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DECISION MAKING MODELING OF CONCRETE REQUIREMENTS

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ABSTRACT

This paper presents the results of an experimental evaluation between predicted and practice concrete strength. The scope of the evaluation is the optimisation of the cement content for different concrete grades as a result of bringing the target mean value of tests cubes closer to the required characteristic strength value by reducing the standard deviation.

Keywords: concrete mix design, acceptance control, optimisation, cement content.

INTRODUCTION

Due to the negative effect that the variation of concrete compressive strength presents, theoretical and practical studies of this trend are of great importance. Taking into account this fact, we can act in the scope of prevention and maintenance (under an acceptable quality and cost level) of concrete compressive strength.

Achieving optimised acceptance criteria for concrete is hampered by the real possibilities of processing and production control of batched concrete. During the last years some progress has been achieved in the field of the control procedures, especially as concerns statistical methods, computer software programs, design of new methods of experimentation and new instrumentation for measurement and monitoring, etc. It is however difficult to underline a close relationship between the quality characteristic of ingredients and those of fresh or hardened concrete. That is why it is necessary to study the influence of characteristics and properties of cement (type, finesse, content, water: cement ratio, etc.) concerning concrete strengths.

This paper emphasizes that the achievement of concrete quality assurance should be backed by specific technical procedures regarding sampling and testing of specimens, workability, compressive strength, etc. The test results obtained on concrete specimens have a high variability, and through statistical data analysis, we can identify the causes that lead to nonconformity, during concrete batching (quality of ingredients, dosage, mixing time etc.), transport, placing, compaction, and curing (segregation, modification of mix design, cracks etc.).

The statistical technique used for the realization of conformity control is that of inspection by variables based on acceptance sampling in compliance with the technical specifications in effect (ENV 206 and ISO 3951). Accordingly, a sample is representative for the quality of the entire lot if it is randomly selected, using methods of mathematical statistics applicable to building materials.

A single sample is taken from a lot and a decision regarding lot acceptance or rejection is drawn in accordance with the sampling plan.

Accepting this assumption, the sample conformity consists of reaching an Acceptable Quality Level (AQL), that is defined as a medium manufacturing quality at the producer of the concrete, that does not exceed the Limiting Quality (LQ) (see fig. 1).

These two terms (AQL and LQ) ensures that a lot with a known AQL will be rejected only with a certain probability α, and a lot with a known LQ will be accepted only with a certain probability β (in this survey it is assumed that $\alpha = \beta = 5\%$).

Note: Discussion is expected before November, 1st 2001. The proper discussion will be published in "Dimensi Teknik Sipil" volume 4 number 1 March 2002.

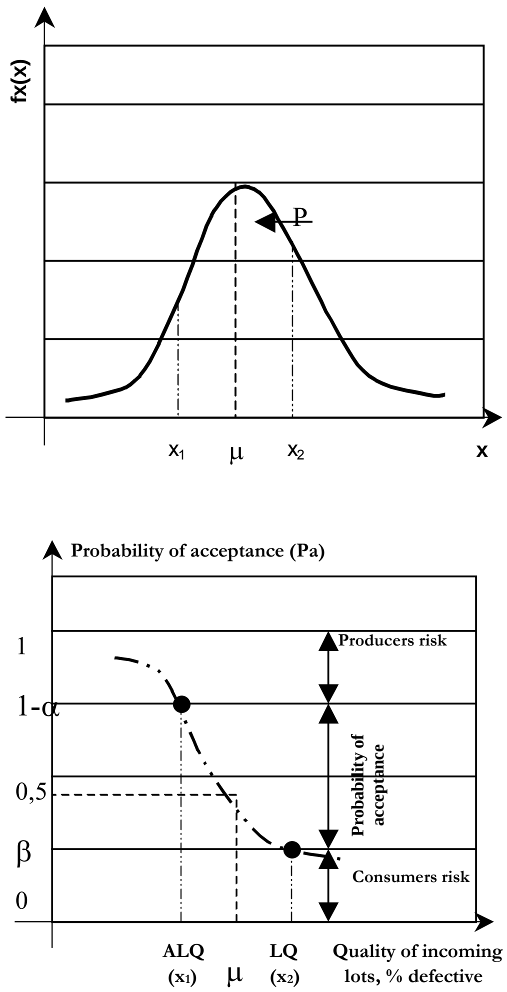

Figure 1. Characteristic Curve Defined through AQL and LQ

On the basis of sample statistics, a compliance function is formed and introduced in a compliance criterion (1) and (2). Depending on the outcoming result, the acceptance and the quality level of a part of a structure can be decided.

According to ISO 3961 and NE 012-99, a lot is accepted when:

$$\bar{x} \geq f_{ck} + \lambda S \quad (1)$$

$$x_{min.} \geq f_{ck} - k \quad (2)$$

where:

f_{ck} – characteristic cub compressive strength at 28 days;
S – sample standard deviation;
λ – constant defining the sample size;
k – constant defining the decision number;
$\bar{x}$ – characteristic's sample mean;
n – sample size.

Using the Stewhart Control Chart (SR ISO 8258/1998) the mean values and sample standard deviation were studied by comparing the observed characteristics of a lot batched on the same production line. Through the analysis, the population parameters do not require permanent adjustment in the scope of maintaining them as close as possible to the required characteristics. The objective is the detection of special causes that lead to excessive variation. Ideally, only common causes should be present in a process as these represent a stable and predictable process that leads to minimum variation.

The scope of the chart is the evaluation of statistical significance through the choice of control limits. These limits alert early strength problems that conduct towards major economic significance and at the same time can conduct towards the identification of these causes. When the variation exceeds the specified limits, it is a signal that the special causes entered the process and they should be investigated and corrected.

EXPERIMENTAL PROGRAM

The parametric study uses details and data generated from a series of projects located in Romania, such as the Ministry of Youth and Sport, the Emergency, Grivi□ia and Filantropia Hospitals (Bucharest) and the University Constantin Brâncoveanu (Pite ti), were over 400, 140 mm concrete cube specimens where taken, analysed and interpreted.

1. Experimental Procedures

The comprehensive approach begins with six different concrete grades that were considered (C8/10, C12/15, C16/20, C18/22.5, C20/25, C 25/30), every grade corresponding to four series of samples (6, 9, 12 and 15 samples).

The characteristics of the main concrete ingredients surveyed are:

1. Cement type and grade: II A - 32,5 R;
2. Concrete consistency: T3/T4 (slump T=100 mm);
3. Concrete workability: L3/L4;
4. Cement content:

Concrete grade	C8/10	C12/15	C16/20	C18/22,5	C20/25	C25/30
Cement content (kg/m^3)	230	265	350	465	500	480

5. Aggregate: siliceous stream deposits, maximum size d = 20 mm, ρ = 2,7 kg/dm^3;
6. Grading zone:

Cement content (kg/m^3)	<200	200-300	300-400	>400
Slump T3/T4	I	I	II	III

7. Water : cement ratio:

Concrete grade	C8/10	C12/15	C16/20	C18/22,5	C20/25	C25/30
W/C	0.74	0.64	0.57	0.53	0.49	0.40

8. Permeability grade: P_4 [10];
9. Freeze – thaw grade: G100;
10. Mixing procedure: mechanical, Carpati – Bujoreni and Premeco S.A. Pitesti, batching plants;
11. Exposure class and environmental conditions: moderate dry environment;
12. Conditions and work technologies: normal work conditions, using plywood modular forms;
13. Concrete transport and placement: transport with transit mix truck and pump placement.

The criteria of examination using the same type of cement, type and size of aggregates, concrete consistency, permeability and freeze – thaw grade allowed a correct assessment of analysed concrete performances, in comparison with the referred concrete (witness) of which just the cement content differs (being the prescribed one).

The methodology and analytical experimentation procedure regarding the compressive resistance of concrete samples, was comprised of:

- Selection of sampling plan according to the concrete volume batched or placed.
- Definition of AQL and LQ limits.
- Preparation the concrete specimens for testing such as: marking them for identification, storing, curing and shipping to the laboratory for testing.
- Design of a computer-based information software program entitled (CCB - Control Calitate Beton / Quality Control of Concrete) that provides the means of automated Statistical Process Control and Inspection.
- Identification and correction action by detection of special causes of variation in the process that leads towards nonconformity, through statistical interpretation analysis of samples tested for compression. That may appear during the mixing of concrete and during transport, placing, consolidation or thermal curing treatment.
- Plotting data, analysis and interpretation of charts and results by acceptance criteria for separate double specification limits.
- Presentation of statistical and graphical data experimental results (see fig.2 to fig. 5);
- Adjustment and modification of process control through the capability index c_{pk}, respectively by changing the specification limits (according to the new determined values of coefficients λ and K) by iteration until the maximum of 5% fractile, corresponding to the definition of f_{ck}.
- Presentation of resulting cost advantages that confirmed the necessity of the study.

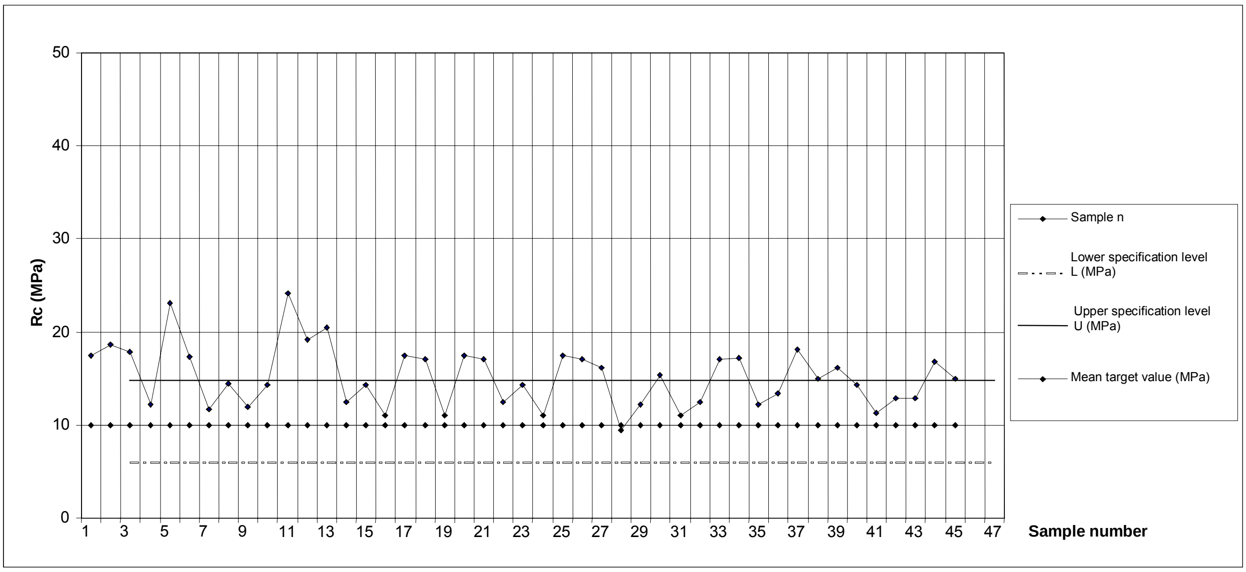

Figure 2. Test Results n=15 Samples Concrete Grade C8/10

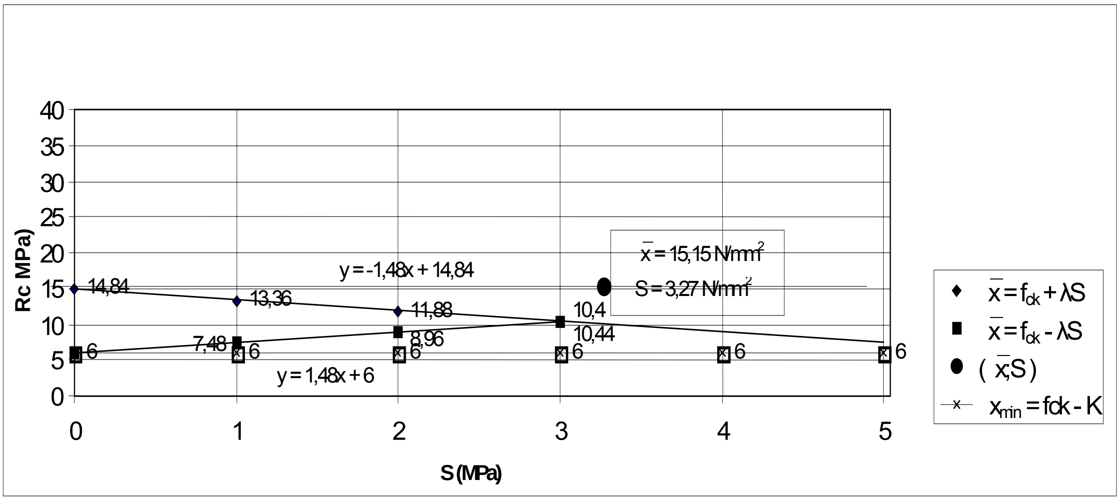

Figure 3. Acceptance Criteria Graph for Separate Double Specification Limits [n=15-C8/10]

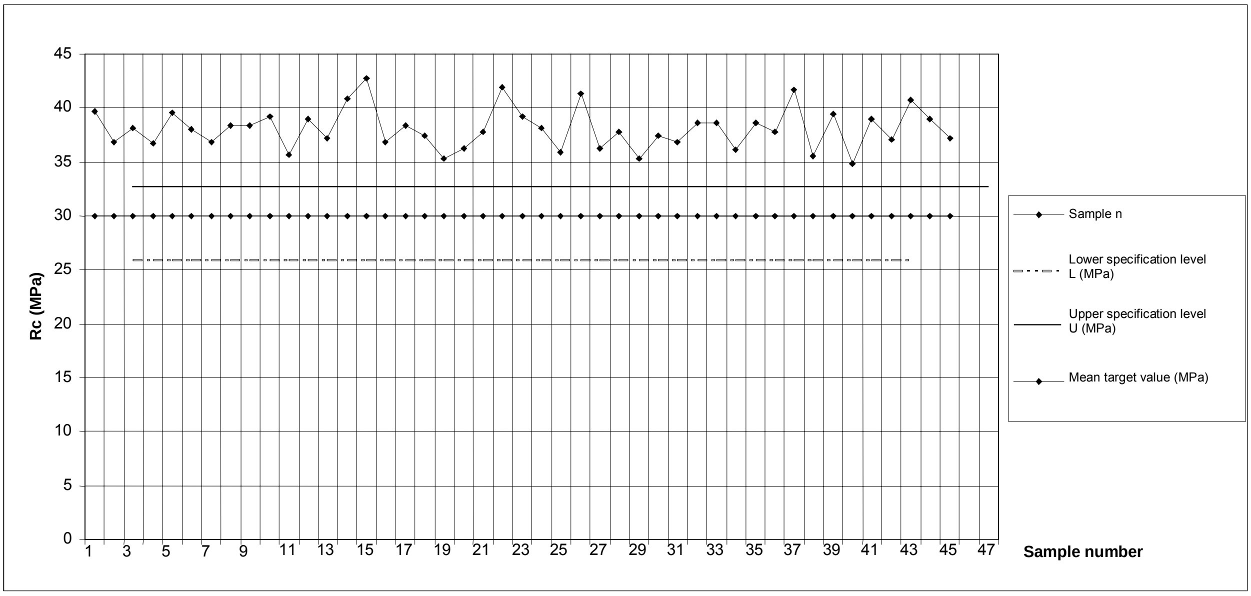

Figure 4. Test Results on n=15 Samples Concrete Grade C25/30

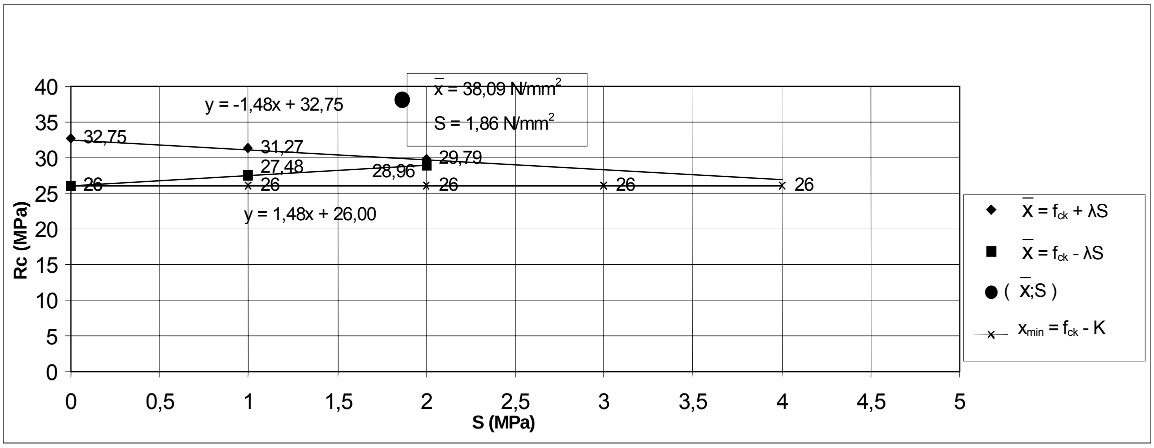

Figure 5. Acceptance Criteria Graph for Separate Double Specification Limits [n=15-C25/30]

RESULTS AND DISCUSSIONS

Due to the imposed conditions regarding workability, strength and durability we found a superior compressive strength of the analysed concrete compared with the witness concrete (see Table 1).

We noted that the high value of the compressive strength assures important strength reserves for the concrete. But these reserves are not justified, if we assume (incorrect) that through these artificial superior strengths we can face the final losses of strength (due to special causes) that are caused by numerous reasons: variation of properties of ingredients, instability of concrete composition, transport, placing, various degrees of mix consolidation, different curing conditions.

Table 1.

Concrete grade	Target value	Mean percentage value of compression strength determined against the target value	Determined cement content	Referred cement content
C8/10	10,0 MPa	51,5% superior	approx. 25% inferior 230 kg/m³	310 kg/m³
C12/15	15,0 MPa	52,6% superior	approx. 18% inferior 265 kg/m³	325 kg/m³
C16/20	20,0 MPa	29% superior	approx. 10% superior 370 kg/m³	335 kg/m³
C18/22,5	22,5 MPa	35% superior	approx. 37% superior 465 kg/m³	350 kg/m³
C20/25	25,0 MPa	36% superior	approx. 37% superior 500 kg/m³	365 kg/m³
C25/30	30,0 MPa	27% superior	approx. 12% superior 480 kg/m³	430 kg/m³

After the detection and elimination of special causes, by searching for unusual patterns and nonrandomness (Nelson 1984, 1985), the following values are recorded (see Table 2).

Table 2.

Concrete grade	Target value of cub compression strength	Mean percentage value of compression strength determined against the target value
C8/10	10,0 MPa	approx. 49% superior
C12/15	15,0 MPa	approx. 53% superior
C16/20	20,0 MPa	approx. 35% superior
C18/22,5	22,5 MPa	approx. 33% superior
C20/25	25,0 MPa	approx. 36% superior
C25/30	30,0 MPa	approx. 26% superior

The analyses of obtained results demonstrates that the simple mix design of concrete, according to NE 012-99, is not sufficient and it needs be improved by a proposal of adequate cement content resulted by conformity control. The optimisation of specification limits is achieved by limiting of sample results variation so that they do not exceed the specification limits imposed.

Through the study of sample test results and through the optimisation (by iterations for a 5% maximum fractile) of specification limits, we propose the following values for the constant λ and K (see Table 3).

Table 3.

Sample n	λ according to NE 012-99	K according to NE 012-99)	Proposal of optimising K and constants											
			CONCRETE GRADE											
			C8/10		C12/15		C16/20		C18/22,5		C20/25		C25/30	
			λ	K	λ	K	λ	K	λ	K	λ	K	λ	K
6	1,87	3	1,44	3	1,2	3	1,22	1	0,58	1	2,68	1	3,22	1
7	1,77	3		3		3		1		1		1		1
8	1,72	3		3		3		1		1		1		1
9	1,67	3	1,49	3	1,17	3	1,44	1	0,96	1	2,37	1	2,48	1
10	1,62	4		3		3		1		1		1		1
11	1,58	4		3		3		1		1		1		1
12	1,55	4	1,60	3	1,16	3	1,34	1	0,72	1	2,50	1	2,53	1
13	1,52	4		3		3		1		1		1		1
14	1,50	4		3		3		1		1		1		1
15	1,48	4	1,66	3	1,15	3	1,25	1	0,84	1	2,70	1	2,88	1

Experimenting with the new proposed limits we noted that in reality the dispersion is grater once the concrete grade is smaller, while once the concrete grade is higher the dispersion is smaller than that of the proposed target value.

According to the above findings, the dispersion and mean value of the process greatly influences in great deal the lowering of the process limits. Even if it requires the identification and eliminating of special causes, the dispersion decreases, but it does not reduce significantly (by this matter the proposal of coefficient value λ modification, for concrete grades C>C16/20, is not feasible).

Regarding the determination of coefficient value λ, for concrete grade C>C16/20 (but also for optimisation of grade C<C16/20), we must analyse the interdependence between the quality characteristics of concrete components and those of fresh and hardened concrete.

Having these findings and analysis of percentage growth of concrete strength according to the cement content, we can established that the optimal cement content that must be used for the achievement of required compressive strength, is presented in Table 4 and Fig. 6.

Table 4.

Compressive strength of concrete MPa	Cement Content (Kg/m³)		
	prescribed	practice	proposal
10,0	310	230	185
15,0	325	265	215
20,0	335	370	310
22,5	350	465	315
25,0	365	500	325
30,0	430	510	430
35,0	480	502	450

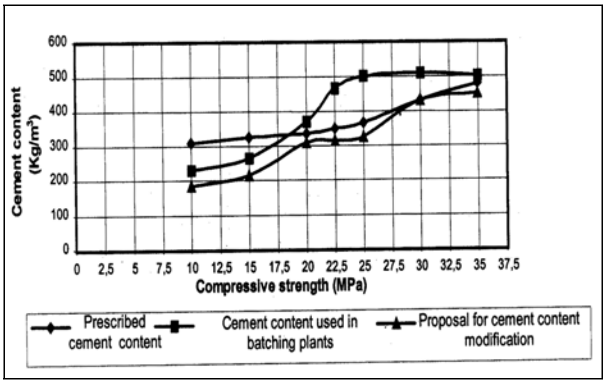

Figure 6. Concrete Strength Variation for Workability L4, Aggregate Maximum Size 20 mm, Type Cement IIA-S 32,5 R

CONCLUSIONS

Based on the measured and predicted results obtained in this study, the following conclusions may by drawn:

1. The recommendations and proposals for improving the existing situation are different, according to the factors (human in regard of efficiency of personnel/labour discipline and technological in regard of production process) that intervene in the achievement of the considered concrete mix at a minimum cost.
2. For given results, the consumers risk is much lower than that of the producer, this having negative implication on the final cost of the product, unnecessarily increasing it.
3. Normally the cost of 1 m^3 concrete, is comprised of the cost of cement approx. 60% and that of the aggregate approx. 30%. After the optimisation of the cement content through the proposed specification limits (concretised through the lowering of the mean strength value) the product cost is decreased with approx. 10-30%.
4. Through the prevention of defects and nonconformities of concrete (concretised through the lowering of the standard deviation S), the product cost is lowered with another 5-10% of the product cost.

REFERENCES

1. Ilinoiu, O.G., *Contributions to the Iimplementation of Technologies and Modern Procedures for the Protection and Rehabilitation of Construction Members*, Ph.D. Thesis, Technical University of Civil Engineering of Bucharest, 2000.

2. Juran J.M., Gryna F. M., *Quality Planning and Analysis*, McGraw-Hill, New York ,1993, pp.377-402.

3. Guner A., Dawod A.M., *Function of Control Standard in Optimised Mix Design of Concrete*, Proceeding of the Second International RILEM/CEB Symposium. Ghent 12-14, 1991, pp.105-112.

4. Ammar C., *Concrete Conformity: A study of ENV 206 and NBN B15*, Proceeding of the Second International RILEM/CEB Symposium. Ghent 12-14, 1991, pp.501-534.

5. NE 012-99, Cod de Practică pentru Executarea Lucrărilor din Beton, Beton Armatşi Beton Precomprimat;

6. SR ISO 3951/1998, Sampling procedures and charts for inspection by variables for percent nonconforming;

7. SR ISO 8423+C1/1997, *Sequential Sampling Plans for Inspection by Variables for Percent Nonconforming (Known Standard Deviation) and with the Incorporation of Technical Corrigendum 1*, Cor. 1:1993".

8. SR ISO 7966/1999, Acceptance Control Charts.

9. SR ISO 8258/1998, Stewhart Control Charts.