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Timber structures — Bending strength of I-beams —

Part 1:
Testing, evaluation and characterization

Structures en bois — Résistance à la flexion des poutres en I —

Partie 1: Essais, évaluation et caractérisation

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 22389-1 was prepared by Technical Committee ISO/TC165, *Timber structures*.

ISO 22389 consists of the following part, under the general title *Timber structures — Bending strength of I-beams:*

— *Part 1: Testing, evaluation and characterization*

Component performance and manufacturing requirements is to form the subject of a part 2.

This part of ISO 22389 is based, with permission of ASTM International, on ASTM D 5055, *Standard Specification for Establishing and Monitoring Structural Capacities of Prefabricated Wood I-Joists*, copyright ASTM International.

Introduction

Prefabricated wood-based I-beams are being produced in many countries under different national standards and these products are being exported from one country to another. While the national standards have many similarities, there are also many areas of dissimilarity. Consequently, there is need for the development of an International Standard to establish consistency between these standards to ensure the suitability of prefabricated wood-based I-beams for structural end-use applications regardless of country of manufacture or country of end use. It is intended that the development of this part of ISO 22389 will have value to industry, consumers, governments and distributors.

INTERNATIONAL STANDARD **ISO 22389-1:2010(E)**

Timber structures — Bending strength of I-beams —

Part 1:
Testing, evaluation and characterization

1 Scope

This part of ISO 22389 specifies the requirements for prefabricated wood-based I-beams used as structural members in bending applications.

It gives procedures for establishing and evaluating structural capacities of prefabricated wood-based I-beams. The capacities considered are shear, moment, stiffness, bearing, and flange tension and compression. Procedures for establishing common details are given and certain end-use considerations specific to wood-based I-beams are itemized.

Wood-based I-beams tested according to this part of ISO 22389 are intended for use under covered conditions and utilize components that are able to resist the effects of moisture on structural performance due to construction delays or other conditions of similar severity, but are not intended to be permanently exposed to the weather.

This part of ISO 22389 is not applicable to fire performance, formaldehyde requirements and biological durability. It does not cover manufacturing requirements for prefabricated wood-based I-beams.

NOTE Procedures set out in this part of ISO 22389 are applicable to I-beams defined by a standard or a manufacturer's specification that includes requirements for the flanges, webs and bonding, and production controls, including ongoing conformity assessment.

This part of ISO 22389 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 part of ISO 22389 to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. A specific precautionary statement is given in 5.1.5.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20152-1, *Timber structures — Bond performance of adhesives — Part 1: Basic requirements*

EN 789, *Timber structures — Test methods — Determination of mechanical properties of wood based panels*

ASTM D2915, *Standard Practice for Evaluating Allowable Properties for Grades of Structural Lumber*

ASTM D5456, *Standard Specification for Evaluation of Structural Composite Lumber Products*

3 Terms and definitions

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

3.1

prefabricated wood-based I-beam

structural member manufactured using sawn or structural composite lumber flanges and structural panel webs, forming an “I” cross-sectional shape, bonded together with a structural wood adhesive that possesses the moisture resistance suitable for the conditions specified

NOTE 1 These members are primarily used as joists in floor and roof construction.

NOTE 2 Suitable moisture resistance means resistance under covered conditions and possible exposure to moisture due to construction delays or other conditions of similar severity, but not permanent exposure to the weather.

3.2

characteristic strength and stiffness

population 5th percentile strength value at a 75 % confidence level or the 50th percentile (mean) for bending stiffness value when determined using the test specified in this part of ISO 22389

3.3

structural composite lumber

composite of wood elements bonded with a structural wood adhesive that possesses the moisture resistance suitable for the conditions specified and intended for structural use in dry service conditions

NOTE 1 Examples of wood elements include wood strands, strips, veneer sheets or a combination thereof.

NOTE 2 Suitable moisture resistance means resistance under covered conditions and possible exposure to moisture due to construction delays or other conditions of similar severity, but not permanent exposure to the weather.

4 Materials

4.1 Flange stock

When the flange material is structural composite lumber, the following properties shall be determined in accordance with ASTM D5456 or EN 789:

a) modulus of elasticity;

b) tension parallel to grain;

c) compression parallel to grain;

d) compression perpendicular to grain.

NOTE National standards or governing codes can be applicable to all flange material.

End joints in purchased flange stock are permitted, provided such joints conform to the general intent and 5.8.

4.2 Web material

Web materials covered by this part of ISO 22389 are intended for end-use conditions specified in the Scope (third paragraph) and 3.1, Note 2.

NOTE Manufacturing or performance standards of wood-based panels recognized by national standards or governing codes can be applicable to web materials.

4.3 Adhesives

Adhesives used to fabricate components as well as the finished products shall conform to ISO 20152-1.

NOTE National standards or governing codes can be applicable.

5 Product evaluation

5.1 General

Product evaluation shall be conducted for establishing the characteristic capacities of prefabricated wood-based I-beams for use in building design. In addition, product evaluation shall be conducted for certain common I-beam details since they often influence the I-beam characteristic capacities.

5.1.1 Sample size

The number of specimens specified in this part of ISO 22389 is a minimum. The use of a larger number of samples may be evaluated using ASTM D2915 or an applicable International Standard[1)].

5.1.2 Specimens

Materials and fabrication procedures of specimens shall be as typical of intended production as can be obtained at the time of manufacturing the specimens. Specimens shall be tested at indoor ambient laboratory conditions, which shall be reported.

It is recommended that preliminary tests be conducted to aid the selection of representative specimens.

5.1.3 Test accuracy

Tests in accordance with this part of ISO 22389 shall be conducted in a machine or apparatus calibrated to an error not exceeding ±2,0 %.

5.1.4 Test methods

Methods generally applicable to the full-size I-beam tests required in this part of ISO 22389 shall consider the following:

a) the methods are applicable to both product evaluation and quality control;

b) load rate shall be as specified in the following subclauses;

c) delays between load increments are not required.

5.1.5 Test safety

All full-scale mechanical tests are potentially hazardous and appropriate safety precautions shall be observed at all times. Appropriate lateral restraint shall be provided at all times during full-size I-beam tests to prevent lateral buckling.

[1)] It is intended to develop an International Standard on the evaluation of characteristic values for structural timber.

5.2 Characteristic shear capacity

5.2.1 Characteristic shear capacity shall be established from test results obtained in accordance with this part of ISO 22389.

5.2.2 Web factors that influence characteristic shear capacities and include web type, thickness, orientation, grade, web to flange joint and joint type in web (machined, butted, glued or not, reinforced), shall be tested in accordance with this subclause.

5.2.2.1 Each combination of these web factors shall be tested separately, unless the critical combination in a proposed grouping is first established by test. Flange stiffness influences characteristic shear capacities.

5.2.2.2 If a range of flange sizes is intended to be used with a given combination of web factors, all sizes shall be tested unless all values are intended to be based on tests with the least stiff flange.

5.2.2.3 When it is intended to group a range of species or grades of either sawn or structural composite lumber flanges, preliminary tests shall be conducted to determine which is critical to the performance of the I-beam.

5.2.2.4 I-beams with structural composite lumber flanges shall be tested separately from joists with sawn lumber flanges.

5.2.3 For each web factor combination identified in 5.2.2, a minimum of 10 specimens shall be tested for each critical joist depth. Critical joist depths are minimum and maximum product depths with approximate 102 mm depth increments in between. If the installation of specific reinforcement, as defined in the manufacturer's handbook, is required at a certain depth to maintain product performance in the progression of a series of depths within a combination, the product shall be tested at this depth plus the adjacent depth, which does not require specific reinforcement.

5.2.4 Specimen length shall be that which usually produces failures in shear and shall not extend past each bearing support by more than 6,4 mm. The bearing length shall be adequate to usually produce shear failure instead of a bearing failure, but shall not exceed 102 mm, unless justified. There shall be a minimum horizontal distance of 1 1/2 times the joist depth between the face of the support and the edge of the load pad.

NOTE Typical I-beam failure modes are shown in Annex B.

5.2.5 On one end of the specimen, a vertical web joint, if used, shall be located approximately 305 mm from the face of the support or half the distance between the support and the load pad.

5.2.6 The load shall be applied to the top flange either as a single-point load at centre span or as two-point loads of equal distance from the centre span. Load pads shall have a sufficient length to prevent local failure.

5.2.7 The load shall be applied at a uniform rate, such that anticipated failure occurs in not less than 1 min.

5.2.8 Any required web reinforcements shall be installed at supports. When required to prevent failure at a load point, additional reinforcement shall be installed, provided such reinforcement is not wider than the load pad.

5.2.9 Ultimate load and mode of failure shall be recorded in addition to product and test set-up descriptions. If any specimen fails in bending, the data shall be excluded. However, for purposes of evaluating characteristic shear capacities, bearing failure may be considered a mode of shear failure.

5.2.10 The dead load of the specimen shall be included in the ultimate load calculation, when specified by the producer.

5.2.11 Mean ultimate shear capacities of an I-beam series or selected grouping of series shall show a linear increase with increasing I-beam depth. A linear regression analysis of the mean values shall have a coefficient of determination, r^2, of at least 0,9, or the specified tests of 5.2.3 shall be repeated. If the second test set fails to meet the criteria, all depths which have been skipped shall also be tested.

5.2.11.1 Data from joist depths where failure is web buckling shall be excluded from the regression analysis, if

a) including the results causes failure to meet the criteria of 5.2.11, or

b) the producer determines the reduction in regression line slope to be unacceptable.

In either case, all depths greater than the shallowest excluded shall be tested.

Depending on joist details and material, there is some depth where web buckling appears as a mode of failure. Further increases in depth will result in consistent web buckling, and at some point, the ultimate shear capacities will be reduced compared to shallower joists.

5.2.11.2 When it is intended to evaluate no more than three depths, the regression analysis is not necessary; nevertheless, each depth shall be tested.

5.2.12 Characteristic shear capacity of the product shall be limited to that calculated by taking into account sample size, test result variability and reduction factors. Data from tests at different joist depths included in the regression analysis are permitted to be combined to obtain a pooled estimate of variability.

5.2.12.1 When combining data, the mean shear capacity, P_e, for depth, d_i, shall be calculated using Equation (1):

$$P_\mathrm{e} = A + B\, d_\mathrm{i} \tag{1}$$

where A and B are intercept and slope of Equation (1), respectively.

5.2.12.2 Where too few depths are involved for correlation in 5.2.11, the tests fail the regression criteria, or depths are excluded from the correlation, test data shall not be combined and each such depth shall be evaluated separately.

5.2.12.3 The coefficient of variation, $C_{V,\mathrm{i}}$, of each individual depth tested shall be calculated using Equation (2):

$$C_{V,\mathrm{i}} = \frac{S_\mathrm{i}}{\overline{P}_\mathrm{i}} \tag{2}$$

where $\overline{P}_\mathrm{i}$ and S_i are the mean and standard deviation of the data from each depth tested, respectively.

The coefficient of variation of the combined data sets, C_V, shall be calculated using Equation (3):

$$C_V = \sqrt{\frac{\sum_{i=1}^{J}[(n_\mathrm{i}-1)\, C_{V,\mathrm{i}}{}^2]}{\sum_{i=1}^{J} n_\mathrm{i} - J}} \tag{3}$$

where

n_i is the number of tests for each depth, d_i, tested and included in the regression analysis;

J is the number of depths included in the regression analysis.

Also, the summation is from $i = 1$ to J.

5.2.12.4 The characteristic shear capacity, P_{s}, shall be calculated using Equation (4):

$$P_{\mathrm{s}} = P_{\mathrm{e}} - K \times C_V \times P_{\mathrm{e}} \tag{4}$$

where

K is the factor for 5th percentile with 75 % confidence for a normal distribution [from ASTM D2915 or an applicable International Standard$^{1)}$];

P_{e} is the ultimate mean shear capacity from Equation (1) or the mean of any depth in accordance with 5.2.12.2;

C_V is the coefficient of variation of combined data from Equation (3) or Equation (2), when any depth is evaluated alone.

5.2.12.5 When data are combined, the factor, K, shall be based on a sample size $N = \sum_{i=1}^{J} n_{\mathrm{i}} - J$. When the criteria of 5.2.11 are not met and for depths excluded from the regression analysis, the characteristic shear capacity, P_{s}, shall be computed separately for each such depth using Equation (5):

$$P_{\mathrm{s}} = (\overline{P}_{\mathrm{i}} - K \times C_{V,\mathrm{i}} \times \overline{P}_{\mathrm{i}}) \tag{5}$$

where the factor K shall be based on a sample size of n_{i}.

5.3 Characteristic bearing capacity

5.3.1 General

5.3.1.1 This subclause provides procedures for establishing the characteristic bearing capacities of prefabricated wood-based I-beams. This subclause does not preclude the development of alternative characteristic bearing capacity evaluation procedures meeting the intent of this part of ISO 22389. If required by national standards or governing codes, documentation showing equivalency to each of the evaluation requirements in this subclause shall be provided.

NOTE This subclause was developed in the light of manufactured products, produced from materials defined in Clause 4. New materials can require new or revised procedures to provide comparable levels of safety and performance.

5.3.1.2 Factors that influence characteristic I-beam bearing capacities, including bearing length, web (type, orientation, thickness and grade), rout geometry, adhesive type, joist depth, flange (type, size, species and grade), and web stiffeners (see 5.3.7), shall be tested in accordance with this subclause.

5.3.1.2.1 Each combination of these factors shall be tested separately according to 5.3.1.4, unless the critical combination is first established by test.

5.3.1.2.2 Joists with structural composite lumber flanges shall be tested and analysed separately from joists with sawn lumber flanges.

5.3.1.3 Testing for both end and intermediate bearing capacities shall be undertaken and analysed as independent test programmes.

5.3.1.4 The minimum sample size for either an end or intermediate bearing capacity evaluation programme shall be 40 for a series of I-beams with the same materials except for the joist depth. The test specimens shall be evenly divided into groups which represent the extremes of bearing length and joist depth for evaluation. Extrapolation beyond the tested extremes of bearing length and joist depth shall not be permitted. Bearing lengths less than 38 mm are not recommended due to concerns regarding construction tolerances and building code requirements.

5.3.1.5 End and intermediate bearing capacity evaluations shall follow either the “default” or “regression-based” procedures. Any data set that does not support the minimum coefficient of determination, r^2, requirement for a “regression-based” evaluation shall be re-analysed as a “default” evaluation.

5.3.1.5.1 A “default” evaluation shall be conducted by testing independent groups at the extremes of bearing length and joist depth intended to be evaluated. Additional test groups may be added to the programme, provided the minimum sample size in each additional group is 10 and the minimum sample size for the entire I-beam series is 40. Each group shall be analysed independently to determine a characteristic value using the procedures of 5.3.4.

NOTE The following represent typical default test programmes that would meet the minimum sampling criteria to evaluate a joist series for end or intermediate bearing capacities:

a) four test groups with $n = 10$ at the extremes of bearing length and depth to evaluate a range for both variables;

b) two test groups with $n = 20$, when one bearing length is evaluated for a range of depths;

c) one test group with $n = 40$, when only a single bearing length and depth are evaluated.

5.3.1.5.2 In a “regression-based” evaluation, the characteristic I-beam bearing capacity shall be a linear function of bearing length. As a minimum, the test programme shall include the shallowest and deepest joist depths that can be evaluated. At least three evenly spaced increments of bearing length shall be evaluated for each joist depth tested. Provided the resulting regressions maintain a minimum coefficient of determination, r^2, of 0,9 for each joist depth, they may be reduced to a characteristic value using the procedures of 5.3.5. If the regressions do not comply with this requirement, a “default” evaluation shall be conducted in accordance with 5.3.4.

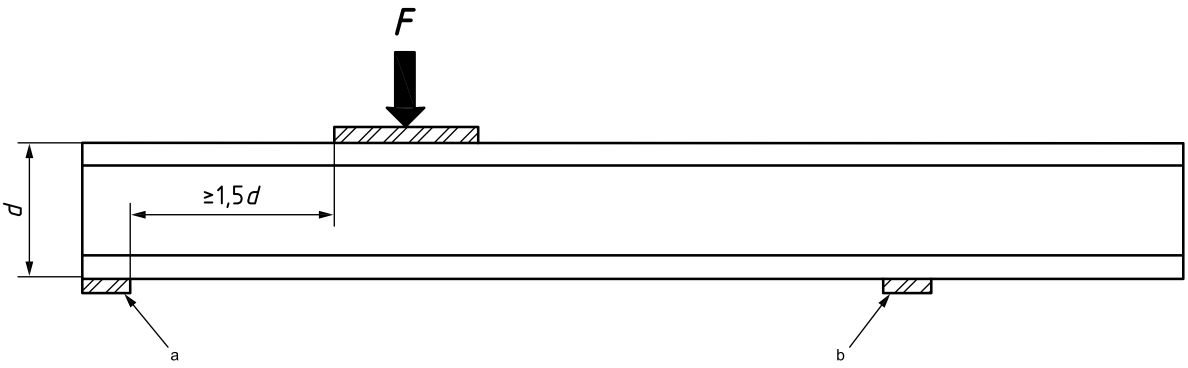
A typical regression-based test programme to establish end or intermediate bearing capacity shall consist of six groups with $n = 7$ for each group. A minimum of three bearing lengths shall be tested at the maximum and minimum joist depths that can be evaluated. The data for each depth shall be combined using a linear regression to define the bearing strength as a function of bearing length at the extreme depths.

5.3.2 Test methods

5.3.2.1 End bearing

For end bearing, specimens shall be tested according to either Figure 1 or 2. The test span shall be that which usually produces end bearing failures. In Figure 1, a single concentrated load shall be placed off-centre toward the test bearing. In Figure 2, the load shall be applied at the centre of the test span as either a single concentrated load, as shown, or as two-point loads placed symmetrically about the centre of the test span. For both Figures 1 and 2, the applied load shall have a clear distance of at least 1 1/2 times the joist depth, d, between the inside face of bearing and the edge of the load pad. The load shall be applied via a steel load pad at a uniform rate, such that anticipated failure does not occur in less than 1 min. Bearings shall consist of steel blocks representing the tested end bearing length. The load pad shall be of sufficient length to prevent local failure under the load point. Additional reinforcement may be installed, when required, to prevent failure at a load point or non-test bearing. Such reinforcement shall not be wider than the length of the load pad or bearing surface. Load cells shall record the test bearing, but half the total applied load shall be appropriate for the set-up shown in Figure 2. Perforated knockouts (38 mm maximum diameter) shall be randomly located within the joist specimen, as they would occur in application. Web-to-web joints may be randomly located when characteristic shear capacity is evaluated using an independent test programme. Otherwise, a web joint shall be positioned at the mid-point between the edge of the load and bearing plates.

NOTE Figure 1 allows for one overhang no longer than half of the test span. This set-up allows the joist to be turned end-for-end to perform a second test, with the failed end as the overhang for the second test. Figure 2 allows for only one test per specimen.



Key

d I-joist depth

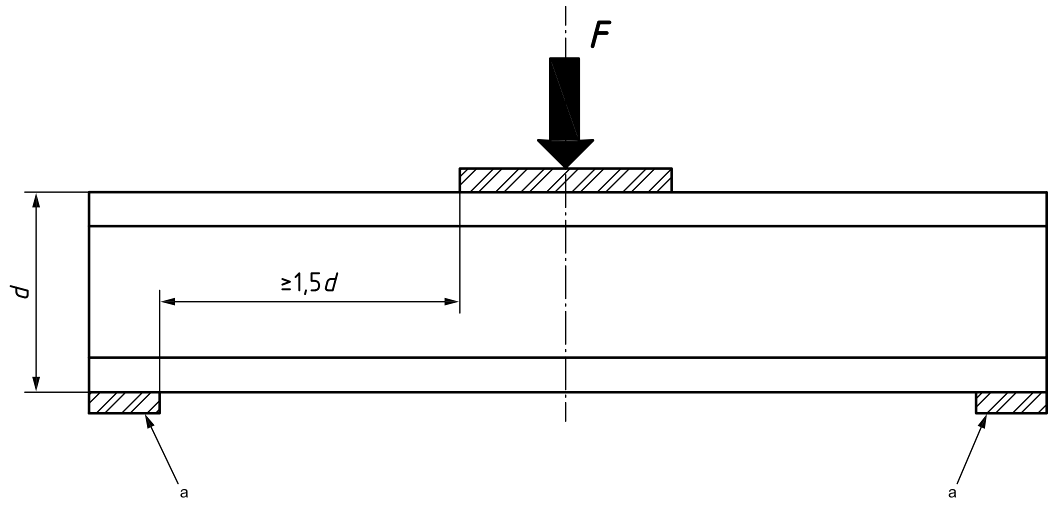
F applied load

a Test reaction.

b Non-test reaction.

NOTE Non-symmetric set-up allows for two end bearing tests per specimen.

Figure 1 — End bearing test set-up



Key

d I-joist depth

F applied load

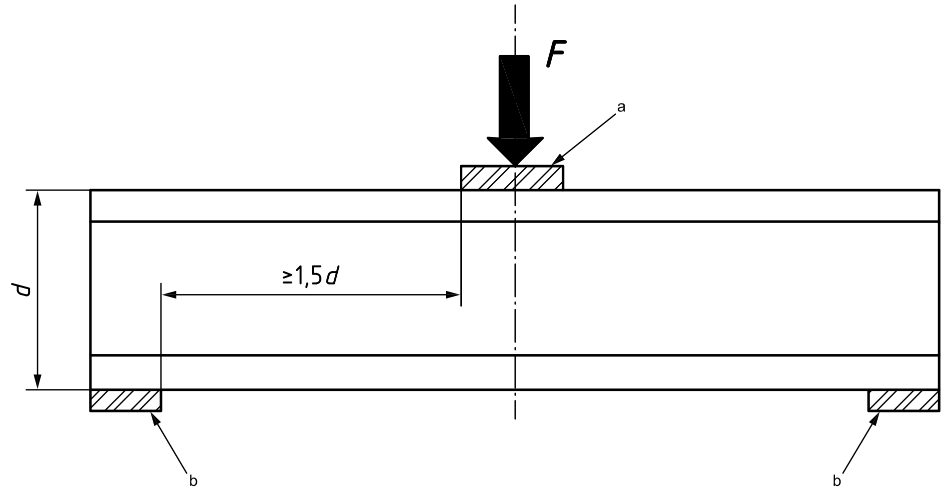
a Test reaction.

NOTE Symmetric set-up allows for one end bearing test per specimen.

Figure 2 — End bearing test set-up

5.3.2.2 Intermediate bearing

Specimens shall be tested according to either Figure 3 or 4. The test span(s) shall be that which usually produces intermediate bearing failures. In Figure 3, the load shall be applied at the centre of the test span through a steel load pad representing the tested intermediate bearing length. In Figure 4, the loads shall be applied symmetrically about the test bearing through steel load pads of sufficient length to prevent local failure under load points. For both Figures 3 and 4, the applied load(s) shall have a clear distance of at least 1,5 times the joist depth, d, between the inside face of bearing and the edge of the load pad. The load shall be applied at a uniform rate such that anticipated failure does not occur in less than 1 min. Additional reinforcement may be installed, when required, to prevent failure at a load point or non-test bearing. Such reinforcement shall not be wider than the length of the load pad or bearing surface. Load cells shall record the test reaction, but the sum of both reactions shall be appropriate for the set-up shown in Figure 3. Perforated knockouts (38 mm maximum diameter) shall be randomly located within the joist specimen, as they would occur in application. Web-to-web joints may be randomly located when the characteristic shear capacity is evaluated using an independent test programme. Otherwise, a web joint shall be positioned at the mid-point between the edge of the load and bearing plates.



Key

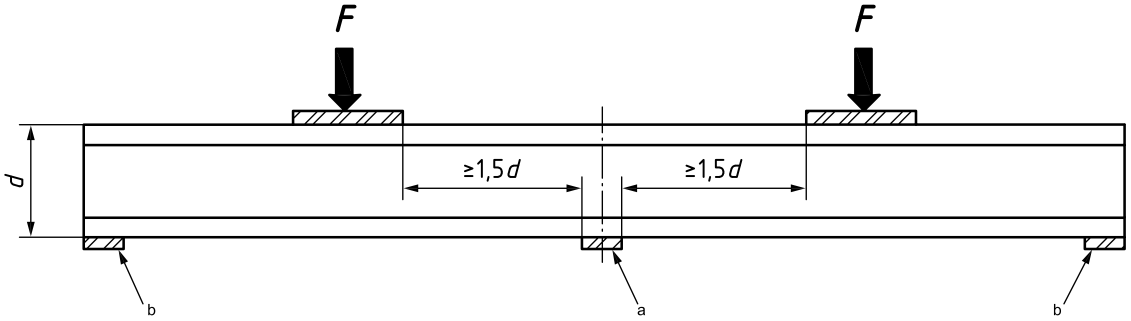
d I-joist depth

F applied load

[a] Test reaction.

[b] Non-test reaction.

Figure 3 — Three-point intermediate bearing test set-up



Key

d I-joist depth

F applied load

[a] Test reaction.

[b] Non-test reaction.

Figure 4 — Five-point intermediate bearing test set-up

5.3.2.3 Loads and modes of failure

Ultimate loads and modes of failure shall be recorded.

5.3.3 Data analysis

5.3.3.1 Each end and intermediate bearing evaluation data set shall be independently analysed.

5.3.3.2 Bending failures may be excluded from the data set. However, the minimum sample size provisions of 5.3.1.4 shall be maintained after any exclusion.

5.3.3.3 The mean, $\overline{P}_{\mathrm{i}}$, and standard deviation, S_{i}, shall be calculated for each individual test group. The coefficient of variation, C_V, for each group is defined in Equation (2).

5.3.3.4 The analysis of data from either a default or regression-based evaluation require the C_V from individual test groups to be combined into a single C_V as part of the characteristic value derivation process as outlined in 5.3.4 and 5.3.5, respectively. No combined C_V shall be less than the minimum permitted, $C_{V,\mathrm{min}}$, which shall be equal to 0,10 for an end bearing evaluation and 0,08 for an intermediate bearing evaluation.

NOTE Due to the limited evaluation samples and lack of ongoing quality assurance requirements, the specified minimum coefficients of variation, $C_{V,\mathrm{min}}$, are intended to provide a rational coefficient of variation for I-beam bearing capacities and were established based on industry data.

5.3.4 Specific analysis provisions for a default evaluation

5.3.4.1 The combined coefficient of variation for an end or intermediate bearing evaluation data set in a "default" evaluation, $C_{V,\mathrm{d}}$, shall be computed using Equation (6):

$$C_{V,\mathrm{d}} = \sqrt{\frac{\sum_{i=1}^{J_{\mathrm{d}}} \left[(n_{\mathrm{i}} - 1)\, {C_{V,\mathrm{i}}}^{2} \right]}{\sum_{i=1}^{J_{\mathrm{d}}} n_{\mathrm{i}} - J_{\mathrm{d}}}} \geqslant C_{V,\mathrm{min}} \tag{6}$$

where

n_{i} is the sample size within an individual test group;

$C_{V,\mathrm{i}}$ is the coefficient of variation, C_V, for an individual test group;

$C_{V,\mathrm{min}}$ is the minimum combined C_V permitted ($C_{V,\mathrm{min}}$ = 0,10 for end bearing, $C_{V,\mathrm{min}}$ = 0,08 for intermediate bearing);

J_{d} is the total number of groups tested in a default evaluation.

5.3.4.2 The characteristic bearing capacity for each tested group, P_{B}, in kilonewtons, shall be individually computed using Equation (7):

$$P_{\mathrm{B}} = P_{\mathrm{i}} - K \times C_{V,\mathrm{d}} \times P_{\mathrm{i}} \tag{7}$$

where

P_{i} is the mean bearing capacity within a tested group, in kilonewtons;

$C_{V,\mathrm{d}}$ is the combined C_V for the default test programme from 5.3.4.1;

K is the factor for 5th percentile with 75 % confidence for a normal distribution based on the sample size for the individual test group being analysed, n_i. Values for this factor are given in ASTM D2915 ($K = 2{,}104$ for $n_\text{i} = 10$) or may be specified by an applicable International Standard$^{1)}$.

5.3.4.3 Characteristic bearing capacity for bearing lengths and joist depths between the tested groups may be linearly interpolated. Extrapolation beyond the tested extremes of bearing length and joist depth shall not be permitted.

5.3.5 Specific analysis provisions for a regression-based evaluation

5.3.5.1 Shear failures may be excluded from the data set provided the characteristic I-beam shear capacity is evaluated using a separate test programme and the sample size provisions of 5.3.1.4 are maintained.

5.3.5.2 Data sets that show different characteristic bearing capacities for different joist depths shall have independent linear regressions developed for each of the tested depths. Data sets that do not show different characteristic bearing capacities for different joist depths shall have the data from all of the tested depths combined into a single regression that covers the full range of depths included in the evaluation.

5.3.5.3 Linear regressions shall be developed to define the relationship between bearing length and the characteristic bearing capacity using Equation (8):

$$P_\text{e} = A + B \times b_\text{i} \tag{8}$$

where

P_e is the predicted ultimate mean bearing capacity, in kilonewtons;

b_i is the bearing length, in millimetres;

A is the intercept of the best fit line fitting the test data, in kilonewtons;

B is the slope of the best fit line fitting the test data, in kilonewtons per millimetre.

5.3.5.4 A combined coefficient of variation, $C_{V,\text{r}}$, shall be computed for each regression equation developed using Equation (9):

$$C_{V,\text{r}} = \sqrt{\frac{\sum_{i=1}^{J_\text{r}} \left[(n_\text{i} - 1)\, C_{V,\text{i}}{}^2 \right]}{\sum_{i=1}^{j_r} n_\text{i} - J_\text{r}}} \geqslant C_{V,\text{min}} \tag{9}$$

where

n_i is the sample size within an individual test group;

$C_{V,\text{i}}$ is the C_V for an individual test group;

$C_{V,\text{min}}$ is the minimum combined C_V permitted ($C_{V,\text{min}} = 0{,}10$ for end bearing, $C_{V,\text{min}} = 0{,}08$ for intermediate bearing);

J_r is the number of tested bearing lengths combined into a single regression.

5.3.5.5 Each regression from 5.3.5.4 shall be reduced to a regression using Equation (10):

$$P_{\mathrm{B}} = P_{\mathrm{e}} - K \times C_{V,\mathrm{r}} \times P_{\mathrm{e}} \tag{10}$$

where

P_{B} is the characteristic bearing capacity, in kilonewtons;

P_{e} is the predicted mean ultimate bearing capacity (regression developed in 5.3.5.3), in kilonewtons;

$C_{V,\mathrm{r}}$ is the combined C_V for the regression from 5.3.5.4;

K is the factor for 5th percentile with 75 % confidence for a normal distribution based on the sample size for the regression being analysed ($\sum_{i=1}^{J_{\mathrm{r}}} n_{\mathrm{i}} - J_{\mathrm{r}}$). Values for this factor are given in ASTM D2915 ($K = 1{,}952$ for $\sum_{i=1}^{J_{\mathrm{r}}} n_{\mathrm{i}} - J_{\mathrm{r}} = 18$) or may be otherwise specified in an applicable International Standard1).

5.3.5.6 The regressions developed in 5.3.5.5 shall be used to develop the characteristic bearing capacity for bearing lengths between those tested. In test programmes where the bearing capacity does not vary with joist depth, the single regression developed shall be applied to the full range of depths tested. For those test programmes where bearing capacity is also found to be a function of joist depth, linear interpolation between regressions may be used to determine the characteristic bearing capacity for joist depths between those tested. Extrapolation beyond the extreme bearing lengths and joist depths tested shall not be permitted.

5.3.6 Compression perpendicular to grain

The compression perpendicular to grain capacity of the flange material can limit characteristic bearing capacity determined in accordance with 5.3.4.2 and 5.3.5.5 and shall be analysed separately. Lumber wane and edge easing of flange material shall be considered in the analysis.

The compression perpendicular to grain capacity of the supporting material can also limit characteristic bearing capacity of the I-beam. Consideration of the support material's compressive capacity as a factor limiting characteristic bearing capacity should be accounted for in end-use applications.

5.3.7 Web stiffeners

If a manufacturer wishes to establish characteristic bearing capacities with web stiffeners, testing shall follow the sampling, test methods, and data analysis detailed above. Data analysis shall be conducted independently of that for characteristic bearing capacities without web stiffeners. Web stiffener material and dimension, along with fastener size and number, shall be clearly identified. Web stiffener details permitted in application shall be equivalent to those which were evaluated.

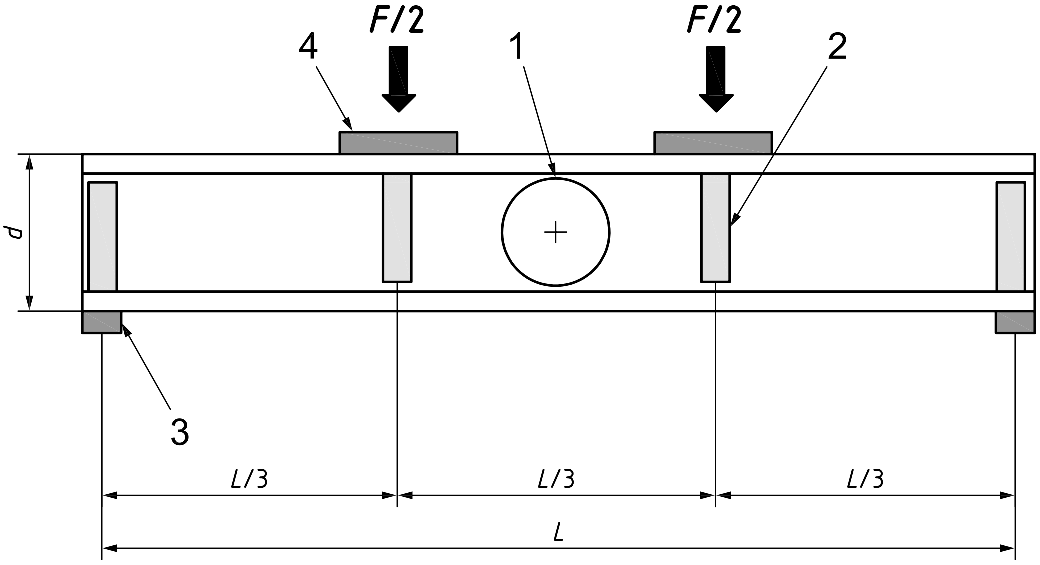
5.4 Characteristic bending capacity

Characteristic bending capacity shall be determined either empirically from the results of full-scale I-beam bending tests or analytically from the characteristic properties of flange materials.

NOTE Annex A contains an acceptable analytical method that can be used to determine the characteristic bending capacity, provided the analytical bending capacity is confirmed by full-scale bending tests in accordance with 5.4.4.

5.4.1 Test procedure

Bending tests shall be conducted on a span of 17 times to 21 times the joist depth, as shown in Figure 5. Two-point loads shall be placed symmetrically about the centre and the spacing between such load points shall be a minimum of one-third of the span. Joists shall be reinforced under the load points when necessary to prevent local failure. Load rate shall be adjusted to produce failure in not less than 1 min. Maximum bending capacity (moment) and the location of failure shall be recorded.



Key

1	maximum permissible web hole
2	web stiffeners
3	bearing plate
4	loading plate
d	I-joist depth
F	total applied load
L	test span

Figure 5 — Third-point bending test set-up

5.4.2 Specimens

Specimens shall be typical of intended production. I-beams made with different flange material, grade, dimension and species, combined with each web type, thickness and grade, shall be tested. When flanges contain end joints, such joints shall be evaluated in accordance with 5.8, and all bending test specimens shall include at least one joint in the tension flange located between the load points. When holes are allowed in the web in accordance with 5.6.2, the maximum permitted hole shall be located approximately at the centre of the span. Sufficient bearing length or reinforcement, or both, shall be provided at supports to prevent bearing failures.

5.4.3 Sample size and analysis for empirical test method

5.4.3.1 For empirical test method, a minimum of 28 specimens shall be required for each tested depth.

5.4.3.2 Testing shall be at joist depth intervals no greater than 76 mm, with a minimum of four depths tested, including the minimum and maximum joist depths.

5.4.3.3 The mean I-beam bending capacity shall show a linear increase with increasing I-beam depth squared. A linear regression analysis of the mean values shall have a coefficient of determination, r^2, of at least 0,9.

5.4.3.4 If the manufacturer produces fewer than four depths, 53 specimens of each depth shall be tested, but the requirement for a coefficient of determination shall not apply.

5.4.3.5 Characteristic I-beam bending capacity shall be based on the lower 5th percentile with 75 % confidence.

5.4.3.6 Joist depths not tested shall be assigned characteristic I-beam bending capacity based on a linear increase of the depth squared between values assigned at the nearest depths tested to either side of the I-beam depth.

5.4.4 Sample size and analysis for analytical method

5.4.4.1 A minimum of 10 I-beam specimens shall be tested at each of the extremes of flange size, flange characteristic tensile strength and joist depth.

NOTE This testing is considered necessary for any new product to confirm the overall performance of the assembled components. This testing is also necessary to satisfy the requirements of 5.6.

5.4.4.2 Test set-up and procedures shall conform to the requirements of 5.4.1, except that loading may simulate uniform load with load points spaced no greater than 610 mm on centre. In addition, the maximum permitted web hole specified in 5.4.2 is optional.

5.4.4.3 The reason for failures below the calculated characteristic I-beam bending capacity shall be carefully evaluated and further tests conducted.

NOTE Any specimen falling below the calculated characteristic I-beam bending capacity indicates the possibility of errors in manufacturing, material selection or calculation.

5.5 Characteristic bending stiffness and creep

5.5.1 Test procedures

The tests of 5.4.4 or the first 10 tests at the extremes of depth in accordance with 5.4.3 shall be used to confirm characteristic bending stiffness and evaluate creep characteristics. Centre span deflection measurements shall be recorded at a minimum of four increments to 0,7 times the characteristic I-beam bending capacity. Deflection measurements shall consider the potential crushing at the bearing.

5.5.2 Bending stiffness

Any equation that accurately predicts the effects of both bending and shear deformation may be used. The equation shall be adjusted when the mean of the ratios of test deflections at 0,47 times the characteristic I-beam bending capacity load (determined from a least square line fitted through the data points), to predicted deflection is more than $1,0 + S/(N^{1/2})$, where S is the standard deviation of the ratios of test to predicted deflections and N is the total number of deflection tests conducted.

NOTE The term of $S/(N^{1/2})$ is used to account for test uncertainty by allowing for the upper confidence bound on the mean. Usually, a required adjustment is applied only to the flange modulus of elasticity used in the equation. For stiffness-limited applications of I-beams, the largest percentage of deflection is typically attributed to bending, and because of the section geometry, the principal elastic modulus is that of the flange material. Therefore, the emphasis is placed on the flange modulus of elasticity.

5.5.3 Creep

Two of the I-beam specimens shall be loaded to 0,1 times the characteristic I-beam bending capacity and centre-span deflection readings shall be taken. For the purposes of this test, this loading is assumed to be typical basic dead load (BDL). The specimen shall then be loaded to 0,7 times the characteristic I-beam bending capacity for 1 h and deflection readings taken. The specimen shall be unloaded to BDL and deflection readings shall be taken after 15 min. The specimens shall recover an average of 90 % of the total deflection from BDL to the end of the 1 h load period. Failure to meet this requirement is an indication of excessive residual creep deflection that shall be considered in the product use recommendation.

5.5.4 Elastic properties

Mean values of the I-beam stiffness shall be used for the deflection calculations.

5.5.4.1 When flange modulus of elasticity cannot be obtained from tables of recognized values, it shall be obtained from tests of the flange material used to establish characteristic I-beam bending capacity in accordance with 5.4.4.

5.5.4.2 When characteristic I-beam bending strength is determined in accordance with 5.4.3, the flange modulus of elasticity shall be obtained from tables of recognized values or tests of the flange material.

5.5.4.3 Elastic properties of the web material, such as edgewise modulus of elasticity and shear rigidity, shall be obtained from an appropriate national standard.

5.6 Web openings and other considerations

5.6.1 General

Web openings, which affect I-beam performance, shall be evaluated by testing.

5.6.2 Web openings

5.6.2.1 Holes which remove a significant portion of the web reduce characteristic I-beam shear capacity at that section of I-beam. Tests shall be conducted to define such reductions for varying size and shape openings. A minimum of five specimens of at least three depths encompassing the product range shall be tested for each depth/opening combination. Test specimens and set-up may be the same as specified in 5.2 with an opening located between support and load points and centred on a web joint, when web joints exist in the product.

5.6.2.2 Maximum hole size, which can be located anywhere in the web, and spacing of multiple holes, when permitted, shall be tested using the test specimen and set-up similar to 5.2.

5.7 Flange tension tests

5.7.1 For flange materials that do not have characteristic values published by a national standard, tension tests parallel to grain shall be conducted on a gauge length (distance between grips), to which national standards or governing codes can be applicable.

5.7.2 When flanges utilize sawn lumber or structural composite lumber of a length shorter than the standard length recognized by national standards or governing codes, the characteristic end joint spacing for the sample shall be documented for quality control purposes.

NOTE For additional information on the characteristic end joint spacing, see Annex A.

5.7.3 Testing speed shall be such that the sample target failure load would be achieved in approximately 1 min.

Failure load should not be reached in less than 10 s nor more than 10 min.

5.7.4 The minimum sample size shall be 53. The characteristic tensile strength shall be determined in accordance with ASTM D2915 or other applicable International Standard[1]. The flange material variability (coefficient of variation) and tension gauge length shall be reported.

5.8 End joint tension tests

5.8.1 Adhesives used in end joints shall conform to the requirements of 4.3.

5.8.2 Tension tests parallel to grain on full-section joints shall be conducted on a standard gauge length (distance between grips), to which national standards or governing codes can be applicable.

5.8.3 Testing speed shall be such that the sample target failure load would be achieved in approximately 1 min.

Failure load should not be reached in less than 10 s nor more than 10 min.

5.8.4 The minimum sample size shall be 53. The characteristic tensile strength shall be determined from tests conducted on a gauge length (distance between grips) to which national standards or governing codes can be applicable. End joint coefficient of variation shall be reported.

Annex A
(informative)

Analytical method for I-beam bending capacities

A.1 Flange materials

Flange materials fall into one of the following three categories.

a) Flanges utilizing a standard length of sawn lumber of a standard grade permitted by the governing code and lumber grading rules. The tabulated tensile strength parallel to grain value, F_t, is assumed to be based on a gauge length published by a national standard for the country of end use. End joints, when used, shall be evaluated in accordance with 5.8.

b) Flanges utilizing a standard length of sawn lumber or structural composite lumber, but failing to meet the standard grade criteria of item a). Evaluation testing and analysis shall be in accordance with 5.7. End joints, when used, shall be evaluated in accordance with 5.8.

c) Flanges utilizing structural composite lumber or sawn lumber in lengths shorter than a standard length before end jointing. Evaluation testing and analysis shall be in accordance with 5.7. Specimens shall be used to establish a characteristic (that is, average) joint spacing as noted in Equation (A.1). Average joint spacing in individual flanges in the evaluation sample shall be not less than 75 % of the established characteristic joint spacing. The characteristic joint spacing, L_j, in millimetres, established during evaluation, shall be maintained in subsequent production:

$$L_j = \frac{L} {N} \tag{A.1}$$

where

L is the total length of flange in the gauge length for the evaluation sample, in millimetres;

N is the total number of joints in the gauge length for the evaluation sample.

NOTE It is possible that items b) and c) are not applicable for all countries.

A.2 Length adjustment

The length adjustment factor, K_L, is the lesser of 1,0 or the value computed using Equation (A.2):

$$K_L = K_s \left(\frac{L_1}{L}\right)^z \leqslant 1{,}0 \tag{A.2}$$

where

K_s is the stress distribution adjustment factor [adjusts characteristic flange axial strength, F_a, from full-length constant stress (such as a tension test) to the reference bending stress condition, $K_s = 1{,}15$];

L_1 is the gauge length in millimetres. For A.1 a) utilizing flange strength, L_1 = standard length published by the governing code and lumber grading rules. For A.1 b) utilizing flange strength, L_1 = distance between tension tester grips. For A.1 c) utilizing flange strength, L_1 = distance between tension tester grips. For A.1 a) and b) utilizing end joint strength, L_1 = minimum end joint spacing allowed in the I-beam;

L is the joist span = 18 times the joist depth, in millimetres;

z is the exponent for Equation (A.2) in accordance with Table A.1.

NOTE K_L is not intended for use as an adjustment factor for specific application lengths. It is a modifier for determining characteristic I-beam bending capacity by depth [see Equation (A.4)].

Table A.1 — Exponent, Z, for Equation (A.2)[a]

C_V [b] %	Z
$\leqslant$ 10	0,06
15	0,09
20	0,12
25	0,15
$\geqslant$ 30	0,19

[a] Interpolation between tabular values is permitted.

[b] Coefficient of variation of the full data set based on a normal distribution, taken as not less than the higher C_V attained from the tensile strength of flange material or end joints.

A.3 Characteristic compressive strength

The characteristic compressive strength, F_{ci}, of the flange shall be established by either using recognized characteristic compressive strength, testing the material in compression or testing the material in tension and assigning a value in compression in accordance with Equation (A.3):

$$F_{ci} = F_{ti} \frac{F_c}{F_t} \qquad \text{(A.3)}$$

where

F_t is the published characteristic tensile strength for same species and size as tested pieces;

F_c is the published characteristic value in compression for same grade, species and size as F_t;

F_{ti} is the characteristic tensile strength as determined in accordance with 5.7.

NOTE The published characteristic values are those established by the governing national standard or code.

A.4 Analytical I-beam bending capacities

In this method, the I-beam characteristic bending strength, M_e, shall be determined using Equation (A.4):

$$M_e = K_L F_a A_{net} y \qquad \text{(A.4)}$$

where

K_L is the length adjustment factor, computed in accordance with Equation (A.2). The factor adjusts flange material, F_a, as a function of joist span and stress. Joist depth, tension test gauge length, finger joint spacing and material or joint variability are utilized in determining K_L;

A_{net} is the net area of one flange (excluding areas of all web material and rout);

y is the distance between flange centroids (with the rout removed);

F_a is the characteristic flange axial strength, taken as the lower of characteristic flange tensile strength adjusted to the reference gauge length or characteristic end joint tensile stress computed in accordance with 5.7 and 5.8, or characteristic flange compressive stress computed in accordance with Equation (A.3).

NOTE The assessment of characteristic axial strength on the basis of average strength at a given cross-section matches experimental data based on joists in which the thickness of an individual flange is less than approximately one-sixth of the overall joist depth. For joists not meeting this criterion, additional consideration of the extreme fibre strength can be necessary.

Annex B
(informative)

Failure coding in tests of prefabricated wood-based I-beams

B.1 General

Particularly in shear testing, a wide variety of failure modes is observed; many of these do not correspond with the appearance and mode of shear failures in other wood members. In fact, it can be argued that many of the observed modes are not shear failures at all. Nonetheless, most of these observed modes do influence the shear capacity and, with the exception of stiffness-related web buckling, they are usually not separated in capacity evaluation. This annex is offered primarily to avoid confusion due to the variety of failure modes often simply categorized as “shear failures.” A partial list of “shear” failure modes is given along with those of bending.

B.2 Example coding system

B.2.1 This coding system is designed to assist in describing failures of I-beams tested for product evaluation, or quality-control purposes. Use of a coding system like the one shown in Figure B.1 can facilitate official documentation of test results. As failure trends develop, additional codings may be added to the list. Codes should be listed on the data sheet in the order that they were perceived to have contributed to failure, that is, major causes first. Use qualifiers in conjunction with codes (ZW with 152 mm of web-web joint involved). Evaluate glue line quality of joint failures by estimating percent wood failure at surfaces.

B.2.2 Failure codes associated with short-span shear tests

a) ZJ Failure line runs horizontally along bottom flange-web joint at end of the beam, then proceeds vertically along a web-web joint, then horizontally along the top flange-web joint toward the centre span. Failure lines primarily follow glue joints.

b) ZW Same as ZJ, except the web failure line does not involve a web-web joint and the line usually runs nearer to 45° than vertical. Combinations of ZJ and ZW occur, with various amounts of the web-web joint involved.

c) IJ Similar to Z-type failures, but with the horizontal flange-web joint failures extending both ways from the vertical web-web failure line.

d) FWJ Flange-web joint shear failure at the bottom or top joint.

e) WWJ Web-web joint vertical shear failure.

f) WHS Horizontal shear failure in web (mostly in plywood webs).

g) WRS Rolling shear in web at web-flange joint (for plywood webs).

h) WC Web crushing, usually at end reaction with unstiffened ends.

i) WB Web buckle at end-reaction; usually without stiffeners.

j) FS Flange joint split at end reaction. Qualify with notes of minor, major or measure and record length of split.

k) ER End rotation causes end bearing or FS failure. Additional lateral support probably required.

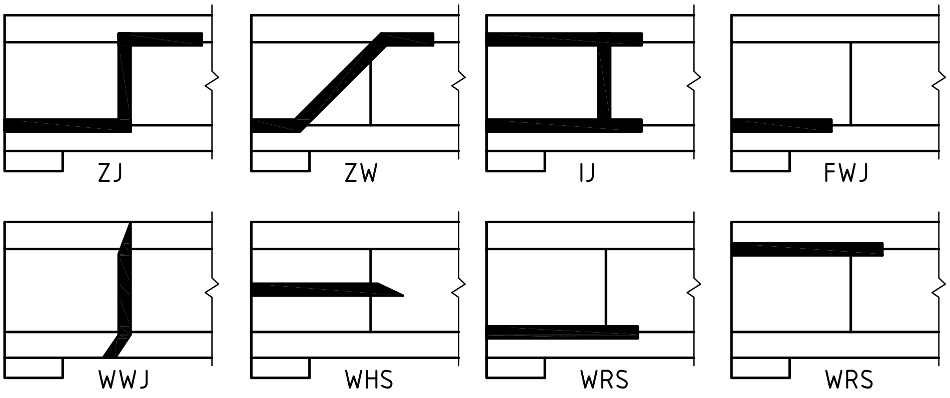
l)	FF	Occasionally, specimens fail in bending. Such failures should be excluded from shear data and one of the codes listed in B.3 can be added.

B.3 Failure codes associated with long-span bending moment tests

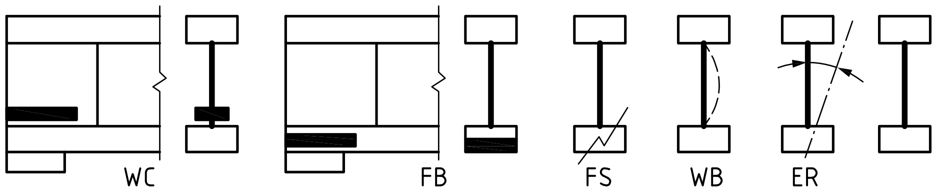
a)	FT	Flange failure in tension. Record distance from centre-line or end. Record type, size and location of defect(s) involved. Evaluate if flange was on grade relative to visual specs.
b)	FTJ	Flange failure in tension at finger joint. Read per cent of joint involved and per cent of wood failure on failed surfaces [for example (40 %/80 %)].
c)	FC	Flange failure in flexural compression. Commonly near load points.
d)	FCB	Flange failure in buckling. Usually due to inadequate lateral support.
e)	SOG	Slope-of-grain in flange. Either local, as around knots, or general. Measure general SOG and record, if not in accordance with specification.

B.4 Qualifier codes

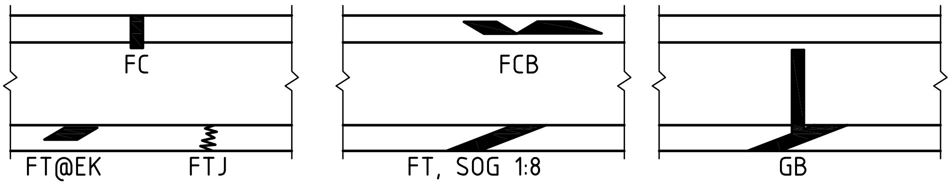
a)	BB	Bad bond or no glue bond. Wood failure along glue joints is 0 % to 30 %.
b)	PB	Poor bonding. Wood failure along glue joints is 30 % to 70 %.
c)	GB	Good bonding. Wood failure along glue joints is 70 % to 100 %.
d)	GM	Glue missing in joint.
e)	NGT	No glue transfer. Glue was spread, but did not transfer to mating surface. Usually due to inadequate assembly pressure, long open assembly time, or misfabrication. Measure length of joint involved.
f)	PTT	Prior to test. Relates to a process or a material defect observed before test.
g)	OGM	Off-grade material. It is best to identify and record PTT.
h)	% MC	Percent moisture content [for example (15 % MC)].
i)	NRP	Not representative of production. It is best to identify and record PTT.
j)	MAJ	Major or primary cause or effect.
k)	MIN	Minor or secondary cause or effect.



a) Typical shear failures



b) Typical end-reaction failures



c) Typical bending failures

Figure B.1 — Failure codes for full-scale tests

Bibliography

[1] ASTM D5055, *Standard Specification for Establishing and Monitoring Structural Capacities of Prefabricated Wood I-Joists*

[2] ETA-03/0056, *Wood-based I-shaped composite beams and columns for structural purposes*

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