# A SURFACE STEEL REINFORCEMENT FOR ASPHALT PAVEMENTS USING 3D FINITE ELEMENT MODEL

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## ABSTRACT

In this research the authors study the effect of steel reinforcement in asphalt pavement according to three dimentional finite element simulations. In particular, the asphalt pavement with and without steel reinforcement was studied in a static load condition. The modeling simulates the exact geometry of steel reinforcement interlayer and the hot mix asphalt as a viscoelastic material that changes its mechanical performances according to the temperature and thermal sensitivity of the mix asphalt concrete used in laboratory tests. The comparison between modeling and laboratory test results confirmed the three dimensional finite element model (3D-FEM) consistency. The analysis shows the effect in the pavement layers of steel reinforcement in terms of strain field variation in comparison with unreinforced pavements. This numerical simulation allows to identify the advantage this reinforced location can induce in the performance of asphalt pavement.
*Keywords: reinforced pavements, steel mesh, 3D-FEM analysis*

# 1. INTRODUCTION

One of the recent suggestions in asphalt pavement technology is to insert a reinforcement system among pavement layers. Initially, the idea to insert a net in the pavement layers interface was thought up as antireflective cracking system. In a second time, some authors, Brown (2001), Al-Qadi et al. (2003,a), took into account the mechanical contribution of nets and started to investigate their structural effects. Following this concept, some companies began to produce different pavement reinforcement nets: fiber glass grids, polypropylene grids, steel net, etc..

Generally, the nets used to enhance the pavement performance are inserted between the base layer and the sub-base layer. Recently, some researchers from the University of Parma (Montepara et al. 2005,a) proposed to use a steel reinforcement net in a more superficial position as a maintenance method: the idea is to place the reinforcement between the binder layer and the base layer during a rehabilitation work, without demolishing the entire pavement.

This paper presents a 3D-FEM to investigate the reinforced pavements behavior with surface steel net making a comparison between reinforced and unreinforced pavements. The model has been made thinking to pavement as a three-dimensional structure, so the layer has been modeled without taking into account its macrostructure, but considering its overall mechanical behavior.

# 2. GOAL AND METODOLOGY

The main goal of this research work was to evaluate stress and strain in a flexible pavement with and without steel reinforcement. Following previous experimental experiences (Montepara et al. 2005,b), it takes into consideration a laboratory test (three point bending test) performed on 50x50 cm rectangular plates. The size and the characteristics of the specimens used in the considered three point bending tests (3-PB Test) are designed to prevent the size of the netting mesh from generating scaling effects (Fig. 1). At the same time, they are also meant to help emphasizing the plate behavior induced by the reinforcement. The decision to make a two-layers specimen has been taken in order to make it the most representative as possible of superficial layers of real pavement.

In the simplifying example of viscoelastic material, we carried out some laboratory tests in order to detect the temperature range that validates the underlying hypothesis.

The materials used in the experimental steps (binder and wearing course) have been submitted to complex modulus tests following the AASHTO 2002 methodology. Considered the types of bituminous mixture used, the tests showed a viscoelastic behavior at a temperature ranging from 5°C to 25°C. In the light of these evidences, the complex moduli have been modeled implementing the finite elements in Abaqus under the hypothesis of viscoelastic material.

The comparison between the data recorded in the laboratory tests and the results of the modeling in terms of deformations show a good consistency.

By way of example, here follows the comparison between the deformation wave recorded in the laboratory tests on the binder layer at the T= 21°C and at the frequency of 0.1 Hz and the deformation calculated by the numerical analysis as regards viscoelastic material (Fig. 2).

Defined the range of temperatures in test, the laboratory tests could be further carried on. Three point bending tests with load application of 5.04 mm/min have been carried out on bituminous mixture plates with and without reinforcement at the temperatures of 5°C and 25°C. The plates made up of a 5cm-thick binder layer and 3cm-thick wearing course stand for the real superficial layers of a road pavement.

The experimental survey produced the results in Figure 3,4.

The results of the failure tests on the surface, wearing and binder layers show that the netting is able to furnish high post-fracture resistance to the asphalt pavement at all temperatures. Regardless the maximal resistance, it was observed that the steel reinforcement is able to increase it and that the more evident the growth, the higher the test temperature.

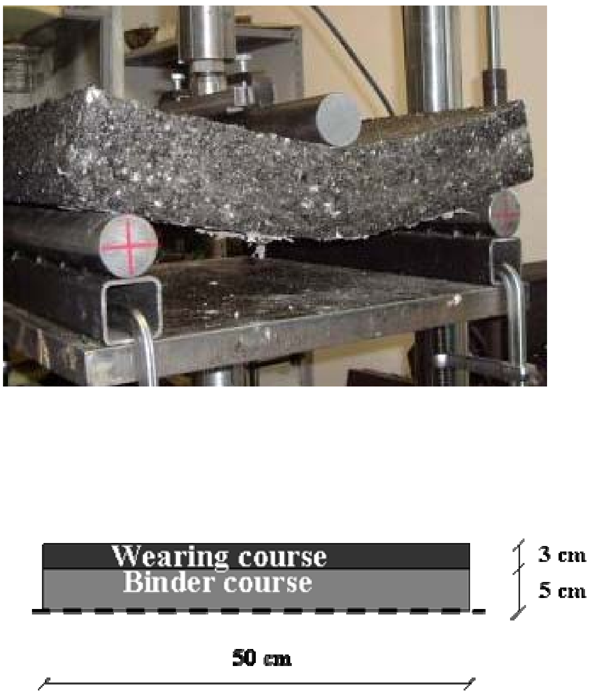


**Figure 1 3-PB Test**

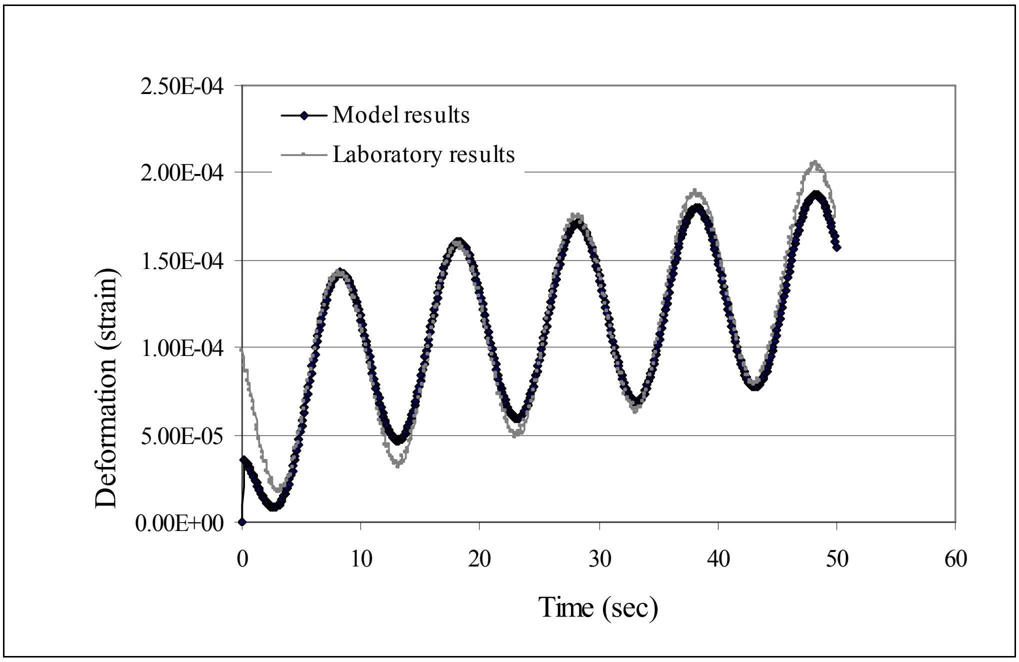


**Figure 2 AASHTO 2002 Test**

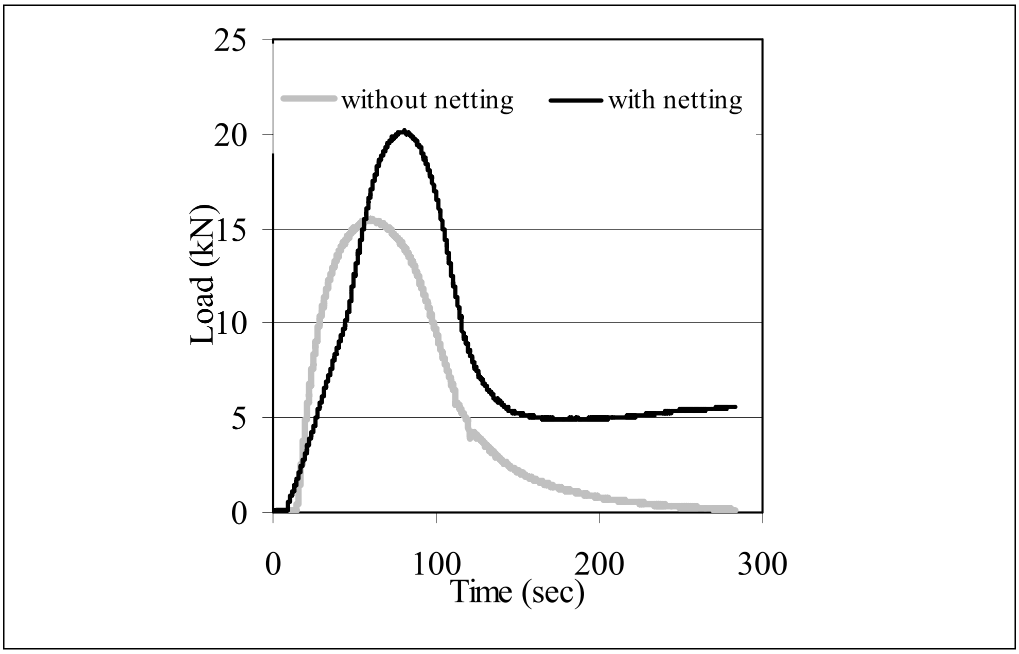


**Figure 3 3-PB Test results at 5°C.**

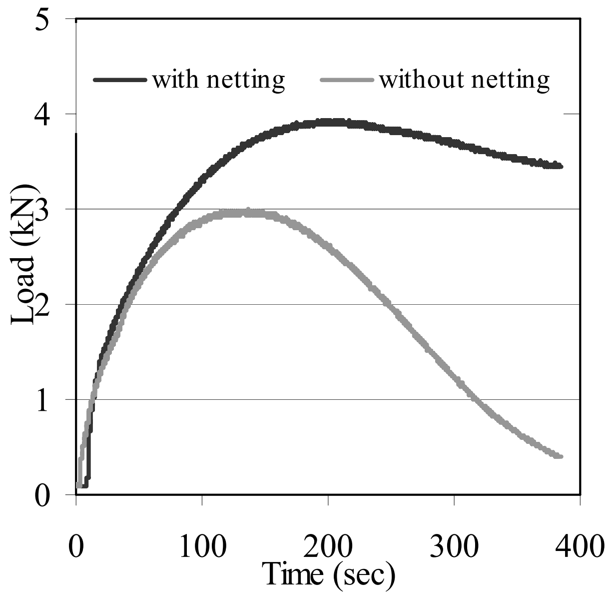


**Figure 4 3-PB Test results at 25°C.**

# 3. NUMERICAL MODELLING

## 3.1 Geometry of the model

Following some important analyses taken from the literature (Thom 2000), (Elseifi et al. 2003,b), (Uddin et al. 1995), (Uddin et al. 2000) the modeling has been developed using the program ABAQUS 6.4.

In order to simulate the two different asphalt layers, three-dimensional 8-node brick elements C3D8 have been used (Fig. 5). To model a 50cm x 50cm x 8 cm specimen, the mesh is 2cm x 2cm x h, where h is the layers thickness. Moreover, to increase the accuracy, the mesh had been thickened in the load application area.

The steel reinforcement has been modeled using three-dimensional two-node beam elements B33, characterized by 6 degrees of freedom (DOF) for each node, of which three translational and three rotational. Each element is related to a beam section property, which defines the material associated to the element and the profile of the section of the element itself. To define the behavior of the cross section, the solid cross section has been chosen. Consequently, the beam geometry has been modeled choosing circular sections with the same size as the real reinforcing netting (2.4 mm for the netting diameter and 4.4 mm for the bar diameter).

All beams have been created on a single surface in order to simulate the interaction with the bituminous mixture and the three-dimensional behavior of the netting.

The decision of using beams ensues from the fact that the transmission of axial stress only has not been rated sufficient to model the netting: in fact, the reinforcement may be put under great bending stresses especially when the bending test reaches great curvatures (Uddin et al. 2000).

We proceeded modeling the contacts between the surfaces enjoining the same deformations of the surface over the binder layer, which is set as master surface, as in the surface below the slave. In fact, the first analysis of the laboratory tests showed a fully bounding behaviour between the layers.

After the FEM modeling of the specimen, we proceeded with the test simulation.

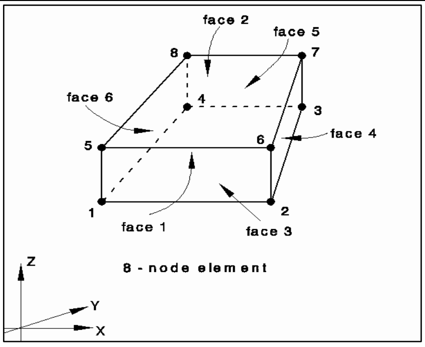


**Figure 5 8-Node brick element C3D8**

## 3.2 Types of analysis

Taking into account the results of laboratory materials characterization, only the viscoelastic behavior has been modeled.

The parameters required by the program (ABAQUS 6.4) for this type of analysis are $g^*_{real}$, $g^*_{imm}$, $k^*_{rea}l$ e $k^*_{imm}$. For each frequency, we used the values of the dynamic modulus and of the phase angle to obtain these parameters using the following equations:

$$g^*_{real}=G_{0real}/G_0 \tag{1}$$

$$g^*_{imm}=1-G_{0imm}/G_0 \tag{2}$$

$$k^*_{real}=k_{0real}/k_0 \tag{3}$$

$$k^*_{imm}=1-k_{0imm}/k_o \tag{4}$$

The value of the shear modulus $G_0$ related to the elastic modulus E0 is given by:

$$G0=E0/2(1+\nu) \tag{5}$$

Where ν is the Poisson coefficient (literature value) equal to 0.35. Since it is a complex relation, it may be factorized in real and imaginary part, obtaining $G_{0real}$ and G0imm from the components $E_{real}$=E*cosδ and $E_{imm}$=E*senδ of the complex modulus (δ is the phase angle). The value $G_0$ is the long- term shear modulus.

While G is the shear strength, k gives an indication of the compressibility of the material. The higher the value, the more compressible the material. The procedure to obtain $k_{0real}$ , $k_{0imm}$ and $k_0$ is similar to what followed for the shear modulus. The only difference is that, in this case, the starting point is the link between elastic and Bulk modulus, obtained from the relation:

$$k_0=E_0/3(1-2\nu) \tag{6}$$

## 4. EVALUATION OF NETTING CONTRIBUTION

The effect of the netting contribution has been evaluated comparing the bending stress of the material obtained by the 3-PB Test simulations on reinforced and unreinforced specimens at the reference temperatures of 5°C and 25°C.

### 4.1 3-PB Test

To simulate the three point bending test, we modelled also a steel cylinder, which applies the load. Also the static law has been set directly on the cylinder (Fig. 6).

The comparison between reinforced and unreinforced specimen underlines a re-organization of the bending state induced by the steel netting mesh (Fig.7-10). In particular, the area close to the axis where the load is applied shows a distribution effect, whose first consequence is a consistent reduction of the area interested by the maximal bending. All this is even more evident at the temperature of 25°C.

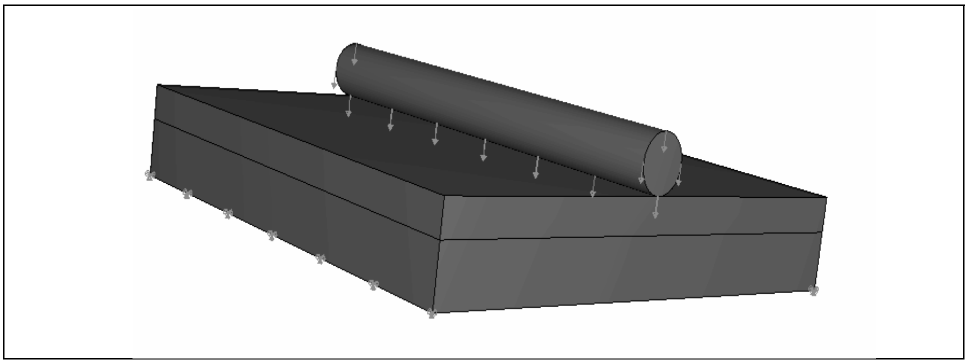

**Figure 6 Three point bending test simulation**

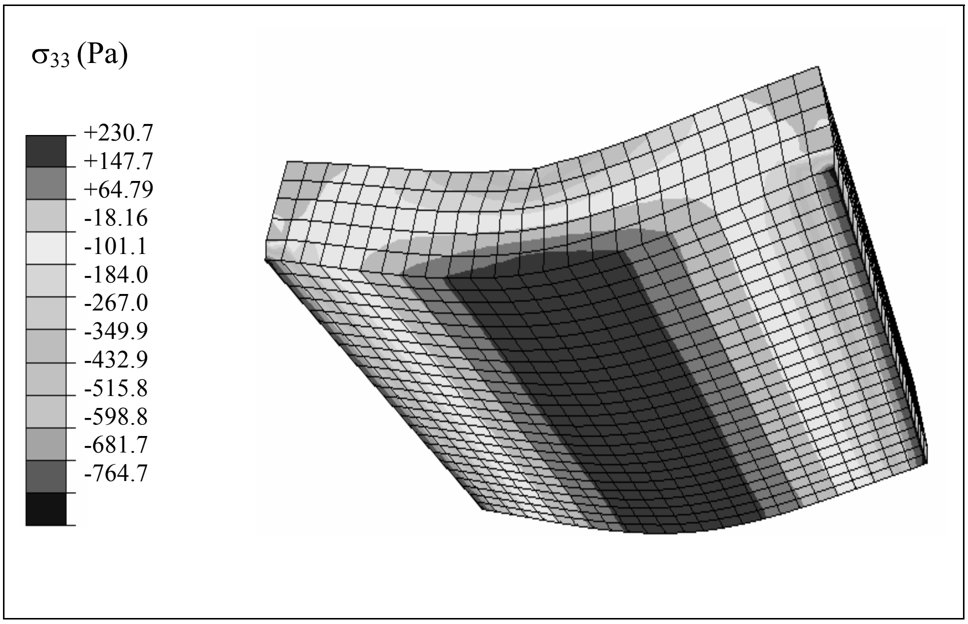


**Figure 7 Model without netting at 5C° (viscoelastic field): vertical stress**

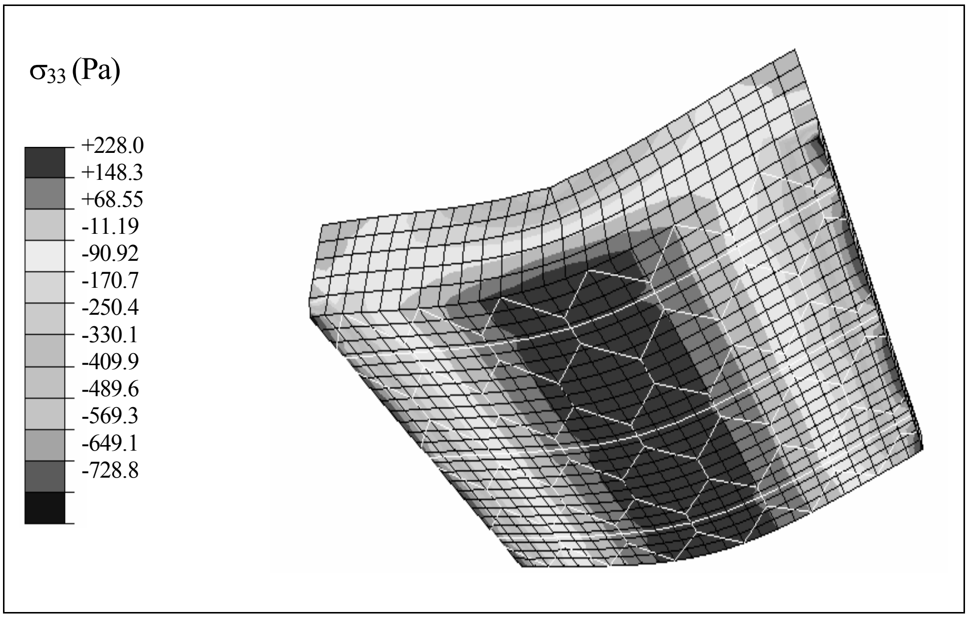


**Figure 8 Model with netting at 5C° (viscoelastic field): vertical stress**

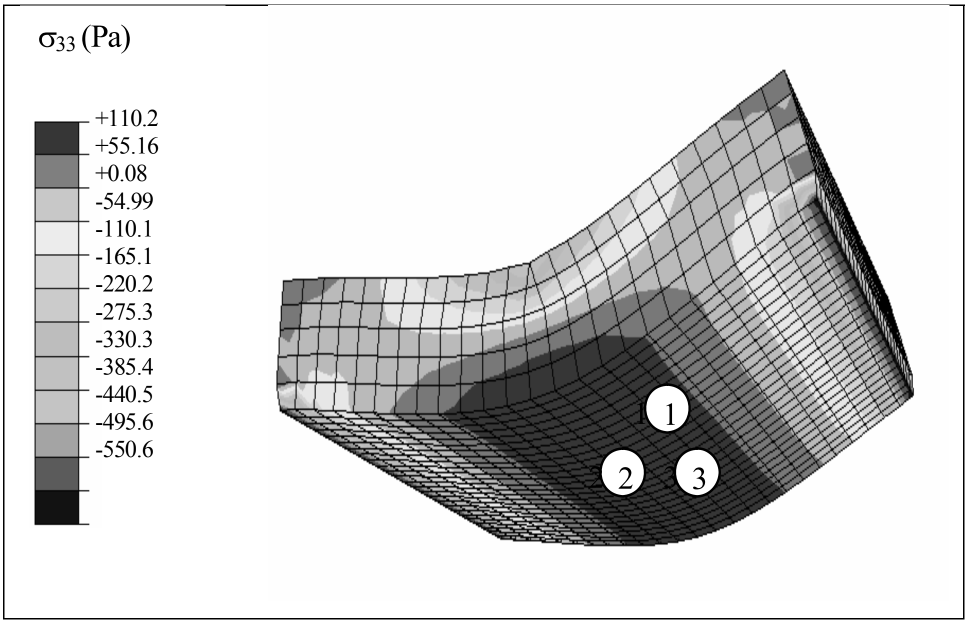


**Figure 9 Model without netting at 25C° (viscoelastic field): vertical stress**

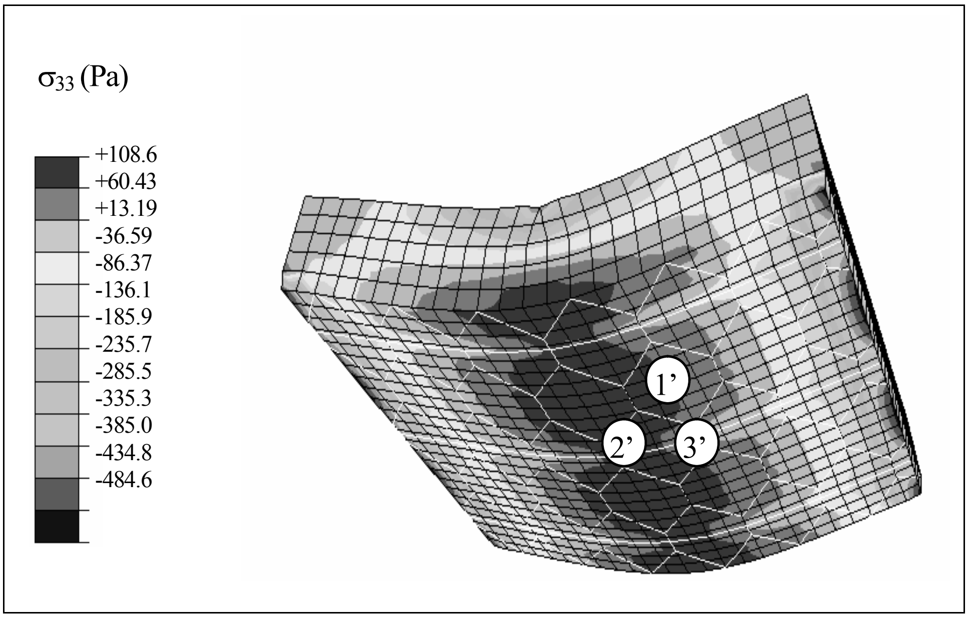


**Figure 10 Model with netting at 25C° (viscoelastic field): vertical stress**

In particular it is observed that the effect enduced by steel net on distribution of the vertical stresses (fig. 9,10), in other words the tensions that are the stresses on the below layers, are higher near the steel stiffening bars and around the hexagonal meshes (Tab. 1). This effect reduces the area of higher stress and slows the loads damage. The post failure strenght, as shown by tests, confirms that. On the contrary, in the specimen without reinforcement the fracture is followed from collaps of specimen. It is possible to see that in the figure 11, where, at the end of the test, in the specimen without net there is a macro fracture that divides in two distinct shares the specimen, while the reinforced specimen preserves the material continuity.

**Table 1. Modeling at 25°C of 3-PB tests Stress reduction**

| **Positions*** | | **Vertical stress reduction** |
|---|---|---|
| **1** | 5 cm near load area | 15% |
| **2** | Under load area near the steel netting | 25% |
| **3** | 5 cm near load area near the steel netting | 50% |
| * Point refered to Figure 9 and 10 | | |

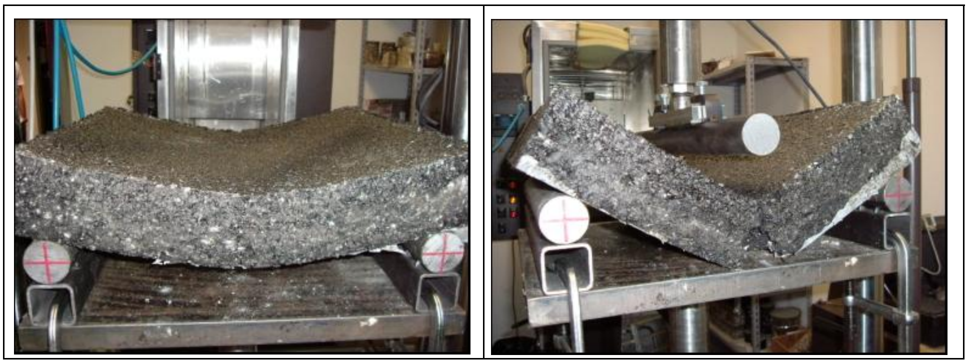

**Figure 11. Specimens after the failure.**

## 5. CONCLUSION

This paper presents a numerical analysis evaluation of the efficiency of a steel reinforcement net placed between the binder layer and the base layer in order to provide a good support to the pavement design.

In order to achieve this goal, it is essential to verify the accuracy of the proposed modeling by comparing the experimental results obtained in laboratory tests and the numerical analysis.

Both results show that at each temperature an improvement of the global mechanical behavior is reached. This is mainly due to the following elements:

•At 5°C, the stiffness of the asphalt mixture does not allow the reinforcement to be totally effective; moreover there is no correspondence between an increase in maximum strength and an increase in deformability:

•At 25°C, the asphalt mixture performances decrease allowing the net to work by increasing both the maximum strength and the failure strain;

At the same time, the finite element model developed is able to estimate the stress decrease due to the presence of the reinforcement. On equal loads, the strains in the specimen without netting are larger than the ones in the reinforced specimen. Besides, on equal strains, the qualitative trend of stresses in the specimen without net are larger than the ones in the reinforced specimen. Finally, the great contribution of the bars on the stress state decrease. This is highlighted by the fact that the steel net distributes the load on a wider area. Therefore, it can be supposed that the reinforcement might be able to increase the fatigue resistance and the pavement service life.

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