Combined methods of determining control measures of concrete quality

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Main specifications are formulated for methods of determining control measures of concrete quality. The expediency of applying combined methods in some cases is substantiated. The known approaches to the application of combined methods are summarized; they arise from the need to upgrade the reliability and accuracy of determining the control measure and to decrease the labour consumption of testing.

1. INTRODUCTION

The possibility of using combined methods, particularly to determine concrete quality, has been known for a long time [1-6]. Some experts note the efficiency of utilizing combined methods, while others consider that the use of combined methods may not be economically justified. The present paper is an attempt to analyse the efficiency of utilizing combined methods to determine the concrete quality measures.

2. GENERAL

2.1 Terms and definitions

Concrete properties are its objective features which may be manifested in the course of preparation, storage or performance. An example of a concrete property is its ability to withstand, without failure, a certain force.

A concrete quality measure is the qualitative characteristic of either one or several properties which govern the concrete quality, and which is considered with reference to manufacture and operation conditions. Concrete strength is an example of a concrete quality measure.

A testing method includes rules for applying certain principles and equipment for testing concrete.

Testing data are values of characteristics, test conditions and other parameters, which are required for subsequent processing; these data are to be recorded in the course of testing. For example, in ultrasonic testing of concrete, these data include the transit time of an ultrasonic pulse, path length, concrete humidity etc.

A test result is the evaluation of characteristics of concrete properties, determination of concrete conformity with preset requirements from testing data, and results of analysis. For the above example, a test result means the value of the pulse velocity.

A direct test is a test in which, directly from the experimental data, the value of a concrete characteristic is determined, making use of functional relationships which are adopted for determining this characteristic. For example, when determining the value of compressive concrete strength $f_c$, the breaking force $F$ and specimen cross-section $A$ are measured in the direct test, following which the strength value is calculated from the formula

$$f_c = \frac{F}{A}$$

The meaning of the term 'direct test' adopted in the present study does not coincide with the term 'direct measurement', used in metrology and meaning that a value sought for is found directly from experimental data. Some examples of direct measurement are the determination of specimen mass on equal-arm beam balances and length determination with the use of linear measures.

An indirect test is a test in which, on the basis of a direct test of one concrete characteristic, another characteristic sought is determined from previously obtained relationships. For example, the ultrasonic pulse velocity in concrete has been found in a direct test. At the same time, determination of concrete strength from this characteristic with the use of a correlation relationship is an indirect test.

The accepted meaning of the term 'indirect test' does not coincide with the term 'indirect measurement', used in metrology. The latter means that a value sought for is found on the basis of a known relationship between this quantity and those subject to direct measurement. For example, in this case a traditional determination of concrete mean density by the method of weighing is an indirect measurement, since the value of this quantity is found from measured values of mass and geometric dimensions instead of by direct measurement.

A location (according to BS 1881 [7]) is a region of concrete that is being assessed and that, for practical purposes, is assumed to be of uniform quality.

2.2 Requirements for selection of a method

Thus, the quality control system of concrete mix and concrete measures comprises the following subsystems: assigning the required value of a measure, determining its actual value, assessing by comparing actual and required values, and regulating from control results.
The basis for choosing elements of a system for control of concrete quality measures consists in the provision of its economical efficiency. In all cases, the value of the effect obtained through the system application should exceed the expenses caused by the use of this system.

The method of determining the concrete control measure, proceeding from the need to ensure economical efficiency from its application, should be reliable and precise, with minimum labour consumption, and should be sufficiently rapid.

2.3 Reliability of method

A control measure determination method should be regarded as reliable for a specific production technology (or specific operation conditions) if in its use the relationship between the structure control measure (for example, concrete strength) and its test measure (for instance, rebound number) is not violated by deviations taking place in the specific production process (or changes under these operation conditions). The sense of this determination is explained in Fig. 1. For example, if in a decrease of the control measure from $X_1$ down to $X_2$ point 2 has remained within confidence limits of the ‘test (indirect) measure–control measure’ ($H - X$) relationship, then the method is reliable for specific conditions (Fig. 1a). Otherwise, the method is unreliable (Fig. 1b). The relationship between test and control measures may be expressed by a numerical coefficient as well, e.g. in core testing. An important requirement is that the reliability of the method should be determined in connection with specific conditions.

2.4 Accuracy of method

Under measurement (test or method) accuracy we shall understand the possibility of obtaining, at the preset probability $P_q$ (Fig. 2), a sample average value of concrete measure at an acceptable error between the above sample average and the true average.

The measurement accuracy depends on device and operator errors. The test accuracy is determined by the accuracies of all measurements accomplished in a test and characterizes the accuracy of determining a test (indirect) measure. The method accuracy depends on the test accuracy and sensitivity, $\eta$, of the ‘test (indirect) measure–control measure’ correlation relationship:

$$\eta = \frac{\Delta H / \hat{H}}{\Delta X / \bar{X}}$$

where $\Delta H$ is the variation interval of an indirect measure; $\Delta X$ is the variation interval of a control measure, corresponding to an interval $\Delta H$ from the correlation relationship; $\hat{H}$ is the average value of an indirect measure for the interval $\Delta H$; and $\bar{X}$ is the average value of a control measure for the interval $\Delta X$ (Fig. 3).

With the same accuracy of determining an indirect measure $H$, the highest accuracy of determination of a control measure $X$ is achieved by the use of methods in which the correlation relationship makes an angle of 45° with the $H$ and $X$ axes, i.e. in the equation $X = a_0 + a_1 H$, $a_1 = 1$ (Fig. 3a).

An increase in method accuracy consists in a decrease of the region within confidence limits of the correlation.