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ICS

English version

Temporary works equipment - ~~Scaffolds~~ - Part 3: Load testing

Equipments temporaires de chantiers – ~~Echafaudages –~~ Partie 3: Essais de charges

Temporäre Konstruktionen für Bauwerke – ~~Arbeitsgerüste –~~ Teil 3: Versuche zum Tragverhalten

This draft European Standard is submitted to CEN members for CEN enquiry. It has been drawn up by CEN/TC 53.

If this draft becomes a European Standard, 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.

This draft European Standard was established by CEN 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 Central Secretariat has the same status as the official versions.

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CEN

European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Central Secretariat: rue de Stassart 36, B-1050-Brussels

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Contents

Foreword

This European Standard has been prepared by the Technical Committee CEN/TC 53 "Temporary works equipment, the secretariat of which is held by DIN. "

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

Part 1: Performance requirements and general design

Part 2: Information on materials

Part 3: Load testing

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

1 Scope

~~This standard specifies general rules for~~

~~- testing,~~

~~- the documentation of test results and~~

~~- the evaluation of test results~~

~~in the field of (non mechanical) temporary works items.~~

This 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.

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, *Tensile testing of metallic materials; method of test at ambient temperature (including Corrigendum AC1:1990)*

ENV 1993 part 1.3: 1996-04, *Eurocode 3: Design of steel structures - Part 1-3: General rules - Supplementary rules for cold formed thin gauge members and sheeting*

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

ISO 6507-1, *Metallic materials - Vickers hardness test - Part 1: Test method*

ISO 6507-2, *Metallic materials - Vickers hardness test – Part 2: Verification of testing machines*

ISO 6507-3, *Metallic materials - Vickers hardness test – Part 3 : Calibration of reference blocks*

3 Definitions

For the purposes of this standard, the following definitions apply:

3.1 S~~s~~ystem
(e. g. scaffold system, trench lining system):
- The set of interconnectable ~~complete set of matching~~ components, mostly purpose designed for the system and
- The assessed set of system configurations and
- ~~instruction~~ The product manual

~~**3.2 assembly**~~

~~smaller set of two or a few matching components, e. g. an upright and a diagonal and their detachable connection~~

~~3.3~~3.2 C~~c~~omponent
~~detachable~~ A dismantleble part of the system, e. g. a diagonal, a vertical frame

~~3.4~~3.3 E~~e~~lement
An integral (e. g. welded) part of a component, e. g. a transom of a vertical frame

3.4 Connection
A devicet for the connection of components

3.5 C~~c~~onfiguration
A particular arrangement of ~~matching assemblies and~~connected components by means of connections

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

3.7 S~~s~~tandard set of system configurations
~~variants~~ The specified range of system configurations ~~which represent the most unfavourable configurations as the basis~~ for the purpose of structural design and assessment

3.8 ~~looseness~~Looseness
The real or fictitious (resulting from the evaluation procedure) play of a connection between two components

3.9 ~~cyclic~~ Cyclic loading tests
~~tests~~ 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 H~~h~~ysteresis loops
~~resulting~~ Resulting moment-rotation or the force-displacement curves from cycling loading tests

3.11 R~~r~~epeated loading tests
~~tests~~ Tests in which the load is applied and removed a number of times but is not reversed in sign

3.12 Assessment
The checking process establishing whether everything complies with the specified requirements

4 Typical test procedures

4.1 Basis

~~When the calculation models available are not sufficient, experimental assessment shall be undertaken in place of design by calculation or to supplement design by calculation.~~
~~Experimental verification may also be undertaken where the rules for design by calculation given in the relevant standards would lead to results too far on the safe side. However, the conservative assumptions in the specified calculation models (which are intended to account for unfavourable calculation influences not explicitly considered in the specified calculation models) shall not be by-passed.~~

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 calculati~~ng~~on models of the relevant standards.

4.2 ~~Provided kinds~~ Types of tests

~~Table 1 lists up typical kinds of tests. It is not exhaustive.~~

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

Table 1 - Possible kinds of tests

	~~Kind~~ Type of test	~~Tested i~~Item tested s system con-figuration a ~~assembly~~ configuration c component e element	Examples
1	~~determination of stiffness and/or~~ 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 ~~- pressed-in tube connection~~
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

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 ~~assembly~~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 ~~assembly~~configuration, but each step shall not exceed 10% of the maximum load. Load may be applied continuously, subject~~ed~~ to the limit rate of loading ~~conditions~~ outlined above, 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. ~~The samples shall be representative for the relevant properties.~~
~~There are two major purposes for material tests:~~
Tests on materials may be needed:

- to check, whether the used materials comply with the specifications given by the manufacturer;
- to determine parameters for the evaluation of test results.

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

- the yield stress or the proof stress;
- the tensile strength;
- the elongation.

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

- bending strength;
- the density;
- moisture content.

6.2 Sampling

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

~~As far as possible, test samples shall be cut 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 ~~assemblies~~ configurations or components, samples shall be taken from all materials which can contribute to the failure or can cause the failure ~~themselves~~.

> NOTE 1 A series of ~~assembly~~ configuration tests could show the failure for one element; ~~assembly~~ 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:

- the sample was not subjected to plastic deformations and that sustained elastic deformations were low during the test;
- 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 may vary within the cross section.

~~If samples are not taken from each assembly or component test, at least three samples shall be taken for each material, when testing metallic material .~~

~~When testing timber based materials, at least five samples of each grade of timber shall be taken.~~

When samples are not taken from each ~~assembly~~configuration or component tested, 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 preferance or EN ISO 6507-1. ~~Alternatively tests may be made in accordance with ISO 6507.~~

~~While testing samples of whole sections, also stub column tests may be carried out~~ In addition to testing samples of whole sections, tests may be carried out on stub columns in accordance with the recommendations of Annex A.3.2 of ENV 1993 part 1.3:1996-04.

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 ~~components,~~and components~~configurations and connections~~ ~~assemblies and components~~

7.1 ~~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, ~~and~~ stiffness and looseness

7.2.1 General

For ~~components or assemblies~~ configurations and components which are ~~only loaded in one load direction unidirectional tests may be carried out until failure occurs. Sufficient unloadings from different~~intended to be subjected to stress reversals, full cyclic loading (c_{full}) shall be carried out to measure the characteristic structural behaviour. ~~load levels shall be provided.~~

For any configurations and components which may exhibit looseness, limited cyclic loading (c_{lim}) shall be applied before loading to failure. Sufficient unloading curves shall be provided.

~~As a rule, for other assemblies, particularly for connection devices (e. g. modular nodes, horizontal planes), cyclic loading tests shall be carried out to measure the characteristic structural behaviour (see 7.2).~~

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
~~Cyclic loading tests are required for assemblies~~ ~~configurations and components which experience substantial~~ ~~significant stress reversal, such as detachable connections.~~

~~The purpose of a cyclic loading test is:~~

~~a)either to measure the characteristic structural behaviour of an assembly such as the detachable dimantible connection between components (e. g. a wedge connection);~~

~~b)or to check whether the structural behaviour of the permanent connection between two elements (e. g. the connection between an upright and the spigot by swaging) changes significantly as a consequence of being subjected to a major number of load cycles.~~

~~For case a), the number of cycles and the intensity of load shall be taken as follows. The cycling loading shall be carried out over a load range of~~

$$+1{,}0\times\frac{R_k^+}{\gamma_M\times\gamma_F}\;;\;-1{,}0\times\frac{R_k^-}{\gamma_M\times\gamma_F}$$

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,

γ_M ~~-~~ is the partial safety factor for the resistance,

γ_F is the partial safety factor for the action.

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

~~At least, three cycles shall be made at each of the following load levels:~~

$$\cancel{+0{,}5\times\frac{R_k^+}{1{,}1\times1{,}5}\;;\;-0{,}5\times\frac{R_k^-}{1{,}1\times1{,}5}}$$

$$\cancel{+1{,}0\times\frac{R_k^+}{1{,}1\times1{,}5}\;;\;-1{,}0\times\frac{R_k^-}{1{,}1\times1{,}5}}$$

$$\cancel{+1{,}2\times\frac{R_k^+}{1{,}1\times1{,}5}\;;\;-1{,}2\times\frac{R_k^-}{1{,}1\times1{,}5}}$$

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.

~~For case b)., the sample shall be subjected to not less than 3 000 cycles of the load and the load intensity shall be equal to service conditions.~~
7.2.2.2 For limited cyclic loading (c_{lim}), three cycles shall be carried out over a load range of

$$+0{,}1\times\frac{R_k^+}{\gamma_M\times\gamma_F}\;;\;-0{,}1\times\frac{R_k^-}{\gamma_M\times\gamma_F}$$

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

7.3 Repeated loading

Repeated loading test are required for ~~assemblies~~ 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 ~~assembly~~ 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 basi~~e~~s ~~calculated on a rational base, bearing in mind~~ by considering ~~of~~ the anticipated life ~~of the components~~ and ~~the~~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 ~~a load~~ one that produces the same effects as the service load.

NOTE ~~As a rule, sS~~Normally, such test are not required for temporary works equipment. ~~Fatigue problems should be avoided by suitable constructive design.~~

7.4 Vibration tests

~~It is appropriate to carry out vibration tests on assemblies, such as wedged connections, which may be susceptible to loosening under the effects of frequent load reversals.~~
Vibration tests are carried out on ~~assemblies~~configurations, such as include wedge~~d~~ connections, which may be susceptible to loosening when subject to frequent load reversals.

Normally, such tests shall be carried out

- at a load intensity of

$$\pm 0{,}1 \times \frac{R_k}{\gamma_M \times \gamma_F}$$

where

R_k is the characteristic value of the resistance

γ_M is the partial safety factor for the resistance,

γ_F is the partial safety factor for the action.

- at a frequency of 5 cycles per second;
- with a minimum duration of 3 000 cycles ~~at least~~.

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 (e. g. of the wedge) shall be checked. Movement of the wedge is not permissible.

7.5 Impact tests

The main purposes of impact tests are ~~to determine~~:

a) ~~To check of~~to determine the load bearing capacity of ~~assemblies~~ 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 ~~assembly~~ configuration will experience in service.

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

c) ~~The checking of~~To find out structural~~ly~~ inadequa~~te~~cy ~~details~~ of ~~assemblies~~ 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 second order analysis has been 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 only a first order analysis has been carried out 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 :

- drawings;
- photo~~s~~graphs;
- plots and
- tables.

9.2 Content ~~Organization~~ of ~~the~~ test report

The test report shall include the following ~~contents~~:

- title page;
- list of contents;
- preliminary remarks;
- the tested items;
- test programme;
- test arrangement and procedure;
- results;
- summary;
- list of appendices;
- appendices.

9.3 Detailed instructions to the content~~s~~

9.3.1 Title page

The title page shall include ~~at least~~ as a minimum:

- The name and identity of the test laboratory;
- the title and identification number of the report;
- the date of the report;
- the number of pages and the number of appendices;
- an indication of the tested ~~objects~~ items;
- the name and the adress of the customer.

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

- the address of the laboratory, telephone and fax numbers and the e-mail address;
- name of the department or division responsible.

9.3.2 Preliminary remarks

The following information shall be given:

- The date of the tests,
- the reason and the base for the tests (e.g. approval procedure, the number of the EN);
- the date of the assent of the certification body to the test programme if available or necessary.

9.3.3 The tested ~~objects~~ items

The tested ~~components~~ 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 progamme

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

- the objectives (e. g. stiffness, load bearing capacity);
- the number of tests;
- the kind of loading and ist parameters, with loading sketches where necessary;
- 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 kind 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 ~~on computer disc~~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, ~~and~~ stiffness from testing metallic ~~assemblies~~ configurations and components

10.1 General

~~The c~~Clause 10 shall be used for all kinds of metallic components including ~~the~~ connections such as modular nodes or ~~as~~ between decking components and transoms.

Results from ~~component~~ such tests shall be evaluated to determine:

- the value of the characteristic resistance, ~~;~~
- the stiffness, ~~;~~
- the looseness and
- the partial safety factor γ_{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

~~As a rule~~ For preference, the force-displacement behaviour or the moment-rotation behaviour determined by tests while loading and while unloading ~~shall~~ 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 $R^2 \geq 0{,}95$. 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. ~~Graphical methods are an acceptable alternative.~~

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 ~~The~~ An ~~presence of looseness or~~ 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
	Determination of	
1.1	- the approximation functions	10.2
1.2	- the n ultimate values $r^a_{u,i}$	10.3
1.3	- the n quotients q_e which represent the dissipation of energy	10.4
1.4	- the mean $\bar{q}_e$	10.5
1.5	- the partial safety factor γ_{R2} 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
	Adjustment of each failure value $r^b_{u,i}$ to $r^c_{u,i}$ depending on the material properties in case of	10.7
2.1	- material failure	
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 be used with the slope of the appriximation 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 In many cases, a straight line is suitable as approximation function for the unloading curve.

Annex A shows an example.

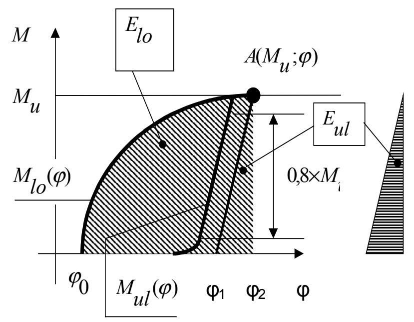

Figure 1 - Example for the dissipation of energy in case of a *M*-φ curve.

~~10.3 Definition of t~~<u>T</u>~~he ultimate value of the resistance $r^a_{u,i}$~~

~~The first maximum of the force-displacement curve or the moment-rotation curve of the test i shall be taken as the ultimate value $r^a_{u,i}$ of the resistance. Normally, for friction connections, the level of sliding friction shall be taken as ultimate value if sliding friction arises~~ <u>occurs</u>~~. This may be lower than the first maximum.~~

10.~~4~~<u>3</u> Dissipation of energy

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

$$q_e = \frac{E_{lo}}{E_{ul}} \qquad (1)$$

where

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

$$E_{lo} = \int_{\varphi_0}^{\varphi_2} M_{lo}(\varphi)d\varphi \qquad (2)$$

$$E_{ul} = \int_{\varphi_1}^{\varphi_2} M_{ul}(\varphi)d\varphi \qquad (3)$$

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

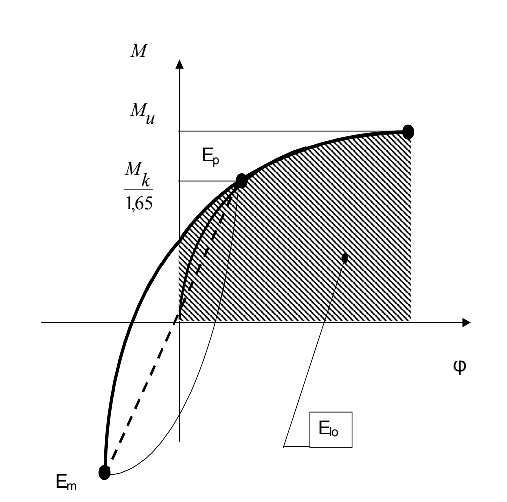

Figure 2 - Example for the determination of E_{lo} in case of a variant of the hysteresis loop

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.

<u>Graphical methods are an acceptable alternative.</u>

<u>10.4 The ultimate value of the resistance $r^a_{u,i}$</u>

<u>The ultimate value $r^a_{u,i}$ 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.</u>

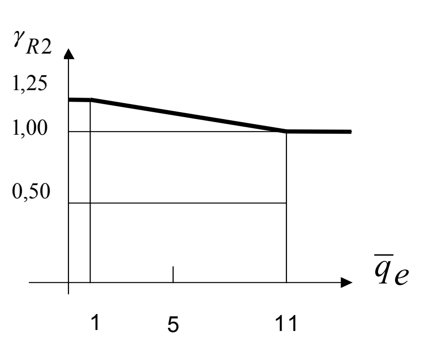

Figure 3 - Partial safety figure γ_{R2} as a function of $\overline{q}_e$

10.5 ~~Definition of t~~ The partial safety factor γ_{R2} depending on the ductility

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

$$\bar{q}_e = \frac{1}{n} \times \sum_{i=1}^{i=n} q_e(i) \qquad (4)$$

$$1{,}25 \geq \gamma_{R2} = -0{,}025 \times \bar{q}_e + 1{,}275 \geq 1{,}00 \quad (5)$$

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. ~~The ultimate values of test results~~ $\cancel{r_{u,i}^a}$ ~~may not be increased when the actual cross- section parameters (e.g. area, bending resistance, moment of inertia,) fall below the nominal values.~~

~~A distinction shall be made between tests on longitudinally oriented components such as props and struts and tests on assemblies such as nodes and horizontal planes when adjusting the test results to take into account of variations in geometry.~~

~~For assemblies, an adjustment of the test results is not required if the dimensions lie within the specified tolerances. Where the dimensions are found to be outside the specified tolerances tests with new components shall be carried out.~~

~~For longitudinally oriented components, a linear reduction shall be carried out when the deviation of the controlling cross section parameter exceeds the nominal value by more than 1%. Where the deviation is found to be more than 10% tests with new components shall be carried out.~~
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 table.

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 ξ_a shall be taken in accordance with ~~the equation (7) and equation (8~~ table 3~~)~~.

$$r_{u,i}^{c} = \frac{r_{u,i}^{b}}{\xi_a} \qquad (6)$$

$$\xi_a = \xi_y \qquad if \quad 0 \leq \bar{\lambda} \leq 0{,}2 \qquad (7)$$

$$\xi_a = \xi_y - (\xi_y - 1) \times \frac{\bar{\lambda} - 0{,}2}{d_M} \qquad if \quad 0{,}2 \prec \bar{\lambda} \leq (d_M + 0{,}2) \qquad (8)$$

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

where

d_M	~~is taken as~~ 1,3 for components made of steel;
d_M	~~is taken as~~ 1,5 for components made of aluminium
d_M	~~is taken as~~ 1,7 for components made of cast material
~~ξ_y~~	~~is calculated in accordance with equation (11)~~
~~$\xi_{y,r}$~~	~~is calculated with equation (12)~~
$\bar{\lambda}$	~~is the~~ related slenderness calculated from equation (~~9~~10)

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

N_{pl}	~~is~~ the normal force in the full plastic condition calculated from $N_{pl} = A_{nom} \times f_{y,k}$
A_{nom}	~~is the~~ area of the cross section
$f_{y,k}$	~~is the~~ characteristic value of the yield stress
$f_{y,a}$	actual value of the yield stress
N_{ci}	~~is the~~ 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 (1~~0~~1) for a column hinged at both ends with a constant cross section.

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

where

$(E*I)_k$	~~is the~~ characteristic value of the stiffness of the cross section
l	~~is the~~ length of the column.

~~Depending on the kind of failure, the adjustment shall be carried out in accordance with table 3.~~

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

	Kind of failure	Adjustment coefficient
1	buckling [1]	ξ_a in accordance with equation (7) and (8)
2	fracture [2]	$\xi_a = \xi_y$ ~~in accordance with equation (12)~~
3	Crippling	
4	large deformations without failure [2]	
5	slipping of friction connection	no reduction

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

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

$$\cancel{\xi_y = \frac{f_{y,a}}{f_{y,k}} \qquad (11)}$$

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

$$f_{y,a} = f_{y,k} \times \frac{f_{u,a}}{f_{u,k}} \qquad (12)$$

$$\cancel{f_{y,c} = \frac{En_a}{\varepsilon_{u,k}} \geq f_{y,a} \qquad (13)}$$

$$\cancel{En_a = \int_0^{\varepsilon_{u,a}} \sigma_a(\varepsilon)\, d\varepsilon \qquad (14)}$$

where

$f_{y,k}$ ~~is the characteristic value of the (guaranteed) yield stress~~

$f_{y,a}$ ~~is the yield stress of the actual value of the yield stress of the material~~

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

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

$f_{y,c}$ ~~is a fictitious yield stress for the purpose of comparison~~

$\varepsilon_{u,k}$ ~~is the elongation of the guaranteed material~~

$\varepsilon_{u,a}$ ~~is the elongation of the actual material~~

$\sigma_a(\varepsilon)$ ~~is the $\sigma - \varepsilon$ -curve for the actual material~~

The values $f_{y,k} \equiv R_{eH}$ or $f_{y,k} \equiv R_{e0,2}$ and $f_{u,k} \equiv R_m$ and $\varepsilon_{u,k}$ 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 $\varepsilon_{u,k}$.

~~The coefficient $\xi_{y,r}$ is determined via an energy comparison (see figure 4). At first, the energy En_a is to be calculated with equation (14). En_a represents the energy which must be put in to reach the elongation $\varepsilon_{u,a}$ of the actual material. Secondly, the comparison yield stress $f_{y,c}$ is to be determined with equation (13). Equation (13) is based on the following assumptions:~~

~~a) $f_{y,c}$ belongs to an fictitious ideal-elastic, ideal-plastic material,~~

~~b) the triangle with the small share of energy $\frac{1}{2} \times \frac{f_{y,c}^2}{E}$ can be neglected,~~

~~(1) the elongation $\varepsilon_{u,k}$ is taken from the guaranteed material.~~

~~NOTE The restriction to an ideal-elastic, ideal-plastic material takes into account the respective calculation restriction $\sigma \leq f_{y,k}$ and the requirement of 4.1.~~

~~If the tensile strength can be determined only through hardness testing, ξ_y shall be determined with equation (15).~~

$$f_{y,c} = f_{y,k} \times \frac{f_{u,a}}{f_{u,k}} \qquad (15)$$

~~where~~

$f_{u,a}$ *is the actual tensile strength*

$f_{u,k}$ *is guaranteed tensile strength*

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 not heat effected material.

~~When the influence of the yield stress can be determined by assembly tests for components with different values of the respective yield stress so that the relation between the resistance looked for ($r_{u,i}^{c}$) and the yield stress can be evaluated suitably, the resistance $r_{u,i}^{c}$ for the nominal value of the yield stress may be determined by intrapolation or small extrapolation.~~

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 $r_{u,i}^{c}$ 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 ~~3~~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 $R_{k,nom}$

The nominal characteristic value of the resistance $R_{k,nom}$ shall be calculated from the basic characteristic value $R_{k,b}$ with the equation (1~~6~~3). The partial safety factor γ_{R2} shall be taken as a function of $\overline{q}_e$ from 10.5.

$$R_{k,nom} = \frac{R_{k,b}}{\gamma_{R2}} \qquad (13)$$

Table 34 - 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 5) 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 $\bar{d}_0$ obtained from a minimum of five tests shall be used.

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

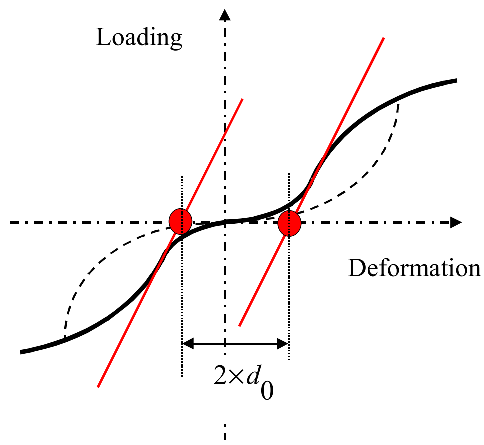

Figure 4. Determination of the original looseness

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

- the mean curve $R_{lo,mean}$ (BEF) of all loading curves;
- the mean curve $R_{ul,mean}$ (DE) of all unloading curves starting from the point E or close to it; normally, the approximate curves may be used;~~ in case of significant differences between the unloading curves for different load levels, those unloading curves close to R=R_k/1.65 shall be used,~~

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

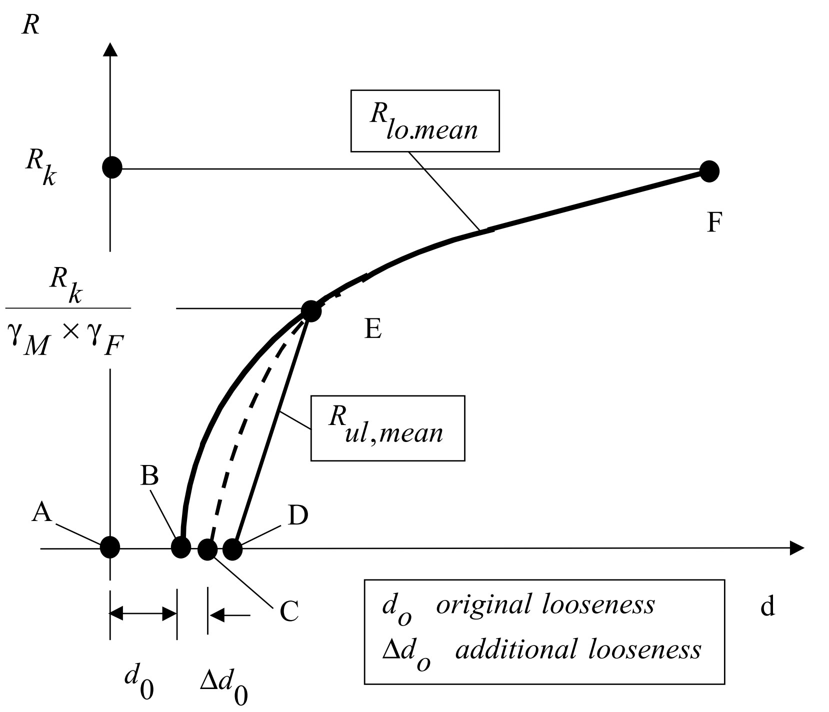

Figure 5 - Evaluation of stiffness

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~~7~~)), the characteristic value of the stiffness shall be determined in accordance with the following table.

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

~~following variants shall be distinguished:~~

a)~~If the variation coefficient v_x is not greater than 0,01, the stiffness relations shall be used as determined;~~

~~b)If the variation coefficient v_x is greater than 0,01 but not greater than 0,02, the respective stiffnesses shall be reduced by 10%;~~

~~c)If the variation coefficient v_x is greater than 0,02, the component or structure shall 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 $\bar{c}_{pp}$ between C_p and E_p (see figure 5), respectively the linearized inclination $\bar{c}_{pp}$ between the zero point and E_p (see figure 2), and the linearized inclination in negative load direction $\bar{c}_{mm}$ between C_m and E_m (analogous to figure 5), respectively the linearized inclination $\bar{c}_{mm}$ between the zero point and E_m (analogous to figure 2), differ not more than 10% (see equation 1~~8~~5).

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.

$$v_x = \frac{s_x}{\bar{x}} \qquad (14)$$

where

s_x *is* the standard deviation for the n test results

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

where the letter p labels the positive load direction and the letter m labels the negative load direction

$$\left| \frac{\left|\bar{c}_{pp}\right| - \left|\bar{c}_{mm}\right|}{\left|\bar{c}_{pp}\right| + \left|\bar{c}_{mm}\right|} \right| \times 100 \leq 10 \qquad (15)$$

When the equation (1~~8~~5) 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

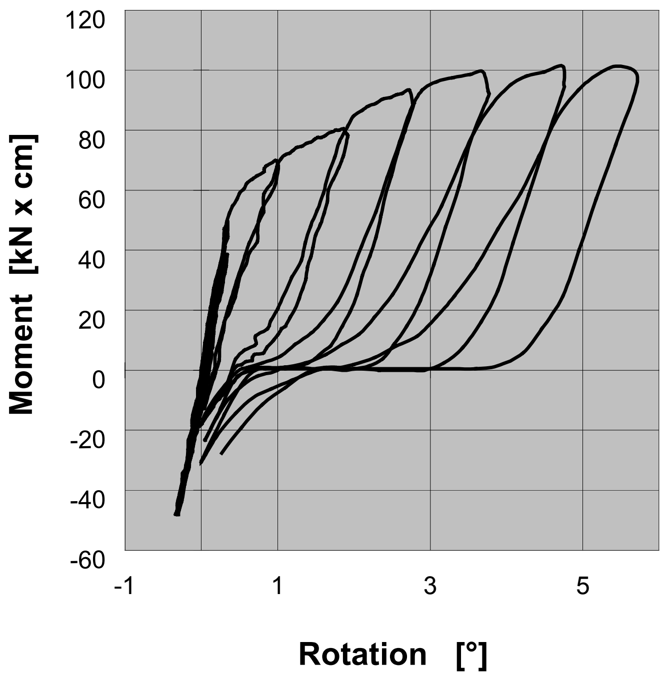

Figure A.1 – ~~Assembly~~ Configuration testing; upright-transom connection; moment rotation

$\frac{R_k^+}{1{,}1 \times 1{,}5}$ and $\frac{R_k^-}{1{,}1 \times 1{,}5}$ were estimated to $\pm 40\ kN \times cm$. ~~Therefore~~ In this case, cycles were carried out for $\pm 20\ kN \times cm$, $\pm 40\ kN \times cm$ and $\pm 48\ kN \times cm$. After that the tests were continued in positive moment direction until failure. Altogether 10 tests were carried out.

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.

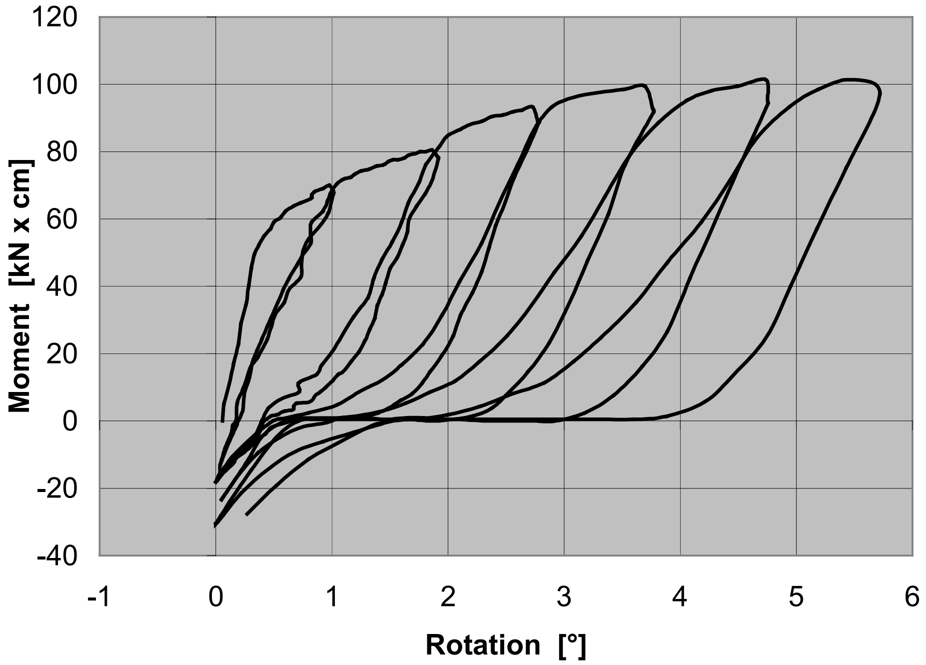

Figure A.2 – Moment rotation curve of figure A.1 without the cyclic loading parts of the curves

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

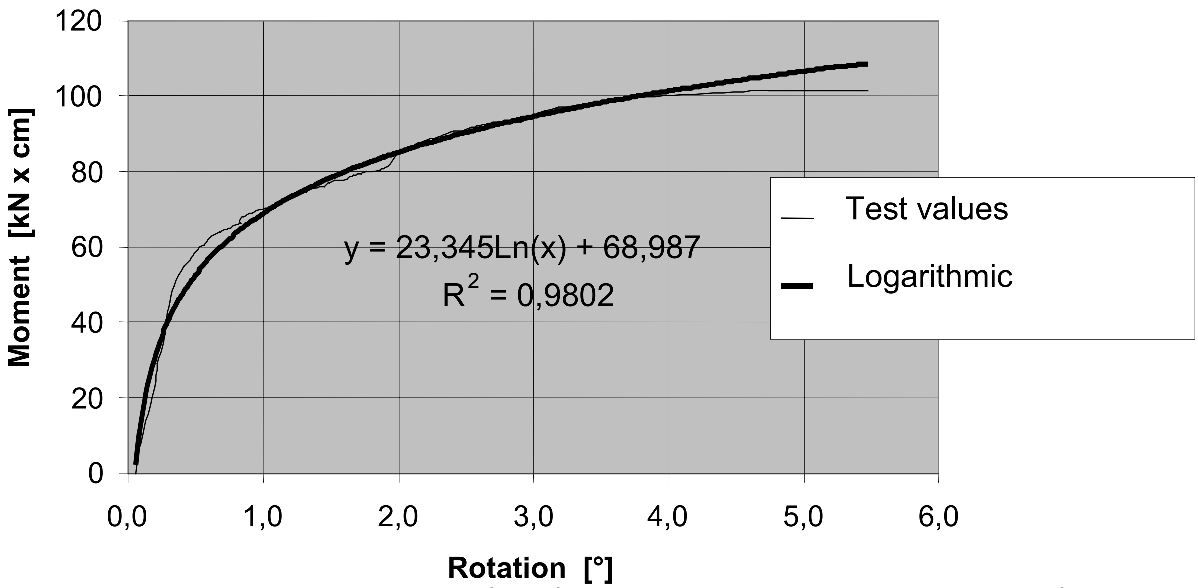

Figure A.3 – Moment rotation curve from figure A.2 without the unloading parts of curves

Figure A.4 shows the approximation curve for the unloading part closest to the failure moment $M_{ul}^{\bullet} = 68{,}113\varphi - 294{,}68$. 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 $R^2 = 0{,}9908$ fulfills the in requirement given in 10.2.

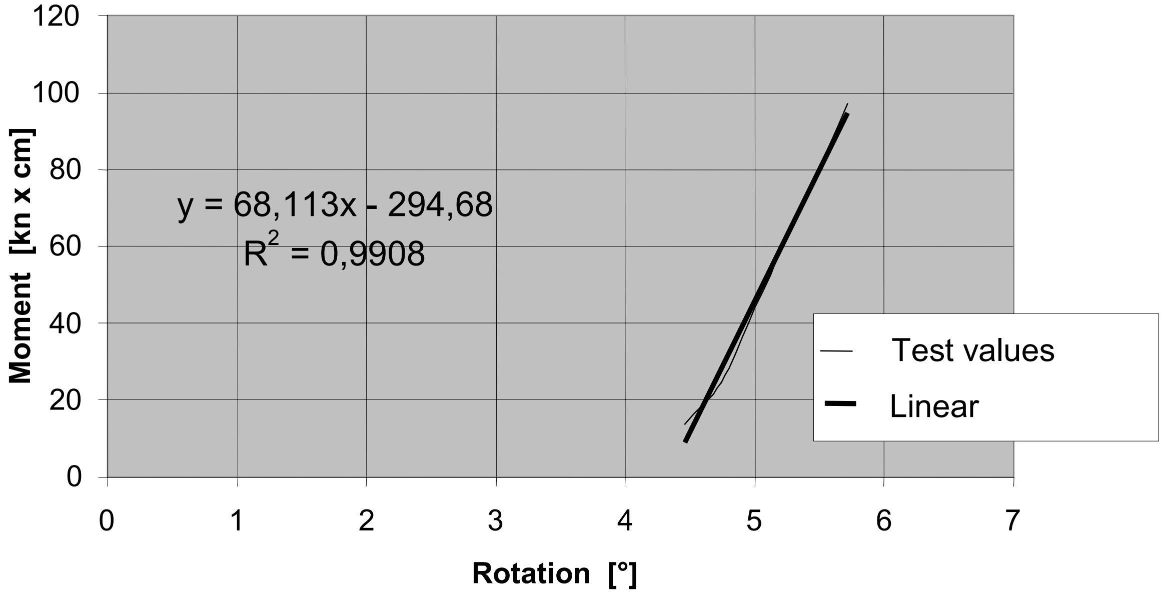

Figure A.4 – Moment rotation curve from figure A.1 for the part of the last unloading

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

A.3 Dissipation of energy

In accordance with 10.4, the integrals E_{lo} and E_{ul} shall be determined by equation (A.1):

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

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

$$E_{ul} = \int_{3{,}98}^{5{,}47} (68{,}113\varphi - 271{,}2) d\varphi = 75{,}5 \qquad \text{(A.2)}$$

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; $\varphi_u = 5{,}47^0$).

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

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

A.4 Partial safety factor γ_{R2}

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 $q_e(i)$ shall be determined by equation (A.4):

$$\overline{q}_e = \frac{1}{n}\sum_{i=1}^{n} q_e(i) = 6,23 \qquad \text{(A.4)}$$

The partial safety factor γ_{R2} is as equation (A.5)

$$\gamma_{R2} = -0,025 \times \overline{q}_e + 1,275 = 1,12 \,. \qquad \text{(A.5)}$$

Annex B (informative)

Example for the statistical evaluation of test results and the 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 $r_{u,i}^{a}$ were determined as the first maximum of the respective moment rotation curve in accordance with 10.3. After evaluating the results in accordance with 10.6.and 10.7, the ten values $r_{u,i}^{c}$ of table B.1 result.

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

1	Test number i	1	2	3	4	5	6	7	8	9	10
2	$r_{u,i}^{c}$ kN*cm	75,7	76,8	77,2	77,9	78,1	78,8	79,5	80,2	81,8	83,2
3	$y_i = \ln(r_{u,i}^{c})$	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 Transform the values $r_{u,i}^{c}$ to logarithmic values y_i using the equation (B.1).

$$y_i = \ln(r_{u,i}^{c}) \qquad (B.1)$$

For the example, the results are given in the row 3 of table B.1.

B.2.2 Calculate the average value of the values y_i from the equation (B.2) and the standard deviation from the equation (B.3).

$$\bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_i \qquad (B.2)$$

$$s_y^2 = \frac{1}{n-1} \sum_{i=1}^{n} (y_i - \bar{y})^2 \qquad (B.3)$$

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

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

$$y_5 = \bar{y} - k_{s,k} \times s_y \qquad (B.4)$$

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 Reverse the logarithmic transformation to obtain the basic characteristic value using the equation (B.5).

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

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

B.2.5 Calculate the nominal characteristic value of the moment from the equation (~~10~~ ~~14~~13). With the partial safety factor $\gamma_{R2} = 1{,}12$ from the annex A, the nominal characteristic value of the moment becomes $R_{k,nom} = 66{,}25 \quad kN \times cm$.

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 ~~10-~~2. Its values c_p and c_m (see 10.10) for the three cycles on the load level $\pm 1{,}0 \times \frac{R_k}{1{,}1 \times 1{,}5}$ and the mean values $\bar{c}_{p,7}$ and $\bar{c}_{m,7}$ are listed in table C.1.

Table C.1. - Stiffnesses c_p and c_m for Test from figure A.1.

Cycle number	$kN \times cm/[°]$	
	$c_{p,7}$	$c_{m,7}$
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 test 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	$\bar{c}_{p,i}$	$kN \times cm/[°]$	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 direction

In accordance with 10.10, the mean values of the stiffnesses shall be 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:

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

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

The application of equation (15~~7~~) gives equation (C.3):

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

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 may 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 equatione (C.1), (C.5) and (C.6).

For moments above $\pm\frac{R_k}{1{,}1\times 1{,}5}=\pm 40\ kN\times cm$, the moment-rotation curve is linearized in accordance with 10.10. The averaged rotations for $R_k = 66{,}0\ kN\times cm$ and for $R_k = -66{,}0\ kN\times cm$ differ not more than 10% also. Therefore a mean value $\pm 0{,}88°$ can be assumed.

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

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

$$M(\varphi)=138{,}9\times\varphi \qquad (C.4)$$

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

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

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

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

$$M(\varphi) = 43{,}915\times\varphi - 27{,}351 \qquad (C.6)$$

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

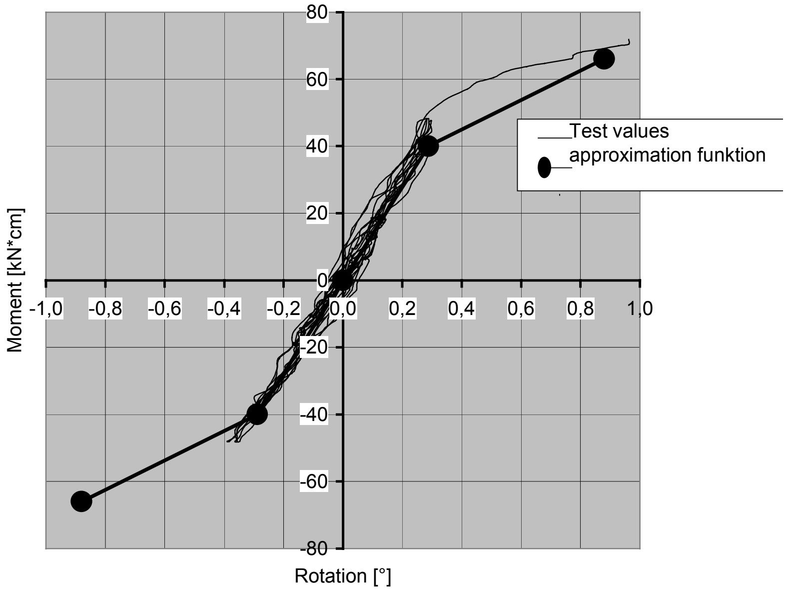

Figure C.1 – Evaluated moment-rotation curve plotted in one test curve