consistent with the laboratory tests and is possible to note that the deformations in the block with no netting are higher than the correspondent deformations calculated for the block with the netting in all the three positions analyzed. The net reduces the stresses about 2 kg/cm$^2$ after 30 sec. after test starts (Figure 14).

This performance improvement leads to the hypothesis that the double twist reinforcement can improve the pavement fatigue resistance.
3 point bending test numeric modelling of the problem has been elaborated to understand the real performance of the net in the asphalt mix during the load time, and to appreciate how the hexagonal mesh and reinforced bars work in the pavement.
According to Figure 15 the numeric modellings lead to see the different performance that hexagonal mesh and reinforced bars can carry on when they are working.
The mesh spreads the tensions to the surrounding pavement and the very rigid bars absorb the just spread tensions. Figure 15.

FIGURE 14 – Central compression test FEM model results: strain A) with net, B) without net

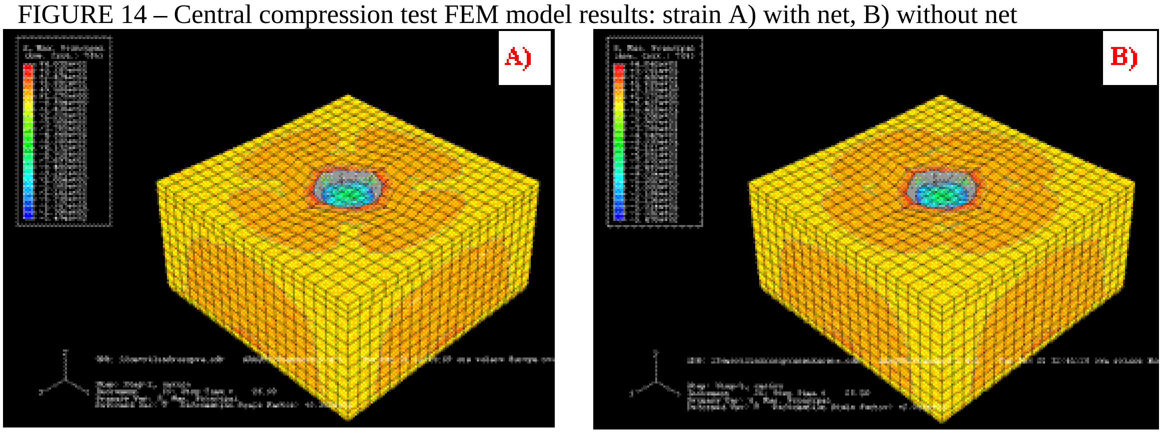
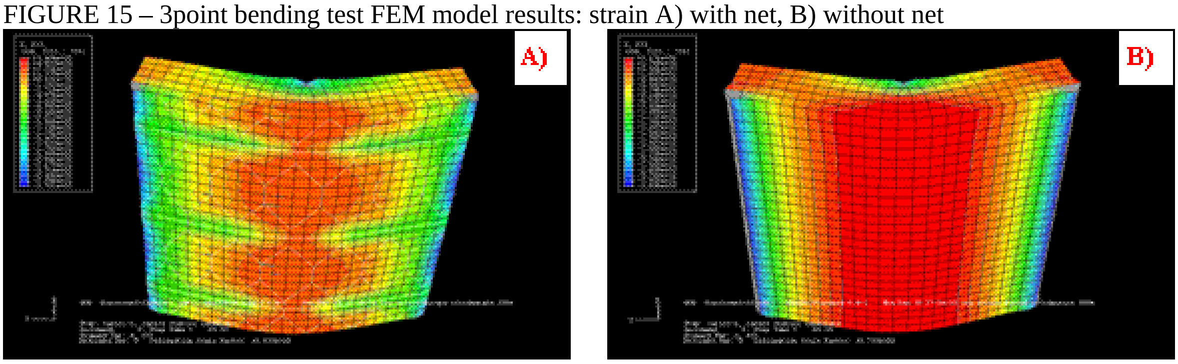



FIGURE 15 – 3point bending test FEM model results: strain A) with net, B) without net




## 6 CONCLUSIONS AND NEXT STEPS OF THE RESEARCH

The experimental work investigated the effect of a double twisted netting in the asphalt pavement, in the hypothesis a rehabilitation method for low volume road. The research has been supported from an experimental section, a laboratory analysis and a FEM analysis by ABAQUS.
From the results obtained at this point of the work in the experimental stretch, it can be concluded that asphalt blocks of 50x50 cm dimensions are suitable for a scale laboratory study.
The tests performed using different height specimens let to the following conclusions about the effects that the double twisted steel wire mesh gives to the pavement:
• a residual strength in the surface layer, that allows the layer to absorb much more fracture energy;
• a plate behavior which increase the compressive strength due to a concentrate load.
The finite element analysis showed that, at the same load, the net presence causes a strain value decrease in the base/binder interface; this might increase the pavement fatigue strength.

The research work will keep on developing the experimental section, the laboratory tests and the numeric modeling at the same time.
The experimental section provided an adequate number of data to allow the elaboration of a reinforced pavement modeling which leads to the following results: the deformations in the block with no netting are higher than the correspondent deformations calculated for the block with the netting and it's evident the difference between the performance given from hexagonal mesh and reinforced bars.
Regardless the experimental section, the surveying, in different environmental and solicitation conditions, will first aim at providing an adequate number of data to allow the elaboration of a modeling for reinforced pavement. The second and middle-term objective is to verify directly the hypothesis at the base of the research, that is to evaluate the effectiveness of the steel reinforcement placed in the interface between base and binder layer.
In particular the first data collected in the experimental section at 25°C shows a pavement performance increase related to reinforcement use (25÷30% strain decrease): the laboratory research confirmed that the pavement with netting is able to increase the performance of asphalt pavements.
The laboratory tests and the numeric modeling will aim at comparing the performance during the works and in terms of fatigue resistance of reinforced and unreinforced pavements.
The complete analysis of the results will conclude with the evaluation of costs and benefits to rehabilitate low volume roads following this method.

## ACKNOWLEDGEMENTS

The Authors would like to thank the Parma Provincial Administration and the Officine Maccaferri S.p.A. for the support in this research. Also, a special thanks to Nicholas C. Reck, Elena Romeo and Marco Vicari for the important suggestions and the scientific support during the work.

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