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Modelling an asphalt pavement in Portugal

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Summary

This article presents the modelling procedure of an existent pavement in Portugal, carried out by the author in the frame of "Leonardo da Vinci" Student Mobility Program, Contract RO/2004/PL93209/S, at Universidade do Minho - Center of Civil Engineering.

The 6 years old pavement under study exhibited an important extent of cracking and ravelling with high severity level, indicative of premature failure.

The assessment of the structural condition of the pavement requires the definition of its model. The adopted model is based on multilayer elastic (MLE) theory as it is one of most used models.

The establishment of the model comprised several tasks, such as: i) surface condition assessment, based on visual inspection; ii) coring in and out of the wheel path and over cracks; iii) deflection measurement by means of a falling weight deflectometer; iv) definition of homogeneous subsections; v) back calculation of the stiffness moduli using Bisar 3.0 Program; vi) temperature correction.

The back calculation of the stiffness modulus presented some difficulties as far as curve fitting is concerned. This might have been a consequence of using simplified models. Therefore, further research should focus this topic.

KEYWORDS: pavement modelling, stiffness module, homogeneous subsection, deflections.

1. INTRODUCTION

The tools available for modelling at the present time are wide. Despite that, simple models, such as multi-layered elastic models, are preferred, although asphalt pavements behaviour is viscoelastic. Enhanced models require data which is difficult to obtain and they are often time consuming.

ISSN 1582-3024

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The layered elastic theory is credited to V.J. Boussinesq, who published his work in 1885 [1]. Boussinesq's multi-layered elastic model assumes that each pavement structural layer is homogeneous, isotropic, and linearly elastic.

The basic assumptions of these relatively simple mathematical models are: pavement layers extend infinitely in the horizontal direction, the bottom layer (usually the subgrade) extends infinitely downward and materials are not stressed beyond their elastic ranges.

A layered elastic model requires a minimum number of inputs to adequately characterize a pavement structure and its response to loading, which are: material properties of each layer (stiffness modulus, Poisson ratio), pavement layer thicknesses and interface, loading conditions. The outputs are the stresses, strains, and deflections in the pavement [1].

Bousinesq's model is currently used for designing new pavements and overlays. It is also used for assessing the structural condition of an existent pavement by back calculating the stiffness modulus of each layer. The back calculation procedure is based on comparisons between deflections calculated using a computer program and deflections measured on the pavement under evaluation.

One of the widely used computer programs for modelling flexible pavement systems is Elmod. Elmod is a component of a number of integrated software packages available from Dynatest for effective and efficient analysis and management of pavements. Elmod forms the core module of the Dynatest suite analytical programs [2].

In the United States, Washington State DOT has developed the Everseries Pavement Analysis Program. Everseries contains three independent programs for layered elastic analysis (Everstress), FWD pavement modulus back calculation (Evercalc) and flexible pavement overlay design (Everpave) [1].

Shell International Petroleum Company has developed the Bisar program for stress and strain calculations in asphalt pavement models [3]. The Shell methodology is widely used for modelling flexible pavements behaviour.

If the main issue is to calculate the stiffness modulus for the existent asphalt layers when modelling a pavement, than a back calculation procedure is required. COST Project 336 [4] presents a procedure fallowed by many institutions.

ISSN 1582-3024

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INTERSECTII
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In this work the guidelines presented in the COST Project 336 have been fallowed in order to establish the model of the national road "EN 206 Variant" between Carreira and Guimarães, in Portugal, aiming at assessing its structural condition.

The model definition comprised the following steps, developed on next sections: i) surface condition assessment; ii) coring; iii) deflection measurement; iv) definition of homogeneous subsections; v) back calculation of the stiffness moduli; vi) temperature correction.

2. ROAD AND PAVEMENT GEOMETRY

The EN 206 Variant between Carreira and Guimarães, shown in Figure 1, is 2 km long and it is constituted by 2 lanes per direction (3.5 m each), a 3 m separation between carriageways, 2 service lanes (2.5 m each), and shoulders (1 m each). The current cross-section has a transversal slope of 2.5 % to both sides.

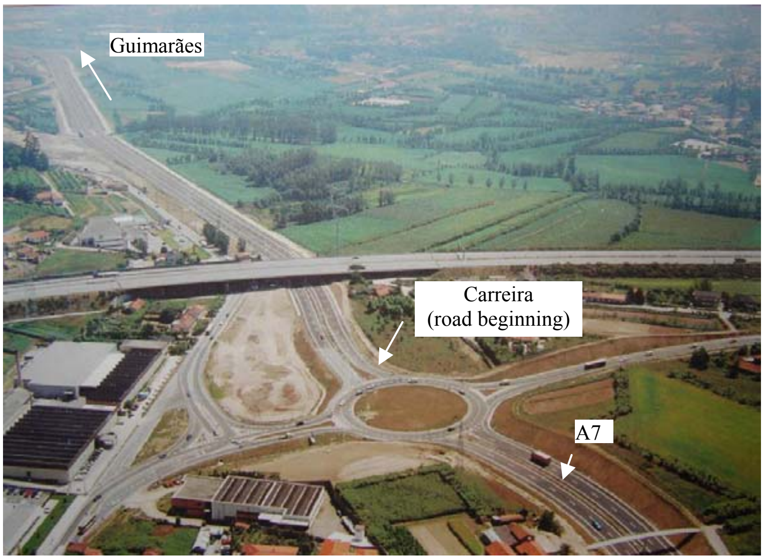

Figure1. General view of the EN 206 Variant

The design structure of the pavement is shown in Figure 2. It is constituted by 3 asphalt layers (wearing course – 6 cm; binder course – 6 cm; base layer – 12 cm) and an unbound sub base (graded aggregates – 20 cm).

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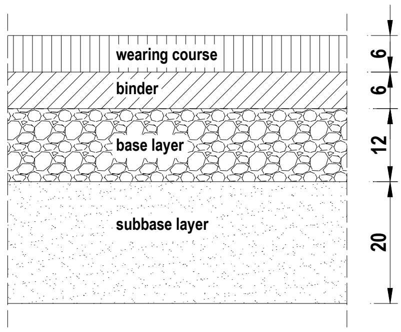

Figure2. Pavement structure

3. SURFACE CONDITION

The assessment of the surface condition was performed through visual inspection. The main distresses recorded were ravelling and cracking.

It was observed that, in general, the exterior lanes are more distressed than the interior ones. A different behaviour between driving directions was registered. In the direction from Guimarães to Carreira, the condition of the pavement is rather homogenous and better compared to the other direction. A small increase of the distress severity is recorded near the A7 roundabout, probably due to the high tangential forces as a result of breaking.

On the Carreira–Guimarães direction, two homogenous stretches can be established regarding the distress severity. The most distressed one is comprised in the first 700 m of the analyzed length and exhibits the highest distress severity and extent, if compared to the other stretches.

The ravelling observed on the surface of the road exhibits different levels of severity (Figure 3a). Some possible causes for the appearance of ravelling are: loss of bond between the aggregate particles and the asphalt binder; aggregate segregation; inadequate compaction during construction; mechanical dislodging by certain types of traffic such as vehicles with studded tires.
The cracking observed also exhibits different levels of severity as shown in Figure 3b.

Under repeated loading, longitudinal cracks begin to form at the base of the asphalt and propagate upwards (usually in the wheel paths). Then, these longitudinal

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cracks connect forming many-sided sharp-angled pieces that develop into a pattern resembling the back of an alligator or crocodile (alligator cracking). This leads to roughness, indicator of structural failure, cracks allow moisture infiltration into the base and subgrade and eventually results in potholes and pavement disintegration if not treated.

a) b)

Figure 3. Distresses on EN 206 VARIANT: a) ravelling; b) cracking

Alligator cracking occurs when there is an inadequate structural support for the given loading, which can be caused by many factors. Some of the most common are: decrease in pavement load supporting characteristics; stripping on the bottom of the hot mix asphalt layer; increase in loading (the pavement might loaded more heavily than anticipated in design); inadequate structural design; poor construction. Longitudinal cracking, transversal cracking and potholes were also found. These distresses are clearly the result of poor construction.

4. CORING

In order to investigate the causes of the early distresses observed, two slabs and several cores were extracted. One slab was extracted from an area exhibiting high severity distress and the other one in an area without distresses, located respectively at the wheel path on the direction Carreira – Guimarães at PK 0,26 km and at the shoulder on direction Guimarães – Carreira at PK 0,60 km. The cores were extracted all over the road, including on cracks.

ISSN 1582-3024

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Infrastructure Engineering

INTERSECTII
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Coring allowed for checking design thickness, assessing construction quality and cracking direction.

It was found that layers thickness is similar to the one assumed in the design, nevertheless a severe reduction of the thickness near the right wheel path towards the shoulder was observed. This might partly explain the distress observed on the right lane. In addition to that, poor quality of top layers (wearing and binder coarse) was observed (Figure 4 a).

As a consequence of the surface poor quality, cracking started at the top of the asphalt layer and progressed downwards. This was stated in all cores extracted over cracks (Figure 4 b).

a) b)

Figure 4. Coring: a) splitting of the asphalt layer; b) top-down cracking

5. HOMOGENEOUS SUBSECTIONS

The homogeneous subsections have been established using the deflection measured with the FWD under the loading plate, every 20 m. 4 subsections with similar deflection were found. For each subsection a representative deflection bowl was selected. The representative deflection bowl is the one measured which best fits the 85 percentile theoretical deflection bowl calculated over all deflections of each homogeneous subsection. Table 3 shows the location of the 4 selected

ISSN 1582-3024

homogeneous subsections and Table 4 and Figure 5 present the representative deflection for each subsection.

Table 3. Kilometric position of homogeneous subsections

Carreira - Guimarães		Guimarães - Carreira	
A	0 → 1+340 m	C	0 → 0+640 m
B	1+340 → 1+980 m	D	0+640 → 1+980 m

Table 4. Representative deflections on each homogeneous subsection

	Sensors [mm]	0	300	450	600	900	1200	1500	1800	2100
A	average	323,6	262,5	225,8	192,9	132,5	92,3	63,3	46,6	35,3
	standard deviation	70,4	53,8	44,9	37,6	25,9	18,3	12,5	9,1	6,9
	rep. deflection (85%)	**396,5**	**318,3**	**272,3**	**231,8**	**159,4**	**111,3**	**76,3**	**56,0**	**42,4**
B	average	386,7	311,0	266,8	228,6	157,9	111,1	76,5	56,7	42,3
	standard deviation	98,1	68,2	54,7	43,2	27,1	17,9	11,6	8,6	6,7
	rep. deflection (85%)	**488,3**	**381,7**	**323,6**	**273,3**	**186,0**	**129,7**	**88,6**	**65,6**	**49,3**
C	average	554,2	427,9	354,1	288,2	182,9	119,0	78,7	58,1	42,9
	standard deviation	171,9	122,6	93,7	65,1	34,0	19,2	12,0	7,9	5,9
	rep. deflection (85%)	**732,4**	**555,0**	**451,2**	**355,7**	**218,2**	**138,9**	**91,1**	**66,3**	**48,9**
D	average	391,9	302,9	254,7	213,5	138,5	93,2	62,1	44,6	33,3
	standard deviation	130,0	81,4	60,9	45,0	21,7	13,1	7,2	5,0	3,7
	rep. deflection (85%)	**526,6**	**387,3**	**317,8**	**260,1**	**161,0**	**106,8**	**69,6**	**49,8**	**37,1**

These results correlate with the surface condition assessment: Section A, (Guimarães - Carreira, PK 0+000 to 1+340) presented less distress than the other sections, and also presented the smaller deflections.

Section C (Carreira - Guimarães, PK 0+000 to 0+640), the most damaged section, presented the highest deflection which is nearly twice the deflection of section A. Deflection on sections B and D do not seem significantly different and they are slightly higher than in section A.

ISSN 1582-3024

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6. BACKCALCULATION OF STIFFNESS MODULI FROM FWD SURVEY

In order to calculate the stiffness modulus for each layer, the representative deflections of the homogeneous subsections were used as input data into Elmod 5 software. Initial stiffness moduli were obtained with this procedure.

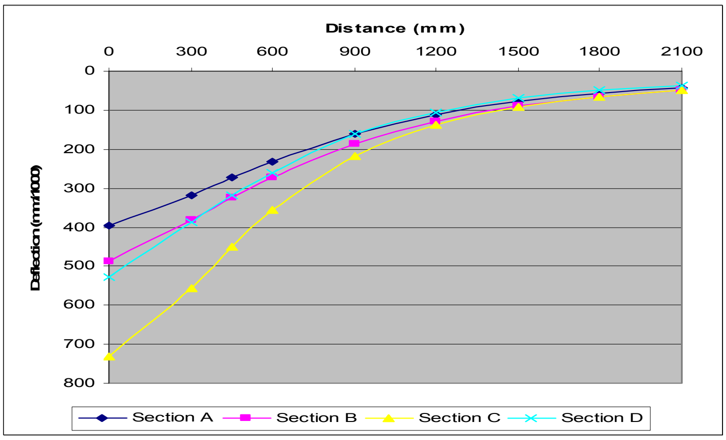

Figure 4 - Representative deflection bowls for each road section

Later the stiffness moduli were optimized by using Bisar3.0 software. A stiff layer with a modulus of 1500 MPa was introduced 2.0 m below the top of the sub grade in order to increase accuracy and to simulate the non-linear behaviour of the sub grade [5]. In Table 5 the adopted thicknesses for each layer as well as the stiffness modulus obtained from Bisar 3.0, which led to deflections that matched the representative deflections bowls for each section can be found. In Table 6 the corresponding calculated deflections are presented.

Table 5. Stiffness moduli for each section

Layer	Thickness (m)	Poisson's Ratio	Stiffness modulus (MPa)			
			Section A	Section B	Section C	Section D
Asphalt	0,24	0,35	5000	3700	2100	2700
Sub-base	0,20	0,40	220	220	100	165
Subgrade	2,00	0,45	60	50	46	62
Stiff layer	-	0,35	1500	1500	1500	1500

ISSN 1582-3024

Transportation
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Table 6. Calculated deflections

Distance from loading (m)	Deflection (µm)			
	Section A	Section B	Section C	Section D
0,0	395,4	485,8	720,0	518,1
0,3	316,2	383,0	542,6	384,9
0,5	274,0	330,2	454,8	321,2
0,6	233,6	280,2	374,5	263,6
0,9	162,6	193,3	241,8	169,7
1,2	106,9	125,9	146,1	102,8
1,5	65,7	76,5	80,9	57,5
1,8	36,8	41,9	38,8	28,4
2,1	17,3	18,9	12,9	10,5

Figure 4 presents both the representative deflection bowl and the one obtained with BISAR for sections A to D.

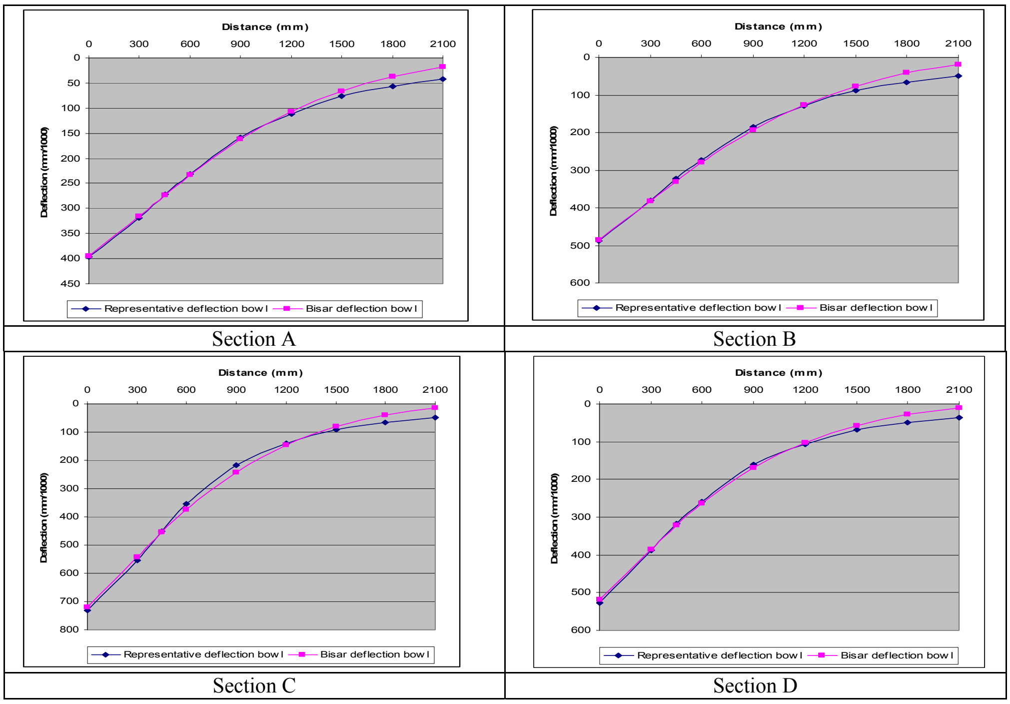

Figure 4. Measured and calculated deflection bowls

ISSN 1582-3024

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INTERSECTII
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As it can be observed in Figure 4, from the centre of the loading plate to 1200 mm a good match has been achieved. From 1200 mm to 2100 mm, the deviation between bowls increases with a higher value for the measured deflection. The end part of the deflection bowl is representative of the response of the subgrade to loading. This means that linear elastic programs are not reliable when the subgrade is concerned and back analysis procedure should be reviewed in order to take into account the effect of the increase of asphalt layers thickness on stress distribution.

7. TEMPERATURE CORRECTION

The stiffness modulus of asphalt layers is highly dependent on temperature. Comparisons can be made only if the moduli are determined for the same temperature. Taking this into account, the moduli calculated for each homogeneous section must be corrected in order to assess its evolution regarding design assumptions. The temperature at mead depth of the asphalt layer when the deflection was performed was nearly 16^0 C for all homogeneous sections. In view of the fact that the design temperature is $24{,}5^{\circ}$ C, a correction of the stiffness moduli is required. This correction has been made using Equation (1), which is suggested in several bibliographic sources [5].

$$\frac{E_{T1}}{E_{T2}} = \frac{1{,}635 - 0{,}0317 \cdot T_1}{1{,}635 - 0{,}0317 \cdot T_2} \tag{1}$$

In Table 7 the stiffness moduli for asphalt layers, after temperature corrections from 16ºC to 24,5ºC, are presented.

Table 7. Final stiffness moduli after temperature correction

Stiffness moduli (MPa) at 24,5ºC				
Design	Section A	Section B	Section C	Section D
3800	3805	2816	1598	2054
200	220	220	100	165
100	60	50	46	62

As expected, a great reduction on asphalt layers stiffness took place after 6 years under traffic loading in sections B, C and D. Sections C and D also show an important decrease of the stiffness of the unbound layer and subgrade. This means that the bearing capacity is significantly reduced.

ISSN 1582-3024

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8. CONCLUSION

This paper is the result of the work performed at the “Universidade do Minho” - Center of Civil Engineering in the frame of “Leonardo da Vinci” Student Mobility Program, Contract RO/2004/PL93209/S. The work focused the structural assessment of the road “Variant to EN 206”, in Guimarães, Portugal, aiming at designing an appropriate overlay.

The structural assessment comprised several tasks such as: i. surface condition assessment; ii. coring; iii. deflection measurement; iv. definition of homogeneous subsections; v. back calculation of the stiffness moduli; vi. temperature correction.

It was found that ravelling and cracking are the main distresses, both with an important extent of high severity level. Poor quality of surface layers (wearing course and binder course) was highlighted by coring, what might have caused cracking which progressed from the top downwards. In addition, the analysis of the deflection measured with the FWD correlated with the distress severity levels observed on the surface and led to the definition of 4 homogeneous sections.

The back analysis procedure, based on the multilayer linear elastic analysis theory, has shown to be unsuitable for back calculating the subgrade modulus. This is indicative that results from linear elastic programs might not be reliable when the subgrade is concerned and that back analysis procedure should be reviewed.

Finally, as expected, it was found that surface modulus of sections B, C and D have reduced significantly after 6 years under loading. Further work should focus the causes of premature failure of the asphalt layers as well as a suitable approach for back calculation of subgrade stiffness modulus.

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ISSN 1582-3024