Designation: C1067 – 12

Standard Practice for Conducting a Ruggedness Evaluation or Screening Program for Test Methods for Construction Materials[1]

This standard is issued under the fixed designation C1067; 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 evaluating the ruggedness of a test method by determining the effects of different experimental factors on the variation of test results. The procedure is intended for use during the development of a test method before the interlaboratory study is executed, such as those described in Practices C802 and E691.

1.2 This practice covers, in general terms, techniques for planning, collecting data, and analyzing results from a few laboratories. Appendix X1 provides the details of the procedure with an example and Appendix X2 provides additional information on the methodology.

1.3 The practice is not intended to give information pertinent to estimating multilaboratory precision.

1.4 The system of units for this practice is not specified. Dimensional quantities in the practice are presented only in illustrations of calculation methods.

1.5 *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]

C670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
C802 Practice for Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods for Construction Materials
E456 Terminology Relating to Quality and Statistics
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E1169 Practice for Conducting Ruggedness Tests

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of statistical terms used in this standard, refer to Terminology E456.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *determination, n*—numerical value of a characteristic of a test specimen measured in accordance with the given the test method.

3.2.2 *effect, n—of a factor*, the difference in the measured characteristics at each level of a factor averaged over all levels of other factors in the experiment.

3.2.3 *factor, n*—a condition or element in the test procedure or laboratory environment that can be controlled and that is a potential source of variation of determinations.

3.2.4 *level, n*—the value or setting of a factor associated with a determination.

3.2.5 *replication, n*—the act of obtaining, under specified conditions, two or more determinations on identical specimens.

3.2.5.1 *Discussion*—Replicate determinations are typically required to be obtained by the same operator, using the same apparatus, on specimens that are similar as possible, and during a short time interval.

3.2.6 *ruggedness, n*—the characteristic of a test method such that determinations are not influenced to a statistically significant degree by small changes in the testing procedure or environment.

3.2.6.1 *Discussion*—Statistical significance is evaluated by comparing the observed variation due to a factor to the expected variation due to chance alone.

3.2.7 *screening, n*—a planned experiment using a low number of determinations to detect among many factors those that have a significant effect on variation of determinations compared with chance variation.

3.2.7.1 *Discussion*—In this practice, the influence of seven factors is evaluated using a replicated set of eight determinations, that is, a total of 16 determinations.

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[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.

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

4. Summary of Practice

4.1 The practice requires that the user develop, from theoretical or practical knowledge, or both, a list of factors that plausibly would cause significant variation in test results (determinations) if the factors were not controlled. The technique is limited to the analysis of the effects of seven factors and requires ⅛ of the determinations that would be required to evaluate seven factors in a full factorial study. Procedures exist for analysis of smaller and larger numbers of factors (see Guide E1169), but seven is a convenient number for many test methods for construction materials. The seven-factor analysis requires 16 determinations by each laboratory. The procedure can be executed usefully by a single laboratory, but sometimes additional information can be obtained if it is repeated in one or two additional laboratories.

4.2 The procedure requires that two levels of each factor be identified, and 16 determinations be obtained with prescribed combinations of factor levels. The levels assigned to a factor may be quantitative or qualitative (for example, 20°C versus 25°C or brass versus steel).

4.3 After data are acquired, a statistical procedure is applied to establish which of the factors under study have a statistically significant effect on test results.

5. Significance and Use

5.1 The purpose of a ruggedness evaluation, or screening program, is to determine the sensitivity of the test method to changes in levels of pertinent operating factors using a small number of tests. Normally, operating conditions for a test method are defined along with allowable tolerances. A ruggedness analysis determines the effect of "worst-case" variation in operating conditions within the specified tolerances. If the ruggedness evaluation indicates high variation (poor precision), the method can be revised with smaller tolerances on operating conditions to improve the precision.

5.2 This practice evaluates the effects of seven factors using eight treatments. The disadvantage of this approach is that it only estimates the main effects of the factors and does not detect the effects of interactions among factors. For this reason, this is a screening program and additional investigation is required to investigate whether there are interaction effects.

5.3 A major reason for poor precision in test methods is the lack of adequate control over the sources of variation in testing procedures or testing environments. These sources of variation often are not controlled adequately because they were not identified during the development of the test procedures as having a large effect on the determinations. This practice provides a systematic procedure to establish the required degree of control for different testing parameters.

5.4 All new test methods must be subjected to an interlaboratory program to develop a precision and bias statement. These programs can be expensive and lengthy, and the result may show that the method is too variable and should not be published without further revision. Interlaboratory studies may give the subcommittee an indication that the method is too variable, but they do not usually give a clear picture of the causes of the variation. Application of this practice using one or two laboratories before finalizing the test method and conducting the interlaboratory study is an economical way to determine these causes.

5.5 Many existing test methods were developed before there was a requirement for precision and bias statements. Since this became a requirement, most of these test methods have developed precision and bias statements, and the result is that many have been found to suffer from relatively large amount of variation. This practice provides a relatively simple and economical way to investigate the causes of variation in test methods, so that a subcommittee will have some guidance as to which parts of the test method need to be revised.

5.6 The procedure can be used for a screening program within a single laboratory, but involvement of at least three laboratories is recommended, particularly if the single laboratory were to be the one that developed the test method. This is particularly important for new test methods. The originating laboratory is so much a part of the development of the test method that it is difficult for it to be objective in spotting any problems in the clarity of the test method directions. Two additional laboratories will probably contribute fresh critical review of the validity of the test method and provide assistance in clarifying the instructions of the test method when needed. This practice, however, is not intended to provide information on multilaboratory precision, but it does provide some information on single-operator precision, which could be used to develop a temporary repeatability statement until the interlaboratory study is completed.

6. Materials

6.1 The number and types of material shall cover the range of material properties to which the test method is applicable. The test method may not apply to material types or property values outside the range evaluated. Three to five materials with different properties will usually be sufficient.

6.1.1 Some preliminary testing may help the laboratories involved determine the materials that will be used in the screening program.

7. Procedure

7.1 Determine the number of laboratories that will participate in the screening program and which materials each will use. The maximum amount of information is obtained if all laboratories include all materials in their part of the program, however, cost can be reduced if each laboratory uses a different material. In this case, caution must be exercised in interpreting the results because laboratory-dependent effects cannot be separated from material-dependent effects.

7.2 Factors that are likely to have the greatest effect on the variability of the determinations are selected for study. Levels of these factors are determined by selecting the minimum and maximum levels that would plausibly occur in the execution of the test method if there were no particular efforts to control them. Levels often represent quantitative factors, such as temperature or pressure, but they may also represent qualitative factors, such as old versus new or wet versus dry. Only two levels are allowed for each factor. In this practice, factors are

TABLE 1 Pattern of Assigning Levels[A] to Seven Factors

Determination Number	Factor						
	A	B	C	D	E	F	G
1 (9)[B]	a	b	c	D	E	F	g
2 (10)	a	b	C	D	e	f	G
3 (11)	a	B	c	d	E	f	G
4 (12)	a	B	C	d	e	F	g
5 (13)	A	b	c	d	e	F	G
6 (14)	A	b	C	d	E	f	g
7 (15)	A	B	c	D	e	f	g
8 (16)	A	B	C	D	E	F	G

[A] Lower case letter indicates one level for the factor and upper case letter indicates the other level.
[B] The numbers in parentheses refer to the determinations in replicate set 2.

assigned letter designations, *A* through *G*, and the two levels of each factor are designated with upper and lower cases of these letters, as shown in Table 1.

NOTE 1—In textbooks dealing with design of experiments, factor levels are often denoted with plus (+) and minus (-) signs.

7.3 Assign combinations of factor levels to each determination according to Table 1. The eight determinations will be replicated; therefore, the full study on each material will require 16 determinations. Run the 16 determinations in random order.

7.4 To analyze the results, construct a 16 row by 16 column results matrix composed of ±1 values as shown in Table 2. The values in row 1 are all +1. The values in rows 2 to 8 for each replicate set correspond to the high and low settings of the factors as given in Table 1. The pattern in rows 1 to 8 of the first replicate set is repeated for rows 9 to 16 of the second replicate set. For rows 9 to 16 of the second replicate set, the signs are reversed from those in the first set. The various combinations of plus and minus values in Table 2 are applied to the values of the 16 determinations and various sums of the signed determinations are calculated. For each row of Table 2, calculate the *Z* and *W* statistics using Eq 1 and 2.

$$Z_r = \sum_{i=1}^{16} \alpha_{ri} d_i \tag{1}$$

$$W_r = \frac{Z_r^2}{16} \tag{2}$$

where:

r = row number as shown in Table 2, where r = 1 to 16,
i = determination number ranging from 1 to 16,
α_{ri} = +1 or -1 as defined in Table 2 for each row number and determination number, and
d_i = determination number i as defined in Table 1.

7.5 The *Z*-statistic for row 1 (Z_1) represents the sum of the 16 determinations and $Z_1/16$ is the overall average of the 16 determinations. The *Z*-statistics for rows 2 through 8 (Z_2 through Z_8) are related to the effects of each of the seven factors (see Note 2). These values of *Z* represent the differences between the sum of the determinations at the high level of the factor and the sum of the determinations at the low level of the factor. The *Z*-values are divided by eight to obtain the effect of each factor averaged of over the levels of the other factors. For example, $Z_3/8$ is the average effect of factor *B* as it is varied from the low level to the high level.

NOTE 2—A positive value for an effect of a factor means that the response increases as the factor level is changed from its low level to its high level. The opposite is the case for a negative effect. Recall that an effect is the difference between the average of the determinations at the high setting minus the average at the low setting of the factor.

7.6 The *W* values are various mean squares. W_1 is the mean of the square of the sum of all determinations and is not used in this analysis. The values W_2 to W_8 are the mean squares for each factor and are compared with the random error (see Note 3). The *W* values for rows 9 through 16 (W_9 to W_{16}) are used to calculate the error variance (s^2) according to Eq 3 (see Note 4).

$$s^2 = \frac{\sum_{r=9}^{16} W_r}{8} \tag{3}$$

NOTE 3—Appendix X2 provides additional information of the meaning of the term "mean squares."

NOTE 4—The error variance s^2 is the pooled variance of the two replicate determinations for each of the eight conditions.

7.7 To establish whether a factor has a statistically significant effect on the results, compute the *F* statistic for each factor using Eq 4.

$$F_f = \frac{W_r}{s^2} \tag{4}$$

TABLE 2 Matrix of Signs to be Applied to 16 Determinations (d_1 to d_{16}) to Calculate *Z*- and *W*-Statistics

	Sign Applied to Each Determination in Computing Z_i																	
	Eight Determinations for Replicate Set 1								Eight Determinations for Replicate Set 2									
row	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	*Z*	*W*
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Z_1	W_1
2	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	Z_2	W_2
3	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	Z_3	W_3
4	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	Z_4	W_4
5	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	Z_5	W_5
6	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1	Z_6	W_6
7	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	Z_7	W_7
8	-1	1	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	Z_8	W_8
9	1	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	Z_9	W_9
10	-1	-1	-1	-1	1	1	1	1	1	1	1	1	-1	-1	-1	-1	Z_{10}	W_{10}
11	-1	-1	1	1	-1	-1	1	1	1	1	-1	-1	1	1	-1	-1	Z_{11}	W_{11}
12	-1	1	-1	1	-1	1	-1	1	1	-1	1	-1	1	-1	1	-1	Z_{12}	W_{12}
13	1	1	-1	-1	-1	-1	1	1	-1	-1	1	1	1	1	-1	-1	Z_{13}	W_{13}
14	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1	1	-1	1	-1	Z_{14}	W_{14}
15	1	-1	-1	1	1	-1	-1	1	-1	1	1	-1	-1	1	1	-1	Z_{15}	W_{15}
16	-1	1	1	-1	1	-1	-1	1	1	-1	-1	1	-1	1	1	-1	Z_{16}	W_{16}

TABLE 3 Summary of Statistics for Seven Factors and Random Error

Factor	W	F
A	W_2	$F_A = W_2/s^2$
B	W_3	$F_B = W_3/s^2$
C	W_4	$F_C = W_4/s^2$
D	W_5	$F_D = W_5/s^2$
E	W_6	$F_E = W_6/s^2$
F	W_7	$F_F = W_7/s^2$
G	W_8	$F_G = W_8/s^2$
	W_9	
	W_{10}	
	W_{11}	
	W_{12}	$s^2 = \frac{\sum_{r=9}^{16} W_r}{8}$
	W_{13}	
	W_{14}	
	W_{15}	
	W_{16}	

where:

F_f = value of F-statistic for factor f (A through G) for the corresponding row (2 through 8) of Table 2.

Table 3 summarizes the calculations given by Eq 3 and 4.

7.8 An F_f value that is ≥ 5.32 represents a statistically significant effect for factor f at a probability of not greater than 5 % for drawing an erroneous conclusion.

7.9 An example of an analysis of data representing results on 4 materials from 3 laboratories is presented in Appendix X1.

7.10 If desired, one of the alternative methods discussed in X2.5 of Appendix X2 is permitted for determining which factors have statistically significant effects.

8. Keywords

8.1 analysis of variance; precision; ruggedness; screening; test method; variation

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLE OF A RUGGEDNESS PROGRAM

X1.1 This appendix describes the procedure for conducting a ruggedness evaluation using as an example a proposed test method for measuring the viscosity of asphalt. Three laboratories participated in the program.

X1.2 As the first step in the ruggedness evaluation, each of the laboratories critically examined the procedure in the proposed test method. The objectives of the examination were as follows:

1. To determine if the instructions were clear, concise, and complete,
2. To decide which factors were likely to influence test results and therefore should be included in the study,
3. To select materials that covered the range of the property of interest for the range of physical forms of the materials to be tested, and
4. To determine the proper levels to be evaluated for each of the chosen factors.

X1.3 In this example, representatives of the three laboratories, after familiarizing themselves with the proposed test method, met and tried to improve the instructions for the viscosity measurement. They selected factors and levels that they believed could affect the measured viscosities. In a preliminary investigation, one of the laboratories measured viscosity at 24°C, 25°C, and 26°C and found that there was about a 10 % variation with a change of 1°C. This was considered too large so 24.6 and 25.4°C were selected as the lower and upper temperature levels for the ruggedness evaluation. In the same manner, the effects of the other factors were examined and the two levels to be used for each factor were selected. The seven factors selected for the program and their levels are shown in Table X1.1. The levels of the factors were assigned to each of the eight determinations in accordance with Table 1 from the body of this practice. Table X1.2 shows the testing conditions (or treatments) for each of the eight replicated determinations.

X1.4 Four materials were selected to cover the range of viscosities to be measured by the test method. For each testing condition, the viscosities were determined by each of the three laboratories with one replication. Thus each laboratory conducted 16 determinations for each material, for a total of 64 determinations. For each material, the 16 determinations were acquired in random order. This is a critical part of the program to guard against systematic variations in the testing conditions. The tests results, grouped by laboratory, are shown in Table X1.3.

X1.5 After the data were obtained, the results for each laboratory-material combination were analyzed independently. Thus in this program, there are 12 analyses corresponding to each row of data in Table X1.3. To proceed with each analysis, the relevant row of data from Table X1.3 is copied into 16 rows to create a 16 by 16 matrix. Each column corresponds to a determination and the value of that determination is repeated 16 times. The numbers in the matrix are multiplied by the corresponding values of +1 or -1 given in Table 2 in the body of this practice. Table X1.4 is an example of the resulting matrix derived from the data for Material 1 and Laboratory 1 in Table X1.3.

X1.6 After the 16 by 16 matrix with the proper signs applied to each determination has been created, the next step is to calculate the sum of each row, with due regard to sign, to obtain 16 Z-values, which are identified as Z_1 to Z_{16}. Table X1.5 shows the resulting sums for Laboratory 1 and Material 1. The value Z_1 represents the sum of all viscosities and $Z_1/16$ is the overall average viscosity for the laboratory-material combination. The value Z_2 represents the difference between the results at the high level of factor A and at the low level. In this case factor A is temperature, so Z_2 measures the effect of temperature. In the same manner, Z_3 measures the effect of the factor B, the age of the viscometer. The value Z_4 measures the effect of factor C, the vacuum level. The value Z_5 measures the effect of factor D, whether or not the sample is stirred before filling the viscometer. The value Z_6 measures the effect of factor E, whether the viscometer is vertical or slanted slightly. The value Z_7 measures the effect of factor F, the variation of the height of the asphalt when the viscometer is filled. The value Z_8 measures the effect of factor G, the time that the viscometer is kept in the water bath before testing. Each of these Z-values comprises eight determinations at one level of the factor and eight determinations at the other level. Therefore, the effect of a factor is obtained by dividing the corresponding Z-value by eight.

X1.7 The next step in the analysis is to square the Z-values and divide the squares by 16. The resulting values, which are denoted W_1 to W_{16} are various kinds of "mean sum of squares." As far as the ruggedness evaluation is concerned, the values W_2 to W_8 are measures of the variance of the means associated with each factor level. For example W_2 is the variance associated with the average values of the determinations obtained at the high and low temperatures. See Appendix X2 for more discussion on the meaning of the W-values.

X1.8 To determine if a factor has a statistically significant effect, the values of W_2 to W_8 are compared with the error variance (also called the mean square error). The error variance is the within-test variance calculated from the replicate determinations for each of the eight conditions and it indicates the random error associated with the test method. The error variance is obtained by calculating the sum of W_9 to W_{16} and diving by 8 as indicated by Eq 3 in the body of this practice. The calculated values of s^2 for each laboratory-material combination are shown in Tables X1.5-X1.16. If there are duplicate determinations, as is the case in this program, the error variance can also be determined as follows:

$$s^2 = \frac{\sum_{1}^{k} \Delta^2}{2k} \quad \text{(X1.1)}$$

where:

s^2 = error variance or the pooled within-test variance,
Δ = the difference between duplicate determinations, and
k = number of pairs of determinations (k=8 in this program).

X1.9 The final step in the analysis is to compute the F-values for each of the factors by dividing W_2 to W_8 by s^2 as indicated by Eq 4 in the body of the practice. The calculated F-values for each laboratory-material combination are shown in Tables X1.5-X1.16. These values are compared with the critical F-value at a significance level of 0.05 for 1 degree of freedom for the numerator and 8 degrees of freedom for the denominator. The critical value is 5.32. If the calculated F-value for a factor is ≥5.32, the factor has a statically significant effect with no more than a 5 % probability of making the incorrect inference.

X1.10 The calculated F-values that exceed the critical value are shown as bold numbers in Tables X1.5-X1.16. Table X1.17 summarizes the calculated F-values for all factors an all laboratory-material combinations. All F-values that are less than 5.32 are indicated in the table as NS to show that they are not statistically significant, and the corresponding factor does not have a statistically significant effect on the results. The effect of temperature (factor A) was found to be highly significant for every material and every laboratory indicating the importance of tight control of temperature. The effect of variation in the level of vacuum (factor C) showed five statistically significant F-values indicating a need for tight tolerance on the applied vacuum. The effect of the viscometer deviating from the vertical position (factor E) was statistically significant in six of the laboratory-material combinations indicating the need for tight tolerance on the alignment of the viscometer. The other factors showed a scattering of barely significant values, but these were not judged to be of sufficient importance to require tighter controls.

X1.11 Representatives of the three laboratories met after completion of the ruggedness evaluation. After discussion of the results, the decision was made that it was practical and desirable to control temperature, vacuum, and the angle of the viscosity tube to within the following limits:

Temperature: 25.0 ± 0.1°C
Vacuum: 300 ± 2 mmHg
Angle with horizontal: 90.0 ± 1.0°

X1.11.1 With these changes, an interlaboratory study was organized and carried out using the revised test method.

TABLE X1.1 Levels Assigned to Seven Factors

Factor	Level
A: Temperature	a = 24.6°C A = 25.4°C
B: Age of viscometer tube	b = New B = Old
C: Applied vacuum	c = 310 mmHg C = 290 mmHg
D: Stirring sample before charging viscometer	d = No stirring D = Stir for 1 minute
E: Angle of viscometer	e = 87° from horizontal E = 90° from horizontal
F: Height of filling	f = 6 mm (1 mm above line) F = 4 mm (1 mm bellow line)
G: Time viscometer held in bath	g = 40 min (10 min more than specified) G = 20 min (10 min less than specified)

TABLE X1.2 Conditions for Each Determination

Determination Number	Factor *A* Temperature	*B* Viscometer	*C* Vacuum	*D* Stirring	*E* Angle	*F* Fill Height	*G* Time in Bath
1 (9)	24.6°C	New	310 mmHg	1 min	90º	4 mm	40 min
2 (10)	24.6°C	New	290 mmHg	1 min	87º	6 mm	20 min
3 (11)	24.6°C	Old	310 mmHg	No	90º	6 mm	20 min
4 (12)	24.6°C	Old	290 mmHg	No	87º	4 mm	40 min
5 (13)	25.4°C	New	310 mmHg	No	87º	4 mm	20 min
6 (14)	25.4°C	New	290 mmHg	No	90º	6 mm	40 min
7 (15)	25.4°C	Old	310 mmHg	1 min	87º	6 mm	40 min
8 (16)	25.4°C	Old	290 mmHg	1 min	90º	4 mm	20 min

TABLE X1.3 Viscosity Data

Material	Viscosity First Replicate Determination Number								Second Replicate Determination Number							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
								Laboratory 1								
1	2370	2258	2355	2185	1825	1845	1820	1830	2320	2275	2350	2380	1840	1850	1825	1820
2	520	495	519	480	401	404	398	402	492	516	490	522	390	408	402	395
3	4205	4006	4191	3846	3212	3284	3185	3221	4200	4160	4130	4020	3218	3180	3280	3280
4	1075	1061	1060	961	803	793	801	805	1050	1070	1015	1000	808	790	795	805
								Laboratory 2								
1	2350	2240	2335	2165	1805	1825	1800	1810	2280	2310	2400	2120	1825	1806	1809	1812
2	540	515	539	500	421	424	418	422	518	545	524	492	410	425	430	420
3	4235	4036	4121	3876	3242	3314	3117	3250	4250	4142	3960	4205	3310	3112	3240	3117
4	1102	1040	1085	980	820	811	824	828	1110	1125	1040	1050	825	804	816	835
								Laboratory 3								
1	2390	2278	2375	2205	1845	1865	1840	1850	2400	2268	2350	2250	1860	1850	1870	1845
2	510	485	509	470	391	394	388	392	505	482	510	480	395	390	385	392
3	4200	3975	4160	3816	3190	3246	3150	3200	4180	3990	4140	3890	3200	3180	3220	3195
4	1050	990	1035	930	786	766	775	780	1040	980	1050	970	780	760	785	782

TABLE X1.4 Analysis Matrix Based on Applying Signs in Table 1 to Data for Laboratory 1 and Material 1

NOTE 1—The data in Tables X1.5-X1.16 are derived from matrices constructed as illustrated by this table for each of the remaining eleven laboratory-material combinations from Table X1.3.

Row	Replicate 1 d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	Replicate 2 d_9	d_{10}	d_{11}	d_{12}	d_{13}	d_{14}	d_{15}	d_{16}
1	2370	2258	2355	2185	1825	1845	1820	1830	2320	2275	2350	2380	1840	1850	1825	1820
2	-2370	-2258	-2355	-2185	1825	1845	1820	1830	-2320	-2275	-2350	-2380	1840	1850	1825	1820
3	-2370	-2258	2355	2185	-1825	-1845	1820	1830	-2320	-2275	2350	2380	-1840	-1850	1825	1820
4	-2370	2258	-2355	2185	-1825	1845	-1820	1830	-2320	2275	-2350	2380	-1840	1850	-1825	1820
5	2370	2258	-2355	-2185	-1825	-1845	1820	1830	2320	2275	-2350	-2380	-1840	-1850	1825	1820
6	2370	-2258	2355	-2185	-1825	1845	-1820	1830	2320	-2275	2350	-2380	-1840	1850	-1825	1820
7	2370	-2258	-2355	2185	1825	-1845	-1820	1830	2320	-2275	-2350	2380	1840	-1850	-1825	1820
8	-2370	2258	2355	-2185	1825	-1845	-1820	1830	-2320	2275	2350	-2380	1840	-1850	-1825	1820
9	2370	2258	2355	2185	1825	1845	1820	1830	-2320	-2275	-2350	-2380	-1840	-1850	-1825	-1820
10	-2370	-2258	-2355	-2185	1825	1845	1820	1830	2320	2275	2350	2380	-1840	-1850	-1825	-1820
11	-2370	-2258	2355	2185	-1825	-1845	1820	1830	2320	2275	-2350	-2380	1840	1850	-1825	-1820
12	-2370	2258	-2355	2185	-1825	1845	-1820	1830	2320	-2275	2350	-2380	1840	-1850	1825	-1820
13	2370	2258	-2355	-2185	-1825	-1845	1820	1830	-2320	-2275	2350	2380	1840	1850	-1825	-1820
14	2370	-2258	2355	-2185	-1825	1845	-1820	1830	-2320	2275	-2350	2380	1840	-1850	1825	-1820
15	2370	-2258	-2355	2185	1825	-1845	-1820	1830	-2320	2275	2350	-2380	-1840	1850	1825	-1820
16	-2370	2258	2355	-2185	1825	-1845	-1820	1830	2320	-2275	-2350	2380	-1840	1850	1825	-1820