Judgment of Concrete Quality in Transportation Structures

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This paper deals with the present method of judgment of the quality of fresh and hardened concrete used in transportation structures in Czechoslovakia. Standard methods and criteria are presented for estimating properties of fresh concrete mixes and hardened concretes for different types of structures. In the case of hardened concretes, destructive and nondestructive methods of testing concrete properties are analyzed and evaluation techniques are given. The problems of quality control of cements and aggregates are studied. The judgment of the acceptability of fresh concretes in relation to their composition and workability is analyzed. Requirements are presented for such properties as concrete strength and properties related to short- and long-term deformation. Sclerometric and acoustic methods of nondestructive testing are discussed. Various methods for the judgment of acceptability of concrete are analyzed by using large and small samples and standard Czechoslovak specifications. Statistical evaluation is emphasized. Acceptability criteria for safety, homogeneity, and economy are presented.

The intent of this paper is to show the complexity of the judgment procedure used in the quality control of concrete on the basis of current Czechoslovak standards. Judgment of concrete quality involves the choice of the physicomechanical characteristics to be tested and the testing procedures and evaluation methods to be used. This paper addresses all of these problems. The possibility of using a refined procedure of statistical quality control for concrete produced over longer periods is also discussed.

CONTROL OF QUALITY PARAMETERS

Because transportation construction deals with different kinds of structures and these structures involve different requirements, the control procedure used must also be different. The most pronounced difference in estimating quality parameters occurs between concretes used for road and airport pavements and concretes used in other transportation-related structures.

Quality parameters are estimated by using three categories of tests that correspond with the different time periods of a construction project. Some of these tests are prescribed by standards; the rest are optional or recommended. The test categories are as follows:

1. Agreement tests carried out before the start of the construction work;
2. Control tests, which include the production control tests carried out by the producer of the structure and the official control tests carried out by government agencies; and
3. Acceptance tests, which are carried out by the consumer of the structure.

TESTS FOR ROAD AND AIRPORT PAVEMENT CONCRETES

According to Czechoslovak standards, the following tests are carried out for road and airport pavement concretes.

Agreement Tests

The following agreement tests are prescribed:

1. For concrete mix and concrete—workability of the concrete mix, air content when air-entrainment admixtures are used, bulk density of fresh compacted concrete, and flexural strength of concrete;
2. For cement—estimation of the normal consistency of cement paste, initial set and time of setting, fineness, volume stability, and strength;
3. For aggregate—grading, bulk density of loose and compacted aggregate, specific gravity, contents of sulfur compounds, water absorption, contents of clay, sand equivalent, humus content, and humidity;
4. For water—testing only in cases of doubt; and
5. For admixtures—in addition to the prescribed tests, proof of the influence of admixtures on the concrete mix and concrete.

The following agreement tests are recommended:

1. For concrete mix and concrete—bulk density of concrete, compressive strength of concrete, splitting tensile strength, volumetric changes, Young's modulus, deformation properties, water absorption, water permeability, and frost resistance;
2. For cement—resistence to cracking, specific gravity, and volumetric changes of cement mortar; and
3. For aggregate—particle shape, mica particles content, influence of the aggregate on the volume changes of concrete, and abrasion of coarse aggregate by the Los Angeles machine.

Agreement tests are essential for gaining permission to start the production.

Control Tests

Control tests are carried out continuously over the entire period of construction. The sampling of concrete mixes is carried out as often as necessary to ensure the presence of the required properties according to prescribed and recommended tests; these tests involve a control of components, concrete mixes, and concretes similar to that applied in the agreement tests.

The extent of production control tests is prescribed by standards, as follows: Workability and air content are to be examined at least once during a shift; flexural strength must be assessed on three specimens 15 by 15 by 70 cm in size for each 1000 m^2 of pavement; the quality parameters of cement and aggregate must be evaluated at least once for each 3000 m^2 of pavement; and the test results should be summarized in a test record that is kept at the site for inspection purposes.

Official control tests are carried out according to a decision made by the pertinent supervising authority. This authority decides which concrete properties or components are to be tested.

Acceptance Tests

Acceptance tests are only used to control finished pavements. The number of samples is determined according to the pavement area. For up to 2000 m^2, two samples are tested. For every additional 2000 m^2, another specimen is tested. Nondestructive methods can be used to estimate pavement quality provided an experimental relation between the destructive and the nondestructive test values has been determined. Combining several nondestructive methods is advisable to increase the exactness of values determined by such methods. The flexural strength of concrete is determined according to the results of production control tests. In acceptance of the pavement, it is essential to assess whether (a) the design strength was achieved and (b) the coefficient of variation computed from the production control tests shows lower than prescribed values. The homogeneity of the cast concrete is tested by nondestructive methods (e.g., the pulse velocity method). If the splitting tensile test or nondestructive testing is done on cores, the relation between these values and the splitting tensile strength tests carried out with normally cast specimens must be determined.

The control procedure for transportation-related structures other than pavements also involves the determination of properties of concrete mix components; properties of concrete mixes in the processes of mixing, transport, and casting; curing of hardened concrete during casting; 28-d cube strength; and cube strength at the time of formwork removal and structure loading. Other properties prescribed by the design—e.g., flexural strength, water permeability, frost resistance, and volume changes—are also tested. The control procedure is divided into the same test categories as those used for pavements—i.e., agreement, control, and acceptance tests.

Control tests are carried out for each 500 Mg of the material. In prestressed structures, the number of tests is prescribed by the design. The workability and the air content of the mix are examined at least once a day. If doubts arise, the concrete composition should be checked. In hardened concrete, the cube strength is controlled; other properties are examined only when such examination is prescribed by the design. Samples are taken from each 200 m^3 of concrete. In mixing plants that use semiautomatic or fully automatic mixing machines with a capacity greater than 300 m^3/d, samples are taken from each 500 m^3. In prestressed structures, one sample is taken from each 25 m^3 of concrete in such a way that a sample is taken when the prestressing is applied and another sample is taken to determine the 28-d strength. The strength at the time when prestressing is applied can be found by using a nondestructive test method; the strength values are derived from a calibration diagram.

METHODS OF DETERMINING PROPERTIES OF CONCRETE MIXES AND CONCRETES

Testing Concrete Mix Properties

The workability of plastic concrete mixes is assessed by means of slump tests. For no-slump concretes, the VeBe method is prescribed. Czechoslovak standards allow the use of two methods: the Skramtayev test and the technical viscosimeter test.

The air content in the concrete mix is determined by the volumetric and pressure method. The analysis of the concrete mix can be performed either by sieve analysis or by drying.

Testing Hardened Concrete Properties

The compressive strength of concrete is determined by testing at least three specimens and using the mean value of the three tests as the test result. Compressive strength is estimated by testing cube strength, cylinder strength, and prism strength.

The basic cube has a side length of 20 cm. Standards allow the use of cubes with side lengths of 10, 15, 30, and 40 cm, but the strength results determined on these cubes are converted to the strength obtained on 20-cm cubes. The basic cylinder has a height of 30 cm and a diameter of 15 cm. Cylinders of different sizes can also be used if the results are converted to conform to the basic cylinder size. The basic specimen for determining prism strength measures 15 by 15 by 60 cm. When an appropriate strength coefficient is applied, 10 by 10 by 40-cm and 20 by 20 by 80-cm prisms can also be used. The direct tension test is carried out on 15 by 30-cm cylinders and 10 by 10 by 30-cm prisms by using clamps glued on the ends of the specimens. The basic specimen used in determining flexural strength is a 15 by 15 by 60-cm beam; beams 10 by 10 by 40 cm and 20 by 20 by 80 cm can also be used. The beams are tested by using third-point loading. Splitting tensile strength is determined on cubes loaded parallel with their diagonal, and the basic test specimen has a side length of 20 cm. Splitting tensile strength can also be determined on cylinders. The size of the basic specimen in this case is 15 by 30 cm, but specimens of different sizes can be used.

In the determination of Young's modulus of elasticity, the specimens used are of the same size as those used for the testing of prism and cylinder strength. The initial Young's modulus is determined at a stress equal to 20 percent of the crushing strength. Shrinkage, swelling, and creep of concrete are investigated on specimens used for the prism strength tests.

Water permeability is tested on at least three specimens. These specimens are plates measuring 30 by 30 by 15 cm or cylinders measuring 15 by 30 or 15 by 15 cm. The frost resistance of concrete is estimated for at least three beams that have the same dimensions as those used for testing flexural strength. The freezing of specimens takes place in the air, and the thawing is done in water. One freeze-thaw cycle consists of 4 h of freezing at a temperature of -20°C and 2 h of thawing at a temperature of +20°C. Frost resistance can be investigated by using destructive or nondestructive methods.

Czechoslovak standards distinguish the following methods for nondestructive testing of concrete properties: the pulse velocity method; the resonance frequency method; and four types of surface-hardness tests—(a) the Waitzman method, (b) the Bauman-Steinrück-Franck spring hammer, (c) the Schmidt test hammer, and (d) the mechanical pick hardness tester.

The Waitzman method uses a steel ball projected by hand simultaneously onto a concrete surface and a control steel bar of known mechanical properties. The compressive strength is determined by comparing and evaluating the diameter of both indentations.

The Bauman-Steinrück-Franck hammer consists of a spring-controlled mechanism housed in a tubular frame. The tip of the hammer is fitted with a ball, and the impact is effected by placing the hammer up against the concrete surface and triggering the spring mechanism. The diameter of the indentation is measured, and this in turn is correlated with the compressive strength of the concrete.

The Schmidt test hammer testing procedure consists of releasing a plunger from its locked position by pressing it against the concrete surface. Then the spring-loaded weight is released from its locked position, which produces an impact. While the hammer is still in its testing position, the sliding index is read to the nearest whole number. This reading is designated as the hammer rebound number. Each hammer is furnished with a calibration chart supplied by the manufacturer.

When the mechanical pick hardness tester is used, the number of impacts necessary to excavate an indentation of prescribed depth is counted and the concrete strength is evaluated from the number of impacts.

These nondestructive methods may have the character of either approximative or refined tests. In approximative tests, the strength of concrete is estimated with the help of a general calibration relation. In refined tests, relations are experimentally established.

The grindability of concrete is tested by using a machine with a circular test track. The resulting loss of weight is the measure of grindability. Concrete is also tested by means of other methods not included in Czechoslovak standards. These methods are not dealt with in this paper.

METHODS OF ESTIMATING CONCRETE QUALITY ACCORDING TO TEST RESULTS

Czechoslovak standards distinguish among seven strength classes, including concretes with a cube strength in the 6- to 55-MPa range. In each class the following characteristics are given: an upper limit for the average strengths, the value of the so-called control strength (R_{bk}) estimated with a probability of 0.90; and a further strength characteristic estimated with a probability of 0.95, the design strength that serves for the design of concrete mixes. The result of a test is understood to be the average of strengths obtained on three 20-cm cubes. The judgment of acceptability of concrete can be conventional or statistical. In both cases the average strength of all cube-strength tests must be equal to or higher than the class value of the concrete but lower than the upper limit of average strength. The samples for each control test must be taken from a different batch, and none of the obtained results can be disregarded.

Conventional Judgment

When a judgment is made according to 1 or 2 tests, none of the results must fall below 1.2 R_{bk}. When 3 to 9 tests are performed, none of the results must fall below R_{bk} or the class value. When 10 or more tests are used, a maximum of 10 percent of the results may fall below the value of 0.8 R_{bk}.

Quantitative and Qualitative Statistical Judgment

In any basic set of specimens, a maximum of 5 percent of the values may fall below a value (R_{bcu}). According to Czechoslovak standards, the results are judged according to quantitative and qualitative characteristics.

Quantitative Approach

Essentially, two main criteria and a supplementary criterion are applied in the quantitative approach. The main criteria are those of safety and economy, and the supplementary criterion is that of homogeneity. A statistical judgment made according to these criteria is based on a random sample (n) taken from a set of specimens. The average ($\bar{x}$), standard deviation (s_x), variation coefficient (v_x), and (in the case of large samples) skewness are computed for the random sample. A small sample is $16 \leq n < 100$; a large one is $n > 100$. In the case of a small sample, the theoretical model of the normal distribution is used because skewness cannot be determined with sufficient exactness for small samples. The Pearson distribution is used for large samples.

By applying the safety criterion, it can be determined whether the occurrence of a characteristic in a certain set is lower than (first-case characteristics) or higher than (second-case characteristics) a certain value (x_{cu}), but the difference must not be larger than the value that could occur with a probability (p). The decision can only be made from the random sample by using a certain predetermined reliability (q). Usually p = 0.05 and q = 0.80. In the instance of a first-case characteristic,

$$t = (\bar{x} - x_{cu})/s_x \qquad (1)$$

and in the instance of a second-case characteristic,

$$t = (x_{cu} - \bar{x})/s_x \qquad (2)$$

When a sample is small, the t values are compared with values (t_{min}) and t_{max}), which were derived from the "noncentral" distribution (t) and are a function of probability (p) and reliability (q). If $t > t_{max}$, the concrete is satisfactory from the safety point of view, and if $t < t_{min}$, the concrete is unsatisfactory from this point of view. If $t_{min} \leq t \leq t_{max}$, no decision can be made and the random sample must be enlarged until a decision can be made.

By applying the economy criterion, it can be determined if the computed average ($\bar{x}$) is within the prescribed limits. The concrete is satisfactory if $\bar{x}_{min} \leq \bar{x} \leq \bar{x}_{max}$. By applying the homogeneity criterion, it can be determined if the computed coefficient of variation (v_x) is lower than the highest allowable coefficient of variation (v_{xmax}). The concrete is satisfactory if $v_x \leq v_{xmax}$. The homogeneity of concrete can also be determined by the pulse velocity method. If $n \geq 16$ and the coefficient of variation of the pulse velocity is ≤ 0.05, the homogeneity of concrete can be considered to be satisfactory.

The quantitative approach is usually used to determine strength in compression and tension as well as bulk density. Czechoslovak standards allow the use of the quantitative judgment approach in other cases too, but these should be either agreed on or ordered by an authority.

Qualitative Approach

Qualitative judgment is based on the model of the binomial distribution. The aim is to find out whether the number of faulty elements coming from concrete production or production of concrete elements is larger than agreed on or ordered. The portion of faulty specimens (Z) in a random sample is determined and compared with the value (Z_{crit}). A decision concerning the whole set can be made from the random sample only by using a certain predetermined reliability. In this way the range within which Z_{min} and Z_{max} occur can be determined. In the case of a small sample, the concrete is satisfactory if $Z < Z_{min}$ and is unsatisfactory if $Z > Z_{max}$. No decision can be made if $Z_{min} \leq Z \leq Z_{max}$. In the case of a large sample, Z_{min} and Z_{max} merge with Z_{crit}.

PROPOSED METHOD FOR REFINED STATISTICAL QUALITY CONTROL OF CONCRETE

The production of concrete is usually statistically tested over a time period (T). The question arises, Can the concrete production over a long period be characterized by a standard population (S) of size (N) of parameter value (X) obtained by the experiment (E_o) typical for the concrete production during the whole period (T), i.e., by a standard population with an approximate normal distribution $N(\mu, \sigma^2)$? In other words, are the following two requirements on which the Czechoslovak standards are based fulfilled?

1. Over the entire period in which quality control is carried out, are the conditions influencing the tested characteristic held constant?
2. Are the test conditions (i.e., test procedure, specimen size, age of concrete) held constant?

Let the period (T) be divided into $k \geq 2$ relatively short periods ($C_1, \ldots, C_k$), which do not overlap each other. Assume that the following conditions are fulfilled:

1. Concrete production is carried out during the periods ($C_1, \ldots, C_k$) under conditions that do not influence each other.
2. Concrete production in periods ($C_1, \ldots, C_k$) can be characterized by standard populations ($S_1, \ldots, S_k$) of the same size (M) of characteristic values ($X_1, \ldots, X_k$) obtained by experiments ($E_{o,1}, \ldots, E_{o,k}$) typical for the production in $C_1, \ldots, C_k$.
3. The standard populations ($S_1, \ldots, S_k$) have an approximately normal distribution [$N(\mu_1, \sigma_1^2), \ldots, N(\mu_k, \sigma_k^2)$], where $\mu_1, \ldots, \mu_k$ are the mean values and $\sigma_1^2, \ldots, \sigma_k^2$ are the variances of the standard populations ($S_1, \ldots, S_k$).

It is evident that the first and second conditions are fulfilled only in the case in which the following two conditions are also satisfied:

$$\sigma_1^2 = \ldots = \sigma_k^2 = \sigma^2 \tag{3}$$

$$\mu_1 = \ldots = \mu_k = \mu \tag{4}$$

If only one of these conditions is fulfilled, it is certain that the first requirement in the list given above is not fulfilled, and usually neither is the second requirement.

Two problems arise:

1. Is the first condition (Equation 3) fulfilled or not?
2. Is the second condition (Equation 4) fulfilled or not?

Methods of solving these problems have been proposed. It should be noted, however, that the method of solving problem 2 can be applied only when the answer to problem 1 is positive.

In solving the two problems, assume that the time period (T) was divided into $k \geq 5$ periods ($C_1, \ldots, C_k$) and that random samples ($V_1, \ldots, V_k$) of equal size ($m \geq 5$) taken from standard populations ($S_1, \ldots, S_k$), characterizing concrete production in periods ($C_1, \ldots, C_k$) are available.

Problem 1 (Equation 3) is solved as follows. On the significance level ($\alpha = 0.05$), the hypothesis (H)—$\sigma_1^2 = \ldots \sigma_k^2$—is tested against alternative ($\bar{H}$) by asserting that at least two of the variances ($\sigma_1^2, \ldots, \sigma_k^2$) are different. The test is carried out by using the Bartlett formula (1):

$$B = 2.302\,59/\{1 + [(k+1)/3k(m-1)]\} \left[\log S^2 - (1/k)\sum_{i=1}^{k} \log S_j^2\right] \tag{5}$$

where $S_1^2, \ldots, S_k^2$ are variances of random samples ($V_1, \ldots, V_k$),

$$S^2 = (1/k)\sum_{j=1}^{k} S_j^2 \tag{6}$$

Log S_j^2 and S^2 are Briggs' logarithms of S_j^2 and S^2. The value (B) is compared with the critical value [$X^2_{0.05}$ ($f = k - 1$)] of the X^2 distribution with ($f = k - 1$) degrees of freedom. One of the following decisions is made:

1. If $B > X^2_{0.05}$ ($f = k - 1$), the hypothesis (H) is rejected in favor of alternative ($\bar{H}$).
2. If $B \leq X^2_{0.05}$ ($f = k - 1$), the hypothesis (H) is not rejected in favor of alternative ($\bar{H}$). S^2 is then assumed as an impartial estimator of variance (σ^2) i.e., $\sigma_1^2 = \ldots = \sigma_k^2$, i.e., an estimator with $f = k(m-1)$ degrees of freedom.

Problem 2 (Equation 4) is solved as follows. On the significance level ($\alpha = 0.05$), the hypothesis (H)—$\mu_1 = \ldots = \mu_k$—is tested against alternative ($\bar{H}$) by asserting that at least two of the mean values ($\mu_1, \ldots, \mu_k$) are different. The test is carried out by using the following formula:

$$F = \left\{[1/(k-1)]\sum_{i=1}^{k} (\bar{x}_j - \bar{x})^2\right\} \Big/ [S^2/km(m-1)] \tag{7}$$

where $\bar{x}_1, \ldots, \bar{x}_k$ are mean values of random samples ($V_1, \ldots, V_k$),

$$\bar{x} = (1/k)\sum_{j=1}^{k} \bar{x}_j \tag{8}$$

and S^2 is the impartial estimator of variance ($\sigma^2 = \sigma_1^2 = \ldots = \sigma_k^2$) computed by using Equation 6. F is compared with the critical value {$F_{0.05}$ [$f_1 = k - 1$; $f_2 = k(m-1)$]} of the distribution (F) with $f_1 = k - 1$ and $f_2 = k(m-1)$ degrees of freedom.

One of the following decisions is made:

1. If $F > F_{0.05}$ [$f_1 = k - 1$; $f_2 = k(m-1)$], the hypothesis (H) is rejected in favor of alternative ($\bar{H}$).
2. If $F \leq F_{0.05}$ [$f_1 = k - 1$; $f_2 = k(m-1)$], the hypothesis (H) is not rejected in favor of alternative ($\bar{H}$). The value ($\bar{x}$) is then assumed as an impartial estimator of the average ($\mu = \mu_1 \ldots \mu_k$).

Procedure in Case of Rejection of Equality of Mean Values

In solving problem 2, it was necessary at a significance level of $\alpha = 0.05$ to reject the hypothesis (H)—$\mu_1 = \ldots = \mu_k$—in favor of alternative ($\bar{H}$)—i.e., at least two of the mean values $\mu_1, \ldots, \mu_k$ are different. The question arises whether among mean values ($\mu_1, \ldots, \mu_k$) there are not two or more groups of equal mean value.

For the solution, the following procedure is proposed. The mean values ($\bar{x}_1, \ldots, \bar{x}_k$) of the random samples ($V_1, \ldots, V_k$) are arranged according to their magnitude:

$$\bar{x}_1' \geq \bar{x}_2' \geq \ldots \geq \bar{x}_{k-1}' \geq \bar{x}_k' \tag{9}$$

Denote the mean values ($\mu_1', \ldots, \mu_k'$), the estimators of which are the mean values ($\bar{x}_1', \ldots, \bar{x}_k'$). The question is whether the hypothesis (H)—$\mu_A = \mu_1' = \ldots = \mu_i' = \mu_B = \mu_{i+1} = \ldots = \mu_k$—for certain $i = 1, \ldots, k - 1$ should not be rejected in favor of alternative ($\bar{H}$)—$\mu_A \neq \mu_B$. Schaffe (2) has proved the following concerning $\hat{L}_i^2$ values:

$$\hat{L}_i^2 = \{[(\bar{x}_1' + \ldots + \bar{x}_i')/i - (\bar{x}_{i+1}' + \ldots + \bar{x}_k')/(k-1)] \div [\sqrt{(k-1)/m}\, S\sqrt{(1/i) + (1/k)}]\}^2 = \{[k(\bar{x}_1' + \ldots + \bar{x}_i') - i(\bar{x}_1' + \ldots + \bar{x}_k')] \div [\sqrt{(k-1)/m}\, S\sqrt{ik(k-i)}]\}^2 \quad (10)$$

where S^2 is the impartial estimator of the variance ($\sigma^2 = \sigma_1^2 = \ldots = \sigma_k^2$), computed according to Equation 6. For each i = 1, ... k - 1, the values have a distribution (F) with $f_1 = k - 1$ and $f_2 = k(m - 1)$ degrees of freedom. This can be used in the following way. All K_i values are computed by using the following formula:

$$K_i = [k(\bar{x}_1' + \ldots + \bar{x}_i') - 2(\bar{x}_1' + \ldots + \bar{x}_k')]/\sqrt{ik(k-i)} \quad (11)$$

i = 1, ..., k - 1, and the maximum value is chosen from them. This maximum K_i value obviously corresponds to the maximum $\hat{L}_i^2$ value, and so does the maximum F value. This leads to the following conclusion: For i, for which the $\hat{L}_i^2$ value is maximal on the lowest possible significance level (α), it is necessary to reject the hypothesis $H - \mu_A = \mu_B$—in favor of alternative $(\bar{H}) - \mu_A \neq \mu_B$.

By means of this procedure the concrete production in the T time period is divided into two approximately equal normal productions, one of which is characterized by standard population (S_A) of size ($N_A = iM$) with an approximately normal distribution [$N(\mu_A, \sigma^2)$] and the other by the standard population (S_B) of size [$N_B = (k - i)M$] with an approximately normal distribution [$N(\mu_B, \sigma^2)$].

From S_A comes the random sample (V_A) of size (N_A = im), and from S_B comes the random sample (V_B) of size [$n_B = (k - i)m$]. Experience shows that it is usually sufficient to divide the concrete production obtained in period (T) into two approximately normal productions.

Proof may be obtained at a significance level ($\alpha = 0.05$) by using the test described previously and substituting the first time into the numerator of Equation 7

$$(1/i)\sum_{j=1}^{i} (\bar{x}_j' - \bar{x}_A')^2 \quad (12)$$

where $\bar{x}_A = (1/i) \sum_{j=1}^{i} \bar{x}_j'$, and the second time

$$[1/(k-i)] \sum_{j=i+1}^{k} (\bar{x}_j' - \bar{x}_B)^2 \quad (13)$$

where $\bar{x}_B = [1/(k-i)] \sum_{j=i+1}^{k} \bar{x}_j'$. $\bar{x}_A$ and $\bar{x}_B$ are impartial estimators of mean values (μ_A) and μ_B.

Evaluation of Production Quality

In evaluating the quality of both approximately normal lots into which the production obtained in the period (T) was divided, the quantitative method described previously in this paper can be used.

If, in the evaluation, the case ($t_{min} \leq t \leq t_{max}$) occurred, it is proposed that the original value ($P_o = 0.05$ to $P_o' = 0.10$) should be increased and it should be verified whether hypothesis (H)—$P = P_o'$—should be rejected in favor of alternative $(\bar{H})$—$P < P_o'$. If, according to the verification, H should be rejected in favor of $\bar{H}$, one lot of concrete or the other should be considered satisfactory. When H should not be rejected in favor of $\bar{H}$, one lot or the other should be considered unsatisfactory.

STANDARDIZATION OF METHODS

The mode of choice of the physicomechanical concrete properties to be tested and the testing methods and evaluation procedures have not as yet been unified on an international basis. For this reason, any discussion dealing with this problem is welcome because it may accelerate the process of international standardization.

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