RIGA TECHNICAL UNIVERSITY
Faculty of Civil Engineering
Institute of Materials and Constructions

Genadij Shakhmenko

INVESTIGATIONS ON CONCRETE MIX DESIGN AND OPTIMIZATION FOR PLASTIC CONCRETE

Civil Engineering, Building Materials and Building Technology (P-06)

Summary of Doctoral Thesis

Supervisor:
Dr.sc.ing., assoc. prof.
Juris Birsh

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GENERAL DESCRIPTION OF THE THESIS

Topicality of the Theme

At present the volumes of building construction in Latvia are steadily increasing. Statistical research shows that in the year 2004 turnover in building construction has reached approximately 550 million lats, here to the amount of investments reaches almost 75 %. With the growing volumes and rates of building construction practical work outpaces quality provision, due to insufficiently developed scientific research. In order to put modern construction technology into practice, it is required to be well aware of characteristics of local constructive materials and their abilities, making use of scientific potential of this country and other states.

The present thesis is fully devoted to issues of optimizing concrete mix and of elaborating new perspective methods. During the recent 15 years, due to changes in political and economic situation in Latvia, there took place fundamental changes in the concrete industry. Restructuring of the concrete industry is observed throughout the whole world. This resulted in broadening the fields of concrete application and the range of concrete products, as well as in increasing the requirements for physical and mechanical characteristics, durability and quality of the material. Nowadays new special types of concrete, such as pumped, high strength, self-compacting concrete, etc. are being increasingly used in building construction.

New types of concrete have specific requirements, in contrast to conventional concrete; these are susceptible in case of changing technological factors (especially of the mix). They require a new approach in issues of concrete mix design. On the other hand, in the conditions of market economy there is a wide range of raw staff offered, and it becomes a live issue to chose Ihe raw staff in such a way, that to achieve maximal economy, and at the same time to provide maximally good characteristics for fresh and hardened concrete (i.e. it is necessary to find a compromise between the price and the characteristics).

Hence, there is a requirement for new, unified and mobile approach in issues of concrete mix design and optimization.

The present thesis draws attention to some live issues, that have the largest impact on obtaining the optimal mix for plastic concrete,

- Grading characteristics of aggregates and investigation of their influence can be pointed out as a guideline, as it is a aggregate that takes up the bulk of concrete volume (60 - 80 %), and densification (packing) of its structure has a large significance. In the transition period live issues are those, which are linked with transition from former standards (GOST) to new ones (primarily EN), as well as those, which are linked with requirements of new standards, and which are to be observed during the stage of mix design.
- Water plays an exceedingly significant role in concrete mix: on the one hand, it provides the mix with determined consistency, on the other hand, the

water/cement ratio determines strength and durability of concrete. Necessary amount of water in concrete mix, in its turn, is directly linked with geometrical characteristics of aggregates. Thus, research of the system "geometrical characteristics of aggregates - water factors" is an important trend in concrete technology.

- The mentioned problems are to be solved in a complex, with regards to concrete mix design optimization, as today effective measures are required to allow choosing the most appropriate raw staff and determining optimal concrete mix from the point of view of economy of materials and quality.

The thesis contains summarized and systematized results of research and practical experience, obtained during the recent 10 years, when working with concrete mixes at the Laboratory of Construction Materials of the Riga Technical University.

Aim of the Thesis

To elaborate the concrete mix design method for plastic concrete mixes, that would base on utilization of grading characteristics of aggregates as the main dominating factor, and to offer methods of determining the optimal mix by using multi-objective optimization elements.

Research tasks

- To elaborate the method allowing to re-estimate the aggregate grading composition from one sieve system to another system, which have holes of different size and shape.
- To work out the method and the algorithm of versatile application to estimate aggregate composition for multi-component mixes. To estimate the offered method application for different types of concrete.
- To mutually compare the two-component mix design estimation results, which are obtained by means of different methods. To establish a database of aggregates available in Latvia.
- To work out a universal (one value) parameter, in order to rationally characterize the aggregate, taking into account its grading composition and shape of particles. The parameter is to determine the water amount, taking into account the concrete consistency.
- To work out the estimation scheme for plastic concrete mix design with the help of granulation method by observing current requirements to plastic concrete mixes.
- To elaborate the multi-objective optimization scheme for concrete mix in order to solve different technological tasks, to offer the method for overall estimation of concrete mix.

Scientific Novelty of the Thesis

- For the first time there is a method elaborated, that allows to mutually re-estimate grading of aggregates from one sieve system to any other.
- There are parameters offered for grading equation of aggregates (the degree n and the curve starting point X_o), with the help of which the ideal grading composition can be determined for different types of concrete.
- For plastic concrete mix design it is offered to make use of the universal parameter - granulation number, which by one digit both characterizes aggregates, and determines connection between geometrical characteristics of aggregates and composition of concrete.
- There is an elastic scheme of concrete mix design and optimization worked out, that makes use of multi-objective optimization elements, provides with possibility to choose the most rational composition and to find the compromise solution between the cost and characteristics of the material.
- There are graphic interpretation variants of the optimization results and the conception of standard concrete, that allow to visually evaluate the efficiency of particular mix.

Practical value of the Thesis

There is the concrete mix design and optimization method elaborated, convenient in practical application, which allows to efficiently determine the optimal concrete mix with the help of computer, thus allowing to considerably reduce the mix production time. There is a database composed of various aggregates available in Latvia.

The following is forwarded to defend the thesis:

- The re-estimation method of the aggregate granulation composition from one sieve system to any other.
- Aggregate grading equation parameters, that determine the desirable aggregate grading for different types of concrete.
- The concrete aggregate composition estimation method with the analytical least square method and with the numerical method.
- Concept of the granulation coefficient and the granulation number for plastic mixes and the concrete mix design method, for which the aggregate granulation number is the chief factor.
- The concrete mix multi-objective (compromise) optimization scheme is elaborated and the optimization parameters are determined.
- Concept of the standard concrete.

Content and volume of the work

Doctorate thesis is composed of the introduction, 4 chapters, conclusion and bibliography. Volume of the work 149 pages, there are 43 drawings, 21 tables and bibliography containing 123 references, 5 appendix.

Approbation of the work and publications

Results of the approbation work have been reported and discussed at international conferences:

- 2nd International PhD Symposium in Civil Engineering, (Budapest, Aug. 1998).
- 6th International Conference "Modern building materials, structures and techniques" (Vilnius, May 1999).
- 7th International Conference "Modern building materials, structures and techniques". (Vilnius, May 2001).
- RTU 42nd International Scientific Conference (Riga, October, 2002)
- 12th International Conference Mechanics of Composite Materials (Riga, June, 2002)
- RTU 43rd International Scientific Conference (Riga, October, 2002).
- RTU 44th International Scientific Conference (Riga, October, 2003).
- 1st Baltic States Conference of Silicate Materials (Riga, May, 2004).

The results of investigations are reffered and discussed in all Latvian Concrete Assotiation annual conferences held from 1997.

The principal results of the work are outlines in 9 publications (p. 21).

It was recieved patent No LV 11681 B of Republic of Latvia "Lihtweight concrete mix composition" (publ. 20.06.1997.)

CONTENT OF THE WORK

The first chapter describes the present situation in issues of concrete mix design and optimization, considers current estimation methods and provides the summary on advantages and deficiencies of different methods.

It is emphasized, that aggregates are of special significance in the concrete structure, as they take up 60...80 % of the material volume. Characteristics of aggregates, that are to be taken account of, when designing a concrete mix, can be conventionally divided into two groups: material characteristics and geometrical (visual) characteristics - shape of aggregate particles, surface condition and granulometric composition (grading).

Geometrical characteristics provide fixing of particles, influence mix consistence and cement consumption. Grading is the most important geometrical characteristic, it determines the relative content of particles with different dimensions. Grading may be defined as relation between the sieve hole dimension X(I), mm and the sieve cumulative passing Y(I), %. To determine grading practically, a standard sieve set with different holes is used. It is to be noted, that currently to determine grading composition there are different system sieves used. When analysing the literature, it is stated, that there is no unified method elaborated, that would allow to re-estimate grading composition from one sieve system to another, as well as to coordinate round-shape and square-shape sieve openings.

As a result of concrete aggregate design, it is necessary to obtain the optimal proportions of components, that would provide fixing of compact particles with a minimal emptiness and allow to reach the required concrete characteristics. Ideal grading curves are most widely used to characterize optimum aggregate grading.

The most well-known is Fuller's "ideal" curve, which almost 100 years ago was offered by Fuller and Thompson. In its essence the Fuller's curve is a inverse parabola, and generally it can be described with the following function:

$$YT(I) = \sqrt{D(I)/D_{max}} = (D(I) / D_{max})^{0.5},$$

where: D(I) is the particle size, mm;
YT(I) is the theoretical (ideal) amount of particles smaller than D(I);
D_{max} is the maximal size of aggregate, mm.

The ideal grading compositions can be also presented by a chart or graphically, as the interval between the two curves.

When designing concrete, the aggregate optimal proportions, that provide the composition to be maximally close to the ideal curve, are to be estimated. The graphic method of determining the Dutch aggregate composition can be mentioned, which was used in designing the stiff concrete mix composition. The Dutch method idea was developed by J.Biršs, when elaborating the method of analitical gravity center and the least square estimation method.

It is to be noted, that the considered estimation method according to the ideal curves does not provide for using the numerical criterion, that determines the real grading correspondence to the ideal curve. Similarly, it is topical to implement the aggregate composition estimation methods to apply them also for modem plastic concrete types (pumped, self-compacting concrete, etc.)

When summarizing the available information on composition design methods, it can be concluded, that the determining principles for plastic concrete mix composition are the absolute volume principle, the water/cement ratio law and the consistence principle, according to which the water amount depends primarily on the mix consistence and aggregate roughness.

It is stated, that the water amount is one of the most sensitive factors of concrete composition design. Water covers aggregate particles with a determined thickness layer, therefore, aggregate geometrical characteristics are very important. There are different parameters used, which characterize the aggregate adsorbing capability (surface shape of the particles, specific surface, etc.). It is proven, that the adsorbed water layer thickness depends on the size of the particles (finer particles have thinner water layer). This provision is observed by the granulation number parameter, which most effectively characterizes the aggregate water adsorbing characteristics and determines the minimal water amount for moistening the particles. The concrete composition design method based on the granulation number was widely used in the 70-s ... 80-s for the concrete impact technology. It is to be noted, that the granulation number method was elaborated for stiff concrete mixes. Thus, it is required to implement the granulation number method and to apply it to plastic mixes.

Having surveyed information about concrete optimization, a conclusion is drawn, that there is no unified approach to issues of concrete mix optimization, and up to now it is difficult to find schemes and methods, which are ready for practical application. The multi-objective (compromise) optimization is the most successful optimization method, which could be applied for concrete mixes. The multi-objective optimization approaches were used in the 90-s by A.Kregers, G.Teters, J. Melnbārdis and M.Rektiņš for investigating characteristics of composite materials. Optimal solution is determined with the help of the integral criterion function **Φ**, which by one value observes several characteristics of the research object, as well as significance of the characteristics.

Thus, there are main trends of research, that influence mostly the optimal composition of plastic mixes, indicated and chosen:

- Aggregate grading characteristics;
- Aggregate ideal curves and the aggregate composition estimation method;
- The water factor and the composition design method, that observes connection between aggregate geometric characteristics and concrete composition;
- Multi-purpose optimization of compositions.

See the summarized research scheme at the Figure 1.

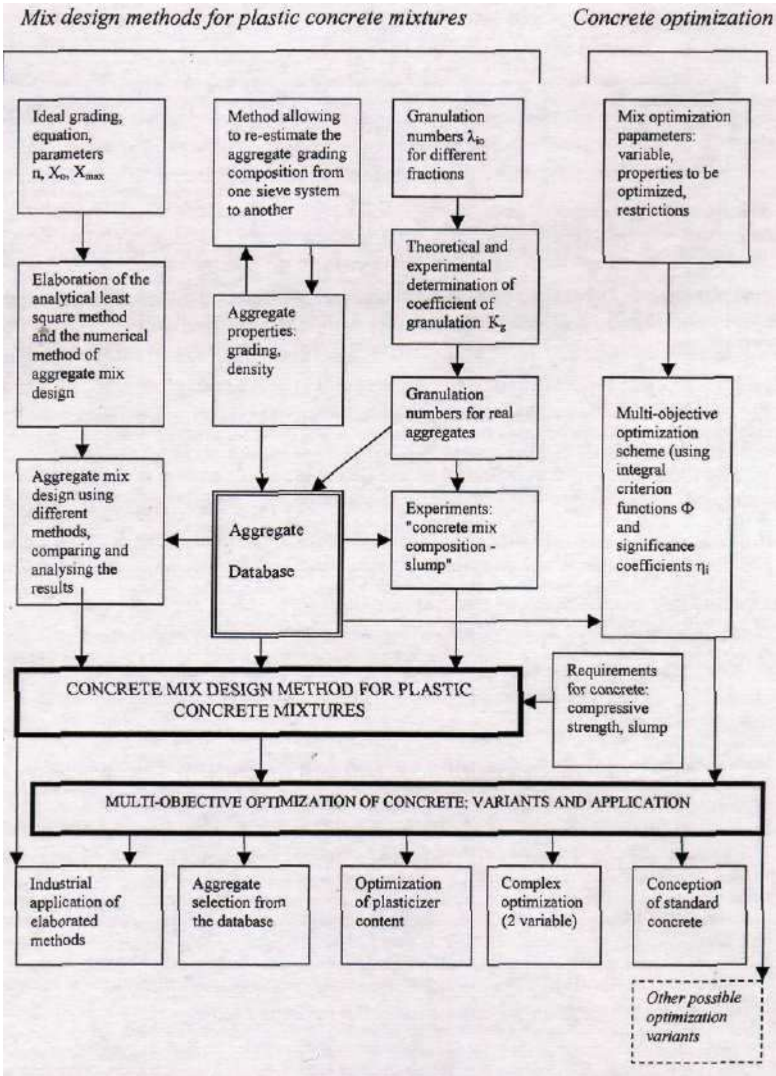


Fig. 1. Research Scheme

The second chapter is devoted to elaboration of new methods in the aggregate composition determination and estimation. The method used in the thesis to investigate the aggregate characteristics is described.

There were practical comparative experiments performed, when one and the same aggregate was bolted through sieve sets with various gradation of holes. The obtained grading compositions were compared and re-estimated by using linear, logarithmic and square root interpolation methods. For re-estimation of compositions there is the round shape and square root sieve hole transition coefficient observed. When processing the results statistically, it is determined, that sufficiently precise results can be obtained through linear interpolation. It is concluded that the least average squared deviation between theoretical and experimental results is achieved with multi-fraction aggregates (S<2.1%). Re-estimation method is not suitable for aggregate having basically one fraction. The aggregate fineness modules obtained with the help of the European standard EN and GOST sieves are compared. The ratio of the FM^{EN} / FM^{GOST} modules for the fine aggregate comprises on average 1.08, whereas for the rough aggregate it is 1.02.

The ideal grading curves found in the literature are analyzed and their graphic comparison with the Fuller's ideal curves is made. For practical application there are modified Fuller's curve equations chosen with changing parameters $\mathbf{X_o}$ (the curve starting point) and **n** (the degree). There are parameter values determined for the stiff, pumped and self-compacting concrete mixes.

To determine the aggregate composition, the following scheme is used: There are **N** aggregates given with the known grading composition

Y(1,I); Y(2,I); ... ;Y(J;I); ...; Y(N,I),

where: **N** is the amount of aggregates;

J is the aggregate ordinal number, I is the sieve ordinal number.

It is required to determine the aggregate proportions **K(J)**, which provide real grading curves **Y(I)** to be maximally close to the ideal curve **YT(I)**. The real curve equation is as follows:

$$Y(I) = \sum_{J=1}^{N} K(J) \cdot Y(J,I).$$

The task is solved by using the least square principle, i.e. by minimizing the sum of deflection square between the ideal curve and the real one.

$$\sum_{I=1}^{M} (YT(I) - Y(I))^2 = \min,$$

where: M is the number of sieves.

There are estimation cases considered, when the end point X_{max} of the ideal curve is fixed (the ideal grading is preset) and the X_{max} is floating (i.e. it depends on the aggregate maximal roughness). There is the following equation system (in the form of a matrix) determined for the variant, when the ideal curve is preset and the amount of source components is not limited:

$$\begin{vmatrix} A(1,1) & A(1,2) & \cdots & A(1,N-1) \\ A(2,1) & A(2,2) & \cdots & A(2,N-1) \\ \cdots & \cdots & \cdots & \cdots \\ A(N-1,1) & A(N-1,2) & \cdots & A(N-1,N-1) \end{vmatrix} \times \begin{vmatrix} K(1) \\ K(2) \\ \cdots \\ K(N-1) \end{vmatrix} = \begin{vmatrix} B(1) \\ B(2) \\ \cdots \\ B(N-1) \end{vmatrix}$$

(matrix of unknown members coeffic.) matrix of unknown members (matrix of free coef.)

It is determined, that coefficients in the equation system change according to the simple logical correlation. There are the following formulas received to determine the coefficients (the estimation is easily done in the computer):

$$A(R,S)=\sum_{I=1}^{M} (Y(N,I) - Y(S,I))\,(Y(N,I) - Y(R,I));$$

$$B(R)=\sum_{I=1}^{M} (Y(N,I) - YT(I))\,(Y(N,I) - Y(R,I)),$$

where: **R** is the equation (the row number);
S is the member (column) number.

There is also the numerical method of the least square elaborated. The principle of the method is to mechanically divide all possible combinations of the aggregate proportions, to choose the composition, for which the square deviation amount between the real and the ideal curves is minimal. The numerical method involves more numerical operations, when comparing it to the analytical method, thus, the estimation time with the modern computer can take more than 20 minutes. There are estimation volumes analyzed depending on the estimation step, the amount of components and the determined boundary, when the two-step numerical method is to be used. There are schemes, algorithms and programs elaborated in Visual Basic to estimate aggregate composition for mixes consisting of up to 5 components with the help of analytical and numerical methods.

Numerical examples used to determine the five-component aggregate mixes (See the Figures 2, 3 and the Table 1) demonstrate that the analytical method can have indeterminate results, in case there are non-standard composition source materials given, especially if the grading curves overlap (See the Figure 3). The numerical method is more stable, and it allows to use wider capabilities of mix design, in comparison with analytical method. Analytical and numerical method results differs not more then 1%.

To evaluate, how well the real grading curve corresponds to the ideal, it is offered to make use of the numerical criterion S (%) - the average squared deviation between the ideal and the real curves.

Composition estimations made with the help of the numerical method for different ideal grading lypes are meant for the stiff, pumped and self-compacting concrete (See the Table 2). The results demonstrate, that, when using the same source materials in different proportions, it is possible to obtain aggregate mixes for different types of concrete.

There is the comparison made of mix design results for the two-component aggregate by using different methods. Comparing the results of the particular two-component mix design, it has been proved that elaborated analytical and numerical method in general show average squared deviation between ideal curve and calculated real mix curve that equals 6.5%; the existing Dutch, analytical and gravity center methods - 7.9, 11.9 un 7.7 % correspondingly.

For the two-component mix, as an alternative variant, it is offered to use the fineness module method, which is simple in application even when not using the computing devices. When calculating finess modulus it is recommended to use additional sieves 5.6 and 11.2 mm. As a result, the accuracy of finess modulus method will be increased and the difference between analytical and finess modulus method up to 2.6 % may be achieved.

In the process of concrete design and optimization it is important to have a fast access to the information on different source materials. For this purpose there is a database established of different aggregates available in Latvia, which include main aggregate indices. The data are summarized in the Excel tables, as well as all the aggregates are collected on a special shelf in separate vessels.

Table 1

Results of Determining the Five-Component Mix

Aggregate	Example No 1		Example No 2	
	Numerically	Analytically	Numerically	Analytically
Gravel 4–16 mm	0.370	0.365	0.440	0.480
Gravel 2–11 mm	0.240	0.247	0.060	-0.037
Sand 0–4 mm	0.310	0.312	0.000	-0.225
Sand 0–3 mm	0.060	0.055	–	–
Sand 0–5 mm	–	–	0.480	0.771
Filler 0–0.063 mm	0.020	0.021	0.002	0.012
S, %	2.78	2.79	1.51	-
Time of calculation, s	43	< 1	43	< 1
				No result

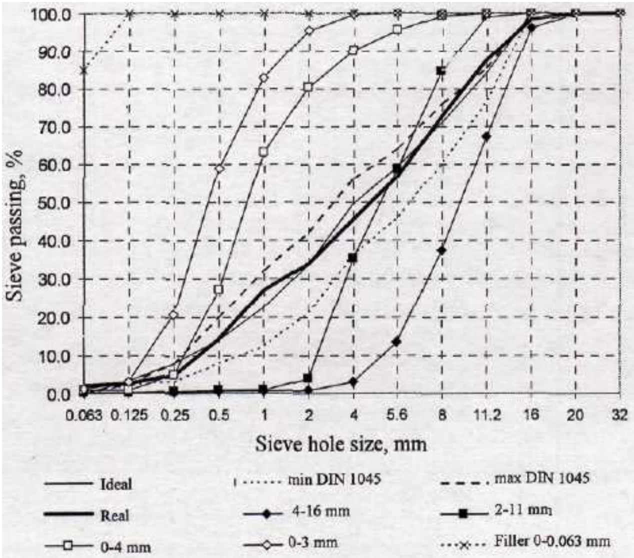


Fig. 2. Grading Curves for the Example No. 1

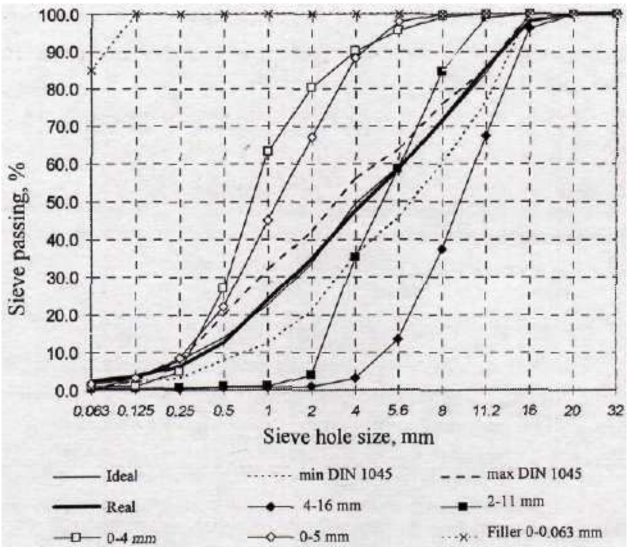


Fig. 3. Grading Curves for the Example No. 2

Table 2

Results of Determining Aggregate Mixes for Different Types of Concrete

Concrete type, (the numb, of components)	Parameters		Proportions, %				S, %
	X_o	n	5-16 mm (142)	0-4 mm (48)	2-5 mm (159)	Filler (13)	
Stiff mixture, SI (2-components)	0.063	0.52	60.0	40.0	-	-	7.82
Stiff mixture, SI (3-components)	0.063	0.43	49.0	25.0	26.0	-	2.42
Pumping, S2...S3 (3-components)	0.063	0.43	44.0	29.0	26.0	1.0	2.41
SCC (4-components)	0.027	0.29	34.0	36.0	23.0	7.0	2.27

The third chapter contains the water factor research for plastic mixes.

To more accurately observe the surface shape of the aggregate particles, it is offered to use the special parameter - the granulation coefficient. It determines the connection between the surface area of the particles and the surface area of the sphere with the same volume:

$$K_g = S / S_o,$$

where: S is the real body surface;

S_o is the sphere surface with equivalent volume.

There is the theoretical estimation made of granulation coefficients for different geometric bodies, as well as experimental determination for real aggregate grains, by using the painting method. For rounded aggregate particles the granulation coefficient values range from 1.07 ... 1.27 and for the angular particles - from 1.37 ... 1.48. The obtained experimental data incorporate into the interval of theoretical results.

The number of granulation is defined as minimal water amount to cover aggregate particles (liter per 100 liter of aggregate by absolute volume).

Determination of the aggregate granulation number is offered to be made according to the formulas:

where: $\lambda(J)$ - is the granulation number for the real aggregate;

$\lambda_O(J)$- is the granulation number for the aggregate with round particles.

$$\lambda_o(J) = \sum_{I=1}^{M} Q(J,I) \cdot \lambda_o(I)/100,$$

where: Q(J,I) - content of fractions in the particular aggregate, %;

$\lambda_O(I)$ - granulation number for particular fraction with round particles.

$$\lambda = \sum_{J=1}^{N} \lambda(J) \cdot K(J),$$

where: λ — is the aggregate mix granulation number.

The research is made to determine connection between the concrete composition and the cone slump. There is the following main formula offered to determine the water amount for plastic mixes (liter per 100 liter of aggregate by absolute volume):

$$W^{100} = \lambda \times K$$

where: K is the consistency coefficient, which depends on the slump.

There is the empiric connection obtained (See the Figure 4) between the cone slump KN and the consistency coefficient: $K=0.19 \cdot \lg(KN) + 2.1$.

It is noted, that for modern plastic concrete mixes it is important to keep the fine particle composition. There are requirements summarized for fine particle amounts for different concrete types. There is the water/cement ratio method specified, taking into account the cement classification according to the European standard.

There is a method elaborated to estimate the concrete composition, by using the granulation number principles and by observing the accuracy corrections for the water/cement ratio and the fine particle composition.

When comparing the designed slump with experimentally observed results, the granulation method shows less difference between theoretical and experimental results. The correlation coefficients comprise correspondingly 0.84 for the standard method and 0.94 for the grading number method (See the Figure 5).

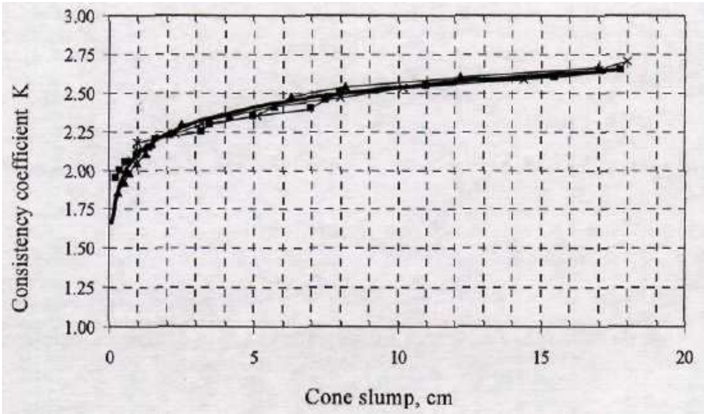


Fig. 4. Connection between the Cone Slump and the Consistency Coefficient

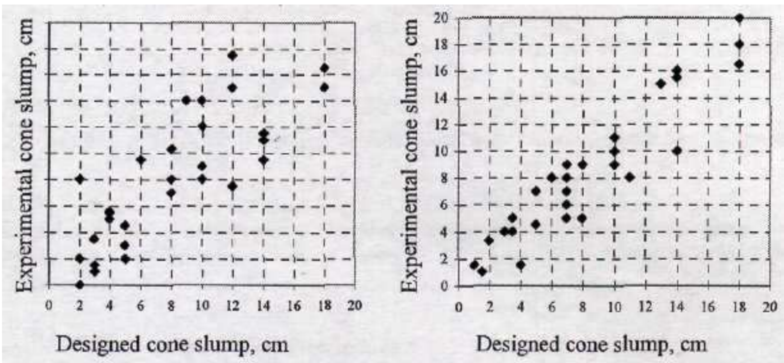


Fig. 5 Correlations between Theoretical (Designed) and Real Cone Slump

a) standard method (coefficient of correlation 0.84),

b) granulation number method (coefficient of correlation 0.94).

The fourth chapter is devoted to the concrete mix optimization issues.

There is the following concrete mix multi-purpose optimization scheme offered.

- Defining the optimization task, determining the parameters, choosing the source material from the database.
- Determining the experiment plan for n compositions.
- Theoretical estimation of the concrete n compositions, taking into account changing source parameters, each theoretical composition having its own optimized values.
- Determining the optimal solution with the help of the Φ integral criterion function:

$$\Phi = (\sum_{i=1}^{n_y} \eta_i \Phi_i^{-2})^{-1/2},$$

where: $\Phi_{i;}$ is the local criterion of the given optimized value,

$0 \leq \Phi_i \leq l$; it is set that $\Phi_i = 0$, if the value has the lowest index, and $\Phi_i = 1$, if the value has the best (desirable) index in the given range;

r|i is the significance coefficient of the optimized values, $0 \leq \eta_i \leq 1$.

There are the optimization parameters determined: Variable parameters x_{i5} optimized values $y_{;}$, as well as the limitations summarized, which are to be taken into account in the mix design.

To investigate the multi-purpose optimization capabilities for concrete mixes, there are the optimization variants elaborated: aggregate choice from the database, plasticizing additive choice and the optimal amount determining and the multipurpose optimization with two changing parameters. They are tested on numerical examples and analysis of the results.

The Figure 6 shows the most appropriate aggregate choice results. For the optimization task there are 5 sand type aggregates given and 4 course aggregates, with the combination number for the two-component mix being 4 x 5 = 20. There are 20 concrete mixes estimated, each composition has its local criteria determined for the following optimized values: water amount W, price C and average quadratic deviation between the ideal and real grading curves S. Numerical values of the integral criterion function Φ are shown in the diagram in the decreasing order, it allows to visually distinguish the best compositions. For the given case, the mix No. 3 meets the requirements in a better way, as alternatives there can be variants 4, 19 and 11 accepted.

There is a mathematical model elaborated for plasticizing action, that allows to observe the diminishing effect of the plasticizing water in the mix estimation and to use a model to solve the mix optimization task.

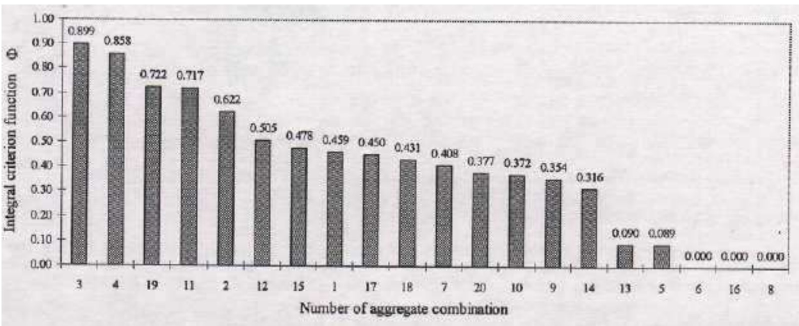


Figure 6. Integral Criterion Functions for Different Concrete Mixes

In case of mix optimization with two changing values, wider capabilities can be implemented, in comparison with the one-factor optimization task. Graphic interpretation of the results in a three-dimensional diagram increases visual presentation of the results. When using the data processing program, it is possible to obtain the function polynomial in order to achieve the optimal result and to predict the change tendencies of the optimized functions (See the Figure 7).

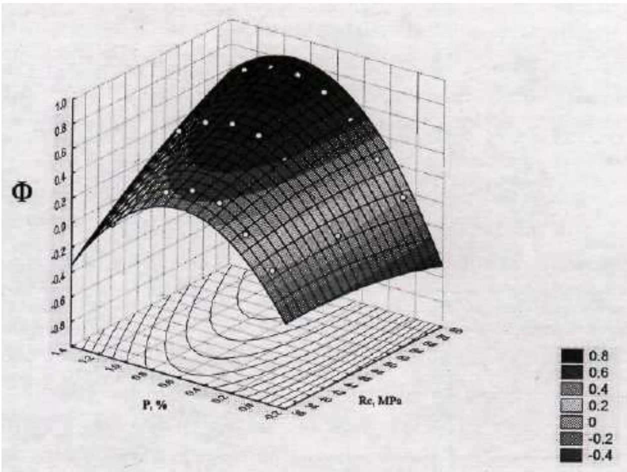
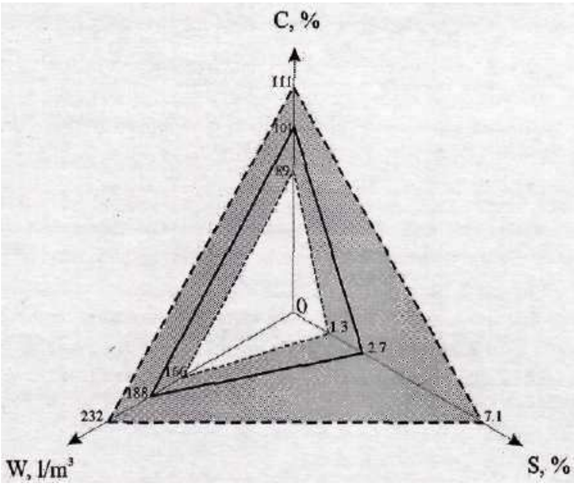


Figure 7. Optimized Function Dependence on the Cement Strength and the Amount of Plasticizer

To solve the task of the concrete mix design and optimization, there are special programs elaborated in MS Excel and Visual Basic. There is a system obtained, that consists of sub-modules (to determine ideal curves for the sub-programs, to estimate grading, to estimate the concrete mix and different optimization variants).

There is the standard concrete conception elaborated. When analyzing different concrete offers and research results, there are statistical data received about concrete of different classes. The offered method allows to evaluate the compared concrete mix according to economic and qualitative criteria. To graphically represent the results, there is a 3-axis diagram used, which in a corresponding scale depicts' concrete properties: relative cost C (%), average squared deviation between the ideal and the real curves S (%) and water amount W ($1/m^3$).

It is to be visually evaluated, whether the given mix triangle fits into the boundaries. The closer to the center the mix indices, the more effective is the concrete (See the Figure 8).



Designations: ——— analyzed concrete;
--------- border of non-effective concrete.

Figure 8. Diagram for the Concrete Mix Evaluation

CONCLUSIONS

- There is a method elaborated to re-estimate the aggregate grading composition from one sieve system to another with the help of the interpolation method, taking into account the transition coefficient of the round form and the square-shaped sieve hole. Having compared the aggregate grading compositions, it is observed that the least average squared deviation between theoretical and experimental results is achieved with multi-fraction aggregates ($S < 2.1\%$). Re-estimation method is not suitable for aggregate having basically one fraction.
- When using the least square method, there are aggregate composition estimation universal methods and algorithms elaborated for the analytical and numerical method, that allow to determine optimal composition for the multi-component aggregate mix. Advantages and drawbacks of elaborated methods are determined. It is concluded that the analytical method has restricted application. The numerical method is more stable, and it allows to use wider capabilities of mix design. The difference of results of analytical and numerical method does not exceed 1%.
- Different ideal grading curves can be formed by using the offered parameters for grading equation of aggregates (the degree n and the curve starting point X_o). When using the elaborated mix design method, it is possible to design compositions for different concrete mix types, starting with stiff and up to self-compacting mixes that was not possible before.
- Elaborated analytical and numerical methods provide results, which better correspond to the aggregate ideal curve, in comparison with the current considered methods. Comparing the results of particular two-component mix design, it has been proved that the elaborated analytical method and numerical method in general show average squared deviation between - ideal curve and calculated real mix curve that equals 6.5%; the existing Dutch, analytical and gravity center methods - 7.9, 11.9 un 7.7% corespondingly.
- There is a universal parameter - the granulation number (λ) for plastic mixes offered, which characterizes the aggregate adsorption capabilities through one value, simultaneously taking into account grading composition and shape of the particles. Estimated empirical relation allow to determine water content in concrete if granulation number and mix consistency are preliminary defined.
- Basing on the granulation number principle, there is the concrete composition design method elaborated for plastic mixes. The granulation number significantly simplifies and makes more accurate the concrete mix estimation. For the granulation method there is less difference between theoretical and experimental results. The correlation coefficients comprise correspondingly 0.84 of the standard method and 0.94 of the granulation number method.

- There are methods elaborated to solve different optimization tasks, including choosing the most appropriate aggregate from the database, determining the plasticizer optimal amount and choosing the cement type. The offered examples of applying the optimization methods demonstrate that the multi-objective optimization elements can be successfully used to solve different practical tasks, when designing the concrete mix. Graphic interpretation of the results in three-dimensional diagrams visually better demonstrates the achieved results and allows to forecast tendencies of the optimized function changes.
- There is the standard concrete conception elaborated, which allows to efficiently compare the price and the main quality criteria of the given composition with the statistically average composition indices, as well as to demonstrate the results in a diagram.

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