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The road network rehabilitation for the 21st Century. A global vision on innovation in road rehabilitation

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Summary

This article intends to be an approach to road network rehabilitation in the context of the new challenges for the near future. Firstly, the current methodology used in the maintenance and rehabilitation and its impact on the pavement life cycle costs is presented. Secondly, the role of innovation at the service of society in the field of road engineering is presented in order to assure a high level of the ride quality, as well as a sustainable construction and rehabilitation of road pavements.

1. INTRODUCTION

Road networks require to be preserved in terms of infrastructures (pavements, bridges, road marking, road signs and safety equipment), using rational maintenance and rehabilitation strategies, which basically would consist in applying the "3 R's strategy": "*the Right treatment, on the Right road, at the Right time*" (FP^2, 2001). The development of this strategy is supported by updated and accurate road information related to the road infrastructure performance, allowing the analysis of data which characterize the condition of the road network, as well as the development of maintenance and rehabilitation strategies, considering given quality standards, or, as an alternative, taking into account available financial resources.

In the road network the pavement constitutes the most important infrastructure as it is submitted to important factors, such as traffic and climate, which have major consequences on the pavement performance. For this reason authorities dedicate significant investments in the construction, maintenance and rehabilitation of road networks which, consequently, become a fundamental domain of research.

Road pavements are designed to support traffic and climatic actions over a certain life time (20 to 40 years, with the objective of offering safe and comfortable ride conditions).

Having into account technical, economic and environmental perspectives for the structural and functional quality standards, after a pavement is constructed for a certain life time, every operation in the infrastructure should be minimised with the

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objective of reducing costs related to its quality maintenance by considering the different stakeholders: i) road administration; ii) users; iii) environment.

Thus, in this context, roads should be seen as infrastructures that should accurately allow a comfortable and safe riding. Moreover they should cause little impact on the environment, what would contribute for the improvement of the quality of life of rural and urban areas.

However, road pavements frequently require premature or non-scheduled maintenance and sometimes reconstruction operations before they reach the end of their lifetime, for which they were designed, with significant costs for every stakeholder.

2. THE REHABILITATION OF THE ROAD NETWORK AND ITS IMPACT ON THE PAVEMENT LIFE CYCLE COSTS

The management of a road should be considered throughout its entire life cycle (20 years average). Hereafter, two rehabilitation strategies are analysed together with the consequences for the road quality and global costs.

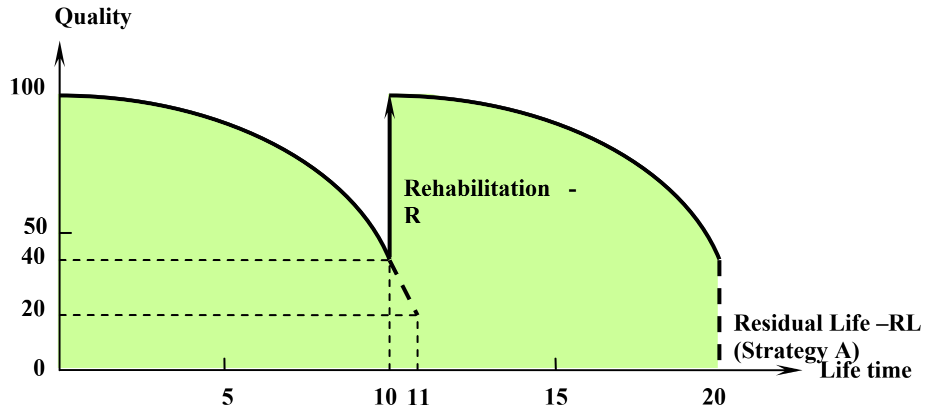

Figure 1 – Pavements life cycle

In general, two alternative strategies could be contemplated: i) maximising the global quality (area of Figure 1), considering available financial resources; ii) minimising the costs for the road administration, for the user rand and for society in general (energy costs), considering given quality standards, being the latter the proactive strategy.

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Figure 1 represents the strategy which comprises a periodic rehabilitation in addition to the current maintenance operations (strategy A). The highlighted area represents the global quality obtained for the overall life cycle. With this strategy the pavement will still show a residual life of RLA at the end of its life cycle.

Photograph 1 – Cracked pavement (alligator cracking): pre-failure condition

Meanwhile, the current practice typically comprises reactive rehabilitation strategies, which act essentially at the structural level, without considering functional components, as it is undertaken when the pavement has already lost its "structural capacity". This type of strategy has a highly negative impact on the life cycle costs of pavements for society, particularly for users.

Considering the pavement shown in Photograph 1, which presents alligator cracking pattern at an initial condition of failure, without apparently showing a severe reduction of its bearing capacity, a complete diagnosis would allow defining future rehabilitation in order to avoid the total loss of its structural capacity.

Alternatively, if nothing is done, this pavement will evolve until complete failure, as it already shows alligator cracking and disaggregation (Photograph 2). This will contribute for an increase of permanent deformation as a result of the ingress of water through the cracks into the granular layers and subgrade. Under these conditions this pavement will require an urgent and costly reconstruction.

In order to support the study of the impact resulting from the adoption of a proactive rehabilitation strategy, an urban road of high traffic capacity with an Average Annual Daily Traffic (AADT) of 40000 to 60000 will be considered, as shown in Photograph 3. In Photograph 4 the high deteriorated condition of the pavement, which had already been repaired, is shown.

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Photograph 2 – Pavement in failure condition

This case study would have been chosen for a strategy of construction-rehabilitation privileging the construction of a pavement of high structural capacity for a long life time, minimising the rehabilitation operations.

Photograph 3 – Urban road of high traffic capacity

Facing a premature degradation of the pavement quality, a deep rehabilitation is needed to diagnose and to eliminate the existing problems. In these situations, by acting at the surface course level only the functional quality will be improved, disguising structural problems temporarily. In addition to direct administration

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costs, these operations will have significant costs for the users. Medium and short term rehabilitation will affect the global costs.

The adoption of a reactive-type strategy, acting only when the residual life of the pavement is very low (Strategy B; Figure 2), will have a significant impact on the costs during the pavement lifetime. Hereafter, these costs are evaluated and compared with those resulting from the strategy defined in Figure 1 (Strategy A).

Photograph 4 – Deteriorated pavement of a high traffic capacity urban road

Rehabilitation strategy B (Figure 2) could be considered as a set of three types of operations: two light rehabilitations, R1 and R3, and a deep rehabilitation, R2, leading to a residual value of RLB. In this strategy B, a quick evolution of the deterioration was observed if compared with strategy A.

Taking into consideration these two rehabilitation strategies, the consequences regarding the following parameters were determined and analyzed:

i) global quality of the pavement, related to all costs and, particularly, vehicle operating costs (VOC);

ii) user costs, represented by the cost concerning the modification of travel time, and by the costs of fuel, as these are significantly relevant;

iii) environmental costs, partially related to the green house effect and to energy consumption.

This case study has a length of 2000 metres, with a cross-section of 2x3 lanes, and a total width of 21 metres, what means that the total area to be rehabilitated is 42000 square metres.

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The value for AADT would be 40000 vehicles: two users per vehicle, totalising 80000 people a day; fuel consumption: 10 litres per hour and vehicle; hourly cost: 25.00€.

Relating the costs of the rehabilitation operations, that of reference, R, (Figure 1) will have a unit cost of 3.00€ per square metre. Rehabilitations R1, R2 e R3, will have a unit cost of 1.50€, 4.00€ e 1.50€, respectively (Figure 2).

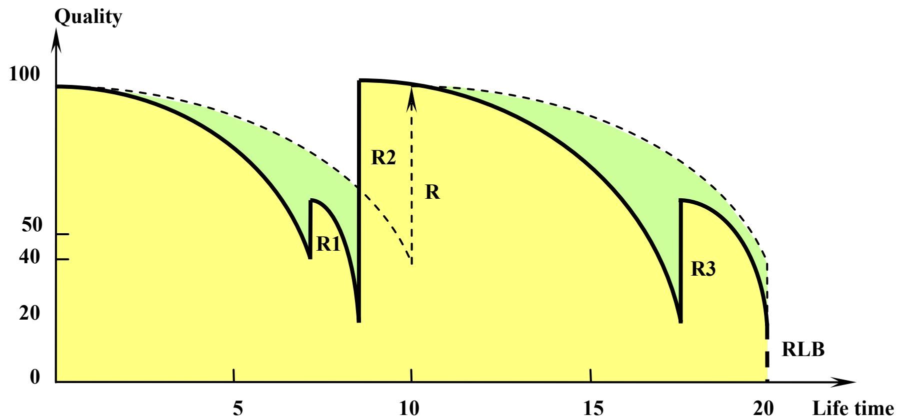

Figure 2 – The consequence of two rehabilitation strategies on the pavement life cycle

Concerning the duration of each rehabilitation, and the corresponding time modification, the following values are considered: i) R1 and R3 with the duration of 3 days and an increase in travel time of 0.2 hours per day of operation; ii) R2, as well as R, will have a duration of 5 days, resulting in an increase in travel time of 0.3 hours per day.

The results obtained with these calculations for strategies A and B are presented in Table 1.

Table 1 – Consequences of two rehabilitation alternatives strategies

Strategy	Rehabilitation costs	Increase on the travel time	Travel time costs	Fuel costs
A	126000€	120000 h	3000000€	780000€
B	294000€ (+133%)	216000 h (+80%)	5400000€ (+80%)	1404000€ (+80%)

Considering the added value of strategy A compared with B, it is possible to compute its impact in terms of the road network length that would be possible to rehabilitate, at a preventive rehabilitation level (R1 e R3 rehabilitation type, with an unit cost of 1.50€ per square meter).

The total added value of strategy A is 168000€ in terms of direct costs for rehabilitation and 3024000€ regarding the direct costs for users (travel time and fuel consumption). Considering a preventive rehabilitation of a road with two lanes, with a width of 7 meters, that amount of added value will allow the rehabilitation of 16 km and 288 km, respectively.

In addition to the significant increase of costs for strategy B, the pollution costs resulting from more than 96000 hours of fuel consumption of a single vehicle should be emphasised as well as the negative impact on the economy derived from an increase of 80% on the imported energy, the vehicle operating costs and the safety and comfort costs.

3. A GLOBAL VISION OF THE CONTRIBUTION OF ROAD REHABILITATION FOR THE QUALITY OF LIFE

In the context of a holistic approach to the quality of life, roads need to be analysed throughout their entire life time, including the following direct and indirect costs: i) construction and rehabilitation costs; ii) user costs, including those resulting from traffic delays due to maintenance and rehabilitation works; iii) environmental costs; iv) societal costs in general.

To accomplish this holistic objective of the road network, a new vision would assume the following predictions (FEHRL, 2004): i) roads will constitute an infrastructure which will promote technical and social developments to be base of a better quality of life; ii) construction and rehabilitation of road infrastructures will be sustainable if they include technical, economic, social and environmental dimensions; to support this objective it is fundamental to *establish the bridge:* "*design-construction-maintenance*"; iii) the road network will be constituted by a set of "*intelligent infrastructures*", in which "*5 star vehicles are driven along 5 star roads*".

In an urban environment, every operation should integrate the existing legislative requirements, namely regarding noise, searching for continuous solutions in terms of service for users. To reach to a solution a global analysis comprising structural and functional components in order to improve the quality offered to users and non users and to minimise the environmental impact needs to be made.

Thus, a new attitude is required: a proactive vision of the road network management in the framework of modern Road Network Management Systems. This activity requires design monitoring, followed by the construction phase, the monitoring of the performance of the road network constructed until the new cycle of maintenance and rehabilitation, according to predefined quality standards.

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This innovative approach should be global, taking into consideration the factors evaluated and the road stakeholders, trying to innovate in order to "*make better with less*".

With this perspective in mind, promoting the structural sustainability of the road infrastructure for a long term is essential. Therefore, it would be possible to concentrate only in the innovation at the level of the surface course, searching for added value for users and non users, particularly in the field of safety, bearing in mind the interaction "*driver-vehicle- road*". At the same time this approach would integrate the concept of "pavements eco-efficacy" for any rehabilitation.

The objective of maintaining a certain level of quality standards of a road network throughout its entire lifetime requires an appropriate road network management in order to analyse the following: i) factors to be evaluated; ii) direct and indirect stakeholders; iii) added value for each management policy.

Any road network rehabilitation study should comprise the following factors: i) road characteristics: road category; traffic volume; ii) marginal occupation; iii) global potential impact of rehabilitation operations; iv) stakeholders (road administrations, users and non users). The practice of integrating the different categories of users in this approach is not usual. However, as they are the main supporters of the overall costs involving any road operation (especially through the taxes they pay) their integration is essential for this process.

For every category of stakeholder the added value of this approach is evident: i) the improvement of the service offered by the road to users in terms of travel time - determinant factor for classifying the quality of the road network; ii) the reduction of the cost for the road administration - less operations and high efficacy of those ones; iii) the reduction of the user and non users costs (the population in general receiving the impact of road and every activity related to its construction and rehabilitation (air and sound pollution); iv) the reduction of environmental costs (air, sound and water pollution); v) the reduction of energy costs.

4. THE ROAD ENGINEERING INNOVATION AT THE SOCIETY'S SERVICE

The starting point for a prospective analysis of innovation in Road Engineering would be the statement "technically everything is possible" (FEHRL, 2004). For example, the development of "intelligent vehicles" will continue forcing the evolution of the road category to the level of "intelligent road": "in the future the road will command the vehicle".

For this approach the research to be undertaken would integrate multidisciplinary competences in the fields of Road Engineering (materials, behaviour, design, performance monitoring and road management), Communication and Information Technology (CIT) and Electronic Engineering. Thus, roads will appeal to innovative materials as well as to intelligent monitoring methods. That would make possible to establish the functional relation "road> manager> user".

4.1. The Innovation at the Travel Quality Level

The road has to serve society in general. Thus, any operation at the level of its main infrastructures (pavement, marking and safety equipment) requires sustainable knowledge about how this infrastructure behaves at the interaction of "driver-vehicle-road" (Figure 3).

At the level of riding safety, the measures to reduce accidents should constitute a multidisciplinary effort shared by all the intervenients. Among those measures there would be a wide set of activities such as the development and management of the infrastructure, the promotion of safer vehicles, the enforcement of law, the preparation of health services, and the transportation planning.

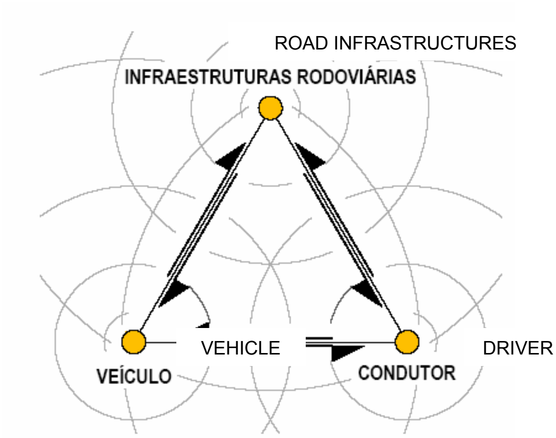

Figure 3 – The interaction "driver-vehicle-road" (adapted from Martins & Nabais, 2006)

The research developed at an international level reveals that drivers are held the main responsible for accidents, followed by the road environment, and, last but not least, the condition of vehicles (Austroads, 2003; Rothengatter & Huguenin, 2004).

At the European Union level, the Project SUNflower+6 (*Comparative Study on the Development of Road Safety in Nine European Countries*), co-financed by the European Commission and leadership by the institute SWOV of the Netherlands, carried out a comparative study of road safety (Figure 4) comprising the following

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nine countries: Sweden, United Kingdom, Netherlands, Hungary, Check Republic, Slovakia, Portugal, Spain and Greece; and in the autonomic region of Catalonia (Macedo et al., 2006).

In these countries, there are still serious problems regarding road safety, such as: i) drunk driving; ii) insufficient child protection inside the vehicles; iii) accidents involving young drivers (mainly at weekends and at night); iv) driving in excess of speed in all types of road; v) a high rate of pedestrian accidents, mainly for children and elderly people; vi) the severity of accidents involving two-wheel motorcycles.

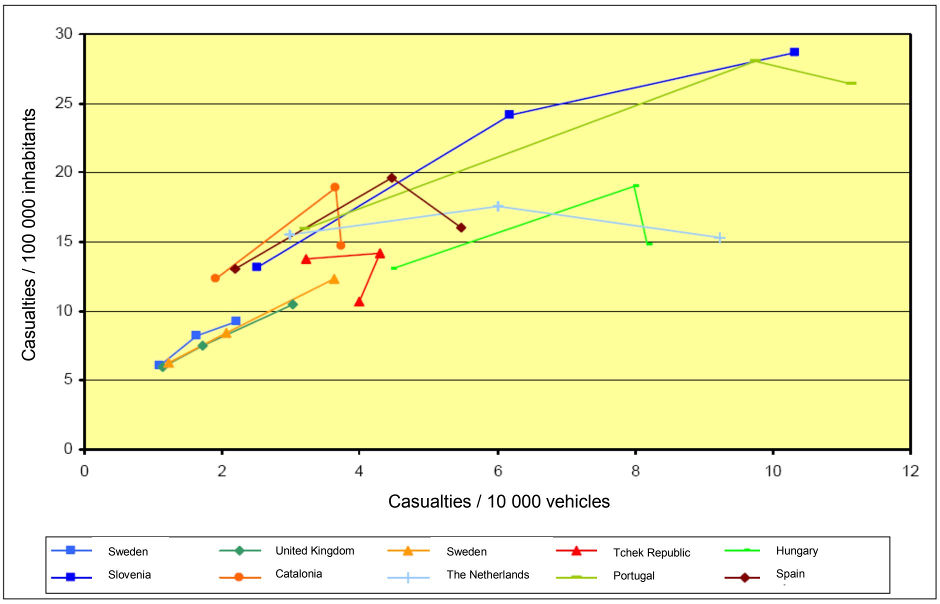

Figure 4 – Road casualties in the European Union (Macedo et al., 2006)

The recommendations arisen from the experience of this project for the European Commission are: i) the reinforcement and the improvement of the efficiency of the supervision; ii) the improvement of means and procedures for the acquisition and treatment of data related to accidents and the drivers' behaviour; iii) the application of measures and operations in road safety as well as the monitoring of its results; iv) the education, training and recycling of the different road users and other intervenients in the various areas related to road safety.

Meanwhile, in addition to the intervention of the driver in every field of road safety, the quantification of the effects of any corrective measure in the road environment is of great importance, as it allows defining the criteria for supporting any decision regarding the most effective measures.

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The existing factors which direct or indirectly provoke road accidents are: i) requests to which drivers are subjected inside the vehicle (use of cell phones and audio equipments as well as the rolling noise; ii) the outside interferences for drivers (publicity boards; iii) meteorological conditions (rainy weather is directly related to road accidents; it may also affect the physical and psychological conditions of drivers); insufficient light; iv) the road alignment and its geometric parameters such as width, slope gradients, shoulders, etc. which determine the driver's behaviour regarding speed; v) the pavement condition - roughness and surface friction of pavements are determinant factors of riding and comfort and safety.

The way drivers detect these factors is essential to develop solutions which allow warning drivers of any changes on the road environment, in particular on the pavement surface.

Riding quality and comfort are intimately bound. Noise also becomes an important factor, if we consider that affects users and non users (neighbourhoods near the "road influence area"). In this context, innovative projects in road surface courses, responsible for ensuring the functional quality of pavements, have been developed what has had a direct impact on the users and on the environment.

In Europe, the current methods used to reduce road noise include noise barriers, traffic control (speed limitation) and the alteration of vertical and horizontal alignment as well as the definition of protected zones.

An innovative method to obtain noise reduction is through "silent pavements" (Camomilla & Luminari, 2004), as the present state-of-the art on vehicle technology does not foresee a significant reduction of the vehicle motor noise and its exhaustion system. The porous surface courses, and more recently, the "*twinlayer*" surface course, have been used in several countries as a noise reduction measure (Hofman & Kooij, 2003).

Noise reduction can also be obtained through the utilization of thin layers such as the "*Poroelastic Surfaces*" (Fujiwara et al., 2005), conceived to control the texture and voids, introducing new materials, such as rubber, and new pavement concepts as the "*Ecotechnic Pavement*" and the "*Euphonic Pavement*" (Camomilla & Luminari, 2004).

Thus, any operation in the urban road environment needs to optimise the choice of the surface course with the aim of reducing the "*road noise influence area*". Figure 5 shows the evolution of the "noise map" after the application of an innovative surface course with a bituminous mixture incorporating tyre recycled rubber modified bitumen.

In addition to this type of impact on the pavement rehabilitation, some others such as the surface drained water quality or the air quality have to be evaluated.

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Figure 5 – Comparative noise map of the rehabilitation consequences (Nobre, 2006)

4.2. Sustainable Construction and Rehabilitation of Road Pavements

Over the last few decades, there has been an increasing concern about the limitation of operations at the level of the surface course in the field of pavement rehabilitation (Nunn, 1997). The surface course may be object of a set of different rehabilitation alternatives, which assure the different functions of the pavement, being a privileged field for fundamental and applied research.

Innovative surface courses need to be resistant, durable and to offer surface conditions capable of guaranteeing ride safety and comfort for the users and economy. At a global level, they need to ensure environmental quality over their life time. In addition to these capabilities, this type of layers would also integrate intelligent referencing and monitoring systems, based on CIT, interacting directly with the management system and with the road user by assuring permanent high quality riding conditions.

However, the implementation of an innovative programme for surface courses also demands changes at the structural level of a pavement, under the leading direction of "*Sustainable Construction and Maintenance of Road Pavements*".

In this context, the structure of pavements has to be durable, by integrating innovative materials, and "environmentally friendly", by incorporating industrial waste materials, including pavement planings. In this way, all over the life time, monitoring costs *in situ and in the laboratory* will be reduced and the accuracy of structural behaviour models will be improved.

Thus, it is necessary to promote the structural sustainability of pavements, aiming at "*perpetual pavements*", which only require superficial periodic rehabilitation. At same time, it should also be assumed that a pavement should be managed as a structure in a "*close cycle*": materials used in the construction phase should be

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reused in posterior phases, minimizing any rejection of materials or the use of new materials over its life time.

4.2.1. Pavement Recycling

For a new approach in the field of Maintenance and Rehabilitation of pavements, recycling will play a fundamental role in the life cycle of pavements. As a consequence, research on this field is being focused on maximizing the incorporation of used materials in every rehabilitation action, as well as in new constructions.

Hereafter, two case studies related to the use of recycled materials are presented (Pereira & Picado-Santos, 2006): i) hot mix recycling; ii) cold recycling *in situ*, with bituminous emulsion.

The first case presents the following characteristics:

- The pavement structure is composed of a surface course of 6 cm of bituminous mixture (0/16), a bituminous macadam layer (0/25), 23 cm thick and a granular sub-base (0/50) with a thickness of 20 cm (Figure 6);
- The traffic for the new life cycle of the pavement is 40×10^6 ESALs (80 kN);
- The pavement has been in service for 7 years;
- The degradation shown by the pavement is top-down cracking reaching 10 cm depth; the granular layers present a good condition, being acceptable to consider a subgrade modulus of 60 MPa;
- The road to be rehabilitated is 10 km long, with four lanes. Total area to be rehabilitated: 160000 m^2.

The second case presents the following characteristics:

- The pavement structure is composed of a surface course (bituminous mixture, 0/16), 5 cm thick, a bituminous macadam base (0/25), 7 cm thick, one granular base (0/40), 20 cm thick and a granular sub-base (0/50), 20 cm thick (Figure 7);
- Traffic calculated for the initial life cycle was of 2×10^6 ESALs (80 kN);
- The pavement has been in service for 12 years;
- Every layer of the pavement is in severe conditions. Complete rehabilitation is required.
- From the analysis of the “in situ” characteristics of the pavement a modulus of 60 MPa was assumed for the subgrade;
- The road to be rehabilitated is 10 km long, with two lanes (total width: 8 metres), Total area to be rehabilitated: 80000 m^2.

In order to evaluate the benefits of the reusing the existing material (recycling) for each case study, two rehabilitation alternatives (milling/traditional overlay or recycling) were adopted. Thus, in the first case the solution consists of milling the

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upper 10 cm (with the transference of the milled material into a deposit), and applying new binder and surface courses. For the second case, a traditional overlay would be applied, including a stress absorbing membrane interlayer (SAMI) to retard crack propagation.

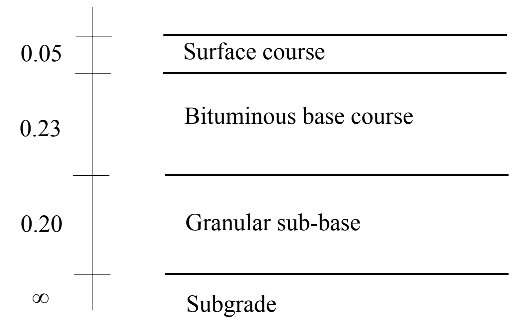

Figure 6 – Pavement structure for the first case study

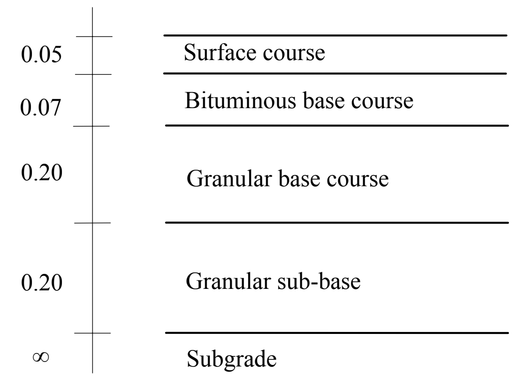

Figure 7 – Pavement structure for the second case study

Concerning the adoption of recycling techniques, milled material will be incorporated in the production (hot mix recycling) of a new bituminous mixture to be applied in the same pavement. In this way, it is possible to reuse 40% of milled material. In the second case the existing pavement will be recycled "in situ", in a depth of 15 cm, with the addition of a bituminous emulsion with 3% of residual bitumen).

Pavement design for each alternative presented was undertaken using the programme BISAR (Shell, 1998). The results obtained for the thickness of new layers are presented in Table 2. Associated costs for each layer, and for the different alternatives, are presented in Table 3 and Figure 8.

Table 2 – Thickness (cm) of the new layers for each alternative

Layer	Case study 1		Case study 2	
	Milling/Overlay	Recycling	Overlay	Recycling
Surface course	5.0	2.0	5.0	5.0
Binder or Base course	11.0	14.0	10.0	15.0

Table 3 – Associated costs for each rehabilitation alternative(in €)

Layer	Case study 1		Case study 2	
	Milling/Overlay	Recycling	Overlay	Recycling
Surface course	800000	352000	400000	400000
Binder or Base course	1232000	1097600	560000	240000
SAMI	--	--	80000	--
Total	2032000*	1449600	1040000	640000
Difference	582400 (28.7%)		400000 (38.5%)	

*The cost associated to dumping the milled material in a landfill is not considered (€20/m^3×16000m^3 = 320000€)

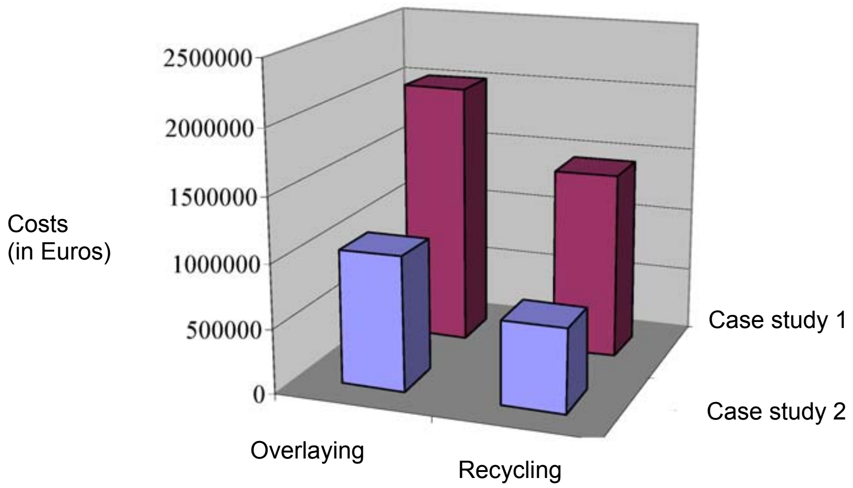

Figure 8 – Costs associated to each rehabilitation alternative

4.2.2. New paving materials

The search of pavement materials with a more accurate behaviour has to include the research of new high performance materials, assuming a minimisation of the maintenance and rehabilitation operations, having as a result the reduction of direct

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costs both for the administration and for users. In addition, the performance of these materials should also allow a reduction of the negative impact on the environment.

The search of high performance material requires the study of bituminous mixtures at the level of microscopic structures.

A micromechanical analysis of bituminous mixtures has been undertaken by several researchers (Buttlar & You, 2001; Silva, 2006). They take advantage of mechanical tests and microstructural models of discrete or finite elements to identify the main causes (at a micro level) of an inadequate behaviour (at a macro level).

According to Buttlar & You (2001), the microstructural modelling of bituminous mixtures is able to simulate the internal structure of aggregates and mastic, predicting accurately their behaviour.

For the study of the bituminous mixtures cracking, the use of a model with *lattice elements* is very efficient due to the importance that the bond between the materials involved (aggregate-aggregate, aggregate-mastic and mastic-mastic) has for the simulation of this phenomenon. In a simplified way, using a lattice model involves the approach to the continuous medium, where each element represents an intact link that could be broken during loading, forming a discontinuity (micro crack). Lattice models can be used to simulate a heterogeneous material, as it is the case of bituminous mixtures.

Recently, Silva (2006) developed a heterogeneous micro structural model made of lattice elements, used to study the evolution of a crack in the mastic and in the bituminous mixtures. The main results obtained with monotonic tensile tests were the tensile resistance, the failure strain and the tangent modulus, in different test configurations. Figure 9 shows the results obtained in the tensile tests carried out for the study of cracking in the mastic (a) and in the bituminous mixtures (b). These results were of fundamental importance for the development of predictive models of the mastic and bituminous mixtures.

Mastic and bituminous mixtures properties were utilised with lattice elements in the microstructural model in order to evaluate the influence of the micromechanical behaviour on the bituminous mixtures cracking. This model simulated the monotonic tensile tests carried out in the laboratory on bituminous mixtures. The aggregate and mastic distribution in the model was supported by digitised images of bituminous mixtures samples.

The factors that allowed the analysis of the quality of the bituminous mixtures predicted behaviour, using the heterogeneous models made of lattice elements, were: i) strength variation with the increase of the deformation, i.e. the non-linear response of bituminous mixtures; ii) cracking pattern observed in the samples.

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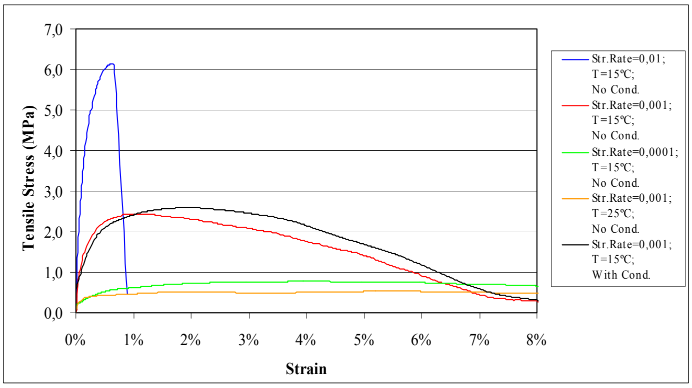
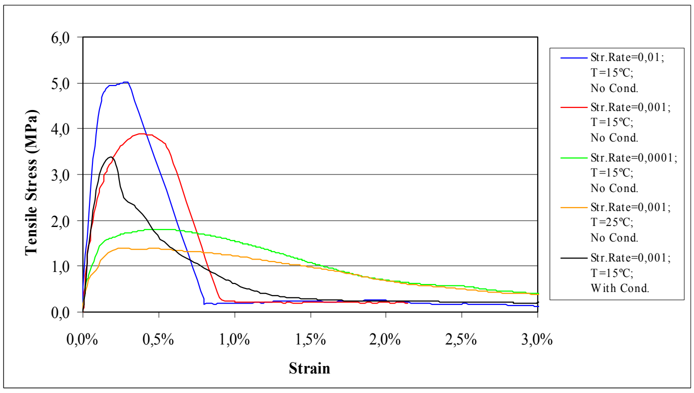


(a)



(b)

Figure 9 – Variation of the tensile stress of mastic (a) and of bituminous mixtures (b) as function of the applied strain

The behaviour obtained in tensile mode in predictive models was compared with that observed in laboratory. A good relationship between the numerical prediction and the experimental results was observed (Figure 10).

The comparative analysis of numerical and experimental results also allows evaluating whether the cracking pattern of models are similar to those observed in laboratory, as shown in Figure 11.

The visual analysis of cracking pattern allows concluding that, in general, cracking patterns observed in laboratory were well predicted by the lattice elements model.

The analysis of this numerical model allows researchers to observe that predicted cracking occurred always through the mastic, generally close to the aggregate surface, what proves the production of cracking in the bond aggregate-mastic due to internal cohesion problems of mastic.

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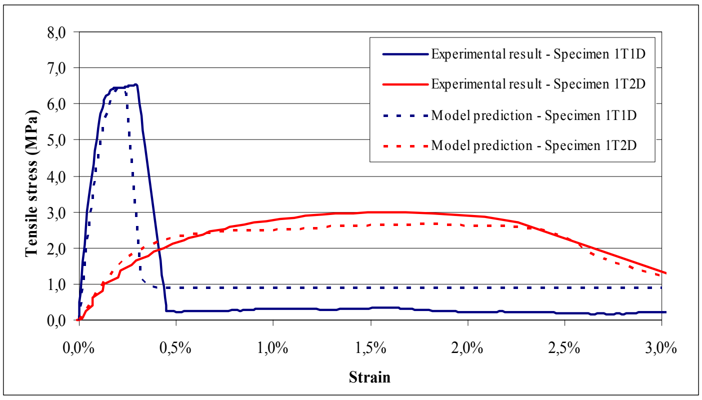

Figure 10 – Bituminous mixtures behaviour observed in laboratory and predicted by the simulation model

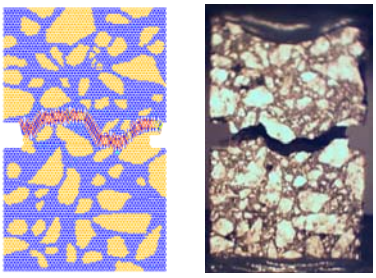

Figure 11 – Cracking pattern predicted in the numerical model observed in laboratory

The introduction of new materials in the constitution of pavement layers and the evolution of heavy vehicle loads configuration lead to the need of updating the current design methods as well as the specifications related to the behaviour of materials that should be demanded from innovative pavement structures.

With the objective of improving the performance of flexible pavements throughout their life cycle, the research of new materials has increased significantly, what means a reduction of future maintenance costs. A common alternative adopted in the field of road engineering is adding polymeric materials to bitumen aiming to improve its properties, mainly those related to thermal susceptibility and fatigue life (Neto, 2003).

Another concern associated to the improvement of the bituminous mixtures is the environment. Experiences with rehabilitated pavements in different countries have demonstrated the excellent structural and functional performance of bituminous mixtures with asphalt rubber modified bitumen.

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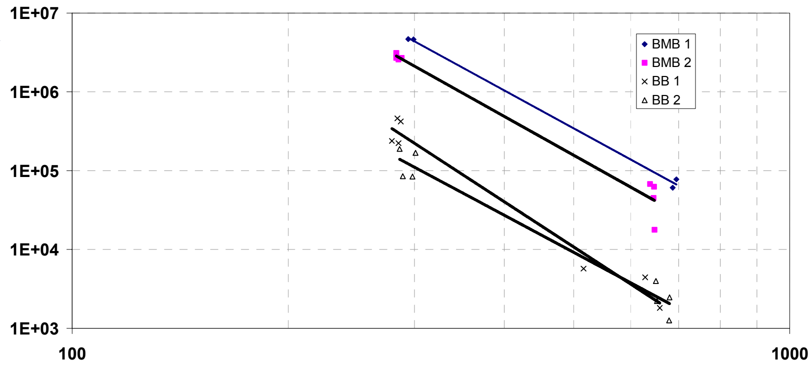

Figure 12 – Laboratorial performance of asphalt rubber and conventional bituminous mixtures

In the context of improving the behaviour of bituminous mixtures and reducing the environmental pollution, bituminous binders modified with rubber from used tires, known as asphalt-rubber, emerge. In general, with this type of new binder, significant improvements are observed: in the fatigue life as well as a reduction in the maintenance costs, an increase of skid resistance, a reduction of the cracking propagation phenomenon and a reduction of the noise level.

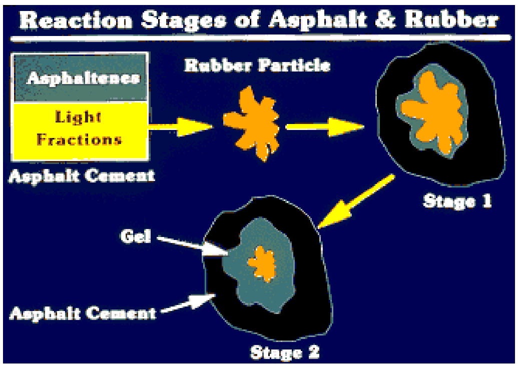

Figure 13 – Hypothetical model of the interaction between rubber particles and the conventional bitumen (Holleran & Reed, 2000)

Using fatigue tests in the four-point bending configuration, a difference in the performance between conventional mixtures and mixtures with asphalt-rubber was observed by Sousa et al. (2000), as shown in Figure 12.

The justification for the different performance of those two mixtures is supported by Holleran & Reed (2000). According to these authors, the asphaltenes and light fractions (maltenes, resins) of conventional bitumen interact with rubber particles.

A reaction is claimed to occur, in which the asphalt and the rubber particle interact to form a gel coated particle (Figure 13). This mechanism allows fixing lighter fractions of bitumen, protecting them from climatic agents and avoiding their evaporation.

The application of numerical modelling to the design of pavement overlays allows to prove that mixtures with asphalt-rubber require a less thick overlay than those using conventional bitumen (Figure 14).

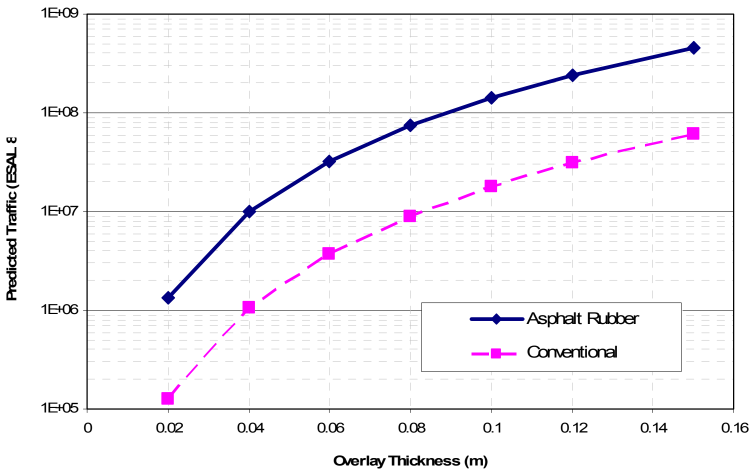

Figure 14 – Influence of bituminous mixture type in the overlay life (Sousa et al., 2005)

5. CONCLUSIONS

In the near future, the rehabilitation of the road network will assume a determinant importance and will lead to the adoption of a proactive vision in the field of road management. This global vision of rehabilitation will integrate all the components of the road network, as well as stakeholders.

In this context, innovation will assume an irreplaceable role by supporting road administrations, including road safety, to integrate the interaction "driver-vehicle-road" and the functional quality for users, non users and the environment. This approach will only be possible with the contribution of a sustainable strategy of construction and rehabilitation which will become part of a strategic cooperation among universities, road administrations and road related companies.

References

1. AIPCR – Technical Committee C7/8, Innovative Pavement Design, Paris (2003).

ISSN 1582-3024

2. FP[2], Foundation for Pavement Preservation, Pavement Preservation Today, Vol.2, nº1, Summer 2001, Virginia (2001).
3. Austroads, Road Environment Safety Guide to Road Safety Program Management, Sydney (2003).
4. Buttlar W., You Z., Discrete element modelling of asphalt concrete: a micro-fabric approach, *TRB 80th Annual Meeting*, Transportation Research Board, Washington D.C. (2001).
5. Camomilla G., Luminari M., Silent road for urban and extra-urban use: the innovative resilient and resonant pavements, *5th symposium on pavement surface characteristics - roads and airports*, World Road Association, CD-Rom. Toronto (2004).
6. FEHRL – Federation of European Highway Research Laboratories, Nr2c – New Road Construction Concepts, Bruxelles (2004).
7. Fujiwara T., Meiarashi S., Namikawa Y., Hasebe M., Noise reduction effect of porous elastic road surface and drainage asphalt pavement, *84th Transportation Research Board Annual Meeting*, Transportation Research Board, Washington, 2005.
8. Hofman R., Kooij J., Results from the dutch noise innovation program road traffic (IPG) and roads to the future program (WnT), *Proceedings of Internoise 2003, 32nd International Congress and Exposition on Noise Control Engineering*, Korea (2003).
9. Holleran, G. e Reed, J.R. Emulsification of asphalt rubber blends, *Asphalt Rubber 2000 Conference*, Vilamoura (2000).
10. Macedo A., Gomes S., Cardoso J., Políticas e programas de segurança rodoviária e sua relação com o risco de acidentes em diferentes países europeus, *Estrada 2006, Centro Rodoviário Português, CD-Rom*, Estoril (2006).
11. Martins P., Nabais E., Segurança rodoviária algumas reflexões sobre metodologias de gestão e sua implementação em Portugal, *Estrada 2006, Centro Rodoviário Português, CD-Rom*, Estoril (2006).
12. Neto, S.A.D., Avaliação das propriedades dos ligantes e das misturas asfálticas modificadas com borracha granulada de pneus usados, *Ph D Thesis*, University of Brasília (2003).
13. Nobre S., Pavimentos modificados em borracha – enquadramento ambiental, *Estrada 2006, Centro Rodoviário Português, CD-Rom*, Estoril (2006).
14. Nunn M., Long-Life Flexible Roads, *8th International Conference on Asphalt Pavements, Vol. I, pp 3-16*, Seattle (1997).
15. Pereira, P. and Picado-Santos, L., Technical-Economical Evaluation of Pavement Recycling Alternatives, *Third Gulf Conference on Roads*, Muscat (2006).
16. Rothengatter T., Huguenin D., Traffic and transport psychology - Theory and application, *Proceedings of the ICTTP 2000*, Oxford, Elsevier (2004).
17. Shell International Oil Product BV, BISAR 3.0 – BItumen Stress Analysis in Roads, *User Manual*, The Hague (1998).
18. Silva H., Characterization of the bituminous mastic and the aggregate-mastic bond: contribution to the study of the bituminous mixtures' behaviour, *Ph D Thesis,* University of Minho, Guimaraes (2006).
19. Sousa, J.B., Pais, J.C. e Way, G.B., A Mechanistic-Empirical Based Overlay Design Method for Reflective Cracking, *Asphalt Rubber 2003 Conference*, Brasilia (2003).
20. Sousa, J.B., Pais, J.C. e Way, G.B., A Mechanistic-Empirical Based Overlay Design Method for Reflective Cracking, *Road Materials and Pavement Design*, nº 3, vol. 6 (2005).