# The Influence Drainage and Climate Factors on Pavement Bearing Capacity

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## ABSTRACT

A mechanistic approach for pavement and overlay design is based on stress and analysis of layered structures.

Deflection analysis is a valid instrument in determining the elastic parameters of soils and pavement layers.

Deflection depends on the load stress and climate factors, such as moisture and temperature.

A large study analysing deflection sensitivities to drainage, as well as climate factors, was undertaken.

Different structures, specially regarding bituminous thickness, in different seasons were evaluated.

Deflection regression models linked to seasonal climatic factors were developed. Both overlays and new pavements were analysed.

In fact, the main conclusion focuses on the influence of drainage conditions, as well as climate factors, on deflection values.

## INTRODUCTION

Flexible road pavements are submitted to stresses, which are due both to vehicle loads as well as to the effects of climatic factors.

The analysis of pavement behaviour, be it in the phase of design of a new road or in that of design of its rehabilitation, renders it essential for one to know the indicators of the bearing capacity of the pavement structure and subgrade.

For a mechanistic approach, deflection is one of the most important structural factors in determining the elastic parameters of pavement layers and subgrade.

Various studies have been undertaken Medina, 1989, Bellanger, 1987 and Bieth, 1991 with the purpose of evaluating the influence of climatic factors on deflection values. These have included aspects such as rainfall intensity and temperature.

The results of this research allow for an improved acquaintance with different pavement behaviour when subjected to different climatic situations. In addition, they permit the suggestion of improvement in construction techniques, especially with regard to drainage

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systems. They too provide important information to be used in pavement maintenance management systems, thus optimizing the investment in the road network.

In Portugal, the road network is somewhat diverse. It includes older pavements of varying structures, where the granular component is predominant, and which frequently possess deficiencies with regard to drainage conditions.

A network of new roads is increasingly prevalent, these having been constructed over the past few years. The older roads have, in the meantime, been rehabilitated with regard to geometry and, more especially, to pavement structure.

A general study of the entire road network was undertaken, with the objective of evaluating the structural behaviour of the road network pavements and, in particular, to analyse the relationship between bearing capacity and climatic factors, as well as drainage conditions.

This study included monitoring during two climatically different periods of the year, Autumn and Spring. A vast group of data related to bearing capacity was also monitored; these include the composition and condition of pavements, climatic conditions and drainage conditions.

The data observed allowed for the establishment of a data base, with separate files for new pavements and overlays.

Using an adequate statistical analysis, various models were developed; these were related to the estimation of the bearing capacity observed under unfavourable conditions, in other words, in Spring.

## 1. PROGRAMME OF RESEARCH

The research programme developed included the following aspects: a definition of the sample to be studied; the data to be observed; the data collection programme; the treatment and analysis of data observed.

### 1.1 - Sampling of the road network

The main objective of the sample definition to be studied was that of obtaining the best representation possible of the national road network.

The national road network prevalently comprises flexible pavements. With regard to their bituminous component, these are of two types: the older ones, with a bituminous wearing course and binder course (many of which already possess an overlay course) and the more recent ones, possessing a wearing course and base course, in bituminous material.

As a result of this, the research undertaken only included the different types of flexible pavements, new and overlaid.

In order to select link tests, apart from the methodology referred by Pereira, 1988, the following sampling criteria were considered:

1. Average Annual Daily Traffic (AADT)
2. Pavement structure, with regard to maintenance (S)
3. The age of the wearing course (AG)
4. Climate

In relation to traffic, links submitted to different levels of intensity were considered. Three groups were defined according to the AADT: light (<4000), medium (4000 to 10 000) and intense traffic (>10 000).

As to the maintenance undertaken, an attempt was made to select a group of pavements still possessing their initial wearing course; these were considered new pavements (N).

Another group of pavements, which had already been overlaid (O), was also selected.

In so doing, and considering both groups of pavements, it was expected that differentiated behaviours would be detected.

When taking the age of the wearing course into consideration, one inevitably comes across pavements which possess different conditions. This parameter constitutes one of the most relevant factors in pavement performance evolution.

With regard to climate, Portugal can be approximately divided into three regions: the northern and central coastal regions which experience medium temperatures and a high rainfall; the northern and central inland regions, with low temperatures and a high rainfall; the southern region where temperatures are high and rainfall is low.

The different link tests were chosen so that they equally represent the three regions defined above.

Once the link tests to be studied were chosen, section tests within each one were considered, each possessing a constant length of 200 metres.

In taking the three basic sampling factors into account (AADT, S, AG), 76 test sections were selected. Their distribution is presented in Table 1.

### 1.2 - Data definition

Considering that the primary objective of this study was that of evaluating the susceptibility to variation of bearing capacity in relation to basic climatic factors (temperature and rainfall), a group of variables was observed; some of these are dependent variables, whereas others are independent variables.

In Table 2, each of the variables observed is defined; some of these are quantitative and others are qualitative.

Bituminous thickness (BT) is the total thickness of all bituminous layers, expressed in centimetres.

Equivalent thickness (ET) is the total thickness equivalent to asphalt concrete, calculated in accordance with equation (1), LCPC, 1965 and RRL, 1952:

$$ET = \sum_{i=0}^{n} ti \sqrt[3]{\frac{Ei}{Ee}} \tag{1}$$

where:
ET - equivalent thickness of asphalt concrete (cm)
ti - thickness of the course i (cm)
Ei - stiffness modulus of the course i (MPa)
Ee - stiffness modulus of the asphalt concrete (MPa)
n - number of layers

The meaning of most of these variables is of common knowledge. However, and in relation to some of them, the meaning is described in greater detail.

As to the stiffness modulus of the bituminous materials, and taking the respective formulation and usage conditions into account, known values relating to identical materials tested in laboratory were used Pereira, 1971.

Table 1 - Sampling of the road network

| S | AG | AADT | | | |
|---|---|---|---|---|---|
| | | < 4000 | 4000 - 10000 | > 10000 | x (%) |
| N | < 3 | 5 | 3 | 1 | 9<br>(33) |
| | 3 - 6 | 2 | 5 | 4 | 11<br>(41) |
| | > 6 | 5 | 2 | 0 | 7<br>(26) |
| y<br>(%) | | 12<br>(44) | 10<br>(37) | 5<br>(19) | 27<br>(100) |
| O | < 3 | 7 | 3 | 4 | 14<br>(29) |
| | 3 - 6 | 7 | 8 | 6 | 21<br>(42) |
| | > 6 | 2 | 9 | 3 | 14<br>(29) |
| y<br>(%) | | 16<br>(32) | 20<br>(41) | 13<br>(27) | 49<br>(100) |

S-Pavement structure; N-New pavements; O-Overlays; AG-Age of the wearing course

Table 2 - Description of variables

| Variable | Description | |
|---|---|---|
| AADT | Average annual daily traffic | (number of total vehicles) |
| TAA | Total accumulated AADT | $(10^6)$ |
| TAH | Total accumulated heavy traffic | $(10^6)$ |
| AG | Age of wearing course | (years) |
| BT | Bituminous thickness | (cm) |
| ET | Equivalent thick. of asphalt concrete | (cm) |
| DS | Spring deflection | (1/100 mm) |
| DA | Autumn deflection | (1/100 mm) |
| CI | Condition index | |
| RI | Roughness index | |
| DC | Drainage conditions | |
| RF | Rainfall intensity | (mm) |
| MT | Minimum temperature | (°C) |

With regard to the stiffness modulus equivalent to granular materials, these are known to be dependent on the support layer material and its own thickness.

Consequently, a formula proposed by Shell, Yoder, 1975 was used (2); it relates the subgrade modulus to a granular layer which is supported by the former.

$$E_2 = k_2 \, . \, E_3 \tag{2}$$

where: $E_2$ = modulus of the granular course
$E_3$ = modulus of subgrade
$k_2 = 0.2\ t_2^{0.45}$ , where: $t_2$ - thickness of granular course (mm).

In relation to the value of the stiffness modulus of the support layer, and despite the formula suggested by various authors, Heuklom, 1960 and Jeuffroy, 1978, a formula proposed by TRRL , Powell, 1984 was used:

$$E_3 = 17.6\ \text{CBR}^{0.64} \qquad E_3\ (\text{MPa}),\ \text{CBR}\ (\%) \tag{3}$$

The deflection in Autumn and Spring, expressed in 1/100 mm, was measured with the aid of a French deflectograh.

The condition index (CI) represents the deterioration of the wearing course surface, including mainly the different types of cracking; this was evaluated visually according to severity and extent.

The roughness index (RI), a geometric indicator of longitudinal pavement evenness, was obtained by using the French analyser APL 25.

The variable DC - Drainage conditions - is a qualitative variable, determined by means of a matrix (Table 3), which takes the following into account: the conditions of the shoulders, (dressed (SDR), undressed (SUD), and dressed in deteriorated condition (SDD)); the gradient of the straight (ascending gradient (GR), level section (LS)), and the setting out of the cross section (cutting (CT), level (LV), embankment (EM).

As can be seen in Table 3, the DC values rank from 1 to 9; these refer to conditions, from best to worst respectively.

The variables relating to rainfall intensity and subgrade water were obtained from the meteorological station nearest to the test section, taking into account local topography and rainfall distribution charts.

Table 3 - DC - Drainage conditions

| SETTING OUT OF CROSS SECTION | CONDITION OF SHOULDERS | | | | | |
|---|---|---|---|---|---|---|
| | SUD | | SDD | | SDR | |
| | LS | GR | LS | GR | LS | GR |
| CT | 9 | 7 | 7 | 5 | 4 | 3 |
| LV | 7 | 5 | 5 | 3 | 3 | 2 |
| EM | 5 | 3 | 3 | 2 | 2 | 1 |

CT - Cutting
LV - Level section
EM - Embankment
SUD - Shoulder undressed
SDD - Shoulder dressed deteriorated
SDR - Shoulder dressed
GR - Ascending gradient
LS - Level section

### 1.3 - Programme of data collection

Both the data related to pavement evaluation (deflection, bearing capacity, condition and roughness), as well as the data linked to drainage conditions, were collected over two seasons: Autumn and the following Spring.

In so doing, the bearing capacity of pavements was observed under two defined situations: under favourable conditions (observation in Autumn) and under unfavourable conditions (observation in Spring).

The variations of this parameter during these seasons were taken into account. Then we related bearing capacity to climatic data, such as rainfall and temperature, as well as to drainage conditions.

The data collected from new roads (N) and overlaid roads (O) were introduced into a data base, with separate files for subsequent statistical treatment.

In order to understand the prevalent variation of each variable considered, the respective statistical values are presented in Tables 4 and 5.

## 2. DEVELOPMENT OF MODELS

The development of deflection models was based on the statistical techniques used in data analysis, these being considered more adequate in undertaking this type of research.

In this study, and given that the comprehension of the relationship between dependent and independent variables is the aim, the regression technique was used, in accordance with Lebart, 1982. Here the objective is to obtain the coefficients of the model.

Table 4 - Statistical data values - New pavements structures (N)

| Variable | units | average | standard dev. | max. value | min. value |
|---|---|---|---|---|---|
| AADT | n° vehicles | 7703 | 7553 | 30000 | 2000 |
| TAA | $10^6$ | 5.82 | 5.70 | 22.00 | 0.40 |
| TAH | $10^6$ | 0.67 | 0.35 | 1.600 | 0.080 |
| AG | n° years | 4.40 | 2.05 | 8.00 | 1.00 |
| BT | cm | 9.8 | 1.4 | 14.00 | 8.0 |
| ET | cm | 31.6 | 4.9 | 42.0 | 20.0 |
| DS | 1/100 mm | 95.7 | 53.3 | 290.0 | 40.0 |
| DA | 1/100 mm | 73.2 | 37.3 | 200.0 | 30.0 |
| CI | | 1.81 | 1.01 | 5.0 | 1.0 |
| RI | | 8.8 | 4.1 | 27.0 | 3.0 |
| DC | | 4.3 | 1.9 | 9.0 | 1.0 |
| RF | mm | 70.3 | 2.39 | 130.0 | 46.0 |
| MT | °C | 6.7 | 2.3 | 9.5 | 2.9 |

Using the data files developed for the two categories of pavement structures (new and overlaid), various models were developed and subsequently analysed, using the SPSS/79 statistical package , Nourisis, 1986.

Table 5 - Statistical data values - Overlaid pavement structures (O)

| Vaiable | units | average | standard dev. | max. value | min. value |
|---|---|---|---|---|---|
| AADT | n° vehicles | 7972 | 6441 | 31400 | 1500 |
| TAA | $10^6$ | 7.69 | 7.43 | 40.90 | 0.50 |
| TAH | $10^6$ | 1.25 | 0.97 | 3.88 | 0.08 |
| AG | n° years | 5.35 | 2.38 | 11.00 | 1.00 |
| BT | cm | 9.82 | 3.35 | 17.0 | 4.0 |
| ET | cm | 24.8 | 7.9 | 46.0 | 12.0 |
| DS | 1/100 mm | 108.4 | 52.3 | 380.0 | 30.0 |
| DA | 1/100 mm | 71.8 | 33.7 | 200.0 | 15.0 |
| CI |  | 2.63 | 1.30 | 5.0 | 1.0 |
| RI |  | 10.8 | 3.7 | 22.0 | 4.0 |
| DC |  | 5.7 | 2.1 | 9.0 | 1.0 |
| RF | mm | 85.3 | 28.7 | 140.0 | 46.0 |
| MT | °C | 6.5 | 1.6 | 9.5 | 2.9 |

In order to test the models developed, and using the population of test sections selected as a starting point, two samples were defined: a work sample and a test sample.

Their similarities were evaluated by means of the Student test included in Tomassone, 1983.

The selected models define the deflection measured in unfavourable conditions as a dependent variable in an attempt to find the most significant explanatory variables.

### 2.1 - New pavement structures

What follows is a presentation of the different DS models developed for these structures. The respective estimate capacity and its validity is evaluated.

#### 2.1.1 - Model DSN1

The most reliable model, obtained from the file relating to this group of structures, allows for the direct correlation of deflection measured in Spring with that measured in Autumn, by means of the following equation:

$$DSN1 = 1.49\ DA \quad (4)$$

with: coeficient of correlation: $R = 0.92$ ($R^2 = 0.85$)
standard error: $E = 22.1$

This is a linear model of high estimate quality ($R^2 = 0.85$) and reduced standard error.

By using this model, and once the deflection observed during a period favourable to bearing capacity is known, it is possible to determine the deflection value which corresponds to the most unfavourable pavement bearing capacity condition.

However, the relation between DS and DA deflection is undoubtedly dependent on other factors such as the constitution of the pavement structure itself (BT and ET), the characteristics of the subgrade (CBR), the climatic conditions (RF and MT) as well as the drainage conditions (DC).

Consequently, additional models were developed with the purpose of showing the possible influence of these factors.

### 2.1.2 - Model DSN2

Starting from an analysis of the data observed, it was possible to obtain a model, in which DS deflection was correlated with both DA deflection and rainfall.

$$DSN2 = -25.3 + 1.29\,DA + 0.66\,RF \qquad (5)$$

with: $R = 0.95$ ($R^2 = 0.90$), and $E = 18.5$

This model possesses an estimate quality which is higher than the previous one. However, the DA variable carries more weight than the RF in the DS estimate.

Nevertheless, the influence of climatic conditions (RF - rainfall intensity) in the evolution of bearing capacity in favourable to unfavourable periods is made evident in this model. This conveys the significance of the influence of water on granular layers and base layers.

Despite the influence of the subgrade stiffness on deflection, the available values of the variable CBR are not of the good quality. Consequently it was not possible to establish an acceptable correlation between deflection and the CBR variable.

In this model, one needs to emphasise that, in the respective equation, the value at the origin is statistically different to zero (Student test) and is negative. Despite this, and from a physical point of view, the model is still considered valid when taking the prevalent RF variable variation into account.

In fact, if one considers the RF variation to be between 46 and 130 mm, the model then possesses the structure of the previous one, with a value at the origine of between +5.1 and + 60.5.

In addition, if one considers the DA variation to be between 30 and 200, one then determines a relation between the DS and DA variables, with a maximum variation rate of between 1.46 and 1.59.

Consequently, it was concluded that Model DSN2 is more adequate than Model DSN1 in determining the influence of the RF climatic variable in the bearing capacity of pavements.

The models developed to estimate the DS are dependent on the DA, which must be known. As a result of this, one needs to be acquainted with the last Autumn deflection value, as this parameter also evolves with time. Only then can one estimate pavement bearing capacity in unfavourable conditions (DS).

Nevertheless, models DSN1 and DSN2 do possess an advantage - they allow for a reliable DS estimate when one needs to know the most unfavourable bearing capacity, provided the DA and RF are also known.

In the meantime, one attemped to develop a DS model, without including the DA value in the independent variables. Variables related to pavement structure, climatic conditions and drainage conditions were used.

### 2.1.3 - Model DSN3

Through the use of statistical analysis of the data observed, another DS model was then developed. Here DS was estimated by means of the RF (rainfall intensity) and ET (equivalent thickness).

$$DSN3 = 139.4 + 1.11\,RF - 4.02\,ET \qquad (6)$$

with: $R = 0.83$ $(R^2 = 0.69)$, and $E = 28.5$

This model possesses a good estimate quality, although this is inferior to the previous models. However, it possesses the advantage of estimating the DS without the need of knowing the DA variable.

In addition, it is on the one hand a model of simple estimate; on the other, it possesses an adequate physical meaning, in relation to the weight of the pavement structure and base layer, through the ET variable.

### 2.1.4 - Model DSN4

The condition of the wearing course probably influences the increase of deflection in an unfavourable period. This is due to water migration which begins on the surface and seeps into the granular layers and base layer below.

An analysis of the correlation matrix of the data observed permitted the finding of a considerable link between the variable explaining DS and the pavement condition represented by the variable CI.

Consequently, one then attempted to obtain a model which would include this variable.

$$DSN4 = 87.2 + 1.06\,RF - 3.19\,ET + 18.01\,CI \qquad (7)$$

with: $R = 0.85$ $(R^2 = 0.72)$, and $E = 26.4$

Model DSN4 possesses a higher estimate quality than that of model DSN3. It includes the CI variable, which represents the influence of the wearing course's sealing condition on the bearing capacity of flexible pavements.

It was concluded that this was the most comprehensive model, from a physical point of view, possessing a good estimate quality of pavement bearing capacity in an unfavourable period.

### 2.2 - Overlaid pavement structures

With regard to overlaid pavement structures, one attempted to obtain significant estimate models of deflection in Spring too, taking more important variables into account.

Given that these structures are older than new structures, a different behaviour was observed and, as a result of this, the models developed were different to the previous ones.

### 2.2.1 - Model DSO1

Having analysed the correlation matrix of data observed in this group, the first model links deflection in Spring, DS, to deflection in Autumn, DA, as well as to the drainage conditions, the DC variable.

$$DSO1 = 0.81\ DA + 9.29\ DC \qquad (8)$$

with: $R = 0.80$ $(R^2 = 0.64)$, and $E = 30.2$

This model possesses two independent variables, DA and DC, both carrying equal weight in the DS estimation.

Thus it was detected that, for this group of structures, drainage conditions possess a determining importance in the evolution of deflection between Autumn and Spring.

It is essential to mention that overlaid pavement structures present more deficient drainage conditions than new structures. The high weight of the DC variable in the DS estimate is thus justified.

### 2.2.2 - Model DSO2

Considering the fact that the estimate quality of the DSO1 model is a medium one, one attempted to develop a new DS model. The DSO1 model includes variables linked to pavement structure composition, as was previously obtained in the case of model DSN3.

The model developed includes independent variables such as the BT variable, bituminous thickness, in addition to those used previously.

$$DSO2 = 35.4 + 0.87\ DA + 8.11\ DC - 2.91\ BT \qquad (9)$$

with: $R = 0.83$ $(R^2 = 0.69)$, and $E = 31.0$

This model possesses an estimate quality which is identical to the previous model. However, it is physically more adequate in estimating unfavourable deflection, DS.

Despite the fact that the ET variable (equivalent thickness of asphalt concrete) represents pavement structure better, it was only possible to find a significant link between DS and BT.

### 2.2.3 - Model DSO3

In this group of structures, an attempt was also made to develop a model which would include the influence of the condition of the wearing course on the evolution of deflection.

After analysing the correlation matrix, another model was developed, DSO3. This model includes the following variables: drainage conditions (DC), climatic conditions (RF) and the condition of the wearing course (CI).

$$DSO3 = 0.61\ RF + 4.52\ DC + 6.89\ CI \qquad (10)$$

with: $R = 0.70$ $(R^2 = 0.49)$, and $E = 34.0$

This model possesses a more reduced global estimate quality when compared to the previous models.

Although it includes variables of significant physical value, especially with regard to pavement structure behaviour, it does not include a variable which represents pavement structure, such as ET or even BT.

As for the independent variables, this model possesses a high RF variable weight, whereas the DC in the DSO2 model presented the most significant weight in DS estimation.

The RF variable was not included in previous models, where DA was present too, due to the fact that RF and DA present some correlation. Consequently these cannot be included in the same group of independent variables.

## 3. CONCLUSIONS

The research undertaken was an attempt to develop models of deflection estimation, these being observed in conditions unfavourable to pavement bearing capacity, or be it, deflection in Spring (DS).

In order to estimate deflection under these conditions, the models indicate some independent variables.

Deflection obtained under favourable conditions, deflection in Autumn (DA), is one of these. Other variables linked to pavement structure are also present: total equivalent thickness (ET), total bituminous thickness (BT), climatic conditions (rainfall intensity (RF) and drainage conditions (DC)).

Various studies have attempted to express unfavourable deflection, DS, by using favourable deflection, DA.

These have taken various factors into account, which influence the relation between the values of these two variables.

In this study, and by using models DSN2 and DSO1, which respectively refer to new and overlaid structures, one can determine the extent of variation of the DS/DA relation.

Tables 6 and 7 represent the results of the calculations dealing with this relation.

Table 6 - Ratio DS/DA - Model DSN2

| DA | RF | | |
|---|---|---|---|
| | 50 | 80 | 120 |
| 50 | 1.29 | 1.58 | 1.98 |
| 100 | 1.29 | 1.44 | 1.64 |
| 150 | 1.29 | 1.39 | 1.52 |

Table 7 - Ratio DS/DA - Model DS01

| DA | DC | | |
|---|---|---|---|
| | 2 | 5 | 9 |
| 60 | 1.12 | 1.58 | 2.20 |
| 120 | 0.96 | 1.20 | 1.51 |
| 180 | 0.91 | 1.07 | 1.27 |

The models mentioned previously were used, and the prevalent variation of the DA, DC and RF variables were considered.

With regard to new structures, DS/DA varies from 1.29 (for low rainfall) to 1.98 (for high rainfull).

It was concluded that the DS/DA relation is more susceptible to RF variation than to the Autumn deflection value, DA.

As for overlaid structures, this relation varies from 0.91 to 2.20. The values which are closer to the unit correspond to those cases where drainage conditions are very good, whereas the values closer to 2.00 correspond to situations where drainage conditions are very bad.

It is thus evident that, an important role is played by all the factors related to the drainage conditions of a flexible pavement, in the evolution of its bearing capacity.

The research referred by CEBTP,1971, suggests a DS/DA relation of between 1.10 and 1.75, in accordance with the base layer's susceptibility to water.

In addition, and in the study which Bellanger, 1987 refers to, DS/DA value ranging from 1.54 to 2.75 were obtained.

The DS/DA variation values, obtained using the models developed in this study, are in accordance with those values, as well as with the parameters considered to influence variation in this relation.

The models developed allow for a rapid deflection estimation; this was obtained, in unfavourable conditions, by means of a reduced, and physically significant, number of independent variables (DA, RF, DC, CI).

These permit one to conclude that the improvement in the present drainage conditions of pavements, as specified in Jacob,1991 and Paute, 1991, is important. In addition, an adequate maintenance of the drainage system quality, such as the condition of shoulders and the sealing of the wearing course, is of equal importance.

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