INTRODUCTION

Numerous evaluations of structural members of sawn lumber have been conducted in accordance with Test Methods D198. While the importance of continued use of a satisfactory standard should not be underestimated, the original standard (1927) was designed primarily for sawn lumber material, such as bridge stringers and joists. With the advent of structural glued laminated (glulam) timbers, structural composite lumber, prefabricated wood I-joists, and even reinforced and prestressed timbers, a procedure adaptable to a wider variety of wood structural members was required and Test Methods D198 has been continuously updated to reflect modern usage.

The present standard provides a means to evaluate the flexure, compression, tension, and torsion strength and stiffness of lumber and wood-based materials in structural sizes. A flexural test to evaluate the shear stiffness is also provided. In general, the goal of the D198 test methods is to provide a reliable and repeatable means to conduct laboratory tests to evaluate the mechanical performance of wood-based materials. While many of the properties tested using these methods may also be evaluated using the field procedures of Test Methods D4761, the more detailed D198 test methods are intended to establish practices that permit correlation of results from different sources through the use of more uniform procedures. The D198 test methods are intended for use in scientific studies, development of design values, quality assurance, or other investigations where a more accurate test method is desired. Provision is made for varying the procedure to account for special problems.

1. Scope

1.1 These test methods cover the evaluation of lumber and wood-based materials in structural sizes by various testing procedures.

1.2 The test methods appear in the following order:

<table>
<thead>
<tr>
<th>Sections</th>
<th>Flexure</th>
<th>Compression (Short Column)</th>
<th>Compression (Long Member)</th>
<th>Tension</th>
<th>Torsion</th>
<th>Shear Modulus</th>
</tr>
</thead>
</table>

1.3 Notations and symbols relating to the various testing procedures are given in Appendix X1.

1.4 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

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

2. Referenced Documents

2.1 ASTM Standards:
- D9 Terminology Relating to Wood and Wood-Based Products
- D1165 Nomenclature of Commercial Hardwoods and Softwoods
- D2395 Test Methods for Density and Specific Gravity (Relative Density) of Wood and Wood-Based Materials
- D2915 Practice for Sampling and Data-Analysis for Structural Wood and Wood-Based Products

2.2 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.
D3737 Practice for Establishing Allowable Properties for Structural Glued Laminated Timber (Glulam)
D4442 Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials
D4761 Test Methods for Mechanical Properties of Lumber and Wood-Based Structural Material
D7438 Practice for Field Calibration and Application of Hand-Held Moisture Meters
E4 Practices for Force Verification of Testing Machines
E6 Terminology Relating to Methods of Mechanical Testing
E83 Practice for Verification and Classification of Extensometer Systems
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E2309 Practices for Verification of Displacement Measuring Systems and Devices Used in Material Testing Machines

3. Terminology

3.1 Definitions—See Terminology E6, Terminology D9, and Nomenclature D1165.

3.2 Definitions: Definitions of Terms Specific to This Standard:

3.2.1 composite wood beam—a laminar construction comprising a combination of wood and other simple or complex materials assembled and intimately fixed in relation to each other so as to use the properties of each to attain specific structural advantage for the whole assembly.

3.2.2 depth of beam (d)—that dimension of the beam that is perpendicular to the span and parallel to the direction in which the load is applied (Fig. 1).

3.2.3 shear span—two times the distance between a reaction and the nearest load point for a symmetrically loaded beam (Fig. 1).

3.2.4 shear span-depth ratio—the numerical ratio of shear span divided by beam depth.

3.2.5 span (ℓ)—the total distance between reactions on which a beam is supported to accommodate a transverse load (Fig. 1).

3.2.6 span-depth ratio (ℓ/d)—the numerical ratio of total span divided by beam depth.

3.2.7 structural beam—sawn lumber, glulam, structural composite lumber, prefabricated wood I-joists, or other similar material for which strength or stiffness, or both, are primary criteria for the intended application and which usually are used in full length and in cross-sectional sizes greater than nominal 2 by 2 in. (38 by 38 mm).

FLEXURE

4. Scope

4.1 This test method covers the determination of the flexural properties of structural beams. This test method is intended primarily for beams of rectangular cross section but is also applicable to beams of round and irregular shapes, such as round posts, pre-fabricated wood I-joists, or other special sections.

5. Summary of Test Method

5.1 The structural member, usually a straight or a slightly cambered beam of rectangular cross section, is subjected to a bending moment by supporting it near its ends, at locations called reactions, and applying transverse loads symmetrically imposed between these reactions. The beam is deflected at a prescribed rate, and coordinated observations of loads and deflections are made until rupture occurs.

6. Significance and Use

6.1 The flexural properties established by this test method provide:

6.1.1 Data for use in development of grading rules and specifications;

6.1.2 Data for use in development of design values for structural members;

6.1.3 Data on the influence of imperfections on mechanical properties of structural members;

6.1.4 Data on strength properties of different species or grades in various structural sizes;

6.1.5 Data for use in checking existing equations or hypotheses relating to the structural behavior of beams;
6.1.6 Data on the effects of chemical or environmental conditions on mechanical properties;
6.1.7 Data on effects of fabrication variables such as depth, taper, notches, or type of end joint in laminations; and
6.1.8 Data on relationships between mechanical and physical properties.

6.2 Procedures are described here in sufficient detail to permit duplication in different laboratories so that comparisons of results from different sources will be valid. Where special circumstances require deviation from some details of these procedures, these deviations shall be carefully described in the report (see Section 11).

7. Apparatus

7.1 Testing Machine—A device that provides (1) a rigid frame to support the specimen yet permit its deflection without restraint, (2) a loading head through which the force is applied without high-stress concentrations in the beam, and (3) a force-measuring device that is calibrated to ensure accuracy in accordance with Practices E4.

7.2 Support Apparatus—Devices that provide support of the specimen at the specified span.

7.2.1 Reaction Bearing Plates—The beam shall be supported by metal bearing plates to prevent damage to the beam at the point of contact between beam and reaction support (Fig. 1). The plates shall be of sufficient length, thickness, and width to provide a firm bearing surface and ensure a uniform bearing stress across the width of the beam.

7.2.2 Reaction Supports—The bearing plates shall be supported by devices that provide unrestricted longitudinal deformation and rotation of the beam at the reactions due to loading. Provisions shall be made to restrict horizontal translation of the beam (see 7.3.1 and Appendix X5).

7.2.3 Reaction Bearing Alignment—Provisions shall be made at the reaction supports to allow for initial twist in the length of the beam. If the bearing surfaces of the beam at its reactions are not parallel, the beam shall be shimmed or the individual bearing plates shall be rotated about an axis parallel to the span to provide full bearing across the width of the specimen. Supports with lateral self-alignment are normally used (Fig. 2).

7.2.4 Lateral Support—Specimens that have a depth-to-width ratio (d/b) of three or greater are subject to out-of-plane lateral instability during loading and require lateral support. Support shall be provided at least at points located about halfway between a reaction and a load point. Additional supports shall be permitted as required to prevent lateral-torsional buckling. Each support shall allow vertical movement without frictional restraint but shall restrict lateral displacement (Fig. 3).

7.3 Load Apparatus—Devices that transfer load from the testing machine at designated points on the specimen. Provisions shall be made to prevent eccentric loading of the load measuring device (see Appendix X5).

7.3.1 Load Bearing Blocks—The load shall be applied through bearing blocks (Fig. 1), which are of sufficient thickness and extending entirely across the beam width to eliminate high-stress concentrations at places of contact between beam and bearing blocks. Load shall be applied to the blocks in such a manner that the blocks shall be permitted to rotate about an axis perpendicular to the span (Fig. 4). To prevent beam deflection without restraint in case of two-point loading, metal bearing plates and rollers shall be used in conjunction with one or both load-bearing blocks, depending on the reaction support conditions (see Appendix X5). Provisions such as rotatable bearings or shims shall be made to ensure full contact between the beam and the loading blocks. The size and shape of these loading blocks, plates, and rollers may vary with the size and shape of the beam, as well as for the reaction bearing plates and supports. For rectangular beams, the loading surface of the blocks shall have a radius of curvature equal to two to four times the beam depth. Beams having circular or irregular cross-sections shall have bearing blocks that distribute the load uniformly to the bearing surface and permit unrestrained deflections.

7.3.2 Load Points—Location of load points relative to the reactions depends on the purpose of testing and shall be recorded (see Appendix X5).

7.3.2.1 Two-Point Loading—The total load on the beam shall be applied equally at two points equidistant from the reactions. The two load points will normally be at a distance from their reaction equal to one third of the span (ℓ/3) (third-point loading), but other distances shall be permitted for special purposes.

7.3.2.2 Center-Point Loading—A single load shall be applied at mid-span.

7.3.2.3 For evaluation of shear properties, center-point loading or two-point loading shall be used (see Appendix X5).

7.4 Deflection-Measuring Apparatus:
7.4.1 General—For modulus of elasticity calculations, devices shall be provided by which the deflection of the neutral axis of the beam at the center of the span is measured with respect to a straight line joining two reference points equidistant from the reactions and on the neutral axis of the beam.

7.4.1.1 The apparent modulus of elasticity ($E_{\text{app}}$) shall be calculated using the full-span deflection ($\Delta$). The reference points for the full-span deflection measurements shall be positioned such that a line perpendicular to the neutral axis at the location of the reference point, passes through the support’s center of rotation.

7.4.1.2 The true or shear-free modulus of elasticity ($E_{\text{sf}}$) shall be calculated using the shear-free deflection. The reference points for the shear-free deflection measurements shall be positioned at cross-sections free of shear and stress concentrations (see Appendix X5).

NOTE 1—The apparent modulus of elasticity ($E_{\text{app}}$) may be converted to the shear-free modulus of elasticity ($E_{\text{sf}}$) by calculation, assuming that the shear modulus ($G$) is known. See Appendix X2.

7.4.2 Wire Deflectometer—A wire stretched taut between two nails, smooth dowels, or other rounded fixtures attached to the neutral axis of the beam directly above the reactions and extending across a scale attached at the neutral axis of the beam at mid-span shall be permitted to read deflections with a telescope or reading glass to magnify the area where the wire crosses the scale. When a reading glass is used, a reflective surface placed adjacent to the scale will help to avoid parallax.

7.4.3 Yoke Deflectometer—A satisfactory device commonly used to measure deflection of the center of the beam with respect to any point along the neutral axis consists of a lightweight U-shaped yoke suspended between nails, smooth dowels, or other rounded fixtures attached to the beam at its neutral axis. An electronic displacement gauge, dial micrometer, or other suitable measurement device attached to the center of the yoke shall be used to measure vertical displacement at mid-span relative to the beam neutral axis (Fig. 4).

7.4.4 Alternative Deflectometers—Deflectometers that do not conform to the general requirements of 7.4.1 shall be permitted provided the mean deflection measurements are not significantly different from those devices conforming to 7.4.1. The equivalency of such devices to deflectometers, such as those described in 7.4.2 or 7.4.3, shall be documented and demonstrated by comparison testing.

NOTE 2—Where possible, equivalency testing should be undertaken in the same type of product and stiffness range for which the device will be used. Issues that should be considered in the equivalency testing include the effect of crushing at and in the vicinity of the load and reaction points, twist in the specimen, and natural variation in properties within a specimen.

7.4.5 Accuracy—The deflection measurement devices and recording system shall be capable of at least a Class B rating when evaluated in accordance with Practice E2309.
8. Test Specimen

8.1 Material—The test specimen shall consist of a structural beam.

8.2 Identification—Material or materials of the test specimen shall be identified as fully as possible by including the origin or source of supply, species, and history of drying and conditioning, chemical treatment, fabrication, and other pertinent physical or mechanical details that potentially affect the strength or stiffness. Details of this information shall depend on the material or materials in the beam. For example, wood beams would be identified by the character of the wood, that is, species, source, and so forth, whereas structural composite lumber would be identified by the grade, species, and source of the material (that is, product manufacturer, manufacturing facility, etc.).

8.3 Specimen Measurements—The weight and dimensions (length and cross-section) of the specimen shall be measured before the test to three significant figures. Sufficient measurements of the cross section shall be made along the length to describe the width and depth of rectangular specimens and to determine the critical section or sections of non-uniform (or non-prismatic) specimens. The physical characteristics of the specimen as described by its density or specific gravity shall be permitted to be determined in accordance with Test Methods D2395.

8.4 Specimen Description—The inherent imperfections or intentional modifications of the composition of the beam shall be fully described by recording the size and location of such factors as knots, checks, and reinforcements. Size and location of intentional modifications such as placement of laminations, glued joints, and reinforcing steel shall be recorded during the fabrication process. The size and location of imperfections in the interior of any beam must be deduced from those on the surface, especially in the case of large sawn members. A sketch or photographic record shall be made of each face and the ends showing the size, location, and type of growth characteristics, including slope of grain, knots, distribution of sapwood and heartwood, location of pitch pockets, direction of annual rings, and such abstract factors as crook, bow, cup, or twist, which might affect the strength of the beam.

8.5 Rules for Determination of Specimen Length—The cross-sectional dimensions of structural beams usually have established sizes, depending upon the manufacturing process and intended use, so that no modification of these dimensions is involved. The length, however, will be established by the type of data desired (see Appendix X5). The span length is determined from knowledge of beam depth, the distance between load points, as well as the type and orientation of material in the beam. The total beam length includes the span (measured from center to center of the reaction supports) and the length of the overhangs (measured from the center of the reaction supports to the ends of the beam). Sufficient length shall be provided so that the beam can accommodate the bearing plates and rollers and will not slip off the reactions during test.

8.5.1 For evaluation of shear properties, the overhang beyond the span shall be minimized, as the shear capacity may be influenced by the length of the overhang. The reaction bearing plates shall be the minimum length necessary to prevent bearing failures. The specimen shall not extend beyond the end of the reaction plates (Fig. X5.3 in Appendix X5) unless longer overhangs are required to simulate a specific design condition.

9. Procedure

9.1 Conditioning—Unless otherwise indicated in the research program or material specification, condition the test specimen to constant weight so it is in moisture equilibrium under the desired environmental conditions. Approximate moisture contents with moisture meters or measure more accurately by weights of samples in accordance with Test Methods D4442.

9.2 Test Setup—Determine the size of the specimen, the span, and the shear span in accordance with 7.3.2 and 8.5. Locate the beam symmetrically on its supports with load bearing and reaction bearing blocks as described in 7.2 – 7.4. The beams shall be adequately supported laterally in accordance with 7.2.4. Set apparatus for measuring deflections in place (see 7.4). Full contact shall be attained between support bearings, loading blocks, and the beam surface.

9.3 Speed of Testing—The loading shall progress at a constant deformation rate such that the average time to maximum load for the test series shall be at least 4 min. It is permissible to initially test a few random specimens from a series at an alternate rate as the test rate is refined. Otherwise, the selected rate shall be held constant for the test series.

9.4 Load-Deflection Curves:

9.4.1 Obtain load-deflection data with apparatus described in 7.4.1. Note the load and deflection at first failure, at the maximum load, and at points of sudden change. Continue loading until complete failure or an arbitrary terminal load has been reached.

9.4.2 If an additional deflection measuring apparatus is provided to measure the shear-free deflection \( \Delta_{sf} \) over a second distance \( (l_{sf}) \) in accordance with 7.4.1.2, such load-deflection data shall be obtained only up to the proportional limit.

9.5 Record of Failures—Describe failures in detail as to type, manner, and order of occurrence, and position in beam. Record descriptions of the failures and relate them to drawings or photographs of the beam referred to in 8.4. Also record notations as the order of their occurrence on such references. Hold the section of the beam containing the failure for examination and reference until analysis of the data has been completed.

9.6 Moisture Content Determination—Following the test, measure the moisture content of the specimen at a location away from the end and as close to the failure zone as practical in accordance with the procedures outlined in Test Methods D4442. Alternatively, the moisture content for a wood specimen shall be permitted to be determined using a calibrated moisture meter according to Standard Practice D7438. The number of moisture content samples shall be determined using Practice D7438 guidelines, with consideration of the expected
moisture content variability, and any related requirements in the referenced product standards.

10. Calculation

10.1 Compute physical and mechanical properties and their appropriate adjustments for the beam in accordance with the relationships in Appendix X2.

11. Report

11.1 Report the following information:

11.1.1 Complete identification of the structural beam, including species, origin, shape and form, fabrication procedure, type and location of imperfections or reinforcements, and pertinent physical or chemical characteristics relating to the quality of the material,
11.1.2 History of seasoning and conditioning,
11.1.3 Loading conditions to portray the load and support mechanics, including type of equipment, lateral supports, if used, the location of load points relative to the reactions, the size of load bearing blocks, reaction bearing plates, clear distances between load block and reaction plate and between load blocks, and the size of overhangs, if present,
11.1.4 Deflection apparatus,
11.1.5 Depth and width of the specimen or pertinent cross-sectional dimensions,
11.1.6 Span length and shear span distance,
11.1.7 Rate of load application,
11.1.8 Computed physical and mechanical properties, including specific gravity or density (as applicable) and moisture content variability, and any related requirements in Table 1.

11.1.9 Data for composite beams include shear and bending moment values and deflections,
11.1.10 Description of failure, and
11.1.11 Details of any deviations from the prescribed or recommended methods as outlined in the standard.

12. Precision and Bias

12.1 Interlaboratory Test Program—An interlaboratory study (ILS) was conducted in 2006–2007 by sixteen laboratories in the United States and Canada in accordance with Practice E691. The scope of this study was limited to the determination of the apparent modulus of elasticity of three different 2 × 4 nominal sized materials tested both edgewise and flatwise. The deflection of the beam’s neutral axis at the mid-span was measured with a yoke according to 7.4. Five specimens of each material were tested in a round-robin fashion in each laboratory, with four test results obtained for each piece of material and test orientation. The resulting precision indexes are shown in Table 1. For further discussion, see Appendix X5.4.

12.2 The terms of repeatability and reproducibility are used as specified in Practice E177.

12.3 Bias—The bias is not determined because the apparent modulus of elasticity is defined in terms of this method, which is generally accepted as a reference (Note 4).

Note 4—Use of this method does not necessarily eliminate laboratory bias or ensure a level of consistency necessary for establishing reference values. The users are encouraged to participate in relevant interlaboratory studies (that is, an ILS involving sizes and types of product similar to those regularly tested by the laboratory) to provide evidence that their

Note 3—Appendix X2 provides acceptable formulae and guidance for determining the flexural properties.

### TABLE 1 Test Materials, Configurations, and Precision Indexes

<table>
<thead>
<tr>
<th>Material</th>
<th>Test Orientation</th>
<th>Width x Depth b x d in. (mm)</th>
<th>Span Test l in. (mm)</th>
<th>Average Apparent Modulus of Elasticity Eapp psi x 10^6 (GPa)</th>
<th>Repeatability Coefficient of Variation CVr</th>
<th>Reproducibility Coefficient of Variation CVr</th>
<th>Repeatability Limits</th>
<th>Reproducibility Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Edgewise</td>
<td>1.5 x 3.5 (38 x 89)</td>
<td>63.0</td>
<td>2.17 (14.9)</td>
<td>1.4 %</td>
<td>2.0 %</td>
<td>2.7 %</td>
<td>3.8 %</td>
<td>4.0 %</td>
</tr>
<tr>
<td>Flatwise</td>
<td>3.5 x 1.5 (89 x 38)</td>
<td>31.5</td>
<td>2.18 (15.0)</td>
<td>1.4 %</td>
<td>3.3 %</td>
<td>2.7 %</td>
<td>3.9 %</td>
<td>6.5 %</td>
</tr>
<tr>
<td>B Edgewise</td>
<td>1.5 x 3.5 (38 x 89)</td>
<td>63.0</td>
<td>1.49 (10.3)</td>
<td>1.0 %</td>
<td>2.1 %</td>
<td>2.0 %</td>
<td>2.8 %</td>
<td>4.2 %</td>
</tr>
<tr>
<td>Flatwise</td>
<td>3.5 x 1.5 (89 x 38)</td>
<td>31.5</td>
<td>1.54 (10.6)</td>
<td>1.3 %</td>
<td>2.7 %</td>
<td>2.6 %</td>
<td>3.6 %</td>
<td>5.3 %</td>
</tr>
<tr>
<td>C Edgewise</td>
<td>1.5 x 3.5 (38 x 89)</td>
<td>63.0</td>
<td>2.35 (16.2)</td>
<td>1.3 %</td>
<td>2.0 %</td>
<td>2.5 %</td>
<td>3.5 %</td>
<td>3.9 %</td>
</tr>
<tr>
<td>Flatwise</td>
<td>3.5 x 1.5 (89 x 38)</td>
<td>31.5</td>
<td>2.78 (19.2)</td>
<td>1.5 %</td>
<td>4.3 %</td>
<td>2.9 %</td>
<td>4.2 %</td>
<td>8.3 %</td>
</tr>
<tr>
<td>All Data Edgewise</td>
<td>1.5 x 3.5 (38 x 89)</td>
<td>63.0</td>
<td>...</td>
<td>1.2 %</td>
<td>2.1 %</td>
<td>2.4 %</td>
<td>3.4 %</td>
<td>4.0 %</td>
</tr>
<tr>
<td>Flatwise</td>
<td>3.5 x 1.5 (89 x 38)</td>
<td>31.5</td>
<td>...</td>
<td>1.4 %</td>
<td>3.4 %</td>
<td>2.7 %</td>
<td>3.9 %</td>
<td>6.7 %</td>
</tr>
</tbody>
</table>

*The precision indexes are the average values of five specimens tested in eleven laboratories which were found to be in statistical control and in compliance with the standard requirements.*
implementation of the Test Method provides levels of repeatability and reproducibility at least comparable to those shown in Table 1. See also X5.4.2 and X5.4.3.

COMPRESSION PARALLEL TO GRAIN (SHORT COLUMN, NO LATERAL SUPPORT, \( l/r < 17 \))

13. Scope
13.1 This test method covers the determination of the compressive properties of elements taken from structural members when such an element has a slenderness ratio (length to least radius of gyration) of less than 17. The method is intended primarily for members of rectangular cross section, but is also applicable to irregularly shaped studs, braces, chords, round poles, or special sections.

14. Summary of Test Method
14.1 The structural member is subjected to a force uniformly distributed on the contact surface of the specimen in a direction generally parallel to the longitudinal axis of the wood fibers, and the force generally is uniformly distributed throughout the specimen during loading to failure without flexure along its length.

15. Significance and Use
15.1 The compressive properties obtained by axial compression will provide information similar to that stipulated for flexural properties in Section 6.
15.2 The compressive properties parallel to grain include modulus of elasticity \( (E_{\text{axial}}) \), stress at proportional limit, compressive strength, and strain data beyond proportional limit.

16. Apparatus
16.1 Testing Machine—Any device having the following is suitable:
16.1.1 Drive Mechanism—A drive mechanism for imparting to a movable loading head a uniform, controlled velocity with respect to the stationary base.
16.1.2 Load Indicator—A load-indicating mechanism capable of showing the total compressive force on the specimen. This force-measuring system shall be calibrated to ensure accuracy in accordance with Practices E4.
16.2 Bearing Blocks—Bearing blocks shall be used to apply the load uniformly over the two contact surfaces and to prevent eccentric loading on the specimen. At least one spherical bearing block shall be used to ensure uniform bearing. Spherical bearing blocks may be used on either or both ends of the specimen, depending on the degree of parallelism of bearing surfaces (Fig. 5). The radius of the sphere shall be as small as practicable, in order to facilitate adjustment of the bearing plate to the specimen, and yet large enough to provide adequate spherical bearing area. This radius is usually one to two times the greatest cross-section dimension. The center of the sphere shall be on the plane of the specimen contact surface. The size of the compression plate shall be larger than the contact surface. It has been found convenient to provide an adjustment for moving the specimen on its bearing plate with respect to the center of spherical rotation to ensure axial loading.

16.3 Compressometer:
16.3.1 Gage Length—For modulus of elasticity calculations, a device shall be provided by which the deformation of the specimen is measured with respect to specific paired gage points defining the gage length. To obtain test data representative of the test material as a whole, such paired gage points shall be located symmetrically on the lengthwise surface of the specimen as far apart as feasible, yet at least one times the larger cross-sectional dimension from each of the contact surfaces. At least two pairs of such gage points on diametrically opposite sides of the specimen shall be used to measure the average deformation.
16.3.2 Accuracy—The device shall be able to measure changes in deformation to three significant figures. Since gage lengths vary over a wide range, the measuring instruments should conform to their appropriate class in accordance with Practice E83.

17. Test Specimen
17.1 Material—The test specimen shall consist of a structural member that is greater than nominal 2 by 2-in. (38 by 38-mm) in cross section (see 3.2.7).
17.2 Identification—Material or materials of the test specimen shall be as fully described as that for beams in 8.2.
17.3 Specimen Measurements—The weight and dimensions (length and cross-section) of the specimen, shall be measured
before the test to three significant figures. Sufficient measurements of the cross section shall be made along the length of the specimen to describe shape characteristics and to determine the smallest section. The physical characteristics of the specimen, as described by its density or specific gravity, shall be permitted to be determined in accordance with Test Method D2395.

17.4 Specimen Description—The inherent imperfections and intentional modifications shall be described as for beams in 8.4.

17.5 Specimen Length—The length of the specimen shall be such that the compressive force continues to be uniformly distributed throughout the specimen during loading—hence no flexure occurs. To meet this requirement, the specimen shall be a short column having a maximum length, \( l \), less than 17 times the least radius of gyration, \( r \), of the cross section of the specimen (see compressive notations). The minimum length of the specimen for stress and strain measurements shall be greater than three times the larger cross section dimension or about ten times the radius of gyration.

18. Procedure

18.1 Conditioning—Unless otherwise indicated in the research program or material specification, condition the test specimen to constant weight so it is at moisture equilibrium, under the desired environment. Approximate moisture contents with moisture meters or measure more accurately by weights of samples in accordance with Test Methods D4442.

18.2 Test Setup:

18.2.1 Bearing Surfaces—After the specimen length has been calculated in accordance with 18.5, cut the specimen to the proper length so that the contact surfaces are plane, parallel to each other, and normal to the long axis of the specimen. Furthermore, the axis of the specimen shall be generally parallel to the fibers of the wood.

NOTE 5—A sharp fine-toothed saw of either the crosscut or “novelty” crosscut type has been used satisfactorily for obtaining the proper end surfaces. Power equipment with accurate table guides is especially recommended for this work.

NOTE 6—It is desirable to have failures occur in the body of the specimen and not adjacent to the contact surface. Therefore, the cross-sectional areas adjacent to the loaded surface may be reinforced.

18.2.2 Centering—First geometrically center the specimens on the bearing plates and then adjust the spherical seats so that the specimen is loaded uniformly and axially.

18.3 Speed of Testing—The loading shall progress at a constant deformation rate such that the average time to maximum load for the test series shall be at least 4 min. It is permissible to initially test a few random specimens from a series at an alternate rate as the test rate is refined. Otherwise, the selected rate shall be held constant for the test series.

18.4 Load-Deformation Curves—If load-deformation data have been obtained, note the load and deflection at first failure, at changes in slope of curve, and at maximum load.

18.5 Records—Record the maximum load, as well as a description and sketch of the failure relating the latter to the location of imperfections in the specimen. Reexamine the section of the specimen containing the failure during analysis of the data.

18.6 Moisture Content Determination—Determine the specimen moisture content in accordance with 9.6.

19. Calculation

19.1 Compute physical and mechanical properties in accordance with Terminology E6, and as follows (see compressive notations):

19.1.1 Stress at proportional limit, \( \sigma_p = P/A \) in psi (MPa).

19.1.2 Compressive strength, \( \sigma_c = P/A \) in psi (MPa).

19.1.3 Modulus of elasticity, \( E_{axial} = P/A\varepsilon \) in psi (MPa).

20. Report

20.1 Report the following information:

20.1.1 Complete identification;

20.1.2 History of seasoning and conditioning;

20.1.3 Load apparatus;

20.1.4 Deflection apparatus;

20.1.5 Length and cross-section dimensions;

20.1.6 Gage length;

20.1.7 Rate of load application;

20.1.8 Computed physical and mechanical properties, including specific gravity and moisture content, compressive strength, stress at proportional limit, modulus of elasticity, and a statistical measure of variability of these values;

20.1.9 Description of failure; and

20.1.10 Details of any deviations from the prescribed or recommended methods as outlined in the standard.

COMPRESSION PARALLEL TO GRAIN (CRUSHING STRENGTH OF LATERALLY SUPPORTED LONG MEMBER, EFFECTIVE \( l/r < 17 \))

21. Scope

21.1 This test method covers the determination of the compressive properties of structural members when such a member has a slenderness ratio (length to least radius of gyration) of more than 17, and when such a member is to be evaluated in full size but with lateral supports that are spaced to produce an effective slenderness ratio, \( l/r \), of less than 17. This test method is intended primarily for members of rectangular cross section but is also applicable to irregularly shaped studs, braces, chords, round poles and piles, or special sections.

22. Summary of Test Method

22.1 The structural member is subjected to a force uniformly distributed on the contact surface of the specimen in a direction generally parallel to the longitudinal axis of the wood fibers, and the force generally is uniformly distributed throughout the specimen during loading to failure without flexure along its length.

23. Significance and Use

23.1 The compressive properties obtained by axial compression will provide information similar to that stipulated for flexural properties in Section 6.
23.2 The compressive properties parallel to grain include modulus of elasticity \(E_{axial}\), stress at proportional limit, compressive strength, and strain data beyond proportional limit.

24. Apparatus

24.1 Testing Machine—Any device having the following is suitable:

24.1.1 Drive Mechanism—A drive mechanism for imparting to a movable loading head a uniform, controlled velocity with respect to the stationary base.

24.1.2 Load Indicator—A load-indicating mechanism capable of showing the total compressive force on the specimen. This force-measuring system shall be calibrated to ensure accuracy in accordance with Practices E4.

24.2 Bearing Blocks—Bearing blocks shall be used to apply the load uniformly over the two contact surfaces and to prevent eccentric loading on the specimen. One spherical bearing block shall be used to ensure uniform bearing, or a rocker-type eccentric loading on the specimen. One spherical bearing block the load uniformly over the two contact surfaces and to prevent specimen contact surface. The size of the compression plate is usually one to two times the greatest cross-section dimension. The center of the sphere shall be on the plane of the specimen, and yet large enough to provide adequate spherical bearing area. This radius is usually one to two times the greatest cross-section dimension. The center of the sphere shall be on the plane of the specimen contact surface. The size of the compression plate shall be larger than the contact surface.

24.3 Lateral Support:

24.3.1 General—Evaluation of the crushing strength of long structural members requires that they be supported laterally to prevent buckling during the test without undue pressure against the sides of the specimen. Furthermore, the support shall not restrain either the longitudinal compressive deformation or load during test. The support shall be either continuous or intermittent. Intermittent supports shall be spaced so that the distance between supports \(\ell_1\) or \(\ell_2\) is less than 17 times the least radius of gyration of the cross section.

24.3.2 Rectangular Members—The general rules for structural members apply to rectangular structural members. However, the effective column length as controlled by intermittent support spacing on flatwise face \(\ell_2\) need not equal that on edgewise face \(\ell_1\). The minimum spacing of the supports on the flatwise face shall be 17 times the least radius of gyration of the cross section, which is about the centroidal axis parallel to flat face. And the minimum spacing of the supports on the edgewise face shall be 17 times the other radius of gyration (Fig. 6). A satisfactory method of providing lateral support for 2-in. nominal (38-mm) dimension stock is shown in Fig. 7. A 27-in. (686-mm) I-beam provides the frame for the test machine. Small I-beams provide reactions for longitudinal pressure. A pivoted top I-beam provides lateral support on one flatwise face, while the web of the large I-beam provides support for the other. In between these steel members, metal guides on 3-in. (7.6-cm) spacing (hidden from view) attached to plywood fillers provide the flatwise support and contact surface. In between the flanges of the 27-in. (686-mm) I-beam, fingers and wedges provide edgewise lateral support.

24.4 Compressometer:

24.4.1 Gage Length—For modulus of elasticity \(E_{axial}\) calculations, a device shall be provided by which the deformation of the specimen is measured with respect to specific paired gage points defining the gage length. To obtain data representative of the test material as a whole, such paired gage points shall be located symmetrically on the lengthwise surface of the specimen as far apart as feasible, yet at least one times the larger cross-sectional dimension from each of the contact surfaces. At least two pairs of such gage points on diametrically opposite sides of the specimen shall be used to measure the average deformation.

24.4.2 Accuracy—The device shall be able to measure changes in deformation to three significant figures. Since gage lengths vary over a wide range, the measuring instruments should conform to their appropriate class in accordance with Practice E83.

25. Test Specimen

25.1 Material—The test specimen shall consist of a structural member that is greater than nominal 2 by 2-in. (38 by 38-mm) in cross section (see 3.2.7).

25.2 Identification—Material or materials of the test specimen shall be as fully described as that for beams in 8.2.

25.3 Specimen Measurements—The weight and dimensions (length and cross-section) of the specimen shall be measured before the test to three significant figures. Sufficient measurements of the cross section shall be made along the length of the specimen to describe shape characteristics and to determine the smallest section. The physical characteristics of the specimen, as described by its density or specific gravity shall be permitted to be determined in accordance with Test Methods D2395.

25.4 Specimen Description—The inherent imperfections and intentional modifications shall be described as for beams in 8.4.

25.5 Specimen Length—The cross-sectional and length dimensions of structural members usually have established sizes, depending on the manufacturing process and intended use, so that no modification of these dimensions is involved. Since the length has been approximately established, the full length of the member shall be tested, except for trimming or squaring the bearing surface (see 26.2.1).
26. Procedure

26.1 Preliminary—Unless otherwise indicated in the research program or material specification, condition the test specimen to constant weight so it is at moisture equilibrium, under the desired environment. Moisture contents may be approximated with moisture meters or more accurately measured by weights of samples in accordance with Test Methods D4442.

26.2 Test Setup:

26.2.1 Bearing Surfaces—Cut the bearing surfaces of the specimen so that the contact surfaces are plane, parallel to each other, and normal to the long axis of the specimen.

26.2.2 Setup Method—After physical measurements have been taken and recorded, place the specimen in the testing machine between the bearing blocks at each end and between the lateral supports on the four sides. Center the contact surfaces geometrically on the bearing plates and then adjust the spherical seats for full contact. Apply a slight longitudinal pressure to hold the specimen while the lateral supports are adjusted and fastened to conform to the warp, twist, or bend of the specimen.

26.3 Speed of Testing—The loading shall progress at a constant deformation rate such that the average time to maximum load for the test series shall be at least 4 min. It is permissible to initially test a few random specimens from a series at an alternate rate as the test rate is refined. Otherwise, the selected rate shall be held constant for the test series.

26.4 Load-Deformation Curves—If load-deformation data have been obtained, note load and deflection at first failure, at changes in slope of curve, and at maximum load.

26.5 Records—Record the maximum load as well as a description and sketch of the failure relating the latter to the location of imperfections in the specimen. Reexamine the section of the specimen containing the failure during analysis of the data.

26.6 Moisture Content Determination—Determine the specimen moisture content in accordance with 9.6.

27. Calculation

27.1 Compute physical and mechanical properties in accordance with Terminology E6 and as follows (see Appendix X1):

27.1.1 Stress at proportional limit, \( \sigma'_c = \frac{P'}{A} \) in psi (MPa).

27.1.2 Compressive strength, \( \sigma_c = \frac{P}{A} \) in psi (MPa).

27.1.3 Modulus of elasticity, \( E_{axial} = \frac{P}{Ae} \) in psi (MPa).

28. Report

28.1 Report the following information:

28.1.1 Complete identification;

28.1.2 History of seasoning conditioning;

28.1.3 Load apparatus;

28.1.4 Deflection apparatus;

28.1.5 Length and cross-section dimensions;

28.1.6 Gage length;

28.1.7 Rate of load application;

28.1.8 Computed physical and mechanical properties, including specific gravity of moisture content, compressive strength, stress at proportional limit, modulus of elasticity, and a statistical measure of variability of these values;

28.1.9 Description of failure; and

28.1.10 Details of any deviations from the prescribed or recommended methods as outlined in the standard.
29. Scope

29.1 This test method covers the determination of the tensile properties of structural members made primarily of lumber equal to and greater than nominal 1 in. (19 mm) thick.

30. Summary of Test Method

30.1 The structural member is clamped at the extremities of its length and subjected to a tensile load so that in sections between clamps the tensile forces shall be axial and generally uniformly distributed throughout the cross sections without flexure along its length.

31. Significance and Use

31.1 The tensile properties obtained by axial tension will provide information similar to that stipulated for flexural properties in Section 6.

31.2 The tensile properties obtained include modulus of elasticity \( E_{\text{axial}} \), stress at proportional limit, tensile strength, and strain data beyond proportional limit.

32. Apparatus

32.1 Testing Machine—Any device having the following is suitable:

32.1.1 Drive Mechanism—A drive mechanism for imparting to a movable clamp a uniform, controlled velocity with respect to a stationary clamp.

32.1.2 Load Indicator—A load-indicating mechanism capable of showing the total tensile force on the test section of the tension specimen. This force-measuring system shall be calibrated to ensure accuracy in accordance with Practices E4.

32.1.3 Grips—Suitable grips or fastening devices shall be provided that transmit the tensile load from the movable head of the drive mechanism to one end of the test section of the tension specimen, and similar devices shall be provided to transmit the load from the stationary mechanism to the other end of the test section of the specimen. Such devices shall not apply a bending moment to the test section, allow slippage under load, inflict damage, or inflict stress concentrations to the test section. Such devices may be either plates bonded to the specimen or unbonded plates clamped to the specimen by various pressure modes.

32.1.3.1 Grip Alignment—The fastening device shall apply the tensile loads to the test section of the specimen without applying a bending moment.

Note 7—For ideal test conditions, the grips should be self-aligning, that is, they should be attached to the force mechanism of the machine in such a manner that they will move freely into axial alignment as soon as the load is applied, and thus apply uniformly distributed forces along the test section and across the test cross section (Fig. 8(a)). For less ideal test conditions, each grip should be gimbaled about one axis, which should be perpendicular to the wider surface of the rectangular cross section of the test specimen, and the axis of rotation should be through the fastened area (Fig. 8(b)). When neither self-aligning grips nor single gimbaled grips are available, the specimen may be clamped in the heads of a universal-type testing machine with wedge-type jaws (Fig. 8(c)). A method of providing approximately full spherical alignment has three axes of rotation, not necessarily concurrent but, however, having a common axis longitudinal and through the centroid of the specimen (Fig. 8(d) and Fig. 9).

32.1.3.2 Contact Surface—The contact surface between grips and test specimen shall be such that slippage does not occur.

Note 8—A smooth texture on the grip surface should be avoided, as well as very rough and large projections that damage the contact surface of the wood. Grips that are surfaced with a coarse emery paper (60x aluminum oxide emery belt) have been found satisfactory for softwoods. However, for hardwoods, grips may have to be glued to the specimen to prevent slippage.
32.1.3.3 Contact Pressure—For unbounded grip devices, lateral pressure should be applied to the jaws of the grip so that slippage does not occur between grip and specimen. Such pressure may be applied by means of bolts or wedge-shaped jaws, or both. Wedge-shaped jaws, such as those shown on Fig. 10, which slip on the inclined plane to produce contact pressure, have been found satisfactory. To eliminate stress concentration or compressive damage at the tip end of the jaw, the contact pressure should be reduced to zero. The variable thickness jaws (Fig. 10), which cause a variable contact surface and which produce a lateral pressure gradient, have been found satisfactory.

32.1.4 Extensometer:

32.1.4.1 Gage Length—For modulus of elasticity determinations, a device shall be provided by which the elongation of the test section of the specimen is measured with respect to specific paired gage points defining the gage length. To obtain data representative of the test material as a whole, such gage points shall be symmetrically located on the lengthwise surface of the specimen as far apart as feasible, yet at least two times the larger cross-sectional dimension from each jaw edge. At least two pairs of such gage points on diametrically opposite sides of the specimen shall be used to measure the average deformation.

32.1.4.2 Accuracy—The device shall be able to measure changes in elongation to three significant figures. Since gage lengths vary over a wide range, the measuring instruments should conform to their appropriate class in accordance with Practice E83.

33. Test Specimen

33.1 Material—The test specimen shall consist of a structural member with a size commercially used in structural "tensile" applications, that is, in sizes equal to and greater than nominal 1-in. (32-mm) thick lumber.

33.2 Identification—Material or materials of the test specimen shall be fully described as beams in 8.2.

33.3 Specimen Description—The specimen shall be described in a manner similar to that outlined in 8.3 and 8.4.

33.4 Specimen Length—The tension specimen, which has its long axis parallel to grain in the wood, shall have a length between grips equal to at least eight times the larger cross-sectional dimension when tested in self-aligning grips (see 32.1.3.1). However, when tested without self-aligning grips, it is recommended that the length between grips be at least 20 times the greater cross-sectional dimension.

34. Procedure

34.1 Conditioning—Unless otherwise indicated, condition the specimen as outlined in 9.1.

34.2 Test Setup—After physical measurements have been taken and recorded, place the specimen in the grips of the load mechanism, taking care to have the long axis of the specimen and the grips coincide. The grips should securely clamp the specimen with either bolts or wedge-shaped jaws. If the latter are employed, apply a small preload to ensure that all jaws move an equal amount and maintain axial-alignment of specimen and grips. If either bolts or wedges are employed tighten the grips evenly and firmly to the degree necessary to prevent slippage. Under load, continue the tightening if necessary, even crushing the wood perpendicular to grain, so that no slipping occurs and a tensile failure occurs outside the jaw contact area.

34.3 Speed of Testing—The loading shall progress at a constant deformation rate such that the average time to maximum load for the test series shall be at least 4 min. It is permissible to initially test a few random specimens from a series at an alternate rate as the test rate is refined. Otherwise, the selected rate shall be held constant for the test series.

34.4 Load-Elongation Curves—If load-elongation data have been obtained throughout the test, correlate changes in specimen behavior, such as appearance of cracks or splinters, with elongation data.

34.5 Records—Record the maximum load, as well as a description and sketch of the failure relating the latter to the location of imperfections in the test section. Reexamine the section containing the failure during analysis of data.

34.6 Moisture Content Determination—Determine the specimen moisture content in accordance with 9.6.

35. Calculation

35.1 Compute physical and mechanical properties in accordance with Terminology E6, and as follows (see Appendix X1):

35.1.1 Stress at proportional limit, \( \sigma_p = \frac{P}{A} \) in psi (MPa).
35.1.2 Tensile strength, \( \sigma_t = \frac{P}{A} \) in psi (MPa).
35.1.3 Modulus of elasticity, \( E_{axx} = \frac{P}{A\epsilon} \) in psi (MPa).

36. Report

36.1 Report the following information:
36.1.1 Complete identification,
36.1.2 History of seasoning,
36.1.3 Load apparatus, including type of end condition,
36.1.4 Deflection apparatus,
36.1.5 Length and cross-sectional dimensions,
36.1.6 Gage length,
36.1.7 Rate of load application,
36.1.8 Computed physical and mechanical properties, including specific gravity and moisture content, tensile strength, stress at proportional limit, modulus of elasticity, and a statistical measure of variability of these values,
36.1.9 Description of failures, and
36.1.10 Details of any deviations from the prescribed or recommended methods as outlined in the standard.

TORSION

37. Scope

37.1 This test method covers the determination of the torsional properties of structural members. This test method is intended primarily for specimens of rectangular cross section, but is also applicable to round or irregular shapes.

38. Summary of Test Method

38.1 The specimen is subjected to a torsional moment by clamping it near its ends and applying opposing couples to each clamping device. The specimen is deformed at a prescribed rate and coordinate observations of torque and twist are made for the duration of the test.

39. Significance and Use

39.1 The torsional properties obtained by twisting the specimen will provide information similar to that stipulated for flexural properties in Section 6.

39.2 The torsional properties of the specimen include torsional shear modulus \( G_t \), stress at proportional limit, torsional strength, and twist beyond proportional limit.

40. Apparatus

40.1 Testing Machine—Any device having the following is suitable:
40.1.1 Drive Mechanism—A drive mechanism for imparting an angular displacement at a uniform rate between a movable clamp on one end of the specimen and another clamp at the other end.
40.1.2 Torque Indicator—A torque-indicating mechanism capable of showing the total couple on the specimen. This measuring system shall be calibrated to ensure accuracy in accordance with Practices E4.
40.2 Support Apparatus:
40.2.1 Clamps—Each end of the specimen shall be securely held by metal plates of sufficient bearing area and strength to grip the specimen with a vise-like action without slippage, damage, or stress concentrations in the test section when the torque is applied to the assembly. The plates of the clamps shall be symmetrical about the longitudinal axis of the cross section of the element.
40.2.2 Clamp Supports—Each of the clamps shall be supported by roller bearings or bearing blocks that allow the specimen to rotate about its natural longitudinal axis. Such supports shall be permitted to be ball bearings in a rigid frame of a torque-testing machine (Figs. 11 and 12) or bearing blocks (Figs. 13 and 14) on the stationary and movable frames of a universal-type test machine. Either type of support shall allow the transmission of the couple without friction to the torque measuring device, and shall allow freedom for longitudinal movement of the specimen during the twisting. Apparatus of Fig. 13 is not suitable for large amounts of twist unless the angles are measured at each end to enable proper torque calculation.
40.2.3 Frame—The frame of the torque-testing machine shall be capable of providing the reaction for the drive mechanism, the torque indicator, and the bearings. The framework necessary to provide these reactions in a universal-type test machine shall be two rigid steel beams attached to the movable and stationary heads forming an X. The extremities of the X shall bear on the lever arms attached to the specimen (Fig. 13).

40.3 Troptometer:
40.3.1 Gage Length—For torsional shear modulus calculations, a device shall be provided by which the angle of twist of the specimen is measured with respect to specific paired gage points defining the gage length. To obtain test data representative of the element as a whole, such paired gage points shall be located symmetrically on the lengthwise surface of the specimen as far apart as feasible, yet at least two times the larger cross-sectional dimension from each of the clamps. A yoke (Fig. 15) or other suitable device (Fig. 12) shall be firmly attached at each gage point to permit measurement of the angle of twist. The angle of twist is measured by observing the relative rotation of the two yokes or other devices at the gage points with the aid of any suitable apparatus including a light beam (Fig. 12), dials (Fig. 14), or string and scale (Figs. 15 and 16).
40.3.2 Accuracy—The device shall be able to measure changes in twist to three significant figures. Since gage lengths may vary over a wide range, the measuring instruments should conform to their appropriate class in accordance with Practice E83.

41. Test Specimen

41.1 Material—The specimen shall consist of a structural member in sizes that are commercially used in structural applications.
41.2 Identification—Material or materials of the specimen shall be as fully described as for beams in 8.2.

41.3 Specimen Measurements—The weight and dimensions (length and cross-section) shall be measured to three significant figures. Sufficient measurements of the cross section shall be made along the length of the specimen to describe characteristics and to determine the smallest section. The physical characteristics of the specimen, as described by its density or specific gravity, shall be permitted to be determined in accordance with Test Methods D2395.

41.4 Specimen Description—The inherent imperfections and intentional modifications shall be described as for beams in 8.4.

41.5 Specimen Length—The cross-sectional dimensions are usually established, depending upon the manufacturing process and intended use so that normally no modification of these dimensions is involved. However, the length of the specimen shall be at least eight times the larger cross-sectional dimension.

42. Procedure

42.1 Conditioning—Unless otherwise indicated in the research program or material specification, condition the specimen to constant weight so it is at moisture equilibrium under the desired environment. Approximate moisture contents with moisture meters, or measure more accurately by weights of samples in accordance with Test Methods D4442.

42.2 Test Setups—After physical measurements have been taken and recorded, place the specimen in the clamps of the load mechanism, taking care to have the axis of rotation of the clamps coincide with the longitudinal centroidal axis. Tighten the clamps to securely hold the specimen in either type of testing machine. If the tests are made in a universal-type test machine, the bearing blocks shall be equal distances from the axis of rotation.

42.3 Speed of Testing—The loading shall progress at a constant deformation rate such that the average time to maximum load for the test series shall be at least 4 min. It is permissible to initially test a few random specimens from a series at an alternate rate as the test rate is refined. Otherwise, the selected rate shall be held constant for the test series.

42.4 Torque-Twist Curves—If torque-twist data have been obtained, note torque and twist at first failure, at changes in slope of curve, and at maximum torque.

42.5 Record of Failures—Describe failures in detail as to type, manner, and order of occurrence, angle with the grain,
and position in the specimen. Record descriptions relating to imperfections in the specimen. Reexamine the section of the specimen containing the failure during analysis of the data.

42.6 Moisture Content Determination—Determine the specimen moisture content in accordance with 9.6.

43. Calculation

43.1 Compute physical and mechanical properties in accordance with Terminology E6 and relationships in Tables X3.1 and X3.2.

44. Report

44.1 Report the following information:
44.1.1 Complete identification,
44.1.2 History of seasoning and conditioning,
44.1.3 Apparatus for applying and measuring torque,
44.1.4 Apparatus for measuring angle of twist,
44.1.5 Length and cross-section dimensions,
44.1.6 Gage length,
44.1.7 Rate of twist applications,
44.1.8 Computed physical and mechanical properties, including specific gravity and moisture content, torsional strength, stress at proportional limit, torsional shear modulus, and a statistical measure of variability of these values, and
44.1.9 Description of failures.

45. Scope

45.1 This test method covers the determination of the shear modulus \((G)\) of structural beams made of lumber and wood-based materials. Application to composite constructions can only give a measure of the effective shear modulus. This test method is intended primarily for beams of rectangular cross section but is also applicable to other sections with appropriate modification of equation coefficients.
46. Summary of Test Method

46.1 The structural member, usually a straight or a slightly cambered beam of rectangular cross section, is subjected to a bending moment by supporting it at two locations called reactions, and applying a single transverse load midway between these reactions. The beam is deflected at a prescribed rate and a single observation of coordinate load and deflection is taken. This procedure is repeated on at least four different spans.

47. Significance and Use

47.1 The shear modulus established by this test method will provide information similar to that stipulated for flexural properties in Section 6.

48. Apparatus

48.1 The test machine and specimen configuration, supports, and loading are identical to Section 7 with the following exception:

48.1.1 The load shall be applied as a single, concentrated load midway between the reactions.

49. Test Specimen

49.1 See Section 8.

50. Procedure

50.1 Conditioning—See 9.1.

50.2 Test Setup—Position the specimen in the test machine as described in 9.2 and load in center point bending over at least four different spans with the same cross section at the center of each. Choose the spans so as to give approximately equal increments of \((d/\ell)^2\) between them, within the range from 0.035 to 0.0025. The applied load must be sufficient to provide a reliable estimate of the initial bending stiffness of the specimen, but in no instance shall exceed the proportional limit or shear capacity of the specimen.

NOTE 9—Span-to-depth ratios of 5.5, 6.5, 8.5, and 20.0 meet the \((d/\ell)^2\) requirements of this section.

50.3 Load-Deflection Measurements—Obtain load-deflection data with the apparatus described in 7.4.1. One data point is required on each span tested.

50.4 Records—Record span-to-depth \((\ell/d)\) ratios chosen and load levels achieved on each span.

50.5 Speed of Testing—See 9.3.

51. Calculation

51.1 Determine shear modulus, \(G\), by plotting \(1/E_{\text{app}}\) (where \(E_{\text{app}}\) is the apparent modulus of elasticity calculated under center point loading) versus \((d/\ell)^2\) for each span tested. As indicated in Fig. 17 and in Appendix X4, shear modulus is proportional to the slope of the best-fit line between these points.

52. Report

52.1 See Section 11.
53. Precision and Bias

53.1 The precision and bias of the flexure test method are discussed in Section 12. For the other test methods, the precision and bias have not been established.

54. Keywords

54.1 apparent modulus of elasticity; compression; flexure; lumber; modulus of elasticity; modulus of rupture; shear; shear modulus; shear-free modulus of elasticity; static test; structural members; tension; torsion; torsional shear modulus; wood
### X1.3 TORSION

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G_t$</td>
<td>Torsional shear modulus, psi (MPa).</td>
</tr>
<tr>
<td>$K$</td>
<td>Stiffness-shape factor.$^A$</td>
</tr>
<tr>
<td>$f_g$</td>
<td>Gage length of torsional element, in. (mm).</td>
</tr>
<tr>
<td>$Q$</td>
<td>Stress-shape factor.$^A$</td>
</tr>
<tr>
<td>$D$</td>
<td>Diameter of circular element, in. (mm).</td>
</tr>
<tr>
<td>$S_z$</td>
<td>Fiber shear stress of greatest intensity at middle of long side at maximum torque, psi (MPa).</td>
</tr>
<tr>
<td>$S_z'$</td>
<td>Fiber shear stress of greatest intensity at middle of long side at proportional limit, psi (MPa).</td>
</tr>
<tr>
<td>$S_z''$</td>
<td>Fiber shear stress of greatest intensity at middle of short side at maximum torque, psi (MPa).</td>
</tr>
<tr>
<td>$\tau_{\text{max}}$</td>
<td>Maximum shear stress, psi (MPa).</td>
</tr>
</tbody>
</table>

$^A$ Based upon page 348 of *Roark’s Formulas for Stress and Strain* (1) (see Footnote 4).

### X1.4 SHEAR MODULUS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K$</td>
<td>Shear coefficient. Defined in Appendix X4.</td>
</tr>
<tr>
<td>$K_1$</td>
<td>Slope of line through multiple test data plotted on $(d/t)^2$ versus $(1/E_{\text{app}})$ axes (see Fig. 17).</td>
</tr>
</tbody>
</table>

### X2. FLEXURE

X2.1 Flexure formulas for beams with solid rectangular homogeneous cross-section through their length are shown in Table X2.1. These formulas are generally applicable for lumber and wood-based materials. Beams composed of dissimilar materials (for example, sandwich-type structures) or those assembled with semi-rigid connections (for example, built-up beams with mechanical fasteners) should be analyzed using more rigorous methods.

X2.2 Schematic diagrams of loading methods are shown in Fig. X2.1. In this standard, two-point loading is the case when the load is applied equally at two points equidistant from their reactions (Fig. X2.1(a)). Two-point loading is also known as four-point loading, because there are two loads and two reactions acting on the beam. Third-point loading is a special case of two-point (four-point) loading where the two loads are equally spaced between supports, at one-third span length from reactions (Fig. X2.1(b)). Center-point loading, or center loading, is the case when the load is applied at the mid-span (Fig. X2.1(c)). It is a special case of three-point loading—one load and two reactions.

X2.3 Fiber stress at proportional limit, $S'$, is determined at the last point on the linear portion of stress-strain (or load-deflection) curve. Historically, it has been determined graphically by drawing a straight line through the linear portion, where the modulus of elasticity is determined, and finding the point where the curve deviated from the straight line. If a digital data acquisition is used, the proportional limit (the point of deviation from the straight line) can be determined using a threshold value of the slope deviation or other suitable criteria. The threshold value depends on the material tested; therefore, it should be correlated with the graphical method using a representative subset of the sample. Threshold values and calculation methods should be included in the report.

X2.4 Modulus of rupture, $S_{br}$, is a measure of maximum load carrying capacity of a beam. In most materials, the maximum load and rupture occur beyond the proportional limit where significant plastic deformations develop and the true cross-section stress distribution is unknown. For simplicity, modulus of rupture is calculated assuming the extreme fiber of a beam is a linear elastic and homogeneous material:

$$ S_{br} = \frac{Mc}{T} \quad (X2.1) $$

Generally, modulus of rupture is determined using the bending moment that causes rupture. In this standard, modulus of rupture is calculated using maximum bending moment at the maximum load, $P_{\text{max}}$, borne by the beam, although rupture
TABLE X2.1 Flexure Formulas

<table>
<thead>
<tr>
<th>Line</th>
<th>Mechanical Property</th>
<th>Two-Point Loading (Column A)</th>
<th>Third-Point Loading (Column B)</th>
<th>Center-Point Loading (Column C)</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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<td></td>
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<td></td>
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<td>$\frac{bd}{\ell}$</td>
<td>$\frac{2bd}{3}$</td>
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<tr>
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<td>Apparent modulus of elasticity, $E_{\text{app}}$</td>
<td>$\frac{Pa}{4bd^2\Delta(3\ell^2 - 4a^2)}$</td>
<td>$\frac{23P\ell^3}{108bd^2\Delta}$</td>
<td>$\frac{P\ell^3}{4bd^2\Delta}$</td>
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<tr>
<td>4</td>
<td>Shear-free modulus of elasticity, $E_{\text{sf}}$ (determined using $\Delta$)</td>
<td>$\frac{Pa(3\ell^2 - 4a^2)}{4bd^2\Delta(1 - \frac{3Pa}{5bdG\Delta})}$</td>
<td>$\frac{23P\ell^3}{108bd^2\Delta(1 - \frac{P\ell}{5bdG\Delta})}$</td>
<td>$\frac{P\ell^3}{4bd^2\Delta}$</td>
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<td>5</td>
<td>Shear-free modulus of elasticity, $E_{\text{sf}}$ (determined using $\Delta_{\text{sf}}$)</td>
<td>$\frac{3Pa\ell^2}{4bd^2\Delta_{\text{sf}}}$</td>
<td>$\frac{P\ell^2}{4bd^2\Delta_{\text{sf}}}$</td>
<td>—</td>
</tr>
<tr>
<td>6</td>
<td>Ratio between deflection at the load point and deflection at the midspan, $c_2$</td>
<td>$\frac{4a(3\ell^2 - 4a^2) + 12dE_{fu}}{5\Delta}$</td>
<td>$\frac{20\ell^3 + 12dE_{fu}}{5\Delta}$</td>
<td>—</td>
</tr>
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<td>7</td>
<td>Work to proportional limit per unit volume, $W_{\text{PL}}$</td>
<td>$\frac{P\Delta c_2}{2\ell bd}$</td>
<td>$\frac{P\Delta c_2}{2\ell bd}$</td>
<td>$\frac{P\Delta}{2\ell bd}$</td>
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<td>Approximate work to maximum load per unit volume, $W_{\text{ML}}$</td>
<td>$\frac{A_{\text{ML}}c_2c_3}{\ell bd}$</td>
<td>$\frac{A_{\text{ML}}c_2c_3}{\ell bd}$</td>
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<td>Approximate total work per unit volume, $W_{\text{TL}}$</td>
<td>$\frac{A_{\text{TL}}c_2c_3}{\ell bd}$</td>
<td>$\frac{A_{\text{TL}}c_2c_3}{\ell bd}$</td>
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<td>Maximum shear stress, $\tau_{\text{max}}$</td>
<td>$\frac{3P_{\text{max}}}{4bd}$</td>
<td>$\frac{3P_{\text{max}}}{4bd}$</td>
<td>$\frac{3P_{\text{max}}}{4bd}$</td>
</tr>
</tbody>
</table>

does not always occur at the maximum load and not necessarily in the zone of maximum moment (especially under center-point loading of lumber).

X2.5 Modulus of elasticity in bending, $E_{\text{app}}$, or $E_{sf}$ is determined using linear portion of load-deflection (or stress-strain) curve. The maximum slope should be fitted to the load-deformation data by an acceptable statistical or graphical method. Historically, it has been determined graphically, using the slope of a straight line drawn through the linear portion of the load-deflection curve. If digital data acquisition is used, the straight line should be fitted between two different stress levels below proportional limit using appropriate statistical procedures. It is the user’s responsibility to choose the stress levels and calculation methods that suit the purpose of testing and material tested. Normally, the curve fitting should cover a minimum range of 20 % of $S_R$ (for example, between 10 % and 30 % or between 20 % and 40 % of $S_R$). The stress levels and goodness of fit should be included in the report. If digital methods produce questionable results, graphical method should be used as reference.

X2.6 Apparent modulus of elasticity, $E_{\text{app}}$, includes effect of shear distortion of the beam cross-section. The shear effect is greater in beams with low span-depth ratio and materials with low shear modulus. To determine shear-free modulus of elasticity, $E_{sf}$, deflections are measured in shear-free span between load points, $\ell_{sf}$, using two-point bending method. Alternatively, the shear-free modulus of elasticity can be calculated using full-span deflections, $\Delta$, and assuming that the...
shear modulus, $G$, is known (Table X2.1, Line 4); however, this calculation may not necessarily produce the same results as a test.

X2.7 Formulas for beam work under two-point and third-point loading include factor $c_2$, which relates deflection under the load points to the deflection measured at mid-span. This factor includes shear correction assuming that the ratio $E_f/G$ is known.

X3. TORSION

X3.1 Torsion formulas in Table X3.1 are valid assuming that the tested material is isotropic and linear elastic (obeys the Hooke’s law). The values of St. Venant coefficients in Table X3.2 are from NACA Report No. 334 (2) Table I “Factors for Calculating Torsional Rigidity and Stress of Rectangular Prisms,” which is based on an earlier St. Venant’s publication. If equation format is preferred by the user, Roark’s Formulas for Stress and Strain (1) provides approximate expressions for the St. Venant coefficients with sufficient accuracy.

X3.2 For most wood and composite materials, the torsional shear modulus, $G_t$, obtained using the torsional test method is typically not equivalent to the shear modulus, $G$, used elsewhere in this standard. The $G$ of interest in a flexural application is that which occurs in the plane of flexure. The $G_t$ values derived using the calculations of Table X3.1 represent a
composite shear estimate that combines the performance of all planes which occur parallel to the torsional length based upon an assumption that the materials are isotropic. For materials that are not isotropic, the $G_t$ estimate will be influenced by the shear modulus for each plane that occurs parallel to the torsional length and the cross-sectional geometry relative to those planes.

### X4. SHEAR MODULUS

X4.1 Assuming the tested material is isotropic, the elastic deflection of a prismatic beam under a single-center point load (Fig. X2.1(c)) is (from Gromala (3)):

\[
\Delta = \frac{PL}{48E_{s}I} + \frac{PL}{4GKA} \quad (X4.1)
\]

X4.2 All parameters in Eq X4.1 are specified in Appendix X1 and are self-explanatory with the exception of the shear coefficient, $K$. The shear coefficient is a reciprocal of so-called shape factor, which is a dimensionless quantity dependent on the cross-sectional dimensions of the beam. These shape factors for various beam cross-sections are found in Roark’s Formulas for Stress and Strain (1)\(^5\) and other literature, or can be derived using the second Castigliano’s theorem. Most common shapes of lumber and wood-based materials are rectangular and circular, for which the shear coefficients have the following magnitudes (1)\(^5\):

\[
K = \frac{9}{10} \quad \text{(circular section)} \quad (X4.2)
\]

\[
K = \frac{5}{6} \quad \text{(rectangular section)}
\]

X4.3 Often the relationship between deflection and elastic constants is simplified by ignoring the shear contribution, or the second term in Eq X4.1. The resulting elastic constant is then called the “apparent” modulus of elasticity, $E_{app}$:

\[
\Delta = \frac{PL}{48E_{app}I} \quad (X4.3)
\]

X4.4 At the same deflection the apparent modulus of elasticity, $E_{app}$, can be expressed in terms of the shear-free modulus of elasticity, $E_{sp}$, and the shear modulus, $G$:

\[
\frac{1}{E_{app}} = \frac{1}{E_{sp}} - \frac{K^2}{G} \quad (X4.4)
\]

\(\text{TABLE X3.2 Factors for Calculating Torsional Rigidity and Stress of Rectangular Prisms}

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<th>Ratio of Sides (Column A)</th>
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<th>(\gamma) (Column C)</th>
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</table>

\footnote{Available from page 210 of Roark’s Formulas for Stress and Strain (1).}
X4.1 Eq X4.4 can be expressed as a linear function by substituting 
\( y = 1/E_{\text{app}} \) and \( x = (d/\ell)^2 \). In the resulting line equation, \( y = 1/E_{\text{sfr}} + K_1x \), the slope of the line connecting multiple data points is \( K_1 = 1/KG \) and y-intercept is the reciprocal of the shear-free modulus of elasticity, \( E_{\text{sfr}} \).

X4.7 For a circular section of diameter \( D \), Eq X4.4 reduces to:

\[
\frac{1}{E_{\text{app}}} = \frac{1}{E_{\text{sfr}}} + \frac{3}{4KG} \left( \frac{d}{\ell} \right)^2 \tag{X4.7}
\]

Therefore, \( K_1 = \frac{3}{4KG} \).

X4.8 Using plots for \( 1/E_{\text{app}} \) versus \( (d/\ell)^2 \) for rectangular sections or \( (D/\ell)^2 \) for circular sections and substituting \( K \) from Eq X4.2, shear modulus, \( G \), can be expressed in terms of the slope \( K_1 \) as follows (see also Table X4.1):

\[
G = \frac{5}{6K_1} \text{ (circular section)} \tag{X4.8}
\]

\[
G = \frac{6}{5K_1} \text{ (rectangular section)}
\]

X4.9 Determination of shear modulus for other beam cross sections must start at Eq X4.4, substituting appropriate values for \( I, A, \) and \( K \).

X5. COMMENTARY

X5.1 Flexure Apparatus (Section 7)

X5.1.1 In the first edition of the standard, in 1924, the flexure test guidelines for timbers required third-point loading over a span length of 15 ft (4.57 m). Span-depth ratios between 11 and 15 were recommended for use whenever possible. Center-point loading was not recommended for beams over 4 in. in depth with the span-depth ratio of 15 or less.

X5.1.2 A diagrammatic sketch of the 1924 test setup is shown in Fig. X5.1. The procedure required that the supporting knife-edges be preferably of the half-rocker type, and so placed
to rock outward. To prevent accident or damage from their being thrust suddenly outward on failure of the specimen, they were tied together by means of a slack chain or cable. The load was applied through knife-edges rigidly attached to an auxiliary beam, which in turn was hinged by a knife-edge. Metal bearing plates and rollers were used between each bearing block and its corresponding knife-edge. If the supporting knife-edges were of full-rocker type rather than the half-rocker type, rollers were placed under one loading knife-edge only.

X5.1.3 In 1967, the flexure test description was substantially revised. Specimen length, span-depth ratio, and location of load points were determined depending on the purpose of the test, allowing more freedom in test design. However, center-point loading was no longer mentioned. Description of support apparatus (7.2) allowed a choice between rocker-type reactions and fixed knife-edge reactions in conjunction with bearing plates supported by rollers. Description of load apparatus (7.3) required rollers in conjunction with one load bearing block (Fig. X5.2). The test setup described in Section 7 thus represented completely constrained but statically determinate condition with two rolling supports, one rolling load block, and one pinned load block. This setup reflected the testing practice on machines with load measuring devices built in the support table (for example, Tinius-Olsen machines).

X5.1.4 Most modern machines have load measuring devices (load cells) built in the machine head, that is, located above the specimen. In this case, it is desirable to reverse the location of the pin in the load evener with one of the reaction rollers, so both load blocks are used in conjunction with rollers (or sliders) allowing unrestrained displacement of the load evener along the beam. Unrestrained horizontal sliding of the load evener is especially critical for tests on beams experiencing large deflections (for example, long-span beams, or low-stiffness beams): if one of the load blocks were pinned, the contraction of the top beam fibers could place an eccentric load on the load cell. Apart from biased load readings and potential damage to the load cell, such movement may cause slippage of the pinned load block along the beam producing saw-like load-deflection curve. It is the opinion of the committee that the example of the test setup in Fig. 1 in current edition represents the most common modern practice and is recommended for test machines with load measuring devices built in the load head.

X5.1.5 Reaction Bearing Plates (7.2.1)—The size of the bearing plates may vary with the size and shape of the beam. The minimum length should be selected to prevent bearing failures. In the past, for rectangular beams as large as 12 in. (305 mm) deep by 6 in. (152 mm) wide, the recommended size of bearing plate was ½ in. (13 mm) thick by 6 in. (152 mm) lengthwise and extending entirely across the width of the beam.

X5.1.6 Reaction Supports (7.2.2) and Load Bearing Blocks (7.3.1)—To restrict horizontal translation of the beam in case of two-point loading, one of the supports or load bearing blocks should be constrained from horizontal sliding or rolling (that is, should be “pinned”) to keep the beam statically determinate.

X5.1.7 Load Points (7.3.2)—One of the objectives of two-point loading is to subject the portion of the beam between load points to a uniform bending moment, free of shear, and with comparatively small loads at the load points. For example, to develop a moment of similar magnitude, loads applied at one-third span length from reactions would be less than that applied at one-fourth span length from reaction. When loads are applied at the one-third points, the moment distribution of the beam simulates that for loads uniformly distributed across the span to develop a moment of similar magnitude. If loads are applied at the outer one-fourth points of the span, the maximum moment and shear are the same as the maximum moment and shear for the same total load uniformly distributed across the span. Center-point loading is not recommended for destructive tests on long-span beams with large cross-sections. However, it is acceptable for determination of bending stiffness properties and shear strength.

X5.1.8 Evaluation of Shear Properties (7.3.2.3)—For evaluation of shear properties, it is desirable to minimize shear-free span or minimize span-depth ratio of the beam, or both. The clear distance between the reaction bearing plate and load...
bearing blocks influences the shear stress distribution in the beam. It will normally be at least two times the beam depth. For the two-point loading setup, the clear distance between load bearing blocks will normally not exceed 6 in. (152 mm) (see Fig. X5.3). The clear distance of at least two times the beam depth is intended to limit the influence of compression perpendicular to grain stress on shear stress distribution. For short deep beams with large cross sections, two-point loading is preferred to spread the applied load and avoid crushing of specimen under the load block and also to reduce the effect of the load block on contraction of the contact surface of the beam.

X5.2 Deflection-Measuring Apparatus (7.4)

X5.2.1 The guidance provided in this section assumes that the member is a linear elastic and homogenous material. In general, it is appropriate to make this assumption for sawn lumber and most wood-based materials. Provided a standard loading configuration, such as third-point loading, is followed test results are comparable and repeatable.

X5.2.2 The apparatus used to support the beam, apply the load, and measure the deflection will affect the deflection of the specimen under a specified load. Some materials or materials under certain conditions may be more or less sensitive to departures from these reference test configurations.

X5.2.3 Where the loading configuration cannot be maintained, conversion factors such as those in Practice D2915 may be used, but it should be recognized that use of such equations might introduce bias and errors. Developments of such conversion factors are beyond the scope of this standard. Product specifications will generally provide descriptions of the standard loading configuration and acceptable adjustment procedures.

X5.2.4 Shear-Free Modulus of Elasticity (7.4.1.2)—Reference points for shear-free deflection measurements should be selected such that they avoid areas of stress concentration, but are set far enough apart so that the deflection can be accurately measured with the deflection device. It is recommended that the reference points be offset at least half of the specimen depth towards the mid-span away from the load points.

X5.2.5 Wire Deflectometer (7.4.2) and Yoke Deflectometer (7.4.3):

X5.2.5.1 The intent is not to limit the devices to those described. Other arrangements that meet the requirements of the General Clause are acceptable.

X5.2.5.2 Because the beam deflections are measured relative to the deflectometer, the deflectometer spanning the two reference points should be sufficiently rigid or taut, in the case of a wire. Care should be taken to ensure that the deflectometer is not disturbed while the beam is deflecting. Possible sources of erroneous results include the following: using a spring-loaded deflection measurement device where the spring force is high enough to cause the deflectometer to flex significantly as compared to the beam deflection; and using a deflectometer that rubs against the side of the beam as the beam deflects.

X5.2.6 Alternative Deflectometers (7.4.4):

X5.2.6.1 For long or unusual beam configurations, it may not be practical to follow one of the traditional methods (described in 7.4.2 and 7.4.3). Provided sufficient documentation is provided to demonstrate that the deflection measurements would be equivalent to that from a device meeting specifications in 7.4.1, the method should be acceptable. The note emphasizes that some judgment is required when selecting the samples for demonstrating equivalency.

X5.2.6.2 The intent of this section is to demonstrate equivalency of devices. It is not intended to permit an adjustment factor to be developed or used.

X5.2.7 Accuracy (7.4.5):

X5.2.7.1 When assessing the accuracy of a computer-based displacement recording system, the precision of the displacement transducer and the analog-to-digital (A-to-D) converter should be considered. See Practice E2309.

X5.2.7.2 The number of “significant figures” is the number of figures known with some degree of reliability plus one digit which is an estimate or approximation. It is convenient to use scientific notation when reporting results: for example, 1.23 x 10 mm is the same as 4.84 x 10^{-1} in. (3 significant figures); similarly 1.0 x 10^{-3} in. would be the same as 2.5 x 10^{-2} mm (2 significant figures). When adding or subtracting, the result cannot be more accurate than the least accurate measurement: for example, 110.2 – 1.34 = 108.86 but
report as 108.9. When multiplying or dividing, the result
cannot have more significant figures than the least accurate
measurement: for example, 10.20 / 1.3 = 7.84615… but report
as 7.8.

X5.2.7.3 (See 7.4.5) Because the deformations measured
within the shear-free portion of the beam are only a fraction of
that measured over the total span, more accurate devices are
required. For shear-free deflection measurements, it may be
desirable to use a quarter-point rather than a third-point loading
scheme. When doing so, the consideration should be given to
possible bearing failures and the effect of span on the beam
response.

X5.3 Rules for Determination of Specimen Length (8.5)

X5.3.1 The length of beams is established depending on the
purpose of the test and type of failure desired. For wood beams
of uniform rectangular cross section, the desired span length
can be estimated using the \( a/d \) ratio if approximate values of
modulus of rupture \( (S_R) \) and shear strength \( (\tau_m) \) are known. It
is assumed that when \( a/d = S_R/4\tau_m \) the beam is equally likely
to fail in either shear or in flexure.

X5.3.2 The length of beams intended primarily for evaluation
of shear strength should be such that the shear span is relatively short. For wood beams, it is generally assumed that \( S_R \) is 10 times greater than \( \tau_m \). Therefore, it is assumed that beams with \( a/d \) near 2.5 would produce a high percentage of shear failures. Indeed, the ratio \( S_R/\tau_m \) depends on the lumber grade, type of material tested, and other variables. Often, tests
on short-span beams produce a number of failure modes other
than shear. Statistical analysis and interpretation of test data is
beyond the scope of these test methods. An example of guidance on interpreting of shear strength data can be found in
Practice D3737, Appendix.

X5.3.3 The span length of beams intended primarily for evaluation of flexural properties (bending strength and modulus
of elasticity) should be such that the shear span is relatively long. Wood beams of uniform rectangular cross section having
\( a/d \) ratios from 4 to 6 are in this category. The \( a/d \) values should be somewhat greater than \( S_R/4\tau_m \) so that the beams do not fail
in shear but should not be so large that beam deflections cause
sizable thrust of reactions and thrust values need to be taken
into account. A suggested range of \( a/h \) values is between
approximately 0.4 \( S_R/\tau_m \) and 0.6 \( S_R/\tau_m \). In this range, shear
distortions affect the total deflection, so that flexural properties
may be calculated by formulae provided in Appendix X2.

X5.3.4 The span length of beams intended primarily for evaluation of only the deflection of specimen due to bending
moment should be such that the shear span is long. Solid wood
beams of uniform rectangular cross section in this category have
\( a/d \) ratios greater than 6. The shear stresses and distortions
are assumed to be small so that they can be neglected; hence
the \( a/d \) ratio is suggested to be greater than 0.6 \( S_R/\tau_m \).

X5.4 Precision and Bias of the Flexure Test Method (Section 12)

X5.4.1 Precision indexes stated in Table 1 are based on data
from 11 out of 16 participating laboratories found to be in
statistical control and in general compliance with the standard
requirements. Statistical analysis determined that data from the
five excluded laboratories were out of statistical control.
Further investigation of these excluded cases established non-
compliance to the standard requirements due to mechanical
deficiencies of the test setup or deflection measurement
apparatus, or both, (for example, supports or load heads lacked
free pivoting movement in one or another direction, yoke was
mounted too loose or too tight on the side of the beam, contact
between the displacement transducer and the screw was not
secured, diameter of the load blocks was too small, etc.). Therefore, data from these laboratories were removed from the
analysis, according to Practice E691.

X5.4.2 In this study, the apparent modulus of elasticity, \( E_{app} \), measured in accordance with this test method is the
reference, and therefore, there is no bias (Practice E177, 28.10,
Ex. 10.1). However, there may be laboratory bias due to the
laboratory’s particular implementation of the method or internal
procedures. Because certified reference materials are not
available, interlaboratory testing should be employed (Practice
E177, 20.4) to determine the laboratory bias.

X5.4.3 A laboratory, which follows good professional prac-
tices may be considered competent to use this test method;
however, the real precision and bias of a laboratory can only be
quantified through an ILS. While the precision indexes stated
in Table 1 do not necessarily represent all of the laboratories
involved in the ILS, they set an achievable target for any
competent laboratory. The statistics are valid for the conditions
indicated in Table 1 and can be recommended as a reference for
future interlaboratory comparisons of test results obtained from
the Flexure Test Method for \( E_{app} \).

X5.4.4 The indexes of precision of the tested materials did
not seem to depend on the level of the measured \( E_{app} \); therefore, the indexes based on analysis of the pooled data can
be applied. Reproducibility limits, however, differed consid-
Sibly between the edgewise and flatwise tests and, therefore,
should be stated separately. One reason for higher variation of
the flatwise test results between laboratories can be attributed
to the relative error in the length measurement of the shorter
test span. Twist in the test specimens is also believed to
influence the flatwise test results more than those on the edge,
as the distance between the yoke and the longitudinal axis of
the specimen increases. \( E_{app} \) test results were generally more
consistent when the deflection measurements were taken closer
to the side face of the beam. Higher consistency of results was
observed in a laboratory that used yokes on both sides of the
beam. For further details, please refer to the Research Report
RR: RR:D07-1005.3

X5.5 Shear Modulus

X5.5.1 Calculation (Section 43)—The units for the X and Y
axes in Fig. 17 were chosen for ease of plotting a line in the
format of \( y = nx + b \). Appendix X4 describes the methodology
to convert the slope and intercept of this line to the appropriate
elastic constants \( (E_{yf}, E_{app}, G) \).

X5.6 Speed of Testing

X5.6.1 The bending (9.3), compression (18.3 and 26.3),
tension (34.3), and torsion (42.3) test speeds employed by
these test methods were uniformly updated in 2009. For tests that measured only the peak strength, prior versions specified that the maximum load be achieved in “about” 10 min with a mandatory range for individual specimens of between 5 and 20 min. Slower rates were required for the compression, tension, and torsion test methods when deformations were to be measured. The bending test method specifically stated that the load rate should be “...a constant rate to achieve maximum load in about 10 min, but maximum load should be reached in not less than 6 min nor more than 20 min. A constant rate of outer strain, $z$, of 0.0010 in./in. $\cdot$ min (0.001 mm/mm $\cdot$ min) will usually permit the tests of wood members to be completed in the prescribed time.” When measuring load-deformation data, both of the compression test methods specified that the load be applied at a constant rate of head motion such that the fiber strain was 0.001 in./in. $\cdot$ min (0.001 mm/mm $\cdot$ min). For measuring only compressive strength, the test was permitted to be conducted at a constant rate to achieve maximum load in about 10 min, but not less than 5 nor more than 20 min. The tension method used the same load rate as the compression test when measuring only strength. However, when measuring tension load-deformation data, a constant rate of head motion was required to create a fiber strain of 0.0006 in./in. $\cdot$ min + 25 % (0.0006 mm/mm $\cdot$ min). The torsion test method stated that “For measuring torque-twist data, apply the load at a constant rate of head motion so that the angular detruson of the outer fibers in the test section between gage points is about 0.004 radian per inch of length (0.16 radian per metre of length) per minute $\pm$ 50 %. For measuring only shear strength, the torque may be applied at a constant rate of twist so that maximum torque is achieved in about 10 min but not less than 5 nor more than 20 min.”

X5.6.2 It has long been recognized that the strength of wood products is time dependent and will be sensitive to duration of load effects. Consequently, it is expected that such products will be sensitive to rate of loading at test load durations. To enable test results to be presented on a consistent basis, a target time to failure of “about” 10 min was historically employed in these test methods. Test results obtained using this basis were then typically normalized in the various performance standards from a 10 min test to a 10-year load duration using an adjustment factor of $\frac{1}{1.6}$ based upon the Madison Curve.

X5.6.3 With the advent of full-size lumber and wood-based material testing, it was observed that the rate of loading effects used to establish characteristic property values were inconsistent (4). With load rates that result in times to failure between 4 and 20 min, the rate of loading effect was also not found to be as pronounced as previously thought. These observations were confirmed in analysis performed by Karacabeyli and Barrett on rate of loading data found in the literature (5).

X5.6.4 Faster loading rates that result in average times to failure of in the order of 1 minute have been subsequently permitted in standards such as Test Methods D4761 to efficiently process the larger sample sizes required in structural lumber testing programs. These faster test speeds have also typically been paired with the same adjustment factors that have normally been applied to tests undertaken using a 10 min test duration (that is, $\frac{1}{1.6}$ adjustments factors to convert to a 10-year load duration.)

X5.6.5 The test methods in this standard were uniformly updated to require the average time to maximum load of at least 4 min for each test series in an effort to update the provisions to reflect modern test equipment capabilities and bring these test methods into closer agreement with alternate methods such as Test Methods D4761. Based upon the work of Karacabeyli and Barrett (5), the difference between a 4 and 10 min average time to maximum load was judged to be negligible. Accordingly, it is intended that structural wood products tested with this method should continue to use the existing adjustment factors to convert test data from this standard to common load durations.

X5.6.6 As noted in X5.6.3 and X5.6.5, the justification for the higher rates of loading are based on observations of rate of loading effects in large data sets of common wood products. For product where the rate of loading effect is not clear or where the test set is too small to permit a loading or displacement rate to be selected that meets the time to maximum load specified, the historic load rates outlined in X5.6.1 should be used. With wood products that exhibit considerable variability, an average load rate that well exceeds the 4 min minimum average should be considered. With small test sets, the suggested strain rates provided in X5.6.1 can still be used as an initial estimate that should comply with the provisions of this standard for most wood products.
REFERENCES


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