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Standard Guide for
Evaluating System Effects in Repetitive-Member Wood Assemblies[1]

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INTRODUCTION

The apparent stiffness and strength of repetitive-member wood assemblies is generally greater than the stiffness and strength of the members in the assembly acting alone. The enhanced performance is a result of load sharing, partial composite action, and residual capacity obtained through the joining of members with sheathing or cladding, or by connections directly. The contributions of these effects are quantified by comparing the response of a particular assembly under an applied load to the response of the members of the assembly under the same load. This guide defines the individual effects responsible for enhanced repetitive-member performance and provides general information on the variables that should be considered in the evaluation of the magnitude of such performance.

The influence of load sharing, composite action, and residual capacity on assembly performance varies with assembly configuration and individual member properties, as well as other variables. The relationship between such variables and the effects of load sharing and composite action is discussed in engineering literature. Consensus committees have recognized design stress increases for assemblies based on the contribution of these effects individually or on their combined effect.

The development of a standardized approach to recognize "system effects" in the design of repetitive-member assemblies requires standardized analyses of the effects of assembly construction and performance. Users are cautioned to understand that the performance improvements that might be observed in system testing are often related to load paths or boundary conditions in the assembly that differ from those of individual members. This is especially true for relatively complex assemblies. For such assemblies, users are encouraged to design the test protocols such that internal load paths, as well as summations of "loads in" versus "loads out" are measured (see X3.11.7.1). Data from testing, preferably coupled with analytical predictions, provide the most effective means by which system factors can be developed. When system factors are intended to apply to strength (rather than being limited to stiffness), loads must be applied to produce failures so that the effects of nonlinearities or changes in failure modes can be quantified.

1. Scope

1.1 This guide identifies variables to consider when evaluating repetitive-member assembly performance for parallel framing systems.

1.2 This guide defines terms commonly used to describe interaction mechanisms.

1.3 This guide discusses general approaches to quantifying an assembly adjustment including limitations of methods and materials when evaluating repetitive-member assembly performance.

1.4 This guide does not detail the techniques for modeling or testing repetitive-member assembly performance.

1.5 The analysis and discussion presented in this guideline are based on the assumption that a means exists for distributing applied loads among adjacent, parallel supporting members of the system.

1.6 Evaluation of creep effects is beyond the scope of this guide.

1.7 This guide does not purport to suggest or establish appropriate safety levels for assemblies, but cautions users that designers often interpret that safety levels for assemblies and full structures should be higher than safety levels for individual structural members.

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NOTE 1—Methods other than traditional safety factor approaches, such as reliability methods, are increasingly used to estimate the probability of failure of structural elements. However, the extension of these methods to assemblies or to complete structures is still evolving. For example, complete structures will likely exhibit less variability than individual structural elements. Additionally, there is a potential for beneficial changes in failure modes (that is, more ductile failure modes in systems). These considerations are beyond the scope of this guide.

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

1.9 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D245 Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber

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

D2915 Practice for Sampling and Data-Analysis for Structural Wood and Wood-Based Products

2.2 *Other Documents:*

ANSI/ASAE EP559.1 Design Requirements and Bending Properties for Mechanically-Laminated Wood Assemblies[3]

ASCE/SEI 7 Minimum Design Loads and Associated Criteria for Buildings and Other Structures[4]

ANSI/AWC SPDWS Special Design Provisions for Wind and Seismic[5]

ANSI/AWC NDS National Design Specification (NDS) for Wood Construction[5]

ANSI/TPI 1 National Design Standard for Metal Plate Connected Wood Truss Construction[6]

3. Terminology

3.1 *Definitions:*

3.1.1 *composite action, n*—interaction of two or more connected wood members that increases the effective section properties over that determined for the individual members.

3.1.2 *element, n*—discrete physical piece of a member such as a truss chord.

3.1.3 *global correlation, n*—correlation of member properties based on analysis of property data representative of the species or species group for a large defined area or region rather than mill-by-mill or lot-by-lot data.

3.1.3.1 *Discussion*—The area represented may be defined by political, ecological, or other boundaries.

3.1.4 *load sharing, n*—distribution of load among adjacent, parallel members in proportion to relative member stiffness.

3.1.5 *member, n*—structural wood element or elements such as studs, joists, rafters, trusses, that carry load directly to assembly supports.

3.1.5.1 *Discussion*—A member may consist of one element or multiple elements.

3.1.6 *parallel framing system, n*—system of parallel framing members.

3.1.7 *repetitive-member wood assembly, n*—system in which three or more members are joined using a transverse load-distributing element.

3.1.7.1 *Discussion*—Exception: Two-ply assemblies can be considered repetitive-member assemblies when the members are in direct side-by-side contact and are joined together by mechanical connections or adhesives, or both, to distribute load.

3.1.8 *residual capacity, n*—ratio of the maximum assembly capacity to the assembly capacity at first failure of an individual member or connection.

3.1.9 *sheathing gaps, n*—interruptions in the continuity of a load-distributing element such as joints in sheathing or decking.

3.1.10 *transverse load-distributing elements, n*—structural components such as sheathing, siding and decking that support and distribute load to members.

3.1.10.1 *Discussion*—Other components such as cross bridging, solid blocking, distributed ceiling strapping, strongbacks, and connection systems may also distribute load among members.

4. Significance and Use

4.1 This guide covers variables to be considered in the evaluation of the performance of repetitive-member wood assemblies. System performance is attributable to one or more of the following effects:

4.1.1 Load sharing,

4.1.2 Composite action, or

4.1.3 Residual capacity.

4.2 This guide is intended for use where design stress adjustments for repetitive-member assemblies are being developed.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Society of Agricultural and Biological Engineers (ASABE), 2950 Niles Road, St. Joseph, MI 49085, http://www.asabe.org.

[4] Available from American Society of Civil Engineers (ASCE), 1801 Alexander Bell Dr., Reston, VA 20191, http://www.asce.org.

[5] Available from American Wood Council, 50 Catoctin Circle NE, Suite 201, Leesburg, VA 20176.

[6] Available from Truss Plate Institute, 218 N. Lee Street, Ste. 312, Alexandria, VA 22314.

4.3 This guide serves as a basis to evaluate design stress adjustments developed using a combination of analysis and testing.

Note 2—Enhanced assembly performance due to intentional overdesign or the contribution of elements not considered in the design are beyond the scope of this guide.

5. Load Sharing

5.1 *Explanation of Load Sharing:*

5.1.1 Load sharing reduces apparent stiffness variability of members within a given assembly. In general, member stiffness variability results in a distribution of load that increases load on stiffer members and reduces load on more flexible members.

5.1.2 A positive strength-stiffness correlation for members results in load sharing increases, which give the appearance of higher strength for minimum strength members in an assembly under uniform loads.

Note 3—Positive correlations between modulus of elasticity and strength are generally observed in samples of "mill run" dimension lumber; however, no process is currently in place to ensure or improve the correlation of these relationships on a grade-by-grade or lot-by-lot basis. Where design values for a member grade are based on global values, global correlations may be used with that grade when variability in the stiffness of production lots is taken into account. Users are cautioned to not extrapolate bending strength and stiffness correlations to other properties. As discussed in the appendices, early implementation of repetitive-member factors focused on sawn lumber flexural members. The beneficial load sharing in these systems was often characterized as being related to the positive correlation between flexural strength and stiffness in these elements. For other systems where stresses are primarily axial (compression or tension), the appropriate property correlation (if used in the analysis) should relate axial strength and stiffness rather than flexural correlations.

5.1.3 Load sharing tends to increase as member stiffness variability increases and as transverse load-distributing element stiffness increases. Assembly capacity at first member failure is increased as member strength-stiffness correlation increases.

Note 4—From a practical standpoint, the system performance due to load sharing is bounded by the minimum performance when the minimum member in the assembly acts alone and by the maximum performance when all members in the assembly achieve average performance.

5.2 *Variables Affecting Load Sharing Effects on Stiffness Include:*

5.2.1 Loading conditions;

5.2.2 Member span, end conditions, and support conditions;

5.2.3 Member spacing;

5.2.4 Variability of member stiffness;

5.2.5 Ratio of average transverse load-distributing element stiffness to average member stiffness;

5.2.6 Sheathing gaps;

5.2.7 Number of members;

5.2.8 Load-distributing element end conditions;

5.2.9 Lateral bracing; and

5.2.10 Attachment between members.

5.3 *Variables Affecting Load Sharing Effects on Strength Include:*

5.3.1 Load sharing for stiffness (5.2), and

5.3.2 Level of member strength-stiffness correlation.

6. Composite Action

6.1 *Explanation of Composite Action:*

6.1.1 For bending members, composite action results in increased flexural rigidity by increasing the effective moment of inertia of the combined cross-section. The increased flexural rigidity results in a redistribution of stresses which usually results in increased strength.

6.1.2 Partial composite action is the result of a non-rigid connection between elements which allows interlayer slip under load.

6.1.3 Composite action decreases as the rigidity of the connection between the transverse load-distributing element and the member decreases.

6.2 *Variables Affecting Composite Action Effects on Stiffness Include:*

6.2.1 Loading conditions,

6.2.2 Load magnitude,

6.2.3 Member span,

6.2.4 Member spacing,

6.2.5 Connection type and stiffness,

6.2.6 Sheathing gap stiffness and location in transverse load-distributing elements, and

6.2.7 Stiffness of members and transverse load-distributing elements (see 3.1.5).

6.3 *Variables Affecting Composite Action Effects on Strength Include:*

6.3.1 Composite action for stiffness (6.2), and

6.3.2 Location of sheathing gaps along members.

7. Residual Capacity of the Assembly

7.1 *Explanation of Residual Capacity:*

7.1.1 Residual capacity is a function of load sharing and composite action which occur after first member failure. As a result, actual capacity of an assembly can be higher than capacity at first member failure.

Note 5—Residual capacity theoretically reduces the probability that a "weak-link" failure will propagate into progressive collapse of the assembly. However, an initial failure under a gravity or similar type loading may precipitate dynamic effects resulting in instantaneous collapse.

7.1.2 Residual capacity does not reduce the probability of failure of a single member. In fact, the increased number of members in an assembly reduces the expected load at which first member failure (FMF) will occur (see Note 6). For some specific assemblies, residual capacity from load sharing after FMF may reduce the probability of progressive collapse or catastrophic failure of the assembly.

Note 6—Conventional engineering design criteria do not include factors for residual capacity after FMF in the design of single structural members. The increased probability of FMF with increased number of members can be derived using probability theory and is not unique to wood. The contribution of residual capacity should not be included in the development of system factors unless it can be combined with load sharing beyond FMF and assembly performance criteria which take into account general structural integrity requirements such as avoidance of progressive collapse (that is, increased safety factor, load factor, or reliability index). Development of acceptable assembly criteria should consider the desired reliability of the assembly.

7.2 *Variables Affecting Residual Capacity Effects on Strength Include:*

7.2.1 Loading conditions,

7.2.2 Load sharing,

7.2.3 Composite action,

7.2.4 Number and type of members,

7.2.5 Member ductility (brittle versus ductile),

7.2.6 Connection system,

7.2.7 Contribution from structural or nonstructural elements not considered in design, and

7.2.8 Contribution from structural redundancy.

8. Quantifying Repetitive-Member Effects

8.1 *General*—This section describes procedures for evaluating the system effects in repetitive-member wood assemblies using a combination of analysis and testing. Analysis of results shall follow the requirements of 8.4.

8.2 *Analysis:*

8.2.1 System effects in repetitive-member wood assemblies shall be quantified using methods of mechanics and statistics.

8.2.2 Each component of the system factor shall be considered.

8.2.3 Confirmation tests shall be conducted to verify adequacy of the derivation in 8.2.1 to compute force distributions. Tests shall cover the range of conditions (that is, variables listed in 5.2, 5.3, 6.2, 6.3, and 7.2) anticipated in use. If it is not possible to test the full range of conditions anticipated in use, the results of limited confirmation tests shall be so reported and the application of such test results clearly limited to the range of conditions represented by the tests. Confirmation tests shall reflect the statistical assumptions of 8.2.1.

Note 7—When analyzing the results of confirmation tests, the user is cautioned to differentiate between system effects in repetitive-member wood assemblies that occur prior to first member failure and system effects which occur after first member failure as a result of residual capacity in the test assembly (see Section 7).

8.2.4 If increased performance is to be based on material property variability, the effects of the property variability shall be included in the analysis.

8.2.4.1 For material properties which are assigned using global ingrade test data, the effects of the property variability, including lot-by-lot variation, shall be accounted for through Monte Carlo simulation using validated property distributions based on global ingrade test data (Practice D1990).

8.2.4.2 For material properties that are assigned using mill specific data, the effects of the property variability shall be accounted for using criteria upon which ongoing evaluation of the material properties under consideration are based.

8.2.5 Extrapolation of results beyond the limitations assigned to the analysis of 8.2.1 is not permitted.

8.3 *Testing:*

8.3.1 System effects in repetitive-member wood assemblies quantified primarily based on empirical test results shall be subject to the following limitations:

8.3.1.1 For qualification, a minimum of 28 assembly specimens shall be tested for a reference condition. Additional samples containing 28 assembly specimens shall be tested for additional loading and test conditions.

Exception: When system factors are limited to serviceability, the number of assembly tests need not exceed that required to estimate the mean within ±5 % with 75 % confidence.

Note 8—The minimum sample size of 28 was selected from Table 2 of Practice D2915.

8.3.1.2 Extrapolation of results to other loading and test conditions is not permitted.

8.3.1.3 Interpolation of results between test conditions is limited to one variable.

8.3.1.4 Additional sampling for each of the elements in the assembly shall be selected and tested to ensure that the elements in the test assemblies are representative of the population.

8.3.1.5 An ongoing procedure shall be developed and maintained for quality control of the assembly to which repetitive-member effects quantified in accordance with this guide are to be applied, including construction details, material properties, fabrication quality, and field application limits consistent with the variability considered in the analytical modeling and confirmation testing.

8.4 *Evaluation*—In the absence of a more detailed analysis, the methods in 8.4.1 and 8.4.2 shall be used to evaluate system effects in repetitive-member wood assemblies.

Note 9—Assemblies exhibiting atypical creep or assemblies exhibiting failure modes that differ from individual member tests require additional consideration to account for differences between short-term and long-term performance.

Note 10—For assemblies with the potential to exhibit failures in more than one material type (such as steel failure versus wood failures), users are cautioned to establish reference safety levels for each that are consistent with recognized design standards for those materials, and to limit application of repetitive-member effects only to design for failure modes consistent with what was considered in analysis.

8.4.1 *System Factors for Strength (including Buckling):*

8.4.1.1 The system strength factor for a repetitive-member assembly shall be computed as the ratio of load at first member failure (FMF) in the assembly to load at FMF for the same number of members not in an assembly.

8.4.1.2 The assigned system strength factor, C_r, shall be determined as the ratio of the 5th-percentile tolerance limit of the tested (or simulated) assembly specimens to the 5th-percentile tolerance limit of the tested (or simulated) non-assembly specimens.

8.4.2 *System Factors for Stiffness:*

8.4.2.1 The system stiffness factor for a repetitive-member assembly shall be computed as the inverse ratio of the maximum deflection of the assembly to the maximum deflection of the same members not in an assembly. The deflection ratio shall be calculated at a constant load level.

8.4.2.2 The assigned system stiffness factor, C_E, shall be evaluated at the average deflection ratio.

8.5 *Default System Factors:*

8.5.1 In lieu of the more rigorous methods required by 8.2 – 8.4, system strength factors defined in Table 1 shall be permitted to be used for repetitive-member assemblies. These factors are applied by multiplying the single member allowable design stress by the applicable factor.

9. Keywords

9.1 repetitive members; system effects; system performance; wood assemblies

TABLE 1 Default System Strength Factors, C_r, for Repetitive-Member Assemblies

C_r	Repetitive-Member Assembly
1.15 to 1.50	Bending stress of wall studs in assemblies as specified in ANSI/AWC SPDWS.
1.30 to 1.40	Bending stress of mechanically-laminated 4-ply, visually- and mechanically-graded wood assemblies complying with ANSI/ASAE EP559.1.
1.25 to 1.35	Bending stress of mechanically-laminated 3-ply, visually- and mechanically-graded wood assemblies complying with ANSI/ASAE EP559.1.
1.15	Bending stress of solid sawn wood member (3 or more members spaced not more than 24 in. (610 mm) o.c.) as specified in ANSI/AWC NDS.
1.10	Bending stress of 2-ply solid sawn beams or headers (2 members in direct contact) as specified in ANSI/AWC NDS.
1.10	Axial stress and E_{min} of solid sawn truss chords (3 or more trusses spaced not more than 24 in. (610 mm) o.c.) as specified in ANSI/TPI 1.
1.04	Bending stress of structural composite lumber as specified in ANSI/AWC NDS.

APPENDIXES

(Nonmandatory Information)

X1. BACKGROUND OF ASTM REPETITIVE-MEMBER FACTORS

X1.1 A repetitive-member bending stress increase factor has been provided in Practice D245 for many years. Development and use of new prefabricated structural components and emphasis on reliability-based design formats have focused attention on the basis for this repetitive-member adjustment.

X1.2 The 1.15 repetitive-member bending stress increase factor, referenced in Practice D245, has its root in a short-lived tentative ASTM standard (ASTM D2018-62T). The procedures in D2018 were intended to provide increases in allowable design stresses for any established grade or specific group of framing lumber used as joists, truss chords, rafters, studs, planks, decking, or similar members which are in contact or spaced not more than 24 in. (610 mm) on centers, are not less than three in number and are joined by floor, roof, or other load distributing elements adequate to support the design load.

X2. CONCEPTUAL DISCUSSION OF "SAFETY FACTORS"

X2.1 Acceptable "Safety Factors" for Strength

X2.1.1 The choice of an acceptable "safety factor" for an assembly is complicated. For simplicity, in the context of this discussion, the term "safety factor" is used in a generic sense – as an expression of the ratio of peak load capacity divided by design capacity (neglecting statistical, load duration, or other adjustment factor issues). Since the initial development of this guide in the years prior to 2003, several concepts have evolved that shed additional light on this topic. Most notably, ASCE/SEI 7 has added Commentary (to Chapter 1) that specifies minimum target reliability levels over the design life of the building that are provided as a function of the following:

X2.1.1.1 The occupancy category of the structure,

X2.1.1.2 The consequences of failure of the member (that is, global collapse versus local failure), and

X2.1.1.3 The suddenness of the failure and its predictability (that is, ductile failures versus brittle failures).

X2.1.2 This type of analysis considering these parameters has been applied recently to high-rise buildings, typically related to performance in seismic areas. To date, Subcommittee D07.05 is unaware of any implementation of these procedures on a generic basis or for any wood frame buildings.

X2.2 Safety Factors Versus System Factors

X2.2.1 When all applicable engineering design calculations have been completed and compliance with material and product standards has been confirmed, some product interests have chosen to refine their designs to account for system performance that differs from historical default values. For example, due to the lower variability of some engineered wood products, their underlying product standards specify repetitive-member factors that are lower than the historical 15 % increase permitted for visually-graded sawn lumber. Conversely, it appears that some designers utilize system factors for limited applications that exceed the default values for their designs. In general, the Subcommittee D07.05 recommends that any application of system factors to new materials or those that exceed default values be based on engineering mechanics, have an underlying basis in an applicable product or design standard, and be subject to independent review by a competent independent entity or consensus standards committee. The intent of this commentary is to highlight that safety margins are not to be diminished, relative to those intended for the application, by the use of a system factor.

X2.2.2 Establishment of "system factors" for assemblies of structural wood members requires development of engineering mechanics approaches that define the interactions causing the performance increase, coupled with analyses that quantify the influences (both positive and negative) of variables such as material variability, environmental factors, etc., across the proposed range of assembly configurations. These supplemental analyses are typically conducted on a simulation basis (such as Monte Carlo analysis). It is not feasible to quantify the effect of these variables on a purely test basis.