United States Department of Agriculture

Calculating Strength Ratio and Grade Quality Index of Dimensional Lumber Using ASTM D4761 and ASTM D245

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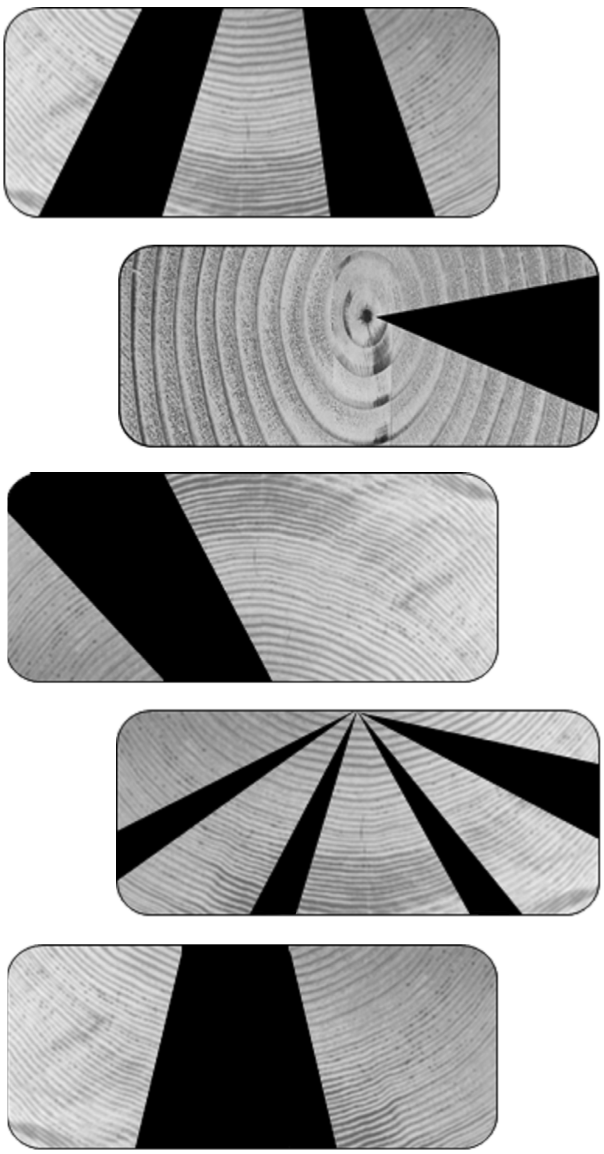

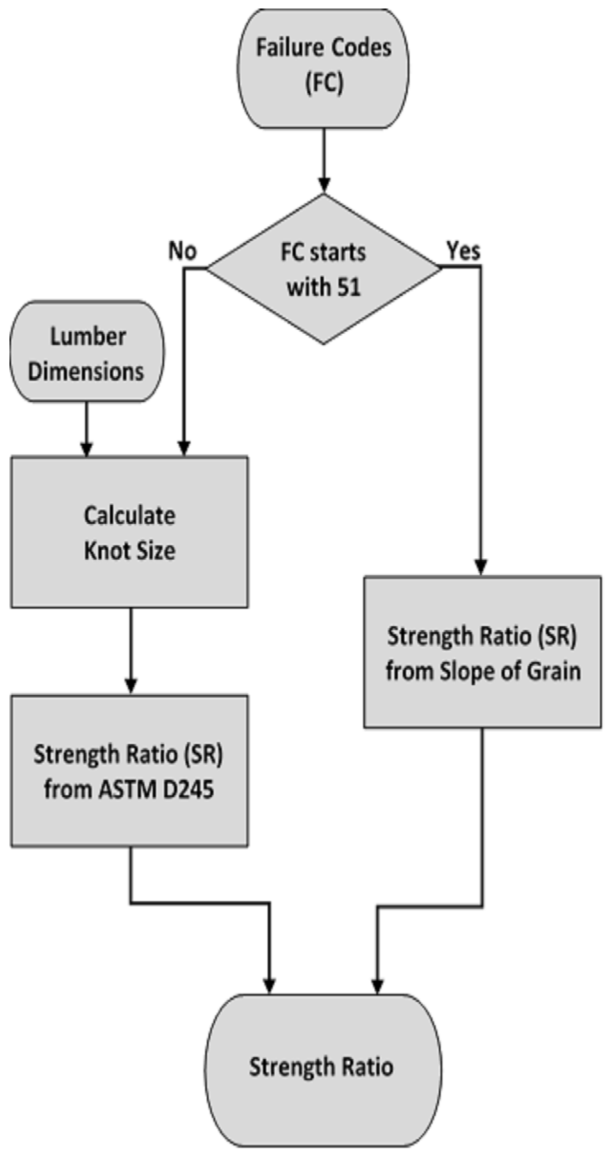

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June 2021

Abstract

The standard for calculating grade quality index (GQI) is a three-step process. First, failure codes are assigned during testing. Second, strength ratios are calculated from failure codes recorded during post-test analysis, not including failure from slope of grain. Third, the lower fifth percentile strength ratio is identified, which is defined as the GQI. In the past, the process of calculating strength ratios required one to correctly interpret and apply calculations per ASTM D4761 (current edition) and ASTM D245 (current edition) or gain remote access to USDA Forest Service, Forest Products Laboratory servers, transfer the failure codes to the servers using file transfer protocol, instruct the resident "SRatio" Fortran program to operate on the transferred files, and then transfer the files back to the local computer. Although the latter yielded consistent and reliable strength ratios, the process was slow and cumbersome and relied upon access to outside computational resources that can now be made available on a local platform. The intended users of this report are those developing design values or performing monitoring programs of dimension lumber. This report describes the process and calculations behind the SRatio program to allow it to be re-created in commonly available applications, such as Excel (Microsoft Corporation, Redmond, Washington, USA). The Excel spreadsheet created and described in this report takes the failure code data from testing and calculates both strength ratios and GQI of the tested lumber samples, which is necessary for determining design values of the tested lumber sample.

Keywords: strength ratios; grade quality index; failure codes GQI; SRatio; computer program; dimensional lumber

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Contents

Conversion table

English unit	Conversion factor	SI unit
inch (in.)	2.54×10^1	millimeter (mm)
Nominal lumber size (in.)		Standard lumber size (mm)
2 by 4 (actual 1.5 by 3.5)		38 by 89
2 by 6 (actual 1.5 by 5.5)		38 by 140
2 by 8 (actual 1.5 by 7.25)		38 by 184
2 by 10 (actual 1.5 by 9.25)		38 by 235

Calculating Strength Ratio and Grade Quality Index of Dimensional Lumber Using ASTM D4761 and ASTM D245

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Introduction

In this report, the process of calculating strength ratios from failure codes recorded during destructive strength testing of dimensional lumber is described. In addition, the process of determining the grade quality index (GQI) of a sample with known strength ratios is described. This report is not intended to provide a full description of the development of design values for lumber; a comprehensive description of that process is given in Evans and others (2001).

The development of design values for dimensional lumber involves several steps. These steps include gathering a representative sample of the lumber grade to be tested, testing the sample to failure, properly recording test results, and, finally, calculating the allowable design values. A part of the test documentation is describing the nature (description and extent) of the failure of individual specimens. A standard set of failure codes is provided in ASTM D4761 (current edition) (ASTM 2018) to aid in the description process.

This report provides a description of those failure codes that have associated strength-reducing characteristics. From these select failure codes, strength ratios are calculated. Strength ratios are approximate ratios of the strength of a piece with the feature described by the failure code and a theoretical piece of lumber devoid of strength-reducing characteristics. The strength ratio is often presented as a percentage. When all the strength ratios from the specimens that make up a sample are calculated, the lower 5th percentile of the strength ratios is determined (for all codes not excluded), which is the GQI for the sample. The rules for determining the applicability of GQI adjustments to a sample are given in ASTM D1990 (current edition) (ASTM 2018). The GQI adjustments are applied to the results (e.g., modulus of elasticity and modulus of rupture) of every specimen in a sample for the specific cell that does not pass the GQI check. A GQI penalty can drastically lower the design values published for lumber in the National Design Specification (NDS) used by engineers in building design. Therefore, the calculations of failure code, strength ratios, and GQI have widespread economic repercussions for the lumber industry. A history of GQI can be found in Kretschmann and Evans (2010).

Background

Relevant ASTM Standards

The process of calculating strength ratio from failure codes and determining the GQI of a sample is described across the current editions of three ASTM standards: ASTM D245, ASTM D1990, and ASTM D4761 (ASTM 2018). The following paragraphs give a brief description of the role each standard fulfills.

ASTM D245 (Current Edition): Standard Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber

This standard describes the basic principles of strength ratio in Section 4. Growth characteristics are described in Section 5. The equations for calculating strength ratio are given in appendix X1 in the back of the standard. The first two digits of the failure code, the failure description “XX”, determine which equation is used to calculate the strength ratio. The last two digits of the failure code, the extent “YY”, provide input into the relevant strength ratio equation along with the specimen thickness or width. All references to ASTM D245 in this report relate to the current edition of the standard.

ASTM D1990 (Current Edition): Standard Practice for Establishing Allowable Properties for Visually Graded Dimensional Lumber from In-Grade Tests of Full-Size Specimens

This standard provides detail on deriving the sample GQI from the specimen strength ratio. Section 3.2.3 defines GQI. Section 8.1 through 8.3.1.2 describes how GQI is determined and applied. Appendix X12 provides a history of GQI, the evolution of its application, and the reasoning behind its usage. The last section of the appendix notes four possible sources of error in determining GQI: measurements, calculations, strength relationships, and resource differences. All references to ASTM D1990 in this report relate to the current edition of the standard.

ASTM D4761 (Current Edition): Standard Test Method for Mechanical Properties of Lumber and Wood-Based Structural Materials

This standard provides information about methodology, collection of data, and data analysis. Appendix X1 describes the recording scheme (i.e., failure coding) for specimen failure. A list of failure codes is given in table X1.1. All references to ASTM D4761 in this report relate to the current edition of the standard.

Failure Type

During post-test evaluation, a specimen failure description that details characteristics present in the failure cross section is needed as per ASTM D4761 appendix X1.1.2. The standard states that the cause of failure is usually associated with a specific characteristic, which is to be recorded in the failure diagraming done after testing. There are six different types of failures that can occur during testing, each with a corresponding code; tension side failure (000), compression side failure (001), combined tension and compression failure (002), lateral buckling failure (003), shear failure (004), grip slip, tension only (005), and failure at edge of grip, tension only (006). Codes 000 through 003 are typically found in bending tests for lumber, whereas codes 005 and 006 are only found during tension testing. Shear failure can occur during both types of tests, although it is not common within bending tests. Although the specimen failure description is not used in strength ratio calculations, it must still be recorded for a more complete data set describing the failure of each sample.

Failure Code

The failure code is four numeric digits in length. The first two digits represent the characteristic that caused the failure and is referred to with the symbol “XX”. The second two digits represent the extent, or size, of the feature and is referred to with the symbol “YY”. A subset of failure code descriptions has been used in the in-grade GQI analysis. Some of the failure code descriptions are non-strength-reducing features, whereas others, such as saw cuts, shakes, splits, timber breaks, and compression wood, have no strength ratio calculations available. Currently, for GQI analysis, only failure codes 11 through 20 (knots), 21 (holes), 34 (distorted grain), and 51 (slope of grain) are used in determining GQI. Any specimen without a strength ratio (i.e., failure characteristics other than those listed) or strength ratio of 100 or greater are removed from the sample for purposes of determining the order statistic, lower 5th percentile value, and GQI. Although this report describes the use of assigned failure codes, it does not describe the process of assigning failure codes.

Calculating Strength Ratios from Failure Codes

Using ASTM D4761, failure code diagrams are drawn for each sample and are used to calculate strength ratios based on the sample’s characteristic (XX) and extent (YY). These codes are then used to determine the specific equation for calculating the strength ratio, as given in the appendix of ASTM D245. The process of deciding which of the equations to employ for which characteristic has been developed through both application of the formalized standard and industry practice. Full descriptions of the formulas used to determine strength ratios based upon failure codes are presented in the following subsections.

The failure code descriptions are given in ASTM D4761, appendix X1, table X1.1. Equations for the strength ratio for knots are presented in ASTM D245, appendix X1, sections X1.2 and X1.3. Both sections contain several equations; the choice of which is dependent upon the width of the lumber and whether the resulting strength ratio is greater than or less than 45%. Table 1 of ASTM D245 is used to calculate the strength ratio for slope of grain.

Failure Codes 11, 12, and 13

Failure codes 11, 12, and 13 represent narrow-face or spike knots that are intergrown, encased, and unsound, respectively. Figure 1 shows an example of a narrow-face knot.

It has been accepted industry practice to convert narrow-face knots to edge-of-wide-face knots for the purpose of calculating strength ratio (Evans and others 2001). The equations used to calculate the strength ratios for this category of failure codes are presented in ASTM D245, appendix X1, section X1.3 (not X1.1, which presents equations for narrow-face knots). The inputs to each strength ratio equation include knot size and actual wide-face width. When section X1.3 is used, the knot size is calculated as a percentage of the wide face covered by the knot as shown in Equation (1). ASTM D4761 requires the extent (YY) to be calculated as a percentage of knot displacement not in knot size in inches as for codes 14-19. As such, the knot size is calculated as

$$\text{Knot size } (k) = \frac{\text{Extent (YY)} \times \text{Actual width of lumber wide face}}{100} \qquad (1)$$

Failure Codes 14, 15, and 16

Failure codes 14, 15, and 16 represent wide-face, centerline knots that are intergrown, encased, and unsound, respectively. Figure 2 shows an example of a wide-face, centerline knot.

The equations used to calculate the strength ratios for this category of failure codes are presented in ASTM D245, appendix X1, section X1.2. The inputs to each equation include knot size and actual wide-face width. The knot size (extent) is recorded as the width of the knot in sixteenths of an inch and is converted to inches as shown in Equation (2).

$$\text{Knot size } (k) = \frac{\text{Extent (YY)}}{16} \qquad (2)$$

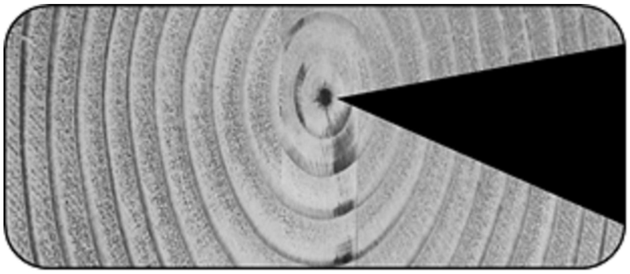

Figure 1. Example of narrow-face knot in dimensional lumber cross section. These knots are identified using failure codes 11, 12, and 13.

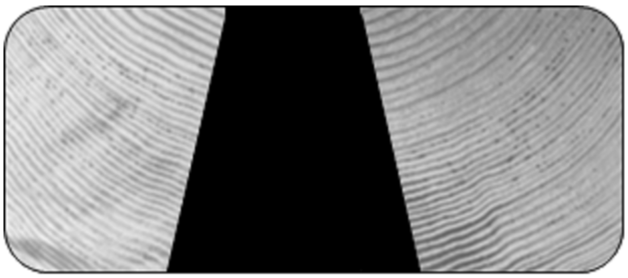

Figure 2. Example of wide-face, centerline knot. These knots are identified using failure codes 14, 15, and 16.

Failure Codes 17, 18, and 19

Failure codes 17, 18, and 19 represent edge-of-wide-face knots that are intergrown, encased, and unsound, respectively. Figure 3 shows an example of an edge-of-wide-face knot.

The equations used to calculate the strength ratios for this category of failure codes are presented in ASTM D245, appendix X1, section X1.3. The inputs to each equation include knot size and actual wide-face width. The knot size is again recorded as the width of the knot in sixteenths of an inch and is converted to inches as shown in Equation (2).

Failure Code 20

Failure code 20 represents knots that are not well spaced or in combinations. Figure 4 shows two examples of knot combinations that would be assigned a failure code of 20.

The equations used to calculate the strength ratios for this category of failure codes are presented in ASTM D245, appendix X1, section X1.2. The inputs to each equation include knot size and actual wide-face width. Because D4761 requires that the extent of the knots be presented as a percentage of the cross section, the knot size is calculated as a percentage of the wide face covered by the knots as shown in Equation (1).

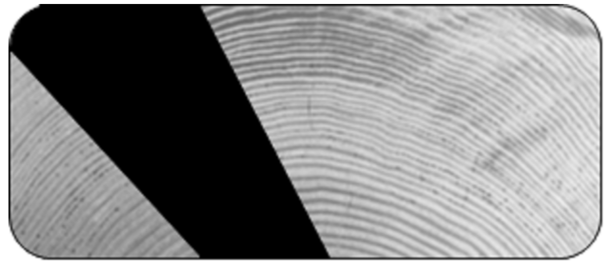

Figure 3. Example of edge-of-wide-face knot. These knots are identified using failure codes 17, 18, and 19.

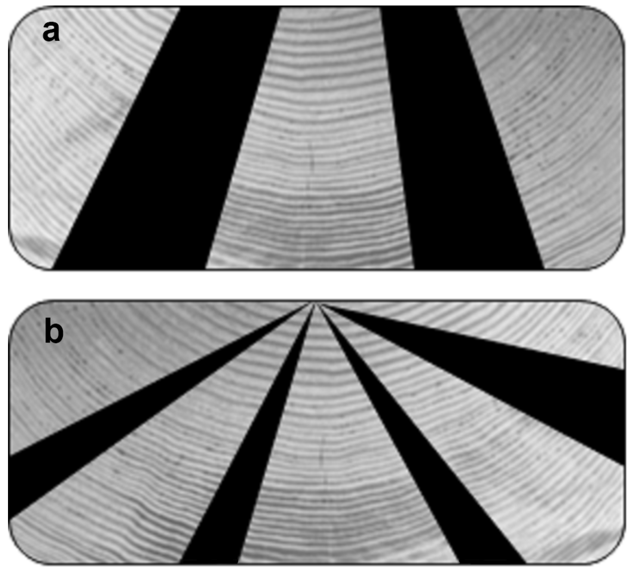

Figure 4. Example of knots that are (a) not well spaced and (b) in combination.

Failure Code 21

Failure code 21 represents a hole. In most cases, a hole is treated as an unsound edge-of-wide-face knot regardless of location. The equations used to calculate the strength ratios for this category of failure codes are presented in ASTM D245, appendix X1, section X1.3. The knot size is the width of the knot in sixteenths of an inch as shown in Equation (2).

Failure Code 34

Failure code 34 represents distorted grain, knot cluster, or burl. The equations used to calculate the strength ratios for this category of failure codes are presented in ASTM D245, appendix X1, section X1.3. The knot size is a percentage of the wide face covered by the knots as shown in Equation (1).

Failure Code 51

Failure code 51 represents slope of grain. Strength ratio for slope of grain is calculated using table 1 of ASTM D245. The strength ratio depends upon the severity of the slope of grain. Table 1 contains the constants used in Equation (3) for calculating the strength ratio for slope of grain. The values presented in Table 1 were determined using a linear regression formula based on data presented in table 1 of ASTM D245 (Evans and others 2001).

$$\text{Strength ratio} = A + B \times \text{Extent (YY)} \tag{3}$$

Table 1—Constants used in slope of grain (SoG) calculation for strength ratios

SoG constants	A	B
18:1 < SoG	–50	7.5
12:1 ≤ SoG < 18:1	36.3	2.7
8:1 ≤ SoG < 12:1	21.0	4.0
SoG < 8:1	1.0	6.5

Grade Quality Index

The GQI is a way to determine if the sample is “on-grade”, meaning the quality of lumber being tested accurately reflects the assumed grade of the test sample. ASTM D1990, section X12.1, states that GQI is meant to ensure that lumber samples (1) represent the quality range expected in production and (2) include pieces representing the maximum knot size and slope of grain described in the grading rules for a specified grade. When lumber design values for lumber from other regions and subregions outside of North America were being proposed, questions arose about how this material would relate to North American practices. In some cases, limited inventory was available for selection of test samples or testing matrixes. Therefore, it was thought necessary to re-examine some of the resource and grade quality assumptions as well as the analysis approaches. There was concern that, because of the lack of a long-established track record of yield and market mixes that was present in North American production, higher grade lumber was likely to be substituted for lower grade pieces during testing to determine lumber design values. This type of substitution would result in artificially elevated design values. GQI was developed and adopted as a form of verification that the test sample was on-grade, was typical of the population, and included pieces with the maximum-sized defects allowed by the grade. Further background and history of GQI is available in ASTM D1990 section X12 and Kretschmann and Evans (2010).

Sensitivity to Small Sample Sizes

GQI is calculated from the strength ratios of the sample. Specimens without a strength ratio or with a strength ratio greater than or equal to 100% are excluded from the determination of GQI. GQI is defined as the value that represents the point estimate of the lower 5th percentile value of the applicable strength ratios, which is the low-end tail of the distribution of values. The tail may contain only a small portion of the overall number of samples. As sample size decreases, the sensitivity of GQI to individual values increases. A single incorrectly recorded failure code has the potential of changing the GQI and altering the design value for the entire sample. For this reason, accuracy and consistency among testing agencies of failure code diagraming and calculating is a high priority. ASTM D1990 X12.5.5 documents problems that can arise when small sample size sets are used to calculate GQI. Information on potential sources of error in measurements, calculations, strength relationships, and resource differences can be found in the appendix of ASTM D1990.

Calculating Grade Quality Index for a Single Cell

A lumber sample of a single species composed of specimens that have the same size and grade is called a cell. Using GQI for verification of whether a sample is on-grade involves two steps. The first step is to compare the calculated GQI (observed GQI) value against the assigned GQI value for the grade. The assigned values for each grade are 45% for No. 2 and 65% for Select Structural (SS), as given in Cheung and Wallace (1989). The rules for comparing the observed GQI with the assigned value are given in ASTM D1990. Adjustment is required if the observed GQI is equal to or more than 7% greater than the allowable limit for the grade. If the observed GQI calculated from the sample is 52% or higher (72% or higher for SS), then GQI adjustment (reduction) is required per Equation (4):

$$\text{GQI factor} = \frac{(\text{Allowable limit GQI} + 5\%)}{\text{Observed GQI}} \tag{4}$$

To determine the GQI of a single cell, the 5th percentile point estimate of the strength ratio values needs to be determined using nonparametric statistics. The values of strength ratios, excluding specimens with strength ratio of 100 and those without a strength ratio, must be ranked and based on the sample size. A nonparametric order statistic provides the estimate of the 5th percentile point estimate. If needed, an interpolation must be done between the two selected values if the order statistic is not a whole number. This method is discussed in ASTM D245 section 4.2.2.

Calculating Grade Quality Index for Combined Cells

There are situations in which the GQI of multiple cells must be considered simultaneously. This is the case when developing design values for a new species. During that process, at least three sizes of dimensional lumber and at least two grades of the species must be tested; therefore, a minimum of six cells are tested for a new species (2 grades × 3 sizes = 6 cells). The two grades always tested are SS and No. 2. Other grades may also be tested, but design values for all other grades of a species are typically calculated from the SS and No. 2 values via interpolation (Evans and others 2001, ASTM D1990). If testing is to be performed on more than one width of the same grade, a combined GQI must be calculated. The combined GQI is the unweighted average of the GQI values of the individual cells within a grade. In practice, samples of 2 by 4 and 2 by 6 are always tested and then a third size, either 2 by 8 or 2 by 10, is tested.

If the average GQI of all cells does not exceed 5% over the assigned strength ratio for the grade, then only those cells with GQI values that exceed the allowable limit by 7% or more are adjusted. If the average GQI of all cells exceeds 5% over the allowable limit, then any individual cell with a GQI over 5% of the allowable limit must be adjusted using Equation (4). These rules are described in ASTM D1990 section 8.3.1.2. and are demonstrated in the following four examples. In the first example, assume three samples of No. 2 grade lumber (allowable limit of 45%) have GQI values of 45%, 46%, and 53%. The average GQI of the three samples is 48%. Because the average GQI does not exceed the allowable limit of 45% by more than 5% (i.e., 50% for No. 2, 70% for SS), only those cells that exceed the allowable limit by 7% or more are adjusted. In this case, only the cell with the GQI value of 53% requires adjustment. It is worth noting that any cell that exceeds the allowable limit for the grade by 7% or more will always require adjustment, regardless of whether a single cell is being evaluated or a combined group of cells. In the second example, assume three samples of No. 2 grade lumber have GQI values of 51%, 49%, and 51%. The average GQI of the three samples is 50.3%. Because the average GQI exceeds the allowable limit for the No. 2 grade of 45% by more than 5%, any cell in the group with a value 5% greater than the allowable limit must be adjusted. Both values of 51% must be adjusted. In the third example, assume three samples of No. 2 grade lumber have GQI values of 51%, 49%, and 53%. The value of 53% should immediately be identified as requiring adjustment because it exceeds the allowable limit by 7% or more. The question remains whether other cells require adjustment. The average GQI value is 51%, which exceeds the allowable limit by more than 5%; therefore, the cell with the 51% GQI value must also be adjusted. In the fourth example, assume three samples of No. 2 grade lumber have GQI values of 51%, 45%, and 53%. In this case, the average GQI is 49.7%, which does not exceed the allowable limit by more than 5%. Unlike the third example, the 51% value does not require adjustment. The value of 53% still requires adjustment because it exceeds the allowable limit by 7% or more.

SRatio Program

The purpose of this report is to describe the process of assigning strength ratios from given failure codes and then to use the strength ratios to calculate the GQI. Once known, these steps are easily programmed into a variety of software packages. There are three appendices to this report that describe the SRatio program. Appendix A contains flowcharts describing the functionality of the SRatio program. Appendix B gives the commands to create an Excel spreadsheet that can perform the described steps. Excel from the Office 365 suite of products (Microsoft Corporation, Redmond, Washington, USA) was chosen because it has wide distribution in office environments. The Excel program presented in this report assumes the following pieces of information are known for each specimen of the sample: lumber thickness, lumber width, and failure code. It is assumed that supplied failure codes are four numeric digits in length and conform to ASTM D4761. The program provided calculates a single cell GQI based upon the given inputs. If multiple samples are to be used to calculate a combined GQI, then the provided program can calculate the GQI of the individual cells, but it is left to the user to follow the procedures provided in this report and ASTM D1990 to determine the combined GQI. Appendix C contains an example data set that can be used for verification of a created SRatio program.

Disclaimer

This report is intended to provide a guide and framework for a reader to create a program with the functionality of the SRatio program currently available on USDA Forest Service, Forest Products Laboratory (FPL) servers. Any program created using this report, including the Excel program provided in Appendix B, must be validated prior to use in monitoring or developing design values for dimensional lumber. The authors and FPL make no claim of accuracy in programs created to perform the functions described within this report in a software platform other than Excel from Microsoft Office 365. The authors and FPL are not liable for errors made by the reader in transcribing Microsoft Excel code from this document.

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Appendix A—SRatio Program Flowcharts

In this appendix, flowcharts describing the functions of the SRatio program are given. In Figure A1, an overall program flowchart is shown. User-supplied failure codes are input to the program. If the first two digits of the failure code are 51, then the strength ratio is computed using slope of grain as shown in Figure A2. If the first two digits of the failure code is not 51, then the lumber dimensions are used to calculate the knot size as shown in Figure A3. With the knot size, lumber dimensions, and failure codes, the strength ratio is calculated using the procedures specified in ASTM D245 as shown in Figure A4.

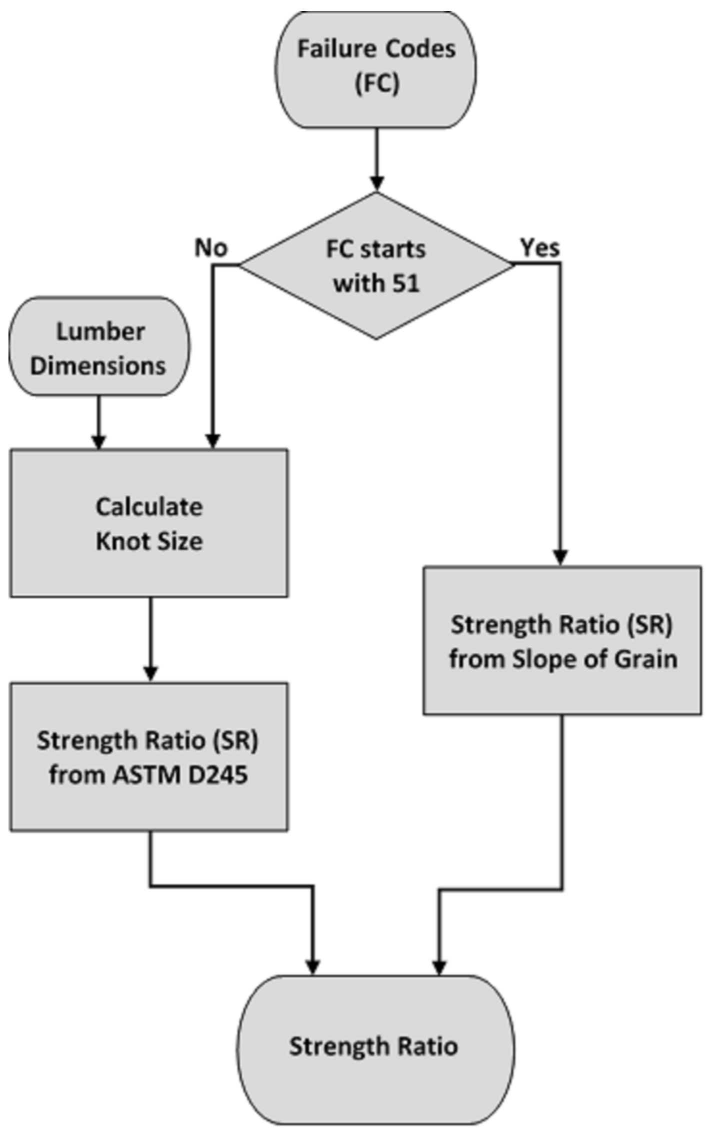

Figure A1. Flowchart showing procedural functions of SRatio program.

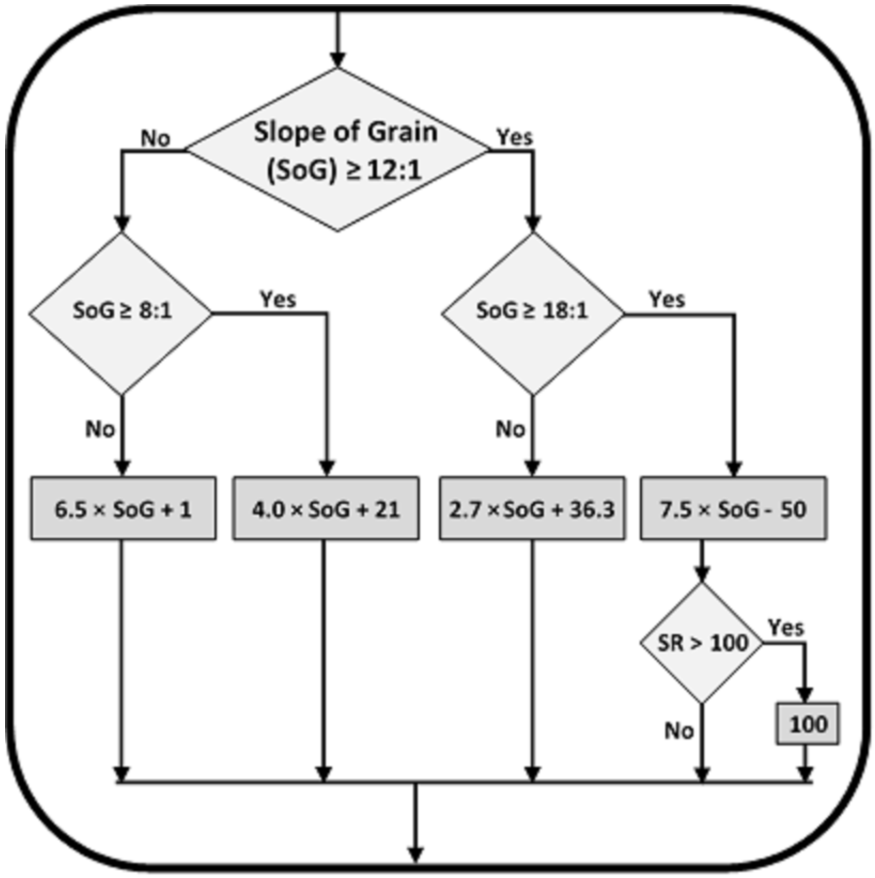

Figure A2. Flowchart showing the calculation of slope of grain.

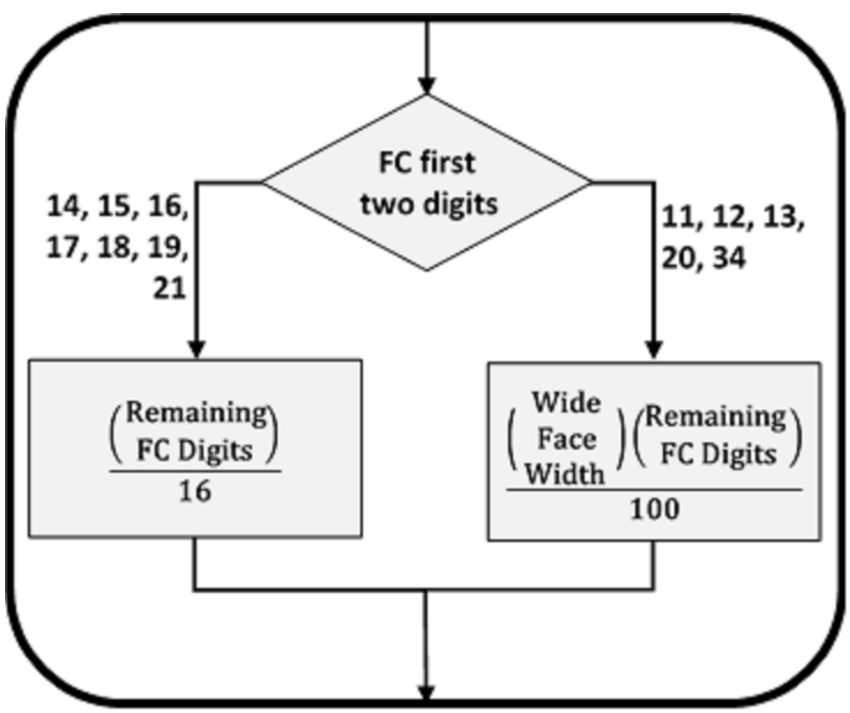

Figure A3. Flowchart showing the calculation of the knot size.

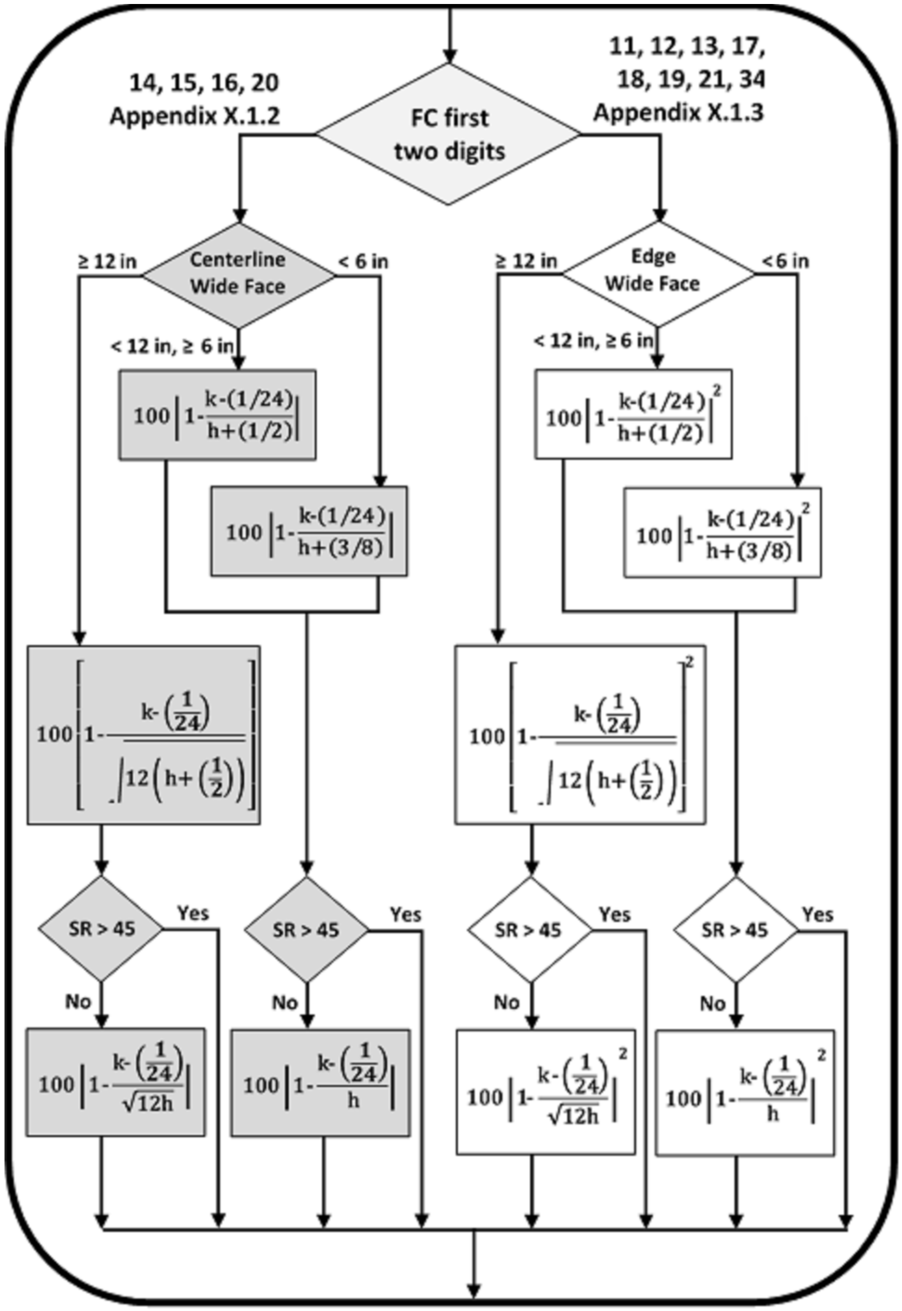

Figure A4. Flowchart showing the calculations of the strength ratios. Variable k is the knot size calculated in Figure A3. Variable h is the user-supplied wide-face width.

Appendix B—Excel-Implemented SRatio Program

The tables in Appendix B give the commands to implement the SRatio program in Excel. It is assumed that the first row of the spreadsheet is reserved for descriptive titles. Therefore, all equations are written such that data begins on the second row.

Table B1 contains the headers for the user inputs. The first column of Table B1 contains the column where the formula should be placed. The second column contains the header that should be placed in the first row of the given column. The third column contains the formula that should be placed in the second row of the given column. For example, in column A, the first row will contain the header text "Specimen ID" and the second row will contain a user-supplied specimen ID. The entries in Table B1 have no formulas because it is assumed that the program user will supply the information from lumber testing.

Table B2 contains headers and associated formulas for 22 calculations needed to calculate the strength ratio for a specimen. Continuing the example above, in column F, the first row will contain the header text "Strength Ratio" and the second row will contain the given formula, "=IF(OR(W2=0,W2>=100)," ",W2)". The equal sign at the start of the formula must be included. The appendix is written such that the reader can copy verbatim the given the formulas into the cell to implement the program.

All 22 formulas from Table B2 are needed to calculate the strength ratio for a single specimen; however, built in Excel functions allow the user to quickly duplicate formulas in the spreadsheet, which greatly reduces the creation process. Duplicating a formula within Excel is accomplished by first highlighting the cell containing the formula. Once the cell is highlighted, the Shift key is pressed. With the shift key pressed, multiple cells can be highlighted. Additional cells are highlighted by continuing to hold the Shift key and pressing the down arrow. When the desired number of cells are highlighted (i.e., a number of rows equal to the number of specimens), the Shift and down arrow keys are released. Excel will fill in the highlighted cells with the formula in the top cell by pressing and holding the Control key and (while still holding the Control key) pressing the D button.

Table B1—User inputs

Column	Header	Data
A	Specimen ID	Specimen ID (supplied by user) (for identification only; not used in calculations)
B	Thickness	Actual thickness of dimension lumber (supplied by user)
C	Width	Actual width of dimension lumber (supplied by user)
D	Type of failure	Type of failure (supplied by user)
E	Failure code	Four-digit failure code (supplied by user)

The formulas in Table B2 use the values given in Table B3 when failure was caused by slope of grain (SoG). The entries given in Table B3 need only be entered once into the spreadsheet; they do not require duplication for the spreadsheet to work. To properly place the entries of Table B3 in the spreadsheet, copy contents from Table B3 into the prescribed row and column. For example, in Row 3 of Column Y, the entry should be "12". The GQI of the tested sample is calculated using the formula in Row 2, Column AC. The formula in that cell is using the values in the range of Column F, Rows 2 through 1,000 to calculate the GQI. The range is specified by the expression, "F2:F1000". The user can change the range by changing this expression. The user should not change the column identifier, F, or the first row identifier, 2. If the user has decided to change the range, then that should be accomplished by changing only the 1,000 value. Blank entries are ignored by the GQI calculation; therefore, the only situation requiring changing the range would be examination of a sample that has 1,000 specimens or more. Samples with less than 1,000 specimens do not require adjustment of the range. The value of 1,000 was chosen arbitrarily as a number likely to exceed most expected sample sizes. It is critical that values within the specified range contain only strength ratios and/or blank cells. The presence of any other numbers or text strings within the range could lead to an erroneous calculation of the GQI value, which may or may not be obvious to the user. Rows 3, 4, and 5 of Column AC should be left blank.

Table B2—Program formulas

Column	Header	Formula
F	Strength ratio	`=IF(OR(W2=0,W2>=100)," ",W2)`
G	Description (XX)	`=IF(LEN(E2)<2,0,VALUE(LEFT(E2,2)))`
H	Extent (YY)	`=IF(LEN(E2)>2,VALUE(RIGHT(E2,LEN(E2)-2)),0)`
I	Knot size (k)	`=IF(OR(G2=11,G2=12,G2=13,G2=20,G2=34,G2=51),C2*(H2/100),0)+IF(OR(G2=14,G2=15,G2=16,G2=17,G2=18,G2=19,G2=21),H2/16,0)`
J	14,15,16,20	`=IF(AND(C2<6,OR(G2=14,G2=15,G2=16,G2=20)),100*(1-((I2-(1/24))/(C2+(3/8)))),0)`
K	11,12,13,17,18,19,21,34	`=IF(AND(C2<6,OR(G2=11,G2=12,G2=13,G2=17,G2=18,G2=19,G2=21,G2=34)),100*(1-((I2-(1/24))/(C2+(3/8))))^2,0)`
L	14,15,16,20	`=IF(AND(C2>=6,C2<=12,OR(G2=14,G2=15,G2=16,G2=20)),100*(1-((I2-(1/24))/(C2+(1/2)))),0)`
M	11,12,13,17,18,19,21,34	`=IF(AND(C2>=6,C2<=12,OR(G2=11,G2=12,G2=13,G2=17,G2=18,G2=19,G2=21,G2=34)),100*(1-((I2-(1/24))/(C2+(1/2))))^2,0)`
N	14,15,16,20	`=IF(AND(C2>12,OR(G2=14,G2=15,G2=16,G2=20)),100*(1-((I2-(1/24))/SQRT(12*(C2+(1/2))))),0)`
O	11,12,13,17,18,19,21,34	`=IF(AND(C2>12,OR(G2=11,G2=12,G2=13,G2=17,G2=18,G2=19,G2=21,G2=34)),100*(1-((I2-(1/24))/SQRT(12*(C2+(1/2)))))^2,0)`
P	51	`=IF(G2=51,IF(H2<$Z$5,$AA$5+($AB$5*H2),0)+IF(AND(H2>=$Y$4,H2<$Z$4),$AA$4+($AB$4*H2),0)+IF(AND(H2>=$Y$3,H2<$Z$3),$AA$3+($AB$3*H2),0)+IF(H2>=$Y$2,$AA$2+($AB$2*H2),0),0)`
Q	10	`=IF(G2=10,100,0)`
R	Initial strength ratios	`=IF(SUM(J2:Q2)>100,100,SUM(J2:Q2))`
S	SR < 45%, h ≤ 12 14,15,16,20	`=IF(AND(OR(G2=14,G2=15,G2=16,G2=20),R2<45,C2<=12),100*(1-(I2-1/24)/C2),0)`
T	SR < 45%, h > 12 14,15,16,20	`=IF(AND(OR(G2=14,G2=15,G2=16,G2=20),R2<45,C2>12),100*(1-(I2-1/24)/SQRT(12*C2)),0)`
U	SR < 45%, h ≤ 12 11,12,13,17,18,19,21,34	`=IF(AND(OR(G2=11,G2=12,G2=13,G2=17,G2=18,G2=19,G2=21,G2=34),R2<45,C2<=12),100*(1-(I2-1/24)/C2)^2,0)`
V	SR < 45%, h > 12 11,12,13,17,18,19,21,34	`=IF(AND(OR(G2=11,G2=12,G2=13,G2=17,G2=18,G2=19,G2=21,G2=34),R2<45,C2>12),100*(1-(I2-1/24)/SQRT(12*C2))^2,0)`
W	Final strength ratios	`=IF(SUM(S2:V2)=0,R2,SUM(S2:V2))`

Table B3—Slope of grain (SoG) constants and grade quality index (GQI) calculations[a]

	Column					
Row	X	Y	Z	AA	AB	AC
1	SoG Failure Code 51	Range low	Range high	Constant	Slope	GQI (text)
2	18:1 ≤ SoG	18	100	–50	7.5	=ROUND(PERCENTILE.EXC(F2:F1000,0.05),1)
3	12:1 ≤ SoG < 18:1	12	18	36.3	2.7	(Empty)
4	8:1 ≤ SoG < 12:1	8	12	21	4	(Empty)
5	SoG < 8:1	0	8	1	6.5	(Empty)

[a]As written, the GQI calculation will include values in column F between rows 2 and 1,000. The value of 2 should remain the same. The user alters the range of values included in the GQI calculation by changing the value of 1,000 to the desired row number.

Appendix C—Verification Data

An example data set is provided in Table C1 to verify the output of the user-made SRatio programs. Each specimen in Table C1 has an associated specimen identification (ID), narrow-face width (Narrow width), wide-face width (Wide width), failure type, failure code, and strength ratio. There are 250 specimens in the sample. When verifying the output of a created SRatio program, the user should enter the ID, narrow width, wide width, failure type, and failure code for each specimen. All failure codes have been verified using an SRatio program created using the formulas and tables given in Appendix B.

Table C1—Spreadsheet strength ratio (SR) verification data (width measurements are in inches (1 in. = 25.4 mm))

ID	Narrow width	Wide width	Failure type	Failure code	SR	ID	Narrow width	Wide width	Failure type	Failure code	SR	ID	Narrow width	Wide width	Failure type	Failure code	SR
1	1.486	3.492	1	2040	65.0	85	1.473	3.503	1	5500	NA	169	1.472	3.486	1	2038	66.8
2	1.505	3.509	1	2039	65.8	86	1.504	3.521	0	2014	88.4	170	1.484	3.495	0	2038	66.8
3	1.484	3.522	1	2030	74.0	87	1.490	3.502	1	2036	68.6	171	1.483	3.486	1	2014	88.4
4	1.491	3.488	0	2034	70.4	88	1.479	3.500	1	1722	38.3	172	1.496	3.528	1	2017	85.7
5	1.494	3.506	0	2030	74.0	89	1.518	3.480	1	2017	85.7	173	1.478	3.483	1	2024	79.4
6	1.476	3.525	0	1000	100	90	1.480	3.490	1	2041	64.1	174	1.509	3.499	0	2022	81.2
7	1.477	3.487	1	2036	68.6	91	1.501	3.525	0	2028	75.8	175	1.479	3.500	0	1000	100
8	1.519	3.504	1	2025	78.5	92	1.508	3.510	1	2033	71.3	176	1.512	3.498	1	1000	100
9	1.501	3.490	0	2025	78.5	93	1.505	3.528	1	2017	85.7	177	1.511	3.508	0	1124	63.0
10	1.498	3.481	1	2020	83.0	94	1.519	3.507	1	2030	74.0	178	1.509	3.515	0	1000	100
11	1.512	3.505	1	2043	62.2	95	1.515	3.523	0	2016	86.6	179	1.484	3.527	1	5108	53.0
12	1.514	3.507	1	2020	83.0	96	1.506	3.525	0	5108	53.0	180	1.477	3.506	1	2015	87.5
13	1.494	3.497	0	2028	75.8	97	1.471	3.484	1	1000	100	181	1.491	3.529	0	1522	65.8
14	1.500	3.501	0	1106	91.5	98	1.512	3.499	1	1118	71.9	182	1.505	3.524	0	2019	83.9
15	1.503	3.520	0	2015	87.5	99	1.482	3.510	1	2031	73.1	183	1.504	3.508	0	1000	100
16	1.520	3.518	0	1000	100	100	1.502	3.489	0	2015	87.5	184	1.496	3.507	0	1000	100
17	1.472	3.506	1	2039	65.8	101	1.504	3.526	1	2029	74.9	185	1.477	3.507	0	1124	63.0
18	1.498	3.492	0	2042	63.2	102	1.485	3.484	0	1000	100	186	1.505	3.502	0	2029	74.9
19	1.483	3.495	0	2023	80.3	103	1.475	3.493	0	2020	83.0	187	1.482	3.491	0	1000	100
20	1.486	3.524	1	2033	71.2	104	1.479	3.483	0	2022	81.2	188	1.500	3.487	1	1000	100
21	1.490	3.526	1	2036	68.5	105	1.493	3.481	1	2011	91.2	189	1.499	3.514	1	1811	69.5
22	1.488	3.500	1	2023	80.3	106	1.500	3.526	1	4211	NA	190	1.504	3.522	1	1000	100.0
23	1.485	3.515	0	1000	100	107	1.474	3.502	0	2039	65.8	191	1.503	3.513	0	519.5	61.0
24	1.508	3.526	0	2023	80.3	108	1.512	3.484	1	2022	81.2	192	1.494	3.529	0	1718	52.2
25	1.474	3.501	0	2017	85.7	109	1.520	3.486	1	2035	69.5	193	1.482	3.494	0	2021	82.1
26	1.488	3.488	1	2013	89.3	110	1.514	3.507	1	2030	74.0	194	1.486	3.492	0	1000	100
27	1.474	3.526	1	1000	100	111	1.512	3.498	0	1000	100	195	1.491	3.519	1	1000	100

Table C1—Spreadsheet strength ratio (SR) verification data (width measurements are in inches (1 in. = 25.4 mm))—continued

ID	Narrow width	Wide width	Failure type	Failure code	SR	ID	Narrow width	Wide width	Failure type	Failure code	SR	ID	Narrow width	Wide width	Failure type	Failure code	SR
28	1.492	3.509	0	2034	70.4	112	1.514	3.517	0	1000	100	196	1.480	3.508	1	4211	NA
29	1.473	3.507	0	1714	61.7	113	1.515	3.492	1	2030	74.0	197	1.502	3.519	1	2019	83.9
30	1.492	3.509	0	1000	100	114	1.499	3.484	1	5108	53.0	198	1.503	3.492	0	1000	100
31	1.500	3.516	0	1805	86.6	115	1.471	3.497	0	1416	75.2	199	1.487	3.500	1	1000	100
32	1.474	3.494	0	2035	69.5	116	1.507	3.505	0	2039	65.8	200	1.502	3.486	0	1718	51.8
33	1.495	3.508	0	1000	100	117	1.489	3.518	0	5108	53.0	201	1.479	3.511	1	1000	100
34	1.508	3.497	0	2027	76.7	118	1.485	3.481	0	2027	76.7	202	1.516	3.521	1	2044	61.3
35	1.475	3.496	0	2022	81.2	119	1.486	3.494	0	1000	100	203	1.485	3.510	1	2043	62.2
36	1.507	3.508	0	2035	69.5	120	1.478	3.510	0	1000	100	204	1.512	3.501	1	2016	86.6
37	1.504	3.497	0	2022	81.2	121	1.477	3.491	0	2025	78.5	205	1.491	3.492	0	1000	100
38	1.500	3.481	0	2025	78.5	122	1.494	3.516	0	2024	79.4	206	1.496	3.520	1	1000	100
39	1.483	3.517	0	2018	84.8	123	1.479	3.528	1	1413	80.3	207	1.510	3.495	1	2019	83.9
40	1.482	3.511	0	2028	75.8	124	1.510	3.495	0	1000	100	208	1.484	3.501	1	1707	80.6
41	1.502	3.528	0	1318	71.9	125	1.498	3.525	0	1709	75.1	209	1.502	3.511	1	1000	100
42	1.502	3.507	1	2013	89.3	126	1.506	3.518	1	2017	85.7	210	1.494	3.494	1	4211	NA
43	1.492	3.494	1	2026	77.6	127	1.489	3.502	1	2050	55.9	211	1.470	3.516	0	2016	86.6
44	1.482	3.500	0	1000	100	128	1.481	3.485	0	4211	NA	212	1.515	3.494	1	2014	88.4
45	1.473	3.514	0	2015	87.5	129	1.511	3.514	1	2033	71.3	213	1.512	3.499	1	2031	73.1
46	1.471	3.504	0	1710	72.2	130	1.504	3.480	0	2021	82.1	214	1.488	3.515	0	1000	100
47	1.516	3.497	0	2019	83.9	131	1.510	3.516	0	2035	69.4	215	1.479	3.493	0	2031	73.1
48	1.478	3.529	1	2020	83.0	132	1.496	3.510	0	2026	77.6	216	1.498	3.508	0	2043	62.2
49	1.519	3.516	1	2026	77.6	133	1.473	3.514	1	2027	76.7	217	1.517	3.502	1	2037	67.7
50	1.498	3.514	0	2022	81.2	134	1.518	3.480	0	2040	65.0	218	1.480	3.499	0	1000	100
51	1.500	3.516	0	2050	55.9	135	1.515	3.510	1	2022	81.2	219	1.481	3.510	1	5108	53.0
52	1.508	3.501	0	2039	65.8	136	1.515	3.508	1	2019	83.9	220	1.520	3.511	0	4211	NA
53	1.474	3.526	0	1000	100	137	1.495	3.490	0	1828	26.1	221	1.491	3.505	0	2022	81.2
54	1.476	3.516	1	1000	100	138	1.497	3.493	0	2023	80.3	222	1.475	3.496	1	4211	NA
55	1.517	3.530	0	2041	64.0	139	1.476	3.481	1	2021	82.1	223	1.475	3.516	1	2031	73.1
56	1.509	3.506	1	1712	66.8	140	1.476	3.504	1	2025	78.5	224	1.487	3.523	1	5110	61.0
57	1.491	3.506	0	1221	67.4	141	1.511	3.490	0	1111	83.1	225	1.495	3.496	1	2021	82.1
58	1.494	3.500	1	3439	38.7	142	1.504	3.481	0	2024	79.4	226	1.513	3.513	0	4211	NA
59	1.495	3.501	0	2034	70.4	143	1.511	3.501	1	2015	87.5	227	1.481	3.521	1	2033	71.2
60	1.502	3.528	0	2028	75.8	144	1.501	3.509	0	2027	76.7	228	1.482	3.480	0	2026	77.6
61	1.516	3.515	1	2030	74.0	145	1.481	3.482	1	1107	89.8	229	1.492	3.506	1	1000	100
62	1.515	3.515	1	2046	59.5	146	1.476	3.510	0	2030	74.0	230	1.481	3.490	0	1000	100
63	1.520	3.511	0	1201	100	147	1.512	3.510	0	2034	70.4	231	1.504	3.516	1	2023	80.3
64	1.473	3.481	1	2047	58.7	148	1.471	3.508	0	2014	88.4	232	1.484	3.517	1	2033	71.3
65	1.479	3.529	0	1408	88.3	149	1.498	3.510	0	1712	66.9	233	1.478	3.495	0	1000	100
66	1.510	3.487	0	1719	49.5	150	1.490	3.499	1	2028	75.8	234	1.491	3.498	1	1000	100

Table C1—Spreadsheet strength ratio (SR) verification data (width measurements are in inches (1 in. = 25.4 mm))—continued

ID	Narrow width	Wide width	Failure type	Failure code	SR	ID	Narrow width	Wide width	Failure type	Failure code	SR	ID	Narrow width	Wide width	Failure type	Failure code	SR
67	1.501	3.483	1	1516	75.2	151	1.519	3.481	0	2024	79.4	235	1.517	3.484	0	2036	68.6
68	1.485	3.494	0	2012	90.2	152	1.498	3.524	1	2032	72.1	236	1.493	3.514	1	1000	100
69	1.505	3.484	1	1107	89.8	153	1.482	3.488	0	1811	69.4	237	1.483	3.492	1	2028	75.8
70	1.518	3.486	0	1000	100	154	1.508	3.493	0	2022	81.2	238	1.495	3.489	0	2035	69.5
71	1.482	3.483	1	2036	68.6	155	1.515	3.508	0	4211	NA	239	1.472	3.509	0	4211	NA
72	1.496	3.481	1	2057	49.6	156	1.519	3.515	0	2033	71.3	240	1.515	3.507	0	2021	82.1
73	1.472	3.494	1	1117	73.5	157	1.496	3.511	0	4211	NA	241	1.479	3.497	1	2029	74.9
74	1.474	3.518	1	1000	100	158	1.478	3.508	1	2044	61.3	242	1.473	3.521	1	1000	100
75	1.477	3.504	1	1408	88.2	159	1.494	3.485	1	1724	33.8	243	1.519	3.498	0	1000	100
76	1.481	3.484	1	2015	87.5	160	1.500	3.507	1	4211	NA	244	1.471	3.487	1	1000	100
77	1.478	3.527	0	1000	100	161	1.509	3.529	1	2013	89.3	245	1.477	3.519	1	2019	83.9
78	1.492	3.498	0	2056	50.5	162	1.478	3.513	0	1000	100	246	1.515	3.489	0	2028	75.8
79	1.476	3.496	0	1000	100	163	1.517	3.482	0	2018	84.8	247	1.517	3.525	0	1410	85.0
80	1.489	3.517	1	2039	65.8	164	1.484	3.509	0	2036	68.5	248	1.478	3.512	0	2028	75.8
81	1.474	3.514	0	2020	83.0	165	1.486	3.526	1	2034	70.3	249	1.493	3.518	0	2043	62.2
82	1.508	3.525	0	1711	69.6	166	1.512	3.502	0	5108	53.0	250	1.500	3.489	0	1720	47.2
83	1.488	3.500	0	2030	74.0	167	1.507	3.484	1	2013	89.3						
84	1.505	3.527	1	2041	64.0	168	1.501	3.513	0	1705	86.6						