EFFECT OF CONCRETE TECHNOLOGY PARAMETERS ON NON-DESTRUCTIVE STRENGTH ESTIMATIONS

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1. Introduction

Non-destructive strength estimations consist in finding some stochastic relationship between the given mechanical property of concrete and the measured physical characteristic (e.g. ultrasonic velocity).

There are great many empirical functions expressing this stochastic relationship, differing with the composition and condition of the tested material, with the circumstances of both non-destructive and ultimate tests, and with the differences in planning and evaluating the tests, factors themselves in interaction.

To have results reflecting the true weight of parameter effects and interactions, a test has been made with all details planned. Selecting the parameters likely of major importance, each of them was represented by at least two levels, throughout the variation possibilities.

Commissioned by the Division of Technical Development of the Ministry of Building and Urban Development, results of this research work [1] are intended to be involved in building codes (standards, technical specifications).

2. Plan of the experiment

The research involved a complete test on nine factors, divided in two groups such as those of the mix (1 to 5) and of the curing (6 to 9).

There are as many elements in such a planned experiment as the product of the numbers of factor levels, amounting to 1152 tests combining 48 mix types and 24 curing methods. Even single tests yielded sufficient data for examining effects and interactions.

Remark that statements on the effect intensities only apply to the tested levels. If these involve local extreme values or at least marked inflexions of the function describing the phenomenon then statements on the effect intensity have to be adjusted.

The tests involved 20 cm cubes subjected to Schmidt-hammer and ultrasonic tests and then tested to failure.

Table 1

Plan of the ultrasonic test and pure effects

Factor		Level		Deviation kp/cm²
No.	Denomination	No.	Denomination	
1.	Cement grade	1	C 450	15
		2	C 350	
2.	D_{max}	1	16 mm	30
		2	32 mm	
3.	Aggregate size	1	fine	50
		2	coarse	
4.	Water–cement ratio	1	0.35	20
		2	0.55	
5.	Paste content	1	minimum	20
		2	medium	20
		3	maximum	
6.	Compaction	1	dense	20
		2	loose	
7.	Curing	1	dry	15
		2	sprinkling	
8.	Age	1	8 days	0
		2	29 days	0
		3	80 days	
9.	Test condition	1	saturated	70
		2	dry	

3. Processing the test results

Instead of regression analysis, stochastic functions were constructed by determining the quantile diagrams by Reimann [2], demonstrating that — provided distribution functions of random variables in the stochastic relationship are known — distribution function values for identical probability levels lie on a diagram termed quantile function. He proved quantile function to express the functional relationship between random variables, simultaneously minimizing the residual deviation with respect to both variables. This method is exempt from a regression analysis error namely that fitting is done by minimizing with respect to one variable at a time.

Distribution functions have been replaced by empirical distribution functions obtained from the ordered samples yielding empirical approximation of the quantile functions. These distribution functions were needless to be constructed. Co-ordinating identically numbered elements of the ordered sample resulted in empirical values of the quantile function, of them value couples with a predetermined confidence level have been plotted.

Consideration of all test results produced a common median curve valid for the entire experiment.

The full effect of some factor was obtained by classifying the ordered sample according to the factor level codes and constructing separate quantile functions for each factor level. Factor effects are expressed by function differences in direction σ.

Interactions were examined similarly except that ordered samples have been classified according to each level combination of interacting factors. To now, only two-fold interactions have been examined. Evaluation is based on the deviation between quantile curves for combination extremes.

4. Evaluation

The stochastic relationship between ultrasonic velocity and compressive strength is seen in Fig. 1 plotted by taking all test results into account.

Fig. 2 shows measurement results for the nine factors, separated according to the test condition. All water saturated specimen results have been plotted. In addition to the quantile (mean) curve fitted to the given field of deviation plots, also the common mean curve for the entire experiment has been plotted.

The full effect of the test condition is seen in Fig. 3 showing much higher strength values to belong to dry concretes for the same ultrasonic velocity.

For other factors, quantile functions plotted for results separated according to factor levels were seen to coincide. The pure effects of factors have been compiled in Table 1.

From among double interaction tests, six interaction cases between factors 1 and 5, cement grade and paste saturation are shown in Fig. 4. The quantile curve obtained for all concretes made with cement grade C 350 and minimum paste content ($T - 100 = 100$ litres of paste deduced from saturated concrete) is the lowermost. The quantile curve obtained for all concretes made with cement grade C 450 and maximum paste content ($T + 100$) is seen to be the topmost. The effect of about 60 kp/sq.cm is due to the double interaction expressed as the standard deviation between the two extreme curves (Table 2).

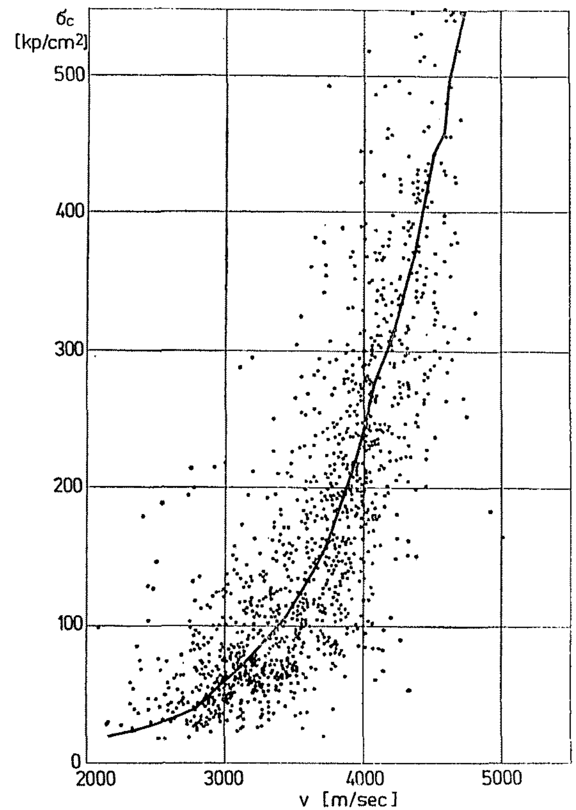

Fig. 1. Ultrasonic velocity vs. compressive strength. Overall

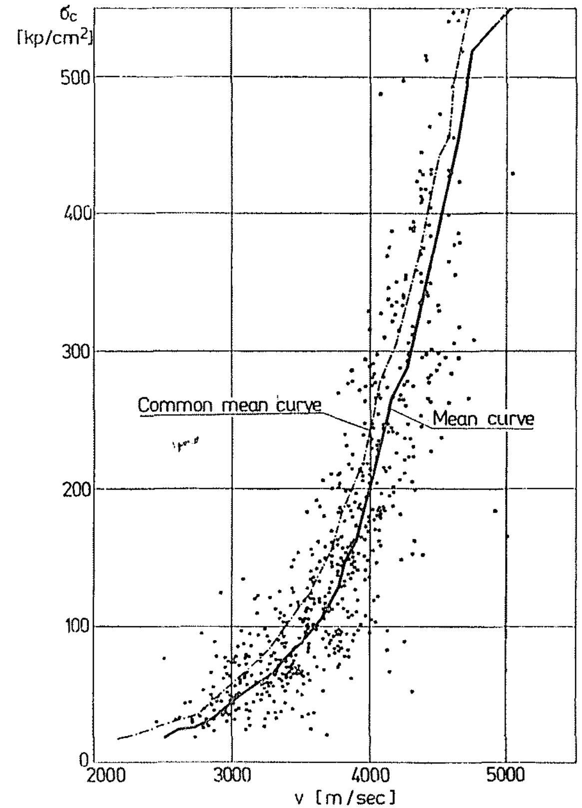

Fig. 2. Ultrasonic velocity vs. compressive strength. Water saturated concretes

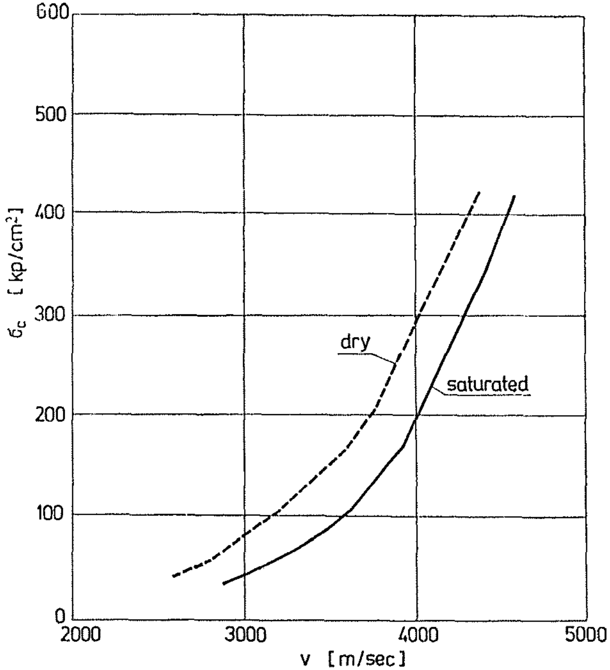

Fig. 3. **Effect of test condition on ultrasonic velocity vs. compressive strength**

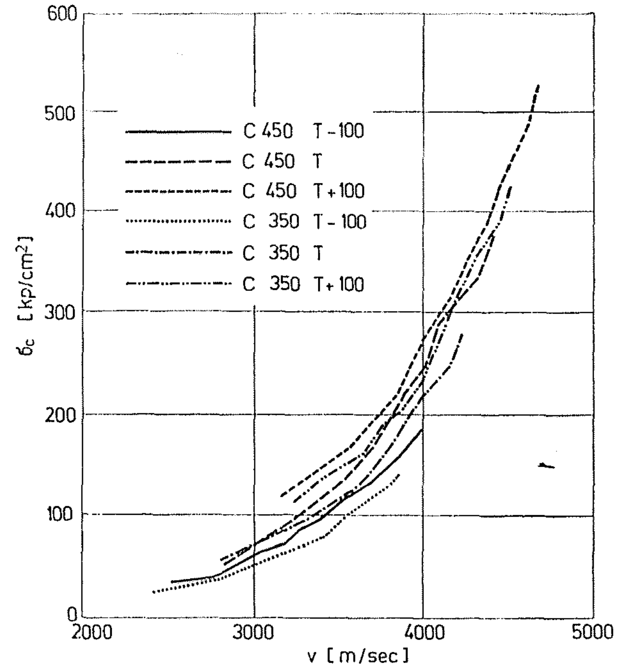

Fig. 4. **Effect of cement grade and paste saturation on ultrasonic velocity vs. compressive strength**

Table 2

Double interactions

Nos.	Factors Denomination	Denomination of levels	Deviation kp/cm²
1,2	Cement — D_{max}	C 450 16 C 350 32	40
1,3	Cement — Grain size	C 450 fine C 350 coarse	60
1,4	Cement — w/c	C 450 0.35 C 350 0.55	50
1,5	Cement — Paste content	C 450 max. C 350 min.	60
1,6	Cement — Compaction	C 450 dense C 350 loose	30
1,7	Cement — Curing	C 450 dry C 350 sprinkling	40
1,8	Cement — Age	C 450 8 days C 350 80 days	20
1,9	Cement — Condition	C 450 dry C 350 saturated	80
2,9	D_{max} — Condition	16 dry 32 saturated	100
3,9	Grain size — Condition	Fine dry Coarse saturated	130 130

Of quantile curves for the ultrasonic velocity to strength relationship, those for all cases of double interaction (about 200 curves) have been examined. Some typical results are shown in Table 2.

All quantile curves purely and in interaction are shown superposed in Fig. 5. Quantile curves constitute a field of probabilities around the mean curve for the entire experiment serving as basis for developing a standard tentative for non-destructive strength assessment [3].

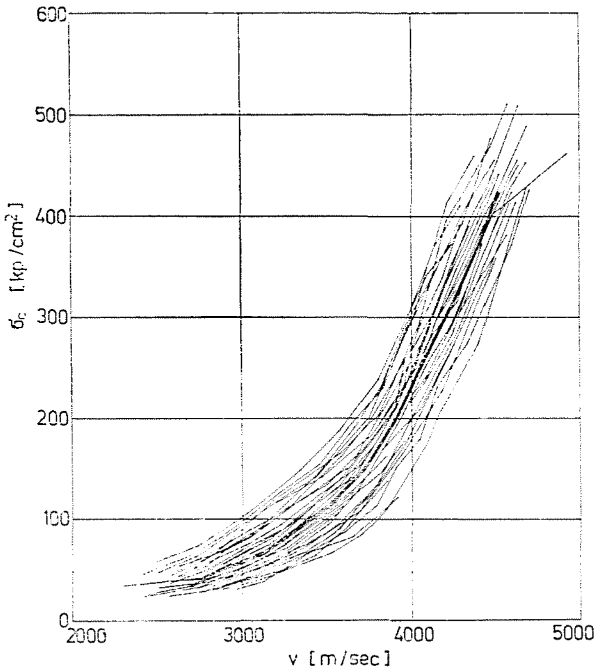

Fig. 5. Field of probabilities of ultrasonic strength assessment functions

Summary

The effect of concrete technology parameters on non-destructive strength assessment relationships has been examined in a fully planned experiment of single tests on nine concrete technology parameters. The analysis of relationships between concrete strength and ultrasonic velocity in 20 cm cubes involved determination of Reimann's quantile functions constructed from ordered samples of test results, separated according to level combinations for examining concrete technology parameter levels and their interactions. These were applied to plot the set of quantile curves referring to the parameter effects.

As a conclusion, not only individual test results scatter in a field around the common mean curve but also the position of mean curves can be considered as a random variable. Analysis of the field of probabilities of mean curves offered a possibility to standardize non-destructive strength assessment.

References

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