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Timber structures — Timber connections and assemblies — Determination of yield and ultimate characteristics and ductility from test data

Structures en bois — Assemblages et composants bois — Détermination des caractéristiques limites et ultimes et de la ductilité à partir des données d'essai

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

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This document was prepared by Technical Committee ISO/TC 165, *Timber structures*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Timber shows generally brittle failure in tension and bending. This characteristic of wood may cause serious damage to buildings due to the lack of energy dissipation during an earthquake. To avoid such damage, it is expected that the joints connecting wooden members dissipate seismic energy instead of the members themselves. Ductility of a structure is one of the most important factors in dissipating seismic energy. In this technical report, the definitions of yield point, ultimate characteristics and ductility factor used in various test standards are reviewed and methods of determining these characteristics from quasi-static and reversed-cyclic loading test data are compared.

Better fits to envelope curves derived from testing, such as more detailed piecewise linearization are permissible, and indeed desirable for whole building design. The derived load-deflection inputs to structural analysis programs of the various structural elements are only applicable to the case of assessing the maximum connection forces under earthquake loading and provide no guarantee that a structure will remain stable beyond the ultimate strength of the system.

TECHNICAL REPORT ISO/TR 21141:2022(E)

Timber structures — Timber connections and assemblies — Determination of yield and ultimate characteristics and ductility from test data

1 Scope

The purpose of this document is to extract the methods for determining the yield and ultimate characteristics and ductility of joints and assemblies from test data by reviewing existing standards in Europe, North America and Far East Asia and to provide the basic data for unifying the evaluation methods of parameters by clarifying their similarities and differences.

These parameters are applied for determining the seismic performance of timber structures. This document deals with the method for determining the mechanical properties of individual joints and assemblies, and it does not refer to the seismic performance of the entire structure.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
envelope curve
locus of extremities of the load-displacement hysteresis loops, either obtained separately for the positive and negative loading directions, or obtained by averaging the absolute values of load and displacement of the corresponding positive and negative envelope points for each cycle in the case of a reversed cyclic loading test (see Clause 5)

3.2
stiffness
K_e
resistance to deformation of a specimen in the elastic range, which can be expressed as a slope measured by the ratio of the resisted load, F_1, to the corresponding displacement, V_1 (see Clause 6)

3.3
elastic range
stress range in which a material, upon unloading, will recover the deformation caused by the application of a stress or force

3.4
yield point
point at which a joint or an assembly begins to deform plastically

3.5
yield load and displacement
F_y, V_y
load and displacement corresponding to the *yield point* (3.4) (see 7.1)

3.6
maximum load
F_{max}
maximum value of the load recorded in a quasi-static test or the maximum value of the load on the average *envelope curve* (3.1) in a reversed-cyclic test or the absolute maximum values of the load recorded in positive and negative directions

3.7
ultimate limit state
failure limit state
state at which a joint or an assembly undergoes a sudden load drop or the load decreases gradually to 80 % of the *maximum load* (3.6), F_{max}, or an excessive deformation (displacement or rotation) occurs (see 8.1 and 8.2)

3.8
ultimate displacement
V_u
failure displacement
displacement corresponding to the *ultimate limit state* (3.7) (see 8.1).

3.9
equivalent energy elastic-plastic curve
EEEP
ideal elastic-plastic curve circumscribing an area equal to the area enclosed by the *envelope curve* (3.1) between the origin, the *ultimate displacement* (3.8), V_u, and the displacement axis (see 8.3)

3.10
equivalent energy elastic-plastic load
F_{eeep}
load corresponding to the upper limit of the *equivalent energy elastic-plastic curve, EEEP,* (3.9)

3.11
ductility
ability of joints or assemblies to undergo large amplitude displacement in the plastic range without a substantial reduction of strength

3.12
ductility factor
μ
ratio between *ultimate displacement* (3.8), V_u, and yield displacement, V_y, (see Clause 9).

3.13
equivalent energy elastic-plastic ductility factor
μ_{eeep}
ratio between *ultimate displacement* (3.8), V_u, and EEEP displacement, V_{eeep}, (see Clause 9).

4 Symbols and abbreviated terms

The following symbols and units apply.

F_1, F_2	any load within the elastic range of the curve, expressed in Newtons
F_{eeep}	equivalent energy elastic-plastic (EEEP) load, expressed in Newtons

F_{eebl}	equivalent energy bilinear ultimate load, expressed in Newtons
$F_{\max}$	maximum load, expressed in Newtons
F_y	yield load, expressed in Newtons
F_u	ultimate (failure) load, expressed in Newtons
K_e	elastic stiffness, expressed in Newtons per millimetre
K_{eeep}	equivalent energy elastic-plastic stiffness, expressed in Newtons per millimetre
V_1, V_2	displacement corresponding to F_1, F_2 within the elastic range, expressed in millimetres
V_{eeep}	equivalent energy elastic-plastic yield displacement, expressed in millimetres
V_y	yield displacement, expressed in millimetres
V_u	ultimate (failure) displacement, expressed in millimetres
μ	ductility factor
μ_{eeep}	equivalent energy elastic-plastic ductility factor

5 Determination of envelope curves

The initial envelope curve for the reversed-cyclic tests is established by connecting the peak loads and/or the peak displacements from the first cycle of each phase of the cyclic loading, whichever better represents the backbone shape of the hysteretic response. The points on the hysteresis loops where the absolute value of the displacement at the peak load is less than that in the previous phase are replaced with points that better represent the hysteretic response.

The envelope curves for the second and subsequent reversed cycles of each phase may be also established if necessary.

If the load-displacement relation is (point) symmetric, envelope curve may be obtained by averaging the absolute values of load and displacement of the corresponding positive and negative envelope points for each cycle (see examples in B.1, B.5, B.6 and B.7).

For joints and assemblies producing asymmetric response, the positive and negative envelopes are analysed separately (*see* examples B.2, B.3, and B.4).

NOTE In Annex B, positive and negative envelope curves are obtained separately if the values of maximum (peak) load or displacement in the positive hysteresis loops in each phase up to the ultimate displacement, V_u, differ more than 20 % from the absolute value of those obtained from the corresponding negative hysteresis loops.

6 Determination of elastic stiffness

Initial stiffness of joints or assemblies, K_e, is determined by the line (a) in Figures 1 a) to 1 d).

Figure 1 a) shows an idealized case where the load-displacement (or envelope) curve starts at the origin and is linear in the elastic range. The load, F_1, and the corresponding displacement, V_1, can be taken anywhere within the elastic range of the curve (see examples in B.1.2 and B.3.2).

Figure 1 b) shows schematically a case of a load-displacement (or envelope) curve with initial slip (horizontal offset) due to slack in the joint or assembly, due to load delay or other reasons. Depending on the reasons, the initial slip may be neglected in the determination of the initial stiffness, as shown in Figure 1 b). However, if the slack is inherent to the performance of the joint or assembly, it is recommended to not neglect it (see example B.2.2).

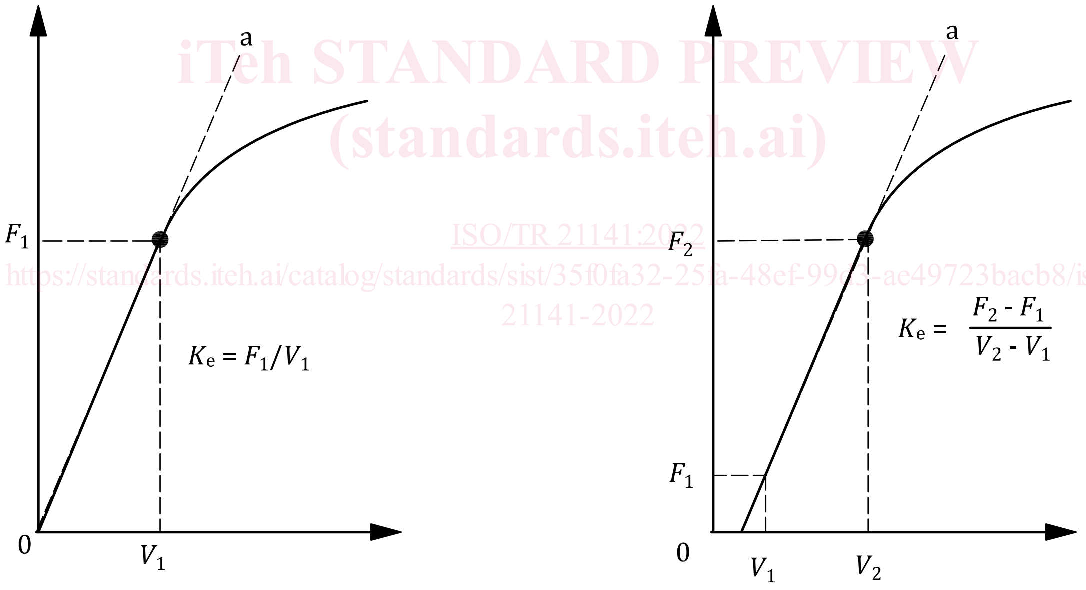
Figure 1.C shows schematically a case of a load-displacement (or envelope) curve with an infinite initial stiffness (vertical offset) due to preload or initial friction in the joint or assembly or other reasons. Depending on the reasons, the offset may be neglected in the determination of the initial stiffness, as shown in Figure 1 c). However, if the high initial stiffness is inherent to the performance of the joint or assembly, it is recommended to not neglect it (see example B.4.2).

Figure 1 d) shows schematically a case of a load-displacement (or envelope) curve without distinct linear portion in the elastic range. In this case, the initial stiffness may be approximated by the slope of a straight line connecting the points between 0,1 and 0,4 times the maximum load, F_{max}. Linear regression may be used to determine the slope of the line (see example in B.6.2).

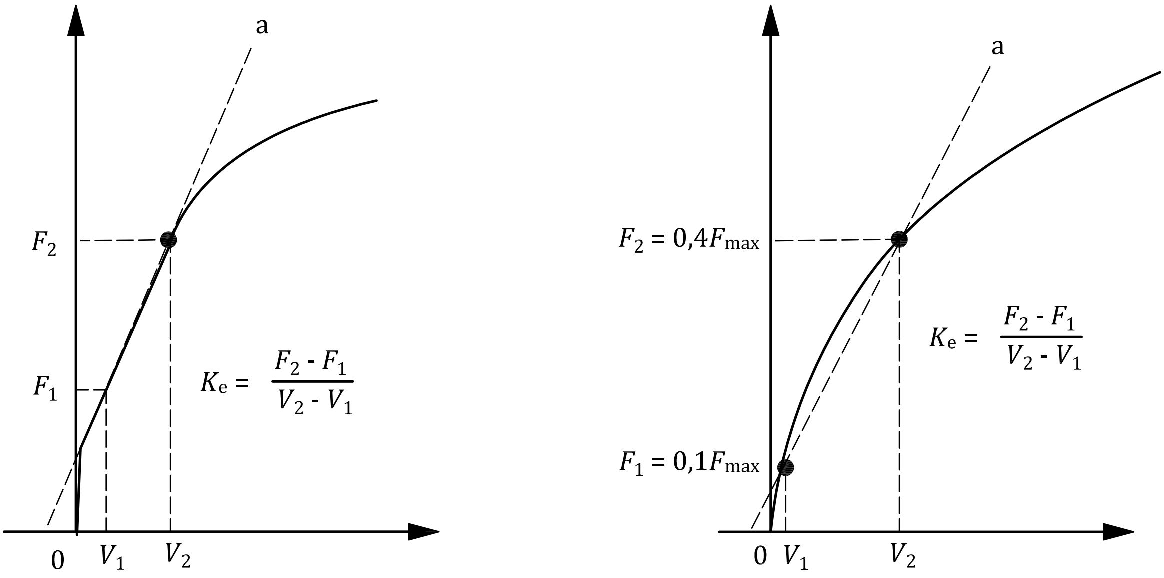
NOTE 1 If the straight line connecting the points between 0,1 and 0,4 F_{max} does not fit the load-displacement (or envelope) curve, this range is not appropriate. Some joints (e.g., with multiple fasteners) produce S-shape load-displacement (or envelope) curves where linear regression in the range 0,1 to 0,4 F_{max} is not appropriate, because the initial take-off can go beyond 0,1 F_{max} and the maximum stiffness (the steepest slope) is achieved beyond 0,4 F_{max}. Also, the 0,4 F_{max} limit is not appropriate when the initial yielding starts below 0,4 F_{max}. It can be observed either in joints with multiple fasteners or where the yield mode is overridden by another failure mode (e.g., tear-through or head pull through). In these cases, ranges other than 0,1 to 0,4 can be appropriate.

NOTE 2 Stiffness for determination of the equivalent energy elastic-plastic curve (K_{eeep}) can be determined differently (see 8.3).

NOTE 3 ISO 6891 will be referred to determine the elastic stiffness in case of the quasi static test.



a) Idealised stiffness **b) Stiffness with initial slip**



c) Stiffness with initial friction **d) Stiffness without linear part**

Figure 1 — Examples of elastic stiffness

7 Determination of yield point

7.1 Determination of yield load

Yield load, F_y, is determined by one of the following methods according to the relevant standard.

Method A1 [EN 12512]: When the load-displacement (or envelope) curve presents two well-defined linear parts, the yield load, F_y, is determined by the intersection of these two lines (lines (a) and (c) in Figure 2 a)).

Method A2 [EN 12512]: When the load-displacement (or envelope) curve does not present well-defined linear parts, the yield load, F_y, is determined by the intersection of two straight lines: the first line-connecting the points between 0,1 and 0,4 times the maximum load, F_{max}, and the second line having the tangent of a slope of 1/6 of the first line (lines (a) and (d) in Figure 2 b)) (see Figures B.2 and B.8).

NOTE 1 EN 12512 intends to apply this method to determine the yield load for timber joints. It has not been confirmed if this method is applicable to determine the yield load of assemblies such as shear walls. It tends to give a higher value than JIS A1414-2 in cases of wood-based shear walls (see Figures B.14 c) and B.20 c)).

NOTE 2 The determined yield load is affected by the slope of the first line as the slope of the second line is determined also according to the slope of the first line. This tendency is more significant when the slope of the first line is low and the envelope curve is convexly rounded after the yielding (see Figure B.5 d)).

Method A3 [JIS A1414-2]: When the load-displacement (or envelope) curve does not present well-defined linear parts, the yield load, F_y, is determined by the intersection of two straight lines: the first line connecting the points between 0,1 and 0,4 times the maximum load, F_{max}, (line (a) in Figure 2 c)) and the second line (line (f) in Figure 2 c)) determined as a tangent to the load-displacement (or envelope) curve and parallel to the line connecting two points corresponding to 0,4 and 0,9 times the maximum load (F_{max}) (line (e) in Figure 2 c)) (see Figure B.20 b)).

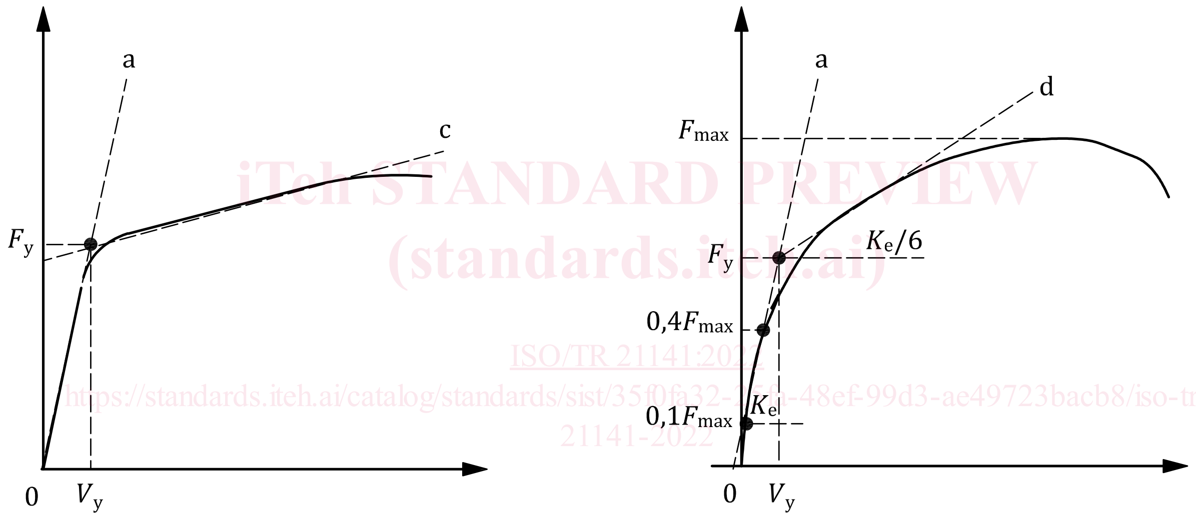
NOTE 1 JIS A1414-2 intends to apply this method to determine the yield load of shear walls. However, this method is applied also to determine the yield load of timber joints.

NOTE 2 If the load-displacement (or envelope) curve is concavely curved and there is no appropriate intersection of lines (a) and (f), the ranges 0,1 to 0,4 and 0,4 to 0,9 times the maximum load, F_{max}, are not appropriate.

Method A4 [ASTM D5652]: For joints with dowel-type fasteners, the yield load, F_y, is determined as follows. Fit a straight line to the initial linear part of the load-displacement (or envelope) curve, offset this line by a displacement equal to 5 % of the nominal fastener diameter (or the measured fastener diameter if the nominal diameter is not determined), and select the load at which the offset line intersects the load-displacement curve (*see* line (a') in Figure 2 d)). If the initial part of the load-displacement (or envelope) curve is nonlinear, use the straight line connecting the points between 0,1 and 0,4 times the maximum load, F_{max}, (see Figures B.4 and B.11 c)).

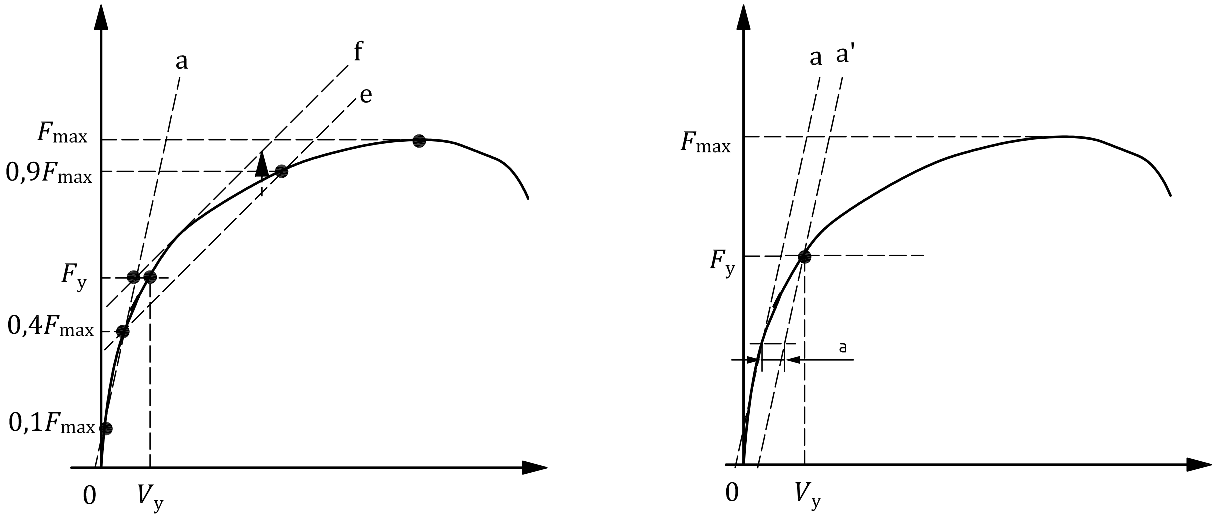
NOTE 1 ASTM D5652 intends to apply this method to determine the yield point of a single-bolt joint. This method is applicable to joints with other types of single dowels such as nails and screws, but it does not apply directly to other types of joints and assemblies such as shear walls. However, it can be applied if the offset criterion is agreed upon.

NOTE 2 In the case where the offset line does not intersect the load-displacement (or envelope) curve, the yield load is not determined.



a) Determination of yield load by lines (a) and (c)

b) Determination of yield load by lines (a) and (d)



c) Determination of yield load by lines (a) and (f)

d) Determination of yield load by line (a')

Key

[a] 5 % off-set of bolt diameter.

Figure 2 — Determination of yield load

7.2 Determination of yield displacement

Yield displacement, V_y, is determined as the displacement at the intersection point of two lines determined for Method A1 or Method A2 (see 7.1) (Figures 2 a) and 2 b)).

Yield displacement, V_y, is determined as the displacement corresponding to the yield load, F_y, on the load-displacement (or envelope) curve for Method A3 or Method A4 (see 7.1) (Figures 2 c) and 2 d)).

8 Determination of ultimate limit state

8.1 Ultimate (failure) displacement

Ultimate (failure) displacement, V_u, is determined as one of the following, whichever occurs first (see Figure 3):

Case (1): displacement corresponding to the ultimate limit state caused by a sudden load drop.

Case (2): displacement corresponding to the ultimate limit state caused by a gradual decrease of load to $0{,}8F_{max}$ after the maximum load, F_{max}, is achieved.

Case (3): displacement 30 mm for joints and rotation or shear deformation angle 1/15 rad. for assemblies (e.g., moment resisting joints, shear walls, etc.).

8.2 Ultimate (failure) load

Ultimate (failure) load, F_u, is determined as one of the following, whichever occurs first (see Figure 3):

Case (1): load recorded at the point immediately preceding the load drop ($F_{max} \geq F_u \geq 0{,}8F_{max}$).

Case (2): 0,8 times maximum load, F_{max}, in case of a gradual load decrease after the maximum load ($F_u = 0{,}8F_{max}$).

Case (3): load corresponding to the ultimate displacement 30 mm for joints and rotation or shear deformation angle 1/15 rad. for assemblies in case of an excessive deformation.