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Definition of homogenous road sectors according to COST 336

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Summary

The present paper presents the work undertaken by the author in the frame of "Leonardo da Vinci" Student Mobility Program, Contract RO/2004/PL93209/S, at Universidade do Minho - Center for Civil Engineering, in Portugal.

The work dealt with the structural assessment and design of the rehabilitation of a highway sector in northern Portugal. A brief description of the main activities performed and the main results of the work are presented. It included, surface and structural condition assessment, coring, laboratory testing, and estimation of residual life and overlay design.

A methodology to divide the road into homogenous sectors, according to recommendations of COST 336 Action Final Report, is applied in order to optimize the rehabilitation activities. The method is based on the computation of the cumulative sum of the deflection, on validation of the homogeneity and analysis of the statistical relevance of the division.

The methodology is easy to use and results, in this case, matched the field visual observations and the results of the laboratory tests. Furthermore, it could be easily integrated in a computer program.

KEYWORDS: Falling Weight Deflectometer, homogenous road sectors, coefficient of variance.

1. INTRODUCTION

One of the steps of rehabilitation design, both at project and at network level, is dividing the road section into homogeneous subsections. Data collection, storing and processing is important and expensive, so it is necessary to define road stretches on which they are to be retrieved and used with efficiency and reliability.

A homogeneous subsection is a part of the road in which the measured deflection bowls (or any other variable) have approximately the same magnitude and where it is not possible to subdivide it into subsections with significantly different behaviour [1].

The subdivision is made not only for determining the stretches on which a certain rehabilitation method will be applied, but also to determine the necessary number and positions of coring location for further testing of the material. It can use a variety of manual and statistical techniques.

The importance of creating proper analysis sections cannot be overemphasised. Without appropriate sections, it is impossible to establish the correct investment decisions for the network. There are two stages for the sectioning process [2]: analysing the attributes of the road network and breaking it into sections and transforming the attributed data so that they adequately represent the road sections for the purposes of analysis.

For flexibility and reliability, it is recommended that road division into homogenous function is done automatically based on available data. McPherson and Bennett [3] recommend the use of an automatic sectioning function to create ‘homogeneous’ sections based on inventory and condition data.

This work particularly addresses the methodology recommended in COST Project 336 [1]. It integrates the procedure used to design the rehabilitation of the national road “EN 206 Variant” between Carreira and Guimarães, in Portugal. Next sections present a brief description and the main achievements of the work undertaken required to designing the overlay and a detailed description of the method applied to establish the homogeneous road sectors.

2. BRIEF DESCRIPTION AND MAIN ACHIEVEMENTS OF THE WORK

The work undertaken dealt with the study of a highway sector in northern Portugal, EN 206, between Guimarães and the A7 Highway distributor ring, a 3100m long road sector, the construction of which ended in 2000. A general view of this road sector is presented in Figure 1. The premature distress occurrence on it required a study of the possible causes of the abnormal situation and the proposal of viable rehabilitation solutions.

The study begins with general presentations on asphalt pavements and their behaviour, the general management and rehabilitation problems at project and network level, the distress types that can occur on flexible pavements and possible technical solutions.

2.1. Road description

The road description accounts for the geometrical characteristics of the longitudinal and transversal profile and for the initial pavement structure given in the design project: wearing course – asphalt mixture (6 cm); binder – asphalt mixture (6 cm); base layer – bituminous macadam (12 cm) and subbase – graded aggregates (20 cm).

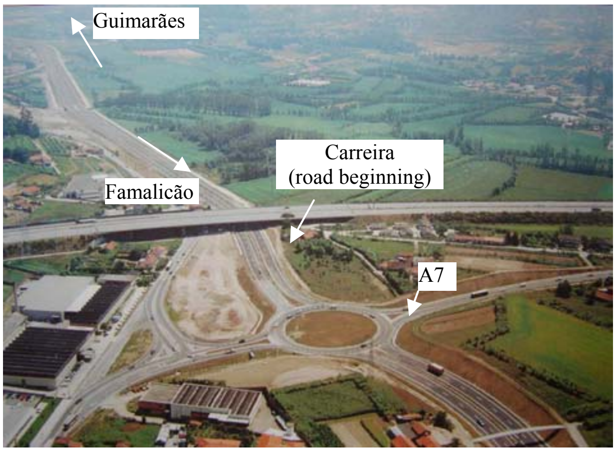

Figure 1. EN 206 Variant – view from the A6 distributor ring

Figure 2 presents the studied pavement system structure. According to the geotechnical study, the foundation soil is granite so the material extracted from the excavations was used for fillings. The soil is generally granite gravel or decomposed granites, with good mechanical characteristics. The quality of materials is attested through quality control performed during the construction works.

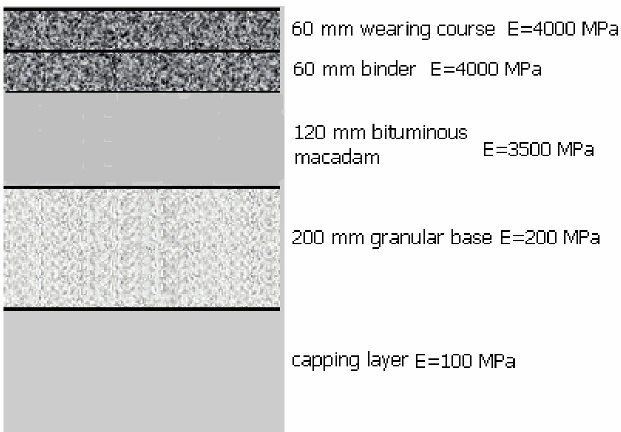

Figure 2. EN 206 Variant – pavement system

2.2. Traffic assessment

The traffic and temperature characteristics were re-evaluated for the initial project and for the present-day situation. A traffic counting was performed, what led to the conclusion that the actual traffic does not exceed the design traffic, eliminating then one of the possible hypotheses for the explanation of early distress occurrence.

2.3. Surface condition assessment

The surface condition assessment was one of the major problems encountered, as the main problems observed were ravelling and alligator cracking. After a brief description of all possible types of distress on flexible pavements, the project focuses on the quantification of these two distress types. The visual inspection and the methodology used led to the conclusion that, although ravelling is generalized and probably an indicator for top-to-bottom problem occurrence (poor wearing course material quality), there are compact sectors on which extended alligator cracking might show that the problem is actually the bearing capacity of the foundation.

Both the Portuguese distress catalogue [4] and the Pavement Condition Rating (PCR) methodology [5] were used in order to quantify in a global index the state of the surface, for each 10 meters sector along the length of the road. Figure 3 presents the result for one direction, both lanes, in terms of deduct points computed with PCR methodology (higher values means higher distress levels).

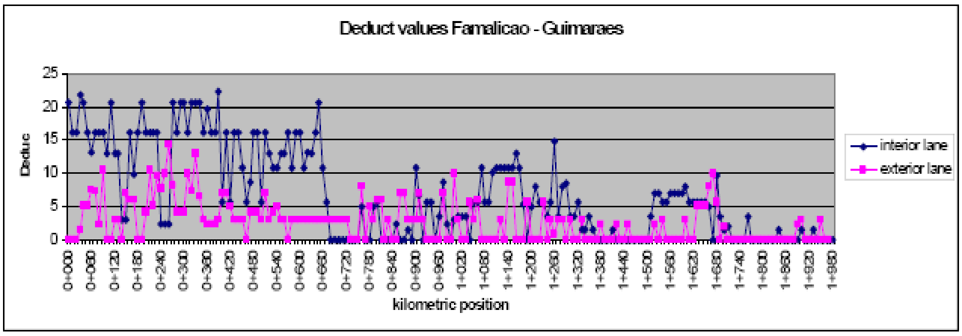

Figure 3. EN 206 Variant – PCR deduct values Famalicão - Guimarães

2.4. Structural condition assessment

The structural condition assessment was done using the falling weight deflectometer (FWD), presented in Figure 4. The studied road sector was divided into homogenous stretches based on the FWD results in correlation with the surface state assessment conclusions.

Figure 4. Falling Weight Deflectometer

2.5. Coring

Coring was also performed to check for the direction of the cracks propagation. The visual inspection showed a bad condition of the wearing course, with top-to-bottom cracking or cracks that go to the whole depth of the asphalt layer. The bituminous macadam condition was usually good. In addition, it was noticed that the bonding between these two layers was weak; they could be easily separated during samples extraction.

2.6. Laboratory testing

The following laboratory tests were performed: grading – sieving method, water content by drying in a ventilated oven, sand equivalent test, methylene blue test, resistance to fragmentation by the Los Angeles test method, determination of the laboratory reference density and water content – Proctor compaction, California bearing ratio, stiffness moduli and fatigue life with the four points bending test, for bituminous layers. Their results generally followed the project specifications. The exception was the content of fine aggregates for the granular base and capping layer from the most damaged sector that was almost twice bigger than maximum admissible.

2.7. Residual life

Residual life was calculated from fatigue tests carried out on the extracted samples and estimated through design data.

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The number of residual standard axle loads calculated from fatigue tests is 5,7E+06 ESAL.

The design values for the fatigue life (N), as given in the project for 2005 and 2016, are respectively 11,7E6 and 29,3E6 ESALs.

The design residual life (N_{rez}) in 2005 was estimated by equation (1).

$$N_{rez} = N_{2016} - N_{2005} = 17{,}61E + 06 \text{ ESALs} \tag{1}$$

The comparison of both residual lives indicates that rehabilitation work might be required.

2.8. Overlay design

The overlay design was carried out after modelling the existent pavement. Modelling relied on deflection measurement with the FWD and back-calculation of stiffness moduli of the pavement layers. The SHELL design criteria were adopted – fatigue cracking of asphalt layers and structural deformation of unbound layer.

All homogenous stretches need structural rehabilitation, the cause relying in both week subgrade and highly damaged surface course. The most damaged stretches required 8 cm while the least distressed portions required only a thin overlay, which for technological reasons was considered 4 cm thick.

3. DIVISION OF A ROAD INTO HOMOGENOUS SECTORS ACCORDING TO COST 336

In order to analyze the present situation with regard to the surface state and structural ability of the pavement system, and to propose a rehabilitation solution, it was necessary to perform the division of the studied road into homogenous road sectors. This task was performed using the methodology proposed by *COST 336 Action Final Report, Cap. 4: FWD Project Level Guide* [1]. This methodology includes the following steps, which are developed in the next sections:

1. Input data: maximum deflections recorded with FWD on the studied road;
2. Computation of the mean maximum deformation;
3. Computation of the cumulative sums (Si);
4. Drawing the graphic (i/S_i);
5. Separating the zones for which the slope of the graph is approximately constant (a change in slope indicates inhomogeneity);
6. Testing the statistical relevance of the division: determination of the homogeneity level for each sector, using the coefficient of variance CV;

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7. Checking if there is a statistically significant difference between means of consecutive homogenous sectors by using Student's t-Test.

3.1. Subsection identification based on cumulative sum of variable

There are several statistical techniques available to divide a series of data into homogeneous parts. One of these techniques is the cumulative sum method. With plots of the cumulative sums of the deviations from the mean of the deflections against test point it is possible to discern these subsections. The cumulative sum is calculated in the following way:

$$S_1 = x_1 - x_m \tag{2}$$

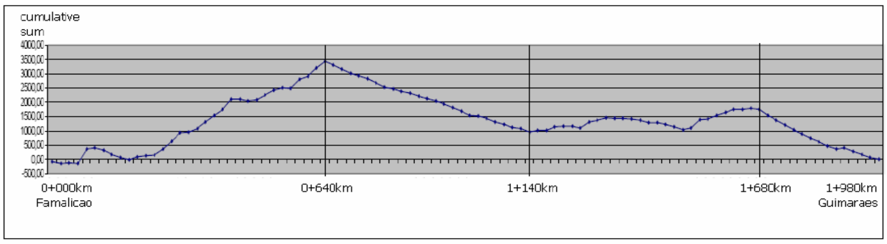
$$S_2 = x_2 - x_m + S_1 \tag{3}$$

$$S_i = x_i - x_m + S_{i-1} \tag{4}$$

Where: x_i - deflection measured at test point i;

x_m - mean deflection of each main section;

S_i - cumulative sum of the deviations from the mean deflection at the test point i.



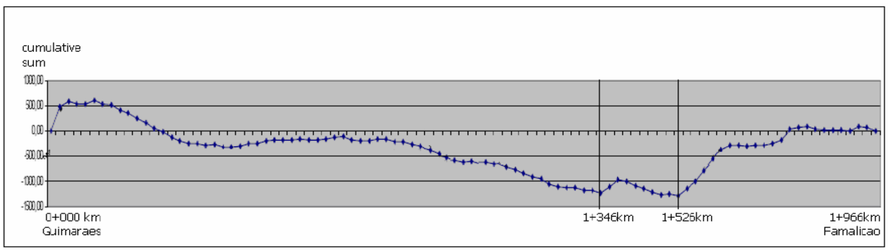


Figure 5. Separation of cumulative sums graphic into regions with almost constant slope

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Using the cumulative sums, the extent to which the measured deflections on a certain part of a road section are different from the mean deflection of the whole section can easily be determined. Changes in slope of the line connecting all cumulative sum values will indicate inhomogeneity [6].

The statistical analysis of the data using this method was performed and the resulting graphics are presented in Figure 5. The corresponding homogeneous road sectors are presented in Table 1.

Table 1. Homogenous road sectors based on cumulative sum analysis

Famalicão - Guimarães	
1	0 → 0+640 m
2	0+660 → 1+140 m
3	1+160 → 1+700 m
4	1+720 → 1+980 m
Guimarães - Famalicão	
1	0 → 1+366 m
2	1+366 → 1+526 m
3	1+526 → 1+966 m

3.2. Testing statistical significance of subdivision

For determining the level of homogeneity, one can make use of the coefficient of variation (CV). This parameter is defined as the ratio of the standard deviation over the mean value per section [6].

The mean value is defined as:

$$\bar{x} = \frac{1}{N} \cdot \sum_{i=1}^{N} x_i = \frac{x_1 + x_2 + \ldots.. + x_N}{N} \tag{5}$$

where: N - number of variables.

The standard deviation is defined as:

$$\sigma = \sqrt{\frac{1}{N} \cdot \sum_{i=1}^{N} \left(x_i - \bar{x}\right)^2} \tag{6}$$

The following list shows typical classes of CV:

CV < 20% - good homogeneity;

20% <= CV < 30% - moderate homogeneity;

30% <= CV < 40% - poor homogeneity;

CV >= 40% - inhomogeneity.

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The CV is a measure of the consistency of the spatial variability measurements within the individual sections/subsections. Although the CV may indicate that a section or a subsection is not very homogeneous, it gives no indication of the possibility of subdividing it. CVs greater than 30% usually indicate a highly skewed distribution produced, for example, by a number of relatively "stiff" test points within a weaker subsection.

For the analyzed homogenous stretches, the homogeneity outcome is presented in Table 2.

Table 2. Statistical data for the homogenous road sectors

Famalicão – Guimarães			
standard deviation 1	156,1667	standard deviation 2	47,51218
mean 1	506,82	mean 2	313,95
CV 1 (%)	30,81281	CV 2 (%)	15,13358
standard deviation 3	99,10054	standard deviation 4	56,3189
mean 3	428,67	mean 4	290,59
CV 3 (%)	23,11818	CV 4 (%)	19,38071
Guimarães – Famalicão			
standard deviation 1	79,45857	standard deviation 2	68,70807
mean 1	293,46	mean 2	286,31
CV 1 (%)	27,07625	CV 2 (%)	23,99783
standard deviation 3	89,99587		
mean 3	360,06		
CV 3 (%)	24,99441		

Averages of deflections are calculated for each test line within each section. If the test lines are considered equal in terms of structure, materials, maintenance, edge support, etc., the averages are then tested for statistical significance of differences between the test lines. This can be done using the Student's t-test.

The variance of the difference between the two means (σ_d^2) and the value of the t-coefficient are:

$$\sigma_d^2 = \frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2} \tag{7}$$

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sigma_d} \tag{8}$$

Tables 3 to 7 present these statistical data and the ones necessary to compute them, for each pair of consecutive homogenous road sectors. Once the t-value was

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computed, a risk level (alpha level) was set and the degree of freedom (the number of testing points on the consecutive tested road sectors minus 2) was determined. The computed t-value was compared to the values tabulated in a standard table of significance (Table 8) to determine whether the t-value is large enough to be significant. In Table 8, at (n_1 + n_2 -2) degrees of freedom (DOF) it is chosen the level of significance required (p = 0,05) and read the tabulated t value. If the calculated t value exceeds the tabulated value then the means are significantly different.

Table 3. Statistical data and t value for stretches 1 and 2, Famalicão - Guimarães

n_1 = 34	n_2 = 24	(σ_d^2)	811,35
$\bar{x}_1$ = 506,82	$\bar{x}_2$ = 313,95	(σ_d)	28,48
σ_1 = 156,17	σ_2 = 47,51	t	6,77
σ_{12} = 24388,03	σ_{22} = 2257,41	DOF	56

Table 4. Statistical data and t value for stretches 2 and 3, Famalicão - Guimarães

n_2 = 24	n_3 = 27	(σ_d^2)	457,79
$\bar{x}_2$ = 313,95	$\bar{x}_3$ = 428,67	(σ_d)	21,39
σ_2 = 47,51	σ_3 = 99,10	t	5,362
σ_2^2 = 2257,41	σ_3^2 = 9820,92	DOF	49

Table 5. Statistical data and t value for stretches 3 and 4, Famalicão - Guimarães

n_3 = 27	n_4 = 12	(σ_d^2)	628,06
$\bar{x}_3$ = 428,67	$\bar{x}_4$ = 290,59	(σ_d)	25,06
σ_3 = 99,10	σ_4 = 56,32	t	5,51
σ_3^2 = 9820,92	σ_4^2 = 3171,82	DOF	37

Table 6. Statistical data and t value for stretches 1 and 2, Guimarães – Famalicão

n_1 = 67	n_2 = 8	(σ_d^2)	684,33
$\bar{x}_1$ = 293,46	$\bar{x}_2$ = 286,31	(σ_d)	26,16
σ_1 = 79,46	σ_2 = 68,71	t	0,27
σ_1^2 = 6313,66	σ_2^2 = 4720,80	DOF	73

Table 7. Statistical data and t value for stretches 2 and 3, Guimarães – Famalicão

n_2 = 8	n_3 =21	(σ_d^2)	975,78
$\bar{x}_2$ = 286,31	$\bar{x}_3$ = 360,06	(σ_d)	31,24
σ_2 = 68,71	σ_3 = 89,99	t	2,36
σ_2^2 = 4720,80	σ_3^2 = 8099,26	DOF	27

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From the data analysis it results that the deflections recorded in the Famalicão – Guimarães direction are substantially different, for any target probability, while in the Guimarães – Famalicão direction stretches 1 and 2 are not statistically significantly different.

Table 8. Limit values for the t-coefficient for various degrees of probability

DOF	Probability, p			
	0,1	0,05	0,01	0,001
20	1,72	2,09	2,85	3,85
21	1,72	2,08	2,83	3,82
22	1,72	2,07	2,82	3,79
23	1,71	2,07	2,82	3,77
24	1,71	2,06	2,80	3,75
25	1,71	2,06	2,79	3,73
26	1,71	2,06	2,78	3,71
27	1,70	2,05	2,77	3,69
28	1,70	2,05	2,76	3,67
29	1,70	2,05	2,76	3,66
30	1,70	2,04	2,75	3,65
40	1,68	2,02	2,70	3,55
60	1,67	2,00	2,66	3,46
120	1,66	1,98	2,62	3,37

As a result, in the Guimarães – Famalicão direction only two homogenous stretches have been considered. The new division is presented in Table 9.

Table 9. Homogenous road sectors – second division

Guimarães - Famalicão	
1	0→ 1+526 m
2	1+526 → 1+966 m

The readings obtained on these two stretches are again analyzed to see if they are significantly different, as shown in Table 10.

Table 10. Statistical data and t value for stretches 1 and 2, Guimarães – Famalicão

$n_1 = 75$ $\bar{x}_1 = 292{,}70$ $\sigma_1 = 78{,}41$ $\sigma_{12} = 6148{,}63$	$n_2 = 21$ $\bar{x}_2 = 360{,}06$ $\sigma_2 = 89{,}99$ $\sigma_{22} = 8099{,}26$	(σ_d^2) (σ_d) t DOF	467,66 21,62 3,12 94

The results are considerably different for these two homogenous stretches. In Figure 6, the homogenous stretches with their (approximate) kilometric positions are presented.

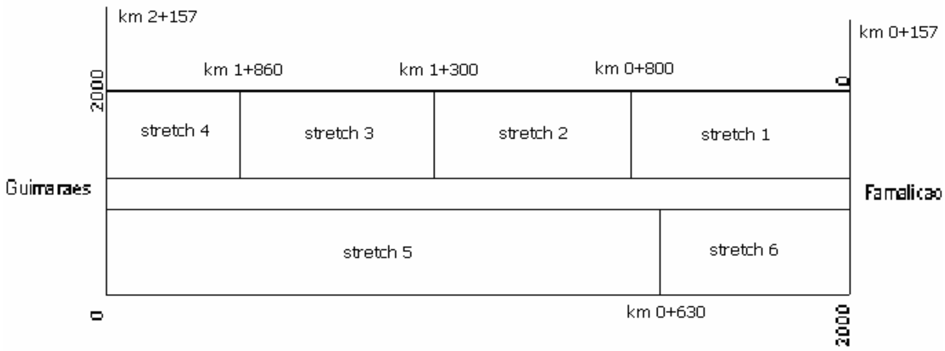

Figure 6. Homogenous sectors on the studied road

4. CONCLUSIONS

The present paper presents the work 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 for Civil Engineering, in Portugal.

This work aimed at designing the rehabilitation of the national road "EN 206 Variant" between Carreira and Guimarães, in Portugal. A brief description and the main achievements of the work undertaken was presented. A detailed description of the procedure for division of the road into homogenous sectors recommended by COST 336 Action Final Report was also presented.

This procedure is easy to be used and grants good results which, in this case, matched the field visual observations and the results of the laboratory tests.

It also appears to be easily adaptable for creating a computer program, since most of the steps involve statistical data analysis.

Human decision intervenes when deciding what the portions of the cumulative sum graphics with constant slope are. However, this can also be included in a program application. A possible approach would be to analyze mathematically the slope variance, starting from the finest division possible, and then to move forward with joining consecutive sectors, as long as the homogeneity condition is fulfilled, until the criterion of significant difference between consecutive sectors is attained.

As recommended by Bennett, Christopher et al. [2], data transformations should be done in two steps: first, the data are transformed from source data into what it is called smallest common denominator sections. These are the smallest intervals that correspond to all data and the analysis sections. The smallest common denominator data are then amalgamated so that they can represent the conditions of the analysis section.

Such an application could be a useful tool for pavement management at both project and network levels.

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