COMPARATIVE ANALYSIS OF RESILIENCE MODULES OBTAINED IN FIELD WITH GEOGAUGE AND THOSE OBTAINED IN THE LABORATORY

Camila Lima Maia[1], Carlos Augusto Uchôa da Silva[2], Suelly Helena de Araújo Barroso[3]

（[1] Federal University of Ceará，Fortaleza, Brazil, camilalima@det.ufc.br）

([2] Federal University of Ceará，Fortaleza, Brazil, uchoa@det.ufc.br)

([3] Federal University of Ceará，Fortaleza, Brazil, suelly@det.ufc.br)

ABSTRACT

With the adoption of mechanistic-empirical design method, that uses as input data to granular layers the Modulus of Resilience (MR), it is necessary the adoption of methods to control this parameter in field. The Geogauge is an equipament the determines MR in situ, however, the module provided by it differs from MR obtained in the laboratory through Triaxial Repeated Load test (TRL) due to some factors, suchs difference in loading, moisture, among others. Therefore, the aim of this study is to obtain a significant correlation between the MR wth obtained with the Geogauge (MR_{GEO}) and mean MR (MR_{Med}) determined through the TRL. To obtain this correlation, tests were carried out in the field whit the Geogauge, sand vial tests and moisture determinations in two sections: a Highway and na Experimental Section of the Federal University of Ceará. Still were held Laboratory tests as LL, LP, granulometry, compaction, CBR and TRL.From the statistical analysis of the field data and laboratory data, obtained a significant linear regression model ($R^2 = 0.64$) between the MR_{GEO} and the MR_{Med}, showing that Geogauge offers potential to be used in the technological control of granular layers of flexible pavements.

Keyword: Geogauge, Modulus of Resilience, Regression Models.

1. INTRODUCTION

In recent years there have been processes of premature deterioration of asphalt pavements, which led to the need to develop new methods of sizing, especially because the design of flexible pavements conducted in Brazil still uses the method of CBR that does not consider the dynamic nature of the loads applied to the pavement, among other factors of deterioration. This new sizing method is based on mechanistic-empirical criteria and uses as one of the main input data for the granular layers, the Resilience Module (MR).

Thus, with the adoption of mechanistic-empirical methods of designing flexible pavements, the need arises to adopt methods and equipment to control MR in the field. In this scenario, equipment such as Geogauge, which seeks to estimate the stiffness of pavement layers in situ, has appeared in recent years, and can be used for technological control during the constructive process of flexible pavements [1].

However, the MR results obtained with this equipment differ from the results determined in the laboratory, through the Triaxial Repeated Load test (TRL), due to some factors such as: the difference in loading, the state of tension, the degree of compaction, moisture, among others. Thus, it is necessary to establish parameters that correlate the results of the in situ tests with the resilience modules determined in the laboratory, in order to develop a mechanism capable of estimating the resilience modules of the pavement layers during the construction process [1]. Therefore, the objective of this study is to obtain a significant correlation between MR obtained with Geogauge (MR_{GEO}) and mean MR (MR_{Med}) determined in the laboratory, through the TRL test.

1.1. Geogauge

The Geogauge is manufactured by Humboldt Manufacturing Company and was developed with the main objective of replacing the methods of quality control of pavements used, and to control parameters of deformability in the field. The equipment weighs about 10 kg, has a height of 28 cm and a diameter of 25.4 cm. It also has a circular foot that allows its positioning directly on the ground. The Geogauge measures rigidities from 3 to 70 MN/m and Young's Module from 26.2 to 610 MPa, with a coefficient of variation of less than 10% and the measuring depth of the equipment is 220 to 310 mm. The Geogauge works with 6 disposable and common D-cell batteries, the battery life being 500 to 1500 measurements and operating at ambient temperature from 0 to 38 ° C [2].

Procedures for using Geogauge are standardized by ASTM D 6758 [3]. In performing the test, the Geogauge imposes on the ground small displacements of the order of 1.27 x 10^{6} m at 25 fixed frequencies between 100 and 196 Hz. Stiffness is determined for each of these 25 stages of frequency and is displayed at the end the mean of the values. The Geogauge test lasts approximately 75 seconds, being a quick and simple test. The user need only insert the Poisson's coefficient of the material and the shear modulus and soil elasticity are determined by the equipment [4].

Several authors have studied the correlations between the modules obtained with Geogauge and the modules obtained by other methods such as Lenke and Mckeen [5], Fortunato [6], Nazzal [7], Sawangsuriya et al. [8], Batista [4], Ferreira [9], Pestana [10], Hossain and Apeagyei [11] and Gudishala [1], who used Geogauge, DCP and LFWD equipment to determine soil resilience modulus in field and correlated the results with laboratory test, reaching satisfactory prediction models.

2. MATERIALS AND METHODS

The methodological steps of this investigation were divided into two phases. The first phase consisted of field trials and material collection for the laboratory tests in two sections: a 600 meter section of a Highway and a 40 meter Experimental Section of the Federal University of Ceará (UFC) built in the premises of Insttale Engenharia. The solution adopted on the Highway was an A-2-4 landfill, a 15 cm thick A-2-4 soil subbase, a 15 cm thick Simple Graduated Brick (BGS) base, of Binder with 6 cm of thickness and the asphaltic concrete coating with 6 cm of thickness. In the experimental section the solution adopted was a subgrade of the natural soil of Insttale, a reinforcement of soil type A-2-4 of 20 cm of thickness, a sub-base of gravel soil of 15 centimeters of thickness, a base of BGS of 15 centimeters of thickness and the asphaltic concrete coating with 5 cm of thickness.

Field tests were carried out with the Geoauge equipment, sand vial tests and moisture determination. In the Experimental Section the field tests were carried out in two points, 20 meters apart, in all layers of the pavement and in the section of the Highway the tests were executed in six points, distant 100 meters each other, in all layers of the pavement. With the samples collected in the stretches, the laboratory tests of Liquidity Limit (LL), Plasticity Limit (LP), Granulometry, Compaction, CBR and TRL were carried out.

The second phase consisted of the analysis of the field data and laboratory data to obtain the correlations between the Geogauge resilience module (MR_{GEO}) and the mean MR (MR_{Med}) obtained in the laboratory through the TRL test. Correlations were obtained through

Excel® software, and the Action supplement, where linear regression analysis was performed, reaching the significant regression model.

3. RESULTS AND DISCUSSIONS

To obtain the correlations, a statistical regression analysis was performed. Regression is a method of analyzing the relationship between two or more variables, so that a variable can be predicted through information from other variables. Therefore, the first step in the development of the regression model was to select the appropriate independent variables to be included in the forecast models. For this it is necessary to calculate the correlation coefficient for all the variables that can be used in the models.

To choose the variables that could be used, the criterion of the highest coefficient of correlation was used, since it provides a convenient indication of the linear relationship between two variables. The maximum value of the correlation coefficient ranges from -1 to +1. A value of ± 1 indicates a very strong relationship between two variables and the correlation coefficient signal suggests a positive or negative relation.

Thus, they were chosen as independent variables the modulus of resilience obtained with the Geogauge device (MR_{GEO}), the Plasticity Index (PI), the apparent specific dry mass, the percentage of material passing through the 0.42 mm aperture sieve and the CBR, and the dependent variable, the average resilience modulus obtained in the laboratory (MR_{Med}). Table 1 presents the correlation coefficients between the selected variables.

TABLE 1. Correlation Matrix.

	MR_{Med}	MR_{GEO}	#0.42mm	PI	App. Spec. Dry Mass	CBR
MR_{Med}	1					
MR_{GEO}	0.127871	1				
#0,42mm	0.268075	0.726544	1			
IP	-0.42318	0.64959	0.437406	1		
App. Spec. Dry Mass	0.781609	0.561018	0.534263	0.064495	1	
CBR	0.747382	-0.15939	-0.17951	-0.46496	0.649433	1

Source: Own Authorship.

In the conception of the regression model, the retroactive elimination method, also known as "backward" was used. In this method, we start with the complete model, with all the independent variables. The variable with the highest P-value is initially removed from the model, provided that the P-value is greater than the level of significance (α). The P-value is the probability of obtaining a test sample statistic value at least as extreme as that resulting from the sample data, assuming that the null hypothesis is true. The procedure is repeated until all the variables of the reduced model are significant, that is, they have P-value lower than the level of significance. In this study, the level of significance considered was 5%.

In this way, the MR_{Med} dependent variable was initially was modeled to the selected independent variables. Thus, the variable with the highest P-value was removed, provided that the P-value was higher than the significance level, until the other variables of the reduced model had a P-value lower than the significance level. At the end, only the MR_{GEO} variable remained, resulting in a simple linear regression model, represented in Equation 1. Figure 1 shows the relationship between MR in situ and MR obtained in the laboratory.

$$MR_{Med} = 2.016581 \times MR_{GEO} \quad R^2 = 0.64 \qquad \text{Eq. (1)}$$

At where:

MR_{Med} is the resiliency module obtained in the laboratory through the TRL

MR_{GEO} is the resiliency module obtained with Geogauge.

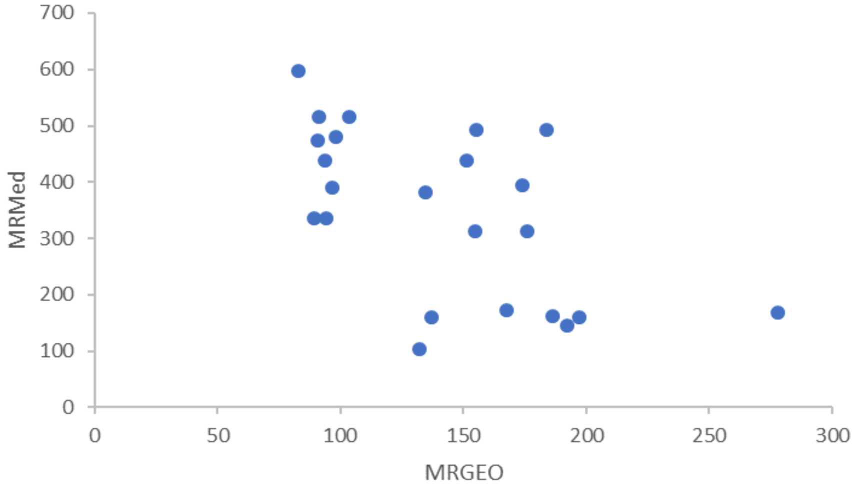

FIGURE 1. MR_{GEO} x MR_{Med}.

Source: Own Authorship.

To verify the significance of the proposed model, some statistical tests were performed, such as an ANOVA test. Table 2 summarizes the results of the regression model. Table 3 shows the ANOVA test result and Table 4 shows the Student's t-distribution test.

TABLE 2. Summary of Regression Model Results.

Regression statistics	
R multiple	0.801793
R-Square	0.642872
R-square adjusted	0.602872
Default error	215.7331
Observations	26

Source: Own Authorship.

TABLE 3. ANOVA Test.

	Gl	SQ	MQ	F	F of significance
Regression	1	2094471	2094471	45.00295	6.13E-07
Residue	25	1163519	46540.76		
Total	26	3257991			

Source: Own Authorship.

TABLE 4. Test of Hypothesis using Student's t-distribution.

	Coef.	Standard Error	Stat t	P-value	95% inf.	95% sup.	Inf. 95,0%	Sup. 95,0%
Intersection	0	#N/D	#N/D	#N/D	#N/D	#N/D	#D	#N/D
MR_{GEO}	2.016581	0.300604	6.708423	4.97E-07	1.397475	2.635688	1.397475	2.635688

Source: Own Authorship.

Table 2 presents the value of the correlation coefficient (r) of 0.8 and the coefficient of determination (R^2) of 0.64. These values indicate that there is a significant linear relationship between the variables and 64% of the variations of y are explained by the model, showing that the model used can be considered a good model to try to explain the y (Middle Module). According to the literature, a coefficient of determination above 0.60 can be considered significant.

Table 3 presents the result of the F of significance for the distribution Chi-Square, presenting a value of 6.13E-07, much lower than the significance level of 5% used in the test. This result shows that the variable x (MR_{GEO}) can be used to explain the variable y (MR_{Med}).

Table 4 presents the t-test result, resulting in a P-value of 4.97E-07 for b1, lower than the significance level of 5%. In the regression model the value of the intercept b0 equals 0. Thus, the sample line can be considered representative of the population regression line.

The linear regression models must meet some premises. One of them is related to the least squares theory. The violation of this premise is termed heterodasticity. To test any possible occurrence of heterodasticity the graph of the residues is evaluated, as shown in Figure 2.

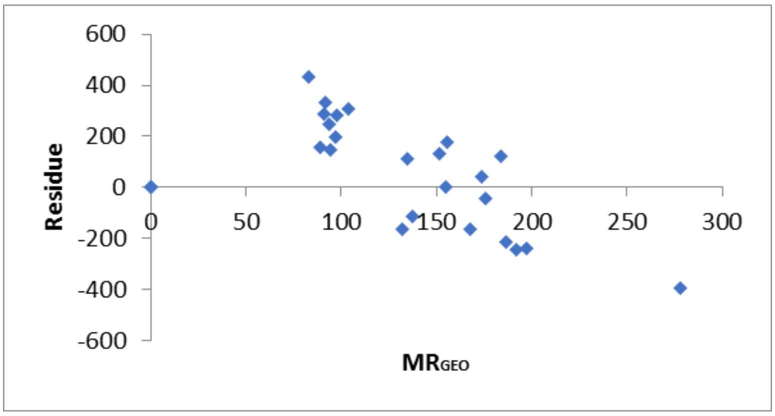

FIGURE 2. Residues.

Source: Own Authorship.

The residuals of the regression model are the difference between the observed sample value and the value of y estimated by the use of the regression line. If the residue graph does not present any pattern, the regression equation is a good representation of the association between the two variables. If the residue graph presents some systematic pattern, the regression equation is not a good representation of the association between the two variables. Thus, it is observed in Figure 2 that there is little evidence of a systematic pattern of residues, indicating that the linear regression model presented may be adequate.

Another premise of the linear regression model is that the residuals should follow a normal distribution with mean 0 and variance σ^2. To infer if the residuals of the simple linear regression model discussed here follow a normal distribution, the Kolmogorov-Smirnov test was used, whose hypotheses are as follows:

H_0: The data follow a normal distribution N (0, σ^2)

H_1: Data do not follow a normal distribution

The test was performed at a significance level of 5% and provides the P-value, and the null hypothesis is rejected if the P-value is lower than the level of significance. The test result can also be confirmed by the existence or not of a randomness of points around the line. Table 5 shows the P-value and Figure 3 shows the test result.

TABLE 5. Normality Test.

Test	Statistical	P-value
Kolmogorov-Smirnov	0.106856152	0.623629527

Source: Own Authorship.

It can be seen in Table 5 that the P-value was higher than the 5% significance level, and it can not reject the null hypothesis that the data follow a normal distribution, given the premise of the model.

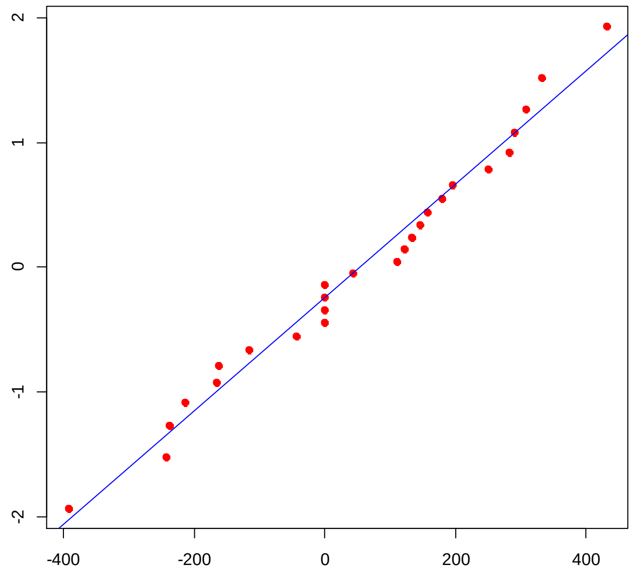

FIGURA 3. Kolmogorov-Smirnov.
Source: Own Authorship.

4. FINAL CONSIDERATIONS

Geogauge is an equipment that provides a direct measure of in situ deformability parameters, besides being a low cost equipment with potential to be used in the technological control of the layers of flexible pavements.

Although the modules obtained with Geogauge were not representative of the module medium determined in the laboratory, through the TRL test, it was possible to obtain a significant correlation ($R^2 = 0.64$) between the modules determined by the two methods.

The use of Geogauge in the pavement quality control is an important step for the dissemination of the mechanistic proposal of sizing of flexible pavements, since it is possible to determine in the field the parameters used as input data for the sizing.

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