



Standard Practice for Determining Variability of Ingredients of Concrete From a Single Source¹

This standard is issued under the fixed designation C1451; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This practice covers a procedure for determining the variability of properties of concrete materials from a single source. It includes recommendations on sampling, testing, analysis of data, and reporting.

1.2 The system of units for this practice is not specified. Dimensional quantities in the practice are presented only as illustrations of calculation methods that are applicable independent of the system of units.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:²

C109/C109M Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)

C125 Terminology Relating to Concrete and Concrete Aggregates

C219 Terminology Relating to Hydraulic Cement

C494/C494M Specification for Chemical Admixtures for Concrete

C917 Test Method for Evaluation of Cement Strength Uniformity From a Single Source

D75 Practice for Sampling Aggregates

D3665 Practice for Random Sampling of Construction Materials

3. Terminology

3.1 Definitions:

¹ This practice is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.94 on Evaluation of Data (Joint C09 and C01).

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.1.1 For definitions of terms relating to this practice refer to Terminology C125 and Terminology C219.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *grab sample, n*—a specified quantity of material obtained in a single operation from a sampling unit.

3.2.1.1 *Discussion*—The goal of procuring a grab sample is to obtain a small portion of material that is characteristic of that in the sampling unit.

3.2.2 *lot, n*—a user-defined quantity, typically representing any amount of material for which variability information is to be calculated.

3.2.2.1 *Discussion*—The minimum lot size is generally the amount of material in a single conveyance, such as a truck load, a rail-car load, or a barge load. At the other extreme, a lot might be defined by a user as the total amount of material used in a single construction or by a supplier as the amount of material produced over a given interval of time.

3.2.3 *sampling unit, n*—amount of material from which a grab sample is taken.

3.2.3.1 *Discussion*—Generally a lot is subdivided into sampling units, and then sampling units are chosen at random for taking of grab samples. The size of the sampling unit is user-defined, depending on the purposes of the evaluation. The term *sub lot* is sometimes used to define this concept.

4. Significance and Use

4.1 This practice provides a systematic procedure for sampling and determining the variability of user-selected properties of ingredients of concrete. Results derived from application of the practice are generally intended for information only and are not requirements of any existing ASTM specification on concrete or concrete materials. A concrete materials specification may make reference to this practice as a means of obtaining variability information, but needs to define the properties to be measured and the lot size and sample unit to be used. The practice is applicable to both producers of concrete materials and to consumers of concrete materials, although details of application of the practice may vary, depending on the intended purpose of the user of the practice.

4.2 The procedure is applicable to any quantitative property of any concrete ingredient that can be measured by a standard

*A Summary of Changes section appears at the end of this standard

test method. The procedure is based on grab samples, which will tend to show the maximum amount of variation in the selected material property. The procedure is useful if grab samples are obtained from sampling units that are being delivered to the user of a material and better represents the variability of the material used in concrete production compared with testing on the material for specification compliance. The procedure was developed for application to materials from a single source, but it can be applied to a materials delivery stream from more than one source, depending on the purposes of the user of the practice. Variations among test results are corrected for testing error, therefore giving an estimate of the variability of the selected material property. The variability of the selected material property provides the user with one indicator of the source variation of the concrete ingredient.

4.3 Although variability in properties of concrete materials can be a significant cause of variability in concrete properties, this practice does not purport to give information on this relationship. This practice does give information on variability of ingredients from which the user can, along with supplementary information or correlative testing of concrete properties, develop quantitative estimates of the effects.

5. Sampling

5.1 The sampling plan underlying the analysis of variability is critical to the interpretation of results. The sampling plan will vary, depending on the details of concrete materials supply and user-defined purpose of the evaluation. The sampling plan should, at a minimum, address the lot size and sampling frequency, location and procedure of sampling from sampling unit, and handling of samples. The required sampling frequency depends on how the data are being used and the nature of the material being evaluated. All sampling is to be performed by personnel specifically trained for this purpose. The sampling plan should be described in the report (Section 8).

5.2 The first step in determining the sampling plan is to define the objective and scope of the evaluation. This requires considerable experience and knowledge of details involved with the particular production under evaluation. The objective and scope of the evaluation may vary between users and producers of materials. It may also range from determining the variability of materials during a relatively small production period to covering a very long production period. If there is no prior knowledge of the variability of a material property, or if it is suspected that the material might show considerable variation, a relatively intense sampling plan might be designed initially. If prior knowledge indicates that the material property is relatively stable, then a less intense sampling plan might be designed.

5.3 The second step is to define the size of the *lot* and the size of the *sampling unit* (see 3.2). Typically a lot is divided into a number of sampling units; then sampling units are selected at random for the taking of grab samples. Typically, the number of sampling units is larger than the number actually sampled, although for small lot sizes, the number of sampling units may equal the number of samples being taken. Alternatively, sampling may be performed on a time-based frequency.

5.4 Take random grab samples from a point in the storage and handling process of the material that will accurately reflect the variability of the material as it will be used in concrete. Practice D3665 provides general guidance. Additional guidance for specific materials is listed in 5.4.1 – 5.4.4. Identify samples by the date on which the material was shipped or received, its source, and designated type and applicable specifications.

5.4.1 Sample cement in accordance with Test Method C917.

5.4.2 Sample fine and coarse aggregates in accordance with Practice D75.

5.4.3 Sample chemical admixtures in accordance with Specification C494/C494M.

5.4.4 Sample pozzolan or slag cement in accordance with Test Method C917.

6. Procedure

6.1 *Total Variation*—Test all samples in accordance with the appropriate ASTM Test Method for the particular property being measured. Choose a property that is expected to have a significant influence on concrete performance, and choose a test method that has good precision so that the material variability is not masked by the testing error. It is also advisable to select a method that does not incur significant cost and is conducted frequently so the operators are proficient with the procedure. Variation within a single source is estimated by first calculating total variation from test data on grab samples, and then correcting this by subtracting variation inherent in the test method (testing error). Best results are obtained if all tests are conducted in the same laboratory, but guidance is provided if it is necessary to use data from more than one laboratory. Calculate the total variation among the samples, as directed in 7.1.3. The total variation includes testing error.

6.2 *Testing Error*—Testing error comprises components due to within-laboratory variation and between-laboratory variation. If results are obtained from only one laboratory, then between-laboratory variation makes no contribution. If data are obtained from more than one laboratory, it is preferable to keep data from each one separate during data analysis, pooling estimates of variation at the end of the analysis.

6.2.1 To estimate within-laboratory testing error, duplicate tests made from a single sample are required. Samples from different days must be tested in duplicate until at least ten samples have been tested in duplicate. The frequency of duplicate tests initially should be at least once in five samples and not less frequently than once per month. Calculate the testing error standard deviation and the coefficient of variation from duplicate tests conducted in each laboratory, as outlined in 7.1.4.

6.2.2 If the testing error exceeds the single laboratory precision (1s or 1s%) reported in the precision statement for the applicable test method, but is less than 1.5 times this value, continue duplicate tests at this same frequency. If the testing error is equal to or less than the testing error reported in the precision statement, reduce the frequency of duplicate testing. If the testing error exceeds 1.5 times the testing error reported in the precision statement, the data are of unacceptable precision, and the laboratory procedure and equipment should

be thoroughly examined. Use the results of duplicate tests, indicating acceptable precision, to estimate the within-laboratory testing error for all other types of similar materials tested in that laboratory during the same period of time.

6.2.3 When two or more laboratories are used to evaluate the variability of a source, then additional tests of a standard sample or exchanged portions of the same sample may be necessary to determine differences in testing that are likely to be obtained in the different laboratories. When two laboratories exchange portions of the sample and run single tests, results from the laboratories shall not differ by more than the multi-laboratory precision (d2s or d2s% value). If a larger number of samples are exchanged, then the difference between laboratories should not exceed the d2s or d2s% more than 5 % of the time.

6.3 *Single-Source Variation*—Calculate single-source variation according to 7.1.5.

7. Calculation

7.1 The calculations shall include the following:

NOTE 1—Standard deviation can be calculated by other methods that are available in MNL 7.³ Electronic calculators and spreadsheets are available for obtaining the average and sample standard deviation directly after entering the test results.

7.1.1 *Average of All Test Results*—Calculate the average of all test results during the report period using Eq 1. Use only the first test result from each sample that is tested in duplicate.

$$\bar{x} = \frac{x_1 + x_2 + \dots + x_n}{n} \quad (1)$$

where:

$\bar{x}$ = average of all test results,
 $x_1, x_2, \dots, x_n$ = individual determinations, and
 n = number of individual determinations.

7.1.2 *Moving Average*—After five test results are obtained, begin to calculate the moving average of the five most recent results using Eq 2. Update the moving average by adding the most recent test result and deleting the oldest previous test result.

$$\bar{x}_5 = \frac{x_{i-4} + x_{i-3} + x_{i-2} + x_{i-1} + x_i}{5} \quad (2)$$

where:

$\bar{x}_5$ = moving average of five consecutive test results, and
 x_i = the most recent of five consecutive test results.

7.1.3 *Total Standard Deviation*:

$$s_t = \sqrt{\frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \dots + (x_n - \bar{x})^2}{(n - 1)}} \quad (3)$$

where:

s_t = total standard deviation in units of measurement.

7.1.4 *Testing Error*:

7.1.4.1 The standard deviation for testing error is calculated as follows (See Note 2):

$$s_e = \sqrt{\frac{\sum d^2}{2k}} \quad (4)$$

where:

s_e = standard deviation for testing error estimated from tests of duplicate determinations made in a single laboratory from different samples,
 d = difference between duplicate determinations for each sample, and
 k = number of sets of duplicate determinations.

NOTE 2—Table 1 is an example of test results obtained from duplicate tests on 10 samples.

7.1.4.2 If the precision of the test method is stated in terms of a coefficient of variation, calculate the coefficient of variation for testing error as follows:

$$CV_e = \frac{s_e}{\bar{x}_d} \quad (5)$$

where:

CV_e = coefficient of variation for testing error estimated from duplicate determinations made in a single laboratory, and
 $\bar{x}_d$ = overall average of duplicate determinations.

7.1.5 *Single-Source Variation*:

7.1.5.1 Variation of material from a single source expressed in terms of standard deviation, corrected for testing error, is calculated as follows:

$$s_c = \sqrt{s_t^2 - s_e^2} \quad (6)$$

where:

s_c = single source standard deviation corrected for testing error.

7.1.5.2 Single-source variation expressed as coefficient of variation (CV), corrected for testing error, is calculated as follows:

$$CV_c = \frac{s_c}{\bar{x}} \quad (7)$$

7.1.5.3 If data are collected from two laboratories, calculate the single source variation for each laboratory using Eq 6. Calculate the pooled single-source standard deviation as follows:

$$\bar{s}_c = \sqrt{\frac{(n_1 - 1)s_{c1}^2 + (n_2 - 1)s_{c2}^2}{n_1 + n_2 - 2}} \quad (8)$$

where:

$\bar{s}_c$ = pooled estimate of single-source standard deviation
 s_{c1} and s_{c2} = standard deviation corrected for testing error from laboratory 1 and laboratory 2, respectively, and
 n_1 and n_2 = number of tests in laboratory 1 and laboratory 2, respectively.

8. Report

8.1 Provide information to identify the material sampled including the following:

8.1.1 Name of manufacturer and location,

³ Manual on Presentation of Data and Control Chart Analysis, MNL7, Committee E11 on Statistical Control, ASTM International, 2010, www.astm.org.

TABLE 1 Example Illustrating Calculation of Testing Error

Date	Sample No.	Test "a," MPa	Test "b," MPa	Average, MPa	d ²
01/06	3	43.9	45.7	44.8	3.24
01/16	6	43.1	41.5	42.3	2.56
01/30	9	41.7	42.2	42.0	0.25
02/05	12	41.5	43.0	42.2	2.25
02/13	15	38.6	37.4	38.0	1.44
02/21	18	37.9	38.1	38.0	0.04
03/04	21	43.6	43.3	43.4	0.09
03/14	24	40.8	41.4	41.1	0.36
03/19	27	43.4	41.7	42.6	2.89
03/27	30	43.8	44.2	44.0	0.16
k = 10			Average, $\bar{x}_d = 41.8$		
					$\sum d^2$ 13.28
Testing Standard Deviation, s_e					0.81
Testing Coefficient of Variation, v_e					1.9 %

8.1.2 Classification or type of material,

8.1.3 Location of sampling,

8.1.4 Laboratory designation,

8.1.5 Period of time represented by the report, and

8.1.6 Description of sampling frequency.

8.2 For ongoing programs, the minimum period covered by the report shall include all tests made in the preceding three months, but in no instances less than that period of time necessary to include 20 consecutive samples.

8.2.1 The report shall not cover a period of time greater than one year or tests of more than 120 samples.

8.3 The report of results shall be either in tabular form or in graphical form at the option of the reporting organization.

NOTE 3—Table 2 is an example of variability test data presented in tabular form, showing the individual test results from each sample and the moving average of the five most recent results. Fig. 1 shows the same data in graphical form. For purposes of analyzing trends, the graphical presentation is recommended.

8.4 Report the results of duplicate tests on the same sample within the period covered by the report. If duplicate tests are made on samples other than those being tested during the same period of time, by the same laboratory, these test results will not normally be reported on a regular basis, but results of such tests will be made available upon request. However, report the standard deviation for testing error.

8.5 The report shall include the following values calculated from the reported data. Each sample shall be represented only by a single result in these calculations. The second of a pair of duplicate test results shall not be included in the overall calculation, but shall be used only to establish testing error.

8.5.1 $\bar{x}$ = the average of all test results (exclude second of duplicate tests on samples),

8.5.2 s_t = the total standard deviation,

8.5.3 s_e = the standard deviation for testing error,

8.5.4 n = the number of samples tested,

8.5.5 s_c = the single source variation expressed in terms of standard deviation corrected for testing, and

8.5.6 x_5 = the moving average of the five consecutive test results.

8.6 If the reporting agency concludes that a consistent change in properties has occurred, at its option, it may

**TABLE 2 Example of Variability Test Report
ABC Cement Inc., Qualitytown, NJ**

Material Tested				Type I Portland Cement			
Sampling Location				Truck loading, Qualitytown			
Tested at				ABC Qualitytown Laboratory			
Dates Represented				January – March, 20XX			
Property measured				28-day strength, Test Method C109/C109M			
Sampling Frequency				10 per month			
Duplicate test frequency				1 in 3			
Average Strength, MPa				41.2			
Total Standard Deviation, MPa, s_t				2.10			
Number of Tests (n)				30			
Testing Standard Deviation, MPa, s_e				0.81			
Number of Duplicate tests (k)				10			
Single Source Standard Deviation, MPa, s_c				1.94			
Single Source Coefficient of Variation, v_c				4.7 %			

Date Shipped	Sample No. ^A	Test "a," MPa	Moving Avg. of 5, MPa	Date Shipped	Sample No.	Test "a," MPa	Moving Avg. of 5, MPa
01/02	1	42.3		02/17	16	43.6	41.1
01/03	2	37.2		02/19	17	39.0	40.6
01/06	3a	43.9		02/21	18a	37.9	39.4
01/08	4	40.8		02/25	19	40.0	39.8
01/14	5	39.5	40.7	02/27	20	39.2	39.9
01/16	6a	43.1	40.9	03/04	21a	43.6	39.9
01/21	7	41.5	41.8	03/07	22	40.8	40.3
01/24	8	43.6	41.7	03/12	23	42.9	41.3
01/30	9a	41.7	41.9	03/14	24a	40.8	41.5
01/31	10	41.9	42.4	03/15	25	39.1	41.4
02/03	11	38.5	41.4	03/18	26	41.0	40.9
02/05	12a	41.5	41.4	03/19	27a	43.4	41.4
02/06	13	44.1	41.5	03/22	28	42.1	41.3
02/07	14	37.9	40.8	03/25	29	43.2	41.8
02/13	15a	38.6	40.1	03/27	30a	43.8	42.7

^A"a" represents samples in which duplicate tests were conducted but only the first result is reported.

Sample Variability Report

ABC Cement Co., Qualitytown, NJ

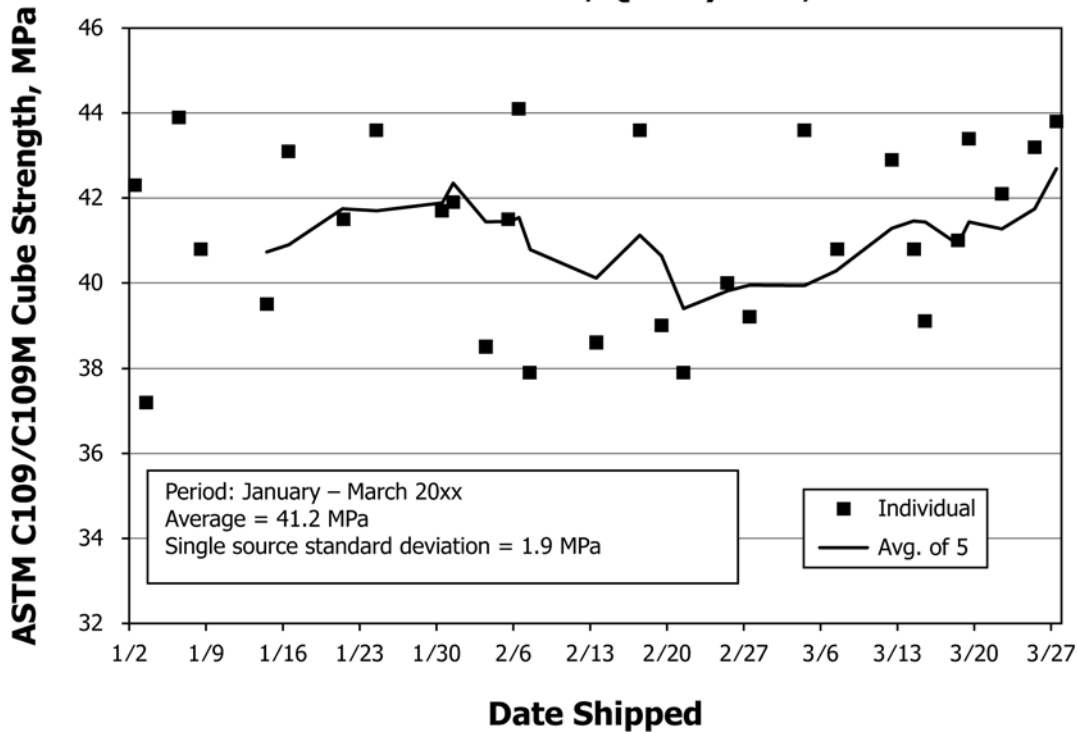


FIG. 1 Plot of Individual Test Results and Moving Average of Five Consecutive Results

discontinue calculation until results from five additional samples have been obtained. In this instance, the values calculated from samples prior to the change shall also be reported.

8.7 When there is a break in the sampling and testing, the sampling dates included in each set of calculated values shall be clearly identified.

9. Keywords

9.1 concrete materials; data analysis; sampling; testing error; variability

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this practice since the last issue, C1451–05, that may impact the use of this practice. (Approved July 1, 2011)

- (1) Removed references to Descriptive Nomenclature C294 and Descriptive Nomenclature C638.
- (2) Deleted 2.2 and moved the cited reference into a footnote.
- (3) Replaced the term “uniformity” with “variability” throughout.
- (4) Revised 1.2 to indicate that this practice does not specify a system of units.

- (5) Added the term **grab sample** to the Terminology section.
- (6) Extensive revisions were made in Sections 4 – 8; specifically, revisions were made to 4.2, 5.1, 5.3, 6.1, 6.2.1, Note 1, 7.1.1, 7.1.2, 7.1.3, 7.1.4.1, Note 2, 7.1.4.2, 7.1.5.1, 7.1.5.2, 7.1.5.3, Note 3, 8.5.1, and 8.7.

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