Analysis over the use of reinforced flexible pavement with steel mesh in climbing lanes

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ABSTRACT: The growth of the sugar alcohol sector in various regions of the São Paulo state, which has mostly one single lane highways, has motivated businessman in the industry to propose partnerships for the construction of climbing lanes, which would allow the transit of heavy vehicles to flow better in these highways. A review of the literature about steel mesh shows that the use of the same avoiding the appearance of cracks in the layers of asphalt layer, acting as a barrier against their spread keeping the uniform distribution of loads. The objective of this research was to develop this technology for construction and rehabilitation of climbing lanes in order to increase its service life through the use of steel mesh. For this, they were analyzed their performance, based on international best practices, using structural and functional evaluation tests in observing their behavior in a test section.

1 INTRODUCTION

In the late 1980s the Brazilian economy had a marked expansion, and this period was popularly known as “Brazilian miracle”. The demand for road transport infrastructure established strong investments both in the construction of new roads as improving and increasing the capacity of existing roads (Arakawa e Olio, 2006).

In order to improve the service level and reduce travel time and also the cost of operating vehicles and a safer trip can be deployed on the climbing lanes, which are auxiliary tracks built to the right side of the tread upwards specifically for heavy traffic.

The construction is justified when the length of the ramp causes a reduction of 15 km/h or more in speed of loaded vehicles according to AASHTO (1994). When a highway is affected on its level of service with a high traffic volume coupled with high percentage of heavy vehicles, the deployment of additional tracks in specific sections has shown that for cumulative number of equivalent standard axles (ESAs) is a viable option.

On the other hand, the growth of the sugar alcohol sector in various regions of the São Paulo state that has mostly one single lane highways, has motivated businessman in the industry to propose partnerships for the construction of climbing lanes which would allow the release of heavy vehicles, however this type of solution turns out to be very costly to the state ultimately leading it to propose other solutions, especially for the construction of the pavement.

As examples of solutions that allow increasing the load bearing capacity applied to the pavement, one has to introduce the metal screen. The choice of the type to be adopted depends on the way that the pavement is compared to the level of structural and functional quality that is intended to reach. According to Fortes et al. (2011), the main causes of degradation of flexible pavements are the permanent deformation and the appearance of fatigue cracks because of the traffic.

The application of reinforcement in flexible pavements using the steel mesh was initiated in the countries of the north Europe around 1970. According to VTI (Swedish National Road and Transport Research Institute, 2003), after the application in some roads, the potential of the steel mesh was seen as reinforcement for pavements.

Thus, this technique brought the interest of organizations creating investigations as, for example, the project sponsored by the European Union called REFLEX (Reinforcement of Flexible Road Structures with Steel Fabrics you the Prolong Service Life). This project showed interesting conclusions concerning the improvements by the introduction of the steel mesh as reinforcement, based on practical cases of roads in Sweden, Finland and Italy, helping to define guidelines to dimension and execution of reinforcement of pavements with the use of steel mesh.

2 METHODOLOGICAL ASPECTS

A bibliographical survey on national and international specific literature was accomplished presenting the condition of art on the subject. After this analysis, an inspection in the existing experimental section near Campo Limpo Paulista city was made. The conduction of the steel mesh was verified through functional evaluations of the experimental stretch, mapping of cracks, situation of the welded screen, and execution of diggings and also blocking for verifying the condition of the existing layers.

From this first experimental behavior diagnosis of the pavement executed with steel mesh, an analysis by the DER/SP (Department of Transportation of São Paulo) was taken while seeking new stretch where they could apply the steel mesh again but this time to recover additional tracks. We adopted the case study as a research strategy, aiming to apply the steel mesh on a highway that was already in the work in progress.

After analysis of DER/SP staff, it was decided to take advantage of the stretch ahead of the first experiment using steel mesh on Highway Edgard Máximo Zamboto - SP-354. It was then defined the km 68 for the test section, near the city of Campo Limpo Paulista. This section was chosen because of the construction of climbing lanes due to the high traffic of heavy vehicles had already been decided to be built.

3 REVIEW ABOUT STEEL MESH

The use of steel mesh as reinforcement of flexible pavements in general, according to Asphalt Academy (2008), aims to improve the roads giving the pavement a clear benefit for one or more structural features essentially increasing their lifetime use, so that there is an expenditure of less natural resources, as well as becoming more economic.

The application of steel mesh reinforcement is recommended on overlay of bituminous layers in order, essentially, to the control of differential settlements and increased pavement loading capacity according to (Heavy Vehicle Simulator) HVS – Nordic (1998). Investigation in Finland and Sweden has shown that reinforcement of flexible pavements with steel mesh is an economical construction technique to prevent the appearance of longitudinal cracks (Rathmayer et al., 2002).

3.1 *Reflex project*

The REFLEX project (Reinforcement of Flexible Road Structures with Steel Fabrics to Prolong Service Life), funded by the European Union began in March 1999 and was conducted over a period of three years until February 2002. The main goal of the project was to develop a new methodology in construction and restoration of roads using steel mesh, to make the road infrastructure obtain an increase in its useful life, leading to a reduction in the use of natural resources, reducing the need for maintenance, reducing accidents and improving road traffic safety.

Research conducted in Finland and Sweden indicated that the enhancement of flexible pavements with steel mesh is a low-cost method to avoid longitudinal cracks according to Halonen et al. (2000). Field and laboratory testing still showed other applications in the construction and restoration of roads to give a better final performance as increased load capacity, preventing plastic deformation, avoiding cracks reflective etc.

3.2 *First application of steel mesh in SP-354*

In November 2012 was executed the first test section with the use of steel mesh near the city of Campo Limpo Paulista (Fortes et al., 2013a). The existing pavement rehabilitation project on the section of the SP-354 has a length of 400 m divided into 4 parts of 100m.

Through this study, was investigated the performance of the steel mesh as anti-reflection method of cracks in asphalt pavements for new layers of recapping. It was observed that between screens and the edges reflection cracks occurred mainly in positions overlapping length of the meshes (amendment). In addition, these points the displacement of the belt was resulting in undulation thereof and with decreasing thickness of repaving, the surface presented pathologies that have evolved for potholes (Fortes et al., 2013b).

The best performance was in the subsection which was milled and had the fixing the steel mesh to the existing pavement and no overlap was performed. Thus is prevented from being moved and consequently prevents appearance of cracks. After 1 year of running this experimental subsection, in September 2014, it was observed that there was no evolution of defects that arose after the execution, in other words the cracking due to amendment of the screens, as can be seen in Figure 1 (a) and (b).

Figure 1. (a) Crack that appeared in March 1, 2013.

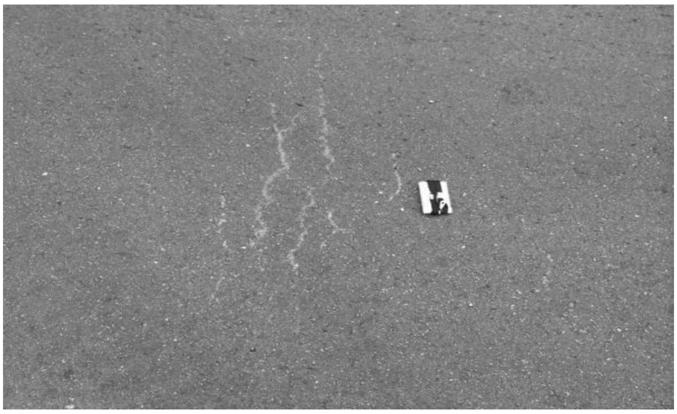

Figure 1. (b) The same crack in March 31, 2014.

Also they were removed minor irregularities during milling even the pavement which resulted in a better screen settlement, avoiding the ripples that occur mainly due to the same irregularity and also while running the screen due to the movement of the construction equipments (Fortes et al., 2013c).

In general, it was observed that the construction using this new technology are in good condition and the pathologies that occurred was crack that emerged soon after the construction due to longitudinal seams and these defects have not been treated and have also suffered no evolution.

4 NEW CASE STUDY IN CLIMBING LANE

At the end of October 2013 began the construction using reflex in deteriorated pavement in the climbing lane. The segment under study is located at km 68. In this local, the highway cross the city of Campo Limpo Paulista, where there is a break in the highway in the intersection to the urban area that accesses the city of Jarinu. The steel mesh was implanted on track towards Jarinu - Campo Limpo Paulista (track with heavier traffic).

The ground of the SP-354 has wavy features, with the presence of steep slopes reaching over 4.5% incline. In these passages, heavy vehicles inevitably lose speed in relation to passenger cars and therefore there is a greater demand for overtaking in these segments. Low-speed operation segments are, in general, those with greater need to implement additional tracks.

4.1 *Existing road structure*

The improvements that were made on Highway SP-354 consisted in the deployment of climbing lanes with a total width of 4.70 m platform, the width of 3.50 m intended for traffic of commercial vehicles and 1.20 m safety range. To evaluate the general condition of the pavement structure was performed functional survey of the segment comprising the additional track. The number N designed for the project period was 2,93E+07 (USACE) and 1,55E+07 (AASHTO).

It was found that after one year of construction of the additional track, the asphalt coating had patches, patch deterioration and shoving. In some segments located there was almost complete pavement distress with localized areas presenting local settlement, corrugations, ruttings and alligator cracks.

Through the geotechnical studies it was found that the subgrade soil types are LG 'NG' ON 'and NS' according to the classification of soils MCT (Miniature, Compacted, Tropical classification). Note that all geotechnical tests (CBR and expansion) of the subgrade soils were performed on soil samples molded in Energy Standard Proctor. Table 1 is the solution adopted for construction of climbing lane.

Table 1. Structure of climbing lane pavement.

Layer	Thickness (mm)
Asphalt concrete	130
Graded crushed stone	200
Cracked rock	200

4.2 *Study on welded mesh splices*

These studies were oriented in "*Estudo do Comportamento de Estruturas de Concreto Armadas com Telas Soldadas: Ensaios sobre Emendas* ", published by the IBTS (Brazilian Institute of Mesh Welded), by the technical bulletin - 3rd edition - 1997 - IBTS "*Como projetar e construir estruturas de concreto com qualidade e produtividade*" - IBTS - Technical Information and ABNT NBR 16055 - concrete walls molded in locus for the construction of buildings - Requirements and Procedures. Their characteristics are given in Table 2.

Table 2. Characteristics of the welded mesh Q138.

Steel	Spacing		Diameter		Dimensions	
CA60	cm	inches	mm	inches	width(m)	length(m)
Q138	10	3.94"	0.32	0.13"	2,45	6

The study aimed to define the splice procedure to be applied in the experimental section of the SP354, on the development of technology defined as Reflex (Reinforcement of Flexible Road Structures with Steel Fabrics to Prolong Service Life). The main objective was to complement the study for development of a new technology for the construction and rehabilitation / recovery highways, with the use of welded steel mesh in order to increase the life thereof, as well as allowing the reduction of use of natural resources.

A welded mesh panel covers a certain area on the reinforcement on the pavement, in order to perform the Reflex method, it is necessary to make an installation of welded mesh panels, so that the entire area is covered. When the distribution of the welded mesh on the pavement surface is held, so that the reinforcement becomes continuous throughout its length, it is necessary to splice the panels which are given by the overlap of meshes.

Splices of the longitudinal reinforcement must be tied with annealed wire, in the same plane. In the case of transversal splices, the spliced wires should also be in the same plane. Services of cutting and mooring shall be executed at the construction site. Figure 2 shows the lateral splices and the detail of the overlapping meshes. This overlapping must be avoided because it was observed that the pathologies (potholes) occurred in the coating, where the welded mesh was overlaid, resulting in a thickness of more than 3 wires.

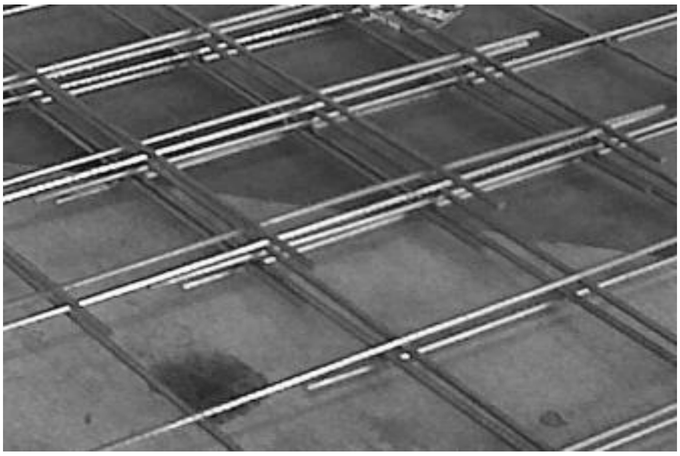

Figure 2. Detail of overlapping meshes.

4.3 *Construction of test section in climbing lane*

The experiment was held on 23.10.2013 in a local with a ramp slope of 3.6%. The main reason for mesh application in the climbing lane was that due to the new improvements made by the DER / SP in the SP-354 in 2012, part of the commercial vehicle traffic bordering highways as Anhanguera Highway (SP-330), was diverted causing an increase in requests in the pavement above the estimated project.

According to official data of the DER/SP, in 2012, there was an increase of 37% in the number of commercial vehicles passage (Table 3). Due to this new scenario, the pavement began to show high presence of potholes and alligator cracks.

Table 3. Evolution of traffic volume.

	Heavy Vehicle	
YEAR	Average Daily Traffic (ADT)	Growth Rate (%)
2008	1.501	-
2009	1.588	6
2010	1.690	6
2011	1.750	4
2012	2.393	37
2013	2.515	5
2014	2.584	3

Taking these data into consideration, it was decided the milling of the pavement and the application of the reflex technology (Figure 3). This option was adopted due to the first experiment conducted on the SP-354, which found the best performance in the section which was milled and applied the reflex. Milling was performed with 6 cm of thickness (Figure 4). We adopted a small change in the positioning of the mesh, as had been implemented in the first experiments, that is, the mesh placement with rails down and as a result, with the bars up, reversing the side.

Figure 3. Pavement milling.

Figure 4. 6 cm of thickness milling.

This care occurred trying to reduce the thickness in placing screens, avoiding overlap. The coatings on the mend in the longitudinal direction was executed without overlapping any screen. In addition, there was an improvement in fixing them, going to use 5 mm steel bars, driven into the milled pavement (Figure 5). There was also careful to cut fabrics, in the corners, which occurred overlap of all screens, so there would overlap a maximum of two wires.

After the mesh fixations were applied binder layers and waterproof according to the rules of the DER/SP, besides the layer Hot Mix Asphalt (HMA) in thickness of 6 cm compacted.

Figure 5. Detail of steel mesh.

4.4 *Field measurements*

In order to evaluate the structural behavior deflectometric evaluations were done with the use of Benkelman beam. These offset measurements were performed according to the Pavement Restoration Manual Asphalt DNIT (2006). The deflectometric measure did before the reflex application and after the restoration of the same was carried out. From the results it was observed that the structural behavior difference among portions with and without the mesh is still not significant. The tendency is that the difference grows with the age of the pavement using the reflex technology.

4.5 *Structural assessment*

The reinforcement design methods with steel mesh, in the bibliography, are based mainly on observation of experience works and laboratory testing. The use of numerical models appears as the appropriate means to the structural analysis of reinforced pavements using steel mesh according to Alves (2007). In this research we chose to make simplified structural analysis of the pavement test section with multiple layers with linear elastic behavior model. All calculations were performed using the Elsym-5 program.

The mechanical parameters of the material on different layers are described by their thickness, Young's modulus and Poisson's ratio, as soon as the calculation parameter, it is considered the layer with elastic modulus equivalent layer steel mesh (EL) where it can be determined according models REFLEX (2001). The equivalent modulus is given by Equation 1:

$$E_{El} = \frac{E_{steel} \cdot I_{steel} + E_{asphalt} \cdot I_{asphalt}}{I_{El}} \quad (1)$$

where E_{steel} = modulus of elasticity of the steel; I_{steel} = moment of inertia of steel; $E_{asphalt}$ = modulus of elasticity of the asphalt; $I_{asphalt}$ = moment of inertia of asphalt; E_{El} = modulus of elasticity of equivalent layer and I_{El} = moment of inertia of equivalent layer.

Using data from the steel mesh (Table 2) the cross section of steel bar has been converted into a square equivalent section. For a mesh with 10.0 cm spacing of # and a 4.2 mm of diameter, the equivalent layer elastic modulus was calculated as follows in Equation 2:

$$A_{\circ} = A_{\square} \Rightarrow \pi . r^2 = a.b \Rightarrow b = 3{,}30mm$$

$$E_{steel} . \frac{3{,}3 . 4{,}2^3}{12} + E_{asphalt} . \frac{(100 - 3{,}30) . 4{,}2^3}{12} = E_{El} . \frac{100 . 4{,}2^3}{12}$$

$$E_{El} = \frac{1}{100} . (210000 . 3{,}3 + E_{asfalto} . 96{,}7) \quad (2)$$

The effect of reinforcement with steel mesh was analyzed for the typical structure of DER/SP flexible pavement design. The structure consists of a 13cm of asphalt concrete, 20cm of graded crushed stone and 20cm of cracked rock. The mechanical properties of all materials can be seen in Table 4.

Table 4. Pavement structure adopted in the test section.

Layer	Thickness (mm)	Modulus of Elasticity (MPa)	Poisson (υ)
HMA	60	4,000	0.30
Steel Mesh	-	10,798	0.30
HMA	70	4,000	0.30
Graded crushed stone	200	300	0.35
Cracked rock	200	250	0.35
Subgrade	-	70	0.45

Using the elasticity modulus of 4,000 MPa for asphalt concrete, as seen in Table 4, the elastic modulus equivalent to layer may be calculated according to the procedure described above (Equation 2), and then the modulus of elasticity was calculated with a value of 10,798 MPa.

To quantify the contribution of steel reinforcement to the early stages of a pavement's service life, a classical fatigue law was adopted in this study (Equation 3) where N=number of cycles for crack initiation; and et=tensile strain at the bottom of the HMA layers. This equation, which was adopted by the Arizona Department of Transportation (ADOT), was calibrated by the fatigue behavior of 20 selected experimental sections. It should be noted that although there is a large variation among fatigue equations for HMA materials, the previous equation was used for relative comparison between reinforced and unreinforced cases (Elseifi et al., 2005).

$$N_{AASHTO} = 9.33x10^{-7} e_t^{-3.84} \quad (3)$$

Compared with the year 2014, the data in Table 3 were used to calculate a new cumulative number of standard axle passes of 80 kN in the stretch with and without wire mesh and based on the design criteria to fatigue and specific deformation defined by the horizontal draw Dormon method (Equation 4), the N_{dim} values were calculated for both criteria assuming that the different pavements could support the same damage as seen in Table 5 and 6.

$$N_{USACE} = 6.067x10^{-10} e_v^{-4.762} \quad (4)$$

Table 5. Admissible values

Type of pavement	Number of standard axle 80kN USACE	AASHTO
Without Steel With Steel	5.35E+07	1.34E+07

Table 6. Mechanistic check

Pavement	Layer	Acting values εt (cm/cm)	Acting values εv (cm/cm)	Admissible values εt (cm/cm)	Admissible values εv (cm/cm)
Without Steel	HMA	1.73E-04	-	3,75E-04	-
	Subgrade	-	3,12E-04	-	2,76E-04
With Steel	HMA	2,10E-05	-	3,75E-04	-
	Subgrade	-	1,68E-04	-	2,76E-04

It appears from the results obtained using the computer program Elsym-5 that the active values of horizontal tensile strain at the bottom fiber HMA layer (= 2.10 x 10^{-5} εtadm and 1.73 x 10^{-4}) respectively to the sections with and without steel mesh are below the permissible values (= 3.75 x 10^{-4} εtadm), however the deformation analysis specifies compression vertical εv, the active value of the non-display option was higher than the permissible value. Therefore, the pavement structure using the scaled steel mesh according DER (2006), it was acceptable to serve the traffic in 2014.

5 CONCLUSION

The comparison of a highway traditionally built and the use of reflex technology was discussed in this paper, mainly the use of the mesh in the rehabilitation of flexible pavements for additional tracks. Thus it can be concluded that in general, the results have highlighted the structural behavior of the pavement.

From the construction point of view, the greatest difficulties were felt in fixing the wire mesh to the underlying bituminous layer, essential to prevent its movement or lifting during movement of work equipment. It is considered that the results achieved in this study were satisfactory.

It should be noted that the research is still in progress and that the problems of the amendments are being studied, since there is the willingness of manufacturers to provide the steel mesh in rolls which would facilitate its implementation. For future studies it is suggested to develop more appropriate study the wire mesh in the presence of the pavement structure, for example, programs with use of the finite element method.

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