Overlay Design in Mexican Roads

E. Padilla
COSIC S.A. School of Civil Engineering, Autonomous University of Guadalajara, Guadalajara, Mexico

G.Padilla
CIMAT. Research Center in Mathematics, Guanajuato, México

ABSTRACT: The rehabilitation of roads is not a simple task. This process requires systematic techniques to evaluate the current state of the road as well as techniques to select the most plausible reinforcement works. This work describes the studies and evaluation process to rehabilitate a highway located in the east access of the city of Guadalajara, the second largest city in Mexico. Particularly, the works focused on the left body of the Zapotlanejo-Guadalajara highway which experiences high volumes of heavy transit. The recycling technique was chosen to reinforce the highway. The recycling works uses recovered material in the formation of the hydraulic base as well as the material used in the asphalt surface of the new pavement. This paper describes the works performed before the rehabilitation works. These works include the results of the superficial evaluation, the structural analysis, the reinforcement design, the constructive procedure, and the performance studies covering ten years of successful operation of the highway.

KEY WORDS: Asphalt pavement, evaluation, rehabilitation, recycling,.

1 INTRODUCTION

The Zapotlanejo-Guadalajara highway is located on the east access of the city of Guadalajara. This highway has two bodies with two circulation lanes each one. The crown of each body has 11.0 m width and 26.0 km length. This highway has been operating for more than 35 years. During the year 2004 the daily transit record shows an average of 22,000 vehicles where 28% of them corresponds to heavy load vehicles.

The geological characteristics of the zone, where the highway is located, are formed by flat lands and hills which are constituted of extrusive igneous materials. The materials on this zone contain superficially pumice tuffs with different degrees of arrangement and cementation. Subjacent to these materials deposits of basaltic materials can be found in some sites.

The left body of the highway was put into operation in 1969. Some years later (1994), the construction of the right body was finished and the left body was rehabilitated. This paper describes the studies performed to rehabilitate the left body of the highway.

This paper is structured as follows: in Section 2, an overview of the evaluation works is described. Section 3 presents the structural analysis of the existing pavement. In Section 4, the results of the reinforcement design are discussed. Section 5 describes the constructive procedure. Next, the performance during 10 years of the rehabilitated pavement is discussed in Section 6. Finally, conclusions and final remarks on this paper are presented.

2 EVALUATION WORKS

2.1 Superficial Evaluation

The left body of the highway was analyzed entirely to determine the Present Serviceability Rating (PSR) and to quantify the superficial defects on the road. The analysis covered the entire 26.0 km length. The results showed that the left body had a PSR average of 2.8 varying from 2.4 to 3.1. In addition, the highway showed distress on the surface which could collapse the pavement structure. The most important defects found were:

a) The left body had longitudinal distortions in 25% of the length. These distortions were associated with other defects such as the asphalt surface loosening.
b) The pavement had rutdepths with values up to 30mm. These defects were associated with other defects such as patchs, potholes, and bleedings.
c) The asphalt surface had a severe pavement cracking over 30% of its area.
d) On the asphalt surface can be observed patched areas over 10% of the asphalt surface.
e) Bleeding zones can be observed, also associated with other defects.

2.2 Structural Evaluation

Measures with Benkelman beam and plate bearing tests were collected to analyze the structure of the highway.

a) Benkelman beam measurements

The Canadian method of recovered deflection (i.e., rebound test) was used with standard load of 80.4 kN and contact pressure of 549 kN/m^2. In addition, measurement works were performed for the semidiameter of deflection and the asphalt surface temperature.

The measured values showed an average deflection of 0.70 mm, standard deviation of 0.11, and variation coefficient of 0.21. These values show a medium bearing capacity.

b) Plate bearing tests

Using the measurements obtained from the Benkelman beam, six points for plate tests were chosen. Two points were located in places with low deflection, two in places with average deflection, and the two remaining in places with high deflection. In three points, the test was performed on the asphalt surface and the other three points were performed on the surface, base, and subgrade layers respectively. These results were used to design the pavement.

For all tests, the non-repeated load method was utilized with a contact plate having diameter of 304 mm, and maximum pressure of 657 kN/m^2. A total of 12 plate bearing tests were carried out.

The measured deformation modules using a pressure of 549 kN/m^2 are shown in Table 1. This table also shows the corresponding Benkelman beam deflection. The data in Table 1 describes the congruence between the Benkelman beam measurements and the plate bearing tests; the same it is appraised in Figure 1.

Table 1: Results of bearing capacity tests.

Location Km	Benkelman beam deflection mm	Plate bearing test Module of deformation kN/m^2x10^3		
		Surface	Base	Subbase
3+000	0.76	110	-	-
3+840	0.81	87	51	55
10+500	0.61	151	-	-
12+000	0.86	76	43	48
19+500	0.71	119	--	--
21+090	0.51	154	84	60

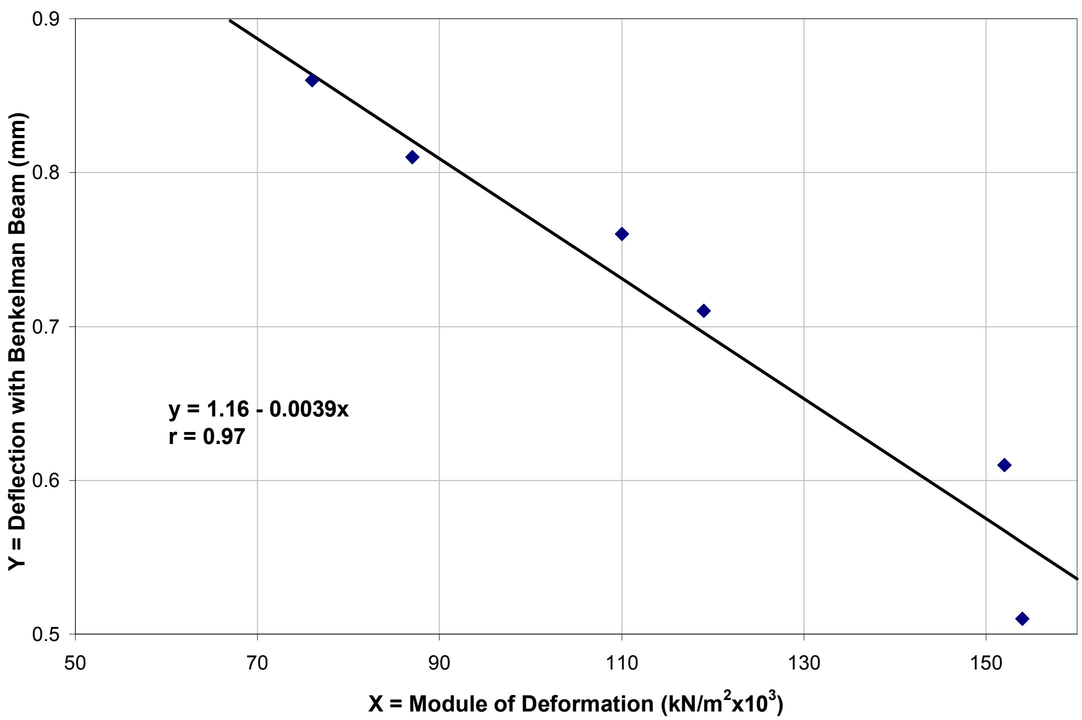

Figure 1: Relation between results of plate bearing test and Benkelman beam.

3 STRUCTURAL ANALYSIS

Thickness measurements were performed using the holes made for the plate tests, showed in Table 2. Using this information the general conditions of the structure were determined. The results of plate test correspond to the structure. In other words, greater deformation module (154 kN/m^2x10^3) corresponds to the location with greater surface thickness (250 mm) having subgrades of good resistance, whereas smaller deformation module (76 kN/m^2x10^3) corresponds to the location with drainage problems where the pavement layer has an excess of humidity. This excess of humidity reduces the pavement resistance.

Table 2: Results from the structural pavement analysis.

Location, Km	Thickness of layer, mm	Module of deformation kN/m^2x10^3	Observations
3+840	S = 210 B = 160 SB = 130 SG = 165	87 51 - 55	Base having medium quality
12+000	S = 200 B = 100 SB = 150 SG = 250	76 43 - 48	Problem of drainage, suspended water, layers with excess of humidity
21+090	S = 250 B = 150 SB = 110 SG = 280	154 84 - 60	Transition between cut and embankment

S=Surface B= base SB= Subbase SG= Compacted subgrade

The performed studies showed that the surface layer has a thickness average of 210 mm, the base has a thickness average of 150 mm, the subbase has an average of 140 mm, and the compacted subgrade has an average of 180 mm. These results were obtained by combining the data shown in Table 1 and Table 3 together with data provided by the Communications and Transportation Secretariat (SCT).

The analysis of the materials, revealed the following facts:

a) The asphalt surface was composed of several layers having different thicknesses and qualities. Parallel to the mentioned analysis, another study was performed. This study extracts six core samples from the highway but it was not possible to extract the cores in three locations since the asphalt concrete was too fragile, the samples were shelled easily. There were several causes of this fragility such as the asphalt shortage, oxidation of the asphalt, contamination of the mixture with clay, etc.

b) In general, the base, subbase and subgrade materials fulfilled the established quality norms.

In summary, the structural analysis showed why the highway surface tests described a medium resistance, regardless of the asphalt surface thickness (i.e., 210mm). The causes of these results where the bad state of those layers together with a big variability in the thicknesses of the underling layers as shown in Table 2. An important issue was the fact that all thick aggregate of the existing surface was crushed basalt which had excellent quality.

4 DESIGN OF THE REINFORCEMENT

In order to calculate the reinforcement we followed two approaches:

a) The required thickness was calculated as the variation between the thickness necessary for a new pavement and the effective thickness of the existing pavement.
b) The overlay thickness was calculated using a criterion which reduces the current level of superficial deflection to an acceptable level.

With the first approach three methods were utilized: Elastic Layers (Padilla, 1982, Padilla, 1991), Asphalt Institute (AI, 1982), and AASHTO (1991), while for the second approach only the Asphalt Institute method was utilized. In all cases, a design period of 12 years was considered. The corresponding results are shown in Table 3.

Table 3: Results of the application of the reinforcement design methods.

Method	Required thickness of asphalt concrete (mm)	
	Effective thickness	Deflections
Elastic layers	160 (220)	-
Asphalt Institute	220	120
AASHTO	200	-

(220): Required thickness on the base layer

The limitation of the method based on deflections was corroborated using the data showed in Table 3. For example, if we would apply an overlay of 120mm (based only on the deflection information) then we would find problems in short time due to the bad state of the existing surface course. Using the data provided by other methods (i.e., Asphalt Institute and AASHTO) required values between 160 and 220mm, 75% more than the first one. This variation suggests than the latter methods might detect more serious structural problems rather than the first method.

The previous situation was confirmed when the results from plate bearing tests on the existing base layer were obtained. The results from the elastic layers methods show a required thickness of 220mm. If we assume to use the existing surface course then it is required 160mm to reinforce the previous one. Therefore, the existing surface course contributes with 60mm, which is equivalent to a structural coefficient for this layer of 0.28, a low value which reflects the bad state of the course.

The previous situation, the fact of having excellent quality in thick aggregates, and the analysis of several alternatives, lead us to select the recovering of the existing surface course up to 210mm depth and to add fresh crushed material to complete a gradation adapted for hydraulic base layer. Finally, it was designed to build a surface course with 120mm of thickness. This solution gives a thickness index (TI) on the existing base:

$$TI = 210 \times 1.0 + 120 \times 2.0 = 450mm$$

These 450mm, equivalent to 220mm of asphalt concrete, satisfied the thickness requirements found in the elastic layers method as well as the others methods.

Other alternative analyzed was the stabilization of the recovered product with asphalt or Portland cement. The final choice was based on economic criteria, construction process, and technical information (as the information shown in this section).

5 CONSTRUCTIVE PROCEDURE

The main stages of the constructive procedure are described next:

a) The milled of the existing surface course was carried out down to the hydraulic base. The average depth was 210mm and a wide in tangent of 7.0ms, including both lanes of circulation; in horizontal curves the milled was extended up to the shoulder in the internal part of the curve. The recovered material was stored in appropriate place and it was protected to avoid its contamination.
b) The recompactation of the existing hydraulic base was carried out with the scarification of 150mm. The material was stored on site to be eventually tending and compacting to 100% of its maximum density.
c) The “recovered hydraulic base” is formed with a mixture of the recycled material and fresh crushed basaltic. The thickness average was of 210mm or more up to the grade line, having special care in not leaving depressions or deformations that could affect the vertical alignment during the laying of the new surface course. This layer also was compacted 100% of its maximum density.
   The optimal mixture for the recycled base are made with 60% of recuperated material and 40% of fresh aggregate with maximum size of 38mm (11/2”), fulfilling all specifications for hydraulic base.
d) An asphalt prime coat was applied on the surface of the base, with the use of cutback asphalt MC-30 at the rate of $0.0012m^3/m^2$.
e) On the impregnated base was applied a bond asphalt treatment using cutback asphalt RC-250 at the rate of $0.0005m^3/m^2$ (over the entire crown).
f) On the hydraulic base and after of the bound treatment, a surface coarse of asphalt concrete of 120mmm of thickness was tended over the entire crown. The compaction was of 95% of its maximum density determined by the Marshall test.
   The asphalt concrete was formed with 60% of fresh aggregate and 40% of recuperated material; this mixture fulfills all the specifications.
g) Finally, an asphalt slurry seal of 6mm of thickness and made with emulsified asphalt was applied on the entire crown.

6 PERFORMANCE

During 10 years of operation, after their rehabilitation, several evaluations have been performed on the left body of the Guadalajara-Zapotlanejo highway. These physical evaluations covered two aspects: first, pavement condition studies such as the Present Serviceability Rating (PSR), the International Roughness Index (IRI) with laser equipment, and the quantification of the superficial distress like distortions, crackings, etc; second, the structural evaluation with measurements of deflection with falling weight deflectometer (FWD).

Table 4 shows the results from superficial evaluations of the first and the last measurements made. It can be noticed that the highway presents good conditions of service up to date (2005).

Table 4: Superficial evaluation results.

Characteristics	Guadalajara-Zapotlanejo highway left body	
Date of measurement	October 1995	August 2004
Accumulated equivalent transit. Axles of 8.2t	–	7’392,000
Present Serviceability Rating (PSR)	4.2	3.0
Rutdepth, mm	4.3	9.0
International Roughness Index, IRI (m/Km)	–	3.1

7 CONCLUSIONS

The conclusions from the presented work are:

a) The performance that the left body of the Guadalajara-Zapotlanejo highway has shown is excellent, considering that has an International Roughness Index (IRI) of 2.9m/Km, after ten years of service.
b) The recuperated hydraulic base is a good alternative when recuperated material and fresh aggregate of high quality are both found. This situation allowed to construct a layer of hydraulic base of high resistance having CBR test values greater than 140%.
c) The constructive procedure and quality control were fundamental factors to the project success since the expected behavior of the road has been the planned in the project.

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