Case Study: Monitoring and Analysis of two road stretches applying Pavement Rehabilitation Solutions in State of Ceará/Brazil

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ABSTRACT

Since 2009, the Ceará State Road Department (DER/CE) applied solutions of pavement rehabilitation on more than 2,020km of the State’s roadways. The stretches that received these solutions are continuously monitored. Pavement Surface Defect Surveys and International Roughness Index (IRI) measurements of the pavement surface are made.

This study aims at investigating the effects of pavement rehabilitation on roads lifetime, on the re-establishment of good service conditions, and on the costs when compared to reconstruction. For the elaboration of this work, a database of 40 pavement stretches was used containing results from monitoring, survey, and measurements performed in the rehabilitated stretches prior to and after interventions have been carried out. This database is kept on Pavement Management System called SIGMA (Integrated System of Maintenance Management).

A Case Study of two Stretches where pavement rehabilitation solutions have been applied will be presented in more details. A critical analysis of the impact of the intervention in matters such as surface conditions, pavement lifetime extension, comfort, and economic criteria such as user costs (operational cost and travel time) is presented. Through the software HDM4 - Highway Development & Management, the study evaluates and compares the technical and economic viability of the pavement rehabilitation as an alternative to the reconstruction of the Pavement.

Keywords: Pavement Rehabilitation, Pavement management, Monitoring, Pavement Surface Defect Survey, International Roughness Index

1. INTRODUCTION

The Ceará State Road Department (*Departamento Estadual de Rodovias* – DER/CE) has under his jurisdiction a road mesh with 7,578.94 km [1]. These roads are continuously monitored. Every year, Pavement Surface Defect Surveys are made throughout all the length of the State’s road mesh. At the same time, the measurement of the International Roughness Index (IRI) of the pavement surface is made in selected stretches.

Until 2009, DER/CE mainly did 3 kinds of intervention on the road mesh: paving, reconstruction, and duplication of highways, besides routine maintenance actions. Preventive actions were not frequent. With the development of technology and the rise of new concepts, techniques, and materials, engineering analysts have been searching new ways to reduce costs, increase the quality and productivity of the road works, and reduce environmental impact. Thereby, aiming at improving the road mesh condition, DER/CE implemented its Pavement Rehabilitation Program.

Pavement rehabilitation's main goal is to re-establish the pavement functionality. It increases the lifespan of the highway, bringing back good service conditions, comfort for the users, and reducing operational costs and travel time, mitigating the effects of rutting, fatigue cracking, and other distresses [2].

Asphalt pavements rehabilitation usually involves milling and resurfacing of the existing pavement. The main overlay techniques are: asphalt mixture over asphalt mixture, concrete over asphalt mixture, milling and overlay, milling and inlay. All these solutions can be designed either as a structural or as a non-structural improvement, depending on issues with the existing material, vertical limitations, subgrade and base support. When the pavement is at the end of its service life, recycling solutions may be recommended [3].

The choice of road segments to be rehabilitated should be aided by a Pavement Management System, especially in a scenario of budget restriction [4]. DER/CE currently uses a database for Pavement Management System information (SIGMA) containing Pavement Surface Defect Surveys (made annually in all road mesh extension) and a software for Highway Development & Management (HDM-4).

In order to define alternatives for pavement rehabilitation solutions, a pavement evaluation must be carried out. The pavement evaluation involves relating the symptoms of pavement distress to their causes and explaining the development of the distresses. In order to achieve this goal, it is necessary to assess the functional (visual rating, functional testing) and structural (response to load) conditions of the existent pavement. A prediction of the future conditions should also be performed [2,5]. DER/CE keeps on SIGMA: pavement surface defects, IRI, deflection, and traffic. This database facilitates pavement evaluation and also the monitoring of the segments that have received pavement rehabilitation solutions.

The DER Pavement Rehabilitation Program has been providing good results, with an average increase in the lifespan of the highways in 5 years, at a cost from 3 to 5 times lower than reconstruction. These results made the Pavement Rehabilitation Program a useful way to optimize the investment of the resources, covering a bigger extension of the State road mesh at a lower cost and enhancing the overall pavement quality.

In this document, two cases (out of 40 analyzed) of road stretches are presented in which were applied pavement rehabilitation solutions. These stretches have been monitored since then. Pavement condition, IRI, and economic viability will be evaluated.

2. METHOD

The monitoring of the paved road mesh under DER/CE jurisdiction is held every year through a group of surveys and field studies. The data obtained from the monitoring are registered into SIGMA. This data forms a database with information about each road segment, making it possible to monitor the performance of the road stretches that received pavement rehabilitation solutions before and after the intervention.

Among the monitoring actions and field studies carried out by DER/CE, Pavement Surface Defect Surveys (Continuous Visual Survey – CVS) and the measurement of the International Roughness Index (IRI) of the pavement surface were used as analysis tools. The Pavement Surface Defect Survey is made with an automated apparatus. A digital odometer, GPS, two high-definition cameras (one on the top of the vehicle, for a panoramic register, and the other on the hood, aiming at the pavement, for defects registration) and a computer with a defect registration system are attached to the vehicle, as seen on Figure 1. The IRI measurement is done with the same equipment set, adding the Laser Surface Profilometer.

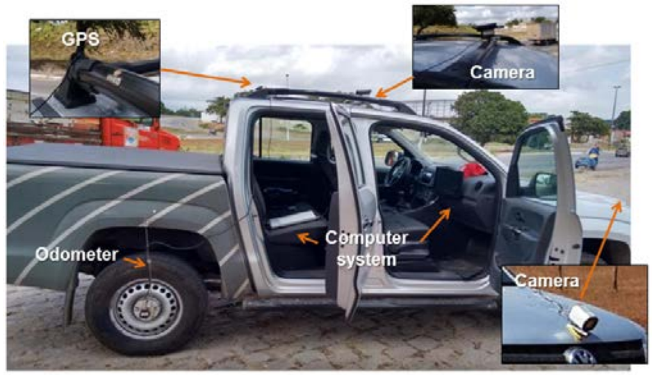


FIGURE 1 Vehicle used in field surveys

The pavement condition was evaluated by the visual identification of the surface defects and their degree of severity, both being results of the CVS. The following defects are registered in the survey: fatigue cracking, block cracking, patching (including full-depth repairs) or potholes, surface wearing, and rutting. One of the SIGMA outputs, after the processing of CVS data, is a Pavement quality index based on Pavement Condition Index (PCI) [6].

The IRI measurement, a way to evaluate the pavement smoothness (ride quality) was done with a Laser Surface Profilometer (Class II Equipment). This equipment has a road pavement longitudinal profiling system, which is aided by distance sensors (lasers), accelerometers, odometer, and speedometer, and it collects inputs for the IRI calculation by a microprocessed system [7]. IRI values were calculated for every 200m of the segments. In this work, the weighted average of the values is presented.

In order to evaluate the benefits achieved with the application of pavement rehabilitation solutions in comparison with the investment made for its execution, an Economic Viability Study of the analyzed stretches has been done. The economic evaluation has been carried out through the calculation of an Internal Rate of Return (IRR) using the methodology of the HDM-4 software. The IRR is a metric commonly used by International Banks and Financing Agencies as a way to measure the profitability of potential investments. The analysis of the selected stretches was conducted considering the different kinds of solutions proposed, estimating construction and maintenance costs of the highways, as well as user's costs (operational costs of the vehicles and travel time). In the HDM-4 methodology, variables related to highway geometry, pavement structure, traffic volume and its composition, growth rates, maintenance policies and others are involved [8].

This analysis was carried out for 40 stretches rehabilitated by DER/CE. In this paper, two stretches are presented in more details. The stretch selection was done trying to comprise different original surfacing materials and pavement rehabilitation solutions, and, in addition, their logistic significance on the State's road mesh was taken into account.

3. RESULTS AND DISCUSSION

3.1 Stretch 1: CE-265 - Morada Nova – Quixadá

The first case study is a stretch of CE-265, connecting the cities of Morada Nova and Quixadá, with 73.15km of extension. The Average Daily Traffic (ADT) of the segment in 2012 was 1,127 vehicles daily, 30% of them being heavy-vehicles (buses and trucks). The expected annual growth rate was 7.33% [8].

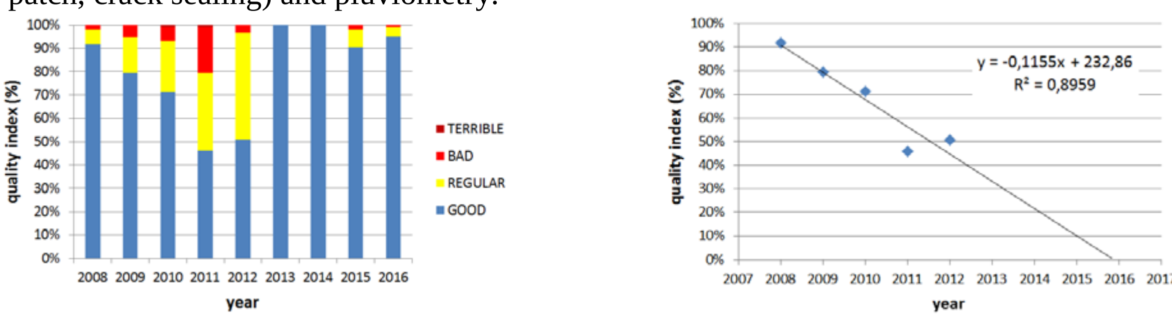
The segment's original surfacing was a Double Surface Treatment (DST) and has already shown surface wearing, fatigue cracking and patching. At that time, maintenance actions were solicited more frequently and their costs were increasing.

After a previous evaluation, functional and structural surveys, and a field inspection, the pavement rehabilitation solution designed was a full-depth reclamation (blending the full thickness of the surface with the base) with a Double Surface Treatment re-surfacing in places where a more severe intervention was needed (on approximately 20% of the stretch), and the application of 2-layers cold microsurfacing (on the remaining 80% of the extension of the segment). The road works were carried out between July and November of 2013, with an average cost of R$ 94,501.95 (US$ 41,857.62) per km, in terms of costs at the time of the intervention [9]. Figure 2 shows pictures before (a) and after (b) the road works.

(a) before – 09/2012 (b) after – 10/2016

FIGURE 2 Pictures before and after the pavement rehabilitation in Stretch 1

Figure 3(a) shows the evolution graph of the pavement surface quality, classified in 4 groups: good, regular, bad and terrible. The data shown on this graph is a quality index calculated by SIGMA for each segment of state road mesh, based on distresses registered on CVS surveys. In the graph, it is possible to observe that even after 4 years of the pavement rehabilitation, 95% of its extension can be classified as being in good condition. A trend line with the data prior intervention (R^2 = 90%) was traced, as seen in Figure 3(b). It is possible to notice that, without any action, the segment would be completely collapsed by 2016. Due to the small variation in the quality index, the trend line obtained after the intervention is not accurate (R^2 was lower than 50%). The variance on the results shown in the graph is explained by its dependence on other factors such as the amount of investment on minor maintenance actions (e.g., patch, crack sealing) and pluviometry.



(a) Evolution of the pavement quality (b) Prior intervention trend line

FIGURE 3 Pavement quality analysis prior to and after the pavement rehabilitation in Stretch 1

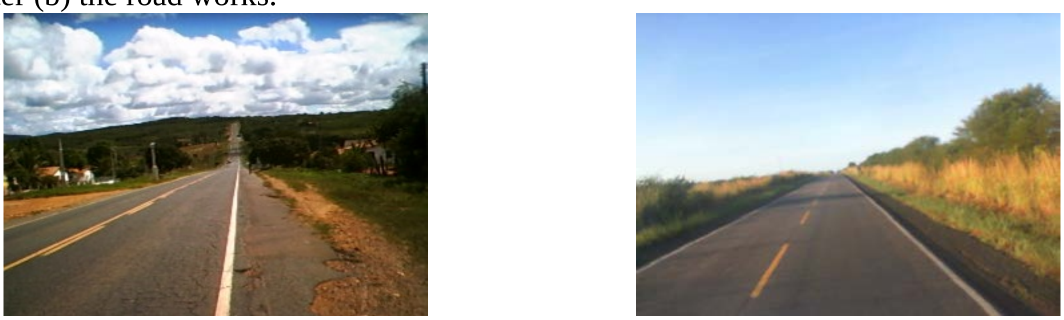
Prior to the pavement rehabilitation, the IRI values were rising, from 2.465mm/m in 2008, to 2.788mm/m in 2012 (measurement made before the intervention). In 2016, measured IRI was 2.714mm/m. According to DNIT (2013)[10], which defines limits for IRI values as: good (IRI < 3mm/m), regular (3mm/m $\leqslant$ IRI < 4,5mm/m), and bad (IRI $\geqslant$ 4.5mm/m), the stretch was classified as good, even after 3 years of pavement rehabilitation works.

The economic evaluation of the pavement rehabilitation on this segment was made using the HDM-4 methodology, comparing two different scenarios. The first scenario presents no intervention, while the second one considers that an investment is made for pavement rehabilitation. The results obtained on the report “Economic Indicators Summary”, an output from HDM-4, indicates that the investment made on this stretch had an IRR of 17.6%. It should be pointed out that BID (*Banco Interamericano de Desenvolvimento*), the main financing agency in Latin America, including for DER/CE, demands an IRR above 12% to consider a project as economically viable.

3.2 Stretch 2: CE-293 - BR-116 intersection - Barbalha

The second case study is the stretch located on CE-293, connecting BR-116 intersection to the city of Barbalha, with 50.7km of extension. BR-116 is one of the main Brazilian roads, crossing the whole country from north to south (Fortaleza, Ceará, to Jaguarão, Rio Grande do Sul). Barbalha is located on Cariri’s Metropolitan Region, one of the biggest social and economic centers on the Ceará country-side, with industries, universities, and tourism.

The ADT of the segment in 2012 was 5,788 vehicles daily, 11.3% of them being heavy-vehicles (buses and trucks). The expected annual growth rate was 6.74% [8]. The segment original surfacing was Asphalt Concrete (AC), and the most common distress was fatigue cracking. Rutting or other deformations were not observed. Figure 4 shows pictures before (a) and after (b) the road works.

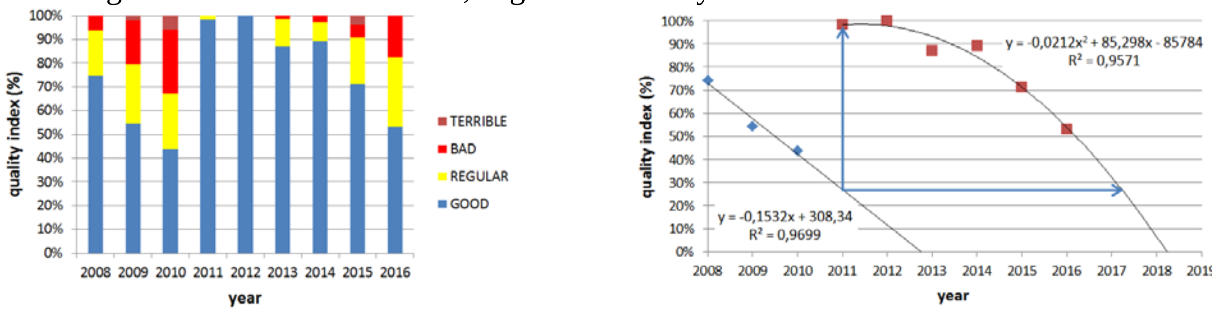


(a) before – 09/2010 (b) after – 10/2016

FIGURE 4 Pictures before and after the pavement rehabilitation in Stretch 2

The duplication of this segment was scheduled to happen in 2017. The main goal of Pavement Rehabilitation on this case was to keep the stretch in good conditions until the execution of the road works. The proposed solution was resurfacing the whole extension with AC with a thickness of 3cm and full-depth reclamation or milling, in the more degraded segments at an average cost of R$ 139,427.46 (US$ 89,376.58) per km, in terms of costs at the time of the intervention. It is worth to mention that if a wider intervention on the highway were not scheduled in a mid-term, crack control measures, such as Stress Absorbing Membrane Interlayers (SAMI), constructed under asphalt overlays should be designed, in order to achieve a longer lifespan of the rehabilitated pavement [2].

Monitoring of this stretch shows that the objective was accomplished. The Pavement Surface Quality evolution graph (Figure 5 (a)) shows that the percentage of the highway extension considered good went from 44% to 98%, and it was expected to return to its previous stage by the middle of 2017. If no measures were taken, the segment would be collapsed by 2013 (Figure 5 (b)). The duplication road works in an extension of 22km within this segment, connecting Missão Velha to Barbalha, began in February 2017.



(a) Evolution of the pavement quality (b) Prior to and after intervention trend line

FIGURE 5 Pavement quality analysis prior to and after the pavement rehabilitation in Stretch 2

On this stretch, pavement rehabilitation had a considerable impact on IRI, making its classification go from regular in 2008 (3.295mm/m) to good (2.511 mm/m) in 2011. On the last measurement made after the intervention, in 2016, the measured value was 3.021mm/m. The results obtained from the economic evaluation of the pavement rehabilitation on this segment indicates that the investment made on this stretch had an IRR of 15.2% .

4. CONCLUSION

Due to budget restrictions, Brazilian highways, especially the ones under states jurisdiction, are designed for a relatively short lifespan (on average, 10 years), requiring recurrent maintenance and reconstruction actions (including expansion of its capacity, change of road class, duplication, and others), when needed. Preventive measures, as pavement rehabilitation, done on the right timing, bring benefits to the highway itself, to the overall road mesh quality and to its users, increasing the lifespan of the highways at a lower cost than reconstruction, and reducing maintenance costs too. Currently, DER/CE invests, on average, R$ 800,000.00 (U$ 247,600.00) per km for reconstruction, when pavement rehabilitation costs vary from about R$ 150,000.00 (U$ 46,000.00) to R$ 300,000.00 (U$ 92,000.00) per km, depending on the solution designed.

Monitoring and managing of the road mesh is essential for decision-makers to know where and when to invest resources, and also, to evaluate the performance of the designed solutions. The Pavement Rehabilitation Program, held by DER/CE, has been showing good results, according to the systematic monitoring of the road mesh. As a matter of fact, a gain of 2 additional years beyond the prediction of the designed solutions has been observed. It is worth noticing that pavement rehabilitation does not substitute reconstruction, but delays it, and sometimes, it can make it cheaper, because it maintains the pavement (including the granular layers) in better conditions. Users benefits should also be considered, in aspects such as safety, comfort, and operational costs, and also societal benefits (with a more rational use of the public resources).

REFERENCES

[1] DER. Sistema Rodoviário Estadual. Departamento Estadual de Rodovias, Fortaleza/CE, Brazil. 2016.

[2] TMR. Pavement Rehabilitation Manual, Queensland Department of Transport and Main Roads, Brisbane/Q, Australia. 2012.

[3] RETTNER, D. How to Select the Appropriate Pavement Rehabilitation Option, North Dakota Local Technical Assistance Program, North Dakota, USA, pp. 01-58. 2010.

[4] LIMA, J. P.; RAMOS, R. A. R; JÚNIOR, J. L. F. Priorização de pavimentos com o uso da Metodologia de análise multicritério e SIG, ENGEVISTA, v. 10, n. 2, p. 132-144, Rio de Janeiro/RJ , Brazil. 2008.

[5] BERNUCCI, L. B.; MOTTA, L. M.; CERATTI, J. A. P.; SOARES, J. B Pavimentação Asfáltica: Formação Básica para Engenheiros, p. 463, PETROBRÁS:ABEDA, Rio de Janeiro/RJ, Brazil. 2007.

[6] CUNHA, C. R. Determinação de modelo de deterioração dos pavimentos para a malha rodoviária do Estado do Ceará, p. 95. Universidade Federal do Ceará, Fortaleza/CE, Brazil, 2008.

[7] SEVERO, L. E. P.; RUWER, P.; KLEIN, R. J.; BARELLA, R. M.; MASSARA, S.; GONÇALVES, F. P.. Utilização de perfilômetro laser para a medida de irregularidade longitudinal e do afundamento em trilhas de roda, 9º ENACOR – Encontro Nacional de Conservação Rodoviária, Natal/RN, Brazil. p. 9. 2004.

[8] DER. Plano Diretor Rodoviário, Departamento Estadual de Rodovias, Fortaleza/CE, Brazil. 2012.

[9] DER. SIGDER - Sistema Integrado de Gestão do DER. Departamento Estadual de Rodovias, Fortaleza/CE, Brazil. 2017.

[10] DNIT. Relatório dos Levantamentos Funcionais das Rodovias Federais, p. 20, Departamento Nacional de Infraestrutura de Transportes. Porto Velho/RO, Brazil. 2013.