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

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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:*

D 198 Test Methods of Static Tests of Lumbers in Structural Sizes[2]

D 245 Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber[2]

D 2559 Specification for Adhesives for Structural Laminated Wood Products for Use Under Exterior (Wet Use) Exposure Conditions[3]

D 2915 Practices for Evaluating Allowable Properties for Grades of Structural Lumber[2]

D 4761 Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Material[2]

E 4 Practices for Force Verification of Testing Machines[4]

E 380 Practice for Use of the International System of Units (SI) (The Modernized Metric System)[5]

E 529 Guide for Conducting Flexural Tests on Beams and Girders for Building Construction[6]

E 699 Practice for Criteria for Evaluation of Agencies Involved in Testing, Quality Assurance, and Evaluating Building Components in Accordance With Test Methods Promulgated By ASTM Committee E-6[6]

2.2 *Other Standards:*

U.S. Product Standard PS-1 Construction and Industrial Plywood[7]

U.S. Product Standard PS-2 Performance Standard for Wood-Based Structural-Use Panels[7]

CSA O112.7 Resorcinol and Phenol-Resorcinal Resin Adhesives[8]

CSA O151 Canadian Softwood Plywood[8]

CSA O325.0 Construction Sheathing[8]

CSA O452 Design Rated OSB[8]

Lumber Grading Rules Approved by American Lumber Standards Committee (ALSC) or Canadian Lumber Standards Accreditation Board (CLSAB)[9]

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.

3.2 *Definitions of Terms Specific to This Standard:*

[1] This specification is under the jurisdiction of ASTM Committee D7 on Wood and is the direct responsibility of Subcommittee D07.02 on Lumber and Engineered Wood Products.

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[2] *Annual Book of ASTM Standards*, Vol 04.10.

[3] *Annual Book of ASTM Standards*, Vol 15.06.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

[5] *Annual Book of ASTM Standards*, Vol 14.02.

[6] *Annual Book of ASTM Standards*, Vol 04.07.

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

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

[9] 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, B.C., Canada V6E 2E9.

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*—Prefabricated wood I-joists are permitted to have the following moment capacity adjustment increases for repetitive member use depending upon the type of flange material:

Visually graded solid-sawn lumber	15 %
Machine stress-rated lumber	7 %
Structural composite lumber	4 %

4.1.2.1 To qualify for the increase, the wood I-joists must be part of a wood-framing system consisting of at least three wood I-joists joined by transverse load distributing elements adequate to support the design load. The wood I-joists shall not be spaced more than 24 in. on center.

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.

4.3 *Volume Effects*—A brief discussion of volume effects in I-joists is given in Appendix X2.

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 2—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 Methods 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 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. 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 3—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:

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

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 *Analytic Method*:

6.3.1.1 In this method, the moment capacity is the product of the net flange section modulus (all web material removed) of the member (computed as a transformed section when appropriate) and the axial stress capacity of the flange material obtained from:

(a) Tables of values for 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).

(b) The testing and analysis of 6.3.1.2 when flanges are structural composite lumber. Structural composite lumber shall conform to the general intent of this specification and to the requirements of Section 10.

(c) The procedures detailed in 6.3.1.2, 6.3.1.3, and 6.3.1.4 for flanges of sawn lumber which do not meet the requirements of 6.3.1.1 (*a*).

(d) Section 6.4 for end joints used in any flange material, when the tensile capacity is less than that of the material.

6.3.1.2 In cases where the flange material is of a solid sawn lumber which has undergone a specified proof load or other continuous regrading process such that there is no axial stress capacity assigned by the code, the capacity shall be determined from test results.

6.3.1.3 Tension tests parallel to grain shall be conducted on a length not less than 8 ft (2.44 m) between grips, with load rate to produce failure in not less than 1 min. Minimum sample size shall be 53.

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

$$F_{ci} = F_{ti}(F_c/F_t) \quad (6)$$

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 *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 4—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 5—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 shall conform to the requirements of 5.3. Standards recognized by the governing code are acceptable for tensile strength qualification, provided such standards include full-section tension tests, a minimum sample size of 53, and conform to the general intent and Section 10 of this specification.

6.4.2 *In-House Joints*—End joints produced by the I-joist manufacturer shall be qualified in accordance with 6.4.1 or the provisions of this specification. Adhesives shall conform to the requirements of 5.3. Tensile strength capacity shall be determined in accordance with 6.3.1.3, except that length between grips may be reduced to a minimum of 2 ft (0.61 m).

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.

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 6—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.

9.2 *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 Practices E 4 and other appropriate procedures, 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 to destruction. 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, the testing of that section shall be included in daily quality-control tests.

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 6 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.

11.4 *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 Practice 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 D-7 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 The allowable bending strength increases for repetitive member use were derived taking into consideration the coefficient of variation (COV) of the stiffness of various flange materials. The original theory justifying this type of increase seems to be based on the relative stiffness of the members and positive correlation between bending strength and stiffness. Logic indicates that as stiffness COV decreases so would the load sharing. That is, as stiffness COV tends to zero, lack of differential deflection eliminates load transfer.

X1.4.1.1 For purposes of this specification, it was determined that visually graded lumber would have a stiffness COV of 25 %, and in that case the appropriate load sharing factor would be 15 % which has been accepted by the model building codes. It was judged the MSR lumber stiffness COV would be 11 %, and structural composite lumber stiffness COV would be 7 %. It was also judged that the load sharing factors appropriate for MSR and SCL would be proportional to the stiffness COV. This gives the 7 % for MSR and the 4 % for SCL (Note X1.1).

Visually graded solid-sawn lumber	15 %
Machine stress-rated lumber	7 %
Structural composite lumber	4 %

NOTE X1.1—It is not intended that the reduced factors be applied to members other than wood I-joists.

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*—Changes in member volume and the stress distribution within the member (related to type of loading and support conditions) are known to affect the strength of structural members.

X2.2 *Discussion:*

X2.2.1 In a weak-link analysis, the greater the volume of material at a given stress level, the greater the probability of failure. The usual net effect is that strength decreases with increasing volume. The theoretical prediction of this effect is dependent on the strength distribution developed from tests of members at a constant volume and stress distribution. The effects can be determined empirically by testing over a full range of size and stress conditions, but it is often more practical to combine theory with some range of tests which demonstrates agreement with theory.

X2.2.2 *Shear Capacity Effect*—Because the specification requires testing on full-size specimens in the full range of product size, it is expected that a volume factor for shear is unnecessary for design analysis.

X2.2.3 *Moment Capacity Effect*—If the empirical method of 6.3.3 is used to determine bending capacity, then as with shear, volume effect is included in the test results, since the specimen length required is expected to approximate the maximum usable span (certain I-joists are produced to satisfy specific application requirements which may have a maximum span requirement less than that of 6.3.3; in such cases the maximum application span would be tested). In other cases, significant volume effect related primarily to member length is anticipated. However, preliminary theoretical analysis indicates that the provisions of this version of the specification produce conservative bending capacity for relatively "short" members and slightly non-conservative capacity for "long" members. In cases where flange tensile capacity (of any flange material) is determined by test, it is advised that length in such tests should not be too short or nonconservative bending capacity can result.