# TECHNICAL REPORT

# ISO/TR 21141

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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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# Foreword

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

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# 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.

# 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**
$\mu$
ratio between *ultimate displacement* (3.8), $V_u$, and yield displacement, $V_y$, (see Clause 9).

**3.13**
**equivalent energy elastic-plastic ductility factor**
$\mu_{eeep}$
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

$\mu$ ductility factor

$\mu_{eeep}$ 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).

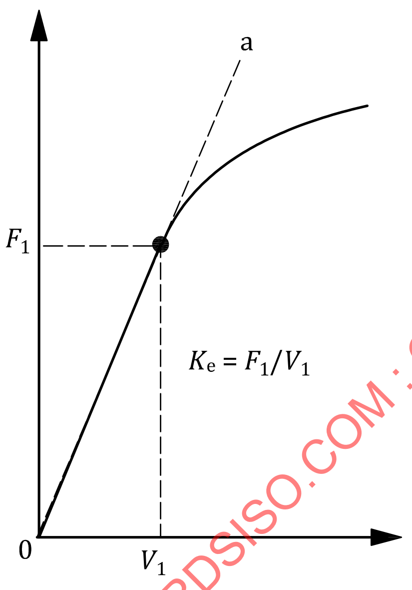
Figure 1.C shows schematically a case of a load-displacement (or envelope) curve with an infinite initial stiffness (vertical offset) due to preload or initial friction in the joint or assembly or other reasons. Depending on the reasons, the offset may be neglected in the determination of the initial 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).

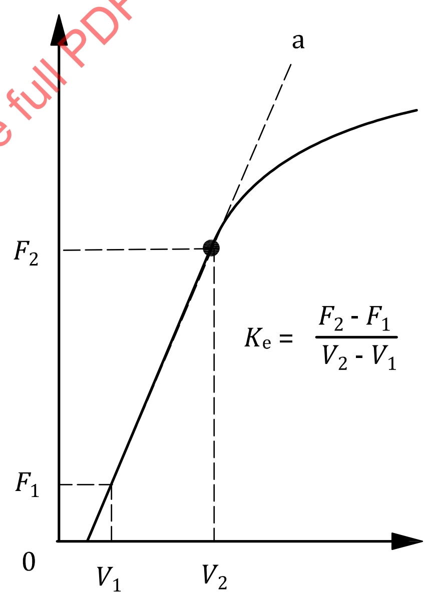
NOTE 1 If the straight line connecting the points between 0,1 and 0,4 $F_{max}$ does not fit the load-displacement (or envelope) curve, this range is not appropriate. Some joints (e.g., with multiple fasteners) produce S-shape load-displacement (or envelope) curves where linear regression in the range 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.



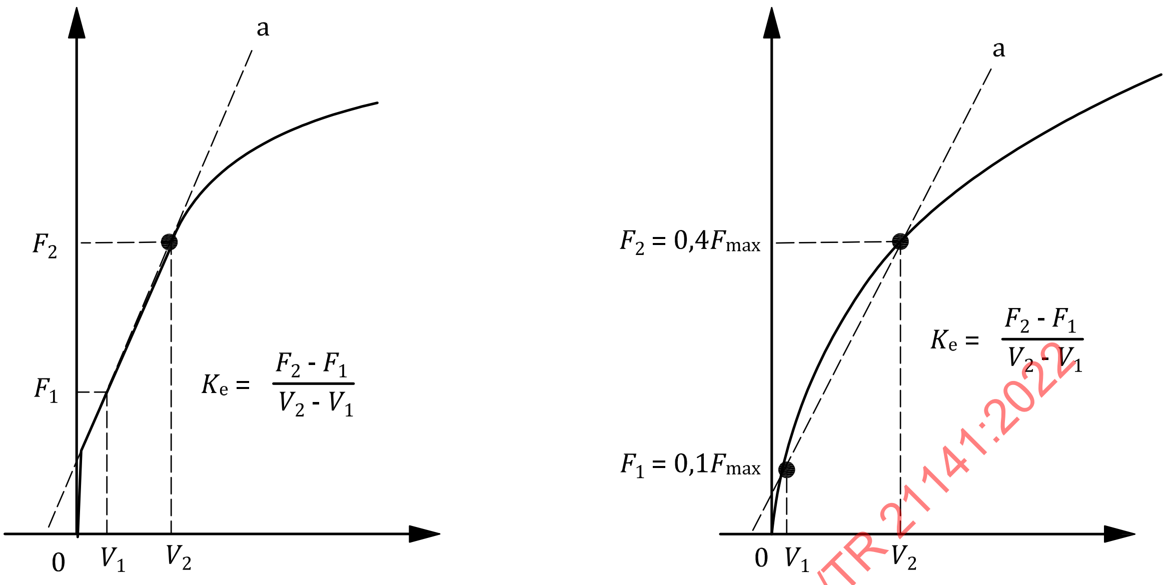

**a) Idealised stiffness**




**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.

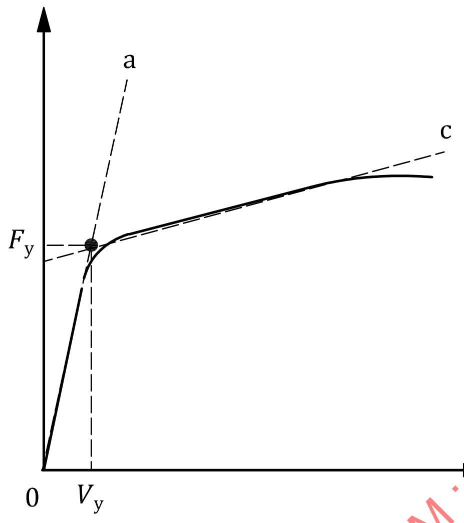
NOTE 2 If the load-displacement (or envelope) curve is concavely curved and there is no appropriate intersection of lines (a) and (f), the ranges 0,1 to 0,4 and 0,4 to 0,9 times the maximum load, $F_{max}$, are not appropriate.

**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)).

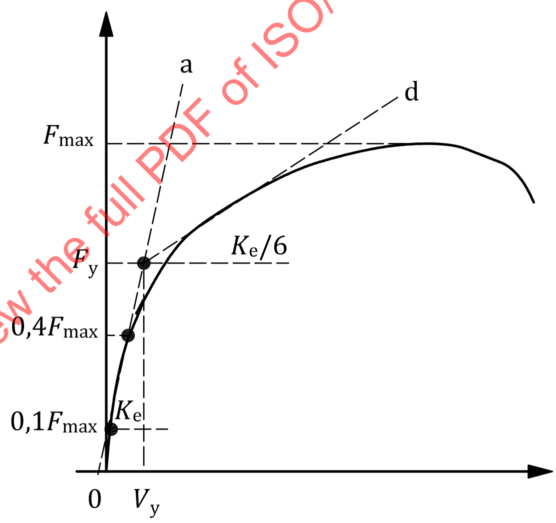
NOTE 1 ASTM D5652 intends to apply this method to determine the yield point of a single-bolt joint. This method is applicable to joints with other types of single dowels such as nails and screws, but it does not apply directly to other types of joints and assemblies such as shear walls. However, it can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

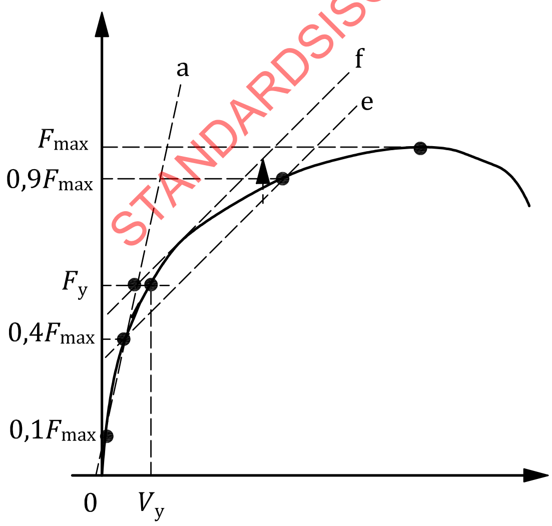




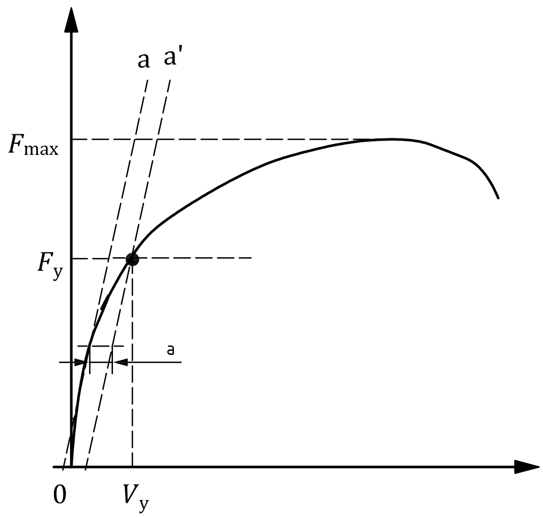

**a) Determination of yield load by lines (a) and (c)**




**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.).

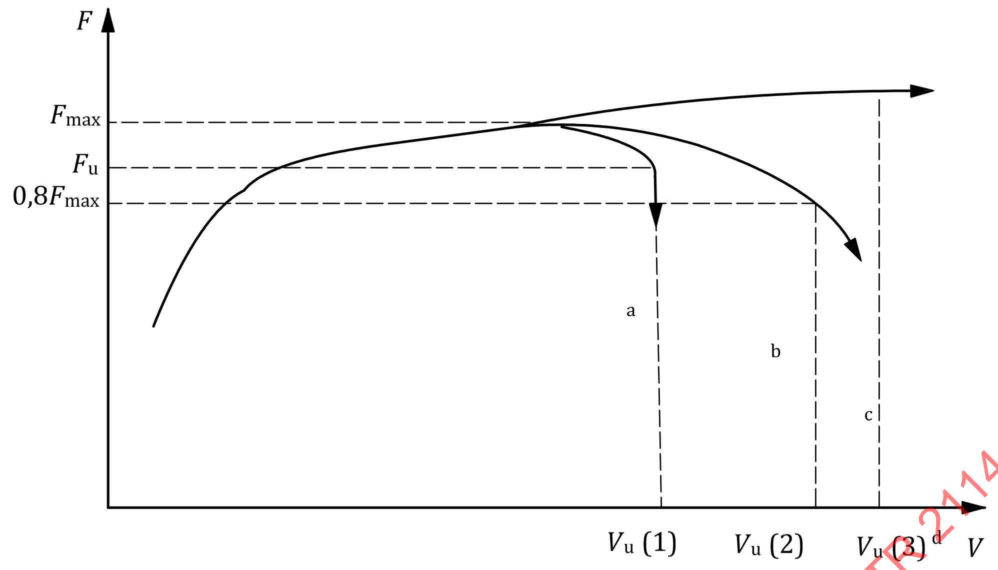
### 8.2 Ultimate (failure) load

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.




**Key**

a Case (1).

b Case (2).

c Case (3).

d (30 mm or 1/15 rad.).

**Figure 3 — Definition of ultimate displacement, $V_u$**

## 8.3 Equivalent energy elastic-plastic load and stiffness

Equivalent energy elastic-plastic (EEEP) curve is determined by equating the area, $A$, under the load-displacement (or envelope) curve up to the ultimate displacement, $V_u$, and the area limited by the straight lines: line (b) representing the equivalent energy elastic-plastic stiffness, $K_{eeep}$, and line (g) representing the equivalent energy elastic-plastic load, $F_{eeep}$, up to the ultimate displacement, $V_u$, (see Figures 4 a) and 4 b)).

Equivalent energy elastic-plastic load, $F_{eeep}$, is calculated using Formula (1):

$$F_{eeep} = \left[ V_u - \sqrt{V_u^2 - \frac{2A}{K_{eeep}}} \right] K_{eeep} \tag{1}$$

If $V_u^2 < \dfrac{2A}{K_{eeep}}$, it is permitted to take $F_{eeep} = 0{,}85 F_{max}$.

Equivalent energy elastic-plastic stiffness, $K_{eeep}$, is determined using one of the following methods.

**Method B1** [ASTM E2126]: The equivalent energy elastic-plastic stiffness, $K_{eeep}$, is determined by a straight line passing through the origin and $0{,}4F_{max}$ on the load-displacement (or envelope) curve (see Figures 4 a) and B.18 a)).

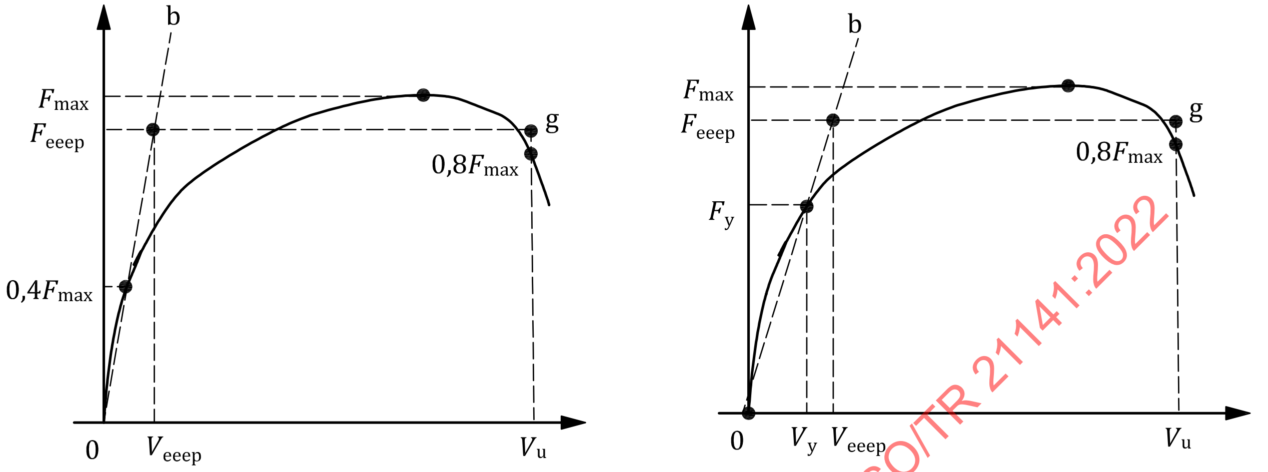
**Method B2** [JIS A1414-2]: The equivalent energy elastic-plastic stiffness, $K_{eeep}$, is determined by a straight line passing through the origin and the yield point on the load-displacement (or envelope) curve determined using Method A3 (see 7.1) (see Figures 4 b) and B.18 b)).

NOTE 1 Method B1 tends to give smaller $V_{eeep}$ and consequently larger $\mu_{eeep}$ than Method B2(*see* examples in B.5.3, B.6.3 and B.7.3).



NOTE 2 If the equivalent energy elastic-plastic model does not produce satisfactory results, an equivalent energy bi-linear model can be applied. In this case, the equivalent energy bilinear ultimate load, $F_{eebl}$,can be determined so that the area limited by the bi-linear curve up to the ultimate displacement equals the area limited by the load-displacement (or envelope) curve (*see* example in A.2).




**a) Determination of the EEEP stiffness ($K_{eeep}$)(line (b)) and the EEEP load ($F_{eeep}$) (line (g))**

**b) Determination of the EEEP stiffness ($K_{eeep}$) (line (b)) and the EEEP load ($F_{eeep}$) (line (g))**

**Figure 4 — Determination of the EEEP stiffness**

## 9 Determination of ductility factor

Ductility factor is determined using one of the following methods.

**Method C1** [EN 12512]**:** Ductility factor, $\mu$, is calculated from Formula 2 as the ratio of the ultimate displacement, $V_u$, (see 8.1) to the yield displacement, $V_y$, (see 7.2)(see Figure A.1).

$$\mu = V_u / V_y \quad (2)$$

**Method C2** [ASTM E2126, JIS A1414-2]**:** Equivalent energy elastic-plastic ductility factor, $\mu_{eeep}$, is calculated from Formula 3 as the ratio of the ultimate displacement, $V_u$, (see8.1) to the equivalent energy elastic-plastic yield displacement, $V_{eeep}$, (see Figures 4 a) and 4 b)).

$$\mu_{eeep} = V_u / V_{eeep} \quad (3)$$

where, $V_{eeep}$ is the displacement at the intersection of lines (b) and (g) in Figure 4.

NOTE 1 The relationship between $\mu$ and $\mu_{eeep}$ is expressed as follows:

$$\mu_{eeep} = \mu \frac{F_y}{F_{eeep}}$$

Examples of determination of the elastic stiffness, yield point, ultimate characteristics and ductility factor for joints and assemblies are shown in Annex B.

Determination method of impairment of strength (strength degradation) and energy dissipation in connections and assemblies are shown in Annex C.

# Annex A
(informative)

# Examples of modelling of envelope curves

## A.1 Elastic-plastic model

Most envelope curves can be modelled generally by elastic–plastic model as shown in Figure A.1. This model determines the ratio, $R_{eeep}$, of the linear force response, $F_0$, to the ultimate capacity of the joints or assemblies, $F_{eeep}$, which has the equivalent energy dissipation in elastic-plastic model as shown in Figure A.1. The value of $R_{eeep}$ is the ratio of the linear seismic response to non-linear response and expressed as follows by using equivalent energy elastic-plastic ductility factor, $\mu_{eeep}$.

$$R_{eeep} = \frac{F_0}{F_{eeep}} = \sqrt{2\mu_{eeep} - 1}$$

The ratio, $R_y$, defined by the ratio $F_0$ to $F_y$ is determined by using the ductility factor, $\mu$, and strength ratio, $r_u$.

$$R_y = \frac{F_0}{F_y} = \sqrt{r_u(2\mu - r_u)}$$

$$\mu = V_u / V_y \quad r_u = F_{eeep} / F_y$$

where $F_0$ is the maximum linear force response.

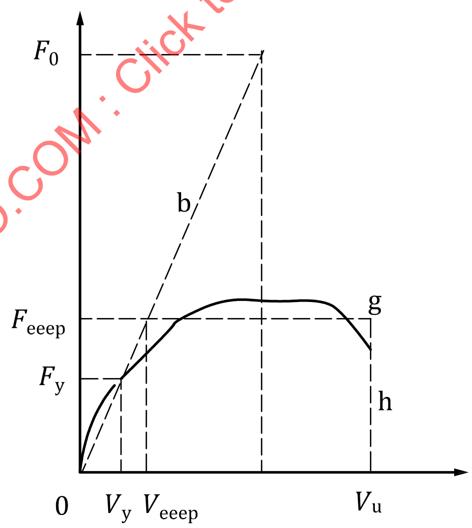



**Figure A.1 — Linear response and response by elastic-plastic model**

## A.2 Bi-linear model

In case the envelope curve is modelled by bi-linear model, the inclination of the second line (g) is determined so that the area surrounded by the lines (b), (g), (h) and displacement axis equals to the area surrounded by the envelope curves as shown in Figure A.2. This model determines the ratio, $R_y$, defined by the ratio of the linear force response, $F_0$, to the yield strength, $F_y$, of the joints or assemblies which has the equivalent energy dissipation in bi-linear model. The value of $R_y$ is expressed as follows by using ductility factor, $\mu$, and strength ratio, $r_u$.

$$R_y = \frac{F_0}{F_y} = \sqrt{(r_u + 1) \cdot \mu - r_u}$$

where, $r_u = F_{eebl} / F_y$ $(F_{eebl} \leqq F_{max})$

where

$F_{eebl}$ is the equivalent energy bi-linear ultimate load;

$F_0$ is the maximum linear force response.

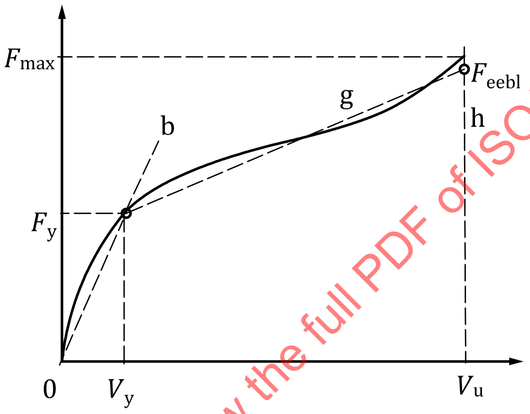



**Figure A.2 — Example of modeling by bilinear model**

# Annex B
(informative)

# Examples of test data

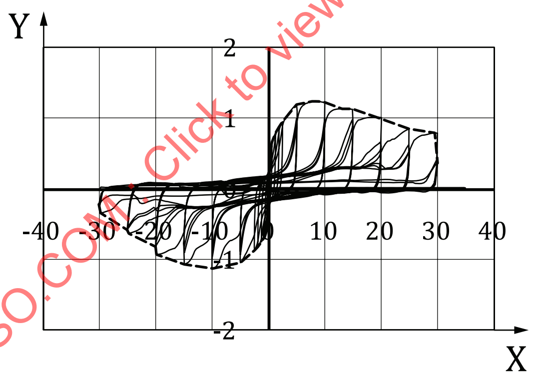
## B.1 General

Yield and ultimate characteristics and ductility of several joints and assemblies are determined from test data with different evaluation methods presented in this technical report. These examples are provided for understanding the effect of the determination methods on a particular load-displacement relation. These examples do not intend to evaluate the performance of the specific joints and assemblies by comparing the evaluation methods. They are evaluated by producing an average envelope curve except for examples in B.3, B.4 and B.5 in which positive and negative envelope curves are produced separately and the average of positive and negative values are taken. Tests in examples B.2, B.3, B.4 and B.5 are based on ISO 16670 tests and examples B.6, B7 and B.8 are based on ISO 21581 tests.

## B.2 Plywood-to-wood nailed joints

### B.2.1 Load displacement relation

An example of load-displacement relation in reversed cyclic shear test of nailed joint is shown in Figure B.1. Yield point and ultimate characteristics are determined from the average envelope curve.




**Key**

X displacement (mm)

Y load (kN)

$F_{max}$ 1,17 kN

$V_{max}$ 9,95 mm

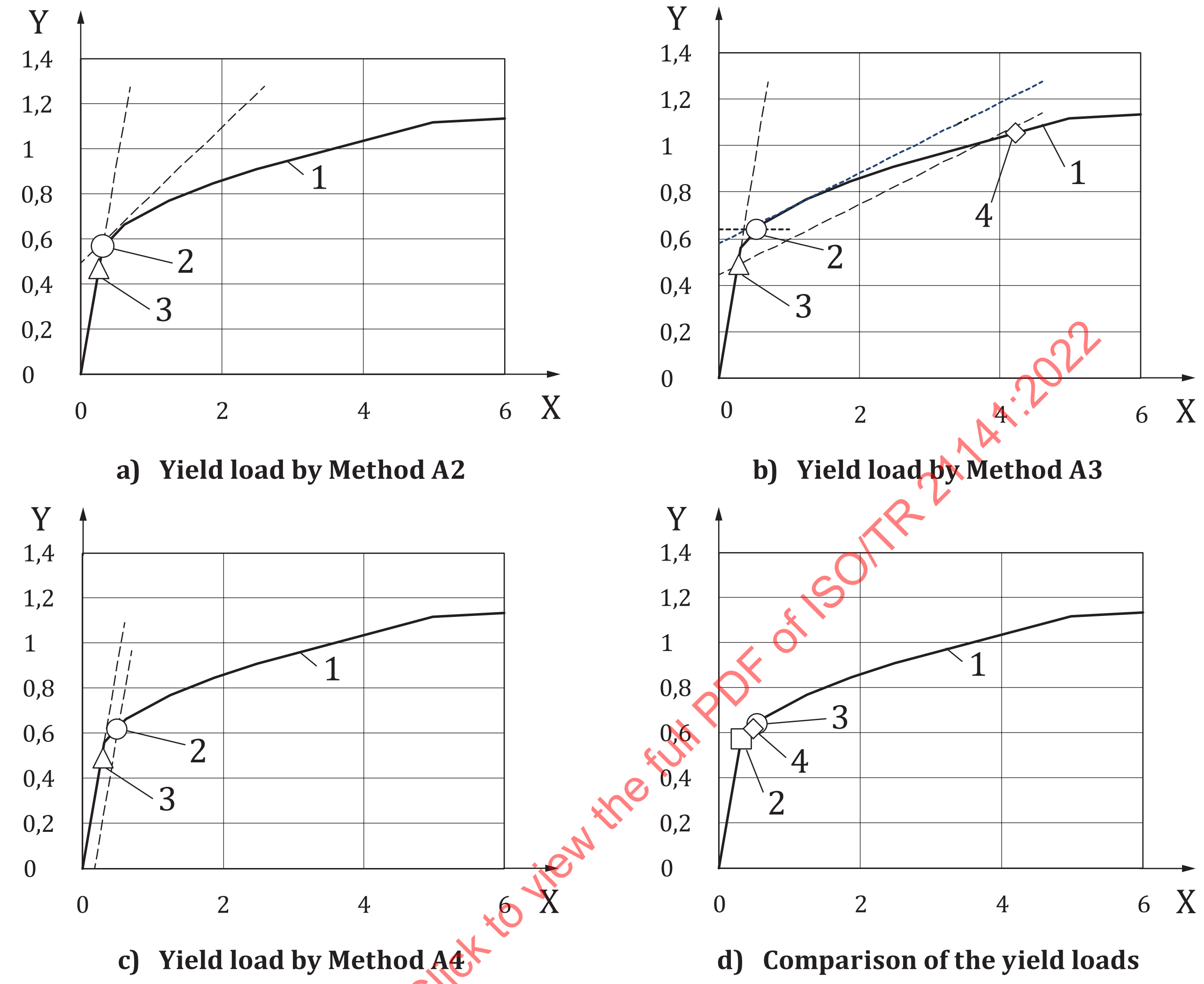
**Figure B.1 — Example of load-displacement relation in plywood-to-wood nailed joint (9 mm thick plywood with CN50 nails, loading parallel to the grain)**

### B.2.2 Determination of yield load

Envelope curve and yield load, $F_y$, determined by Methods A2, A3 and A4 (see 7.1) are shown in Figures B.2, B.3 and B.4, respectively. Comparison of yield loads, $F_y$, determined by each method is shown in Figure B.5 and Table B.1.






**Key**

a) to c)

X displacement (mm)

Y load (kN)

1 envelope curve(av.)

2 $F_y$

3 0,4Fmax

4 0,9Fmax

d)

X displacement (mm)

Y load (kN)

1 envelope curve(av.)

2 $F_y$_A2(EN)

3 $F_y$_A3(JIS)

4 $F_y$_A4(ASTM)

**Figure B.2 — Examples of yield load**

**Table B.1 — Comparison of yield point and maximum values**

| | Method A2 (see 7.1) | Method A3 (see 7.1) | Method A4 (see 7.1) |
|---|---|---|---|
| $K_e$ (kN/mm) | 1,81 | 1,81 | 1,81 |
| $F_y$ (kN) | 0,57 | 0,64 | 0,62 |
| $V_y$ (mm) | 0,32 | 0,54 | 0,49 |
| $F_y/V_y$ (kN/mm) | 1,81 | 1,18 | 1,27 |
| $F_y/F_{max}$ | 0,49 | 0,54 | 0,53 |

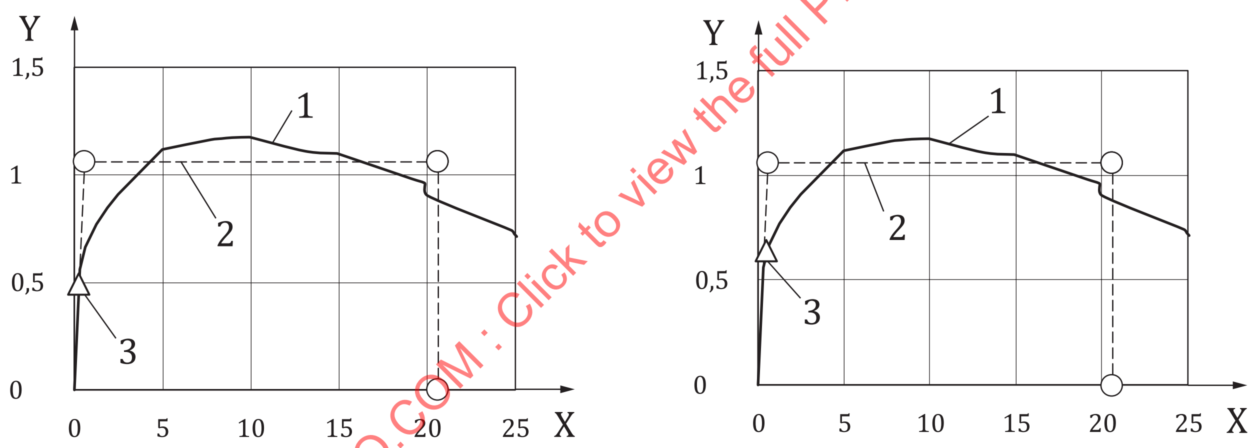
NOTE 1 Yield loads, $F_y$, determined by Methods A3 and A4 show close agreement and that determined by Method A2 is approximately 10 % lower.

NOTE 2 Yield displacement, $V_y$, determined by Method A4 is approximately 10 % smaller than that determined by Method A3. Yield displacement, $V_y$, determined by Method A2 is 40 % and 35 % smaller than those determined by Methods A3 and A4, respectively. This result is caused by the difference of the definition of yield point: whether it is based on the intersection of two lines or the corresponding point on the envelope curve.

NOTE 3 Yield loads, $F_y$, determined by Methods A2, A3 and A4 are approximately half of the maximum load, $F_{max}$, regardless of the determination method.

## B.2.3 Determination of ultimate characteristics

Ultimate characteristics determined by Methods B1 and B2 (see 8.3) are shown in Figures B.3 a) and B.3 b), respectively.




**a) Determination of EEEP model by Method B1 – average envelope**

**b) Determination of EEEP model by Method B2 – average envelope**

**Key**

a)

X displacement (mm)

Y load (kN)

1 envelope curve(av.)

2 EEEP Model_B1(ASTM)

3 0,4Fmax

b)

X displacement (mm)

Y load (kN)

1 envelope curve(av.)

2 EEEP Model_B2(JIS)

3 $F_y$

**Figure B.3 — Determination of EEEP model**

## B.2.4 Comparison of methods

Comparison of ultimate characteristics and ductility determined by each method are shown in Table B.2.

**Table B.2 — Comparison of ultimate characteristics and ductility**

| | see 8.2 | **Method B2** (see 8.3) | **Method B1** (see 8.3) |
|---|---|---|---|
| $F_{eeep}$ (kN) | — | 1,07 | 1,06 |
| $V_{eeep}$ (mm) | — | 0,91 | 0,58 |
| $F_u$ (kN) | 0,94 | — | — |
| $V_u$ (mm) | 20,63 | 20,63 | 20,63 |
| $\mu(V_u/V_y)$ | 64,46 | 38,20 | 42,10 |
| $\mu_{eeep}(V_u/V_{eeep})$ | — | 22,67 | 35,56 |

NOTE 1 EEEP loads, $F_{eeep,}$ determined by Methods B1 and B2 show similar values.

NOTE 2 EEEP displacement, $V_{eeep,}$ determined by Method B1 is 36 % smaller than that determined by Method B2. Consequently, EEEP ductility factor, $\mu_{eeep,}$ determined by Method B1 is 57 % larger than that determined by Method B2.

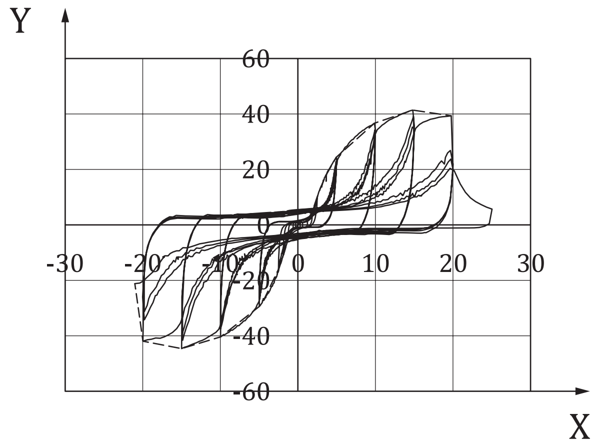
NOTE 3 Ductility factors, $\mu$, determined using $V_y$ determined by Method A3 and Method A4 show comparatively similar values. When the ductility is high, the difference between these two methods is not relevant.

NOTE 4 Determined EEEP ductility factors, $\mu_{eeep,}$ are 22,7 and 35,6. Ductility factor, $\mu$, is 64,5 when determined using $V_u$ determined by 8.2. These extremely large ductility factors result from the small yield displacement, $V_{y,}$ in nailed joints. In this case the ultimate displacements, $V_u$, will be a more important indicator than the ductility factor, $\mu$.

## B.3 Wood-to-wood bolted joints

### B.3.1 Load displacement relation

An example of load-displacement relation in reversed cyclic shear test of bolted joint is shown in Figure B.4. Yield point and ultimate characteristics are determined separately from the positive and negative envelope curves.




**Key**

X displacement (mm)

Y load (kN)

positive envelope curve

$F_{max}$ 41,40 kN

$V_{max}$ 14,82 mm

negative envelope curve

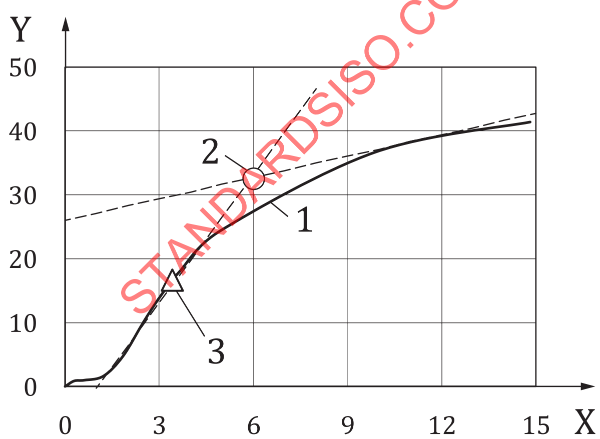
$F_{max}$ 44,61 kN

$V_{max}$ 14,99 mm

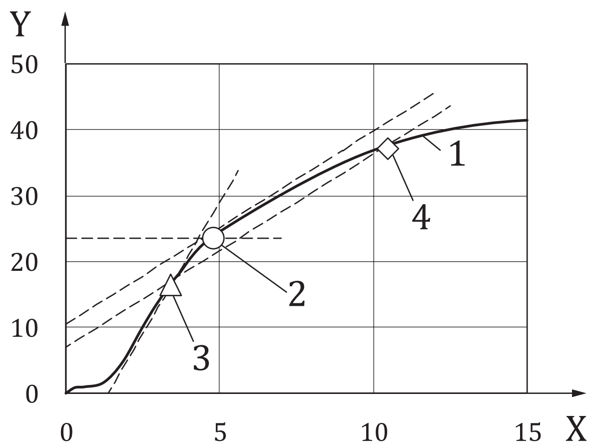
**Figure B.4 — Example of load-displacement relation of wood-to-wood joint (105 mm thick *Sugi* lumber with 16 mm diameter bolts, loading parallel to the grain)**

### B.3.2 Determination of yield load

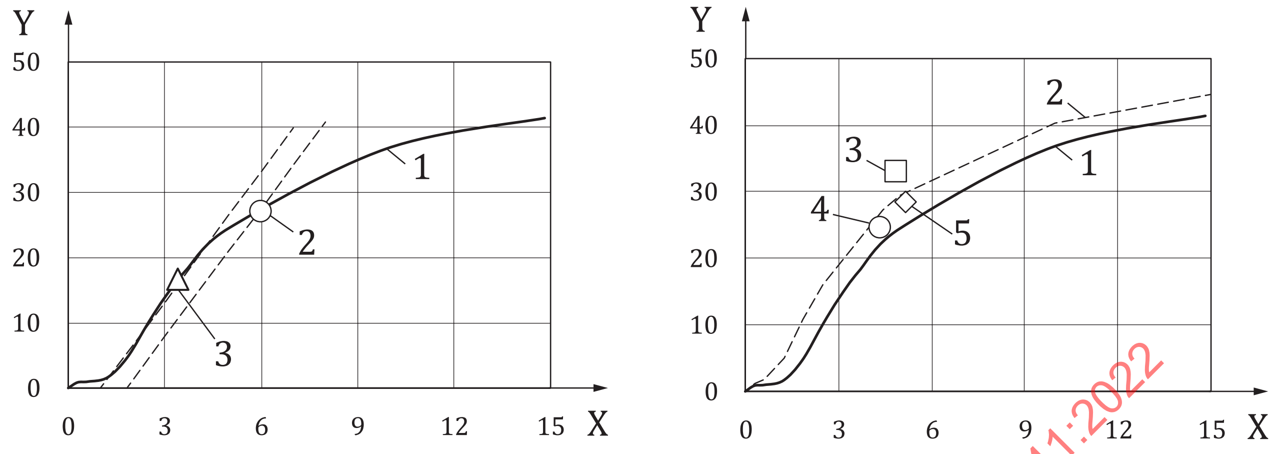
Envelope curves and yield load, $F_y$, determined by Methods A2, A3 and A4 (see 7.1) are shown in Figures B.5 a), B.5 b) and B.5 c), respectively. Comparison of yield loads by each method is shown in Figure B.5 d) and Table B.3




**a) Yield load by Method A2 - positive envelope**




**b) Yield load by Method A3 – positive envelope**




**c) Yield load by Method A4 positive envelope**

**d) Comparison of yield load – positive and negative envelope and average values**

**Key**

a) to c)

X displacement (mm)
Y load (kN)
1 envelope curve(+)
2 Fy
3 0,4Fmax
4 0,9Fmax

d)

X displacement (mm)
Y load (kN)
1 envelope curve(+)
2 envelope curve(-)
3 Fy_A2(EN)
4 Fy_A3(JIS)
5 Fy_A4(ASTM)

**Figure B.5 — Examples of yield load**



**Table B.3 — Comparison of yield point and maximum values**

| | Method A2 (see 7.1) | | Method A3 (see 7.1) | | Method A4 (see 7.1) | |
|---|---|---|---|---|---|---|
| | Positive | Negative | Positive | Negative | Positive | Negative |
| $K_e$ (kN/mm) | 6,60 | 7,80 | 6,60 | 7,80 | 6,60 | 7,80 |
| $F_y$ (kN) | 32,43 | 33,79 | 23,53 | 25,94 | 26,98 | 29,89 |
| $F_y$ (kN) from average envelope curve | 33,58 | | 25,09 | | 28,62 | |
| $F_y$ (kN) average of positive and negative curves | 33,11 | | 24,74 | | 28,44 | |
| $V_y$ (mm) | 6,02 | 4,88 | 4,81 | 4,33 | 5,99 | 5,18 |
| $F_y/V_y$ (kN/mm) | 5,39 | 6,92 | 4,89 | 5,99 | 4,50 | 5,77 |
| $F_y/F_{max}$ | 0,78 | 0,76 | 0,57 | 0,58 | 0,65 | 0,67 |

NOTE 1 Yield load, $F_y$, determined by Method A4 shows approximately 15 % greater value than that determined by Method A3, and that determined by A2 shows 34 % and 16 % greater values than those determined by Methods A3 and A4, respectively.

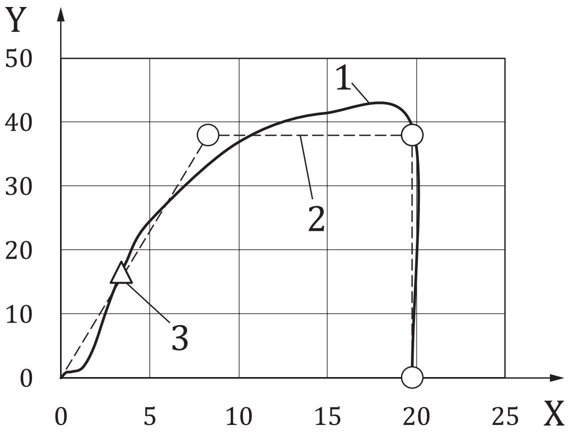
NOTE 2 Yield displacement, $V_y$, determined by Method A4 is 22 % larger than that determined by Method A3.

NOTE 3 Yield loads, $F_y$, determined by Methods A3 and A4 are approximately 58 % and 66 % of the maximum load, $F_{max}$, and that determined by Method A2 are approximately 77 % of the maximum load, $F_{max}$.

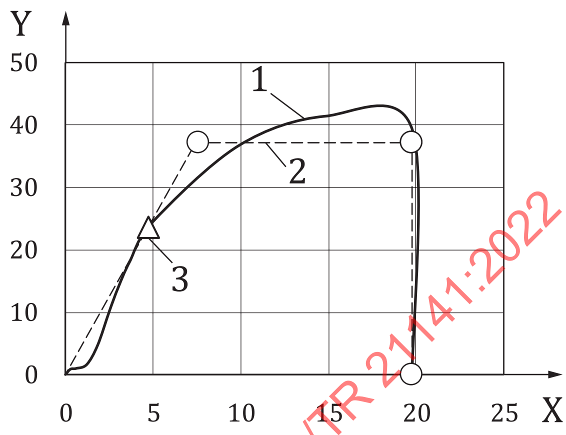
NOTE 4 Yield loads, $F_y$, determined from the average envelope are close to the average of positive and negative values.

### B.3.3 Determination of ultimate characteristics

Ultimate characteristics determined by Methods B1 and B2 (see 8.3) are shown in Figures B.6 a) and B.6 b), respectively.




**a) Determination of EEEP model by Method B1 – positive envelope**




**b) Determination of EEEP model by Method B2 – positive envelope**

**Key**

a)

X displacement (mm)

Y load (kN)

1 envelope curve(+)

2 EEEP Model_B1(ASTM)

3 0,4Fmax

b)

X displacement (mm)

Y load (kN)

1 envelope curve(+)

2 EEEP Model_B2(JIS)

3 Fy

**Figure B.6 — Determination of EEEP model — Positive envelope**

### B.3.4 Comparison of methods

Comparison of ultimate characteristics and ductility by each method are shown in Table B.4.

**Table B.4 — Comparison of ultimate characteristics and ductility**

| | see 8.2 | | Method B2 (see 8.3) | | Method B1 (see 8.3) | |
|---|---|---|---|---|---|---|
| | Positive | Negative | Positive | Negative | Positive | Negative |
| $F_{eeep}$ (kN) | — | — | 37,15 | 40,81 | 37,96 | 40,33 |
| $V_{eeep}$ (mm) | — | — | 7,59 | 6,81 | 8,28 | 6,42 |
| $F_u$ (kN) | 39,33 | 41,94 | — | — | — | — |
| $V_u$ (mm) | 19,77 | 19,98 | 19,77 | 19,98 | 19,77 | 19,98 |
| $\mu$ ($V_u/V_y$) | 3,28 | 4,09 | 4,11 | 4,61 | 3,30 | 3,80 |
| $\mu$($V_u/V_y$) from average envelope curve | 3,54 | — | 4,28 | — | 3,49 | — |

NOTE 1 EEEP loads, $F_{eeep}$, determined by Methods B1 and B2 show similar values.

NOTE 2 EEEP displacements, $V_{eeep}$, determined by Methods B1 and B2 both show about 7,3 mm in positive and negative average. Consequently, EEEP ductility factors, $\mu_{eeep}$, determined by Methods B1 and B2 are very close.

NOTE 3 The obtained EEEP ductility factors, $\mu_{eeep}$, by Methods B1 and B2 lie between 2.4 and 3.1. Ductility factor, $\mu$, determined by 8.2 is close to that determined by Method B1. These results can be influenced by the initial slips which are excluded to determine the strength but included for the determination of the displacement.

**Table B.4** *(continued)*

| | see 8.2 | | Method B2 (see 8.3) | | Method B1 (see 8.3) | |
|---|---|---|---|---|---|---|
| | **Positive** | **Negative** | **Positive** | **Negative** | **Positive** | **Negative** |
| $\mu(V_u/V_y)$ average of positive and negative curves | 3,69 | — | 4,36 | — | 3,55 | — |
| $\mu_{eeep}(V_u/V_{eeep})$ | — | — | 2,60 | 2,93 | 2,39 | 3,11 |

NOTE 1 EEEP loads, $F_{eeep}$, determined by Methods B1 and B2 show similar values.

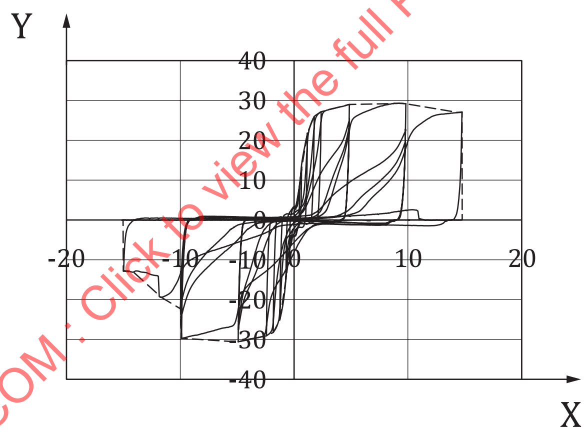
NOTE 2 EEEP displacements, $V_{eeep}$, determined by Methods B1 and B2 both show about 7,3 mm in positive and negative average. Consequently, EEEP ductility factors, $\mu_{eeep}$, determined by Methods B1 and B2 are very close.

NOTE 3 The obtained EEEP ductility factors, $\mu_{eeep}$, by Methods B1 and B2 lie between 2.4 and 3.1. Ductility factor, $\mu$, determined by 8.2 is close to that determined by Method B1. These results can be influenced by the initial slips which are excluded to determine the strength but included for the determination of the displacement.

## B.4 Steel-to-wood lag-screw joints

### B.4.1 Load displacement relation

An example of load-displacement relation in reversed cyclic shear test of lag-screw joint is shown in Figure B.7. Yield point and ultimate characteristics are determined separately from the positive and negative envelope curves.




**Key**

X displacement (mm)

Y load (kN)

positive envelope curve

$F_{max}$ 29,21 kN

$V_{max}$ 9,74 mm

negative envelope curve

$F_{max}$ 30,61 kN

$V_{max}$ 4,93 mm

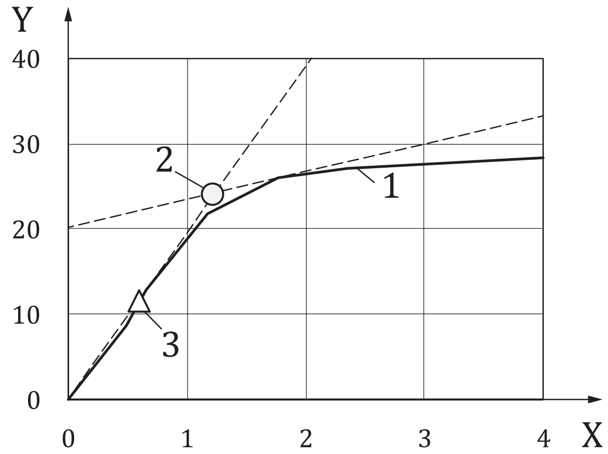
**Figure B.7 — Example of load-displacement relation in lag-screw joint (12 mm thick steel plate and lumber with 12 mm diameter lagscrews, loading parallel to the grain)**

### B.4.2 Determination of yield load

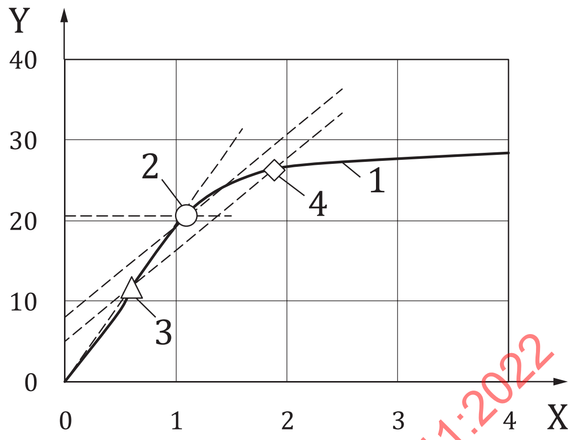
Envelope curves and yield load, $F_y$, determined by Methods A2, A3 and A4 (see 7.1) are shown in Figures B.8 a), B.4.3 and B.4.4, respectively. Comparison of yield loads, $F_y$, by each method is shown in Figure B.8 d) and Table B.5



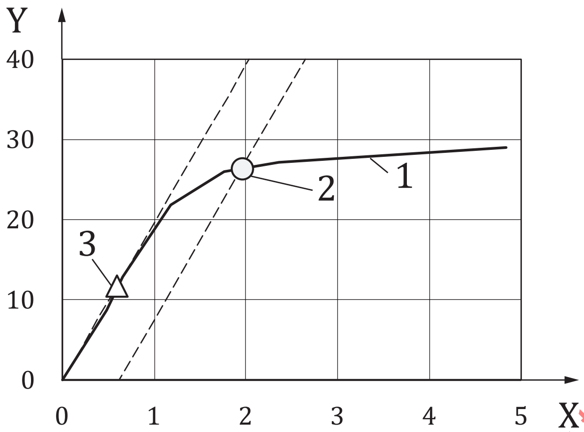
 



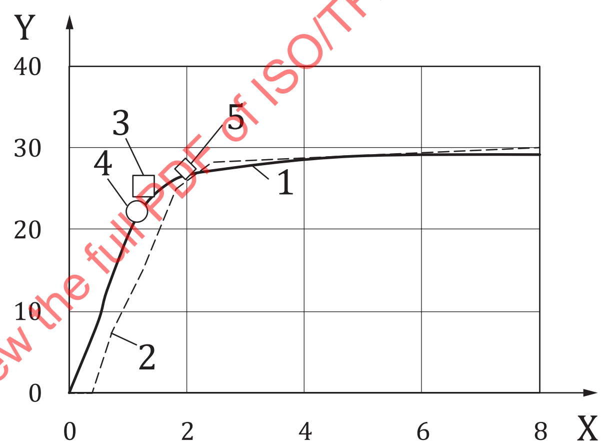

**a) Yield load by Method A2 - positive envelope**




**b) Yield load by Method A3 - positive envelope**




**c) Yield load by Method A4 - positive envelope**




**d) Comparison of yield loads – positive and negative envelope curves and average values**

**Key**

a) to c)

X displacement (mm)

Y load (kN)

1 envelope curve(+)

2 $F_y$

3 0,4Fmax

4 0,9Fmax

d)

X displacement (mm)

Y load (kN)

1 envelope curve(+)

2 envelope curve(-)

3 $F_y$_A2(EN)

4 $F_y$_A3(JIS)

5 $F_y$_A4(ASTM)

**Figure B.8 — Examples of yield load — Positive envelope**

**Table B.5 — Comparison of yield point and maximum values**

| | Method A2 (see 7.1) | | Method A3 (see 7.1) | | Method A4 (see 7.1) | |
|---|---|---|---|---|---|---|
| | Positive | Negative | Positive | Negative | Positive | Negative |
| $K_e$ (kN/mm) | 19,62 | 20,86 | 19,62 | 20,86 | 19,62 | 20,86 |
| $F_y$ (kN) | 24,37 | 26,32 | 20,58 | 23,70 | 26,40 | 28,44 |
| $F_y$ (kN) from average envelope curve | 25,35 | | 22,06 | | 27,42 | |
| $F_y$ (kN) average of positive and negative curves | 25,35 | | 22,14 | | 27,42 | |
| $V_y$ (mm) | 1,26 | 1,27 | 1,10 | 1,17 | 1,96 | 1,98 |
| $F_y/V_y$ (kN/mm) | 19,34 | 20,72 | 18,71 | 20,26 | 13,47 | 14,36 |
| $F_y/F_{max}$ | 0,83 | 0,86 | 0,70 | 0,77 | 0,90 | 0,93 |

NOTE 1 Yield load, $F_y$, determined by Method A4 shows 24 % higher value than that determined by Method A3, and the yield load, $F_y$, determined by Method A2 shows 14 % higher value than that determined by Method A3 and 8 % lower value than that determined by Method A4.

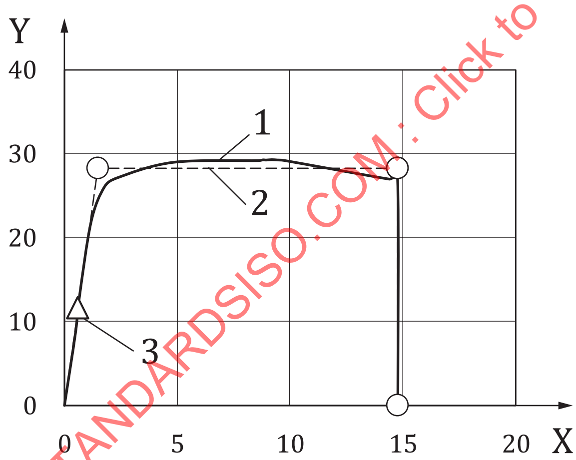
NOTE 2 Yield displacement, $V_y$, determined by Method A4 is 74 % larger than that determined by Method A3, and the yield displacement, $V_y$, determined by A2 shows 11 % larger value than that determined by Method A3 and 36 % smaller value than that determined by Method A4.

NOTE 3 Yield loads, $F_y$, determined by Methods A2, A3 and A4 are 85 %, 74 % and 92 % of the maximum load, $F_{max}$, respectively.

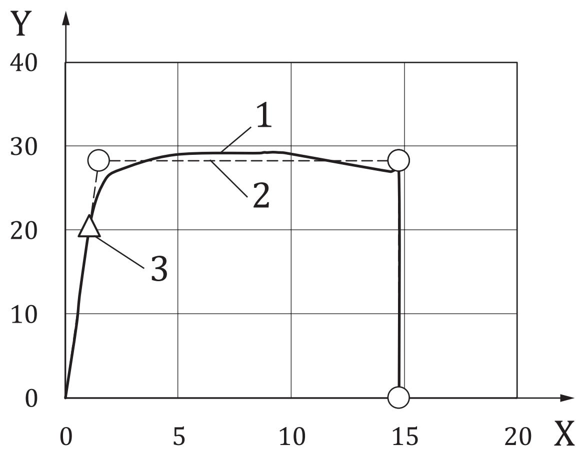


### B.4.3 Determination of ultimate characteristics

Ultimate characteristics determined by Methods B1 and B2 are shown in Figures B.9 a) and B.9 b), respectively.




a) Determination of EEEP model by Method B1 - positive envelope




b) Determination of EEEP model by Method B2 - positive envelope

**Key**

a)

X displacement (mm)

Y load (kN)

1 envelope curve(+)

2 EEEP Model_B1(ASTM)

3 0,4Fmax

b)

X displacement (mm)

Y load (kN)

1 envelope curve(+)

2 EEEP Model_B2(JIS)

3 $F_y$

**Figure B.9 — Determination of EEEP model — Positive envelope**

### B.4.4 Comparison of methods

Comparison of ultimate characteristics and ductility determined by each method are shown in Table B.6

**Table B.6 — Comparison of ultimate characteristics and ductility**

| | see 8.2 | | Method B2 (see 8.3) | | Method B1 (see 8.3) | |
|---|---|---|---|---|---|---|
| | **Positive** | **Negative** | **Positive** | **Negative** | **Positive** | **Negative** |
| $F_{eeep}$ (kN) | — | — | 28,32 | 28,37 | 28,28 | 29,01 |
| $V_{eeep}$ (mm) | — | — | 1,52 | 2,09 | 1,48 | 2,49 |
| $F_u$ (kN) | 27,11 | 28,55 | — | — | — | — |
| $V_u$ (mm) | 14,76 | 9,90 | 14,76 | 9,90 | 14,76 | 9,90 |
| $\mu(V_u/V_y)$ | 11,71 | 7,80 | 13,42 | 8,46 | 7,53 | 5,00 |
| $\mu(V_u/V_y)$ from average envelope curve | 10,10 | | 11,28 | | 6,50 | |
| $\mu(V_u/V_y)$ average of positive and negative curves | 9,76 | | 10,94 | | 6,27 | |
| $\mu_{eeep}(V_u/V_{eeep})$ | — | — | 9,71 | 4,74 | 9,97 | 3,98 |

NOTE 1 EEEP loads, $F_{eeep}$, determined by Methods B1 and B2 show similar values.

NOTE 2 EEEP displacements, $V_{eeep}$, determined by Methods B1 and B2 show similar values. Consequently, EEEP ductility factors, $\mu_{eeep}$, determined by Methods B1 and B2 are very close.

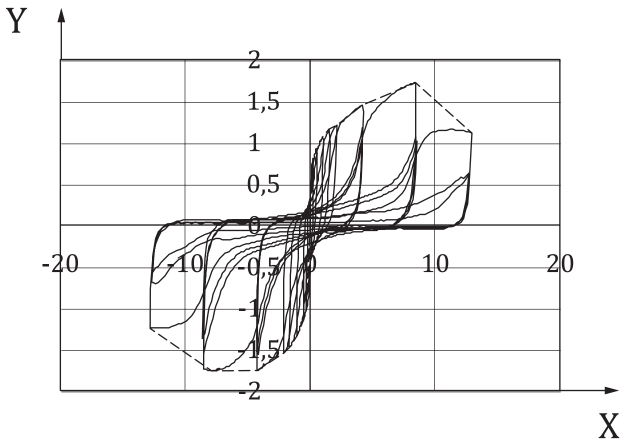
NOTE 3 EEEP ductility factors, $\mu_{eeep}$, determined by Methods B1 and B2 are 6.7 and 7.2 in positive and negative averages, respectively and the ductility factor, $\mu$ determined by Method A2 is 9.76.

NOTE 4 Ductility factors, $\mu$, determined from the average envelope curves are slightly larger than average of positive and negative values, although the differences are small.

## B.5 Plywood-to-wood screw joints

### B.5.1 Load displacement relation

An example of load-displacement relation in reversed cyclic shear test of screw joint is shown in Figure B.10. Yield points and ultimate characteristics are determined separately from the positive and negative envelope curves.




**Key**

X displacement (mm)

Y load (kN)

positive envelope curve

$F_{max}$ 1,72 kN

$V_{max}$ 8,50 mm

negative envelope curve

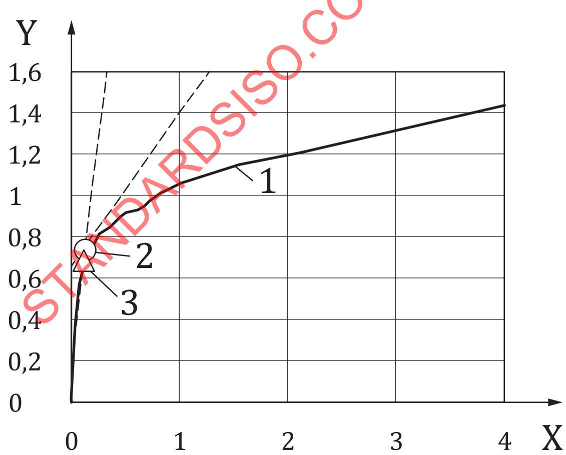
$F_{max}$ 1,76 kN

$V_{max}$ 4,31 mm

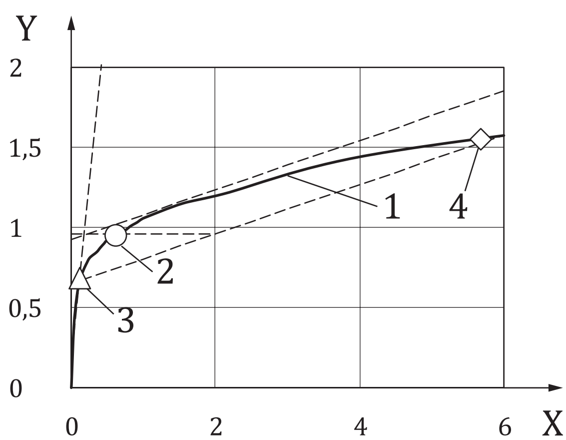
**Figure B.10 — Example of load-displacement relation in plywood-to-wood screw joint (9 mm thick plywood with 4,1 *φ*-38 mm screw joints, loading parallel to the grain)**

## B.5.2 Determination of yield load

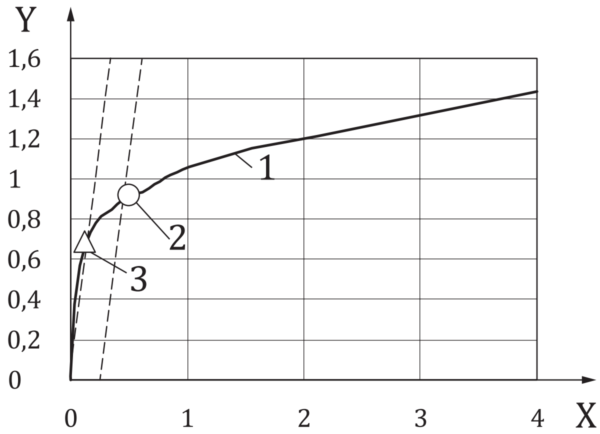
Envelope curves and yield load, $F_y$, determined by Methods A2, A3 and A4 (see 7.1) are shown in Figures B.11 a), B.11 b) and B.11 c), respectively. Comparison of yield load, $F_y$, determined by each method is shown in Figure B.11 d) and Table B.7.



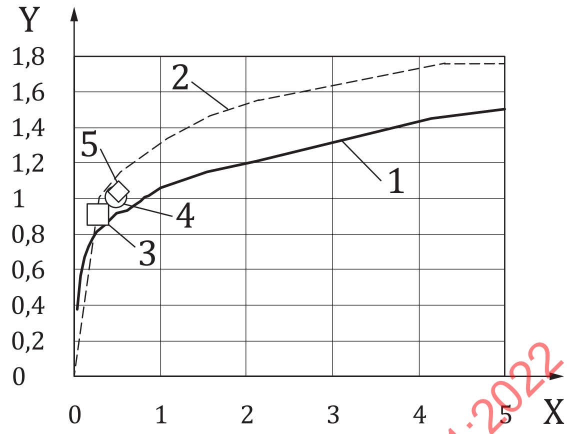

**a) Yield load by Method A2 - positive envelope**




**b) Yield load by Method A3 - positive envelope**




**c) Yield load by Method A4 - positive envelope**




**d) Comparison of yield loads – positive and negative envelope curves and average values**

**Key**

a) to c)

X displacement (mm)
Y load (kN)
1 envelope curve(+)
2 $F_y$
3 0,4Fmax
4 0,9Fmax

d)

X displacement (mm)
Y load (kN)
1 envelope curve(+)
2 envelope curve(-)
3 $F_y$_A2(EN)
4 $F_y$_A3(JIS)
5 $F_y$_A4(ASTM)

**Figure B.11 — Examples of yield load — Positive envelope**

**Table B.7 — Comparison of yield point and maximum values**

| | Method A2 (see 7.1) | | Method A3 (see 7.1) | | Method A4 (see 7.1) | |
|---|---|---|---|---|---|---|
| | Positive | Negative | Positive | Negative | Positive | Negative |
| $K_e$ (kN/mm) | 4,44 | 3,58 | 4,44 | 3,58 | 4,44 | 3,58 |
| $F_y$ (kN) | 0,74 | 1,01 | 0,96 | 1,06 | 0,92 | 1,15 |
| $F_y$ (kN) from average envelope curve | 0,91 | | 1,02 | | 1,04 | |
| $F_y$ (kN) average of positive and negative curves | 0,88 | | 1,01 | | 1,04 | |
| $V_y$ (mm) | 0,13 | 0,28 | 0,63 | 0,38 | 0,50 | 0,53 |

NOTE 1 Yield loads, $F_y$, determined by Methods A3 and A4 show similar values, and yield load ($F_y$) determined by Method A2 shows 13 % and 15 % lower values in positive and negative average than those determined by Methods A3 and A4, respectively.

NOTE 2 Yield displacements, $V_y$, determined by Methods A3 and A4 show similar values in positive and negative average, and yield displacement, $V_y$, determined by Method A2 is approximately 60 % smaller than those determined by Methods A3 and A4.

NOTE 3 Yield loads, $F_y$, determined by Methods A2, A3 and A4 are approximately 43-65 % of the maximum load, $F_{max}$, respectively. Overall, this example illustrates that the yield point is determined more consistently when the transition between the elastic and the plastic ranges is more distinct.

NOTE 4 Yield loads, $F_y$, determined from the average envelope are close to the average of positive and negative values.

**Table B.7** *(continued)*

| | Method A2 (see 7.1) | | Method A3 (see 7.1) | | Method A4 (see 7.1) | |
|---|---|---|---|---|---|---|
| | **Positive** | **Negative** | **Positive** | **Negative** | **Positive** | **Negative** |
| $F_y/V_y$ (kN/mm) | 5,69 | 3,55 | 1,52 | 2,79 | 1,84 | 2,17 |
| $F_y/F_{max}$ | 0,43 | 0,57 | 0,56 | 0,60 | 0,53 | 0,65 |

NOTE 1 Yield loads, $F_y$, determined by Methods A3 and A4 show similar values, and yield load ($F_y$) determined by Method A2 shows 13 % and 15 % lower values in positive and negative average than those determined by Methods A3 and A4, respectively.

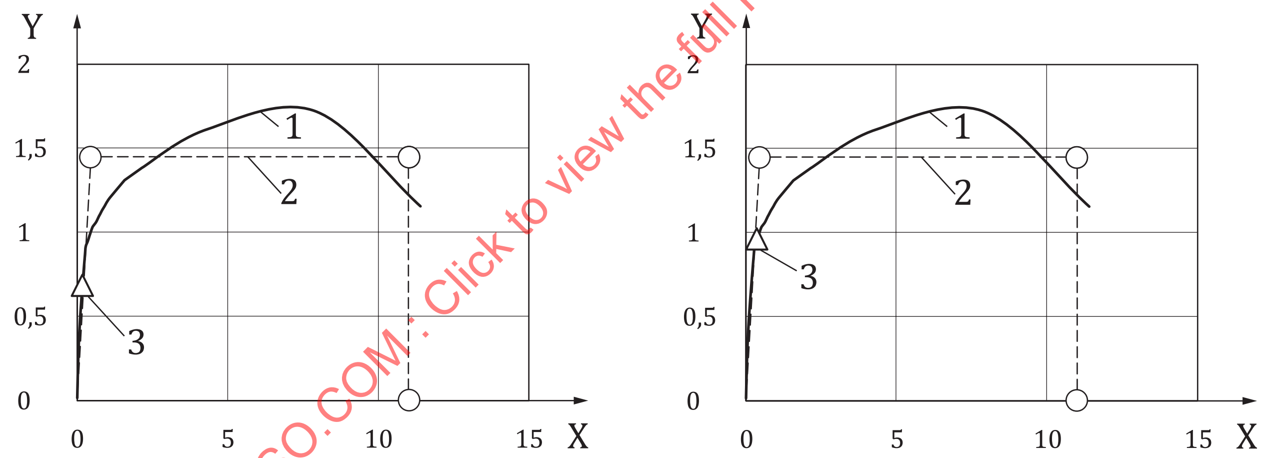
NOTE 2 Yield displacements, $V_y$, determined by Methods A3 and A4 show similar values in positive and negative average, and yield displacement, $V_y$, determined by Method A2 is approximately 60 % smaller than those determined by Methods A3 and A4.

NOTE 3 Yield loads, $F_y$, determined by Methods A2, A3 and A4 are approximately 43-65 % of the maximum load, $F_{max}$, respectively. Overall, this example illustrates that the yield point is determined more consistently when the transition between the elastic and the plastic ranges is more distinct.

NOTE 4 Yield loads, $F_y$, determined from the average envelope are close to the average of positive and negative values.

### B.5.3 Determination of ultimate characteristics

Ultimate characteristics determined by Methods B1 and B2 (see 8.3) are shown in Figures B.12 a) and B.12 b), respectively.




**a) Determination of ultimate EEEP model by Method B1 – positive envelope**

**b) Determination of EEEP model by Method B2 – positive envelope**

**Key**

a)

X displacement (mm)

Y load (kN)

1 envelope curve(+)

2 EEEP Model_B1(ASTM)

3 0,4Fmax

b)

X displacement (mm)

Y load (kN)

1 envelope curve(+)

2 EEEP Model_B2(JIS)

3 $F_y$

**Figure B.12 — Determination of ultimate EEEP model — Positive envelope**

### B.5.4 Comparison of methods

Comparison of ultimate characteristics and ductility determined by each method is shown in Table B.8.

**Table B.8 — Comparison of ultimate characteristics and ductility**

| | see 8.2 | | Method B2 (see 8.3) | | Method B1 (see 8.3) | |
|---|---|---|---|---|---|---|
| | **Positive** | **Negative** | **Positive** | **Negative** | **Positive** | **Negative** |
| $F_{eeep}$ (kN) | — | — | 1,48 | 1,63 | 1,45 | 1,62 |
| $V_{eeep}$ (mm) | — | — | 0,97 | 0,58 | 0,46 | 0,46 |
| $F_u$ (kN) | 1,38 | 1,41 | — | — | — | — |
| $V_u$ (mm) | 11,00 | 11,40 | 11,00 | 11,40 | 11,00 | 11,40 |
| $\mu(V_u/V_y)$ | 42,41 | 40,07 | 17,50 | 30,28 | 22,00 | 21,51 |
| $\mu(V_u/V_y)$ from average envelope curve | 41,39 | | 23,49 | | 22,06 | |
| $\mu(V_u/V_y)$ average of positive and negative curves | 41,24 | | 23,89 | | 21,76 | |
| $\mu_{eeep}(V_u/V_{eeep})$ | — | — | 11,29 | 19,73 | 23,89 | 24,86 |

Note 1 EEEP loads ($F_{eeep}$) determined by methods B1 and B2 show similar values.

Note 2 EEEP displacements ($V_{eeep}$) determined by Method B2 is 68 % greater than that determined by Method B1. Consequently, EEEP ductility factor ($\mu_{eeep}$) determined by Method B2 is 36 % less than that determined by Method B1.

Note 3 Ductility factors (μ) determined using $V_y$ determined by Methods A3 and A4 are 23,9 and 21,8 in positive and negative average and show similar values. The ductility factor (μ) determined by Method A2 is 41,2 in positive and negative average and is approximately twice the value of those determined by Method A3 and Method A4.

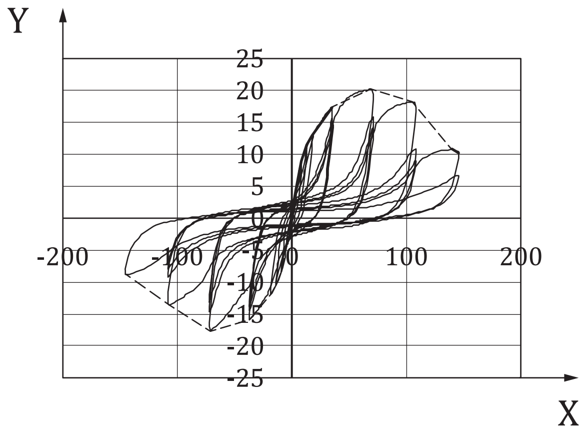
Note 4 These extremely large ductility factors result from the small yield displacement ($V_y$) in screwed joints. In this case the ultimate displacements ($V_u$) will be a more important indicator than the ductility factor (μ).

Note 5 Ductility factor (μ) determined from the average envelope curves are close to average of positive and negative values.

## B.6 Plywood-sheathed shear walls with nailed joints

### B.6.1 Load displacement relation

An example of load-displacement relation in reversed cyclic lateral loading test of a plywood sheathed shear wall is shown in Figure B.13.




**Key**

X storey drift (mm)

Y lateral load (kN)

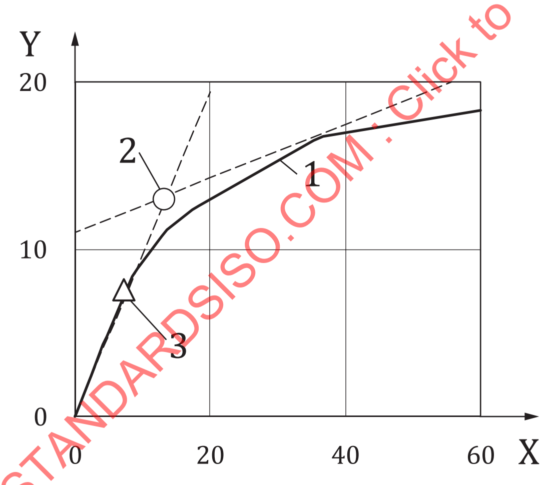
$F_{max}$ 18,96 kN

$V_{max}$ 70,20 mm

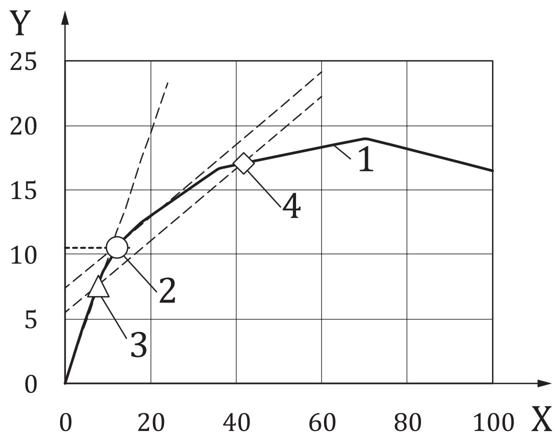
**Figure B.13 — Example of load-displacement relation of plywood- sheathed shear wall with nailed joints (9 mm thick plywood with CN50 nails)**

## B.6.2 Determination of yield load

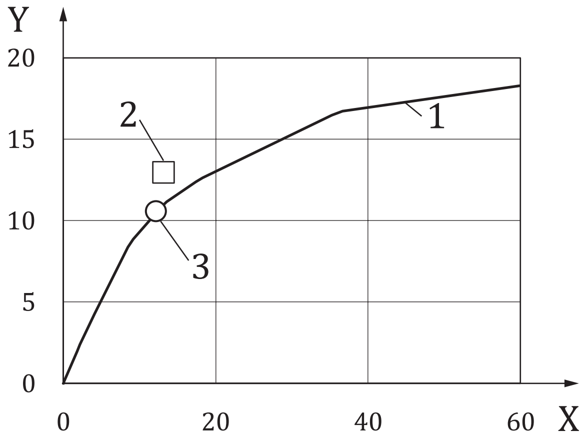
Envelope curves and modelling by Method A2 and Method A3 (see 7.1) are shown in Figures B.14 a) and B.14 b), respectively. Comparison of yield loads, $F_y$, by each method is shown in Figure B.14 c) and Table B.9.




**a) Yield load by Method A2**




**b) Yield load by Method A3**




c) **Comparison of yield loads**

**Key**

a), b)

X storey drift (mm)

Y lateral load (kN)

1 envelope curve(av.)

2 $F_y$

3 0,4$F_{max}$

4 0,9*F*max

c)

X storey drift (mm)

Y lateral load (kN)

1 envelope curve(av.)

2 $F_y$_A2(EN)

3 $F_y$_A3(JIS)

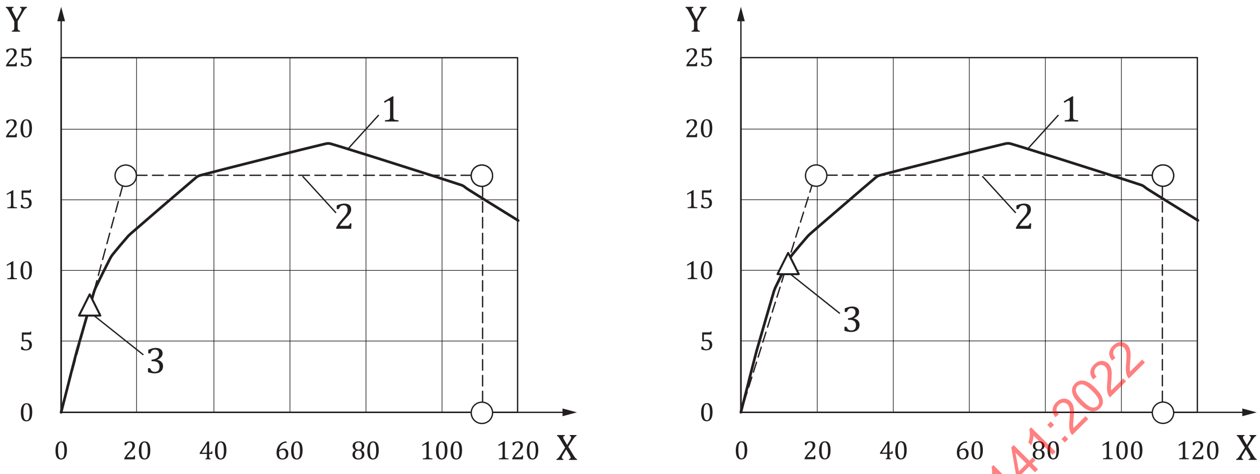
**Figure B.14 — Examples of yield load**

**Table B.9 — Comparison of yield point and maximum values**

| | **Method A2** (see 7.1) | **Method A3** (see 7.1) |
|---|---|---|
| $K_e$ (kN/mm) | 0,97 | 0,97 |
| $F_y$ (kN) | 12,98 | 10,51 |
| $V_y$ (mm) | 13,25 | 12,29 |
| $F_y/V_y$ (kN/mm) | 0,98 | 0,86 |
| $F_y/F_{max}$ | 0,68 | 0,55 |
| NOTE 1 Yield load, $F_y$, determined by Method A2 is 24 % greater than value than that determined by Method A3. | | |
| NOTE 2 Yield displacement, $V_y$, determined by Method A2 is 8 % larger than that determined by method A3. | | |
| NOTE 3 Yield loads, $F_y$, determined by Methods A2 and A3 are 68 % and 55 % of the maximum loads, $F_{max}$, respectively. | | |

## B.6.3 Determination of ultimate characteristics

Ultimate characteristics determined by Methods B1 and B2 (see 8.3) are shown in Figures B.15 a) and B.15 b), respectively.




**a) Determination of EEEP model by Method B1**

**b) Determination of EEEP model by Method B2**

**Key**

Figure B.5.5

X storey drift (mm)
Y lateral load (kN)
1 envelope curve(av.)
2 EEEP Model_B1(ASTM)
3 0,4Fmax

Figure B.5.6

X storey drift (mm)
Y lateral load (kN)
1 envelope curve(av.)
2 EEEP Model_B2(JIS)
3 $F_y$

**Figure B.15 — Determination of EEEP model**

## B.6.4 Comparison of methods

Comparison of ultimate characteristics and ductility determined by each method is shown in Table B.10.

**Table B.10 — Comparison of ultimate characteristics and ductility**

| | see 8.2 | **Method B2** (see 8.3) | **Method B1** (see 8.3) |
|---|---|---|---|
| $F_{eeep}$ (kN) | — | 16,94 | 16,71 |
| $V_{eeep}$ (mm) | — | 19,80 | 16,93 |
| $F_u$ (kN) | 15,17 | — | — |
| $V_u$ (mm) | 110,8 | 110,8 | 110,8 |
| $\mu(V_u/V_y)$ | 8,36 | 9,01 | — |
| $\mu_{eeep}(V_u/V_{eeep})$ | — | 5,59 | 6,54 |

NOTE 1 EEEP loads, $F_{eeep}$, determined by Methods B1 and B2 show similar values.

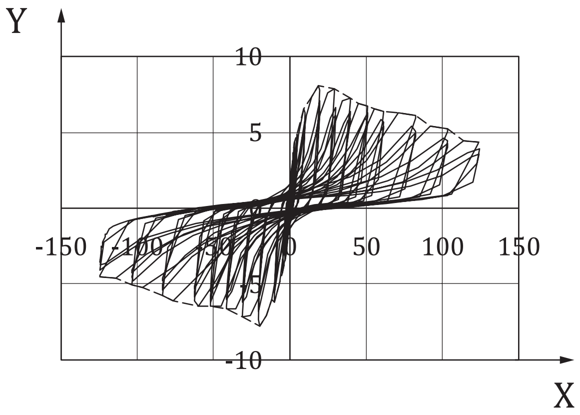
NOTE 2 EEEP displacement, $V_{eeep}$, determined by Method B1 is 14 % smaller than that determined by B2. Consequently, EEEP ductility factor, $\mu_{eeep}$, determined by Method B1 is 17 % greater than that determined by Method B2.

NOTE 3 Ductility factor, $\mu$, determined using $V_y$ determined by Method A2 is 7 % smaller than that determined by Method A3. Some compatibility is supposed between the ductility factors, $\mu$, by Method A2 and Method A3.

## B.7 Gypsum board-sheathed shear walls with screw joints

### B.7.1 Load displacement relation

An example of load-displacement relation in reversed cyclic lateral loading test of a gypsum board-sheathed shear wall is shown in Figure B.16.




**Key**

X storey drift (mm)

Y lateral load (kN)

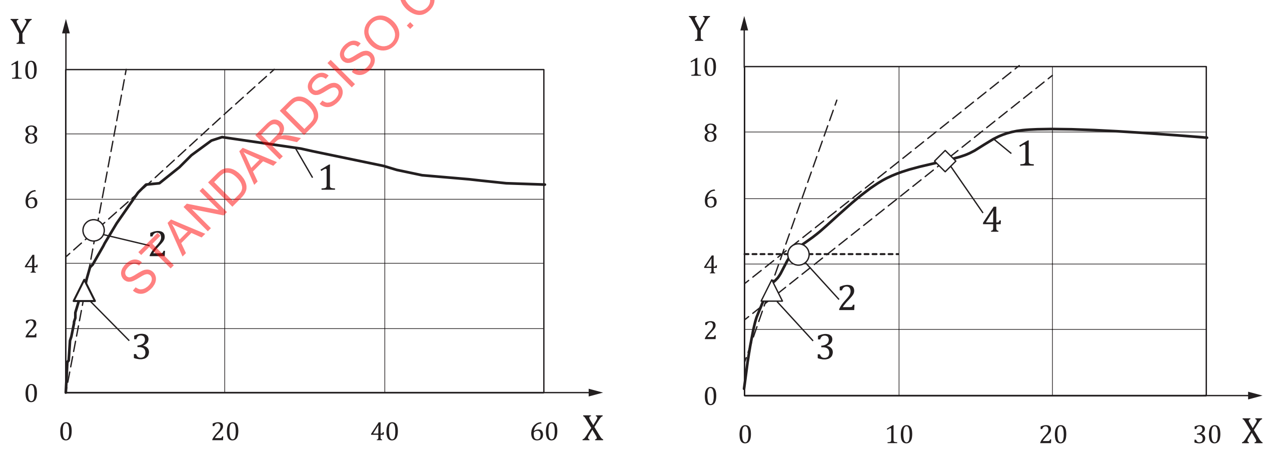
$F_{max}$ 7,92 kN

$V_{max}$ 18,98 mm

**Figure B.16 — Example of load-displacement relation of gypsum board-sheathed shear wall (12,5 mm thick gypsum-board with 4,1 φ-38 mm screws)**

### B.7.2 Determination of yield load

Envelope curves and determined yield load by Method A2 and Method A3 (see 7.1) are shown in Figures B.17 a) and B.17 b), respectively. Comparison of yield loads, $F_y$, by each method is shown in Figure B.17 c) and Table B.11.




a) **Yield load by Method A2**

b) **Yield load by Method A3**