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Autor: Bocca, Pietro

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The Use of Microcores in Structural Assessment

Utilisation de microcarottes dans l'évaluation de l'état des structures

Betondruckfestigkeits – Bestimmung mit Mikrobohrkernen

Pietro BOCCA
Associate Professor
Ist. Univ. di Archit.
Venice, Italy

Pietro Bocca received his degree in engineering from Politecnico di Torino in 1973. He has published more than 40 papers on mechanical behaviour of structures and materials. He is Director of the Non Destructive Experimental Laboratory of the University of Venice.

SUMMARY
The problem of evaluating concrete structures' strength by means of microcores is analyzed. We consider concrete structures both of good and poor quality. For the latter we formulate a combination of test methods and apply Bayes theorem to process experimental data. The highly degraded concrete of a factory building is used as an application example.

RÉSUMÉ
Le problème de l'évaluation de la résistance des structures en béton armé est abordé à l'aide des microcarottes. Différentes structures dont le béton était de bonne ou mauvaise qualité ont été pris en compte. Lorsque le béton est de mauvaise qualité on a proposé la combinaison de différentes méthodes et l'utilisation du théorème de Bayes afin d'élaborer les données. Un bâtiment industriel vieux et délabré a été testé de cette façon.

ZUSAMMENFASSUNG
Das Problem der Druckfestigkeitbestimmung des Betons von Stahlbetonbauten wird anhand von Mikrobohrkernen angegangen. Es werden Bauten guter und schlechter Betonqualität geprüft. Bei letzteren wird eine Kombination der Prüfverfahren empfohlen, bei welchen die Prüfergebnisse mit Hilfe des Lehrsatzes von Bayes ermittelt werden. Als Beispiel wird der degradierte Beton eines alten Fabrikgebäudes geprüft.

1. INTRODUCTION.

Recent papers [1] [2] [3] confirm the possibility of evaluating concrete structure strength by means of microcores analyses. No problems arise if the core diameter for a good quality concretes is reduced to values far below those usually employed [4] [5] [6]. Corresponding to size effects [2] [7] (almost zero) and to acceptable dispersion values [1] there is associated a strength reduction, due to damage and specimen dimension errors, quantifiable within precise limits. With inhomogeneous concrete structures the use of microcores is possible only if combined with other test methods [8] [9]. If this is the case the approach is always of a statistical kind. In the present article we describe a routine, based on the analyses of microcores and cores altogether or, alternatively, of microcores and ultrasonic waves. The fundamental aspect is the application of Bayes theorem [10] to the experimental data. Finally, we apply the routine to a factory building sited in Torino whose structures are quite degraded.

2. MICROCORES AND THE STRUCTURAL PROBLEM.

Microcores' geometrical characteristics are optimized for a good evaluation of the material strength. We chose a ratio $H/D = 1$ (H is the height and D is the diameter) in order to avoid problems of form effects when comparing the thrust values of standard cubes. For normally employed concretes in the structural field and with a maximum inert diameter up to 16 mm one can sample microcores with a diameter $D = 2.8$ cm [1].

As already said, the procedures of evaluating the strength are functions of the type of structure.

Microcore tests furnish sufficient information for a detailed picture of the strength if the material is a homogeneous concrete (*).

Poor quality concrete structures degraded or damaged by external factors, for example fire, the mentioned test should be combined with other methods: quasi-destructive or non-destructive [8] [9] [11]. Among these, the following are particularly useful:

- Generalized microcore sampling for the total structure and a core sampling only in important points;
- Microcores sampling and ultrasonic tests on the structure;
- Statistical data processing by means of Bayes theorem.

3. GOOD QUALITY CONCRETE STRUCTURES.

The cubic compression strength R of homogeneous concrete structures is obtainable from the crushing strength of microcores R_{mic} by means of the following expression:

$$R = k \cdot R_{mic} \tag{1}$$

where $k = k_o \cdot k_1$ - the factor k_o accounts corrections due to size effects - the factor k_1 accounts corrections due to microcores damage wich occur during sampling and to geometrical errors.

Fig. 1 is the plot, in bilogarithmic scale, of the compression strength of concretes with different homogeneity as function of core diameter [2]. To zero slope on the curve corresponds zero size effect and k_o is equal to 1.

Correction factors are sketched in fig.2 as functions of the concrete homogeneity (represented by the variation parameter C_v) based on performed experiments. For $C_v < 5\%$, from figure 2, one computes the following mean values:

$k_o = 0.95$; $k_1 = 1.20$ (for accurate microcore sampling).

And finally we have from (1):

(*) The homogeneity index can be assumed as the coefficient of variation values C_v. Some authors assume $C_v < 5\%$ for homogeneous concretes and $C_v > 5\%$ for inhomogeneous one.

(2) $R = 1.14\ R_{mic}$

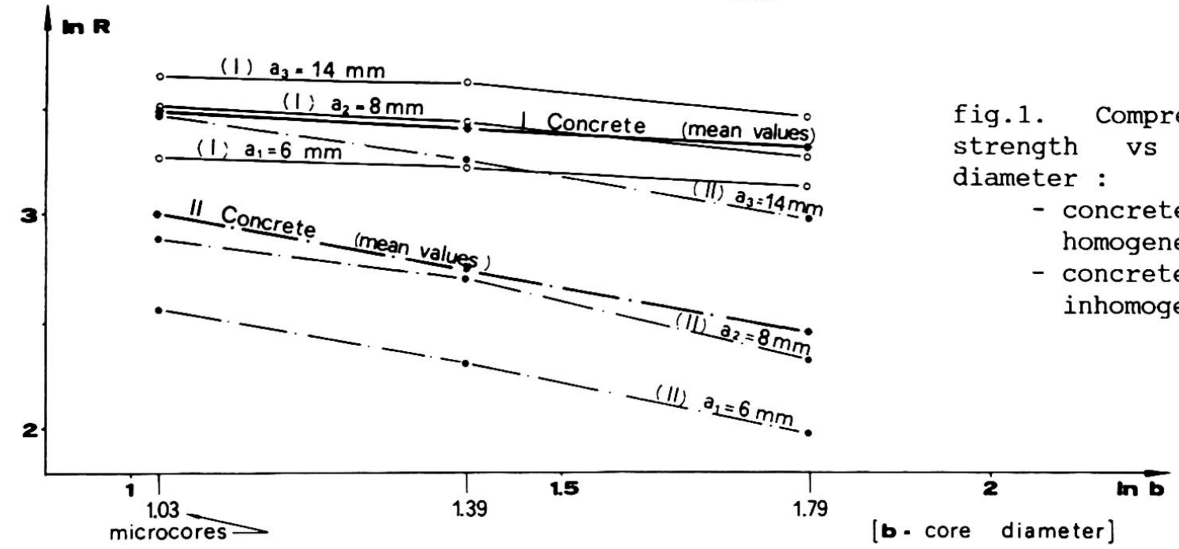

fig.1. Compression strength vs core diameter :
- concrete I homogeneous
- concrete II inhomogeneous

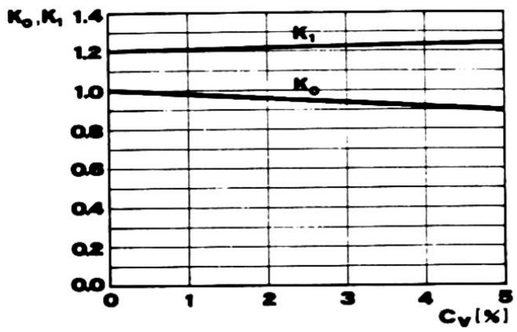

fig.2. Correction factors k_o, k_1 vs concrete variation parameter c_v.

4. POOR QUALITY CONCRETE STRUCTURES

Due to size effects, sample damage and dispersion values the use of only microcore tests, as a rule, should be avoided when estimating the strength of inhomogeneous concrete structures.

Better results are obtained with one of the following methods:
- 1. Microcore and core sampling;
- 2. Microcore sampling and ultrasonic tests.

We illustrate now how Bayes theorem works when data are treated statistically.

In the Bayesian approach the unknown parameters are considered random variables. They are, for example, the mean concrete strength R = M and the standard deviation δ = Σ. The estimation of the true value of such parameters is obtainable from the posterior probability density. The scheme is sketched in fig. 3.

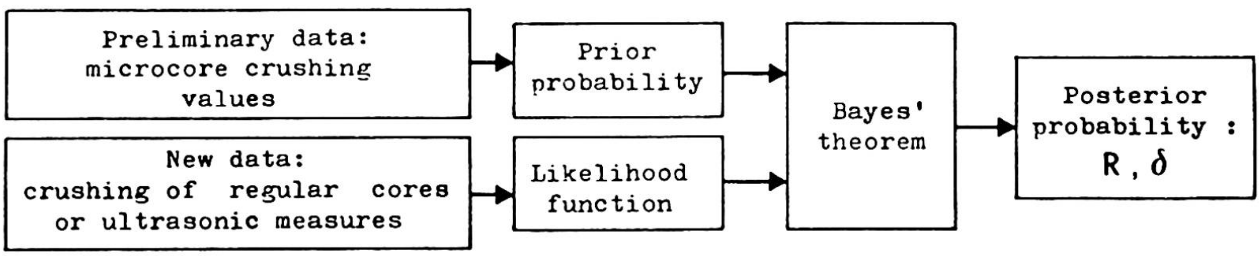

fig.3.

Here we hypothesyze that the distribution of R , the concrete strength, is the same as the one determined by means of microcores, of cores and ultrasonic tests. With such a condition one writes [10]:

$$f''_{M,\Sigma}(m,\sigma) = f'_{M,\Sigma}(m,\sigma)\ L(m,\sigma/x_1,\ldots,x_n) \tag{3}$$

We can use, in virtue of the above equation, instead of the prior estimate $f'_{M,\Sigma}(m,\sigma)$ of R with a posterior estimate $f''_{M,\Sigma}(m,\sigma)$ with the introduction of new parameters x_j, i.e. core crushing or ultrasonic measure.

From (3) the posterior density $f''_{M,\Sigma}(m,\sigma)$ is given by the product of the prior distribution $f'_{M,\Sigma}(m,\sigma)$ and the likelihood function $L(m,\sigma/x_1,\ldots,x_n)$, apart from the normalizing constant N.

The l.h.s. of eq. (3) written more explicitily looks like:

$$L(m,\sigma/x_1,\ldots,x_n) = \{(\sigma)^{-1}\cdot\exp(A)\}\cdot\{(\sigma)^{1-n}\cdot\exp(B)\}$$

$$A = -\tfrac{1}{2}[(m-\bar{x})/(\sigma\cdot\sqrt{m})]^2 \qquad B = -\tfrac{1}{2}(n-1)\cdot(s/\sigma)^2$$

n, $\dot{x}$, s^2 represent size, mean and variance of the cores or of the ultrasound values; $\bar{x} = \Sigma\, x/n$, $\quad s^2 = \dfrac{1}{n-1}\Sigma\,(x_i - \bar{x})^2$

$$f'_{M,\Sigma}(m,\sigma) = \left\{\frac{1}{\sqrt{2\pi}\,\sigma/\sqrt{n'}}\exp\left[-\frac{1}{2}\left(\frac{m-\bar{x}'}{\sigma/\sqrt{n'}}\right)^2\right]\right\} \times \left\{\frac{\left(\frac{n'-1}{2}\right)^{\frac{n'-2}{2}}}{\Gamma\left(\frac{n'-2}{2}\right)}\frac{2}{s'}\left(\frac{s'^2}{\sigma^2}\right)^{\frac{n'-1}{2}}\exp\left(-\frac{n'-1}{2}\,\frac{s'^2}{\sigma^2}\right)\right\}$$

where n',x' and s'^2 are the parameters of the prior joint density function of the microcores values.

- N is the normalizing constant - $f''_{M,\Sigma}(m,\sigma)$ has the same form as the prior joint density function, with different parameters obtainable from the following relations:

$$n'' = n + n' \tag{4}$$
$$\bar{x}'' = (n\bar{x} + n'\bar{x}')/(n + n') \tag{5}$$
$$s''^2 = [(n-1)s^2 + (n'-1)s'^2 + n\bar{x}^2 + n'\bar{x}'^2 - n''\bar{x}''^2]/(n''-1) \tag{6}$$

The mean M and the variance Σ are obtained by integration of equation 1., we have then:

$$\mu_M = \overline{x''} \tag{7}$$
$$s^2_M = s''^2(n''-1)/[n''(n''-2)] \tag{8}$$

the mean and variance of the standard deviation are:

$$\mu_\Sigma = s''[(n''-1)/2]^{\frac{1}{2}}\Gamma[(n''-3)/2]/\Gamma[(n''-2)/2] \qquad n'' > 3 \tag{9}$$
$$s^2_\Sigma = s''^2(n''-1)/(n''-4) - (\mu_\Sigma)^2 \qquad n'' > 4 \tag{10}$$

5. EXAMPLE

In order to illustrate the routine the following example is useful. to establish the recoverability or not of a factory building it is necessary to evaluate the strength of the horizontal carrying parts. The three floor factory was built at the turn of the century (see fig.4)

One easely observes that the eastern part is highly degraded (double floors 7 ÷14 in fig.4). Here we realize a first sounding with microcores. The sampling is uniformly distributed between chords and secondary beams. While 15 cm diameter cores where sampled after and limited in number. We summarize the results in table 1. The mean strength, computed from eqs. (5) (7), is reported in the last column.

In tab. 2. are reported the initial distribution parameters of all values obtained with microcores ($n', s'^2, \bar{x}^2$) together with those (n, s_t^2, x_t) obtained from cores relative to the east part.

FLOOR	STRUCTURAL ELEMENT	MICROCORES		CORES 15 CM		
		n'	$\bar{x}'$ [MPa]	n'	x' [MPa]	
1°	CHORDS	8	14.6	3	11.7	13.8
1°	SECONDARY BEAMS	8	15.1	3	17.8	15.8
2°	CHORDS	10	14.2	4	13.6	14.0
2°	SECONDARY BEAMS	08	16.6	3	12.9	15.6
3°	CHORDS	08	08.7	3	09.0	08.8
3°	SECONDARY BEAMS	08	10.1	3	09.3	09.9

tab.1.

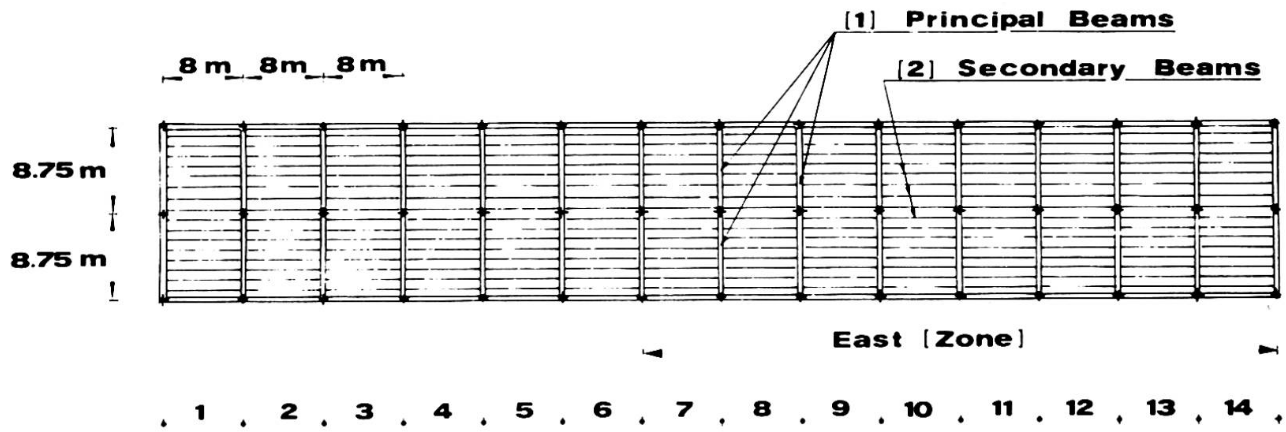

fig.4. Industrial building map.

Prior distr. microc.			New data -15cm Cores			Mean Strength	
n'	x'_t [MPa]	s'_t [MPa]	n	x_t [MPa]	s^2_t [MPa]	x''_t [MPa]	s^2_M [MPa]
50	13.2	$(6.8)^2$	19	12.4	$(6.0)^2$	13.0	6.2

tab.2.

Worth noting is the small difference between the value x' (i.e. mean strength of microcores) and x_t. Probably this is due to a combination of size effect with sample execution errors. It is interesting to note that the values s and s are quite similar. In such a case one can reduce the variance of the mean strengths computed s_M^2 (last column of table 2) obtained from eq. (6) (8), i.e.

$$(11)\quad s^2_M = (n''-1)[n''(n''-2)(n''-1)]^{-1}[(n-1)s^2_\varepsilon + (n'-1)s'^2_\varepsilon + n\bar{x}^2_\varepsilon + n'x'^2_\varepsilon - n''\bar{x}''^2_\varepsilon$$

increasing indifferently the number n of microcore samples or the number of core samples. In a different fashion, while keeping s^2_M constant one can decrease the number n' (cores) and increase n (microcores) according to (11). One can easily imagine the practical advantages.

NOTATION:

M, Σ = mean value, standard deviation of strength
m, σ = values of M and Σ
μ_Σ = mean value of standard deviation
s^2_M = variance of mean value
n, x, s^2 = size, mean and variance of new values
μ_M = mean value of M
R, δ = mean value, standard deviation of compressive strength
$n, x, s'^2, n'', x'', s''^2$ = parameters of prior and posterior joint density functions respectively
x'' = R

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