BRITISH STANDARD

BS EN 12811-3:2002

Temporary works equipment —

Part 3: Load testing

The European Standard EN 12811-3:2002 has the status of a British Standard

ICS 91.220

British Standards

National foreword

This British Standard is the official English language version of EN 12811-3:2002.

The UK participation in its preparation was entrusted by Technical Committee B/514, Access and support equipment, to Subcommittee B/514/21, Access and working scaffolds, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the *BSI Catalogue* under the section entitled “International Standards Correspondence Index”, or by using the “Search” facility of the *BSI Electronic Catalogue* or of British Standards Online.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

This British Standard, having been prepared under the direction of the Building and Civil Engineering Sector Policy and Strategy Committee, was published under the authority of the Standards Policy and Strategy Committee on 5 December 2002

Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 35 and a back cover.

The BSI copyright date displayed in this document indicates when the document was last issued.

Amendments issued since publication

Amd. No.	Date	Comments

ISBN 0 580 40896 5

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 12811-3

November 2002

ICS 91.220

English version

Temporary works equipment - Part 3: Load testing

Equipements temporaires de chantiers - Partie 3: Essais de charges

Temporäre Konstruktionen für Bauwerke - Teil 3: Versuche zum Tragverhalten

This European Standard was approved by CEN on 14 September 2002.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Ref. No. EN 12811-3:2002 E

Contents

Foreword

This document (EN 12811-3:2002) has been prepared by Technical Committee CEN/TC 53 "Temporary works equipment", the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by May 2003, and conflicting national standards shall be withdrawn at the latest by May 2003.

This European Standard consists of the following parts under the general title: Temporary works equipment - :

Part 1: Performance requirements and general design

Part 2: Information on materials

Part 3: Load testing

Annexes A to C are informative.

This document includes a Bibliography.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

1 Scope

This European Standard specifies rules for load testing, documentation and evaluation of test results in the field of non mechanical temporary work items.

NOTE This standard is provided for use by all working groups of CEN/TC53 as a basis for standards which include testing. While this standard provides general rules, it is anticipated that where special requirements are necessary, they will be specified in the individual standard, for example the details of the test procedure.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text, and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 408, *Timber structures – Structural timber and glued laminated timber – Determination of some physical and mechanical properties.*

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

EN 10002-1, *Materials – Tensile testing – Method of tests (at ambient temperature).*

EN ISO 6506-1, *Metallic materials – Brinell hardness test – Part 1: Test method (ISO 6506-1:1999).*

EN ISO 6507-1, *Metallic materials – Vickers hardness test – Part 1: Test method (ISO 6507-1:1997).*

3 Terms and definitions

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

3.1
system

(e.g. scaffold system, trench lining system):

- set of interconnectable components, mostly purpose designed for the system and

- assessed set of system configurations and

- product manual

3.2
component

dismantable part of the system, e.g. a diagonal, a vertical frame

3.3
element

integral (e. g. welded) part of a component, e.g. a transom of a vertical frame

3.4
connection

device for the connection of components

3.5

configuration

particular arrangement of connected components by means of connections

3.6

system configuration

configuration of the system comprising a complete structure (e.g. a scaffold, a load bearing tower) or a representative section from it

3.7

standard set of system configurations

specified range of system configurations for the purpose of structural design and assessment

3.8

looseness

real (original) or fictitious (additional looseness resulting from the evaluation procedure) play of a connection between two components

3.9

cyclic loading test

tests in which the load is cycled several times through zero so that reversals of load and its effects occur in the test sample

3.10

hysteresis loops

resulting moment-rotation or the force-displacement curves from cycling loading tests

3.11

repeated loading tests

tests in which the load is applied and removed a number of times but is not reversed in sign

3.12

assessment

checking process establishing whether everything complies with the specified requirements

4 Typical test procedures

4.1 Basis

European standards for structural design shall be the basis of the structural design of temporary works, however when suitable calculation models do not exist in such standards, then testing shall be undertaken in place by calculation.

Tests may not be made simply to circumvent conservative assumptions made in the calculation models of the relevant standards.

4.2 Types of tests

A non-exhaustive list of typical tests is given in Table 1.

Table 1 — Typical kinds of tests

	Type of test	Item tested	Examples
1	load bearing capacity and stiffness	s,a,c	- connection device - modular node - horizontal plane
2	verification of the results of static calculation	s (in particular) a,c	- system configuration
3	checking the influence of cyclic loading on the characteristic structural behaviour	a,c,e	- connection device - modular node - horizontal plane
4	checking of the influence of repeated loading	a,c,e	- stair treads
5	checking of the usability in case of - repeated attaching - vibrations	a,c	- wedge connection - couplers
6	checking the influence of impact loading	a,c	- decking components and their supports - side protection components and their supports
s system configuration, a configuration, c component, e element			

5 General requirements for load testing

The load(s) and the relevant displacements or rotations shall be recorded at a sufficient number of steps during loading and unloading to define the deformation curves fully. A running plot of the principal deformation against load should be available during the test. For preference, the tests shall be carried out under displacement control. The rate of loading shall be slow enough to allow full development of plastic deformations.

The loading rate for static loading may be adjusted to the behaviour of the tested component or configuration, but shall not be more than 25 % of the estimated maximum load per minute. Similarly, the size of the load steps may be adjusted to the behaviour of the tested component or configuration, but each step shall not exceed 10 % of the maximum load. Load may be applied continuously, subject to the limit rate of loading outlined in Table 1, for cycling loading see 7.2.

6 Testing of materials

6.1 General

Material tests shall be carried out in order to determine the actual mechanical properties of the tested components or elements.

Tests on materials may be needed:

¾ to check, whether the used materials comply with the specifications given by the manufacturer;

¾ to determine parameters for the evaluation of test results.

Normally for metallic materials, the parameters to be determined are (see also 6.3.1):

¾ the yield stress or the proof stress;

¾ the tensile strength;

¾ the elongation.

Normally for timber based materials, the parameters to be determined are:

¾ bending strength;

¾ the density;

¾ moisture content.

6.2 Sampling

The samples shall be representative for the relevant properties and shall be cut, where possible, from tested items.

Where there is a significant variation in the material properties of similar items, samples should be taken from each tested item.

When testing configurations or components, samples shall be taken from all materials which can contribute to the failure or can cause the failure.

NOTE 1 A series of configuration tests could show the failure for one element; configuration tests with another batch could produce the failure for another element, owing to variations in material properties.

When sampling from the tested items, the samples shall be cut from parts where the preceding testing has no influence on the material test results. This means:

¾ the sample was not subjected to plastic deformations and that sustained elastic deformations were low during the test;

¾ the sample was not cut from a heat effected zone.

When the samples are taken from items which have not been tested they shall be of the same type and from the same batch as the tested elements.

In circumstances where the material properties differ significantly within the cross section, it is recommended that samples of the whole cross section are taken.

NOTE 2 For cold-formed sections or extruded materials, the properties can vary within the cross section.

When samples are not taken from each configuration or component tested, at least the following number of tests shall be carried out:

- metallic materials: 3 of each material;
- timber based materials: 5 of each grade.

6.3 Test methods

6.3.1 Metallic materials

For determining the mechanical properties, tensile tests shall be carried out in accordance with EN 10002-1.

In cases where the samples cannot be taken with standardised dimensions or when whole sections are tested, the length shall be three to five times the greatest cross-section dimension.

NOTE This requirement reduces the influence of the end sections.

If tensile tests are not possible (e. g. for smaller elements of cast iron), hardness tests shall be carried out in accordance with EN ISO 6506-1 for preference or EN ISO 6507-1.

In addition to testing samples of whole sections, tests may be carried out on stub columns in accordance with the recommendations of ENV 1993-1-3:1996, A.3.2.

6.3.2 Wood based materials

Tests for determining the mechanical properties shall be carried out in accordance with EN 408 or with EN 789.

7 Testing of configurations and components

7.1 General

Connections using wedges or bolts shall be assembled and dismantled three times before assembly for any test.

7.2 Tests to determine load bearing capacity, stiffness and looseness

7.2.1 General

Before loading to failure, cyclic loading shall be carried out in the following cases:

a) full cyclic loading (c_{full}) shall be carried out for configurations and components which are intended to subject to stress reversals to measure the characteristic structural behaviour (see 7.2.2.1).

b) limited cyclic loading (c_{lim}) shall be carried out for configurations and components which may exhibit looseness if not a) is required.

7.2.2 Cyclic loading

7.2.2.1 For full cyclic loading (c_{full}), tests shall be carried out over a load range of:

$$+1{,}0 \quad \frac{R_{\mathrm{k}}^{+}}{\mathrm{M} \quad \mathrm{F}}; \quad 1{,}0 \quad \frac{R_{\mathrm{k}}}{\mathrm{M} \quad \mathrm{F}}$$

where

R_{k}^{+} is the characteristic value of the resistance in positive load direction;

R_{k} is the characteristic value of the resistance in negative load direction;

$_{\mathrm{M}}$ is the partial safety factor for the resistance;

$_{\mathrm{F}}$ is the partial safety factor for the action.

At least, three cycles shall be made at this one load level. On completion of such loading, the load shall be increased in one load direction until failure occurs with some unloadings back to the zero level.

Since the characteristic resistances R_{k} are not known at the beginning of the tests estimated values for instance from pilot tests may be accepted.

At least five equal tests shall be carried out for each traced parameter.

A test may be made either with one load (or moment) or with combinations of loading to determine the interaction behaviour.

7.2.2.2 For limited cyclic loading (c_{lim}), three cycles shall be carried out over a load range of:

$$+0{,}1\ \frac{R_{\mathrm{k}}^{+}}{_{\mathrm{M}}\quad _{\mathrm{F}}}\ ;\quad 0{,}1\ \frac{R_{\mathrm{k}}}{_{\mathrm{M}}\quad _{\mathrm{F}}}$$

at first and then the load shall be increased to failure with some unloadings. At least five tests shall be carried out for each traced parameter.

7.3 Repeated loading

Repeated loading tests are required for configurations and components, where the load is essentially unidirectional and the load repetition is expected to be high.

The purpose of a repeated loading test is to check that the serviceability of the configuration or the component is not adversely affected when the sample is repeatedly loaded and unloaded a representative number of times.

For repeated loading tests, the number of load applications shall be determined on a rational basis by considering the anticipated life and the expected frequency of use.

As an example, 300 000 load applications would be appropriate for treads of stairways.

The load intensity shall be equal to the service load, or one that produces the same effects as the service load.

NOTE Normally, such tests are not required for temporary works equipment.

7.4 Vibration tests

Vibration tests are carried out on configurations, which may be susceptible to loosening when subject to frequent load reversals for example, those incorporating wedge connections.

Normally, such tests shall be carried out

¾ at a load intensity of:

$$0{,}1 \quad \frac{R_{\mathrm{k}}}{\mathrm{M} \quad \mathrm{F}}$$

where

R_{k} is the characteristic value of the resistance;

$_{\mathrm{M}}$ is the partial safety factor for the resistance;

$_{\mathrm{F}}$ is the partial safety factor for the action.

¾ at a frequency of 5 cycles per second;

¾ with a minimum duration of 3 000 cycles.

At least three identical tests shall be carried out.

After each vibration test, the position of the components and the parts of the connection device shall be checked. Movement of any component or part, e.g. the wedge, is not permissible.

7.5 Impact tests

The main purposes of impact tests are:

a) to determine the load bearing capacity of configurations and/or components, which can be expected to experience such loading in normal working life. Example: Side protection components and their supports, which are designed to catch falling bodies. The magnitude of the dynamic effect specified for the test shall be measured by the kinetic energy of a moving body at the point of impact and shall be equal to the actual impact energy that the component or configuration will experience in service;

b) to determine the magnification of static loads by dynamic effects. Example: Decking components and their supports, which can be loaded by moving persons;

c) to find out structural inadequacy of configuration or components. Example: Decking components and their supports.

Details are to be provided by the respective standard.

8 Testing of system configurations

Generally full scale tests for system configurations shall only be carried out for verification purposes to confirm that the assumptions used in the analysis model chosen by the designer are conservative.

The system configuration and the chosen loading shall be representative. The main components and connections shall be activated during the tests.

Only the applied forces and some significant displacements need to be recorded.

No statistical treatment of the results is required.

When a pure second order analysis is carried out the load displacement curves determined in the tests shall be compared with those determined by calculation. The calculated curves shall be on the conservative side up to failure.

When the influence of the deformations on the equilibrium is considered by a modified calculation following first order analysis, the test shall provide a basis for estimating the ideal buckling load via the failure load and the eigen-function. Where the primary loads are axial only, additional small perturbating horizontal loads may be induced which will stimulate the eigen-function corresponding to the lowest buckling load.

9 Documentation of test results

9.1 General

Details of the tested components, the test arrangement, the test programme and procedure as well as the results shall be fully documented. Text shall be adequately supported by:

¾ drawings;

¾ photographs;

¾ plots and

¾ tables.

9.2 Content of test report

The test report shall include the following:

¾ title page;

¾ list of contents;

¾ preliminary remarks;

¾ the tested items;

¾ test programme;

¾ test arrangement and procedure;

¾ results;

¾ summary;

¾ a reference to this standard;

¾ list of appendices;

¾ appendices.

9.3 Detailed instructions to the content

9.3.1 Title page

The title page shall include as a minimum:

¾ the name and identity of the test laboratory;

¾ the title and identification number of the report;

¾ the date of the report;

¾ the number of pages and the number of appendices;

¾ an indication of the tested items;

¾ the name and the address of the customer.

If they are not written elsewhere in the report, other information may be included such as:

¾ the address of the laboratory, telephone and fax numbers and the e-mail address;

¾ name of the department or division responsible.

9.3.2 Preliminary remarks

The following information shall be given:

¾ the date of the tests;

¾ the reason and the reference for the tests (e.g. approval procedure, the number of the EN);

¾ the date of the assent of the certification body to the test programme if available or necessary.

9.3.3 The tested items

The tested items shall be documented by drawings or by other means. The form, dimensions, materials and the nature of corrosion protection shall be clearly defined. The production process shall be stated (e.g. forged, punched, cast, cold-formed).

Information about the sampling shall be given, whether the components are selected by the test laboratory or sent by the manufacturer, whether the components are new or used.

The primary dimensions and the mechanical properties of relevant materials shall be measured and listed. Significant deviations shall be indicated. Chemical properties of materials shall only be controlled where relevant.

9.3.4 Test programme

The test programme shall be compiled. The following shall be stated for each test type:

¾ the objectives (e.g. stiffness, load bearing capacity);

¾ the number of tests;

¾ the type of loading and its parameters, with loading sketches where necessary;

¾ a brief description.

9.3.5 Test arrangement and procedure

The test arrangement shall be fully detailed, documented by drawings and by photos where appropriate. The boundary conditions for the tested components shall be clearly defined. The positions of loads and of gauges as well as the positions of supports shall be indicated by precise dimensions.

The type and the accuracy of the equipment for loading and measuring shall be stated. The type of loading, displacement- or force-controlled, shall be indicated. Characteristics such as loading rate, unloadings, and hysteresis loops shall be documented.

9.3.6 Results

For every test, the results, all load steps (e.g. force, moment) and the corresponding deformations (e.g. displacements, angles), shall be provided numerically either as hardcopy or electronically. The primary load-deformation-curves shall be presented graphically also. For every test type, photos of broken components or of components with plastic deformations shall be provided. The parts of the components which cause the failure and the reasons for failure shall be indicated. Explanatory comments shall be made about unusual test results.

10 Evaluation of load bearing capacity, stiffness from testing metallic configurations and components

10.1 General

Clause 10 shall be used for all types of metallic components including connections such as modular nodes or between decking components and transoms.

Results from such tests shall be evaluated to determine:

- the value of the characteristic resistance;
- the stiffness;
- the looseness and
- the partial safety factor $_{R2}$,

Table 2 shows the steps for the determination of the value of the characteristic resistance. Annex A illustrates the procedure for the step numbers 1.1 until 2.2 of Table 2 with an example.

10.2 Approximation functions

For preference, the force-displacement behaviour or the moment-rotation behaviour determined by tests while loading and while unloading may be represented each by a suitable approximation function using the method of least square fitting. An approximation function may be accepted if the correlation coefficient is R^2 0,95 . In cases where it is not possible to achieve this for the whole curve by a single function more than one approximation functions may be established.

A straight horizontal line may be assumed around the zero point modelling the looseness as determined in accordance with 10.10 to achieve a curve as it is shown in Figure 1.

NOTE 1 An asymetrical behaviour in the positive and the negative loading direction can make it necessary to use more than one approximation function.

NOTE 2 Good spread sheet computer programmes have the capability of determining an approximation function and the correlation coefficient.

NOTE 3 When using polynomials as approximation functions attention should be given to the possible waving in the gaps between the points of measured values. Likely uniformly distributed points of measured values should be strived for.

Table 2 — Steps for the determination of the nominal value $R_{k,nom}$ of the characteristic resistance

Step number	Step action (n is the number of test results)	Clause
1.1	Determination of - the approximation functions	10.2
1.2	- the n quotients q_e which represent the dissipation of energy	10.3
1.3	- the n ultimate values $r^{a}_{u,i}$	10.4
1.4	- the mean $\bar{q}_{e}$	10.5
1.5	- the partial safety factor $_{R 2}$ as a function of $\bar{q}_{e}$	
1.6	Adjustment of each ultimate value $r^{a}_{u,i}$ to $r^{b}_{u,i}$ depending on the deviation of the dimensions of the cross sections	10.6
2.1	Adjustment of each failure value $r^{b}_{u,i}$ to $r^{c}_{u,i}$ depending on the material properties in case of - material failure	10.7
2.2	- stability failure	
3.1	Statistical determination of the basic characteristic value of the resistance $R_{k,b}$	10.8
3.2	Determination of the nominal characteristic value of the resistance $R_{k,nom}$	10.9

As a rule, only the test values between 10 % and 90 % of the action need to be taken into account for unloading curves. For the part below 10 %, respectively above 90 %, a straight line may be used with the slope of the approximation function for 10 %, respectively 90 %. If the approximation function does not deviate significantly from these straight lines, the approximation function may be taken also.

NOTE 4 In many cases, a straight line is suitable as an approximation function for the unloading curve.

Annex A shows an example.

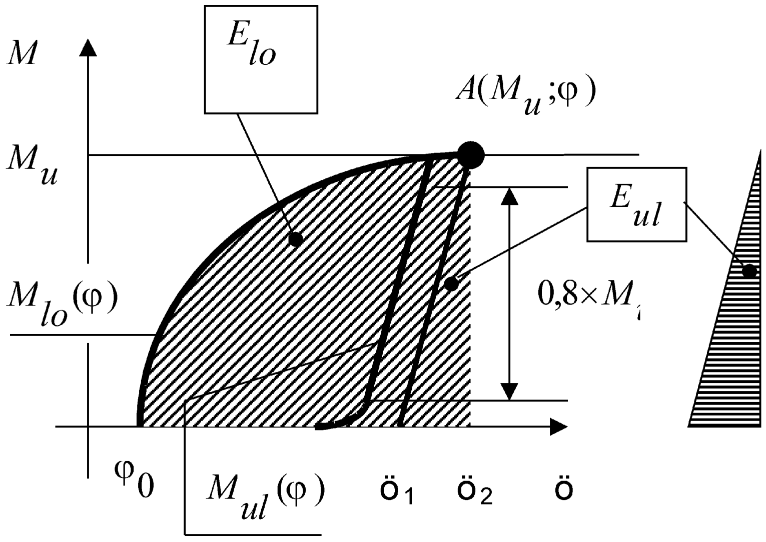


Figure 1 — Example for the dissipation of energy in case of a ***M*-φ** curve

10.3 Dissipation of energy

For further evaluation, the quotient q_e shall be calculated from equation (1):

$$q_{\mathrm{e}} = \frac{E_{\mathrm{lo}}}{E_{\mathrm{ul}}} \qquad (1)$$

where

E_{lo} is the energy which is put in during loading, for the example in Figure 1 in accordance with equation (2).

$$E_{\mathrm{lo}} = \int_{0}^{2} M_{\mathrm{lo}}(\ )d \qquad (2)$$

$$E_{\mathrm{ul}} = \int_{1}^{2} M_{\mathrm{ul}}(\ )d \qquad (3)$$

E_{ul} is the energy which can be regained during unloading, for the example in Figure 1 in accordance with equation (3).

If the unloading curve $M_{\mathrm{ul}}(\ )$ in Figure 1 was not determined for the point A the last unloading curve before failure shall be taken and moved parallel.

In the case of test results such as those given in Figure 2, E_{lo} shall be calculated as the hatched area. Note that for the hysteresis loops, the envelope curve shall be taken as the loading curve, not the curve of the first loading.

Graphical methods are an acceptable alternative.

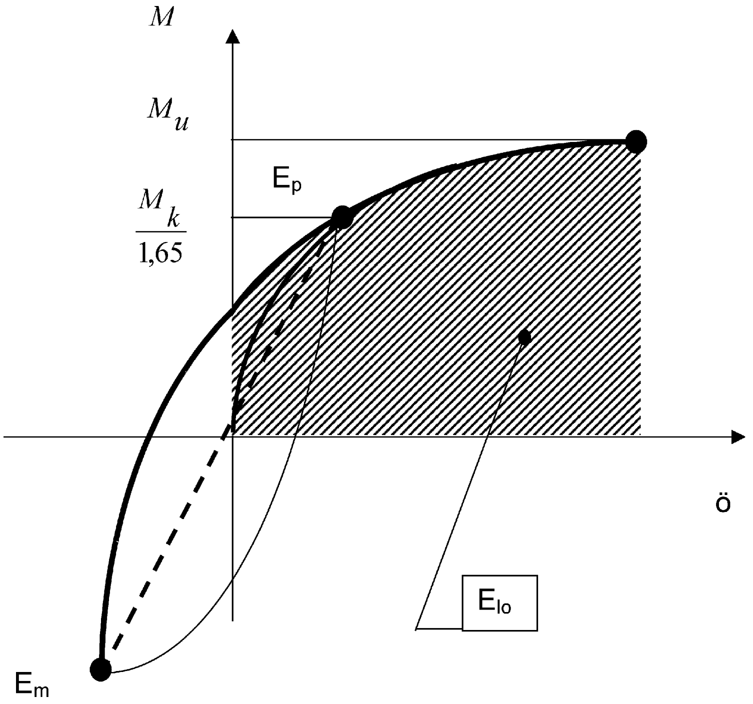


Figure 2 — Example for the determination of E_{lo} in case of a variant of the hysteresis loop

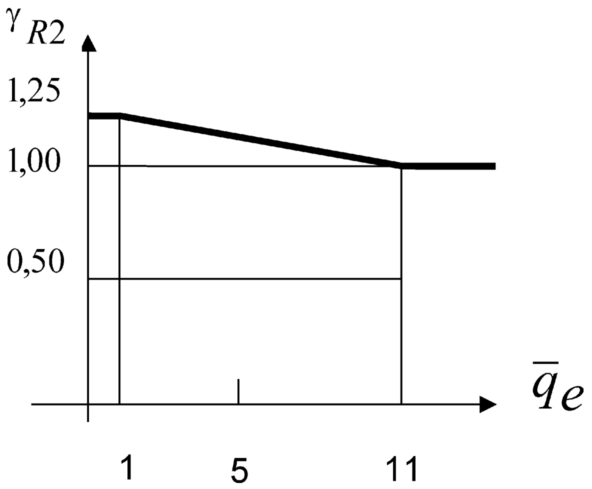


Figure 3 — Partial safety figure γ_{R2} as a function of $\bar{q}_e$

10.4 The ultimate value of the resistance $r_{u,i}^{a}$

The ultimate value $r_{u,i}^{a}$ of the resistance of the test i shall be taken as the first maximum of the force-displacement curve respectively the moment-rotation curve or the force respectively the moment for q_e = 11 whatever occurs first. Normally, for friction connections, sliding friction shall be taken as ultimate value if sliding occurs. This may be lower than the first maximum.

10.5 The partial safety factor ${}_{R2}$ depending on the ductility

The partial safety factor ${}_{R2}$ shall be determined as a function of the quotient $\overline{q}_e$ in accordance with equation (5) which is shown graphically in Figure 3. $\overline{q}_e$ is the arithmetic mean of the quotients q_e determined for a series of identical tests (equation (4)).

$$\overline{q}_{e} = \frac{1}{n} \sum_{i=1}^{i=n} q_{e}(i) \tag{4}$$

$$1{,}25 \quad {}_{R2} = \quad 0{,}025 \ \overline{q}_{e} + 1{,}275 \quad 1{,}00 \tag{5}$$

10.6 Adjustment of the ultimate values $r_{u,i}^{a}$ to $r_{u,i}^{b}$ depending on deviations of the dimensions of the cross section

The failure values $r_{u,i}^{a}$ shall be adjusted to $r_{u,i}^{b}$ to account for variations in the actual dimensions of cross-sections from the nominal ones.

While an increase of the failure values may not be made, reduction shall be carried out depending on the deviations of the controlling cross section parameters (e.g. area, bending resistance, moment of inertia) from the nominal values.

For longitudinally oriented compressed components (e.g. props, struts), the reduction shall be carried out in accordance with the following:

Deviation of the controlling parameter	action
$d \leq 0{,}01$	No reduction required
$0{,}01 < d \leq 0{,}10$	linear reduction
$0{,}10 < d$	tests with new components required

For other components, no reduction is required if the relevant dimensions of the cross sections lie within the specified tolerances. Where the dimensions are found to be outside the specific tolerances, tests with new components shall be carried out.

10.7 Adjustment of the ultimate values $r_{u,i}^{b}$ to $r_{u,i}^{c}$ depending on the material properties

The failure values $r_{u,i}^{b}$ shall be adjusted to $r_{u,i}^{c}$ depending on the proportion of actual to guaranteed material properties.

The adjustment of the failure values shall be carried out by equation (6) where ${}_{a}$ shall be taken in accordance with Table 3.

$$r_{u,i}^{c} = \frac{r_{u,i}^{b}}{{}_{a}} \tag{6}$$

$$\mathrm{a} = \mathrm{y} \qquad if \quad 0 \quad \overline{} \quad 0{,}2 \tag{7}$$

$${}_{a} = {}_{y} \quad ({}_{y} \quad 1) \quad \frac{\overline{} \quad 0{,}2}{d_{M}} \qquad if \quad 0{,}2 \prec \overline{} \quad (d_{M} + 0{,}2) \tag{8}$$

$$y = \frac{f_{y,a}}{f_{y,k}} \qquad (9)$$

where

d_M 1,3 for components made of steel;

d_M 1,5 for components made of aluminium;

d_M 1,7 for components made of cast material;

$\bar{}$ related slenderness calculated from equation (10):

$$\bar{} = \sqrt{\frac{N_{pl}}{N_{ci}}} \qquad (10)$$

N_{pl} the normal force in the full plastic condition:

calculated from: $N_{pl} = A_{nom} \quad f_{y,k}$

A_{nom} area of the cross section;

$f_{y,k}$ characteristic value of the yield stress;

$f_{y,a}$ actual value of the yield stress;

N_{ci} elastic buckling load;

N_{ci} shall be determined for the relevant buckling situation in accordance with elastic theory.

NOTE For example N_{ci} shall be calculated from the equation (11) for a column hinged at both ends with a constant cross section.

$$N_{ci} = \frac{{}^{2} \quad (E \quad I)_k}{l^2} \qquad (11)$$

where

$(E^*I)_k$ characteristic value of the stiffness of the cross section;

l length of the column.

Table 3 — Adjustment of the test results depending on the kind of failure

No	Kind of failure	Adjustment coefficient
1	buckling [a]	$_{\mathrm{a}}$ in accordance with equation (7) and (8)
2	fracture [b]	$_{\mathrm{a}} = {}_{\mathrm{y}}$
3	Crippling	
4	large deformations without failure [b]	
5	slipping of friction connection	no reduction

[a] Stability failure occurs where, for components under pressure or bending, the deformations grow rapidly for small increments of the load.

[b] In case of several involved elements with different materials, which could fail also, the most unfavourable reduction coefficient shall be taken into account.

If the tensile strength can be determined only through hardness testing, $f_{y,a}$ shall be determined with equation (12).

$$f_{\mathrm{y,a}} = f_{\mathrm{y,k}} \; \frac{f_{\mathrm{u,a}}}{f_{\mathrm{u,k}}} \tag{12}$$

where

$f_{\mathrm{u,k}}$ characteristic value of the tensile strength

$f_{\mathrm{u,a}}$ actual value of the tensile strength

The values $f_{\mathrm{y,k}}$ R_{eH} or $f_{\mathrm{y,k}}$ $R_{\mathrm{e0,2}}$ and $f_{\mathrm{u,k}}$ R_{m} and $_{\mathrm{u,k}}$ shall be taken from the relevant standards. When the relevant standards define a range for the elongation of the material the minimum value shall be taken into account for $_{\mathrm{u,k}}$.

If it is difficult to determine the material properties of smaller manufactured elements whether the original properties are modified during the production process or the elements are made of cast metal the adjustment may be limited to a value guaranteed by the manufacturer. In this case the manufacturer shall ensure that the resistance of the corresponding component does not fall short of the guaranteed value during production.

When a heat affected zone of an aluminium alloy can contribute to the failure the reduction coefficient shall be evaluated with the parameters associated with the material not effected by heat.

If the relationship between the yield stress of the critical elements of a configuration and the ultimate value of the parameter concerned has been established by tests, then adjustment to the ultimate values may be made by intrapolation.

10.8 Statistical determination of the basic characteristic value of the resistance $R_{k,b}$

The adjusted ultimate values $r_{\mathrm{u,i}}^{\mathrm{c}}$ shall be evaluated statistically to determine the basic characteristic value of the resistance $R_{k,b}$ whereby $R_{k,b}$ is defined as the 5%-quantile for a confidence level of 75 %. Table 4 gives values for k_{sk}. Normally, a logarithmic normal distribution may be assumed. The annex B illustrates the procedure with an example.

10.9 Determination of the nominal characteristic value of the resistance $R_{\mathrm{k,nom}}$

The nominal characteristic value of the resistance $R_{\mathrm{k,nom}}$ shall be calculated from the basic characteristic value $R_{\mathrm{k,b}}$ with the equation (13). The partial safety factor $_{\mathrm{R2}}$ shall be taken as a function of $\overline{q}_{\mathrm{e}}$ from 10.5.

$$R_{\mathrm{k,nom}} = \frac{R_{\mathrm{k,b}}}{\mathrm{R2}} \tag{13}$$

Table 4 — Quantile factors k_{sk} (quantile: 5 %; confidence level: 75 %)

n			3	4	5	6	7	8	9	10
k_{sk}			3,15	2,68	2,46	2,33	2,25	2,19	2,14	2,1
n	11	12	13	14	15	16	17	18	19	20
k_{sk}	2,07	2,05	2,03	2	1,99	1,98	1,96	1,95	1,94	1,93
n	21	22	23	24	25	**30**	**35**	**40**	**45**	**50**
k_{sk}	1,92	1,92	1,91	1,90	1,90	1,87	1,85	1,83	1,82	1,81

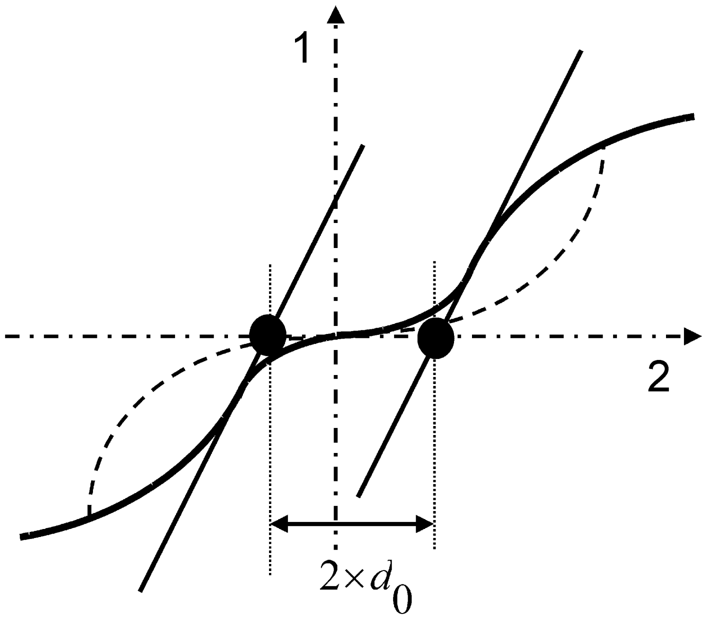
10.10 Evaluation of looseness, stiffness

The results of the third cycle of the cyclic loading, respectively the results following the third cycle, shall be taken for the evaluation of looseness and stiffness.

The original looseness, d_0, (see Figure 4) shall determined as follows.

When the type of curve corresponds to Figure 1 the original looseness shall be obtained by extrapolating the load-deformation curves back to the horizontal axis as shown in Figure 4. The distance between the two points of intersection shall be taken as twice the original looseness. The average value $\overline{d}_0$ obtained from a minimum of five tests shall be used.

When the type of curve corresponds to Figure 2 the original looseness is zero.



Keys

1 Deformation
2 Loading

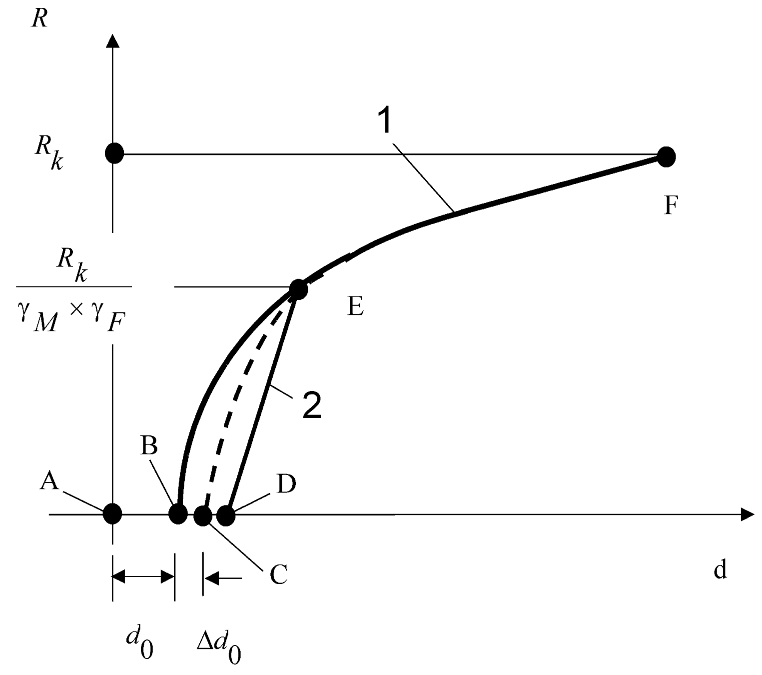
Figure 4 — Determination of the original looseness

When the type of curve corresponds to Figure 1 the approximation functions for the n test series shall be used to evaluate (see Figure 1 and Figure 5):

¾ the mean curve $R_{\mathrm{lo,mean}}$ (BEF) of all loading curves;

¾ the mean curve $R_{\mathrm{ul,mean}}$ (DE) of all unloading curves starting from the point *E* or close to it; normally, the approximate curves may be used;

¾ the curve (CE) in the middle between $R_{\mathrm{lo,mean}}$ and $R_{\mathrm{ul,mean}}$.



Keys

1 $R_{\mathrm{lo,mean}}$
2 $R_{\mathrm{ul,mean}}$
d_0 Original looseness
Δd_0 Additional looseness

Figure 5 — Evaluation of stiffness

When the type of curve corresponds to Figure 2 the straight line between the zero point and the mean value of E_p and the straight line between the zero point and E_m may be used.

The parts (*CE*) as well as (*EF*) of the curves may be linearized by chords.

The resulting stiffness relations shall be used as the load-deformation characteristic for static calculations.

Depending on the variation coefficient v_x of the stiffnesses c_i (see equation (14)), the characteristic value of the stiffness shall be determined in accordance with the following:

variation coefficient v_x	characteristic value of the stiffness c_k
$v_x \quad 0{,}10$	$\bar{c}$
$0{,}10 < v_x \quad 0{,}20$	0,9 $\bar{c}$
$0{,}20 < v_x \quad 0{,}30$	0,8 $\bar{c}$
$0{,}30 < v_x \quad 0{,}40$	0,7 $\bar{c}$
$0{,}40 < v_x$	configuration to be redesigned

In both cases (Figure 1 and Figure 2), the same stiffness relations may be used in positive and negative load direction so long as the linearized inclination in positive load direction $\bar{c}_{\mathrm{pp}}$ between C_{p} and E_{p} (see Figure 5), respectively the linearized inclination $\bar{c}_{\mathrm{pp}}$ between the zero point and E_{p} (see Figure 2), and the linearized inclination in negative load direction $\bar{c}_{\mathrm{mm}}$ between C_{m} and E_{m} (analogous to Figure 5), respectively the linearized inclination $\bar{c}_{\mathrm{mm}}$ between the zero point and E_{m} (analogous to Figure 2), differ not more than 10 % (see equation 15).

In this context, the index „p“ labels the positive, the index „m“ the negative load direction. The double index „pp“, respectively „mm“, labels mean values from the n carried out tests.

$$v_{\mathrm{x}} = \frac{s_{\mathrm{x}}}{\bar{x}}$$

where

s_{x} *is* the standard deviation for the n test results

$\bar{x}$ *is* the mean value of the n test results $c_{\mathrm{p,i}}$, $c_{\mathrm{m,i}}$

where the letter *p* labels the positive load direction and the letter *m* labels the negative load direction (14)

$$\left| \frac{|\bar{c}\mathrm{pp}| \quad |\bar{c}\mathrm{mm}|}{|\bar{c}\mathrm{pp}| + |\bar{c}\mathrm{mm}|} \right| \quad 100 \quad 10 \qquad (15)$$

When the equation (15) is fulfilled the straight line between E_{p} and E_{m} may be used for the type of curves given in Figure 2.

For the determination of the mean curves, the deformation along lines of constant resistance shall be used. When averageing stiffnesses, the reciprocal values shall be used.

Annex C illustrates the procedure with an example.

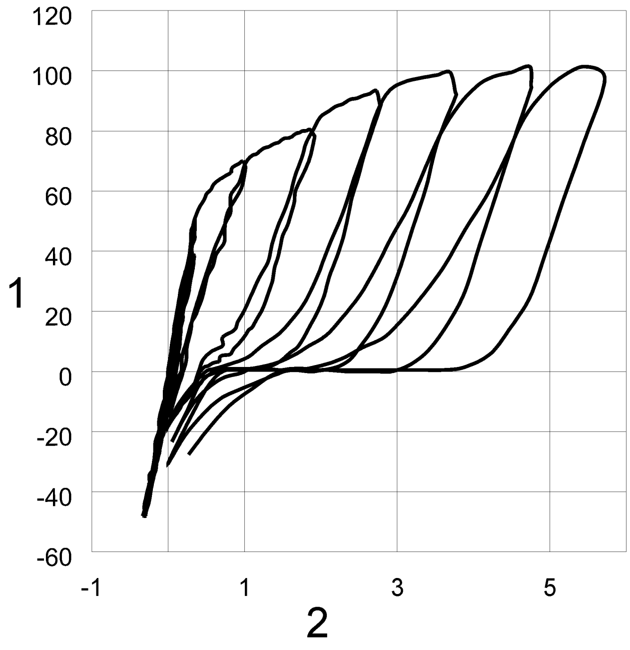
Annex A
(informative)

Example for the determination of an approximation function, of the quotient q_e for the dissipation of energy and of the partial safety factor γ_{R2}

A.1 Basis

As an example, the upright-transom connection of a modular node is taken, particularly the positive junction moment. Figure A.1 shows the moment rotation curve of one test.

In accordance with 7.1, cyclic loading tests were carried out. The values



Key

1 Moment [kN · cm]
2 Rotation [°]

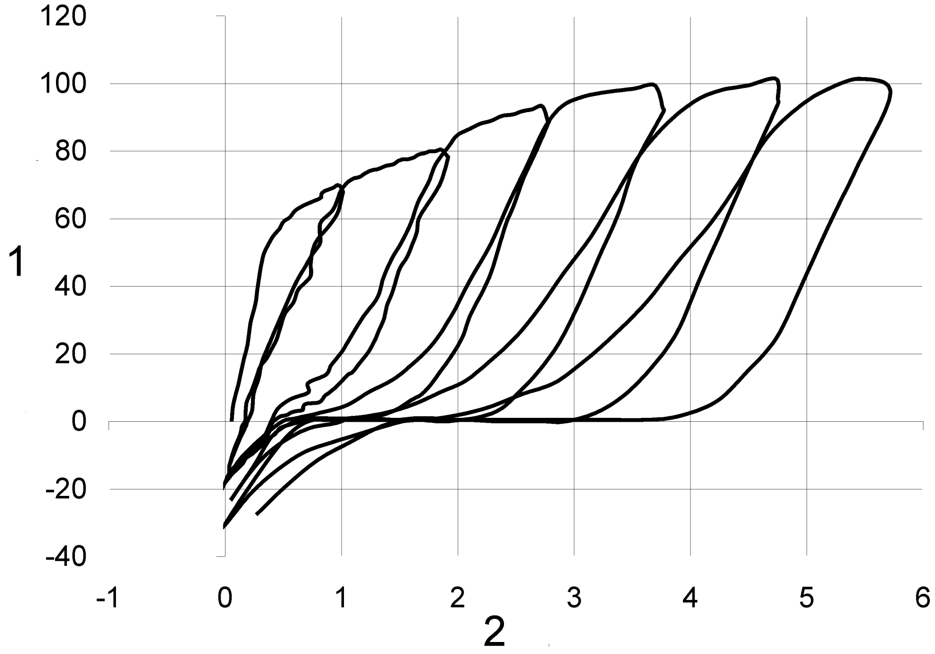
Figure A.1 — Configuration testing; upright-transom connection; moment rotation

$\frac{R_k^+}{1{,}1\ \ 1{,}5}$ and $\frac{R_k}{1{,}1\ \ 1{,}5}$ were estimated to $40\ \mathrm{kN{\times}cm}$. In accordance with 7.2.2.1, cycles are carried out for $40\ \mathrm{kN{\times}cm}$. After that the tests were continued in positive moment direction until failure. Altogether 10 tests were carried out.

NOTE In the example, cycles were carried out on the levels $20\ \mathrm{kN{\times}cm}$ and $48\ \mathrm{kN{\times}cm}$ also.

A.2 Approximation functions

Figure A.2 shows the part of the moment rotation curve of Figure A.1 after the third cyclic loading only.

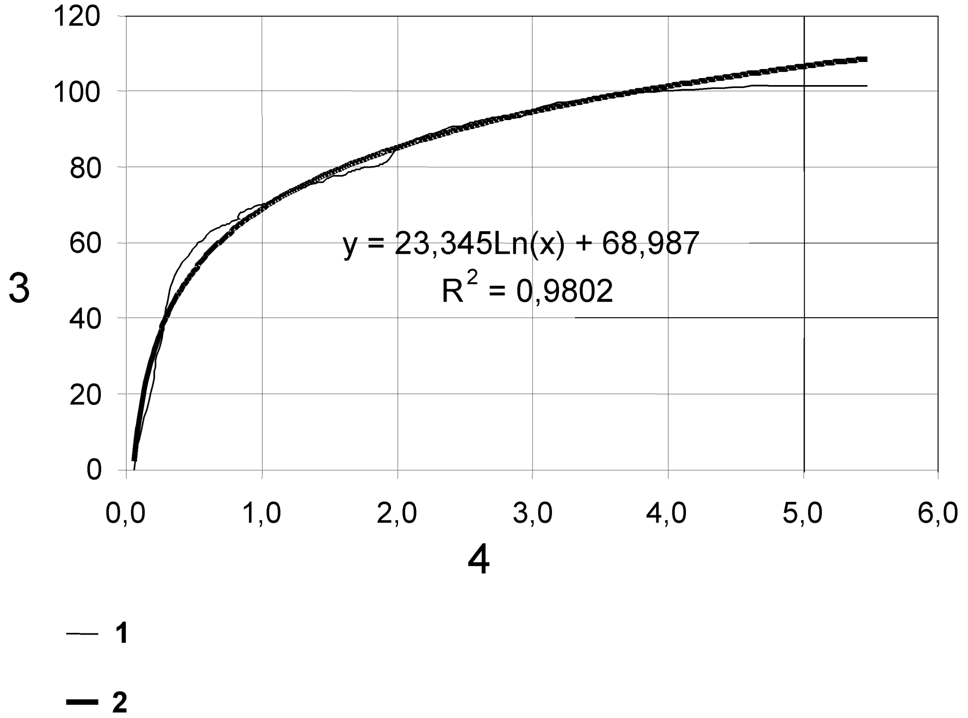


Key

1 Moment [kN · cm]
2 Rotation [°]

Figure A.2 — Moment rotation curve of Figure A.1 without the cyclic loading parts of the curves

Figure A.3 shows the same curve without the unloading curves and the resulting approximation function $M_{\text{lo}} = 23{,}345 \quad \ln \quad + 68{,}987$ (thick curve) which was determined with a spread sheet programme. In this case an ln-function appears to be suitable. The calculated correlation coefficient $R^2 = 0{,}9802 \quad 0{,}95$ fulfills the requirement given in 10.2.

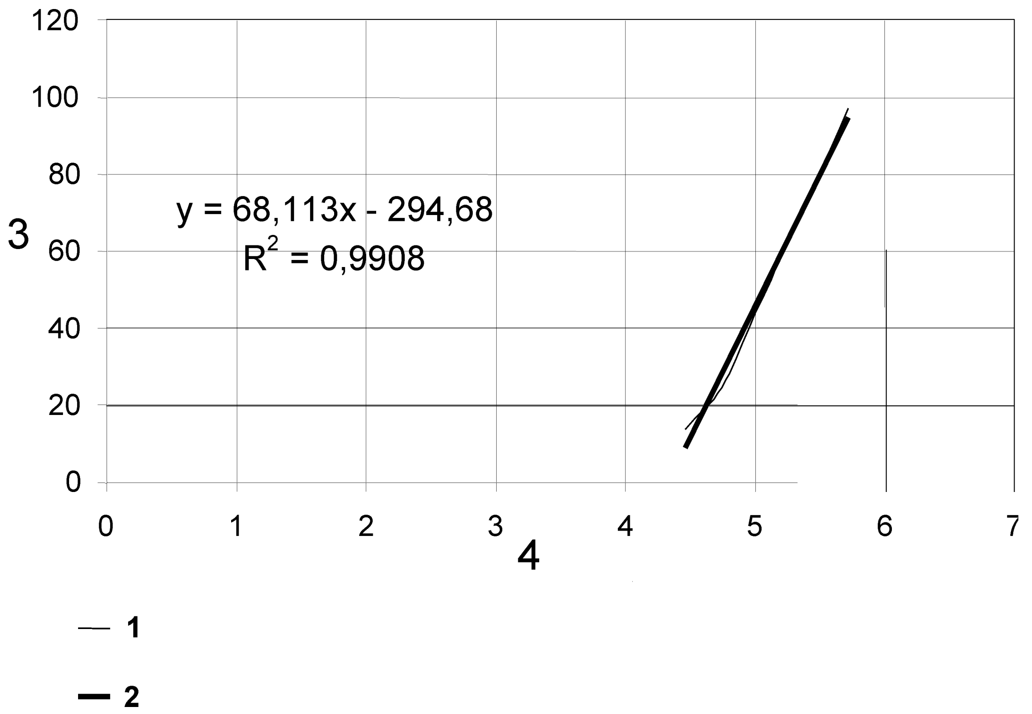


Keys

1	Test values
2	Logarithmic
3	Moment [kN · cm]
4	Rotation [°]

Figure A.3 — Moment rotation curve from Figure A.2 without the unloading parts of curves

Figure A.4 shows the approximation curve for the unloading part closest to the failure moment $M^{\bullet}_{\text{ul}} = 68{,}113 \qquad 294{,}68$. For the determination of this function, only the test values between 10 % and 90 % of the action were taken into account in accordance with 10.2. The resulting correlation coefficient $R^2 = 0{,}9908$ fulfils the requirement given in 10.2.



Keys

1 Test values
2 Linear
3 Moment [kN · cm]
4 Rotation [°]

Figure A.4 — Moment rotation curve from Figure A.1 for the part of the last unloading

The approximation curve for the unloading part is moved in parallel until it runs through the point P_1 (5,47;101,4) of the failure moment $M_{\mathrm{u}} = 101{,}4\ \mathrm{kN}\times\mathrm{cm}$. The result is $M_{\mathrm{ul}} = 68{,}113 \quad 271{,}2$.

A.3 Dissipation of energy

In accordance with 10.3, the integrals E_{lo} and E_{ul} is determined by equation (A.1):

$$E_{\mathrm{lo}} = \int_{0,052}^{5,47} (23{,}345\ln \quad +68{,}987)d \quad = 467{,}9 \tag{A.1}$$

NOTE 1 For the integral for E_{lo}, the approximation function is taken until the rotation of 5,47^0, although the moment for this rotation is higher, but not significantly higher than the failure moment 101,4 $\mathrm{kN}\times\mathrm{cm}$. The deviations of the approximation function do not influence the result of the integral significantly.

$$E_{\mathrm{ul}} = \int_{3,98}^{5,47} (68{,}113 \quad 271{,}2)d \quad = 75{,}5 \tag{A.2}$$

NOTE 2 For the integral for E_{ul} (see equation (A.2), the straight line is taken until the real failure point (M_{u} = 101,4; $_{\mathrm{u}}$ = 5,47^0).

With these values, the quotient (A.3) results:

$$q_{\mathrm{e}} = \frac{467{,}9}{75{,}5} = 6{,}20 \qquad \text{(A.3)}$$

A.4 Partial safety factor $_{\mathrm{R}\,2}$

Table A.1 shows the resulting quotients q_{e} from the ten tests.

Table A.1 — The quotients q_{e}

Test Number i	1	2	3	4	5	6	7	8	9	10
q_{e}(i)	5,95	6,02	6,03	6,18	6,20	6,29	6,35	6,39	6,43	6,50

In accordance with 10.5 the average value of the quotients q_{e}(i) is determined by equation (A.4):

$$\bar{q}_{\mathrm{e}} = \frac{1}{n}\sum_{i=1}^{n} q_{\mathrm{e}}(i) = 6{,}23 \qquad \text{(A.4)}$$

The partial safety factor $_{\mathrm{R}\,2}$ is as equation (A.5)

$$_{\mathrm{R}\,2} = \quad 0{,}025 \quad \bar{q}_{\mathrm{e}} + 1{,}275 = 1{,}12 \qquad \text{(A.5)}$$

Annex B
(informative)

Example for the statistical evaluation of test results and determination of the nominal characteristic value of the resistance

B.1 Basis

As an example, the upright-transom connection of a modular node is taken, particularly the positive junction moment. Figure A.1 shows the moment rotation curve of one test. The test results $r_{\mathrm{u,i}}^{\mathrm{a}}$ were determined as the first maximum of the respective moment rotation curve in accordance with 10.4. After evaluating the results in accordance with 10.6.and 10.7, the ten values $r_{\mathrm{u,i}}^{\mathrm{c}}$ of Table B.1 result.

Table B.1 — Partially evaluated test results $r_{\mathrm{u,i}}^{\mathrm{c}}$

1	Test number i	1	2	3	4	5	6	7	8	9	10
2	$r_{\mathrm{u,i}}^{\mathrm{c}}$ kN*cm	75,7	76,8	77,2	77,9	78,1	78,8	79,5	80,2	81,8	83,2
3	$y_{\mathrm{i}} = \ln(r_{\mathrm{u,i}}^{\mathrm{c}})$	4,327	4,341	4,346	4,355	4,358	4,367	4,376	4,385	4,404	4,421

B.2 Calculations

B.2.1 The values $r_{\mathrm{u,i}}^{\mathrm{c}}$ are transformed to logarithmic values y_{i} using the equation (B.1).

$$\bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_{\mathrm{i}} \tag{B.1}$$

For the example of Table B.1, the results are $\bar{y} = 4{,}368$ and $s_{\mathrm{y}} = 0{,}02907$.

B.2.2 The average value of the values y_{i} is calculated from the equation (B.2) and the standard deviation from the equation (B.3).

$$\bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_{\mathrm{i}} \tag{B.2}$$

$$s_{\mathrm{y}}^{2} = \frac{1}{n-1} \sum_{i=1}^{n} (y_{\mathrm{i}} - \bar{y})^{2} \tag{B.3}$$

For the example of Table B.1, the results are $\bar{y} = 4{,}368$ and $s_{\mathrm{y}} = 0{,}02907$.

B.2.3 The 5 % quantile is calculated from the equation (B.4) for the 75 % level of confidence.

$$y_5 = \bar{y} \quad k_{s,k} \quad s_y \tag{B.4}$$

For the example of Table B.1, the quantile becomes $y_5 = 4{,}307$, in which the factor $k_{s,k} = 2{,}10$ is taken from the Table 3 for n=10.

B.2.4 The logarithmic transformation is reversed to obtain the basic characteristic value using the equation (B.5).

$$R_{k,b} = e^{(y_5)} \tag{B.5}$$

This means, $R_{k,b} = 74{,}2 \quad \text{kN×cm}$.

B.2.5 The nominal characteristic value of the moment is calculated from the equation (13). With the partial safety factor $_{R2} = 1{,}12$ from the annex A, the nominal characteristic value of the moment becomes $R_{k,nom} = 66{,}25 \quad \text{kN×cm}$.

Annex C
(informative)

Example for the evaluation of stiffness

C.1 Basis

As an example, the upright-transom connection of a modular node is taken, in particular the junction moment. Figure A.1 shows the moment rotation curve of one test. The type of the curve corresponds to Figure 2. Its values c_p and c_m (see 10.10) for the three cycles on the load level $1{,}0\ \frac{R_k}{1{,}1\ 1{,}5}$ and the mean values $c_{p,7}$ and $c_{m,7}$ are listed in Table C.1.

Table C.1 — Stiffnessess c_p and c_m for test from Figure A.1

Cycle number	kN ×cm/[°]	
	$c_{p,7}$	$c_{m,7}$
1	136,2	132,7
2	152,3	132,7
3	152,3	134,3
	$\bar{c}_{p,7}$ =147,0	$\bar{c}_{m,7}$ = 133,2

NOTE The small translation of the zero point in the moment rotation curve of Figure A.1 has been adjusted.

Similarly, the stiffness for the other tests were determined. The results of ten tests are listed in Table C.2.

Table C.2 — Stiffnesses c_p and c_m for ten tests

1	Test number		1	2	3	4	5	6	7	8	9	10
2	$\bar{c}_{p,i}$	kN ×cm/[°]	139,8	142,5	144,1	145,2	145,5	146,7	147,0	148,3	149,0	150,1
3	$\bar{c}_{m,i}$		127,6	128,8	130,1	130,3	131,5	132,1	133,2	133,9	135,0	137,4

C.2 Comparison of the averaged stiffnesses in positive $\bar{c}_{pp}$ and negative $\bar{c}_{mm}$ load

In accordance with 10.10, the mean values of the stiffnesses are calculated using the reciprocal values. For the stiffnesses of Table C.2, the mean values of equations (C.1) and equation (C.2) result with the number of tests n = 10:

$$\bar{c}_{pp} = \frac{n}{\sum_{i=1}^{i=n} \frac{1}{\bar{c}_{p,i}}} = 145{,}8\ \text{kN} \times \text{cm}/° \qquad \text{(C.1)}$$

$$\bar{c}_{\mathrm{mm}} = \frac{n}{\sum\limits_{i=1}^{i=n} \frac{1}{\bar{c}_{\mathrm{m,i}}}} = 131{,}9\ \mathrm{kN}\times\ \mathrm{cm}/° \qquad \text{(C.2)}$$

The application of equation (15) gives equation (C.3):

$$\frac{145{,}8 \quad 131{,}9}{145{,}8 + 131{,}9} \ 100 = 5{,}0\% < 10\% \qquad \text{(C.3)}$$

Since the linearized averaged inclinations in positive and in negative load directions differ by not more than 10 %, the straight line between E_p and E_m can be used for the considered moment of the connection.

C.3 Resulting stiffness

For the static calculation, the stiffness relation of the upright-transom connection, in particular of the junction moment can be taken from the moment-rotation curve represented by the equations (C.1), (C.5) and (C.6).

For moments above $\frac{R_\mathrm{k}}{1{,}1 \quad 1{,}5} = \quad 40\ \mathrm{kN}\times\mathrm{cm}$, the moment-rotation curve is linearized in accordance with 10.10.

The averaged rotations for $R_\mathrm{k} = 66{,}0\ \mathrm{kN}\times\mathrm{cm}$ and for $R_\mathrm{k} = \quad 66{,}0\ \mathrm{kN}\times\mathrm{cm}$ differ not more than 10 % also. Therefore a mean value $\quad 0{,}88°$ can be assumed.

NOTE Test results for the negative junction moment are not documented here.

The function given by equation (C.4) applies until the moments $\frac{R_\mathrm{k}}{1{,}1 \quad 1{,}5} = \quad 40\ \mathrm{kN}\times\mathrm{cm}$

$$M(\quad) = 138{,}9 \qquad \text{(C.4)}$$

The inclination 138,9 is the mean value of $\bar{c}_{\mathrm{pp}}$ and $\bar{c}_{\mathrm{mm}}$.

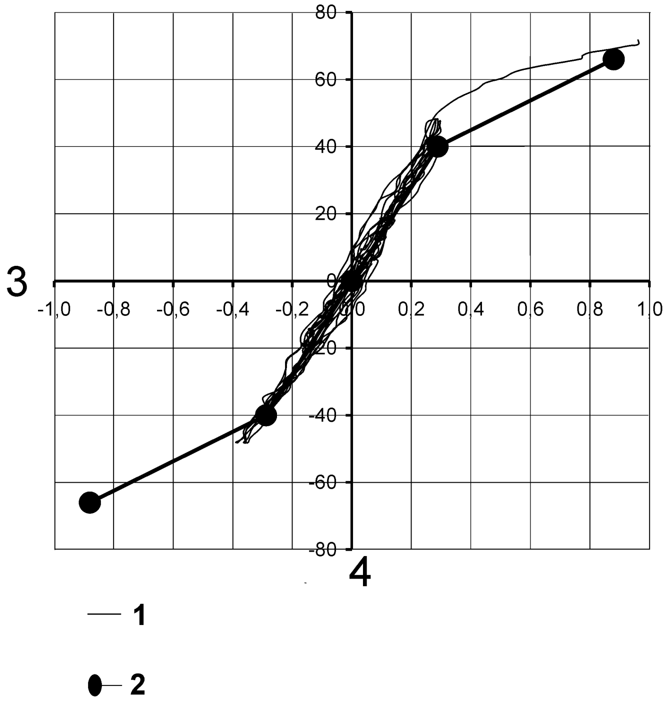
For higher moments than $\frac{R_\mathrm{k}}{1{,}1 \quad 1{,}5}$ until $R_k = 66{,}0\ \mathrm{kN}\times\mathrm{cm}$, the function of the equation (C.5) governs.

For smaller moments than $\frac{R_\mathrm{k}}{1{,}1 \quad 1{,}5}$ until $R_\mathrm{k} = \quad 66{,}0\ \mathrm{kN}\times\mathrm{cm}$, the function of the equation (C.5) governs.

$$M(\quad) = 43{,}915 \qquad + 27{,}351 \qquad \text{(C.5)}$$

$$M(\quad) = 43{,}915 \qquad 27{,}351 \qquad \text{(C.6)}$$

Figure C.1 shows a plot of the equations (C.4), (C.5) and (C.6) additional to a part of the test curve of Figure A.1.



Keys

1 Test values
2 Approximation function
3 Moment [kN · cm]
4 Rotation [°]

Figure C.1 — Evaluated moment-rotation curve plotted in one test curve

Bibliography

ENV 1993-1-3:1996, *Eurocode 3: Design of steel structures – Part 1-3: General rules – Supplementary rules for cold formed thin gauge members and sheeting.*

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover.
Tel: +44 (0)20 8996 9000. Fax: +44 (0)20 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: +44 (0)20 8996 9001.
Fax: +44 (0)20 8996 7001. Email: orders@bsi-global.com. Standards are also available from the BSI website at http://www.bsi-global.com.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre.
Tel: +44 (0)20 8996 7111. Fax: +44 (0)20 8996 7048. Email: info@bsi-global.com.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration.
Tel: +44 (0)20 8996 7002. Fax: +44 (0)20 8996 7001.
Email: membership@bsi-global.com.

Information regarding online access to British Standards via British Standards Online can be found at http://www.bsi-global.com/bsonline.

Further information about BSI is available on the BSI website at http://www.bsi-global.com.

Copyright

BSI
389 Chiswick High Road
London
W4 4AL