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Standard Specification for Establishing and Monitoring Structural Capacities of Prefabricated Wood I-Joists[1]

This standard is issued under the fixed designation D 5055; 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 *General*—This specification gives procedures for establishing, monitoring, and reevaluating structural capacities of prefabricated wood I-joists. Capacities considered are shear, moment, and stiffness. Procedures for establishing common details are given and certain design considerations specific to wood I-joists are itemized.

1.2 *Contents of the Standard*—An index and brief description of the main features of this specification are given in X1.1.1.

1.3 *Development of the Standard*—The development and intent of this specification is discussed in Appendix X1.

1.4 *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.* A specific precautionary statement is given in 6.1.1.5.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 198 Test Methods of Static Tests of Lumber in Structural Sizes

D 245 Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber

D 1990 Practice for Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens

D 2559 Specification for Adhesives for Structural Laminated Wood Products for Use Under Exterior (Wet Use) Exposure Conditions

D 2915 Practice for Evaluating Allowable Properties for Grades of Structural Lumber

D 4761 Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Material

D 5457 Specification for Computing the Reference Resistance of Wood-Based Materials and Structural Connections for Load and Resistance Factor Design

E 4 Practices for Force Verification of Testing Machines

E 529 Guide for Conducting Flexural Tests on Beams and Girders for Building Construction

E 699 Criteria for Evaluation of Agencies Involved in Testing, Quality Assurance, and Evaluating Building Components in Accordance with Test Methods Promulgated by ASTM Committee E06

IEEE/ASTM-S1–10 Standard for Use of the International System of Units (SI): The Modern Metric System

2.2 *Other Standards:*

U.S. Product Standard PS-1 Construction and Industrial Plywood[3]

U.S. Product Standard PS-2 Performance Standard for Wood-Based Structural-Use Panels[3]

CSA O112.7 Resorcinol and Phenol-Resorcinal Resin Adhesives[4]

CSA O151 Canadian Softwood Plywood[4]

CSA O325.0 Construction Sheathing[4]

CSA O452 Design Rated OSB[4]

Lumber Grading Rules Approved by American Lumber Standards Committee (ALSC) or Canadian Lumber Standards Accreditation Board (CLSAB)[5]

3. Terminology

3.1 *Definition:*

3.1.1 *prefabricated wood I-joist*—a structural member manufactured using sawn or structural composite lumber flanges and structural panel webs, bonded together with exterior exposure adhesives, forming an "I" cross-sectional shape. These members are primarily used as joists in floor and roof construction.

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[1] This specification is under the jurisdiction of ASTM Committee D07 on Wood and is the direct responsibility of Subcommittee D07.02 on Lumber and Engineered Wood Products.

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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] Available from APA The Engineered Wood Association, P.O. Box 11700, Tacoma, WA 98411and PFS Research Foundation, 2402 Daniels Street, Madison, WI 53718.

[4] Available from Canadian Standards Association, 178 Rexdale Blvd., Etobicoke, Ontario, Canada M9W 1R3.

[5] Available from American Lumber Standard Committee (ALSC), P.O. Box 210, Germantown, MD 20874. Canadian Lumber Standards Accreditation Board (CLSAB), 1055 W. Hastings St., Vancouver, BC, Canada V6E 2E9.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *capacity (or structural capacity)*—the numeric result of certain calculations specified in this specification.

3.2.2 *design value*—the numeric value claimed by the manufacturer as appropriate for use in structural analysis.

NOTE 1—A brief discussion of this issue is found in X1.9.

3.2.3 *structural composite lumber*—a composite of wood elements (for example, wood strands, strips, veneer sheets, or a combination thereof), bonded with an exterior grade adhesive and intended for structural use in dry service conditions.

4. Design Considerations

4.1 *Design Value Adjustments*:

4.1.1 *Duration of Load*—Prefabricated wood I-joists shall be designed using the strength adjustment for load duration used in sawn lumber. This adjustment is determined in accordance with the section on Duration of Load Under Modification of Allowable Properties for Design Use in Practice D 245.

4.1.2 *Repetitive Members*—The repetitive member factor for prefabricated I-joists shall be taken as 1.0.

NOTE 2—Committee D07 chose to reduce the repetitive member factor to unity primarily for purposes of design simplicity. A discussion of this decision is given in Appendix X1.

4.1.3 *Treatments*—Some pressure treatments affect material strength and the quality of prefabricated wood I-joists. Treated I-joists shall not be used without evaluation of such effects.

4.1.4 *Environment*—The capacities developed in this specification are applicable to joists used under dry conditions such as in most covered structures. Appropriate adjustments for uses in other environments shall be made.

4.2 *Shear Design*:

4.2.1 Neglecting loads within a distance from the support equal to the depth of the member shall not be permitted.

4.2.2 Adjustments to the shear design value near the support or at locations of continuity or where reinforcements are provided must be substantiated by independent testing to the general intended criteria for shear capacity herein.

5. Materials

5.1 *Flange Stock*:

5.1.1 All flange material shall conform to the requirements of 6.3.

5.1.2 End joints in purchased flange stock are permitted provided such joints conform to the general intent and Section 10 of this specification.

5.2 *Web Material*—Panels shall conform to manufacturing or performance standards recognized by the applicable governing code. Examples are U.S. Product Standard PS-1 or CSA O151, and U.S. Product Standard PS-2 or CSA O325.0. In addition, all panels shall meet the equivalent of Exposure I requirements as specified in PS-1 or PS-2.

5.3 *Adhesives*—Adhesives used to fabricate components as well as the finished products shall conform to the requirements in Specification D 2559 (CSA O112.7 in Canada) for use under exterior (wet-use) exposure conditions. Appendix X3 gives additional information and standards that shall be considered when qualifying adhesives and adhesive-bonded materials.

6. Qualification

6.1 *General*—This section describes procedures, both empirical and analytic, for initial qualification of the structural capacities of prefabricated wood I-joists. Qualification is required for certain common details of I-joist application since they often influence structural capacities. All capacities are to be reported with three significant digits. Any time significant changes in joist or application details, manufacturing processes or material specifications occur, qualification is required, as for a new manufacturer or product line.

6.1.1 *Testing*—Qualification tests shall be conducted or witnessed by a qualified agency as defined in 8.1. All test results are to be certified by the qualified agency.

6.1.1.1 *Sample Size*—The number of specimens specified in 6.2, 6.3, 6.4, and 6.5 are minimums. The producer wishing to evaluate the validity of the sample size will find a procedure in 4.7 of Practice D 2915.

6.1.1.2 *Test Specimens*—Materials and fabrication procedures of test specimens shall be as typical of intended production as can be obtained at the time of manufacturing qualification specimens.

NOTE 3—It is desirable to conduct preliminary tests to aid the selection of representative specimens.

6.1.1.3 *Test Accuracy*—Tests in accordance with this specification are to be conducted in a machine or apparatus calibrated in accordance with Practices E 4 except that the percentage error shall not exceed ±2.0.

6.1.1.4 *Test Methods*—Methods generally applicable to the full-section joist tests required herein are in Guide E 529, with the following exceptions: (*a*) the methods are applicable to both qualification and quality control, and; (*b*) load rate shall be as specified in the following sections, and; (*c*) delays between load increments are not required. Required tension and compression tests shall be substantially in accordance with Test Methods D 198 or Test Methods D 4761 with load rates as specified in the following sections. All test report formats and content shall be in keeping with the intended use of the results and be agreed upon by all involved parties prior to the test.

6.1.1.5 *Test Safety*—All full-scale structural tests are potentially hazardous and appropriate safety precautions must be observed at all times. One particular concern is the potential for lateral buckling during full-section I-joist tests and appropriate lateral restraint must be maintained at all times.

6.2 *Shear Capacity Qualification*:

6.2.1 Initial capacity shall be established from either test results or calculations. The equations used for the calculation method shall be confirmed by a test program; the details of which are beyond the scope of this specification. Explanations of the statistics used in the analysis of test results, with an example, are given in Appendix X4.

6.2.2 Factors which influence shear capacity include web type, thickness, and grade; web to flange joint; joint type in web (machined, butted, glued or not, reinforced, etc.). Each combination of these web factors must be tested separately in accordance with 6.2.3, unless the critical combination in a proposed grouping is first established by test. Flange stiffness influences shear strength: if a range of flange sizes is to be used with a given combination of web factors, all sizes must be tested unless all values are to be based on tests with the smallest flange. When a range of species or grades of either sawn or composite lumber is to be grouped, preliminary tests shall be conducted to determine which is critical. Joists with structural composite lumber flanges, such as LVL, must be tested separately from joists with sawn lumber flanges.

6.2.3 For each web factor combination, a minimum of ten specimens shall be tested for each critical joist depth. Critical joist depths are minimum and maximum product depths with approximate 4-in. (102-mm) depth increments between. If the installation of specific reinforcement as defined in the manufacturer's literature is required at a certain depth to maintain product performance in the progression of a series of depths within a combination, the product must be tested at this depth plus the adjacent depth which does not require specific reinforcement.

6.2.4 Specimen length shall be that which usually produces failures in shear and shall not extend past each bearing support more than ¼ in. The bearing length shall be adequate to usually produce shear failure instead of a bearing failure but shall not exceed 4 in. (102 mm), unless justified. There shall be a minimum horizontal distance of 1½ times the joist depth between the face of the support and the edge of the load pad.

6.2.5 On one end of the specimen, a vertical web joint, if used, shall be located approximately 12 in. (305 mm) from the face of the support or ½ the distance between the support and the load pad.

6.2.6 The load shall be applied to the top flange either as a single point load at center span or as two point loads of equal distance from the center span. Load pads shall be of sufficient length to prevent local failure.

6.2.7 The load shall be applied at a uniform rate so that anticipated failure will occur in not less than 1 min.

6.2.8 Any required web reinforcements developed in 6.6.1 shall be installed at supports. When required to prevent failure at a load point, additional reinforcement shall be installed, provided such reinforcement is not wider than the load pad.

6.2.9 Minimum specimen temperature at the time of test shall be 40°F (4°C).

6.2.10 Ultimate load and mode of failure shall be recorded in addition to product and test setup descriptions. If any specimen fail in bending, the data shall be excluded. However, for purposes of evaluating shear capacity, bearing failure is considered a mode of shear failure. Appendix X5 discusses some of the modes of shear failure and offers a possible coding scheme.

6.2.11 The dead load of the specimen is to be included in the ultimate load calculation when specified by the producer.

6.2.12 The mean ultimate shear values shall show logical progression of strength as a function of depth. A linear regression analysis of the mean values shall have a coefficient of determination (r^2) of at least 0.9, or the specified tests of 6.2.3 must be repeated. If the second test set fails to meet the criteria, all depths which have been skipped must also be tested. (A check of the regression criteria is given in X4.4.5.)

6.2.12.1 Data from joist depths where failure is web buckling shall be excluded from the regression analysis, if: (*a*) including the results causes failure to meet the criteria of 6.2.12; or (*b*) the producer determines the reduction in regression line slope is unacceptable. In either case, all depths greater than the shallowest excluded, shall be tested.

NOTE 4—Depending on joist details and material, there will be some depth where web buckling appears as a mode of failure. Further increases in depth will result in consistent web buckling, and at some point ultimate strength will reduce compared to shallower joists.

6.2.12.2 When no more than three depths are to be qualified, the correlation is not necessary, but each depth must be tested.

6.2.13 The shear capacity of the product shall be limited to that calculated by taking into account sample size, test result variability, and reduction factors. Data from tests at different joist depths included in regression analysis are permitted to be combined to obtain a pooled estimate of variability.

6.2.13.1 *Combining Data*—The regression equation from 6.2.12 provides the expected mean shear strength (P_e) for depth (d_i):

$$P_e = A + Bd_i \quad (1)$$

where A and B are intercept and slope of the equation.

6.2.13.2 Where too few depths are involved for correlation in 6.2.12, when the tests fail the regression criteria, or where depths are excluded from the correlation, no combining is allowed and each such depth shall be evaluated separately.

6.2.13.3 The mean and standard deviation of the data from each depth tested are ($\bar{P}_i$) and (S_i). The coefficient of variation is:

$$v_i = S_i/\bar{P}_i \quad (2)$$

Let n_i be the number of tests for each depth (d_i) tested and included in the regression analysis. Then the coefficient of variation in the combined data sets is:

$$v = \sqrt{\frac{\Sigma[(n_i - 1)\, v_i^{\,2}]}{\Sigma n_i - J}} \quad (3)$$

Where J is the number of depths included in the regression analysis and the summation is from $i = 1$ to J.

6.2.13.4 *Shear Capacity*—The shear capacity is calculated as follows:

$$P_s = C\,(P_e - KvP_e)/2.37 \quad (4)$$

where:

K = factor for one-sided 95 % tolerance limit with 75 % confidence for a normal distribution. Values for this factor are given in Appendix X4, Eq X4.20, and Table X4.3.

P_e = ultimate mean shear strength from Eq 1 or the mean of any depth in accordance with 6.2.13.2,

v = coefficient of variation of combined data from Eq 3 or, in accordance with 6.2.13.2, from Eq 2 when any depth is evaluated alone,

C = product of any appropriate special use reduction factors from Appendix X6, and

P_s = shear capacity.

6.2.13.5 When data are combined, the factor K is based on a sample size $N = \Sigma n_i - J$. When the criteria of 6.2.12 are not met and for depths excluded from the regression analysis, then the allowable shear capacity is computed separately for each such depth and is:

$$P_s = C(\bar{P}_i - Kv_i\bar{P}_i)/2.37 \quad (5)$$

and the factor K is for a sample size of n_i. A discussion of the reduction factor (2.37) is given in Appendix X6.

6.3 *Moment Capacity Qualification*—Moment capacity shall be determined either analytically from the characteristics of flange material or empirically from the results of I-joist bending tests. If the empirical method is used to determine moment capacity, one of the methods described in 6.3.3.4 or 6.3.3.5 shall be used.

6.3.1 *Analytical Method*:

6.3.1.1 In this method, the I-joist moment capacity is determined as follows:

$$M_a = K_L F_a A_{net} y \quad (6)$$

where:

K_L = length adjustment factor, computed in accordance with 6.3.1.5. The factor adjusts flange material F_a as a function of joist span and stress. Joist depth, tension test gage length, finger joint spacing, and material or joint variability are utilized in determining K_L,
A_{net} = net area of one flange (excluding areas of all web material and rout),
y = distance between flange centroids (with the rout removed), and
F_a = design flange axial stress, taken as the lower of flange tensile stress adjusted to the reference gage length or end joint tensile stress computed in accordance with 6.3.1.4, or flange compressive stress computed in accordance with 6.3.1.6.

NOTE 5—The assessment of axial stress on the basis of average stress at a given cross section matches committee judgment and experimental evidence based on joists in which the thickness of an individual flange is less than approximately one sixth of the overall joist depth. For joists not meeting this criterion, additional consideration of extreme fiber stresses may be needed.

NOTE 6—The information in this specification is not intended to be limited to the allowable stress design (ASD) format. Provided that appropriate scaling of design values is completed (from ASD to the limit states design (LSD) or load and resistance factor design (LRFD) format) in accordance with applicable standards.

6.3.1.2 *Flange Material Types*—Flange materials fall into one of the following three categories:

(a) Standard Lumber Grades; Standard Lengths—Flanges utilizing nominal 8–ft (2.44–m) and longer sawn lumber of a standard grade permitted by the governing code and graded under standards recognized by American Lumber Standards Committee (ALSC) or Canadian Lumber Standards Accreditation Board (CLSAB). The tabulated allowable tension value, F_t, is assumed to be based on a 12-ft (3.66-m) gage length. End joints, when used, shall be qualified in accordance with 6.4.

(b) Nonstandard Grades; Standard Lengths—Flanges utilizing nominal 8-ft (2.44-m) and longer structural composite or sawn lumber, but not meeting the standard grade criteria of 6.3.1.2 (*a*). Qualification testing and analysis shall be in accordance with 6.3.1.3 and 6.3.1.4. End joints, when used, shall be qualified in accordance with 6.4.

(c) Any Grades; Short Lengths—Flanges utilizing structural composite lumber or sawn lumber in lengths shorter than 8 ft (2.44 m) before end jointing. Qualification testing and analysis shall be in accordance with 6.3.1.3 and 6.3.1.4. Qualification specimens shall be used to establish a characteristic (that is, average) joint spacing as noted in Eq 7. Average joint spacing in individual flanges in the qualification sample shall not be less than 75 % of the established characteristic joint spacing. The characteristic joint spacing established during qualification shall be maintained in subsequent production.

$$L_J = L/N \quad (7)$$

where:

L_J = characteristic joint spacing,
L = total length of flange in the gage length for the qualification sample, and
N = total number of joints in the gage length for the qualification sample.

6.3.1.3 *Tension Tests*—For flange material conforming to 6.3.1.2, (*b*) or (*c*) tension tests parallel to grain shall be conducted on a gage length (distance between grips) of not less than 8 ft (2.44 m) for sawn lumber and 3 ft (0.91 m) for structural composite lumber. When flanges utilize sawn lumber or structural composite lumber less than 8 ft long, the characteristic end joint spacing for the qualification sample shall comply with the provisions of 6.3.1.2 (*c*). Testing speed shall be in accordance with 28.3 of Test Methods D 4761. The minimum sample size shall be 53. The flange material variability (coefficient of variation) and tension gage length shall be reported.

NOTE 7—SPS-4[6] provides alternative methods which comply with the intent of characteristic joint spacing and minimum gage length provisions of 6.3

6.3.1.4 *Capacity*—The tensile capacity shall be the lower 5 % tolerance limit with 75 % confidence, divided by 2.1. The lower 5 % tolerance limit shall be established with 75 % confidence using either parametric or nonparametric procedures; however, if parametric procedures are adopted, an appropriate analysis used to confirm the type of distribution must be presented. Minimal evidence that a distribution fits the data shall consist of a cumulative plot of the data with the chosen distribution superimposed on the data. The latter shall be either a curve as shown in Fig. X4.1 or a linearized plot as shown in Fig. X4.5.

6.3.1.5 The length adjustment factor K_L is the lesser of 1.0 or the value computed as follows:

$$K_L = K_S (L_1/L)^Z \leq 1.0 \quad (8)$$

where:

K_L = length adjustment factor,
K_S = stress distribution adjustment factor (adjusts design flange axial stress (F_a) from full-length constant stress (such as a tension test) to the reference stress condition = 1.15,

[6] National Lumber Grades Authority, SPS – 4 – 2001, Special Products Standard for Fingerjoined Flange Stock Lumber, 2001, New Westminster, BC, Canada.

L_1 = gage length, (in.). For 6.3.1.2 (*a*) utilizing flange stress, L_1 = 144 in. For 6.3.1.2 (*b*) utilizing flange stress, L_1 = distance between tension tester grips. For 6.3.1.2 (*c*) utilizing flange stress, L_1 = distance between tension tester grips. For 6.3.1.2 (*a*) and (*b*) utilizing end joint stress, L_1 = minimum end joint spacing allowed in the I-joist.
L = joist span = 18 times the joist depth (in.), and
Z = exponent for Eq 8 in accordance with Table 1.

NOTE 8—K_L is not intended for use as an adjustment factor for specific application lengths. It is a modifier for assigning design I-Joist moment capacity by depth. See Eq 6.

TABLE 1 Exponent (*Z*) for Eq 8[A]

COV[B,C], %	Z
≤10	0.06
15	0.09
20	0.12
25	0.15
≥30	0.19

[A] Interpolation between tabular values is permitted.
[B] Coefficient of variation of the full data set, taken as not less than the higher COV attained from the tensile strength of flange material or end joints.
[C] Coefficient of variation for 6.3.1.2(*a*) material shall be 20 % for machine-graded lumber (including SPS-4 material) and 25 % for visually graded lumber.

6.3.1.6 Values for compression shall be established by testing the material in tension and assigning a value in compression such that:

$$F_{ci} = F_{ti}(F_c/F_t) \quad (9)$$

where:
F_t = closest assigned code value in tension for same species and size as tested pieces,
F_c = code assigned value in compression for same grade, species, and size as F_t visual grades,
F_{ti} = tensile value as determined in 6.3.1.3, and
F_{ci} = allowable stress in compression.

If F_{ti} is larger than the highest value given in tables of visual grade lumber for the species, then the ratio of tension to compression shall be from tables for the nearest machine stress rated (MSR) lumber grade.

6.3.2 *Analytical Method Confirming Tests*:

6.3.2.1 It is required that a minimum of ten I-joist specimens be tested at each of the extremes of flange size, allowable stress, and joist depth. This testing is not intended to substantiate the moment capacity determined in 6.3.1, but is considered necessary for any new product to generally confirm the overall performance of the assembled components. This testing is also necessary to satisfy the requirements of 6.5.

6.3.2.2 Test setup and procedures shall conform to the requirements of 6.3.3, except that loading may simulate uniform load with load points spaced no greater than 24 in. (610 mm) on center. In addition, the maximum permitted web hole specified in 6.3.3.2 is optional.

6.3.2.3 Any specimen failing at a calculated maximum moment of less than 2.1 times the calculated capacity indicates the possibility of errors in manufacturing, material selection, or calculation. The reason for such failures shall be carefully evaluated and further tests conducted as indicated.

6.3.3 *Empirical Method*:

6.3.3.1 *Test Procedure*—Bending tests are to be conducted on a span of 17 to 21 times the joist depth. Two point loads are to be placed symmetrically about the center and the spacing between such load points shall be a minimum of one third of the span. Joists shall be reinforced under the load points when necessary to prevent local failure. Load rate shall be adjusted to produce failure in not less than 1 min. Maximum moment in the specimen and the location of failure shall be recorded.

NOTE 9—A span to depth ratio of 18 is a frequent international practice.

6.3.3.2 *Specimens Tested*—Specimens shall be typical of intended production. Each flange material, grade, dimension, species and supplier, combined with each web type, thickness and grade, shall be tested. Procedures for evaluating materials from each supplier shall be addressed in the manufacturing standard. One method of evaluation is shown in X1.1.1.8. When flanges contain end joints, such joints shall have been qualified in accordance with 6.4.1, and all bending test specimens shall include at least one joint in the tension flange located between the load points. When holes are allowed in the web in accordance with 6.6, the maximum permitted hole shall be located approximately at the center of the span. Sufficient bearing length or reinforcement, or both, shall be provided at supports to prevent bearing failures.

6.3.3.3 *Remanufactured Solid Sawn Flanges*—When flanges utilize remanufactured lumber, the specimens tested shall be typical of the specifications in the manufacturing standard in accordance with 9.1.1.1.

NOTE 10—It is strongly recommended that plant personnel performing regrading activities be trained by an agency under an accreditation program such as the American Lumber Standards Committee.

6.3.3.4 *Sample Size and Analysis (Alternative 1—Testing to evaluate the web contribution to the joist moment capacity)*—The joist moment capacity shall not exceed the value calculated by multiplying the transformed joist section modulus (deducting the maximum anticipated hole size) and the flange tensile stress. The flange tensile stress shall be determined in accordance with 6.3.1. For qualification, a minimum of 28 specimens in each tested depth shall be tested at joist depth intervals no greater than 4 in. (102 mm). Moment capacity shall be the lower 5 % tolerance limit with 75 % confidence, divided by 2.1. Nonparametric statistics shall be used to determine the tolerance limit and confidence unless justification is presented for using parametric procedures. The moment capacity of I-joist depths not tested shall show logical progression as a function of the transformed joist section modulus between values assigned at the nearest depths tested to either side.

6.3.3.5 *Sample Size and Analysis (Alternative 2—Testing to evaluate joist moment capacity based on full scale bending tests)*—For qualification, a minimum of 28 specimens are required in each tested depth. Testing shall be at joist depth intervals no greater than 3 in. (76 mm), with a minimum of four depths tested, including the minimum and maximum joist depths. The mean ultimate moment capacities shall show logical progression as a function of the depth squared. A linear regression analysis of the mean values shall have a coefficient of determination (r^2) of at least 0.9. If the manufacturer produces less than 4 depths, 53 specimens of each depth shall be tested, but the requirement for a coefficient of determination shall not apply. Moment capacity shall be based on the lower 5 % tolerance limit with 75 % confidence, divided by 2.1. Nonparametric statistics shall be used to determine the tolerance limit and confidence unless justification is presented for using parametric procedures. Joist depths not tested shall be assigned capacities based on a logical progression of the depth squared between values assigned at the nearest depths tested to either side.

6.4 *End Joint Qualification*:

6.4.1 *Standards*—Adhesives used in joints shall conform to the requirements of 5.3.

6.4.2 *Testing*—Tension tests parallel to grain, on full-section joints, shall be conducted on a gage length (distance between grips) of not less than 2 ft (0.61 m). Testing speed shall be in accordance with 28.3 of Test Methods D 4761. The minimum sample size shall be 53. The design stress shall be determined from 6.3.1.4. End joint variability (coefficient of variation) shall be reported.

6.4.3 *Requirements*—Joints in any flange material shall conform to this specification, with particular reference to Section 10 when applicable.

6.5 *Stiffness Capacity and Creep*:

6.5.1 *Tests*—The tests of 6.3.2 or the first ten tests at the extremes of depth in accordance with 6.3.3 shall be used to confirm stiffness capacity and evaluate creep characteristics. Center span deflection measurements shall be recorded at a minimum of four increments to 1½ times expected moment capacity at time of qualification.

6.5.2 *Stiffness Capacity*—Any formula which accurately predicts the effects of both bending and shear deformation is permitted to be used. The equation must be adjusted when the mean of the ratios of test deflections at moment capacity load (determined from a least square line fitted through the data points), to predicted deflection is more than $1.0 + S/\sqrt{N}$, where S is the standard deviation of the ratios of test to predicted deflections and N is the total number of deflection tests conducted.

NOTE 11—Usually, a required adjustment will be applied only to the flange modulus of elasticity used in the equation. For stiffness-limited applications of I-joists, the largest percentage of deflection is typically attributed to bending, and because of the section geometry, the principle elastic modulus is that of the flange material. Therefore, here and in Sections 9 and 11, emphasis is placed on the flange modulus of elasticity (MOE).

6.5.2.1 *Elastic Properties*—Mean values are to be used in the deflection equation (*a*) when flange modulus of elasticity cannot be obtained from tables of recognized values, it shall be obtained from tests of the flange material used to establish moment capacity in accordance with 6.3.1, or (*b*) when moment capacity is determined in accordance with 6.3.3, the flange MOE shall be obtained from tables of recognized values or tests of the flange material. (*c*) Elastic properties of the web material shall be obtained from the appropriate standard.

6.5.3 *Creep*—Two of the I-joist specimens shall be loaded to 20 % of their moment capacity and center-span deflection readings taken. For purposes of this test, 20 % is assumed to be typical basic dead load (BDL). The specimen shall then be loaded to 1½ times the moment capacity for 1 h and deflection readings taken. The specimen shall be unloaded to BDL and deflection readings shall be taken after 15 min. The specimens must recover an average of 90 % of the total deflection from BDL to the end of the 1-h load period.

6.6 *Details of End Use*:

6.6.1 The intent of this section is to define common application details. In addition to the following minimum considerations, other details which affect application performance shall be investigated (for example, minimum nail spacing to avoid splitting).

6.6.2 *Bearing Length Qualification Tests*—Tests shall be conducted to determine recommended bearing lengths. The tests shall establish:

6.6.2.1 The minimum bearing lengths without web reinforcement that will develop ultimate shear capacity.

6.6.2.2 The minimum bearing lengths with specified web reinforcement that will develop ultimate shear capacity.

6.6.2.3 Any special requirements at interior supports of multi-span joists.

6.6.2.4 A minimum of five tests shall be conducted for each of the three conditions. Special details must be qualified with additional test specimens. Reinforcing materials shall be specified including size, fit, tolerance, and connections.

6.6.3 *Web Openings*:

6.6.3.1 Holes which remove a significant portion of the web will reduce shear strength at that section of the I-joist. Tests are to define such reductions for varying size and shape openings so that in application, openings can be located at sections subjected to appropriate shear levels. A minimum of five specimens of at least three depths encompassing the product range shall be tested for each depth/opening combination. Test specimens and setup are permitted to be the same as specified in 6.2 with an opening located between support and load points and centered on a web joint, when web joints exist in the product.

6.6.3.2 Maximum size hole which can be located anywhere in the web, shall be specified by the manufacturer and supported by data.

6.6.3.3 Spacing of allowed multiple holes must be verified by test.

6.6.4 *Special Details*—Depending on joist configuration, concentrated loads require local reinforcement. Loads supported by connection to the web or applied to the bottom flange require special consideration and appropriate details. These and other special conditions of application require appropriate evaluation and testing to ensure the safety provisions of this specification are maintained.

7. Design Values

7.1 *Design Value Limited*—Design values are determined from the analysis and capacities as specified in this specification. In no case shall a design value exceed the capacity determined in Sections 6 or 11. (See definitions of capacity and design value in 3.2.)

7.2 *Design Value*—It is the responsibility of the I-joist producer to determine design values. Judgment is required particularly when assessing design values from qualification tests. Design values shall consider potential low-line lot capacities to avoid marginal application performance or uneconomical reject rates in the quality assurance program.

8. Independent Inspection

8.1 A qualified agency shall be employed by the manufacturer for the purpose of monitoring the quality assurance production process on a random unannounced basis. The qualified independent agency shall establish (or approve) and maintain procedures for quality assurance.

8.2 A qualified agency is defined as one that:

8.2.1 Has trained technical personnel to verify that the grading, measurement, species, construction, shaping, bonding, workmanship, and other characteristics of the products as determined by inspection, sampling, and testing comply with all applicable requirements specified herein;

8.2.2 Has procedures to be followed by its personnel in performance of the inspection and testing; and

8.2.3 Has no financial interest in, or is not financially dependent upon, any single company manufacturing the product being inspected or tested; and is not owned, operated, or controlled by any such company.

9. In-House Quality Assurance

9.1 *Manufacturing Standard*:

9.1.1 A manufacturing standard shall be written and maintained for each product and each production facility and shall be the basis for the qualified agency's specific inspection at that location. As a minimum, it shall include the following:

9.1.1.1 Material specifications, including incoming inspection and acceptance requirements, and specifications for regrading flange stock when applicable,

9.1.1.2 Process controls for each operation in production of the product,

9.1.1.3 Quality control, inspection and testing procedures, and frequencies, and

9.1.1.4 Finished product identification, handling, protection, and shipping requirements.

9.1.1.5 When applicable, the minimum permitted flange joint spacing shall be specified.

9.2 *Inspection Personnel*—All in-house persons responsible for quality control shall demonstrate to the satisfaction of the qualified agency that they have adequate knowledge of the manufacturing process, of the inspection and test procedures used to control the process, of the operation and calibration of the recording and test equipment used, and of the maintenance and interpretation of quality control records.

9.3 *Record Keeping*—All pertinent records shall be maintained on a current basis and be available for review by both in-house and qualified agency inspection personnel. As a minimum, such records shall include:

9.3.1 All inspection reports and records of test equipment calibration whether accomplished by in-house or qualified agency personnel,

9.3.2 All test data, including retests and data associated with rejected production, and

9.3.3 Details of any corrective actions taken and the disposition of any rejected production, resulting from tests or inspections.

9.4 *Testing Equipment*—Testing equipment is to be properly maintained, calibrated, and evaluated for accuracy and adequacy in accordance with 6.1.1.3, at a frequency satisfactory to the qualified agency.

9.5 *I-Joist Quality Control Testing*:

9.5.1 *Objectives*—The following objectives are to be met simultaneously with the quality-control testing program:

9.5.1.1 Provide test data for use in maintaining and updating design values, and

9.5.1.2 Verify production process and material quality on a daily basis.

9.5.2 *Initial Quality Control*—When qualification is based on no more than the minimum testing required in this specification, the producer shall initiate higher test frequencies and retest levels. All new producers are advised to intensify quality control in early production.

9.5.3 *Required Tests*—The following shall be the scope of a minimum testing program:

9.5.3.1 Test methods shall be identical to those of Section 6.

9.5.3.2 The shear strength test described in 6.2 shall be used for quality control of shear strength. This test is required even if qualification is by calculation.

9.5.3.3 If flanges contain end joints qualified in accordance with 6.4, daily tension tests of full-section joints shall be conducted and failure loads recorded. The manufacturing standard must include the characteristic joint spacing that will be maintained in production. Durability tests of such joints are required only at such frequency as required to verify adhesive performance in accordance with 5.3.

9.5.3.4 When flange material is qualified by test in accordance with 6.3.1.2 (*b*) or 6.3.1.2 (*c*), the testing of that section shall be included in daily quality control tests. In all cases, QA provisions shall be established to maintain qualification strength.

9.5.3.5 When moment capacity is determined empirically, the test detailed in 6.3.3 shall be conducted as part of the daily quality-control program. All depths produced shall be tested in this program, and the tests shall include deflection measurement.

9.5.3.6 When the flange material does not have a modulus of elasticity assigned by the code, stiffness measurement of the material shall be part of the quality-control program.

9.5.4 *Data Collection and Analysis*—Test frequency, minimum test values, and rejection criteria for all tests of 9.5.3 shall be chosen to yield quality-control performance which is consistent with design values assigned to the product and its intended use.

10. Qualification and Quality Assurance of I-Joist Components Manufactured by Others

10.1 *Producer's Responsibility*—When the I-joist producer purchases material which would require qualification and quality control under the provision of this specification, the I-joist producer shall be responsible for assuring that, as a minimum, such material conforms to the requirements of Sections 6, 8, 9, and 11 of this specification.

10.2 *Record Keeping*—The I-joist producer shall obtain and maintain records of certification from the outside producer's qualified agency that the components supplied conform to the requirements of this specification.

10.3 *Identification*—All such components shall be appropriately marked as agreed upon between the component and I-joist producers.

11. Periodic Reevaluation of Structural Capacities

11.1 *Reevaluation Required*—Each capacity monitored by the required tests of 9.5.3 shall be reevaluated on a periodic basis. As a minimum, reevaluation shall be accomplished at the end of the first six months of production by any new manufacturer and for any new product line, and thereafter each such capacity shall be reevaluated and audited by the qualified agency at the end of each successive year of production.

11.1.1 *Bearing Capacity Reevaluation*—A one-time reevaluation of bearing capacity shall be accomplished at the end of the first six months of production by any new manufacturer and for any new product line. The reevaluation is to be based on data from specimens selected randomly throughout the six-month period and tested when convenient. Tests are to be conducted in accordance with 6.6.1 on the details (minimum bearing length and reinforcement as required) developed in that section.

11.1.2 *Regraded Solid Sawn Lumber Flanges*—As a minimum, reevaluation shall be conducted every six months for regraded solid sawn lumber flanges as described in 6.3.1.2. The testing shall be that specified in 9.5.3.4 and the test data shall be evaluated in accordance with 6.3.1.4.

11.2 *Minimum Data Base in Periodic Evaluation*:

11.2.1 *Shear and Flange Material Tests*—The minimum number of tests to be included in the analysis is that required for qualification in accordance with Section 6. When it becomes apparent that this requirement will not be met by the initial test frequency established, the frequency of testing shall be increased. Evaluation of test frequency shall be accomplished early in the evaluation period to ensure that test data is representative of production in the period and will be randomly accumulated at time intervals spaced throughout the period.

11.2.2 *Empirical Moment Capacity Tests*—Reevaluation shall be conducted every three months and the minimum number of tests required is that used for qualifying in 6.3.3. Test frequency in the period must be adjusted as necessary to ensure the minimum number of tests are met. If data on the full range of depths is not available, additional depths shall be selected and tested so that the data available is at least equal to that required in 6.3.3, except that if the coefficient of determination (r^2) is at least 0.9 as described in 6.3.3.5, the data for joists where the only change is depth may be combined provided a minimum of 112 tests are conducted every 60 production days, but in a period not to exceed six calendar months. Details of how suppliers are reevaluated shall be a part of the manufacturing standard.

11.3 *Data Analysis*—Data to be included in the analysis is that developed in the latest evaluation period from the testing specified in 9.5.3. Test data which was cause for rejection of a production lot shall be excluded, unless a reduced design value and associated reject level is to be established by the reevaluation. Also, with the agreement of the qualified agency, low test values related to any assignable and correctable cause which has been corrected, shall be excluded from consideration. Analysis of the data shall be identical to that of the applicable qualification section of this specification.

11.3.1 *Flange Strength Distributions*—Flange strength data from the period, including joint strength when applicable, shall be evaluated. If the coefficient of variation of production has increased by more than 1½ % since the last evaluation, the evaluation of 6.3.1.5 shall be repeated and design moment shall be adjusted or corrective action taken that is acceptable to the qualified agency.

11.4 *Adjustment of Design Value*—If the capacity determined in the analysis of 11.3 is less than the current design value, the design values must be reduced or corrective action taken that is acceptable to the qualified agency. When stiffness capacity is determined from flange material stiffness tests or joist bending tests, the comparison shall be between the mean of the tests in the period and the design value; the flange modulus of elasticity in the design equation shall be reduced proportionately when the current test mean is less than the design value.

12. Installation Instructions

12.1 Proper installation instructions or drawings shall accompany the product to the final job site. They shall include any special instructions required for the product, and weather protection and handling requirements. In cases where web reinforcement and attachment requirements, lateral support details, bearing or connection requirements, and web hole cutting limits are not covered by adequate general notes, standard sketches and charts shall be included with the installation instructions, or specific job drawings shall properly cover these requirements.

13. Identification

13.1 The product shall be clearly and properly identified by product and company name, plant location or number, qualified agency name or logo, and a means for establishing the date of manufacture.

APPENDIXES

(Nonmandatory Information)

X1. COMMENTARY ON STANDARD SPECIFICATION FOR ESTABLISHING AND MONITORING STRUCTURAL CAPACITIES OF PREFABRICATED WOOD I-JOISTS

X1.1 *Scope*—This appendix is intended to provide a general background and the underlying philosophies which led to the development of the standard in its present form. Other appendixes explain specific technical aspects of various sections of the specification. The arrangement of this appendix follows the same sequence as the specification, but only certain sections here deal explicitly with sections of the specification.

X1.1.1 *General Index and Description of Major Features of the Standard*:

X1.1.1.1 *Design Considerations*—Some common considerations in application design of I-joists are given in Section 4.

X1.1.1.2 *Materials*—Materials used in fabrication of I-joists as defined in Section 3 are described in Section 5.

X1.1.1.3 *Qualification Required*—Section 6 of this specification specifies the analysis and minimum testing required for establishing structural capacities for new producers and new product lines. Qualification of components can be by other than the I-joist producer, provided the requirements of this specification are met as detailed in Section 10.

(a) Shear Capacity Qualification—Initial capacity may be established either by calculations or from test results, as specified in 6.2.

(b) Moment Capacity Qualification—Three options are detailed in 6.3: The capacity is based upon the flange tensile capacity which is obtained from tables of recognized values as defined or analysis of flange material tensile test results. The third option is capacity based on analysis of I-joist bending tests. When flanges contain end joints, they are qualified by analysis of tension test results and may limit moment capacity, when such capacity is determined from flange tensile capacity.

(c) Stiffness Capacity Qualification—Stiffness capacity is determined analytically using material elastic moduli in an equation which accounts for both bending and shear deformations. Stiffness is determined analytically regardless of procedure used to determine moment capacity. The equation used is confirmed by tests specified in 6.5.

X1.1.1.4 *Details*—Investigation of details which may affect structural capacities is required as part of the qualification specified in 6.6. This includes as a minimum, the bearing lengths and any reinforcing required to maintain shear capacity, and the effect of web-holes on shear capacity.

X1.1.1.5 *Design Values*—Design value and capacity are defined in Section 3. Establishment of design values is discussed in Section 7.

(a) Design Values Monitored by Quality Assurance—Useful definitions of quality assurance and quality control are given in Criteria E 699. Section 9 defines the intent of a required quality assurance program and outlines the minimum content of the program. Section 10 defines requirements for component quality assurance accomplished by other than the I-joist producer.

X1.1.1.6 *Quality Control Testing Required*—In general, when a structural capacity is qualified by test, the same test will be required in the quality-control program. Quality control shear tests are always required even when qualification of shear capacity is by calculation.

(a) Quality Control and Quality Assurance Required—Both in-house and third-party inspections are required. Third-party inspections are performed by a qualified agency, meeting the requirements of Section 8 of this specification.

X1.1.1.7 *Periodic Reevaluation of Structural Capacities*—Section 11 of this specification specifies reevaluation of capacities. In general, the reevaluation is based on data developed in the quality-control testing program.

(a) Intent of Reevaluation—Reevaluation provides a formal confirmation of the quality-control program and a basis for adjusting the design values of the producer.

X1.1.1.8 *Supplier Evaluation for Empirical Moment Method*—The manufacturer may qualify with one supplier at the start to establish design moment capacities. Then at the depth with the highest tension stress (back calculated using the net section), conduct a minimum of 53 bending tests for each additional supplier. The fifth percentile with 75 % confidence must not be less than that of the original supplier. As an alternate, the manufacturer may qualify with one supplier at the start and conduct a minimum of 53 correlating tension tests with matched samples. Then conduct a minimum of 53 tension tests for each supplier. For each supplier used, the fifth percentile with 75 % confidence must not be less than that of the original correlating tension tests. Regardless of how the suppliers are qualified, they must be continuously monitored through quality control.

X1.2 *Need for Standard and History of Development:*

X1.2.1 *Need for Standard*—The wood I-joist is a relatively complex composite member, comprised of a wide range of anisotropic materials which may themselves be composites. The range of sections possible and manufacturing processes which produce more or less continuous lengths, lead to members with possible applications ranging from direct replacement of 2 by 8 floor joists to roof spans of 60 ft or more. The first of these members appeared in the market in the early 1970s. By the early 1980s, a number of products, each with proprietary details and processes had appeared. Because no existing standard suitably addressed the variety of details and processes which evolved, a significant range of approaches to the establishment of design values appeared. The inconsistencies in approaches, rapid growth in the I-joist industry, and requests from building code groups, made obvious the need for a standard general enough to encompass the product range.

X1.2.2 *History of Development*—In the fall of 1981, an interested group of producer's representatives formed an ad-hoc committee to address the issue of a specification. This committee invited participation from various segments of the wood and adhesives industries and began work on a draft specification. By the end of 1985, a document considered complete in most essentials was agreed upon by a majority of the ad-hoc committee and transmitted to the building code groups as a recommended interim specification. The ad-hoc committee then agreed that a consensus specification was desired and requested ASTM Committee D07 to promulgate such a specification. Work began on this specification in the spring of 1986.

X1.3 *General Philosophy*—The intent of the specification is to provide a standard procedure for the evaluation of I-joists such that capacities for any producer will be consistent with the statistics of the producer's strength distributions and thus will result in more or less uniform application performance. Therefore, the specification is as performance-based as was found practical. The qualification section was designed to be a minimum requirement consistent with sound structural engineering. The quality assurance and reevaluation sections are intended to rapidly correct any deficiencies in the qualification procedure. Additional discussion of qualification is in X1.5.

X1.4 *Comments on Design Considerations*—Section 4.1 of the specification refers to the load duration adjustments used for sawn lumber. This was judged appropriate as no evidence to the contrary has appeared for any common wood/adhesive composite. The committee considered this issue most carefully when specifying the time-to-failure (minimum one minute) prescribed in the specification and concluded that the load rates implied were in keeping with currently acceptable ranges (for example, see Test Methods D 4761). Moreover, adjustment to "normal duration" was considered to be a component of the "baseline" ratio of 2.9 explained in X6.3, as it is in factors used to obtain design values in other wood standards (for example, see Practice D 2915, Table 6). Assessing load duration factors for "unusual" components is beyond the scope of this specification.

X1.4.1 *Repetitive Member Factors*—With the recent introduction of ASTM guidelines for development of factors to quantify system effects for wood assemblies, a task group of Specification D 5055 was formed to review the basis of the factors. The task group discussed the fact that historical repetitive member factors actually embodied a combination of load sharing and composite action effects. A review of the literature indicated that the 1.15 factor for lumber would actually compute to roughly 2/3 composite action effects and 1/3 load sharing effects. The literature noted that the amount of composite action is functionally related to the stiffness of the sheathing relative to the framing member and to the connection between them. Similarly, the literature noted that the amount of load sharing is functionally related to the assembly configuration, to the stiffness variability of the framing members, and to the amount of correlation between the strength and stiffness of the framing members. The task group concluded that the amount of composite action in a prefrabricated wood I-joist system would vary broadly across the large range of available I-joist depths. Thus, unless the committee was prepared to propose a series of factors that differed by joist depth, only a factor near unity could be safely applied across all depths. The task group also concluded that the stiffness variability in prefabricated I-joist framing members was significantly lower than that of sawn joists. In addition, data showed that the correlation between I-joist flexural stiffness and moment capacity within a joist series was not consistent-and was often lower than the correlation reported for sawn joists. Thus, unless the committee was prepared to propose a series of factors that differed depending on the measured correlation for a given manufacturer, only a factor near unity could be safely applied across all joists in the marketplace.

X1.4.1.1 The final pieces of the decision process that led to revision of the factor were: *(1)* the acknowledgment that other changes in Specification D 5055 were removing conservatism from various aspects of moment capacity calculation (up to 20 % increases), and *(2)* the desire to take another small step in the direction of simplicity for our designer customers (by removing the separate factor for repetitive member increases from all designs). The former led to the conclusion that the larger factor in the existing Specification D 5055 was too high and the latter leading to the proposal for a factor of unity. It must be noted that some members of the task group believed that the decision to completely remove the repetitive member factor for I-joists adds confusion rather than simplification, for the designer. Their argument was that experienced designers have come to expect a factor for repetitive member use, and its elimination would raise many questions. These task group members voiced their preference for either a constant factor slightly larger than unity (that is, 1.05) or the carry-over of factors consistent with the latest version of the National Design Specification for Wood Construction (that is, 1.04 and 1.07), with either option possibly being tied to applicability to joists up to some maximum depth. It is anticipated that the prefabricated wood I-joist industry will work toward coordinating the introduction of these changes into their literature and software. Because all current code provisions and industry design specifications permit factors higher than unity, it is anticipated that manufacturers will implement the changes into their design information gradually-and with clear guidance on how to apply their moment capacity values relative to repetitive member use.

X1.4.2 Adjustments for unusual moisture conditions may depend on the actual materials used in a given I-joist. Because of the variety of materials in use, any attempt to quantify such adjustments was considered beyond the scope of the specification.

X1.4.3 Generally, it is expected that I-joists will be produced from material which is at moisture content approximating that of "dry use" conditions. For this reason, adjustment of test results is not specified. The reduction factors explained in Appendix X6 makes allowance for some strength loss which might be associated with temporary jobsite wetting.

X1.5 *Comments on Qualification:*

X1.5.1 *Qualification Test Sampling*—The strength of an I-joist is strongly dependent on the quality of the material used. This must be expected to vary from time to time, even in material from the same supply sources. Production process variables may also change with time. For this reason, it was not considered possible to specify a meaningful sampling scheme and it is assumed that the quality assurance program will, with time, define fluctuations due to material and process variables. It is desirable to conduct preliminary tests to aid in the selection of representative specimens. A new producer is advised to give due consideration to these issues when selecting qualification samples.

X1.5.2 *Evaluation of Test Results*—In the case of shear strength, the analyses presented help justify the statistically minimal qualification test sample required. Detailed discussion and examples of this procedure are given in Appendix X4.

X1.6 *Discussion of Independent Inspection*—The requirements of Section 8 and others, help lend credence to the concept of a performance-based specification. Moreover, the vast majority of prefabricated I-joists now being produced are proprietary, and the independent inspection is usually an integral part of building code acceptance of such products.

X1.7 *Philosophy of In-House Quality-Assurance Requirements:*

X1.7.1 Any effective quality-control scheme must be devised with due consideration of production volume, the specific materials and manufacturing processes and their associated variabilities. Because of the wide range of materials, details, manufacturing processes, etc., possible in production of I-joists, detailed quality control procedures, including testing frequency and daily statistical analysis of data, must remain beyond the scope of this specification. Details of quality control are the responsibility of the individual producer, qualified agency, and concerned regulatory organizations.

X1.7.2 In keeping with the concept of a performance-based specification, however, it is appropriate to specify the minimum general objectives and content of the quality-assurance program. More specifically, all major structural properties determined by qualification testing under the provisions of this specification must be monitored by the quality-control program to assure continuing acceptable performance.

X1.8 *Philosophy of Periodic Reevaluation Requirements:*

X1.8.1 This section is intended to ensure that I-joist capacities are related to the actual performance of the members. The evaluation periods specified provide a formal basis for reporting and adjusting. In practice, it is expected that the quality-control program will provide a continuing evaluation in one form or another.

X1.8.2 In this procedure, the difficulty of selecting qualification specimens representative of long-term production is overcome.

X1.8.3 The procedure affords a check of the quality-control process without reference to the details of that process.

X1.8.4 A mechanism is provided for logical adjustment of design values based upon data which encompass the full range of material and manufacturing variables. As an example, qualification testing may, for some reason, indicate capacities which, when incorporated in an effective quality-control system, result in economically unacceptable reject rates; the manufacturer may then choose to include data from reject production and thus adjust values in keeping with some reject rate judged acceptable.

X1.8.5 Shear and bearing capacities are usually considered most sensitive to details of the manufacturing process. Therefore, a shorter initial evaluation period is specified for those test results. Bearing capacity, which is a function of bearing length, flange/web joint, reinforcing details and materials, is considered related to shear strength once testing has occurred over a sufficient time period to stabilize details relative to the full range of material variables. It should be noted that bearing length specified in Section 6 for shear capacity tests is not necessarily the minimum required. This is because the shear test not only demonstrates capacity, but also is considered the best test of product details and manufacturing processes. Therefore, it is desirable that the failure in a shear test usually initiates away from the bearing.

X1.9 *Capacity and Design Value:*

X1.9.1 The descriptions of terms given in 3.2 are intended to encourage some exercise of judgment in assessing design values from the analyses detailed in the specification.

X1.9.2 A few of the factors which may influence a manufacturer to assess a design value less than capacity are:

X1.9.2.1 The qualification test specimens may not be truly representative. See X1.5.1.

X1.9.2.2 The quality of incoming material may vary from time to time or supplier to supplier.

X1.9.2.3 A high design value may result in an uneconomical reject rate in the quality-control program.

X1.9.2.4 The factors in X1.9.2.1-X1.9.2.3, and other factors, are typically difficult to define without substantial time and experience in production.

X2. VOLUME EFFECTS IN PREFABRICATED WOOD I-JOISTS

X2.1 *Scope:*

X2.1.1 The strength of prefabricated wood I-joists is related not only to material properties, but is also a function of member size, longitudinal stress distribution, and the strength and frequency of flange joints. In this specification, volume effects are accounted for either directly in the testing (that is, shear in accordance with 6.2 and moment in accordance with 6.3.3) or indirectly in the analysis (that is, moment in accordance with 6.3.1). The discussions in this appendix provide background to the volume-related provisions of 6.3.1.

X2.1.2 During committee deliberations, it was questioned why prefabricated wood I-joists should account for length effects when competing products in the marketplace might not. A review of available standards and other information revealed that these effects are already included in glulam and structural composite lumber (in their volume factors) and in sawn lumber design (embedded in the Practice D 1990 design value derivation procedures). The committee also noted that this issue is still being studied for trusses at North American research laboratories and is being discussed within the truss industry associations.

X2.2 *Discussion of Flange Material Types:*

X2.2.1 Flange materials are divided into three types to accommodate differences in analysis and testing requirements for each type.

X2.2.2 For material type 6.3.1.2(*a*), published lumber axial design values are used in the computation of moment capacity and no additional tension testing is needed to verify lumber strength. All standard ALS and CLS grades, including standard SPS-4 grades, fit in this category. Because input lumber lengths for this material type are "standard" (that is, 8 ft or longer), the only additional test verification of this flange material is the end joint testing in accordance with 6.4. The user is cautioned that SPS-4 design values may be based on a reference length of 96 in. rather than 144 in. if the product uses sawn lumber in lengths of less than 8 ft.

X2.2.3 For material type 6.3.1.2(*b*), in which the manufacturer is using nonstandard axial design values, separate verification of tension values in accordance with 6.3.1.3 and 6.3.1.4 is required. As with 6.3.1.2(*a*) material, end joints are evaluated in accordance with 6.4.

X2.2.4 For material type 6.3.1.2(*c*), input lengths are not sufficient for separate evaluation of lumber strength. For this material, flange strength is evaluated by testing on a minimum 8-ft gage length with a representative number of end joints present in the test specimens. As indicated in Note 7, SPS-4 provides users with several options for complying with the intent of this section.

X2.3 *Discussion of Length Effect, Stress along the Length, and Joints:*

X2.3.1 The theoretical effects of length and stress variations along the length and the effects of joints in flange material are presented in Footnote 12.[7] A brief discussion of these effects and their inclusion in this specification are included in the following sections.

X2.3.2 *Length Effect Factor Derivation*—Length effect is computed in a weak link analysis of the I-joist tension flange. Since flange tension strength is based on tests of relatively short lengths of flange material, it is appropriate to adjust strengths to typical application lengths. The factors in Table 1 are provided for the convenience of the user and are based on the relationship between Weibull shape parameter and tail-fit (Weibull) coefficient of variation. For ease of use, the table specifies full distribution COV. For simplicity, the tail-fit COV is assumed to be 70 % of the full distribution COV. This judgment is slightly conservative for most of the very large data sets representing common flange materials (that is, lumber, SCL) examined by the committee. The assumed COV's for 6.3.1.2(*a*) lumber products are typical ranges of values. The committee chose to omit provisions including provisions that would permit the user to tail-fit specific data sets to generate alternate exponents for the length effect equation due to concerns related to unrealistically low COV's that could be generated in this manner. It was also determined to utilize the higher COV attained from either the tensile strength of the flange or that of the end joints. In some cases, this would require the COV of the flange to be utilized when checking length effect adjustments for end joints. This approach was taken to account for the reduction that would be seen for the combined effects of the lumber stress distribution and finger joint stress distribution.

X2.3.3 *Length Effect Factor Design Application*—Length effect is computed in a weak link analysis. The length effect factor is intended to be applied only as an adjustment to the basic moment capacity value and not as an application-specific design adjustment. The factor is intended to be computed at a single span-to-depth ratio (18) and incorporated in the published design moment for each I-joist depth by the joist manufacturer. The rationale for this judgment follows. Stress in the I-joist section will vary along the length of the member with the changes in moment diagram. The I-joist application design will be based on the maximum moment in the member which will often occur at only one point, and elsewhere moments will be less. Relative to a member stressed by a constant moment full length, this effect results in expected increase in strength. It was the judgment of the committee that I-joist design moment resistance should be based on simple span and uniform load with a span length of 18 times the joist depth. This judgment included consideration of other arrangements of supports and loading configurations.

X2.3.4 *Stress Distribution Adjustment Factor*—As indicated in the discussion of X2.2.3, offsetting the decrease in strength due to length is the increase in strength due to nonuniform tensile stresses along the length of a flexural member (relative to constant tension full length). The judgment of the committee is that these effects can be computed at a reference condition of simple span and uniform load, and can be reasonably applied to the full range of design applications with negligible error. The factor of 1.15 is viewed as a reasonable value for this parameter.

X2.3.5 The inclusion of joints in the flange introduces an additional failure mode which will affect flange strength, depending on their spacing and relative strength. Footnote 12 provides additional discussion on this topic. The effect of joints is incorporated into this specification in two ways:

(1) The definition of F_a requires that the minimum of flange material axial values or end joint tensile values form the basis of the design calculation. This definition accounts for approximately 95 % of the joint effect for standard lengths of lumber.

(2) The definition of flange material 6.3.1.2(*c*) requires a minimum tension test gage length of 8 ft and additionally requires that qualification specimens contain the characteristic number of end joints. This definition raises the requirement for short-length flange materials to the same level as the other flange material types.

[7] Sharp, D.J., Suddarth, S. K., and Beaulieu, C., "Length Effect in Prefabricated Wood I-Joists," *Forest Products Journal*, Madison, WI., 50(5), 2000, pp. 29-42.

These techniques incorporate approximately 90 to 100 % of the joint effect into the analysis. Given the additional complexity of incorporating a calculation-based joint effect into the standard, it was the judgment of the committee that the additional conservatism of not including the web contribution was adequate to permit the standard to neglect the remaining fraction of joint effect for the limited number of cases for which it would apply. Users are cautioned that use of web contribution factors greater than unity or stress distribution adjustment factors greater than 1.15 violate this judgment and would require explicit consideration of joint effects.

X2.4 *Discussion of Analysis Techniques and Assumptions*—The techniques underlying these provisions are consistent with SCL and glulam volume analyses in their focus on the 2-parameter Weibull distribution as the default distribution form. The data analysis techniques were also chosen to be consistent with Specification D 5457 (LRFD) techniques, which use the 2P Weibull and also permit the option of tail-fitting to improve Weibull fits. Tail-fitting has been shown to result in excellent representation of practically all data sets of engineered wood products.

X2.5 *I-Joist Section Analysis:*

X2.5.1 Since this specification was originally published in 1990 (this paragraph was written in March 2001), the most common method of assigning moment capacity has been the product of the flanges-only section modulus and the tensile stress allowed in the flange material. When compared to test data, it was often observed that this resulted in a somewhat conservative moment capacity. This conservatism was believed to be related to the strength contribution from the web or the bending stress variation across the depth of the flange, or both.

X2.5.2 The inclusion/exclusion of web contribution from the calculation has often been debated in this committee. When moment capacity was computed by a flexural calculation (that is, net flange section modulus), the inclusion of web contribution was viewed to be consistent with the engineering mechanics. However, when moment capacity is computed by a flange tension calculation, the additional inclusion of web contribution is not believed to be consistent from a mechanics perspective. For this reason, it was judged that the web contribution should not be included in the analysis. One additional, pragmatic reason for excluding the web contribution from the calculation is to eliminate opposition to this method based on the argument that full-depth web holes, permitted in application, cannot contribute to increases in moment capacity.

X2.5.3 The bending stress variation across the depth of the flange, implicitly included in prior versions of Specification D 5055 in the "net flange section" calculation, has been eliminated. Eq 6 computes moment capacity using the standard engineering formula for a tensile chord or flange.

X2.6 *Nonuniform Stress Along the Length*—The principles of weak-link theory provide not only for strength decreases for longer length members, but also for strength increases for members at a given length with nonuniform stresses along their length. The factor K_S can be used to calibrate a member under the stress profile of a flexural member subjected to any arbitrary load configuration to the same member subjected to constant tension along its entire length. For purposes of this analysis, the judgment of the committee was to choose a single constant value of K_S (of 1.15) for this factor. The value of 1.15 was computed in accordance with Reference 1 and is within 3 % of the computed value in the range from 10 to 18 % COV.

X3. PREFABRICATED WOOD I-JOIST ADHESIVES

X3.1 *General:*

X3.1.1 Selection of adhesive, qualification, and quality-control procedures must result in performance conforming to the overall intent of the specification. This appendix is intended to serve as a guide and reference for adhesives to be used in the fabrication of wood I-joists. The referenced standards and procedures should be judged for their applicability to the manufacturing process of a given producer.

X3.1.2 All adhesives used, whether in the assembly of joints (flange to flange, end joints, web to flange, or web to web joints), or in composite structural lumber flanges, must be certified as meeting Specification D 2559 for the curing parameters and materials used. Specification D 2559 is titled "Specification for Adhesives for Structural Laminated Wood Products for Use Under Exterior (Wet Use) Exposure Conditions."

X3.1.3 It should be noted that in Canada and in certain other jurisdictions, the use of melamine and melamine-urea adhesives is not allowed even though joints using these adhesives may meet the requirements of Specification D 2559.

X3.2 A number of standards and specifications currently exist for adhesives used in structural products, although such standards may not meet all the requirements of this specification. References for adhesives used in fabrication include:

X3.2.1 *End Joints*:

X3.2.1.1 AITC 200-83, Inspection Manual, Sections 4 through 7.

X3.2.1.2 ASTM D 4688, Test Methods for Evaluating Structural Adhesives for Fingerjointing Lumber.

X3.2.2 A method of interpreting wood failure is described in AITC Inspection Bureau Memo No. 1.

X3.2.3 *Structural Composite Lumber (Includes Laminated Veneer Lumber)*:

X3.2.3.1 AITC 402-83 (contained in *Inspection Manual* AITC 200-83)

X3.2.4 *Plywood*:

X3.2.4.1 U.S. Product Standard PS 1-83 for Construction and Industrial Plywood, Exposure 1 Section 3.7.3 and Exterior Type, Section 3.7.4.

X3.2.5 *Structural Use, Non-Veneer Panel*:

X3.2.5.1 U.S. Product Standard PS-2, Exposure 1, Section 5.5.3.1(b).

X3.3 When qualifying an adhesive for use in wood I-joists, consideration should be given for the process and ultimate end-use application. For example, adhesive qualification testing should reflect the minimum temperature to be used in the manufacturing process.

X3.3.1 Likewise, melamine-urea-based adhesives should not be used when the in-service conditions result in exposure to the combined effects of a moisture content in the wood in excess of 16 % and a temperature of 120°F or greater. These are examples showing how the adhesive manufacturer's recommendations can be helpful when evaluating a particular adhesive for qualification.

X3.4 Full-scale product testing is a requirement of the specification as part of the qualification and quality provisions. An evaluation of the adhesive performance in these tests is recommended and desired. Although the specific tests are for evaluating joist shear, they provide an excellent opportunity to judge the glue line performance.

X3.5 Shear tests may point out if there is a glue line failure. The results must be judged carefully though, since low strength may not be related to a poor glue line.

X3.6 To help with the evaluation, certain levels of wood failure have been used historically to indicate if a glue line performed to an acceptable level. Recognized adhesive performance limits are as follows:

X3.6.1 *Web to Flange Joints*—A wood failure value greater than 70 % should be present.

X3.6.2 *Web to Web Joint (if applicable)*—A wood failure value greater than 50 % should be present.

X4. EXPLANATIONS OF STATISTICS USED IN THE STANDARD AND A SAMPLE EVALUATION OF SHEAR CAPACITY

X4.1 *Scope:*

X4.1.1 *Statistics Used in the Specification*—This appendix provides an explanation of certain terms used in the specification. It is not intended as a general statistical reference, but may be a useful guide for those users with limited statistical background. References are given for those wishing to pursue the subject more thoroughly.

X4.1.2 *Sample Evaluation of Shear Capacity*—Under prescribed conditions, 6.2 permits combining of shear test data from joists of different depths. The relationship between shear strength and depth implied in the analysis is not usual in the statistical sense since the depths are deterministic. The example provides justification for the procedure.

X4.1.2.1 *Reason for Shear Capacity Procedure*—Combining the data gives a better estimate of variability from the larger sample size. The ability to combine data from different depths is a significant benefit in a quality-control program.

X4.1.3 *Units*—In this appendix, English units are used exclusively. Conversion factors for SI and metric units are in IEEE/ASTM-SI-10.

X4.2 *Useful References:*

X4.2.1 Schaum's Theory and Problems of Statistics[8]

X4.2.2 D'Agostino, R. B. and Stephens, M. A., "Goodness of Fit Techniques," Marcel Dekker Inc., New York, NY, 1986.

X4.2.3 "Handbook of Mathematical Functions," Applied Mathematics Series 55, National Institute of Standards and Technology, 1970. Available from Superintendent of Documents, Washington, DC.

X4.2.4 Natrella, M. G., "Experimental Statistics, National Bureau of Standards Handbook 91," 1966. Available from Superintendent of Documents, Washington, DC.

X4.3 *Discussion of Terms:*

X4.3.1 *Normal Distribution*—In this standard, shear strength is assumed to follow a normal distribution.

X4.3.2 *Other Distributions*—This specification presumes distributional knowledge only of shear strength. Flange or bending strengths may be better fitted by the lognormal or Weibull distributions.

X4.3.3 *Tolerance Limit*—Statistical tolerance limit. The proportion of the data expected, with stated confidence, to be below (or above) a given value. For example, in the strength capacity evaluations, we are 75 % confident that no more than 5 % of the data will fall below the calculated value. Equations and a table for factors used to find normal distribution tolerance limits are given in this appendix and in Practice D 2915.

X4.3.4 *Nonparametric Analysis*—Data of an unknown distributional form is said to be nonparametric. Tolerance limits for nonparametric data are defined and appropriate factors given in Practice D 2915.

X4.3.5 *Correlation*—Correlation defines the relationship between variables. Degree of correlation is measured by the coefficient of determination and by the standard error of estimate.

X4.3.6 *Regression*—Regression analysis provides an estimate of the relationship between variables; in this specification, expressed by a linear equation.

X4.4 *Example of Shear Capacity Analysis:*

X4.4.1 *Nomenclature*—This section uses the following nomenclature.

X4.4.1.1

P = ultimate shear for a test specimen,
$\bar{P}_i$ = mean ultimate shear for depth (d_i),
n_i = number of tests at depth (d_i),
S_i = standard deviation of ultimate for depth (d_i),
v_i = coefficient of variation for depth (d_i),
P_e = expected mean from regression analysis,
J = number of depths included in regression analysis,

[8] Schaum's Outline Series on Mathematics, McGraw-Hill Book Company, 1221 Avenue of Americas, New York, NY 10020.

$S_{\bar{P}_i}$ = standard deviation of means of all depths in the regression analysis, and

$S_{\bar{P}_i d_i}$ = standard error of the correlation.

X4.4.2 Other terms are defined where required.

X4.4.3 *Check of Normal Distribution*—Data for examples were provided by Trus Joist Corporation and are results of shear tests (conforming to 6.2) conducted during the period January 1984 through June 1985. The data is for sample purposes only and does not necessarily relate to current production or capacity. Tests were of joists with plywood webs and structural composite lumber flanges; web reinforcing was used at supports on depths of 18 and 20 in. The data is tabulated in Table X4.1.

X4.4.4 *Calculations*:

X4.4.4.1 Equations for computing the normal curve are given in X4.6. The two parameters necessary to define the normal curve are:

$$\bar{P}_i = \Sigma P/n_i \quad \text{(X4.1)}$$

$$S_i = \sqrt{(\Sigma P^2 - n_i \bar{P}_i^2)/(n_i - 1)} \quad \text{(X4.2)}$$

X4.4.4.2 The coefficient of variation is:

$$v_i = S_i/\bar{P}_i \quad \text{(X4.3)}$$

X4.4.4.3 Eq X4.1 and Eq X4.2 (loads divided by 2 for shear) give the example statistics tabulated in Table X4.2.

X4.4.4.4 To check for normal distribution, the 11.875-in. data was used.

X4.4.4.5 A program which follows the procedures of X4.6 and X4.7 was used to fit the normal curve to the data. Two goodness-of-fit tests were computed: The Anderson-Darling statistic A = 0.209 and DMAX for Kolmogorov-Smirnov Test = 0.056. Both indicate a close fit. The data and fitted curve are plotted on Fig. X4.1 where visual inspection also confirms the use of the normal distribution. From Table X4.2, note that data from other depths has similar variability and data range from means is reasonably symmetrical, so we conclude that all the data sets are normally distributed.

TABLE X4.1 Sample Shear Test Data Total Ultimate Load, lb

I-Joist Depth, in.															
9.5		11.875		10.0		12.0		14.0		16.0		18.0		20.0	
3730	5190	4400	5730	3630	6330	4560	6970	4060	7000	5980	8630	6830	9720	6760	10520
4070	5220	4455	5755	3950		5010	7000	4310	7020	6440	8775	7000	9990	7710	10580
4070	5260	4490	5760	4110		5100	7445	5445	7030	6720	8820	7560	10040	7710	10605
4170	5340	4505	5770	4230		5130		5600	7050	6720	8820	7690	11395	7725	10650
4180	5370	4670	5780	4240		5340		5740	7070	6750	8900	7785		7785	10830
4210		4720	5780	4330		5370		5770	7075	6900	8915	7795		7910	10830
4270		4760	5790	4360		5380		5830	7080	6910	8930	7810		8255	10890
4280		4835	5805	4430		5400		5915	7105	7030	9275	7960		8380	11210
4290		4905	5805	4450		5420		5950	7110	7030	9460	8130		8385	11250
4324		4950	5830	4490		5430		5970	7120	7100		8190		8500	11520
4370		4950	5835	4510		5440		6110	7170	7210		8220		8550	
4430		4995	5880	4540		5440		6115	7200	7230		8260		8645	
4440		5035	5925	4560		5440		6215	7250	7230		8390		8740	
4440		5055	5935	4570		5470		6220	7255	7245		8410		8765	
4475		5095	5950	4600		5530		6270	7265	7300		8500		8930	
4480		5095	5955	4650		5590		6290	7300	7340		8510		8970	
4520		5110	5990	4660		5680		6300	7335	7390		8510		9000	
4520		5135	5995	4670		5680		6330	7390	7470		8540		9070	
4540		5220	6020	4710		5780		6340	7580	7480		8570		9160	
4580		5240	6020	4720		5800		6350	7630	7490		8690		9230	
4580		5240	6035	4795		5810		6355	7650	7550		8690		9280	
4580		5250	6050	4850		5845		6365	7740	7620		8780		9380	
4600		5260	6050	4870		5850		6440	7740	7680		8800		9400	
4610		5260	6085	4880		5880		6440	8120	7680		8860		9420	
4640		5270	6100	5025		5890		6450	8370	7720		8880		9440	
4660		5270	6130	5030		5905		6475	8480	7760		8930		9490	
4670		5325	6180	5060		5940		6485	8580	7810		8930		9555	
4670		5340	6195	5110		5995		6500	8600	7900		8930		9560	
4680		5350	6245	5125		6005		6540		7960		8930		9620	
4695		5355	6270	5130		6020		6540		8010		8960		9640	
4705		5360	6300	5165		6040		6555		8100		9010		9830	
4710		5370	6310	5180		6050		6580		8110		9020		9840	
4720		5370	6320	5230		6120		6580		8130		9070		9960	
4730		5370	6365	5260		6170		6610		8130		9220		9970	
4740		5395	6370	5280		6190		6610		8135		9270		10005	
4745		5440	6385	5320		6240		6635		8140		9340		10025	
4750		5470	6390	5340		6260		6645		8220		9350		10045	
4760		5490	6400	5390		6440		6665		8225		9370		10070	
4760		5540	6415	5410		6460		6670		8230		9380		10080	
4770		5550	6420	5420		6480		6685		8270		9400		10140	
4815		5550	6430	5480		6530		6695		8290		9400		10295	
4830		5610	6610	5495		6570		6760		8310		9530		10370	
4915		5640	6630	5507		6580		6800		8320		9530		10390	
4970		5655	6665	5550		6650		6885		8340		9550		10400	
5030		5670	6750	5820		6690		6930		8380		9645		10430	
5125		5695	6980	5850		6770		6930		8550		9665		10450	
5140		5720	7315	5920		6820		6980		8600		9670		10460	

TABLE X4.2 Basic Shear Statistics of Sample Data

d_i	n_i	$\bar{P}_i$	S_i	v_i, %	Range
9.5	52	2321	169	7.28	1865–2685
11.875	94	2841	296	10.42	2200–3658
10	48	2471	272	11.01	1815–3165
12	50	2976	289	9.71	2280–3723
14	75	3368	393	11.67	2030–4300
16	56	3926	369	9.40	2990–4730
18	51	4418	401	9.08	3415–5698
20	57	4777	513	10.74	3380–5760

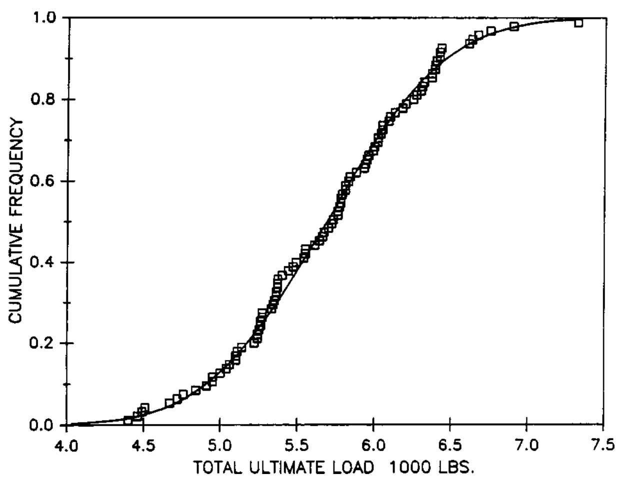


FIG. X4.1 11.875 Data and Normal Distribution

X4.4.5 *Correlation and Regression Analysis*:

X4.4.5.1 The means of the data from Table X4.2 are used to compute the regression equation:

$$P_e = A + Bd_i = 72 + 238d, \quad \text{(X4.4)}$$

X4.4.5.2 The intercept and slope are:

$$A = \frac{\Sigma\bar{P}_i\Sigma d_i^{\,2} - \Sigma d_i\Sigma d_i\bar{P}_i}{J\Sigma d_i^{\,2} - (\Sigma d_i)^2} = 72 \quad \text{(X4.5)}$$

$$B = \frac{J\Sigma d_i\bar{P}_i - \Sigma d_i\Sigma\bar{P}_i}{J\Sigma d_i^{\,2} - (\Sigma d_i)^2} = 238 \quad \text{(X4.6)}$$

X4.4.5.3 The standard error is:

$$S_{\bar{P}_i d_i} = \sqrt{\frac{\Sigma\bar{P}_i{}^2 - A\Sigma\bar{P}_i - B\Sigma d_i\bar{P}_i}{J-2}} = 50 \quad \text{(X4.7)}$$

where summation is from $I = 1$ through J and $J = 8$, the number of depths.

X4.4.5.4 The coefficient of determination is:

$$r^2 = 1 - S^2_{\bar{P}_i d_i}/S^2_{\bar{P}_i} = 1 - (50)^2/(905)^2 = 0.997 \quad \text{(X4.8)}$$

where $S_{\bar{P}i}$ is the standard deviation of the mean shears from Table X4.2.

X4.4.5.5 To check the linear assumption at a lower probability, the 95 % tolerance with 75 % confidence is computed for each depth as follows:

$$P_{0.05} = \bar{P}_i - kS_i \quad \text{(X4.9)}$$

where k depends on the sample size for each depth and is taken from Table X4.3 or Eq X4.20.

X4.4.5.6 Correlating the $P_{0.05}$ values and the depth again results in a coefficient of determination approaching unity. This is expected for reasonably uniform sample sizes and COV's and confirms the approach.

X4.4.5.7 The 95 % tolerance with 75 % confidence has the regression equation $P_{0.05} = 106 + 192d_i$. The equation and the tabulated values of Table X4.4 are plotted on Fig. X4.2, along with the mean values from Table X4.2 and the mean regression equation (Eq X4.4).

X4.4.6 *Determination of Shear Capacity Values from Combined Data*:

X4.4.6.1 In the procedure for combining data, what is really being done is "normalizing" all data to a constant mean value regardless of depth. The underlying implication is that strength difference from depth to depth is solely a function of the depth change and that such difference is reasonably described by a known constant which is defined as the slope (B) of the regression equation. Of course, this is an assumption and the actual assertion is that the best estimate of shear strength is the regression equation rather than the data.

X4.4.6.2 Another way of considering this procedure is that changing section geometry affects shear strength, but unit material and joint strengths, the influences of manufacturing tolerances, etc., are constant for any depth. Test data is being used here because it is not known how to characterize all the individual, but interactive, strength components of the joists, which would presumably allow performance of a calculation that would adequately predict all the failure modes that occur (see Appendix X5 for examples).

X4.4.6.3 The mathematics of the procedure are simplified by using only the data means in the correlation. In the qualification, it is important that the number of tests at each depth included be reasonably consistent.

X4.4.6.4 To demonstrate this process, select some depth (d_n) as a constant and calculate the expected mean P_n (letting the base depth d_n = 10 in.):

$$P_n = 72 + 238(10) = 2452 \quad \text{(X4.10)}$$

The data for all other depths is then normalized by multiplying by the ratio:

$$R = 2452/\bar{P}_i \quad \text{(X4.11)}$$

X4.4.6.5 In this process, the mean for all depths becomes 2452, but the COV for any depth remains unchanged. Multiplying the COV times P_n gives equivalent standard deviations for each depth as listed in Table X4.5. Notice that it is not necessary to actually normalize all the data of Table X4.1 and recompute the standard deviations; multiplying the expected mean value from the regression equation by the known COV for the depth, gives identical results.

X4.4.6.6 Using Eq 3 from 6.2.13.3 provides an estimate of the standard deviation using all of the available data:

$$S = \sqrt{\frac{\Sigma[(n_i - 1)S^2_n]}{\Sigma n_i - J}} = 248 \quad \text{(X4.12)}$$

Where summation is from $i = 1$ to J and J = number of depths; n_i is number of tests for depth i. S_n is the normalized or equivalent standard deviation.

TABLE X4.3 *K*-Factors for One-Sided Tolerance Limits for Normal Distributions[A]

	75 % Confidence (γ = 0.25)				95 % Confidence (γ = 0.05)				99 % Confidence (γ = 0.01)			
1 − p	0.75	0.90	0.95	0.99	0.75	0.90	0.95	0.99	0.75	0.90	0.95	0.99
n												
3	1.464	2.501	3.152	4.397	3.805	6.156	7.657	10.555	8.726	13.997	17.374	23.900
4	1.255	2.134	2.681	3.726	2.617	4.162	5.145	7.044	4.714	7.381	9.085	12.389
5	1.151	1.962	2.464	3.422	2.149	3.407	4.203	5.742	3.453	5.362	6.580	8.941
6	1.087	1.859	2.336	3.244	1.895	3.007	3.708	5.063	2.847	4.412	5.407	7.336
7	1.043	1.790	2.251	3.127	1.732	2.756	3.400	4.643	2.490	3.860	4.729	6.413
8	1.010	1.740	2.189	3.042	1.617	2.582	3.188	4.355	2.253	3.498	4.286	5.813
9	0.984	1.702	2.142	2.978	1.532	2.454	3.032	4.144	2.083	3.241	3.973	5.390
10	0.964	1.671	2.104	2.927	1.465	2.355	2.912	3.982	1.954	3.048	3.739	5.075
11	0.946	1.646	2.074	2.886	1.411	2.276	2.816	3.853	1.852	2.898	3.557	4.830
12	0.932	1.625	2.048	2.852	1.366	2.210	2.737	3.748	1.770	2.777	3.411	4.634
13	0.919	1.607	2.026	2.823	1.328	2.156	2.671	3.660	1.702	2.677	3.290	4.473
14	0.908	1.591	2.008	2.797	1.296	2.109	2.615	3.585	1.644	2.593	3.189	4.338
15	0.899	1.577	1.991	2.776	1.267	2.069	2.566	3.521	1.595	2.522	3.103	4.223
16	0.890	1.565	1.977	2.756	1.242	2.033	2.524	3.465	1.552	2.460	3.028	4.124
17	0.883	1.555	1.964	2.739	1.220	2.002	2.487	3.415	1.514	2.405	2.963	4.037
18	0.876	1.545	1.952	2.724	1.200	1.974	2.453	3.371	1.480	2.357	2.906	3.961
19	0.869	1.536	1.942	2.710	1.182	1.949	2.424	3.331	1.450	2.314	2.854	3.893
20	0.864	1.528	1.932	2.697	1.166	1.926	2.396	3.296	1.423	2.276	2.808	3.832
21	0.858	1.521	1.924	2.686	1.151	1.906	2.372	3.263	1.398	2.241	2.767	3.777
22	0.854	1.514	1.916	2.675	1.138	1.887	2.349	3.234	1.376	2.209	2.729	3.727
23	0.849	1.508	1.908	2.666	1.125	1.869	2.329	3.207	1.355	2.180	2.695	3.682
24	0.845	1.502	1.901	2.657	1.113	1.853	2.310	3.182	1.336	2.154	2.663	3.640
25	0.841	1.497	1.895	2.648	1.103	1.838	2.292	3.159	1.319	2.129	2.634	3.602
30	0.825	1.475	1.869	2.614	1.058	1.778	2.220	3.064	1.247	2.030	2.516	3.447
35	0.812	1.458	1.849	2.588	1.025	1.732	2.167	2.995	1.194	1.958	2.430	3.335
40	0.802	1.445	1.834	2.568	0.999	1.697	2.126	2.941	1.154	1.902	2.365	3.249
45	0.794	1.434	1.822	2.552	0.978	1.669	2.093	2.898	1.121	1.857	2.312	3.181
50	0.788	1.426	1.811	2.539	0.960	1.646	2.065	2.863	1.094	1.821	2.269	3.125
60	0.777	1.412	1.795	2.518	0.932	1.609	2.023	2.808	1.051	1.764	2.203	3.039
70	0.769	1.401	1.783	2.502	0.911	1.581	1.990	2.766	1.019	1.722	2.153	2.974
80	0.762	1.393	1.773	2.489	0.894	1.560	1.965	2.733	0.994	1.689	2.114	2.924
90	0.757	1.386	1.765	2.479	0.881	1.542	1.944	2.707	0.974	1.662	2.083	2.884
100	0.753	1.380	1.758	2.470	0.869	1.527	1.927	2.684	0.957	1.639	2.057	2.850
120	0.745	1.371	1.747	2.456	0.851	1.503	1.900	2.650	0.930	1.604	2.016	2.797
140	0.740	1.364	1.739	2.446	0.837	1.485	1.879	2.623	0.909	1.577	1.985	2.758
160	0.736	1.358	1.733	2.438	0.826	1.471	1.862	2.602	0.893	1.556	1.960	2.726
180	0.732	1.353	1.727	2.431	0.817	1.460	1.849	2.585	0.879	1.539	1.940	2.700
200	0.729	1.350	1.723	2.425	0.809	1.450	1.838	2.570	0.868	1.524	1.923	2.679
250	0.723	1.342	1.714	2.414	0.794	1.431	1.816	2.542	0.846	1.496	1.891	2.638
300	0.719	1.337	1.708	2.406	0.783	1.417	1.800	2.522	0.830	1.476	1.868	2.609
350	0.715	1.332	1.703	2.400	0.775	1.407	1.788	2.507	0.818	1.461	1.850	2.586
400	0.712	1.329	1.699	2.395	0.768	1.398	1.778	2.495	0.809	1.449	1.836	2.568
450	0.710	1.326	1.696	2.391	0.763	1.391	1.770	2.484	0.801	1.438	1.824	2.553
500	0.708	1.324	1.693	2.387	0.758	1.385	1.763	2.476	0.794	1.430	1.815	2.541
600	0.705	1.320	1.689	2.382	0.750	1.376	1.753	2.462	0.783	1.416	1.799	2.521
700	0.703	1.317	1.686	2.378	0.745	1.369	1.744	2.452	0.775	1.406	1.787	2.506
800	0.701	1.315	1.683	2.374	0.740	1.363	1.738	2.443	0.768	1.398	1.777	2.493
900	0.699	1.313	1.681	2.371	0.736	1.358	1.732	2.436	0.762	1.391	1.769	2.483
1000	0.698	1.311	1.679	2.369	0.733	1.354	1.728	2.431	0.758	1.385	1.763	2.475
1500	0.694	1.306	1.672	2.361	0.722	1.340	1.712	2.411	0.742	1.365	1.741	2.447
2000	0.691	1.302	1.669	2.356[B]	0.715	1.332	1.703	2.400[B]	0.733	1.354	1.727	2.431[B]
2500	0.689	1.300[B]	1.666[B]	2.353[B]	0.711	1.326	1.697[B]	2.392[B]	0.727	1.346	1.719[B]	2.419[B]
3000	0.688	1.299[B]	1.664[B]	2.351[B]	0.708	1.323[B]	1.692[B]	2.386[B]	0.722	1.340[B]	1.712[B]	2.411[B]
inf	0.674	1.282	1.645	2.326	0.674	1.282	1.645	2.326	0.674	1.282	1.645	2.326

[A] Obtained from a noncentral *t* inverse approach; see Guttman, Irwin, Statistical Tolerance Regions: Classical and Bayesian, Hafner Publishing Co., Darien, CT, pp. 88–93, 1970.

[B] Computed using Eq X4.20.

TABLE X4.4 95 % Tolerance with 75 % Confidence of Data Sets in Table X4.1

d_i	K	$P_{0.05}$	
9.5	1.80	2017	Correlation
11.875	1.76	2320	
10	1.80	1981	
12	1.80	2456	
14	1.77	2672	Standard Error = 105
16	1.79	3265	r^2 = 0.980
18	1.80	3696	
20	1.79	3859	

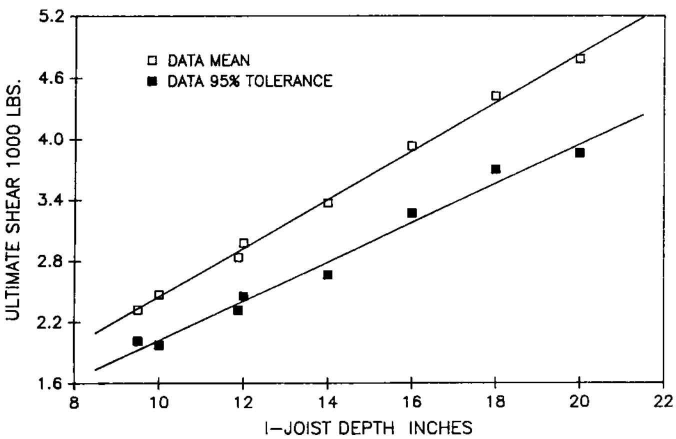


FIG. X4.2 Correlation of Shear Strength and Depth

TABLE X4.5 Normalized Standard Deviations of Data Sets

D	Test COV, v_i	Normalized Standard Deviations, S_n	n_i
9.5	0.0728	179	52
11.875	0.1042	256	94
10	0.1101	270	48
12	0.0971	238	50
14	0.1167	287	75
16	0.094	231	56
18	0.0908	223	51
20	0.1074	264	57

X4.4.6.7 The normalized coefficient of variation becomes:

$$V = \frac{248}{2452} = 0.1013 \quad (X4.13)$$

Identical results are obtained by using (v_i) for (S_n) in Eq X4.12. The combined sample size: N = 483 and from Eq X4.20 for the combined sample, k = 1.69 (for n = 483 − J = 475).

X4.4.6.8 Computing the expected 95 % tolerance with 75 % confidence as a function of depth:

$$P_{0.05} = 72 + 238d_i - 1.69(0.1013)\,[72 + 238d_i] \quad (X4.14)$$

$$P_{0.05} = 60 + 197d_i$$

Compare this result to the regression equation computed through the 95 % tolerance values (Table X4.4) of the data. The difference is insignificant in this case; greater differences should be anticipated given smaller data sets. However, the important point here is that the slope is the same (192 versus 197).

X4.4.6.9 Eq X4.14 gives 95 % tolerance with 75 % confidence values to use in determining the capacity from the data of Table X4.1. That is, in the Eq 4 of 6.2.13.4:

$$(P_e - kvP_e) = 60 + 197d_i \quad (X4.15)$$

and capacity as a function of depth is:

$$P_s = \frac{(60 + 197d_i)}{2.37} = 25 + 83.1d_i \quad (X4.16)$$

X4.4.6.10 A great convenience of this procedure is the ability to combine data from different depths in a daily quality-control scheme. Because the capacity is based on the regression equation, substituting that equation (P_e), X4.4, for (P) in Eq X4.11, gives a ratio which can be applied to any test result to "adjust out" the effect of depth. The resulting relative number can then be compared to the expected mean (P_n) in whatever statistical procedure is used in quality control.

X4.4.7 *Check Requirements of* 6.2.12—Using the random number table from Schaum's, ten data points were selected from Table X4.1 for 10, 14, 16, and 20-in. depths; the resulting values are tabulated in Table X4.6. Basically, this is a simulation of the minimum testing required in 6.2. How valid this simulation is may be questioned since the data in Table X4.1 was collected over a long period and such minimum testing would probably come from a short production run. However, the following calculations show that the criteria of 6.2.12 (min r^2 = 0.9) should be easily met, at least when the linear relationship is valid and the data COV is around 10 %:

Correlation of the means:

$$P_e = -89 + 243d_i \quad (X4.17)$$

Standard Error = 29 $\quad r^2 = 0.999$

Normalizing to 10-in. depth (P_n = 2341) gives:

d_i	Equivalent Standard Deviation = S_n
10	239
14	183
16	283
20	222

Eq X4.12 S = 235 COV = 10.04 %

$$N = 40\ (N - J = 36) \quad (X4.18)$$

$$k = 1.849 \text{ (Table X4.3)}$$

$$P_{0.05} = -89 + 243d - 0.1004\,(1.849)(-89 + 243d)$$

$$= -72 + 198d_i$$

$$P_s = -30 + 84d_i$$

TABLE X4.6 Ten Random Values from Each of Four Depths

	10 in.	14 in.	16 in.	20 in.
	2513	3333	4155	4465
	2270	2870	3615	4700
	2425	3178	4065	5023
	2300	3668	2990	5185
	1975	3348	4170	4323
	2583	3510	3220	4615
	2180	2885	4070	5035
	2120	3270	4055	5040
	2245	3490	4410	3855
	2775	3343	3550	5325
$\bar{P}_i$	2339	3290	3830	4757
S_i	238	257	462	453
v_i	10.2 %	7.8 %	12.1 %	9.5 %

TABLE X4.7 Linear Transformations

NOTE 1—ϵ and μ are location parameters respectively for three parameter Lognormal and Weibull distributions. Setting these values at zero will provide two parameter fits.

Distribution	Y_i	T_i
Normal	X_i	Standard Normal Z for $F_n(X_i)$
Lognormal	$Ln(X_i - \epsilon)$	Standard Normal Z for $F_n(X_i)$
Weibull	$Ln(X_i - \mu)$	$Ln[-Ln\{1 - F_n(X_i)\}]$

which is not significantly different from the previous result.

X4.5 *One-Sided Tolerance Limits for a Normal Distribution*—A one-sided tolerance limit, *PTL*, is a value about which it may be said with confidence l-γ, that at least a proportion, l-p, of the population is greater than *PTL*. The formula is as follows:

$$PTL = \bar{X} - Ks \quad (X4.19)$$

where $\bar{X}$ and *s* are the mean and standard deviation, respectively, calculated from the sample data. *K* depends upon sample size *n*, as well as percentile 100-p and confidence l-γ. *K* values are given in Table X4.3 or they may be calculated from the formula:

$$K = \frac{Z_p g + \sqrt{Z_p{}^2 g^2 - [g^2 - Z_\gamma{}^2/(2(n-1))](Z_p{}^2 - Z_\gamma{}^2/n)}}{g^2 - Z_\gamma{}^2/(2(n-1))} \quad (X4.20)$$

where:
g = $(4n - 5)/(4n - 4)$, and
Z_p and Z_γ = are calculated with the following formula:

$$Z = T - (b_0 + b_1T + b_2T^2)/(1 + b_3T + b_4T^2 + b_5T^3) \quad (X4.21)$$

where:
T = $\sqrt{Ln(1/Q^2)}$ ($Q = p$ for Z_p and $Q = \gamma$ for Z_γ)
b_0 = 2.515517
b_1 = 0.802853
b_2 = 0.010328
b_3 = 1.432788
b_4 = 0.189269
b_5 = 0.001308

NOTE X4.1—*K* values computed using Eq X4.20 are approximations (see Ref (**15**) in Practice D 2915). For small values, the formula can seriously overestimate the *K* factors.

X4.6 *Normal Curve Calculations:*

X4.6.1 Equations X4.21 and X4.22 calculate either *Z* or *Q* for the right half of the normal curve when one or the other are known. Because of symmetry, this half of the standard normal is sufficient to handle any normal curve situation in which areas under the curve and associated abscissa values are involved. From a data set of variables called *X*, the transformation to a corresponding *Z* is:

$$Z = (X - \bar{X})/s \quad (X4.22)$$

where $\bar{X}$ is the mean and *s* is the standard deviation of the data.

X4.6.2 The area shown as *Q* in Fig. X4.3, if *Z* is specified, is given by:

$$R = F(Z)\{a_1T - a_2T^2 + a_3T^3 - a_4T^4 + a_5T^5\} \quad (X4.23)$$

where:
$F(Z)$ = $[1/\sqrt{(2\pi)}]\text{Exp}(-Z^2/2)$,
T = $1/(1 + 0.2316419|Z|)$,
a_1 = 0.31938153
a_2 = 0.356563782
a_3 = 1.781477937
a_4 = 1.821255978
a_5 = 1.330274429
Then $Q = R$ if $Z \geq 0$; $Q = 1 - R$ if $Z < 0$.

X4.7 *Fitting Distribution Curves and Testing Fit Quality*—These fitting procedures are based on the principle of using probability paper graduated for a particular cumulative frequency distribution so as to produce a straight line plot of the data if the distribution fits well. It is, however, no longer necessary to seek out such papers nor is it necessary to plot the data by hand. Desktop or laptop computers can readily transform the axis variables to linear ones which, in effect, create the same linearized space produced by the probability papers. Plotting will produce a straight line path of data points if the curve for which the axes are transformed is appropriate. Simple linear regression line fitting can be accomplished in this space which will yield estimates of the distribution parameters. Tests of goodness of fit can also be made.

X4.7.1 *Plotting and Transformations*:

X4.7.1.1 The fundamental data consists of a rank ordered set of *n* observations arranged in ascending order with the rank one datum being the lowest value and the rank *n* datum being the highest value. The individual data values are labelled X_i and their cumulative frequency position is given by:

$$Fn(Xi) = i/(n + 1) \text{ or } = (i - 0.5)/n \quad (X4.24)$$

where *i* is the rank. The plot of $F_n(X_i)$ *versus* X_i is called the empirical cumulative distribution function or EDF. A typical EDF plot is shown in Fig. X4.4 where compression strength is *X* and cumulative frequency is $F_n(X)$.

X4.7.1.2 A proposed theoretical cumulative distribution can be superimposed on the EDF for visual comparison of fit quality, but it is often difficult to judge how well one curve path fits another. By linearly transforming both variables, it is easier to see whether the path of points is generally linear. Linear transforms of values $F_n(X_i)$ to values Y_i and values X_i to T_i are given in Table X4.8 for Normal, Lognormal, and Weibull distributions. Other transformations are given in X4.2.2. An approximation function for calculating standard normal *Z* values is given in Eq. X4.23. An approximation function for calculating $F(X) = P$ is given in Eq X4.23.

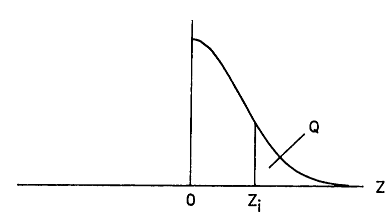


FIG. X4.3 Area (Q) Under Normal Curve

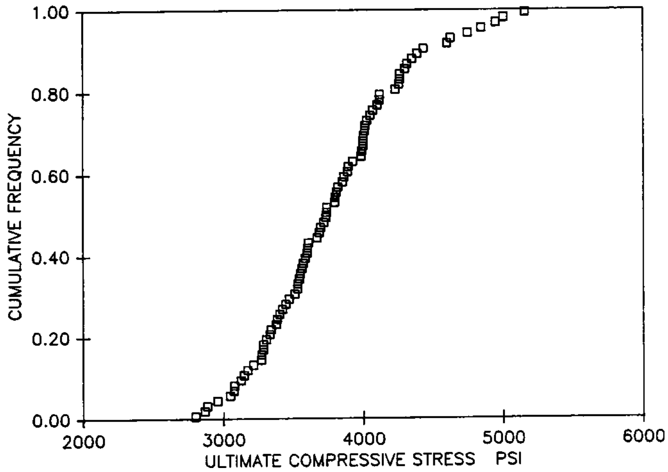


FIG. X4.4 An EDF Plot of 80 Data Points

TABLE X4.8 Critical Values of A for Goodness of Fit Testing Based on the Anderson-Darling Statistic

Significance Level, α	Two-Parameter Distribution	Three-Parameter Distribution
0.01	1.038	...
0.05	0.757	...
0.10	0.637	...

X4.7.1.3 A linear plot in a lognormal transformed space of the data displayed in Fig. X4.4 is shown in Fig. X4.5. The data points generally follow a straight path. The linear, least squares regression line:

$$Y = A + BT \qquad \text{(X4.25)}$$

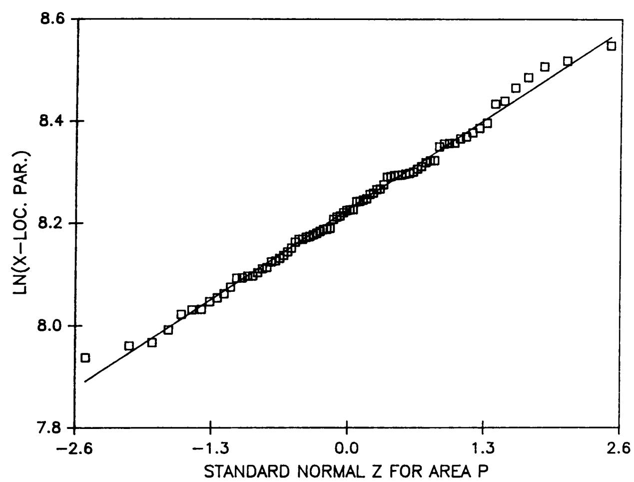


FIG. X4.5 Data Transformed to Linear Lognormal

fitted to the data Y_i, T_i is also shown in Fig. X4.3. It is possible to associate distribution parameters with *A* and *B* and to proceed to calculate goodness of fit statistics in the original F_n (X_i), X_i space. The values of the parameters of the three theoretical distributions, *F* (X_i), are given in Table X4.9. In this case, the logmean is *A* and the logarithmic standard deviation is *B*.

X4.7.2 *Goodness of Fit Tests*:

X4.7.2.1 The correlation coefficient from the linear fit will yield some estimate of how well the data values group around the line, but the distortions of transformations are in this calculation. Measures of fit quality can better be made in the original *F*, *X* space in which the values *F* (X_i) can be tested against their associated values $F_n(X_i)$. The simplest of these is the standard error of estimate, *S*, given by

$$S = \sqrt{\{1/n\Sigma_i[F(X_i) - F_n(x_i)]^2\}} \qquad \text{(X4.26)}$$

X4.7.2.2 The values *F* (X_i) can be calculated as *P* (*x*) given by approximation Eq X4.23. *S* is used to compare the appropriateness of various distributions with regard to a single data set. The lowest value of *S* will indicate the tightest fit. If a three-parameter lognormal or a Weibull is used, various trial values of the location parameter between zero and the lowest data value will usually yield one for which *S* is minimum.

X4.7.2.3 Once the best distribution is chosen in terms of minimum *S*, other statistics can be calculated for comparison with table values which will give a more general indication of fit quality. The Anderson Darling statistic, called A_2, (X4.2.2) has been found to work well in judging goodness of fit of distributions to lumber mechanical properties data.

X4.7.2.4 The quantity $A = A^2(1 + 0.2\sqrt{n})$ may be compared with the entries in Table X4.8 to test the hypothesis that the data come from the population represented by the fitted curve. The hypothesis is rejected, at the significance level α, if *A* exceeds the tabulated value. As the significance level, α, increases the test becomes more stringent requiring lower *A* values to prevent rejection.

TABLE X4.9 Distribution Parameters from Linear Regression in Linearized Plotting Space

NOTE 1—The location parameters ϵ and μ are supplied externally to the fitting process to obtain three parameter Lognormal and Weibull fits. Determining best values for these parameters is discussed in X4.7.2.

F(*X*)	Mean	Standard Deviation	Shape	Scale
Normal	A	B		
Lognormal	A	B		
Wiebull			1/B	Exp(A)

X5. FAILURE CODING IN TESTS OF PREFABRICATED WOOD I-JOISTS

X5.1 *Scope*—Particularly in shear testing, a wide variety of failure modes is observed; many of these do not correspond with the appearance and mode of shear failures in other wood members. In fact, it can be argued that many of the observed modes are not shear failures at all. Nonetheless, most of these observed modes do influence the shear capacity and, with the exception of stiffness related web buckling, they are usually not separated in capacity evaluation. This appendix is offered primarily to avoid confusion due to the variety of failure modes often simply categorized as "shear failures." A partial list of "shear" failure modes is given along with those of bending. One possible coding scheme and test-data sheet are suggested and sketches (Fig. X5.1) are included in explanation of codes.

X5.2 *Example Coding System:*

X5.2.1 This coding system is designed to assist in describing failures of I-joists tested for product qualification, or quality-control purposes. Use of a data sheet like Fig. X5.2 may facilitate official documentation of test results. As failure trends develop, additional codings may be added to the list. Codes should be listed on the data sheet in the order that they

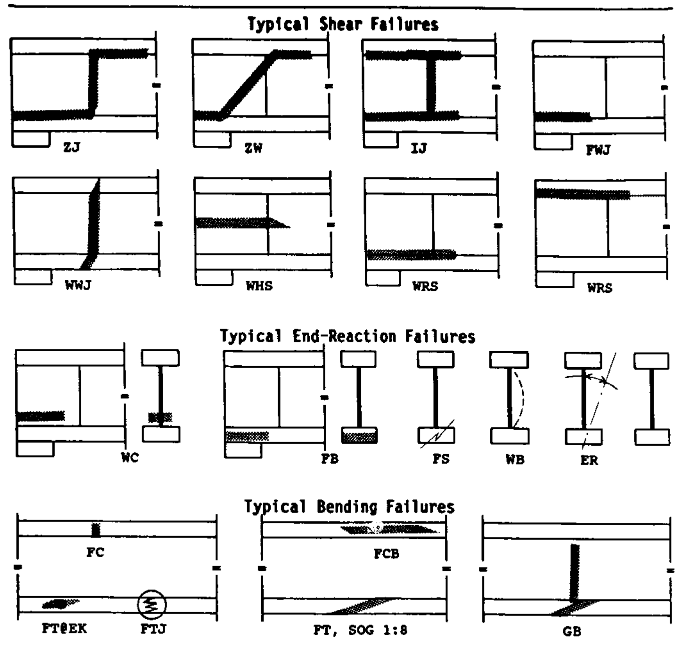
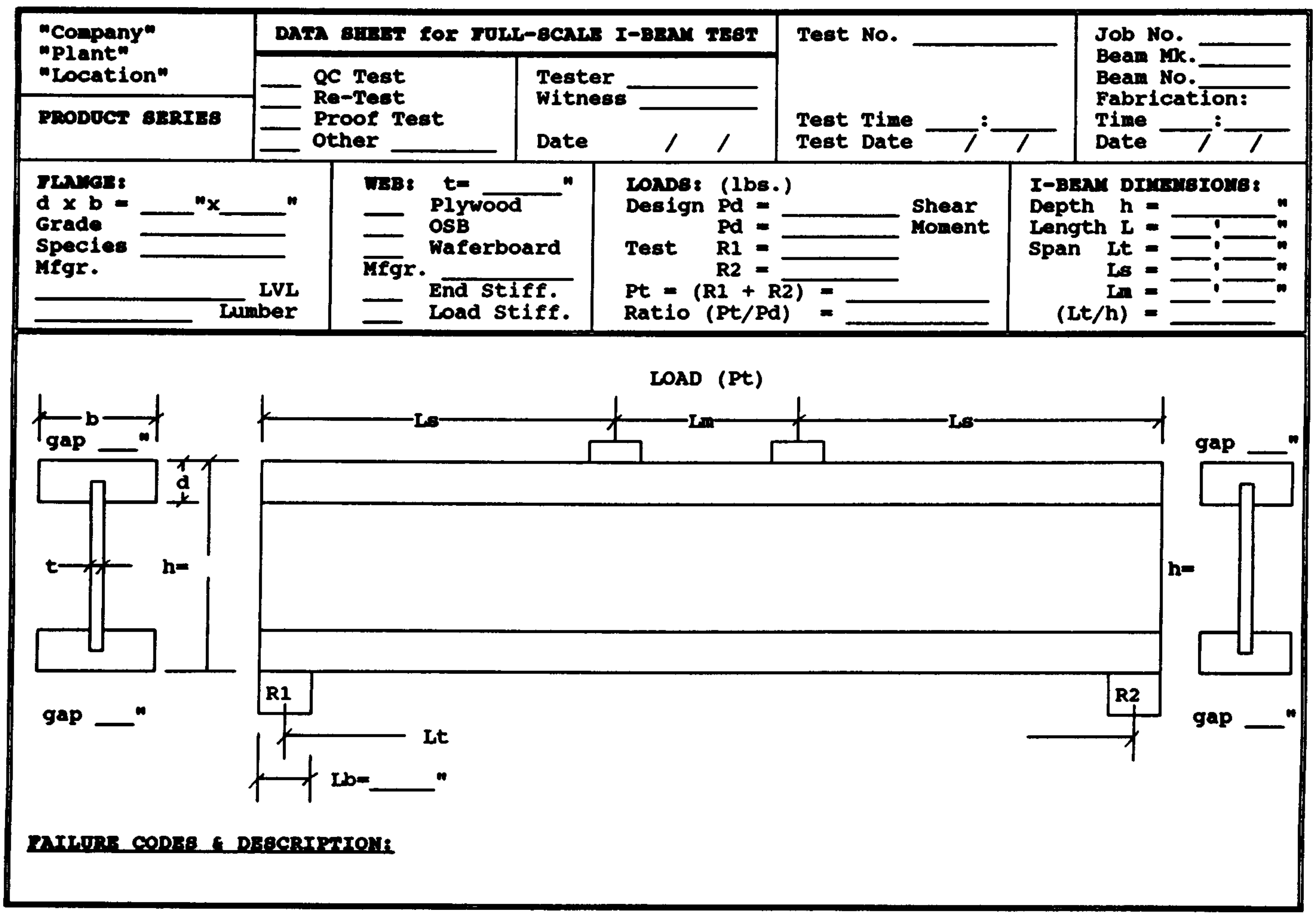


FIG. X5.2 Failure Codes for Full-Scale Tests


"Company"
"Plant"
"Location"
PRODUCT SERIES

DATA SHEET for FULL-SCALE I-BEAM TEST
___ QC Test
___ Re-Test
___ Proof Test
___ Other ________
Tester ________
Witness ________
Date / /

Test No. ________
Test Time ___:___
Test Date / /

Job No. ______
Beam Mk. ______
Beam No. ______
Fabrication:
Time ___:___
Date / /

FLANGE:
d x b = ____"x____"
Grade ________
Species ________
Mfgr.
________ LVL
________ Lumber

WEB: t= _____"
___ Plywood
___ OSB
___ Waferboard
Mfgr. ________
___ End Stiff.
___ Load Stiff.

LOADS: (lbs.)
Design Pd = ________ Shear
Pd = ________ Moment
Test R1 = ________
R2 = ________
Pt = (R1 + R2) = ________
Ratio (Pt/Pd) = ________

I-BEAM DIMENSIONS:
Depth h = ______"
Length L = ___'___"
Span Lt = ___'___"
Ls = ___'___"
Lm = ___'___"
(Lt/h) = ______

LOAD (Pt)
b
gap ___"
d
t
h=
gap ___"
Ls
Lm
Ls
R1
R2
Lt
Lb=____"
gap ___"
h=
gap ___"

FAILURE CODES & DESCRIPTION:

FIG. X5.1 Example of Test Data Sheet

were perceived to have contributed to failure, that is, major causes first. Use qualifiers in conjunction with codes (ZW with 6 in. of web-web joint involved). Evaluate glue line quality of joint failures by estimating percent wood failure at surfaces.

X5.2.2 *Failure Codes Associated with Short-Span Shear Tests*:

X5.2.2.1 *ZJ*—Failure line runs horizontally along bottom flange-web joint at end of the beam, then proceeds vertically along a web-web joint, then horizontally along the top flange-web joint toward the center span. Failure lines primarily follow glue joints.

X5.2.2.2 *ZW*—Same as *ZJ* except the web failure line does not involve a web-web joint, and usually the line runs nearer to 45° than vertical. Combinations of *ZJ* and *ZW* occur, with various amounts of the web-web joint involved.

X5.2.2.3 *IJ*—Similar to *Z* type failures, but with the horizontal flange-web joint failures extending both ways from the vertical web-web failure line.

X5.2.2.4 *FWJ*—Flange-web joint shear failure at the bottom or top joint.

X5.2.2.5 *WWJ*—Web-web joint vertical shear failure.

X5.2.2.6 *WHS*—Horizontal shear failure in web. (Mostly in plywood webs.)

X5.2.2.7 *WRS*—Rolling shear in web at web-flange joint. (For plywood webs.)

X5.2.2.8 *WC*—Web crushing, usually at end reaction with unstiffened ends.

X5.2.2.9 *WB*—Web buckle at end-reaction; usually without stiffeners.

X5.2.2.10 *FS*—Flange joint split at end reaction. Qualify with notes of minor, major, or measure and record length of split.

X5.2.2.11 *ER*—End rotation causes end bearing or *FS* failure. Additional lateral support probably required.

X5.2.2.12 *FF*—Occasionally, specimens fail in bending. Such failures should be excluded from shear data and one of the following codes can be added.

X5.2.3 *Failure Codes Associated with Long-Span Bending Moment Tests*:

X5.2.3.1 *FT*—Flange failure in tension. Record distance from center-line or end. Record type, size, and location of defect(s) involved. Evaluate if flange was on grade relative to visual specs.

X5.2.3.2 *FTJ*—Flange failure in tension at finger joint. Read percent of joint involved and percent of wood failure on failed surfaces (for example, (40/80)).

X5.2.3.3 *FC*—Flange failure in flexural compression. Commonly near load points.

X5.2.3.4 *FCB*—Flange failure in buckling. Usually due to inadequate lateral support.

X5.2.3.5 *SOG*—Slope-of-grain in flange. Either local, as around knots, or general. Measure general SOG and record if not in accordance with specification.

X5.2.4 *Qualifier Codes*:

X5.2.4.1 *BB*—Bad bond or no glue bond. Zero to thirty percent wood failure along glue joints.

X5.2.4.2 *PB*—Poor bonding. Thirty to seventy percent wood failure along glue joints.

X5.2.4.3 *GB*—Good bonding. Seventy to one-hundred percent wood failure along glue joints.

X5.2.4.4 *GM*—Glue missing in joint.

X5.2.4.5 *NGT*—No glue transfer. Glue was spread, but did not transfer to mating surface. Usually due to inadequate assembly pressure, long open assembly time, or misfabrication. Measure length of joint involved.

X5.2.4.6 *PTT*—Prior to test. Relates to a process or a material defect observed before test.

X5.2.4.7 *OGM*—Off grade material. It is best to identify and record PTT.

X5.2.4.8 *% MC*—Percent moisture content. (For example, (15 % MC))

X5.2.4.9 *NRP*—Not representative of production. It is best to identify and record PTT.

X5.2.4.10 *MAJ*—Major or primary cause or effect.

X5.2.4.11 *MIN*—Minor or secondary cause or effect.

X6. SHEAR CAPACITY REDUCTION FACTOR FOR PREFABRICATED WOOD I-JOISTS

X6.1 *Scope*—Eq 4 of 6.2.13.4 and Eq 5 of 6.2.13.5 include a possible factor for special use adjustments (*C*) and a divisor (2.37) to arrive at a capacity considered appropriate for structural members produced and used under the provisions of the specification. This appendix provides an explanation of these factors.

X6.2 *Explanation:*

X6.2.1 The denominator of the equations includes two factors considered appropriate to normal use of I-joists:

$$C_D = 0.62 \text{ to adjust data to normal (10 year) duration.} \quad (X6.1)$$

X6.2.2 $C_B = 0.875$ allows for uncertainties considered usual to normal applications of I-joists. The principle concerns contained in this factor are normal construction tolerances which may reduce specified bearing length, minor damage to joist ends during installation, and some strength loss due to temporary wetting.

X6.3 An additional factor, *F*, to account for sample size and variability is derived as follows:

X6.3.1 It is a committee judgement that a suitable baseline is a ratio of 2.9 between the ultimate mean shear strength, $\bar{P}_i$, and the shear capacity, P_s, under the following standard conditions.

X6.3.1.1 The shear strength, *P*, is normally distributed.

X6.3.1.2 The standard distribution is based on a sample size of $N = 40$ and has a coefficient of variation, *v*, of 0.1. The shear capacity, P_s, as calculated by Eq 5 of 6.2.13.5, is to be the 5 % tolerance limit with 75 % confidence with reference to Table X4.6. The resulting factor, $K = 1.834$.

X6.3.1.3 The factor C in Eq 5 is temporarily set for this derivation at the product of C_D and C_B = 0.5425.

X6.3.2 Eq 5 is now expressed as $P_s = C\bar{P}_i (1 - Kv)/F$,

X6.3.2.1 Rearranging $\bar{P}_i/P_s = 2.9 = F/C\ (1 - KV)$,

X6.3.2.2 Thus $F = 2.9C(1 - Kv) = (2.9)(0.5425)$

$(1 - 0.1834)$

$= 1.285$ for the above conditions.

X6.3.3 Combining F with the temporary C yields $F/C = 2.37$.

X6.3.3.1 Equation with the original C restored but no longer containing C_D or C_B becomes:

$$P_s = C(\bar{P}_i - Kv\bar{P}_i)/2.37 \quad \text{(X6.2)}$$

X6.3.3.2 C now consists of other adjustment factors that may be necessary for satisfactory design. Two of these are:

(a) (*a*) C_R = Effects of treatment, and

(b) (*b*) C_M = Environmental effects such as elevated moisture or temperature.