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Composite Pavement as an Alternative for Heavy Traffic Brazilian Highways

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Abstract

The growing level of heavy traffic observed in Brazilian main roads, predominantly flexible pavements, has shown that these structures are not presenting the expected performance, taking account the investments made. In these structures, the asphaltic surface works under excessive levels of tension strain, which causes earlier cracking. On the other hand, the composite pavements, in which a concrete layer is used as base layer under the asphaltic surface, have been used in several countries, showing good performance. Besides, the fact that this structure presents lower deformability helps the asphaltic surface as it is submitted to lower levels of tension strain, or even in compression regime only, increasing the durability and time to develop fatigue cracking. The present study intends to compare the performance between a conventional flexible pavement and a composite pavement using the Compacted Concrete Rolled – CCR, as base layer, being the asphaltic surface composed of a mixture of asphalt and rubber. In order to carry out this comparison, the pavement design assumed a heavy traffic road (N_{82kN} = 1,0x 10^8, USACE). The sub-grade layer presents a California Bearing Ratio of 7.0%. Also presented in this paper, are the mechanical parameters obtained from the materials applied and the methodology for pavement design. A structural analysis is also presented in order to show the influence of the presence of hot asphalt mixture layer in the settlement of CCR layer and this in the pavement performance. The new methodology is therefore proposed as an alternative in order to improve Brazilian pavement performance for heavy traffic highways.

Keywords: composite pavement, CCR

1 INTRODUCTION

The growing level of heavy traffic observed in Brazilian main roads has led to the conclusion that conventional flexible pavement structures have not shown adequate performance, taking account the investments made.

Flexible pavement structures, composed of base and sub-base layers of coarse well graded materials are largely applied in Brazil. This aspect allied to the lack of the employment of technics such as chemical stabilization of the soil foundation, resulted in high resilient strain pavements. In these structures, the asphaltic surface, works under excessive tension strain which, buy its turn, leads to earlier cracking.

European developed countries (France, Germany, Belgium, Holland, among others), besides using chemical stabilization of the foundation soil, in great scales, have being constructing, in the last decades, pavements combining flexible and rigid materials with the

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objective of increasing highways durability. This type of pavements is called composite pavements.

According to PIARC (Permanent International Association of Road Congresses), composed pavements may be grouped in three types; Type I: a rigid structure (conventional concrete) is covered by an asphaltic surface. Type II: a rigid structure is covered by pre-molded elements (pre-molded elements for pavement construction). Type III: a flexible pavement structure is covered by a rigid layer (withetopping).

A great advantage of type I composed pavement is to combine strength, given by the concreted layer and comfort to the driver given by the asphaltic surface. Furthermore, being this type of structure less deformable, it will garantee that the asphaltic surface works under lower tension strain, increasing its durability regarding to fatigue cracking. Figure 1 shows a structure of the type I, composed of a CCR together with the corresponding design parameters.

It is important to emphasize, nevertheless, that the introduction of a cemented mixture in a pavement structure generates fissures, either due to retraction (early ages) or fatigue (after long time) which will tend to propagate to the asphaltic surface.

The fissures propagation from the cemented layer to the asphaltic surface, occurs due to the relative movement of the lateral sides of the fissures, inducing stress and strain concentrations, which cause a physical failure in the asphaltic surface and propagates through the whole layer. These relative movements may be originated by the following factors:

- Low temperatures;
- Ciclyc temperature variantions; and,
- Traffic loading.

Low temperatures cause contraction of the cimented layer and therefore open cracks. The horizontal contraction movement generates tension stress in the asphaltic surface. In the vicinity of the cracks occurs a stress concentration. By its turn, the asphaltic surface is also submitted later on by tension forces because it also suffers contraction under low temperatures.

The daily cycles of temperature variation also generate thermic tension cracks in the asphaltic surface. That is because these cycles generate thermic gradient in the layer forcing its extreme parts to curve themselves in the vicinity of the cracks. In the coldest period of the day, a crack is open, not as severe as the one generated due to contraction, nevertheless, is more frequent and therefore causes a similar deterioration.

Regarding crack propagation due to loading action, a different displacement mechanism is verified, compared to the previous one mentioned. As axial load, gets nearer to a crack,

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vertical differential deflection causes a mode I propagation (bending - the crack opens) and mode II of propagation (crack shearing or tearing). Although this mechanism is less intense compared to that caused by thermic variations, it happens far more frequently. The higher the percentage of heavy trucks (those with excess load), the thinner the cemented concrete layer and the thickness of the asphaltic surface, faster the cracks propagate. It is important to observe, nevertheless, that in the composite pavement structure the asphaltic surface will "work" under compression, which in turn will minimize the effect of mode I of crack propagation.

Since these cracks are inherent to this type of pavements, it is necessary, therefore, that techniques are applied in order to inhibit or slow down cracks propagation aiming to garantee the desired performance.

2 Composite Pavement Structure Design

The basic pavement structure proposed is shown in Figures 1 and 2. In Figure 1, the CCR layer is built above the coarse well graded material, while in Figure 2, the same layer is constructed above a layer of asphaltic mixture.

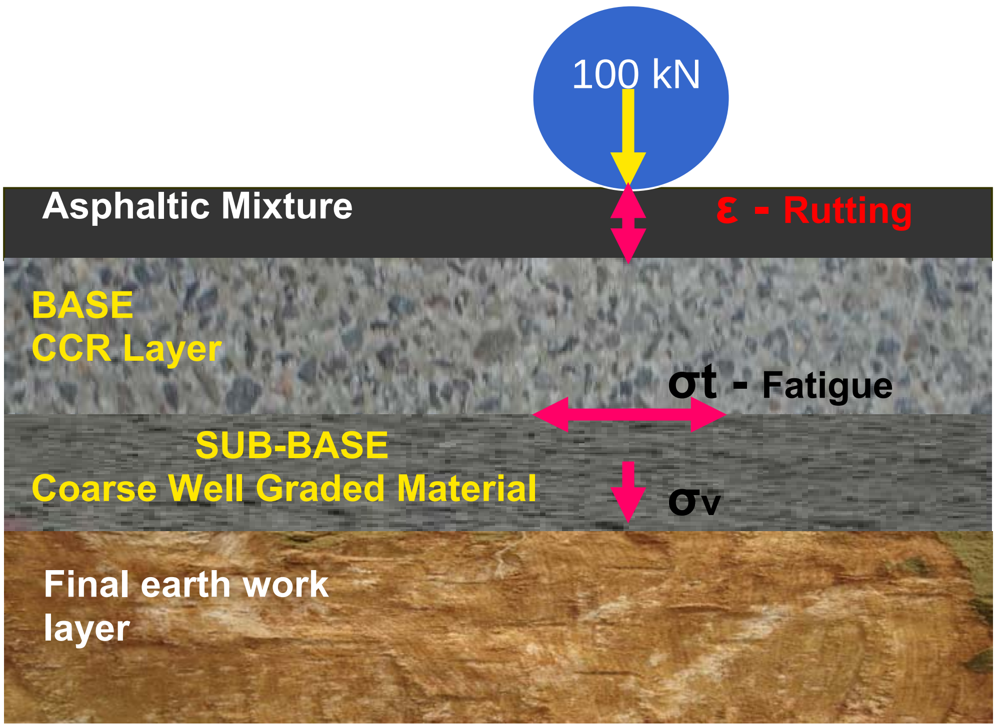

Figure 1 – Composite pavement with CCR layer built above the coarse well graded material.

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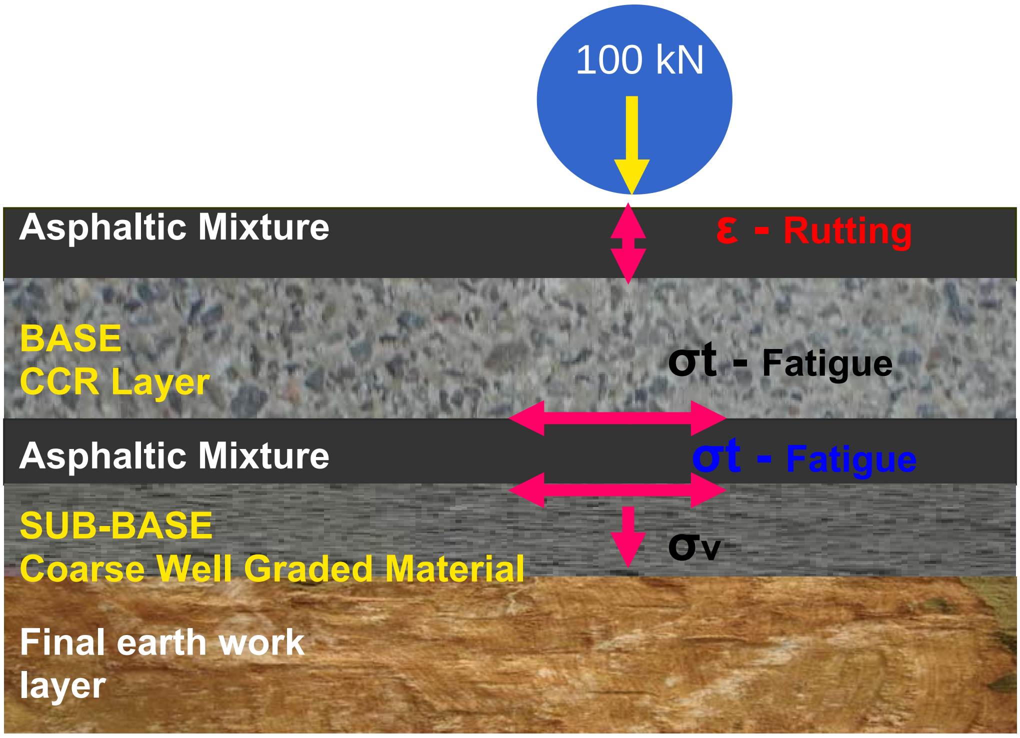

Figure 2 – Composite pavement with CCR layer built above the asphaltic mixture.

The insertion of an asphaltic mixture in the structure of Figure 2, aims to garantee a more uniform accommodation of the CCR layer. The deformability of the asphaltic layer will provide accommodations of the CCR layer due to the thermic variations, humidity and small differential settlements of the final earth work layer. By the other hand, the accommodation of the asphaltic layer with the coarse well graded material will result in a favorable condition to the CCR layer to stay uniformly in contact, allowing therefore a more uniform stress distribution in this layer, improving its mechanical performance. Preferably, this layer should, then, be rich in binder content and possess a good mechanical performance in relation to fatigue. In a general manner, mixtures with higher binder content tend to present a better fatigue behaviour, although it may be subjected to permanent strain. Nevertheless, regarding its location within the pavement structure, there is little or no reason to be concern with permanent strain, due to the "plate" effect that the CCR layer will excert over the asphaltic mixture.

In both structures (Figures 1 and 2), the asphaltic layer will be made of asphaltic mixture with rubber. The aim regarding the utilization of asphalt-rubber is the fact that these structures support higher strains and as result will inhibit or slow down cracks propagation which may appear in the CCR layer, either by contraction or fatigue.

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3 Materials characterization

3.1 CCR Layer

Roller compacted concrete (RCC) was first used as a pavement material in 1930 in Sweden; since then, several examples of successful application of RCC pavements in ports, parking areas, municipal streets, and intersections have been reported (ACI COMMITTEE, 1995)

RCC can be used either as the foundation material for base and sub-base course of an asphalt surface or as the pavement material itself. The utilization of RCC seems very promising, since it provides pavements with a rigid layer, enhancing the durability of the cover asphalt layer. Roller compacted concrete is a dry mixture of aggregates; water and cementing materials compacted by vibratory rollers or plate compaction equipment (ACI COMMITTEE, 1995). Unlike normal concretes, RCC is consolidated by compaction leading to often low water contents as compared to normal concretes (NANNI et al., 1996).

Among the advantages resulting from the use of a cemented layer in the pavement structure, are the following:

- Significant reduction on the levels of deflection of the pavement structure;
- Due to its rigidity, the asphaltic surface resting on it, works almost exclusively under compression, which minimizes the problem of cracking in the mixture due to fatigue. This problem is critical for durability of the asphaltic surface of flexible pavements in our country; and;
- The cemented layer has a final cost unit lower than that of an asphaltic layer. Besides, all the material needed is produced in Brazil.

As has been already emphasized, the presence of cracks is inherent to a cemented mixture, either due to contraction (early ages) or fatigue (after long time), which will tend to propagate to the asphaltic surface. Therefore, the great challenge regarding the use of this type of structure is to find practical efficient ways to inhibit or slow down the propagation of these cracks.

3.1.1 Mechanical Characterization of the Mixture

Grading curve should fit range B, according to DNIT (Brazilan National Department for Infrastructure Transportation) and compacted with an energy correspondent to Intermediate Proctor Energy.

According to Trichês (1993), a cemented granular mixture, of the CCR type, with consuming cement, in weight, ranging from 120 to 160kg/m^3 will present approximately the following mechanical parameters:

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- Compressive strength: from 11.0 to 17.0MPa, after 7 days curing and from 15.0 to 20.0Mpa, after 28 days curing;
- Bending tension strength: from 1.5 to 2.1MPa, after 7 days and from 1.9 to 2.6Mpa, after 28 days; and,
- Deformability module: 21 to 25GPa.

For designing purposes of the structure of the proposed composite pavement, the following mechanical parameters will be adopted for the cemented granular material:

- Compression strength: 18.0MPa;
- Bending tension strength: 1.9MPa; e,
- Deformability module: 21,000.0MPa.

These are expected values to be obtained for the CCR layer, using the coarse well graded material and cement available in the field during construction.

A value of 0.20 will be adopted for Poisson's ratio.

3.1.2 Fatigue behaviour of the cemented mixture

According to Trichês (1993), considering cement consuming from 120 to 160kg/m^3, the fatigue behaviour of the mixture may be stated by the following equation:

$$SR = 0.961 - 0.060 \log N \qquad \text{(Equation 1)}$$

where: SR - is the relation between the tension stress (acting in the most tensioned region) and the bending tension strength of the mixture; and,
N - Is the number of loadings required to reach failure in the mixture.

According to the same author, the bending tension strength, for 28 days curing period, ($fct_{M,28}$) may be estimated from simple compression strength, also after a period of 28 days, through the following correlation:

$$fct_{M,28} = 0.877\,(fck,28)^{0.5} - 1.279 \qquad \text{(Equation 2)}$$

where, $fctM_{,28}$ and $fck_{,28}$ are the strength previously defined.

3.2 Asphaltic Surface and CCR´s Resting Layer

In this type of structure, the asphaltic surface has several functions, besides the conventional ones, like:

- To provide comfort and security to the driver;

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- To protect the cemented layer from the abrasive action of the traffic and;
- To minimize the thermic variation in the CCR layer;

As already mentioned, the use of an asphalt-rubber mixture as rolling surface aims to minimize or slow down cracks propagation generated by the cemented layer (CCR). By its turn, the use of an asphaltic mixture under the CCR layer has the objective to provide an accommodation to the last one, allowing an improvement of the stress distribution acting on it.

For designing purposes, the parameters used for the asphalt-rubber mixture (15% rubber, in weight) and the conventional mixture, were obtained from Fontes (2008). The following parameters, obtained in laboratory, have been used for the asphalt-rubber mixture; the grading curve according to range C (DNIT) and resilient module, MR= 4909MPa. For the CCR layer (conventional mixture – binder 50/70), have been adopted; grading curve according to range C (DNIT) and MR=6314Mpa.

The fatigue curves for the two mixtures are shown in Figure 3. These results have been obtained from laboratory tests carried out on four points beam, under a temperature of 20ºC, 10Hz frequency and under strain controlled conditions.

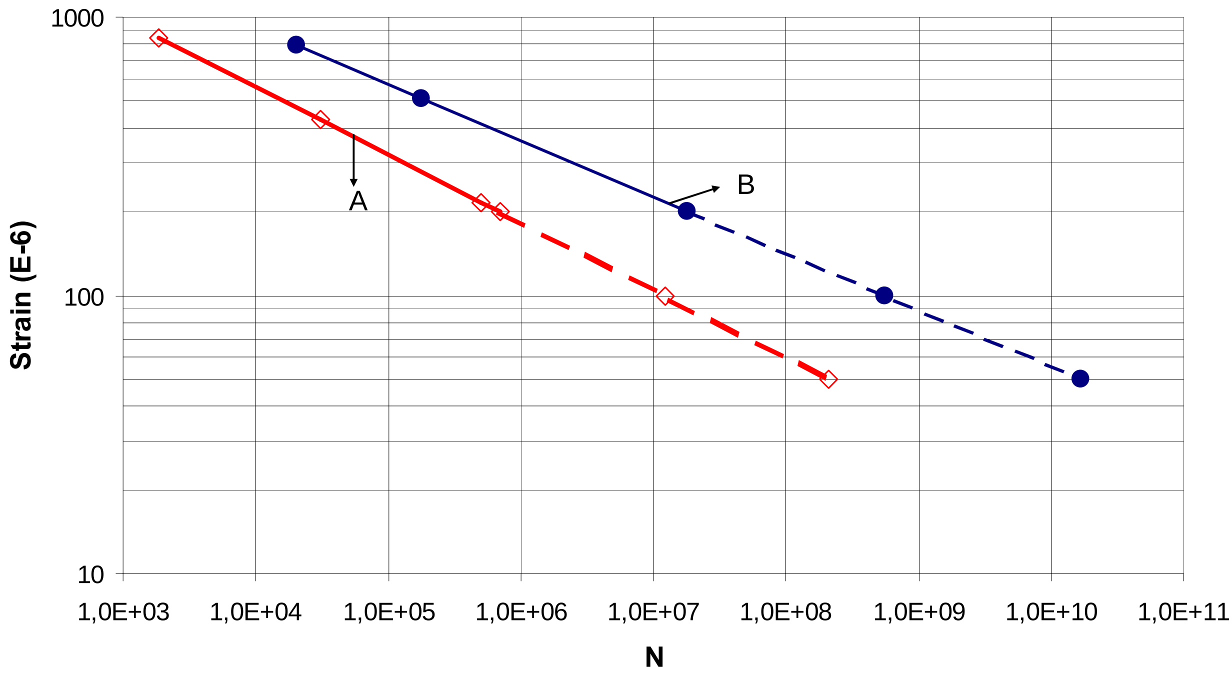

Figure 3 – Fatigue curves for both asphaltic mixtures: Curve A – conventional mixture; Curve B: asphaltic rubber mixture (Fontes et alli, 2008)

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4 Mechanistic Analysis of the Composite Pavement

The structure of the composite pavement was designed to attend a value of N_{82kN} = 1,0x 10^8, USACE). The analysis was performed considering, for the CCR layer, the mechanical parameters obtained by Trichês (1993); for the asphaltic mixture (conventional and asphalt-rubber) obtained by Fontes (2008) and for the coarse well graded material by Fernandes (2001). The soil for the final earth work layer was obtained from a natural deposit located in the city of Florianópolis, state of Santa Catarina, South Brazil.

For the mechanistic analysis of the structure, a software ELSYM5 was used. Were also assumed, a single load axis of 80kN, wheel pressure of 0.57MPa and distance of 32.0cm between center wheels. Simulation also considered a traffic load of 100kN and wheel pressure of 0.63Mpa. The failure criteria adopted in the analysis, assumed the following aspects:

- Tension strain acting on the bottom face of the CCR layer, εtr;
- Tension stress acting on the bottom face of the CCR layer, σt;
- Tension strain acting in the resting layer of the CCR layer, εta; and,
- Compression specific strain acting on the top of the final earth work layer, εvs.

Concerning the compression specific strain acting on the top of the final earth work layer, there are small differences among researchers and the results found in the literature indicate an average value of about 2.6 x 10^{-4} for the estimated traffic of the highway.

Regarding the tension strain acting in the asphaltic surface, the fatigue curve obtained by Fontes (2008) will be used, although in this type of structure the asphaltic surface will work basically under compression.

In relation to the tension strain acting on the asphaltic mixture, located under the CCR, fatigue curve obtained by Fontes (2008) will be used.

The mechanical parameters are shown in Table 1. These parameters should be confirmed by laboratory tests, for the coarse well graded materials and commodities available for the construction of the field experiment.

Table 1 - Mechanical characteristics of the materials

Material	Strength (MPa)	Module (MPa)
Final earth work layer (CBR = 7%)	-	100
Coarse well graded material	-	150 to 300
CCR layer	2.0*	21,000
asphaltic surface	-	4,900
CCR´s resting layer (asphaltic mixture)	-	6,300

* In the construction process, a value of at least *1.9MPa bending strength should be obtained. (Cement consuming of the order of 130kg/m³).*

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The designed pavement structures, based on the parameters adopted, can be summarized in Tables 2 and 3.

Table 2 - Composite pavement structure with CCR layer resting on the Coarse well graded material.

Layer	Module (MPa)	Thickness (cm)	Controlling parameters		
				axle 82kN	axle 100kN
asphaltic surface *	4,900	10.0	Deflexion (10^{-2}mm)	18	22
			εtr **	Compression	Compression
CCR	21,000	19.0	σt (tension) (MPa)	0.74	0.89
Coarse well graded material	150	15.0	-	-	-
Final earth work layer	100	-	εvs (10^{-4})	0.8	1.0

* *Layer built in two stages. The first one, of 5.0cm, should be spread in the border.The second one, of 5.0cm, only in the asphaltic surface.*
** asphaltic surface *"works" under tension.*

Tabela 3 - Composite pavement structure with CCR layer resting on the conventional asphaltic mixture.

Layer	Module (MPa)	Thickness (cm)	Controlling parameters		
				axle 82kN	axle 100kN
asphaltic surface *	4,900	6.0	Deflexion (10^{-2}mm)	18	22
			εtr *	Compression	Compression
CCR	21,000	19.0	σt (tension) (MPa)	0.66	0.80
CCR´s resting layer	6,300	4.0	εt (tension) (10^{-6})	37	46
Coarse well graded material	150	15.0	-	-	-
Final earth work layer	100	-	εvs (10^{-4})	0.8	1.0

* *Surface layer "works" under tension.*

5 Mechanistic Analysis of the Flexible Pavement

The main aim for presenting this item, is to turn possible, through the mechanistic analysis, to compare both pavement structures, that is, a composite pavement and a flexible one.

The mechanistic analysis was carried out on a flexible pavement structure which can be obtained in the way it is usually done, considering a traffic number of the order of 1 x10^8 (USACE), for example, as was done for the duplication of BR – 101, Santa Catarina state. The analyzed structure is composed as follows:

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- Asphaltic surface: Conventional asphaltic mixture with 17,0cm thickness and resilient module of 5500MPa (average value, obtained by the first author, testing asphaltic mixtures used in the state of Santa Catarina);
- Base layer: Coarse well graded material, with 15.0cm thickness and resilient module of 300MPa (Fernandes, 2001);
- Sub-base layer: Gross granular material, with 20.0cm thickness and verage resilient module of 230MPa (Oliveira e Trichês, 2000); and,
- Sub-grade: Soil with CBR of 8% and average resilient module of 100MPa (obtained on tests on soil samples from a natural deposit, located in the city of Florianópolis-SC).

Table 4 shows the results obtained by the mechanistic analysis using the above parameters. In Table 4, the last two columns (Controlling parameters), the first number is related to the surface layer on conventional mixture and the second one, on asphalt-rubber mixture.

Table 4 - Results from the mechanistic analysis performed on the flexible pavement.

Layer	Module (MPa)	Thickness (cm)	Controlling parameters		
				Axle 82kN	Axle 100kN
asphaltic surface	5,500/ 4.900	17.0	Deflexion (10^{-2}mm)	28/28	34/33
			εtr (tension) (10^{-6})	106/113	128/136
Final earth work layer	100	-	εvs (10^{-4})	1.5/1.6	1.9/1.8

6 Analysis of Results

In Table 5, an estimate is shown of the repetitive loading number necessary to cause fatigue failure of analyzed pavement structures. For the composite pavement structure, the criterion adopted to estimate the fatigue life, was tension stress in the CCR layer, while for the flexible pavement, was tension strain acting in the asphaltic surface.

Table 5 - Results of mechanistic anlysis

Type of structure	Axle 82kN	Axle 100kN
Composite pavement	3.2 $x10^9$	1.5 $x10^8$
Composite pavement with CCR layer resting on asphaltic mixture	1.5$x10^{10}$	1.0 $x10^9$
Flexible pavement – conventional mixture	2.0 $x10^7$	0,8 $x10^6$
Flexible pavement – asphalt – rubber mixture	3.8 $x10^8$	1.0 $x10^8$

From the results shown in Table 5, the following conclusions can be made:

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- Both composite pavement structures analyzed satisfy the requirements concerning the estimated traffic for the design period;
- The pavement design, considering a CCR layer resting over an asphaltic mixture, increases, in a significative way, the life of the composite pavement. Is likely that this aspect led some European countries to adopt such a layer in this type of structure;
- Considering the adopted parameters, the flexible pavement structure would not satisfy the requirements concerning the estimated traffic for the period of design, unless the surface layer would be built by an asphalt-rubber mixture. Considering that a mixture asphalt-rubber presents higher cost compared to a conventional mixture, in flexible structure is possible to optmize the cost, subdividing the revetments in 3 layers, where the intermediate layer would be in conventional mixture;
- No economical analysis is presented, for both pavement structures, because it does not concern with the focus of this paper, but rather, to show a comparative analysis between the structures in order to satisfy the requirements concerning heavy traffic, from a mechanistic point of view only.

7 Conclusions and Recommendations

The analysis carried out showed a good perspective in relation to the use of composite pavement structures in order to satisfy the requirements concerning some heavy traffic Brazilian highways. It allies the benefits that cemented materials give to the pavement structure and comfort to the user given by the asphaltic mixture.

Therefore, research is recommended to road administrators, including field experiments, in order to know more about the mechanical performance of composite pavement structure. Is also recommended that more research is done with flexible pavement structure, nowadays built for heavy traffic Brazilian highways, in order to understand better its mechanical performance, because as they are built today they would not satisfy the requirements concerning heavy traffic.

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