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DEVELOPMENT OF COMPUTATIONAL TOOL FOR STATISTICAL ANALYSIS OF CONCRETE'S HOMOGENEITY BY DETERMINATION OF REBOUND HAMMER TEST'S RESULTS

Christian Carneiro de Oliveira
Flávio Barboza de Lima
Christian.oli13@gmail.com
fblima@ctec.ufal.br
Federal University of Alagoas, Center of Technology
Lourival Melo Mota Ave, n/n, Tabuleiro do Martins, Maceió, 57072-970, Alagoas, Brazil

Abstract. This paper presents the development of a computational tool that provides support to in-site structural concrete integrity analysis through the determination of its homogeneity, parameter that is directly related to fundamental aspects of the quoted material, such as resistance and durability. The related homogeneity determination is made by statistical analysis of the results of rebound hammer tests, which are non-destructive tests (that is, tests that does not compromise the integrity and functionality of the measured structural element) that determinates the superficial toughness of concrete. The statistical analysis is consisted in the computational implementation of comparative hypothesis tests associated to a program logic that prioritizes the effectuation of the most statistically trustable, according to the sample characteristics of the rebound hammer test's indexes obtained during the tests. From the comparison between the measured indexes in different regions of the same structural element, it is determined if those are, or not, homogeneous. In addition to this, regions of different elements are also compared to statistically determinate if those are (or not) of equal characteristics concretes. Regarding to the programming language, the tool was written in Visual Basic for Applications (VBA) language linked to Microsoft Excel applications, which provides the automatization of several processes inside Excel's spreadsheets and tables through the creation of personalized routines; Therefore, through the integration with Microsoft Excel, an widely used software, it was possible to create an useful, trustable and easy to access tool of health concrete evaluation and monitorization.

Keywords: Rebound hammer test, concrete's homogeneity, comparison statistical tests, Visual Basic for Applications (VBA)

1 Introduction

Regarding in locus structural concrete's health monitoring, the usage of non-destructive tests has the upside of the possibility to obtain valuable parameters about the hardened concrete without compromising its structural functionality. Among the non-destructive tests, the rebound hammer test, which measures directly the superficial hardness of the concrete, stands out because it demands low-cost equipment and provides fast answers, along with the capability of relating its direct results with other important aspects related to the concrete's health, such as uniaxial compression resistance and homogeneity, being the last one the focus of this paper. According to Mehta and Monteiro (2014), the rebound hammer test allows, in a fast and cheap way, to evaluate the in locus hardened concrete homogeneity. However, the autors do not set a clear and scientific form of verifying it. In this context, the statistical analysis comes up as an alternative to collect and process the obtained data and grant trustable support to decision making, problem solving and actions planning. MONTGOMERY and RUNGER (2008) presents methods and statistic tests that can be used to produce a possible understanding of the variability of the results of consecutive observations of a phenom, once those do not always produce the same results. Hence, a statistic approach can be employed to verify the equality between several results of rebound hammer test's indexes, which, in turn, can be provenient from diverse civil works. The following tests can be used to make such comparisons:

- **One way Anova-Test**

  The one-way ANOVA compares the means between the groups you are interested in and determines whether any of those means are statistically significantly different from each other. Specifically, it tests the null hypothesis that the variances of the groups are equal. If, however, the one-way ANOVA returns a statistically significant result, we accept the alternative hypothesis (H_A), which is that there are at least two group means that are statistically significantly different from each other.

- **Tukey Test**

  Tukey's test is utilized after an Analysis of Variance, as a complement, and determines the individual means which are significantly different from a set of means. Tukey's test is a multiple comparison test and is applicable when there are more than two means being compared. It is calculated through a pairwise comparison of all means.

- **Kruskal-Wallis Test with multiple comparisons**

  It is a non-parametric test used to compare three or more populations. It is used to test the null hypothesis that all populations possess equal distribution function against the hypothesis that at least two of them have different distribution functions.

Both Anova and Tukey test demands that the samples tested possesses similar variances and a normal distribution. To check if the samples attends those needs, the Bartlett test is used to verify if the samples have homogeneous variances and the Shapiro-Wilk test verifies if the samples have normal distribution.

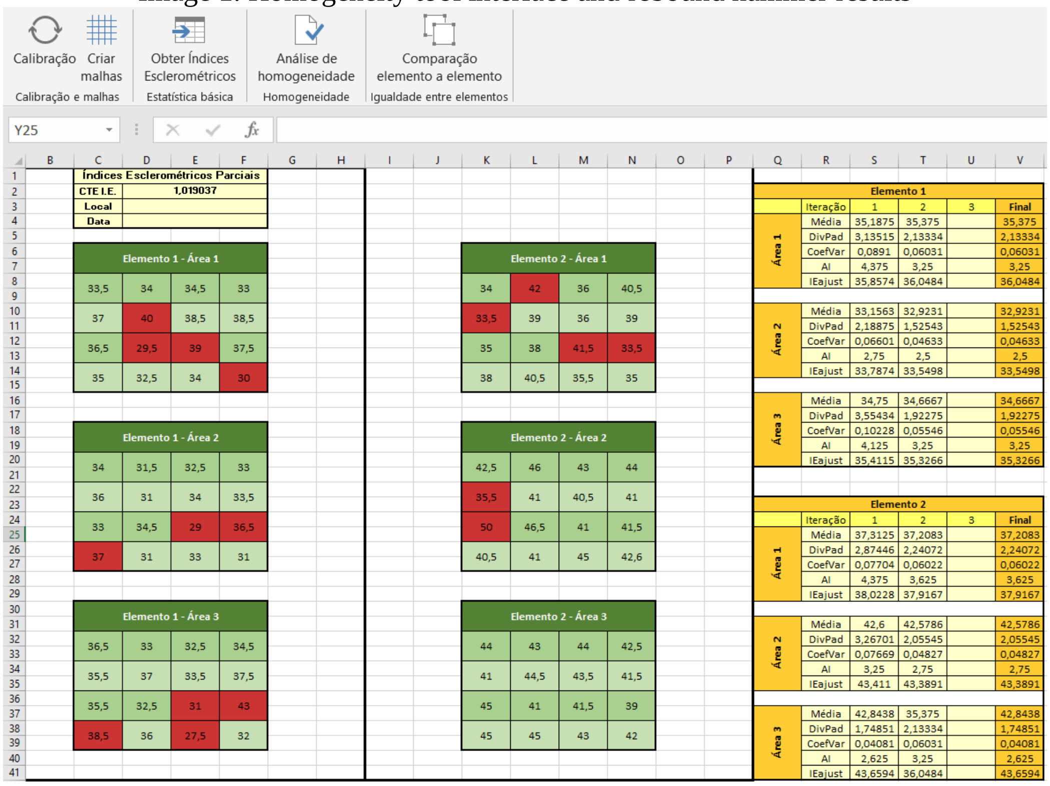
The automatization of processes through the computational implementation of its many stages has become a key factor to acquire reliability and agility within several fields of science and market, once it is capable of conferring fast answers with a lower susceptibility to errors. In this sense, the implementation of programmatic routines focused on the statistical analysis of the results of the rebound hammer test can become the source of a powerful tool of in locus concrete's homogeneity evaluation and monitoring. An alternative to build such a tool can be through the Microsoft Excel, a worldwide used software between the civil engineering community, which provides to the user the possibility to include custom functions and routines (called macros) to its already vast range of tools through an extension of the Visual Basic program language, the Visual Basic for Applications (VBA).

2 Results and Discussions

The programming process involved the following steps, respectively: implementation of the basic statistics, implementation of the statistical tests, implementation of the user's interface. All the implementation was made in VBA language.

To present the results of an application of the tool, data of a rebound hammer test session made in Alagoas, Brazil. Three regions of two pillars were tested and the test's results are presented in the image below. All of the tables are generated automatically by the tool.

Image 1. Homogeneity tool interface and rebound hammer results



In the image above is also possible to see the buttons of the user's interface that unlock the macros' sequence for each action. In the image, there were used two routines, the one activated by the "Create Mesh" button (in Portuguese language), which generates the green table, input area for the in locus test results, and the "Obtain rebound hammer test results" (also in Portuguese Language), which generates the yellow tables, calculating the rebound hammer test's indexes of each region and other basic statistic parameters.

Subsequently, it is presented the outputs of the "Homogeneity analysis" button using the same data and a significance level of 5%.

Table 1. Homogeneity analysis for the pillar 1 (Elemento 1)

Análise estatística da homogeneidade do Elemento 1 sob o intervalo de confiança de 95%															
Área	Normalidade Shapiro-Wilk			Anova			Variância Teste de Barlett			Tukey: TSD				Teste mais confiável	Resultado final
	Shapiro-Wilk	Valor Crítico	Resultado	Anova - F	Valor Crítico	Resultado	Barlett	Valor Crítico	Resultado	TSD	Combinações	Diferenças observadas	Resultado		
1	0.917	0.859	Positivo								1 e 2	2.452	Diferentes		
2	0.933	0.866	Positivo	5.748	3.276	Negativo	1.259	5.991	Positivo	1.853	1 e 3	0.708	Iguais	Anova & Tukey	Não Homogêneo
3	0.926	0.859	Positivo								2 e 3	1.744	Iguais		

Table 2. Homogeneity analysis for the pillar 2 (Elemento 2)

Análise estatística da homogeneidade do Elemento 2 sob o intervalo de confiança de 95%															
Área	Normalidade Shapiro-Wilk			Anova			Variância Teste de Bartlett			Kruskal-Wallis				Teste mais confiável	Resultado final
	Shapiro-Wilk	Valor Crítico	Resultado	Anova - F	Valor Crítico	Resultado	Barlett	Valor Crítico	Resultado	Critical difference	Combinações	Diferenças observadas	Resultado		
1	0.920	0.859	Positivo							11.554	1 e 2	19.083	Diferentes		
2	0.864	0.874	Negativo	32.611	3.238	Negativo	0.795	5.991	Positivo	11.215	1 e 3	21.583	Diferentes	Tukey	Não homogêneo
3	0.939	0.887	Positivo							10.747	2 e 3	2.5	Iguais		

The statistical analysis implies that for the first pillar, called "Elemento 1", that all of its measured regions had normal distributions (Shapiro-Wilk test positive) and similar variances (Bartlett test positive), which means that the Anova and Tukey tests results can be considered, and since these are more precise when compared to Kruskal-Wallis test, these will be the ones that will give the final result. In this sense, once the Anova test resulted as negative, there is evidence to imply that not all regions' distributions are equal. Using the Tukey test to complete the answer, it is registered that, the comparison 1-3 resulted negatively, which means that the regions 1 and 3 had significative difference between its averages. Thus, the final result is that the pillar is not homogeneous

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For the second one, the Anova and Tukey tests do not have its premises attended, leading the program to use the Kruskal-Wallis tests results. These ones indicate that the comparison between the regions 1-2 and 1-3 had differences between the samples were greater than the critical difference adopted in the method. Hence, meaning that there is difference between the distribution of the samples and that the second pillar also is not homogeneous.

The equality between elements analysis follows bellow, with a significance level of 5%, representing the button "Comparison element to element".

Table 3. Pillars 1 and 2 comparison under the homogeneity perspective.

Comparação entre áreas dos elementos 1 e 2 sob o intervalo de confiança de 95%								
Combinações	Tukey: TSD			Kruskal-Wallis			Teste mais confiável	Resultado Final
	TSD	Diferença Observada	Resultado do teste	Diferença Crítica	Diferença Observada	Resultado do teste		
E1A1 – E2A1	2,220596957	1,833333333	Iguais	27,49982379	10	Positivo	Kruskal-Wallis	Diferentes
E1A1 – E2A2		7,203571429	Diferentes	26,49949327	35,41666667	Negativo		
E1A1 – E2A3		7,46875	Diferentes	25,72372971	37,91666667	Negativo		
E1A2 – E2A1		4,28525641	Diferentes	26,9657958	24,73717949	Positivo		
E1A2 – E2A2		9,655494505	Diferentes	25,94488347	50,15384615	Negativo		
E1A2 – E2A3		9,920673077	Diferentes	25,15201989	52,65384615	Negativo		
E1A3 – E2A1		2,541666667	Diferentes	27,49982379	14,16666667	Positivo		
E1A3 – E2A2		7,911904762	Diferentes	26,49949327	39,58333333	Negativo		
E1A3 – E2A3		8,177083333	Diferentes	25,72372971	42,08333333	Negativo		

In this case, once that the test had only two structural elements to compare, the only comparison made is between pillar 1 (Elemento 1) and pillar 2 (Elemento 2). Knowing from the previous results that the samples of the "Elemento 2" did not contemplate the Anova and Tukey-Kramer tests, the program used the Kruskal-Wallis' results again. All regions of the first pillar were compared to all regions of the second one, pair to pair. Once the test had negative answers for more than zero comparisons, resulting that both pillars are not equal from the perspective of its homogeneity

Finally, to verify if the algorithm was leading responses correctly, the results of the tests above were compared with the results of the statistical software Action Stat, a statistical software developed in Brazil with 60.000 users and effectiveness tested and confirmed, using the same input values. Considering that the processes related to the Homogeneity of the pillar 1 involves the realization of all the mentioned statistical tests, in this paper, only the comparisons between the results of the homogeneity tool versus the Action Stat software will be presented.

Table 4. Comparison between the calculated results and the Action's software results, part 1.

Homogeneity analysis						
Tukey-kramer	Combination	Diferença observada		TSD		
		Action	Homogeneity tool	Action	Homogeneity tool
	E1A2-E1A1	2,451923077	2,451923077	1,850668912	1,853104507
	E1A3-E1A1	0,708333333	0,708333333		
	E1A3-E1A2	1,743589744	1,743589744		
Kruskal-Wallis	Combination	Diferença observada		Diferença Crítica	
		Action	Homogeneity tool	Action	Homogeneity tool
	E1A1 - E1A2	12,108974	12,10897436	10,37362	10,37361735
	E1A1 - E1A3	3,583333	3,583333333	10,57906	10,57905545
	E1A2 - E1A3	8,525641	8,525641026	10,37362	10,37361735

Table 5. Comparison between the calculated results and the Action's software results, part 2.

Shapiro-Wilk			Bartlett	
Region	Estatística de Shapiro-Wilk		Estatítstica de Bartlett	
	Action	Homogeneity tool	Action	Homogeneity tool
Area 1	0,91679623	0,916595775	1,258628325	1,258628325
Area 2	0,932656249	0,932766554		
Area 3	0,926260906	0,926073301		

The tables indicate that all of the statistic tests are running correctly, once there is no difference between the calculated results and the Action Stat results. The only minor disparity presented is on the Tukey test, where the Tukey significant difference has differences in the order of magnitude of the thousandths, which is not significant.

3 Conclusions

A precise and useful tool was created in order to better interpretate directly the rebound hammer test results and determinate the hardened concrete's homogeneity, associated with an interface that makes its use easy and with a software platform that is accessible, allowing its use in the concrete's health monitoring routine.

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