Maintenance and Rehabilitation of Pavements and Technological Control

Proceedings of the Fifth International Conference
Park City, Utah, USA
8-10 August, 2007

Edited by

Hosin "David" Lee
M. Asghar Bhatti

Preface

The sustainable maintenance and rehabilitation of pavements is becoming a key challenge in many countries in 21st century. It is well known that road and airfield pavement is the backbone of the economic prosperity and public welfare. But, the sustainability challenges pavement builders and managers to respond creatively to new and dynamic problems of rehabilitating and maintaining pavements in the most environmentally friendly manner by lowering energy cost, reducing traffic noise, and minimizing air and water pollution.

With sustainability as the main theme the **MAIREPAV5** (**MAI**ntenance and **RE**habilitation of **PAV**ements and Technological Control) conference was organized at the Canyons Resort in Park City, Utah, USA by the University of Iowa, from August 8-10, 2007. This is the **5**th International Conference in the series of conferences organized to allow researchers, government agencies, consultants and contractors to exchange technological advancements and innovations of building and maintaining longer-lasting road and airfield pavement. The first conference was held in São Paulo, Brazil by Mackenzie University in 1999, the second in Auburn, USA by the University of Mississippi in 2001, the third in Guimarães, Portugal by University of Minho in 2003, and the fourth in Belfast, Northern Ireland by the University of Ulster in 2005.

This book consists of papers presented at the MAIREPAV5 conference. The book includes two keynote papers on FHWA pavement and materials program and importance of good construction on reducing maintenance costs and eighty-eight peer-reviewed papers. Each paper was reviewed by at least two experts from the International Organizing and Scientific Committee. The final revised manuscripts were then reviewed by the editors to ensure compliance with the recommendations and suggestion made by the reviewers. The book is organized into fifteen sections based on the order of the technical sessions presented at the conference: asphalt pavement materials, concrete pavement materials, pavement construction, asphalt pavement performance modeling, concrete pavement performance modeling, pavement economic analysis, asphalt pavement rehabilitation, concrete pavement rehabilitation and recycling, pavement evaluation, asphalt pavement recycling I, pavement noise and safety, pavement management, asphalt pavement recycling II, sustainable pavement materials, and pavement preservation.

We would like to recognize the co-sponsors of MAIREPAV5: International Society for Maintenance and Rehabilitation of Transportation Infrastructure (iSMARTi), Federal Highway Administration (FHWA), Transportation and Development Institute (T&DI) of American Society of Civil Engineers (ASCE), Transportation Research Board (TRB), Korean Society of Road Engineers (KSRE), and Public Policy Center (PPC) and Civil & Environmental Engineering Department of the University of Iowa. We would like to record our indebtedness to distinguished members of International Organizing and Scientific Committee who have peer-reviewed papers and guided us to the success of this conference. Finally, we would like to thank authors who convened in Park City, Utah from all over the world to share their knowledge and experiences in building and maintaining pavements and their invaluable contributions to this book.

It was our honor and privilege to host MAIREPAV5 and edit this book.

Hosin "David" Lee / M. Asghar Bhatti

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REHABILITATION STUDY OF A HEAVILY TRAFFICKED URBAN ROAD

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Abstract: Rehabilitation of urban roads is usually carried out with special restrictions in order to limit traffic congestion and to assure the link between different routes through the urban areas. Therefore, the user costs resulting from the rehabilitation works should also be taken into consideration in the project phase. The present paper focuses on the analysis of a heavily trafficked urban road rehabilitation project. The original pavement design did not take into account the current traffic levels which are well above the initial values. The pavement is reaching failure in several areas and needs urgent measures to avoid complete failure. The pavement condition is also a result of lack of structural strength and a deficient drainage. Different pavement rehabilitation alternatives were assessed in order to choose the best solution, which should improve the bearing capacity of the pavement, through the rehabilitation of the existing layers and the improvement of the drainage systems, in order to minimize the maintenance operations in the future. The rehabilitation alternatives were also analyzed in terms of the impact of the maintenance operations in the environment.

INTRODUCTION

The type of road studied in the present paper can be classified as a good candidate for the use of Long Life Pavement (LLP) design principles. Due to the very high traffic levels, any maintenance operation causes disruption and delays on the normal flow of the traffic, with increased costs to the users and the environment. An analysis of a part of the UK network whole life cost, carried out by Chenevière and Ramdas (2006), suggests that the adoption of the LLP design principles, on a heavily trafficked road network, presents large potential benefits even before considering the environmental benefits of such an approach. Therefore, a comprehensive study was carried out to analyze the most adequate rehabilitation alternative for this urban road.

CHARACTERIZATION OF THE ROAD AND PAVEMENT CONDITION

The road section studied in this paper (approximately 3 km long) is part of a main link of the city of Braga with the Portuguese highway network. The traffic assessment carried out during this study showed an Average Annual Daily Traffic (AADT) value of about 50000 vehicles, 2000 of which are classified as heavy vehicles. The road cross-section comprises a dual carriageway, each with three traffic lanes, along 1 km, and two traffic lanes along the other 2 km.

Urban roads usually present some restrictions regarding the final level of the pavement surface, due to the presence of adjacent footpaths and infrastructures installed bellow them. This has a significant influence on the solution chosen to rehabilitate the pavement, since it restrains the thickness of eventual overlays. This is the case of the present study.

Although the pavement has been in service for less than 15 years, several maintenance operations have already been carried out, including overlays and surface course replacements in some areas. Nonetheless, the pavement is reaching failure in a major part of the length and a different maintenance strategy is needed for the next pavement rehabilitation. Thus, a comprehensive analysis of the pavement condition and bearing capacity was carried out. Following a visual analysis of the surface, a series of Falling Weight Deflectometer (FWD) tests was performed and some boreholes were opened, in order to collect some samples for further laboratory testing. Visual observation of the pavement condition showed a high level of degradation for several distress types, namely rutting and alligator cracking.

FWD tests were performed on the most trafficked lane of each way with an approximate spacing of 50 meters, in order to characterize the bearing capacity of the pavement throughout the length of the studied road section. The ASHTTO cumulative difference approach has been used to analyze the results in terms of homogeneous sections by plotting the maximum deflection values obtained in each point versus distance along the project (Figure 1) and by calculating the cumulative differences between the area under the response curve at any distance and the total area developed from the overall project average response at the same distance (ARA, 2004). The homogeneous section boundaries are defined as the positions where the slope of the graph changed sign.

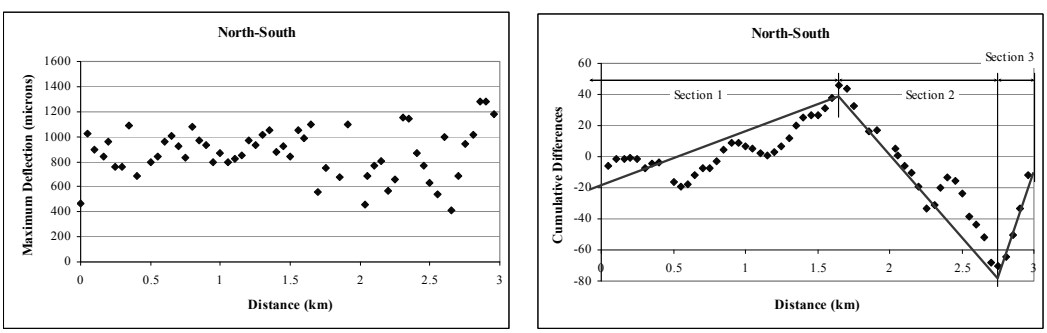

Figure 1 – Maximum deflection values and Homogeneous Sections obtained (North-South way)

According to the results obtained from the previous figure, the characteristic deflection values for each homogenous section were obtained by the statistical analysis of the percentile 85. The resulting values for the North-South way are presented in Table 1. A similar analysis was also carried out for the opposite way.

Table 1 – Characteristic deflection bowls obtained for each homogeneous section (North-South)

Distance (m)	0	0.3	0.45	0.6	0.9	1.2	1.5	1.8	2.1
Def. Section 1 (μm)	1027	638	450	330	190	130	96	76	61
Def. Section 2 (μm)	1028	668	469	340	179	105	74	54	40
Def. Section 3 (μm)	1281	821	566	392	188	112	76	57	46

Based on the results obtained for both ways, boreholes were defined in specific locations with the objective of assessing the pavement structure and the mechanical characteristics of the

materials comprised in each layer. Thus, six boreholes were open (three in each way) and samples were collected from each for further laboratory testing. From the analysis of the pavement structure on the six different locations it was possible to conclude that quality control during the construction phase was not well performed. The same pavement structure (particularly the thickness of each layer) was not found in any of the six different locations. Therefore, it was difficult to define the pavement structure that should be used while modeling the existing pavement to back-calculate the stiffness modulus of each layer. The structures of two points were used as references along the road to represent the existing pavement, according to the deflection values (presented in Table 1 for the North-South way). Thus, one structure was used for Sections 1, and 2 while the other was used for section 3, as can be observed in Figure 2. A similar approach was used for the opposite way. For the two pavement structures presented in Figure 2, the stiffness moduli results obtained by back-calculation are presented in Table 2.

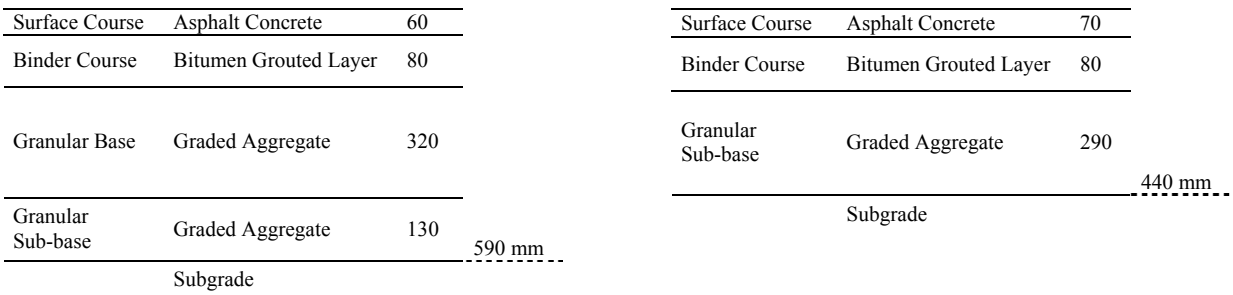

Figure 3 – Reference structures used to model the pavement along the road

Table 2 – Stiffness modulus of each layer obtained by back-calculation

Structure 1		
Layer	Thickness (mm)	Stiffness (MPa)
Surface Course	60	950
Binder Course	80	450
Granular Base	320	300
Granular Sub-base	130	100
Subgrade	----	36

Structure 2		
Layer	Thickness (mm)	Stiffness (MPa)
Surface Course	70	850
Binder Course	80	450
Granular Sub-base	290	250
Subgrade	----	27

There are records of groundwater appearance at the pavement surface in some locations, especially in the raining season. Tests performed over the collected samples confirmed high water content in some subgrade soils. The main reason for this is the absence of a subsurface drainage system, what indirectly contributes to the reduced pavement bearing capacity by decreasing the strength of the granular materials. From the results obtained, it can be concluded that the pavement needs urgent rehabilitation measures in order to avoid total reconstruction and to improve the pavement condition to assure an appropriate service level.

DESIGN OF PAVEMENT REHABILITATION ALTERNATIVES

According to the traffic volume measured in the studied road section, the minimum design life that should be considered in the design of any rehabilitation alternative is 20 years. Thus, the corresponding number of equivalent standard axles (of 80 kN) was estimated to be of 84×10^6. For such a high level of traffic and with an existing pavement in such a poor condition, a partial reconstruction of the pavement was needed. Due to constrain in raising the final level of the pavement surface, the solution would have to include removal of the top part of the pavement and the application of new layers.

The traditional alternative (hereafter mentioned as alternative A) would consist of removing the bound layers (surface and binder courses) of the existing pavement and substituting them by new bituminous layers. The milled material would be dumped into a landfill deposit and new aggregates and binder would be used to produce the mixtures for the new layers. This alternative would also include the construction of a subsurface drainage system to reduce the water susceptibility of the pavement throughout the year.

A different alternative (B) would comprise the recycling of part of the existing materials in order to improve the bearing capacity of the pavement without increasing significantly the amount of new materials used and the disposal of construction waste. In order to reduce the influence of the structure variability throughout the project, this alternative would include the reclamation of the surface course material (to be included in the production of a new bituminous mixture for the new binder course) and the recycling of the remaining material (in a thickness of about 150 to 230 mm) with the addition of cement. This would the main structural layer and the pavement would become semi-rigid. The thickness of the new binder and surface courses would be then calculated in accordance with the design traffic.

A similar alternative (B1) would include the construction of a subsurface drainage system. This should increase the stiffness of the subgrade and granular layers and reduce the thickness of the bituminous bound layers. In both B and B1 alternatives, a Stress Absorbing Membrane Interlayer (SAMI) would be applied between the cement recycled layer and the new bituminous layers in order to reduce the crack propagation phenomenon. This is usually observed in pavements with cementitious base courses.

For each alternative, the thickness of each new/recycled layer was calculated using BISAR 3.0 program. Computations were made until the traditional failure criteria (i.e., fatigue of bound layers and permanent deformation of subgrade) were fulfilled. The criteria used in this study are those developed in the SHELL method (Claessen et al., 1977).Cracking in the cementitious base course (alternatives B and B1) was not taken into account for design purposes, since a SAMI was used to resist the movements of the cracks, reducing the propagation rate to the overlay.

The design calculations resulted in the solutions presented in Tables 3 and 4, in terms of pavement constitution. Table 5 summarizes the thicknesses that need to be milled off for each alternative, as well as the increase in the final level of the pavement surface.

Table 3 – Pavement structure 1 design results for the studied alternatives

Layer	Alternative A		Alternative B		Alternative B1	
	Material	Thickness (mm)	Material	Thickness (mm)	Material	Thickness (mm)
Surface Course	Asphalt Concrete	40	Asphalt Concrete	50	Asphalt Concrete	40
Binder Course	Asphalt Concrete	70	Recycled AC	80	Recycled AC	50
SAMI	--	--	--	10	--	10
Base Course	High Modulus Bituminous Macadam	110	Cement Recycled Material	150	Cement Recycled Material	150

Table 4 – Pavement structure 2 design results for the studied alternatives

Layer	Alternative A		Alternative B		Alternative B1	
	Material	Thickness (mm)	Material	Thickness (mm)	Material	Thickness (mm)
Surface Course	Asphalt Concrete	50	Asphalt Concrete	50	Asphalt Concrete	40
Binder Course	Asphalt Concrete	80	Recycled AC	80	Recycled AC	50
SAMI	--	--	--	10	--	10
Base Course	High Modulus Bituminous Macadam	130	Cement Recycled Material	230	Cement Recycled Material	230

Table 5 – Thickness variations for the studied alternatives

Alternative	Structure	Thickness milled off (mm)	Increase in the final level (mm)
A	1 / 2	140 / 150	80 / 110
B	1 / 2	80	60
B1	1 / 2	80	20

TECHNICAL-ECONOMIC AND ENVIRONMENTAL EVALUATION

According to the principles used in the design program (e.g. linear elastic behavior of all layers), it was not possible to take into account the structural contribution of the SAMI in alternatives B and B1. Thus, the inclusion of the membrane should be assumed as a safety factor, due to its contribution to a better distribution of the traffic loads to the layers underneath. The solutions presented in Table 4 could be assumed as technically equivalent, but the same is not valid in economic and environmental terms. Table 6 shows the costs estimation obtained for each alternative without taking into account the costs of disposing the construction waste in a landfill.

Table 6 – Cost estimation for the studied alternatives

Alternative	Cost (thousand €)			Difference (%)
	Pavement	Drainage	Total	
A	965.8	121.9	1087.7	0.0
B	874.7	0	874.7	-24.3
B1	772.2	121.9	894.1	-21.7

According to the results presented in Table 6, the alternatives which include recycled materials are less expensive than the traditional alternative, even without quantifying the costs of waste disposal. Therefore, in technical and economic terms, the best solution is alternative B1, since it can assure a better behavior of the pavement, with less variation on the bearing capacity of the granular layers due to the reduction of water within the pavement structure. Furthermore, the traditional alternative would result in an increase in the pavement surface level of about 80 to 110mm. In order to apply this solution, it would be necessary to raise all the footpaths adjacent to road, the cost of which was not included in this estimation. On the other hand, the alternative B1 has just a marginal increase of 20 mm which can be made without modifying the footpaths.

IMPACT OF DIFFERENT REHABILITATION ALTERNATIVES ON THE ENVIRONMENT

Even though the cost of new materials has been considered in the previous estimation, the savings obtained by reducing the consumption of natural resources (aggregates and binder) and by reducing the disposal of construction by-products is not easy to quantify. This represents an important part of the environmental costs that are attributed to the traditional rehabilitation alternative. Table 7 shows the estimation of the volumes of materials involved in each alternative, and the percentage of savings obtained by choosing alternatives B and B1 rather than the traditional alternative (A).

Table 7 – Volumes of material used in the studied alternatives

Alternative	New Material (m3)	Savings (%)	Landfill (m3)	Savings (%)	Recycled (m3)
A	12460	0.0	7593	0.0	0
B	5584	-55.2	4056	-46.6	1264
B1	3951	-68.3	4116	-45.8	790

Significant savings can be observed in Table 7 for alternatives B and B1, especially for the environment, with reductions of more than 55% in the consumption of new resources and of more than 45% in the disposal of construction by-products. This is particularly important since the disposed material still presents potential value to be used in the pavement industry.

According to Pereira and Picado-Santos (2006), the cost of milling the top 10 cm of an existing asphalt pavement, transport and disposal of the material in a landfill is close to €20/m^3, on average. Deducting the cost of the milling operation (which has already been taken into account), the cost of transporting and dumping the construction by-products in the landfill would be of about €6.5/m^3. The cost of disposing the milled material in the present project can be estimated in about €50 000, which is a significant value (about 4.5% of the overall costs of alternative A).

Apart from the purely economic point of view, issues like CO_2 emissions are becoming increasingly important nowadays. Therefore, the amount of gas emissions during the overall construction cycle (transport of disposed materials; production of new aggregates and binder; transport of resources to the mixing plant; mixture production; transport of the mixture to site) should be taken into account when selecting any rehabilitation alternative. In the present study, these emissions would be greatly reduced by selecting alternatives B or B1.

CONCLUSIONS

According to the results presented in this paper, the main conclusions to be drawn are as follows:

- Significant savings can be obtained by choosing rehabilitation strategies that include recycled materials in the new layers (overall cost savings of up to 24% in the present project);
- Significant environmental cost savings can be obtained when using recycled materials, (reductions of more than 55% in the consumption of new resources and of more than 45% in the disposal of construction by-products were calculated for the present project);
- CO_2 emissions can be greatly reduced by using rehabilitation strategies comprising “in situ” recycled materials.

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