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ASSESSING STRENGTH VARIABILITY OF CONCRETE STRUCTURAL ELEMENTS

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ABSTRACT

The average in-situ strength of a member, expressed as the strength of an equivalent compression test result, will be lass than of a standard cast specimen of the same concrete, which has been properly compacted and moist-cured for 28 days. The extend of the difference will depend on construction techniques, but general patterns can be defined according to member type. Variations in concrete supply will be due to differences in materials, batching, transport and handling techniques. These will reflect the degree of control over production and will normally be indicated by control and compliance test specimens in which other factors are all standardized.
The present paper analyses the effectiveness of the rebound test and ultrasonic pulse velocity in evaluating the strength variability of concrete structural elements, expressed by: confidence interval, , colours "contour" plots showing areas of equal strength and ANOVA technique. The paper also shows criterion for concrete variability analysis. However, test results, is still small, and these criteria should not be used at random.

Keywords*:* Strength variability, Concrete members, Statistics, UPV test, Rebound test

1. Introduction

Concrete is among the most important structural materials used by the Construction Industry. However, structural performance depends on the concrete in place, which, in turns is related to construction procedure and mixes characteristics. Therefore, concept of strength variability of a structural concrete element is directly related to the uniform distribution of the component materials of the concrete into this element.
In addiction, concrete strength variability in structural elements is related to the concrete production process (mixing, transport, releasing, compacting and cure). When a fail occurs to the production system, anomalies is often indicated by surface of the concrete, i. e., cracking, segregation, excessive bleeding, honeycombing, excessive deflection, etc. The experience with concrete has shown that these anomalies may reduce the durability of the structural element.
The present paper presents three methods for assessing the strength variability of the concrete into the structural elements:

- Confidence Interval Method (CIM), which is based on computing confidence interval of the sample and to exclude all outlier values of the sample recorded. This process is repeated until all value of the sample recorded is into the confidence interval. Then, calculation of the outlier percentage is carried out. The outlier percentage is assumed as the parameter for assessing the concrete strength variability.
- Iso-Energy (rebound hammer number) and/or Iso-Velocity Curves (ultrasonic pulse velocity) Method, which is based on plotting contour curves obtained from class intervals of test results, taken on a regular grid over the member, and relating these intervals to colors that express the strength variability of the concrete.
- Variance Analysis Method (ANOVA), which is based on comparing test results of structural elements area. The structural element is geometrically divided in sample areas for caring out tests. The statistical comparison of those sample areas, by the tests results, allows assessing the concrete strength variability into the structural element.

This paper presents criterions and methodology for assessing the concrete strength variability into the structure.

2. Experimental program

The experimental program was carried out at construction sites, multifamily residential constructions, in Rio de Janeiro. All structure were design for characteristic concrete strength (f_{ck}) of 18 MPa. Structural elements with no defects, easy access and age less than 90 days were chosen for testing. When need structural elements surface were rubbed smooth with carborundum stone. Thus tested surface were smooth, clean and dry.
The experimental program tested more than 40 (forty) structural elements, among columns, beams and slabs. No test results are presented in this paper, they were shown elsewhere [1,2,3]. A column test results will be shown, so that the focus of the present paper will be emphasized.
Tests were carried out on points of a regular grid over structural element, as shown in Fig. 1.

	UPV (km/s)		
	1	**2**	**3**
1	3,02	3,02	3,80
2	4,12	3,95	3,82
3	3,81	3,87	3,96
4	3,82	3,99	3,82
5	3,99	3,86	3,88
6	3,94	3,79	3,88
7	3,94	3,86	3,80
8	3,88	3,81	3,83
9	3,77	3,85	3,82

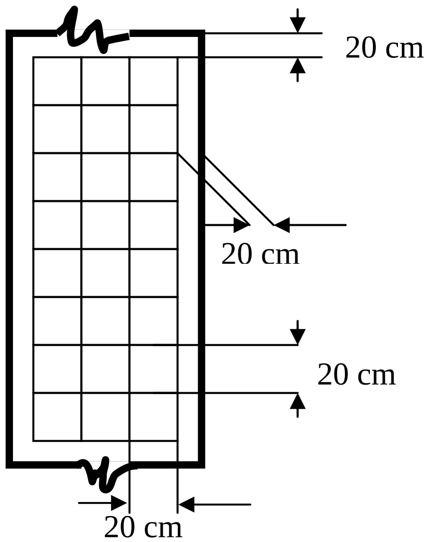


Fig. 1: Grid over a concrete column.

All columns were tested by the largest surface. Lateral, superior and inferior band were used for avoiding reinforcement influence on test result. Covermeter was used to determine the location and cover reinforcement.
Rebound Tests were carried out on points of a regular grid over the same column on opposite faces of that structural element, as shown in Fig. 2.

	FACE A				FACE B		
	1	**2**	**3**		**1**	**2**	**3**
1	35,48	34,32	33,74	**1**	34,53	34,75	33,91
2	32,21	33,05	32,64	**2**	34,91	35,45	35,03
3	33,91	34,55	33,48	**3**	34,41	31,83	34,61
4	34,21	33,19	32,61	**4**	32,77	32,61	34,61
5	36,02	34,78	34,38	**5**	34,65	35,68	39,93
6	35,74	33,65	34,06	**6**	34,28	32,35	33,91
7	34,75	35,66	35,03	**7**	34,61	35,22	33,71
8	33,91	36,58	35,19	**8**	33,91	33,09	37,61
9	34,53	34,47	33,89	**9**	34,26	33,87	35,42

Fig. 2: Rebound tests results.

3. The confidence interval method (CIM)

The method carried out an analyzes on tests results of sample obtained from structural elements at construction site. The analyzes uses statistical parameters of the test results, average (X_{ave}), the standard deviation (s) and an extreme value (X_{ext}). The t_0 value is calculated

$$t_o = | X_{ext} – X_{ave} | / s \qquad (1)$$

and compared with the $t_{\alpha,df}$ value of the Student's distribution.
Whenever $t_0 > t_{\alpha,df}$ the extreme value, X_{ext}, is assumed as outlier and by excluding this value a new analysis is carried out. Therefore, the process is repeated until $t_0 < t_{\alpha,df}$. The percentile of the test results assumed as outlier is calculated.
Confidence Interval Method (CIM) criterion for assessing concrete strength variability, proposed by the authors of the present paper is to assume:

- homogeneous concrete if outlier percentile is below 25%,
- regular concrete if outlier percentile is lies between 25 to 50%;
- heterogeneous concrete if outlier percentile over 50%.

When applying the Confidence Interval Method (CIM) to the UPV tests results shown in Figure 1, the smallest values are assumed as outlier due to:

Average = 3,81 km/s; Standard Deviation = 0,241 km/s,

which follows: $t_{0,05;26}$ = 2,056; t_{0min} = 3,278 and t_{0max} = 1,282.

Thus, a_{11} = 3,02 and a_{12} = 3,02 are outliers and a new rum must be performed.

Therefore, the analysis is now carried out on others 25 values.

Average = 3,87 km/s; Standard Deviation = 0,082 km/s,

which follows: $t_{0,05;24}$ = 2,064; t_{0min} = 1,281 and t_{0max} = 2,993.

As $t_{0max} > t_{0,05;24}$ a new run is need, assuming the maximum velocity of 4,12 km/s as an outlier value.

Then, the Average = 3,86 km/s; Standard Deviation = 0,066 km/s,

which follows: $t_{0,05;23}$ = 2,069; t_{0min} = 1,448 and t_{0max} = 1,823.

Therefore, 3 (three) tests results (11,11%) are assumed as outliers and the concrete of the column is stated as homogeneous.
Applying the same procedure to the Rebound tests results Face A has 3,8% of outliers and Face B 25,92%. This means homogeneous concrete at Face A and regular concrete at Face B.

4. The iso-curves method (ICM)

The Iso-Energy and/or Iso-Velocity Curves Method (ICM), here proposed, is based on plotting contour curves obtained from class intervals of test results, taken on a regular grid over the member, and relating these intervals to colors that express the strength variability of the concrete. The area of contour curves spread out is also a parameter for assessing strength variability. Gray is the representative color for the class interval, which contains the average (I_{ave}) test result. Class intervals of test results bellow the average the color ranges from yellow to red. Class intervals of test results over the average are expressed by colors ranging from light to dark blue, as shown in the Fig. 3.

Fig. 3: Colors pattern of for classes intervals.

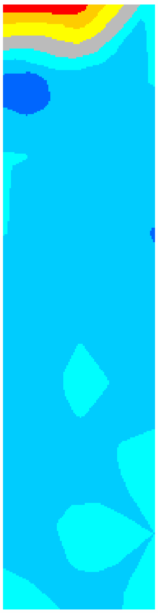
By plotting the curves "contour", concrete strength variability is assessed. The class interval (I_c) is computed by:

$$I_c = (V_{max} - V_{min}) / (n^{0,5}) \qquad (2)$$

where:

V_{max} is the maximum value for the test results of the sample;
V_{min} is the minimum value for the test results of the sample; and
"n" is the number of test results of the sample.

However, assuming 7 (seven) classes interval (I_c) better iso-curve contours are noted.



COLOR	INTERVAL	AREA(cm2)	AREA(%)
	4,01–4,19	128,61	2.00
	3,83–4,01	4793,76	74,93
	3,65–3,83	1099,37	17,18
	3,47–3,65	144,05	2,25
	3,29–3,47	115,01	1,78
	3,11–3,29	81,80	1,28
	2,93–3,11	37,40	0,58

Fig. 4: UPV iso-curves of a column.

Iso-Curves Method was applied to the test results from Fig. 1. The area between that curves were painting with an appropriated color, according to Fig. 4. After that the areas between the curves were calculated, as shown in Table 1. Figs. 5 and 6 show an example of results obtained for Rebound tests applied to the same column shown in Fig. 2.

The ICM criterion for assessing concrete strength variability in a structural element is subjective. Therefore, the color chart can often provide valuable information to a well-trained eye. Color chart visual feature may be related to concrete strength variability.

Table 1: UPV class intervals of column.

COLOR	INTERVAL	AREA (cm^2)	AREA (%)
	4,01 - 4,19	128,60	2,00
	3,83 – 4,01	4793,75	74,93
	3,65 – 3,83	1099,36	17,18
	3,47 – 3,65	144,04	2,25
	3,29 – 3,47	115,01	1,78
	3,11 – 3,29	81,80	1,28
	2,93 – 3,11	37,40	0,58

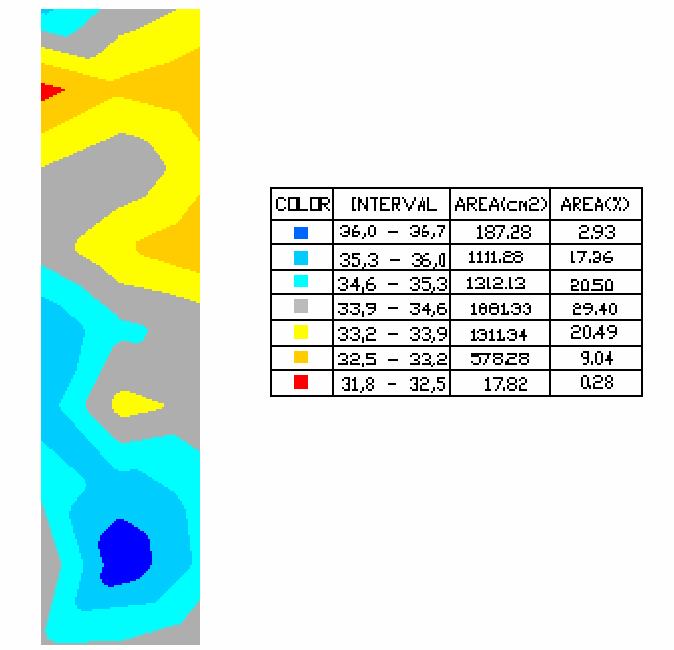


Fig. 5: Face A: rebound iso-curves.

When applying Iso-Curves, the criterion for concrete variability analysis should based on area. For instance, assuming an area percentile over 25% in red to be heterogeneous. However, test results, is still small, and these criteria should not be used at random.

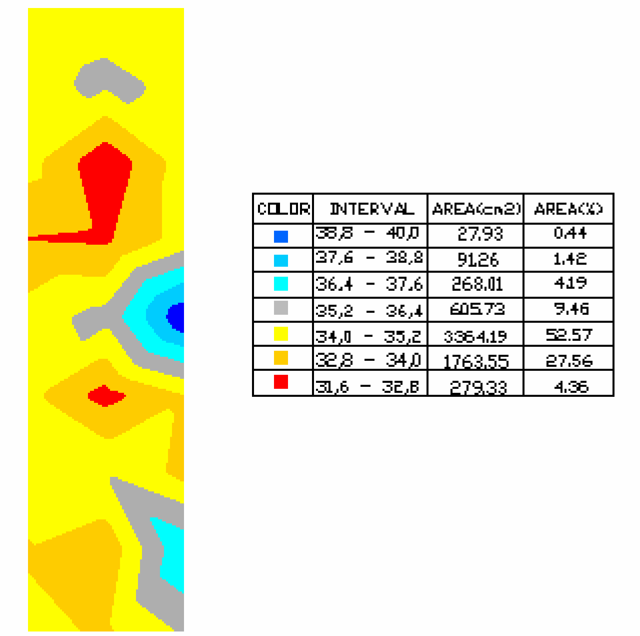


Fig. 6: Face B: rebound iso-curves.

5. Variance analysis method (ANOVA)

This method uses the analysis of the variance technique and statistic hypothesis test for comparing two or more samples averages. Therefore, the method consists of accomplishing tests of hypotheses in the following way:

- H_0: no significant difference between the samples average,
- H_1: t significant difference between the samples average.

The risk of 5% was adopted for the present experimental program.

The structural element is geometrically divided in sample areas for caring out tests. The statistical comparison of that sample areas by the tests results allows to assess the concrete strength variability into the structural element.

The experimental program applied the ANOVA method by carrying out tests to three sample areas of each structural element. Assuming that placing concrete may influence the strength variability, the sample areas were chosen as follow:

- columns: three sample areas bound at almost one third of the column height;
- beams: three sample areas bound at almost one third of the beam span;
- slabs: nine sample areas bound at almost one third of each length direction.

The analysis criterion is significantly dependent on the risk assumed for the test of hypotheses.

5.1 ANOVA application

A column of the experimental program was chosen for the ANOVA application. Three sample areas of ultrasonic pulse velocity test results are shown in Table 2. The ANOVA application, which uses Fischer's distribution, is shown in Table 3.

ANOVA technique shows no significant difference between the UPV test results of the three regions of the column (Top, Medium and Bottom region).

ANOVA technique applied to compare rebound results of Face A and B is shown in Table 4.

There is no significant difference between the Rebound test results of Face A and B of the column.

When applying ANOVA technique, the criterion for concrete variability analysis should be based on significant difference between areas or regions of the structural element.

Table 2: Column: UPV test results.

	UPV (km/s) 1	2	3	
1	3,02	3,02	3,80	TOP
2	4,12	3,95	3,82	
3	3,81	3,87	3,96	
4	3,82	3,99	3,82	MEDIUM REGION
5	3,99	3,86	3,88	
6	3,94	3,79	3,88	
7	3,94	3,86	3,80	BOTTOM
8	3,88	3,81	3,83	
9	3,77	3,85	3,82	

Table 3: ANOVA applied to UPV test results of a column.

Source of variation	*SQ*	*df*	*MQ*	*F*	*P-value*	*F cri*
Between samples	0,152996	2	0,07649803	1,350138	0,278193	3,402832
Within samples	1,359826	24	0,05665944			
Total	1,512823	26				

Table 4: ANOVA applied to rebound test results of a column.

Source of variation	*SQ*	*df*	*MQ*	*F*	*P-value*	*F cri*
Between samples	0,641084	1	0,641084	0,347416	0,558132	4,026631
Within samples	95,95506	52	1,84529			
Total	96,59614	53				

6. Conclusions

The quality of structural elements depends on the concrete production process, i.e., mixing, transport, placing, compaction and cure. Nondestructive tests, at construction site, are usually used for assessing concrete strength into the structure. However, non-destructive tests may also be used for assessing the concrete homogeneity into the structural element. Also, concrete is said to be homogeneous when its component are well distributed into the structural element, and concrete strength is well related to components distribution into the cement matrix.

The experimental program have shown that assessing concrete strength variability by any of the method presented in this papers depend on the number of tests carried out to the structural element.

The Confidence Interval Method (CIM) fits better applied on concrete batch analyze. In general, CIM is to enhance the probability of carrying out the intent of the designs and specifications. This means that the purpose of CIM is to assure that good practices are followed in constructing the project in accordance with the designs specifications.

The Iso-Curves Method (ICM) presents an effective criterion for assessing concrete strength variability into the structural element. Although the percentile limit must be well defined. However, ICM is recommended for assessing anomalies or voids at the interior of concrete structural elements, when UPV tests are carried out.

Rebound test from two surface of a structural element should present results significantly different for ICM analysis. Rebound test results are significantly influenced by mass, compaction, surface carbonation and moisture condition.
The ANOVA technique is particularly adequate for structure production control.
By using non destructive tests, three techniques for assessing concrete strength variability into the structure, were shown. However, there is no standard on the subject so that a common criterion can be applied on a regular base.

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7. References

[1] CASTRO, P. F. "Assessing concrete strength by Insitu Tests", 15th World Conference on Non Destructive Testing, Rome, Italy, 2000.
[2] FERREIRA, A. P. "Ensaios Não Destrutivos: Resistência ao esmgamento do agregado graúdo como variável para avaliação da resistência do concreto", MSc Dissertation, Universidade Federal Fluminense, Niterói, Rio de Janeiro, 1999.
[3] LUDWIG FILHO, U. "A homogeneidade do concreto na estrutura de edifícios", MSc Dissertation, Universidade Federal Fluminense, Niterói, Rio de Janeiro, 1991.
[4] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR – 6118 – Projeto e Execução de Obras de Concreto Armado, Rio de Janeiro, 1990.
[5] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR – 7584 – Avaliação da Dureza Superficial pelo Esclerômetro e Reflexão, Rio de Janeiro, 1982.
[6] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR – 8802 – Determinação da Velocidade de Propagação de Onda Ultra - Sônica, Rio de Janeiro,1984.
[7] BUNGEY, J. H. The Testing of Concrete in Structures, New York; Surrey University Press, 1982.
[8] VENUAT, M. y PAPADAKIS, M. Control y Ensayo de Cementos, Morteros y Hormigones, Bilbao, Urmo, 1966.