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Standard Test Methods for Nondestructive Evaluation of Wood-Based Flexural Members Using Transverse Vibration[1]

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INTRODUCTION

Nondestructive testing methods are used to determine the physical and mechanical properties of wood-based materials. These test methods help ensure structural performance of products manufactured from a variety of wood species and quality levels of raw materials. These test methods also assist in evaluating the influence of environmental conditions on product performance.

These test methods for transverse vibration nondestructive testing of wood-based materials adopt methods used by various testing and research organizations. These test methods will yield results comparable to traditional methods, permitting standardization of results, interchange and correlation of data, and establishment of a cumulative body of information on wood species and products of the world.

1. Scope

1.1 These test methods cover the determination of the flexural stiffness and modulus of elasticity properties of wood-based materials by nondestructive testing using transverse vibration in the vertical direction.

1.2 The test methods are limited to specimens having solid, rectangular sections.

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

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D9 Terminology Relating to Wood and Wood-Based Products [2]

D198 Test Methods of Static Tests of Lumber in Structural Sizes [2]

D1990 Practice for Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens [2]

D2915 Practice for Evaluating Allowable Properties for Grades of Structural Lumber [2]

D4442 Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials [2]

D4444 Test Method for Laboratory Standardization and Calibration of Hand-Held Moisture Meters [2]

D4761 Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Material [3]

E4 Practices for Force Verification of Testing Machines

E1267 Guide for ASTM Standard Specification Quality Statements[4]

2.2 *Other Standard:*

ISO 7626/1 Vibration and Shock-Experimental Determination of Mechanical Mobility—Part 1: Basic Definitions and Transducers[5]

3. Terminology

3.1 *Definitions*—See Terminology D9 and Test Methods D198.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *calibration*—the determination of the relationship between the response of standardized instrumentation to properties of reference material, determined by a standard method.

3.2.2 *fundamental mode of vibration*—the simplest mode of vibration for a simply supported beam is the vertical motion produced from a slight vertical displacement of the member at its mid-span. This is termed its fundamental mode of vibration (Fig. 1) and is the mode to which this standard applies.

[1] These test methods are under the jurisdiction of ASTM Committee D07 on Wood and is the direct responsibility of Subcommittee D07.01 on Fundamental Test Methods and Properties.

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

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

[4] Discontinued 1996, see 1995 *Annual Book of ASTM Standards*, Vol 14.02.

[5] Available from American National Standards Institute, 25 W. 43rd St., 4th Floor, New York, NY 10036.

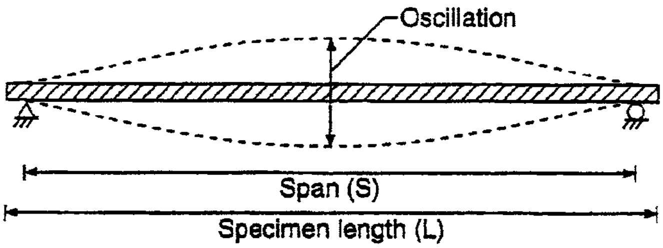

FIG. 1 Transverse Vibration in the Fundamental Mode

3.2.3 *standardization*—the determination of the response of the instrumentation to a reference material.

3.2.4 *transverse vibration*—the oscillation of a simply supported bending member that results from an initial displacement of the member at its mid-span or other means of exciting its fundamental mode of vibration.

4. Summary of Test Method

4.1 The structural member is deflected at its mid-span and allowed to oscillate in a transverse bending mode. Observations of frequency of oscillation are used to calculate modulus of elasticity.

5. Significance and Use

5.1 The dynamic modulus of elasticity provided by these test methods is a fundamental property for the configuration tested. This value can be related to static and other dynamic moduli of elasticity as measured on the same configuration.

5.1.1 The rapidity and ease of application of these test methods facilitate its use as a substitute for static measurements.

5.1.2 Dynamic modulus of elasticity is often used for surveys, for segregation of lumber for test purposes, and to provide indication of environmental or processing effect.

5.2 The modulus of elasticity, whether measured statically or dynamically, is often a useful predictor variable to suggest or explain property relationships.

6. Apparatus

6.1 The testing equipment shall consist of three essential elements:

6.1.1 A support apparatus,

6.1.2 An excitation system, and

6.1.3 A measurement system.

6.2 *Support Apparatus*—The support shall provide vertical support to the ends of the specimen yet permit rotation.

6.2.1 *Reactions*—The specimen shall be supported in a manner to prevent damage to the specimen at the point of contact between it and the reaction support. The reactions shall be such that change in length of the specimen longitudinal movement and rotation of the specimen about the reaction due to deflection will be unrestricted.

6.2.2 *Reaction Alignment*—Provision shall be made at the reactions to allow for initial twist in the length of the specimen. If the bearing surfaces of the specimen at its reaction are not parallel to the bearing surface of the reactions, the specimen shall be shimmed or the bearing surfaces rotated about an axis parallel to the span to provide adequate bearing across the width of the specimen.

6.2.3 *Lateral Support*—No lateral support shall be applied. Specimens unstable in this mode shall not be tested using this method.

6.2.4 *Lengthwise Positioning and Overhang of the Specimen*—The specimen shall be positioned such that an equal portion of the length overhangs each support. Excessive overhang may alter results obtained. If basic equation (Eq 1) is used, then the span(s) to length (L) ratio shall exceed 0.98. If other s/L ratios are used, more exacting analysis and equations shall be used; see Ref (**1**).[6]

NOTE 1—In testing of dimension lumber, an overhang of approximately 1 in. on each end is often used. The amount of overhang may be influenced by the convenience of handling and positioning but should be kept uniform from specimen to specimen.

6.3 *Excitation System*—The member shall be excited so as to produce a vertical oscillation in a reproducible manner in the fundamental mode. The method of analysis is based on oscillation in this mode (Fig. 1).

6.3.1 *Manual Method*—A manual deflection of the specimen will provide sufficient impetus for oscillation for many products. The deflection shall be vertical with an effort to exclude lateral components; neither excessive impact nor prolonged contact with the specimen are recommended.

NOTE 2—For example, a manual tap on a 16-foot 2 by 12, supported flat-wise having a MOE of 2.0×10^6 psi will result in a vertical oscillation of between 3 and 4 Hz.

6.3.2 *Mechanical Methods*—The guidelines of 6.3.1 shall be duplicated with mechanical systems. Specimens with very high stiffness require mechanical excitation by a high force or carefully regulated impact/release.

6.4 *Measurement System*—Measurement of the frequency of oscillation shall be obtained by either a force or displacement measuring device calibrated to ensure accuracy in accordance with Practices E4 and ISO 7626/1.

6.4.1 *Force Measuring System*—Changes in the force in response to the vibration at one or both of the supports are methods used to obtain frequency of oscillation.

6.4.2 *Deflection Measuring System*—Measurement of the mid-span displacement in response to the initial displacement is an alternative method to determine frequency of oscillation.

6.4.3 *Measurement of the Fundamental Mode*—In these test methods, it is critical that only the frequency associated with the fundamental vertical oscillation mode be used. Use a short delay before acquiring the data to ensure the data acquired is only related to the fundamental vertical mode.

7. Test Specimen

7.1 Specimens shall be solid and rectangular. Deviations in shape and uniformity in dimension from end-to-end and side-to-side incidental to sampling, such as wane included in a lumber grade description, shall be noted as part of the sample or specimen description.

[6] The boldface numbers in parentheses refer to the list of references at the end of this standard.

7.2 *Span to Depth Ratio*—The span-to-depth ratio used shall be greater than 20 unless special precautions are taken to permit higher frequency measurements.

7.3 *Moisture Content*—Moisture content of specimens shall be measured in accordance with Test Methods D4442 or D4444D4442D4444, or both. Specific reference to the current moisture status of the specimens shall be made; for example, equilibrated, recently kiln dried containing gradients, air dried, packaged specimens of unknown drying history, and so forth. Use of Test Methods D4444 procedures to identify gradients caused by drying or surface wetting is recommended. MC gradients within a piece may affect the dynamic *E* (see X1.1.17).

8. Procedure

8.1 *Standardization and Calibration*—The testing system shall be standardized and calibrated using standard reference materials. The procedures of Annex A1 shall be followed. The results of this test method are conditional upon proper standardization and appropriate choice of calibration method.

NOTE 3—It has been a practice to use aluminum bars as well as lumber specimens as standardization materials and, often, also for calibration against a standard static test results.

8.2 *Excitation*—The procedures of excitation listed under Section 6 shall be followed. Repetitions are recommended to reduce the chance of bias caused by improper excitation.

8.2.1 To quantify measurement uncertainty for precision and bias estimates, specific data sets shall be taken during the test sequence to allow calculation of this contribution to measurement tolerances.

8.3 *Calculation of Modulus of Elasticity*:

8.3.1 *Basic Equation*—The following formula shall be used to calculate modulus of elasticity from the measured oscillation in the fundamental mode (Fig. 1):

$$E_{tv} = \frac{(f_r)^2 w(s)^3}{K_d I g} \quad (1)$$

where:

E_{tv} = transverse vibration modulus of elasticity, psi (MPa),
s = span, in. (mm),
w = weight of specimen, lbf (N),
f_r = frequency of oscillation, Hz,
I = specimen moment of inertia, $bh^3/12$,
b = breadth (width), in. (mm),
h = height, in. (mm),
g = acceleration due to gravity, 386 in./s^2(9807 mm/s^2), and
K_d = constant for free vibration of a simply supported beam, 2.47.

8.3.2 *Analysis and Presentation of Results*—Analysis of data collected from samples and the presentations of results shall be consistent with the appropriate methods of Practice D2915, Section 4.

8.3.2.1 The presentation of results shall indicate whether the calculations of *E* are based on the actual, individual piece cross section dimensions at the time of test or on standard (design base) dimensions.

8.3.2.2 *Environmental Conditions*—Sensitivity of the test specimens to changes in the test environment shall be considered in calculating apparent modulus of elasticity values. If, for example, the temperature varies during the test and affects the properties of the test material, this shall be considered in presentation of test results. Appropriate adjustments for lumber are included in Practice D1990 and in Ref **(2)**.

8.3.2.3 Adjustments to dynamic *E* values for moisture content of specimens above 22 % MC shall be documented (see X1.1.21).

9. Report

9.1 The report shall be sufficiently complete to permit reproduction of the test, including the calibration process. Inadequate explanation of the basis of the modulus of elasticity measurement results in data of unknown comparability.

9.2 Particular attention shall be given to comprehensive reporting of the traceability of transducer calibrations to nationally acceptable references.

9.3 The report shall contain at least the following elements:

9.3.1 *Equipment*—Description of the apparatus, including the manufacturer of the device, the model, and the calibration system if incorporated in the manufactured device. If mechanical excitation is employed, the mechanism shall be described along with the method of assuring adequate excitation.

9.3.2 *Test Setup*—Description of the specimen supports, if not reported as part of 9.3.1; the support surfaces; and the provisions employed for support of twisted or irregular surfaces.

9.3.3 *Environment*—Describe the temperatures during calibration and data collection and other factors in the operating environment that may affect measurement. Note changes in these factors over the data collection period.

9.3.4 *Calibration*—Identify whether the *E* was calculated using the fundamental formula (Eq 1) or the adjusted formula (see A1.2.4). If the latter was used, describe the source of the factors k_s and *z*. A comprehensive description of the materials used for standardization and for calibration shall be provided.

9.3.5 *Test Data*—Present the test data in the units comparable to those employed in 7.1. The data presentation shall include an estimate of the precision and bias of the data and method of estimation.

9.3.6 *Data Adjustments*—All adjustments made to test data shall be fully explained, including actions taken to meet the reporting requirements of Practice D2915.

10. Precision and Bias

10.1 The precision and bias are dependent upon equipment used (see Section 6) and the Standardization and Calibration practices applied.

ANNEX

(Mandatory Information)

A1. STANDARDIZATION AND CALIBRATION

A1.1 Standardization

A1.1.1 Standardization shall be performed on the dynamic test apparatus to verify the integrity of the system. Suitable reference materials for standardization have properties that are not subject to significant change under the test conditions. Reference materials are often recommended or provided, or both, by the manufacturer of the test system. The standardization test shall provide at least one reference point (output) within the operating range of interest. The standard reference material shall provide vibration performance within the range of vibration frequency of the test.

A1.1.2 Typically, a metal bar had been employed as the reference material for standardization. Care shall be taken to compensate for the effect of temperature variation on the metal properties when standardization tests are repeated over the duration of the test program.

NOTE A1.1—Traditionally, a single metal bar has often been used both for standardization and calibration, thus blurring the distinction between the two functions.

A1.1.3 While wood members and other materials subject to change in properties with change in the test environment may be used, this is discouraged unless the test conditions are maintained sufficiently constant, such as in a conditioning room environment where the wood member is in equilibrium.

A1.1.4 Standardization of the test system shall be repeated at sufficient intervals during the test sequence to ensure continued adequate performance of the system.

A1.2 Calibration

A1.2.1 The test system shall be calibrated against reference materials whose properties are traceable to nationally acceptable standards.

A1.2.2 Transducers incorporated within the test system shall have calibrations traceable to national measurement standards maintained by a National Metrology Institute (NMI).

NOTE A1.2—The NMIs in the United States and Canada are the National Institute of Standards and Technology (NIST) and the National Research Council (NRC), respectively.

A1.2.3 When the E_{tv} values are derived directly from the test system measurements in accordance with Eq 1 of 8.3.1, calibration is dependent solely upon the transducer calibrations; no additional calibration adjustments shall be made.

A1.2.4 When a standardized system output is further adjusted to achieve a calibration against results of another test method (for example, Test Methods D4761 or D198 static tests), Eq 1 shall be modified as follows:

$$E_s = \frac{(f_r)^2 w(s)^3}{k_s b h^3} + z \quad \text{(A1.1)}$$

where E_s is a predicted static modulus of elasticity, k_s is a calibration coefficient established by test with the calibrating material and z is a calibration offset factor.

A1.2.4.1 Calibration of transverse vibration response to predict values related to standard static test values has traditionally often been done with a single reference specimen. With this method, only k_s is determined ($z = 0$) and the calibration cannot represent any intercept adjustment in the correlation between the vibration response and the static response of the specimens.

(*1*) Reference standards for calibration based on a single point should be those whose mechanical properties do not change significantly with time or environmental conditions. The properties of the reference material shall be determined by standard tests and the vibration characteristics shall be in the range of the test.

(*2*) Reference standards whose physical and mechanical properties may change significantly with the environment should be used only in a carefully controlled environment and only under conditions where the properties have been maintained constant in that environment since the static determination. If the properties change significantly with time, the material use should be restricted to tests of short duration and the time period between the static and dynamic tests be limited. The properties of the reference material shall be determined by standard tests and the vibration characteristics shall be in the range of the test.

A1.2.5 Calibration of transverse vibration response that represents the relationship between the dynamic and static differences over the test range with both slope and intercept adjustment requires regressing the response of specimens in both test modes. The result is information that permits use of both slope and intercept adjustment in the formula (Eq A1.1). All cautions in selecting reference standard material noted in A1.2.4.1 apply. Further, the regression developed must fully represent the material characteristics, the material moisture conditions, and the range of properties anticipated in the test.

A1.3 Report

A1.3.1 Test results obtained using Eq A1.1 for analysis require reporting the following elements in addition to those listed in Section 9.

A1.3.1.1 If dynamic modulus of elasticity values are calibrated by or converted to static modulus of elasticity values, the resulting values will reflect the calibration procedures and the error components from both of the test methods. Reports of the statistical analysis and presentation of results shall consider both test methods.

(*1*) Estimates of precision and bias shall consider both error components.