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Steel for the reinforcement and prestressing of concrete — Test methods —

Part 3: Prestressing steel

Aciers pour l'armature et la précontrainte du béton — Méthodes d'essai —

Partie 3: Aciers de précontrainte

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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

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

ISO 15630-3 was prepared by Technical Committee ISO/TC 17, *Steel*, Subcommittee SC 16, *Steels for the reinforcement and prestressing of concrete*.

This second edition cancels and replaces the first edition (ISO 15630-3:2002), which has been technically revised.

ISO 15630 consists of the following parts, under the general title *Steel for the reinforcement and prestressing of concrete — Test methods*:

— *Part 1: Reinforcing bars, wire rod and wire*

— *Part 2: Welded fabric*

— *Part 3: Prestressing steel*

Introduction

The aim of ISO 15630 is to provide all relevant test methods for reinforcing and prestressing steels in one standard. In that context, the existing International Standards for testing these products have been revised and updated. Some further test methods have been added.

Reference is made to International Standards on the testing of metals, in general, as they are applicable. Complementary provisions have been given if needed.

Steel for the reinforcement and prestressing of concrete — Test methods —

Part 3: **Prestressing steel**

1 Scope

This part of ISO 15630 specifies test methods applicable to prestressing steels (bar, wire or strand) for concrete.

2 Normative references

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

ISO 4957, *Tool steels*

ISO 6508-1, *Metallic materials — Rockwell hardness test — Part 1: Test method (scales A, B, C, D, E, F, G, H, K, N, T)*

ISO 6892-1, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

ISO 7500-1, *Metallic materials — Verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Verification and calibration of the force-measuring system*

ISO 7801:1984, *Metallic materials — Wire — Reverse bend test*

ISO 9513, *Metallic materials — Calibration of extensometers used in uniaxial testing*

3 Symbols

The symbols used in this part of ISO 15630 are given in Table 1.

Table 1 — Symbols

Symbol	Unit	Description	Reference
a_{m}	mm	Rib height at the mid-point	13.3, 14.2
a_{max}	mm	Maximum height of rib or depth of indentation	13.3
$a_{\mathrm{s},\,i}$	mm	Average height of a portion i of a rib subdivided into p parts of length Δl	14.2
$a_{1/4}$	mm	Rib height at the quarter-point	13.3, 14.2
$a_{3/4}$	mm	Rib height at the three-quarters point	13.3, 14.2
A	%	Percentage elongation after fracture	5.1, 5.3
A_{gt}	%	Percentage total elongation at maximum force	Clause 5
b	mm	Width of transversal rib at the mid-point	13.3.1.6
c	mm	Rib or indentation spacing	13.3
C	mm	Groove width at nominal diameter of the mandrel, d_{a}, used for the deflected tensile test	11.3.4
d	mm	Nominal diameter of the bar, wire or strand	5.3.1, 7.2, 9.2, 9.4.6, 10.3.4
d_{a}	mm	Nominal diameter of the mandrel used for the deflected tensile test	11.3.4
d_{b}	mm	Diameter with 2 gauge cylinders in the groove of the mandrel used for the deflected tensile test	11.3.4
d_{e}	mm	Diameter of the gauge cylinder used for the deflected tensile test	11.3.4
d_{g}	mm	Diameter of guide hole	7.2
d_{i}	mm	Inner diameter of the groove of the mandrel used for the deflected tensile test	11.3.4
D	%	Average coefficient of reduction of the maximum force in the deflected tensile test	11.2, 11.4
D_{c}	mm	Inner diameter of the cell in the stress corrosion test	10.3.4
D_{i}	%	Individual percentage of reduction of the maximum force in the deflected tensile test	11.4
D_{m}	mm	Diameter of the mandrel of the bending device in the bend test	6.2.1
e	mm	Average gap between two adjacent ribs or indentation rows	13.3.1.4, 13.3.2.5
E	MPa	Modulus of elasticity	5.2, 5.3
f	Hz	Frequency of force cycles in the axial force fatigue test	9.1, 9.4.2
f_{R}	—	Relative rib area	Clause 14
$F_{\mathrm{a,\,i}}$	N	Individual breaking force in the deflected tensile test	11.4
F_{m}	N	Maximum force in the tensile test	5.3
$\bar{F}_{\mathrm{m}}$	N	Mean value of the maximum force	8.2, 10.2, 11.2, 11.4
$F_{\mathrm{p0,1}}$	N	0,1 % proof force, non-proportional extension	5.2, 5.3
$F_{\mathrm{p0,2}}$	N	0,2 % proof force, non-proportional extension	5.2, 5.3
F_{r}	N	Force range in the axial force fatigue test	9.1, 9.3, 9.4.2

Table 1 (*continued*)

Symbol	Unit	Description	Reference
F_{rt}	N	Residual force in the test piece at time t in the relaxation test	8.1
ΔF_{rt}	N	Force loss in the test piece at time t in the relaxation test	8.1
F_R	mm^2	Area of longitudinal section of one rib	14.2
F_{up}	N	Upper force in the axial force fatigue test	9.1, 9.3, 9.4.2
F_0	N	Initial force in the isothermal stress relaxation test and the stress corrosion test	8.1, 8.2, 8.3, 8.4, 10.1, 10.2, 10.4.2
G	mm	Depth of the groove of the mandrel used for the deflected tensile test	11.3.4
h	mm	Distance from the top tangential plane of cylindrical supports to the bottom face of the guide	7.2
h_b	mm	Bow height in the plane of the bow	13.3.4
l	mm	Length of indentation	13.3.2.4
L_t	mm	Length of the test piece in the stress corrosion test	10.2
L_0	mm	Gauge length (without force on the test piece) in the isothermal stress relaxation test Length of the test piece in contact with the solution in the stress corrosion test	8.1, 8.3, 8.4 10.2, 10.3.4, 10.4.1, 10.4.3, 10.4.5
ΔL_0	mm	Elongation of the gauge length, L_0, under force, F_0, in the isothermal stress relaxation test	8.1, 8.3, 8.4
L_1	mm	Length of the passive side in the deflected tensile test	11.3.2
L_2	mm	Length of the active side in the deflected tensile test	11.3.2
m, n	—	Coefficients or numbers	8.4.9, 13.3, 14.2
P	mm	Lay length of a strand	13.3.3
r	mm	Radius of cylindrical supports	7.2
R	mm	Radius at the base of the mandrel used for the deflected tensile test	11.3.4
Ra	µm	Surface roughness of the mandrel used for the deflected tensile test	11.3.4
S_n	mm^2	Nominal cross-sectional area of the test piece	5.3.2
t_a	h	Maximum agreed time for the stress corrosion test	10.4.5
$t_{f,i}$	h	Individual lifetime to fracture in the stress corrosion test	10.4.5
$\bar{t}_f$	h	Median lifetime to fracture in the stress corrosion test	10.4.6
t_0	s	Starting time in the isothermal stress relaxation test and in the stress corrosion test	8.4.2, 10.4
V_0	mm^3	Volume of test solution to fill the test cell in the stress corrosion test	10.4.3
Z	%	Percentage reduction of area	5.3.1
α	°	Angle of deviation in the deflected tensile test	11.3.2
β	°	Rib or indentation angle to the bar or wire axis	13.3
ε_x	—	Value of the strain for a force equal to x	5.3.2
ρ	%	Relaxation	8.4.9
$\sum e_i$	mm	Part of the circumference without indentation or rib	13.3.1.4, 13.3.2.5, 14.2

NOTE 1 MPa = 1 N/mm^2.

4 General provisions concerning test pieces

Unless otherwise agreed or specified in the product standard, the pieces shall be taken from the finished product normally before packaging.

Special care should be taken when sampling is made from the packaged product (e.g. coil or bundle), in order to avoid plastic deformation which could change the properties of the samples used to provide the test pieces.

Specific complementary provisions concerning the test pieces may be indicated in the relevant clauses of this part of ISO 15630, if applicable.

5 Tensile test

5.1 Test piece

In addition to the general provisions given in Clause 4, the free length of the test piece shall be sufficient for the determination of the percentage total elongation at maximum force (A_{gt}) in accordance with 5.3.1.

If the percentage elongation after fracture (A) is determined manually, the test piece shall be marked in accordance with ISO 6892-1.

If the percentage total elongation at maximum force (A_{gt}) is determined by the manual method for bar or wire, equidistant marks shall be made on the free length of the test piece (see ISO 6892-1). The distance between the marks shall be 20 mm, 10 mm or 5 mm, depending on the test piece diameter.

5.2 Test equipment

The test equipment shall be verified and calibrated in accordance with ISO 7500-1 and shall be at least of class 1.

If an extensometer is used, it shall be of class 1 in accordance with ISO 9513 for the determination of E, $F_{p0,1}$ or $F_{p0,2}$; for the determination of A_{gt}, a class 2 extensometer (see ISO 9513) may be used.

Grips shall be such as to avoid breaks in or very near the grips.

5.3 Test procedure

5.3.1 General

The tensile test for the determination of the modulus of elasticity (E), 0,1 % and 0,2 % proof force ($F_{p0,1}$ and $F_{p0,2}$), percentage total elongation at maximum force (A_{gt}) and/or percentage elongation after fracture (A) and percentage reduction of area (Z) shall be carried out in accordance with ISO 6892-1.

An extensometer shall be used for the determination of the modulus of elasticity (E), 0,1 % and 0,2 % proof force ($F_{p0,1}$ and $F_{p0,2}$) and percentage total elongation at maximum force (A_{gt}). The extensometer gauge length shall be as given in the relevant product standard.

Accurate values of A_{gt} can only be obtained with an extensometer. If it is not possible to leave the extensometer on the test piece to fracture, the elongation may be measured as follows.

— Continue loading until the extensometer records an elongation just greater than the elongation corresponding to $F_{p0,2}$, at which the extensometer is removed and the distance between the testing machine cross-heads is noted. The loading is continued until fracture occurs. The final distance between the cross-heads is noted.

— The difference between the cross-head measurements is calculated as a percentage of the original distance between the cross-heads and this value is added to the percentage obtained by an extensometer.

For wire and bars, it is also permissible to determine A_{gt} by the manual method (see ISO 6892-1).

It is preferable to apply a preliminary force to the test piece, e.g. to about 10 % of the expected maximum force before placing the extensometer.

If A_{gt} is not completely determined with an extensometer, this shall be indicated in the test report[1)].

Tensile properties, $F_{p0,1}$, $F_{p0,2}$, F_m, are recorded in force units.

For the determination of percentage elongation after fracture (A), the original gauge length shall be 8 times the nominal diameter (d), unless otherwise specified in the relevant product standard. In case of dispute, A shall be determined manually.

If the rupture occurs within a distance of 3 mm from the grips, the test shall, in principle, be considered as invalid and it shall be permissible to carry out a retest. However, it shall be permitted to take into account the test results if all values meet the relevant specified values.

5.3.2 Determination of the modulus of elasticity

The modulus of elasticity (E) shall be determined from the slope of the linear portion of the force-extension diagram in the range between $0{,}2F_m$ and $0{,}7F_m$, divided by the nominal cross-sectional area of the test piece (S_n).

$$E = \left[(0{,}7F_m - 0{,}2F_m)/(\varepsilon_{0{,}7F_m} - \varepsilon_{0{,}2F_m}) \right] / S_n \qquad (1)$$

The slope may be calculated either by a linear regression of the measured data stored in a data storage facility or by a best-fit visual technique over the above-defined portion of the registered curve.

In some special cases, e.g. hot-rolled and stretched bars, the above-mentioned method cannot be applied; a secant modulus between $0{,}05F_m$ and $0{,}7F_m$ may then be determined as follows:

$$\left[(0{,}7F_m - 0{,}05F_m)/(\varepsilon_{0{,}7F_m} - \varepsilon_{0{,}05F_m}) \right] / S_n$$

In addition to the provisions given in 5.3.1, it shall be ensured that the stress rate shall not be changed within the force range over which the modulus of elasticity is determined.

6 Bend test

6.1 Test piece

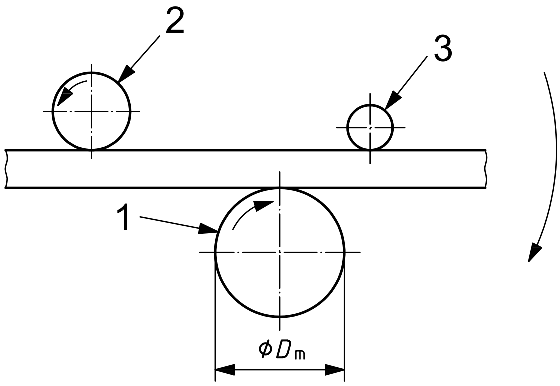
The general provisions given in Clause 4 apply.

1) For routine tests conducted by prestressing steel producers, the test information should be contained within internal documentation.

6.2 Test equipment

6.2.1 A bending device, the principle of which is shown in Figure 1, shall be used.

NOTE Figure 1 shows a configuration where the mandrel and support rotate and the carrier is locked. It is also possible that the carrier rotates and the support or mandrel is locked.



Key

1 mandrel

2 support

3 carrier

Figure 1 — Principle of a bending device

6.2.2 The bend test may also be carried out by using a device with supports and a mandrel (e.g. see ISO 7438).

6.3 Test procedure

The bend test shall be carried out at a temperature between 10 °C and 35 °C. The test piece shall be bent over a mandrel.

The angle of bend and the diameter of the mandrel shall be in accordance with the relevant product standard.

6.4 Interpretation of test results

The interpretation of the bend test shall be carried out in accordance with the requirements of the relevant product standard.

If these requirements are not specified, the absence of cracks visible to a person with normal or corrected vision is considered as evidence that the test piece withstood the bend test.

A superficial ductile tear may occur at the base of the ribs or indentations and is not considered to be a failure. The tear may be considered superficial when the depth of the tear is not greater than the width of the tear.

7 Reverse bend test

7.1 Test piece

In addition to the general provisions given in Clause 4, the test piece shall comply with ISO 7801.

7.2 Test equipment

The test equipment shall comply with ISO 7801:1984, Clause 4.

For wire of nominal diameter 10 mm $< d \leqslant$ 12,5 mm, the following conditions apply to the test equipment as defined in ISO 7801: r = (30 ± 1) mm, h = 125 mm, d_g = 11 mm or 13 mm.

7.3 Test procedure

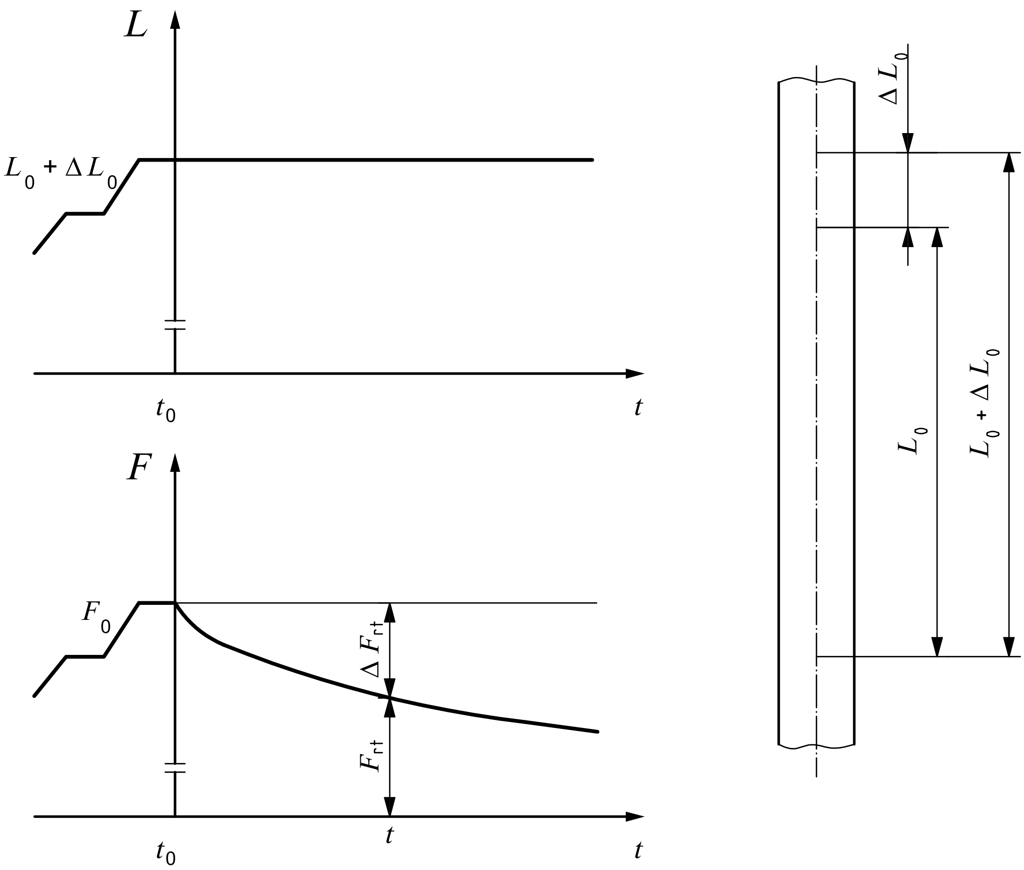
The reverse bend test shall be carried out in accordance with ISO 7801.

8 Isothermal stress relaxation test

8.1 Principle of test

The isothermal stress relaxation test consists of measuring, at a given temperature (generally fixed at 20 °C unless otherwise agreed) the variations of force of a test piece maintained at constant length ($L_0 + \Delta L_0$), from an initial force (F_0) (see Figure 2).

The loss in force is expressed as a percentage of the initial force for a given period of time.



Key

t time

L length

F force

Figure 2 — Principle of the isothermal stress relaxation test

8.2 Test piece

The general provisions given in Clause 4 apply.

The test piece for the relaxation test shall be maintained in a straight condition. The free length of the test piece between the grips shall not be subjected to any mechanical deformation or treatment of any kind.

Two test pieces adjacent to the test pieces for the stress relaxation test shall be taken for the determination of the mean value of maximum force ($\overline{F}_{m}$), if the initial force, F_0, is expressed as a percentage of $\overline{F}_{m}$, e.g. 70 % $\times$ $\overline{F}_{m}$.

8.3 Test equipment

8.3.1 Frame

Any deformation of the frame shall be within such limits that it does not influence the results of the test.

8.3.2 Force-measuring device

The force shall be measured either by a coaxial force cell or another appropriate device (e.g. lever loading system).

The force cell shall be calibrated in accordance with ISO 7500-1 and have an accuracy of ±1 % for forces up to 1 000 kN and ±2 % for forces greater than 1 000 kN.

Any other appropriate device shall provide the same accuracy as the one specified for the force cell.

The resolution of the output of the force-measuring device shall be $5 \times 10^{-4} F_0$ or better.

8.3.3 Length-measuring device (extensometer)

The gauge length (L_0) shall be not less than 200 mm. For strands, it should preferably be 1 000 mm or an integer number of the strand lay length where the actual length ($L_0 + \Delta L_0$) is measured on the same wire of the strand. The extensometer shall have an output or calibration of scale capable of a resolution of at least $1 \times 10^{-6} L_0$ or 1 µm, whichever is the greater.

8.3.4 Anchoring device

The anchoring device shall be constructed in such a way that slipping during the test either is not possible or is corrected and rotation of the anchoring device is prevented.

8.3.5 Loading device

The loading device shall allow a smooth increase in loading the test piece without shock. It shall be constructed in such a way that the length ($L_0 + \Delta L_0$) can be maintained within the limits fixed in 8.4.5, throughout the test, by reduction of force.

8.4 Test procedure

8.4.1 Provisions concerning the test piece

The test piece shall remain at least 24 h in the testing laboratory prior to the test.

The test piece shall be securely gripped in the anchorages of the test device in order to avoid any slip during loading and during the test.

8.4.2 Application of force

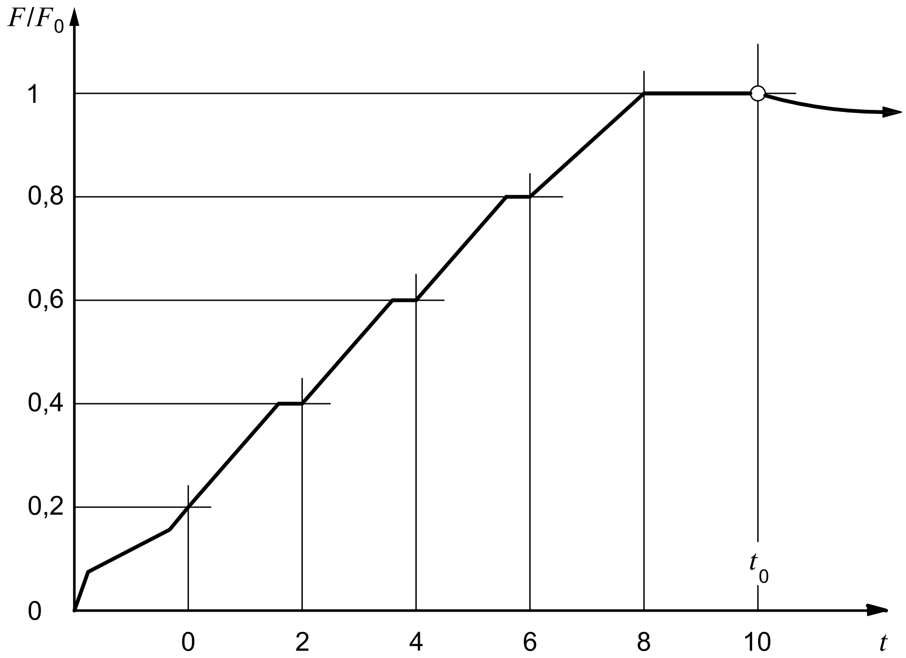
Application of force shall at all times be carried out smoothly and without shock.

The loading up to 20 % of the initial force, F_0, may be carried out as desired. Loading of the test piece from 20 % up to 80 % of F_0 shall be applied continuously or in three or more uniform steps or with a uniform rate of loading and shall be completed within 6 min. Application of the force between 80 % and 100 % of F_0 shall be continuous and shall be completed within 2 min, after achievement of 80 % of F_0.

NOTE A rate of loading up to F_0 of (200 ± 50) MPa·min^{-1} is considered as a uniform rate of loading.

On attainment of the initial force, F_0, the force shall be kept constant for a period of 2 min. Immediately on completion of this 2 min period, time, t_0, is established and recorded. Any subsequent adjustment of force shall only be made in order to ensure that $L_0 + \Delta L_0$ is kept constant.

The application of force is illustrated schematically in Figure 3.



Key

t time (min)

F/F_0 ratio between the applied force and the initial force, F_0

Figure 3 — Application of force in the relaxation test

8.4.3 Initial force

The initial force, F_0, shall be as specified in the appropriate product standard. The measured value of the initial force shall be within the tolerances of the specified value given in Table 2.

Table 2 — Tolerance of F_0

Value of F_0	Tolerance of F_0
$F_0 \leqslant 1\,000$ kN	±1 %
$F_0 > 1\,000$ kN	±2 %

8.4.4 Force during the test

At any time, the force shall not be permitted to exceed the initial force by more than the tolerances given in Table 2.

8.4.5 Maintenance of strain

The strain imposed by the initial force, F_0, at time, t_0, shall be measured with a suitable mechanical, electrical or optical extensometer having the precision defined in 8.3.3 at the selected initial gauge length, L_0. The variation of ΔL_0 shall not exceed 5×10^{-6} L_0 or 5 µm, whichever is the greater, during the force measurement and 7×10^{-6} L_0 or 7 µm, whichever is the greater, between two consecutive force measurements.

8.4.6 Temperature

The temperature of the testing laboratory shall be such that the temperature of the test piece shall be maintained within 20 °C ± 2 °C.

8.4.7 Frequency of force recording

The loss of force shall be continuously recorded or measured at least approximately at the standard time intervals given in Table 3 after starting the test and then at least once per week.

Table 3 — Standard times of force recording

Minutes	1	2	4	8	15	30	60
Hours	2	4	6	24	48	96	120

8.4.8 Frequency of strain recording

The strain measured by the extensometer shall be recorded continuously, or at least during force measurements, and twice between two consecutive force measurements (at equal time intervals).

8.4.9 Duration of the test

The duration of the test shall be not less than 120 h.

NOTE A common duration of a test is 120 h or 1 000 h.

The value of stress relaxation at 1 000 h (or more) may be extrapolated from tests terminating at not less than 120 h, where adequate evidence is provided that the extrapolated 1 000 h (or more) value is equivalent to the actual 1 000 h (or more) value. In this case, the extrapolation method should be described in the test report.

A current method of extrapolation is based on the formula:

$$\log \rho = m \log t + n \quad (2)$$

where

ρ is the relaxation, generally expressed in percent;

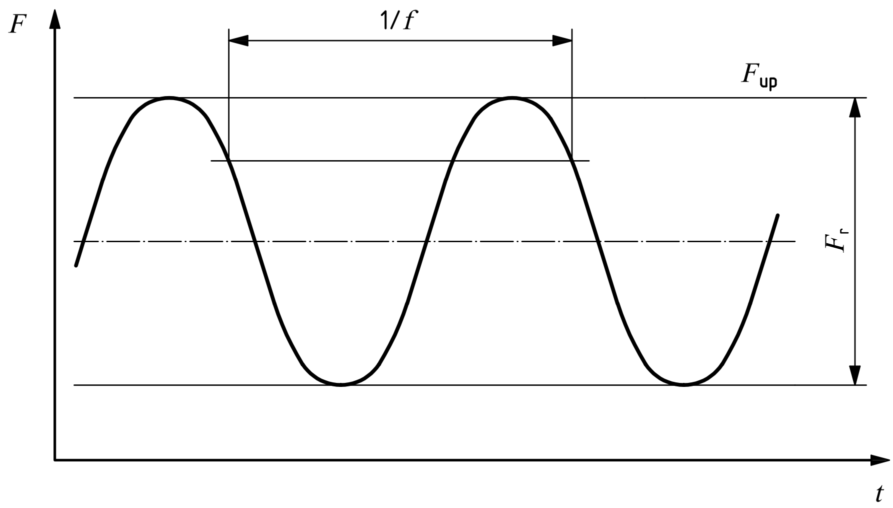
t is the time, expressed in hours;

m and n are coefficients.

9 Axial force fatigue test

9.1 Principle of test

The axial force fatigue test consists of submitting the test piece to an axial tensile force, which varies cyclically according to a sinusoidal wave-form of constant frequency, f, in the elastic range (see Figure 4). The test is carried out until failure of the test piece or until reaching, without failure, the number of force cycles specified in the relevant product standard.



Key

F force

t time

Figure 4 — Force cycle diagram

9.2 Test piece

The general provisions given in Clause 4 apply.

The minimum free length shall be in accordance with Table 4.

Table 4 — Minimum free length of the test piece

Wire and bar	140 mm or 14d, whichever is the greater
Strand	500 mm or twice the lay length, whichever is the greater

The free length of the test piece between the grips shall not be subjected to treatment of any kind.

9.3 Test equipment

The fatigue-testing machine shall be calibrated in accordance with ISO 7500-1. The accuracy shall be at least ±1 %. The testing machine shall be capable of maintaining the upper force (F_{up}) to within ±2 % of the specified value and the force range (F_r) to within ±4 % of the specified value.

9.4 Test procedure

9.4.1 Provisions concerning the test piece

The test piece shall be gripped in the test equipment in such a way that force is transmitted axially and free of any bending moment along the test piece. For strands, it is essential that all constituent wires be equally gripped and the force equally distributed amongst them.

9.4.2 Stability of force and frequency

The test shall be carried out under conditions of stable upper force (F_{up}), force range (F_r) and frequency (f). There shall be no planned interruptions in the cyclic loading throughout the test. However, it is permissible to continue a test which is accidentally interrupted. Any interruption shall be recorded in the test report.

9.4.3 Counting of force cycles

The number of force cycles shall be counted inclusively from the first full force-range cycle.

9.4.4 Frequency

The frequency of force cycles shall be stable during the test and shall be maintained during a series of tests. It shall not exceed

a) 120 Hz for wire and bar, or

b) 20 Hz for strand.

9.4.5 Temperature

The temperature of the test piece shall not exceed 40 °C throughout the test. The temperature of the testing laboratory shall be between 10 °C and 35 °C, unless otherwise specified.

9.4.6 Validity of the test

If failure occurs in the grips or within a distance of $2d$ from the grips, or initiates at an exceptional feature of the test piece, the test may be considered as invalid.

10 Stress corrosion test in a solution of thiocyanate

10.1 Principle of test

The test determines the time to fracture of a test piece maintained at a constant tensile force, F_0, specified in the relevant product standard and immersed in a solution of thiocyanate (see 10.3.5), at a given constant temperature.

10.2 Sample and test piece

The general provisions given in Clause 4 apply to the sample which should provide not less than 6 test pieces for the stress corrosion test and 2 test pieces for the determination of $\overline{F}_m$ by a uniaxial tensile test if the initial force (F_0) is expressed as a percentage of $\overline{F}_m$, e.g. 80 % $\overline{F}_m$.

The length of a test piece, L_t, shall be sufficient to ensure that any bending from the anchorage is minimized and should be preferably twice the length, L_0.

10.3 Test equipment

10.3.1 Frame

A stiff frame shall be used. Loading shall be applied by a lever apparatus or by a hydraulic or mechanical device acting on a closed frame in either the horizontal or vertical orientation.

10.3.2 Force-measuring device

A force-measuring device with an accuracy of at least ±2 % shall be used and calibrated in accordance with ISO 7500-1.

10.3.3 Time-measuring device

The time shall be measured with a resolution of at least 0,01 h. The time-measuring device shall be equipped with an automatic control to stop and retain or record the time at fracture with an accuracy of ±0,1 h. Alternatively, the time to fracture shall be the last manually recorded time prior to fracture.

10.3.4 Cell containing the test solution

The cell containing the test solution should preferably be cylindrical and sealed at both ends. It shall have an inner diameter, D_c, in accordance with the following formula:

$$D_\text{c} \geqslant \sqrt{(200 + d) \times d} \quad \text{(all dimensions in millimetres)} \tag{3}$$

Recommended inner diameters, D_c, are given in Table 5.

Table 5 — Recommended inner diameters, D_c, of the test cell

Dimensions in millimetres

Nominal diameter of the test piece, d	Recommended values of D_c
$d \leqslant 19$	$\geqslant 70$
$19 < d \leqslant 50$	$\geqslant 100$

The cell length shall be sufficient to accommodate a test length, L_0, of at least 200 mm.

The cell shall be manufactured from a material which is chemically resistant to the test solution at 50 °C.

The cell shall be kept closed during the test, and admission of air shall be avoided.

10.3.5 Test solution

The test solution can be selected from one of the two solutions specified below, which present respectively a high and low concentration of thiocyanate.

- Solution A: aqueous solution of ammonium thiocyanate prepared by dissolving 200 g of NH_4SCN in 800 ml of distilled or demineralized water. The ammonium thiocyanate shall be of analytical grade containing at least 99 % of NH_4SCN and a maximum of 0,005 % Cl^-, 0,005 % SO_4^{2-} and 0,001 % S^{2-}.

- Solution B: aqueous solution of potassium sulfate (K_2SO_4), potassium chloride (KCl) and potassium thiocyanate (KSCN) prepared with distilled or demineralized water. Test solution B shall contain 5 g/l of SO_4^{2-}, 0,5 g/l of Cl^- and 1 g/l of SCN^-.

The electrical conductivity of the water used for the preparation of solutions A and B shall not exceed 20 µS/cm.

Attention is drawn to the fact that these two solutions give different results which are not comparable. The solution(s) to be used should be as specified in the product standard.

WARNING — Relevant Material Safety Data Sheet (MSDS) information on handling dangerous chemicals and disposal of these chemicals after use shall be taken into account for the chemicals used in this test.

10.4 Test procedure

10.4.1 Provisions concerning the test pieces

The test pieces shall be cleaned by wiping with a soft cloth and degreased, e.g. with acetone (CH_3COCH_3), and dried in air.

The test piece shall be protected from corrosion by varnish or similar means in the zones where the test piece enters the test cell and for at least 50 mm into the inner part of the cell. The test length (L_0) is the length of the test piece in contact with the solution.

10.4.2 Application and maintenance of force

The test piece is placed in the tensioning frame and the cell is placed on the test piece. Force shall be applied to the test piece until F_0 is reached.

The indicated force for F_0 shall be maintained within ±2 % for the duration of the test.

The value for F_0 shall be recorded at time, t_0, and shall be confirmed and, if necessary, adjusted at appropriate intervals during the test.

10.4.3 Filling of the cell

Upon completion of loading, the cell shall be sealed to prevent leakage and a volume, V_0, of test solution, which shall be a new one for each test, preheated to a temperature between 50 °C and 55 °C poured into the cell. V_0 shall be at least 5 ml per cm^2 of surface area of the test piece along the test length, L_0. Filling of the cell shall be finished within 1 min and then the time-measuring device shall be set to the starting time, t_0.

The solution shall not be circulated during the test.

10.4.4 Temperature during the test

Within the time interval t_0 and (t_0 + 5) min, the temperature of the test solution shall be adjusted to (50 ± 1) °C for wires and strands and (50 ± 2) °C for bars and shall be maintained in the relevant range throughout the test.

10.4.5 Termination of the test

The test shall be considered to have reached completion either on fracture of the test piece or at an agreed time, t_a.

In the case of strands, the test shall be considered to have reached completion if at least one wire is broken. If fracture of the test piece occurs outside the test length, L_0, the test shall be considered as invalid.

The time to fracture, $t_{f,i}$, shall be measured and recorded to the nearest 0,1 h. If fracture has not occurred within the time, t_a, the result shall be recorded as $t_{f,i} > t_a$.

10.4.6 Determination of median lifetime to fracture ($\overline{t}_f$)

When all the test pieces in the series have been tested, the results $t_{f,i}$ shall be ordered according to the values of lifetime to fracture. The median value ($\overline{t}_f$) is that in the middle of this ordered series, or the arithmetic mean of the two in the middle if there is an even number of test results.

11 Deflected tensile test

11.1 Principle of test

The test consists of determining the reduction coefficient of the maximum force in uniaxial tension due to a deviation of 20° around a specified mandrel, for 5 test pieces of a sample of strand with a nominal diameter equal to or greater than 12,5 mm.

11.2 Sample and test piece

The general provisions given in Clause 4 apply to a sample of sufficient length to provide at least 12 test pieces.

One test piece taken from each end of the sample shall be used in the uniaxial tensile tests to determine $\overline{F}_m$.

The remainder of the test sample shall be cut into at least 10 test pieces for deflected tensile tests.

Five valid test results are sufficient to calculate the D-value (see 11.4). But as invalid tests can occur, it is suggested that at least 10 available test pieces be provided.

The length of each test piece shall be appropriate to the testing and anchoring device.

The test pieces shall not be subject to any treatment or preparation other than cutting.

11.3 Test equipment

11.3.1 General description

The test machine shall have a stiff frame and shall fulfil the requirements specified in 11.3.2 to 11.3.5. The test machine consists of a fixed passive anchorage, a movable active anchorage to which a force-measuring device is attached, a loading device and a fixed grooved mandrel of specified dimensions.

11.3.2 Dimensions

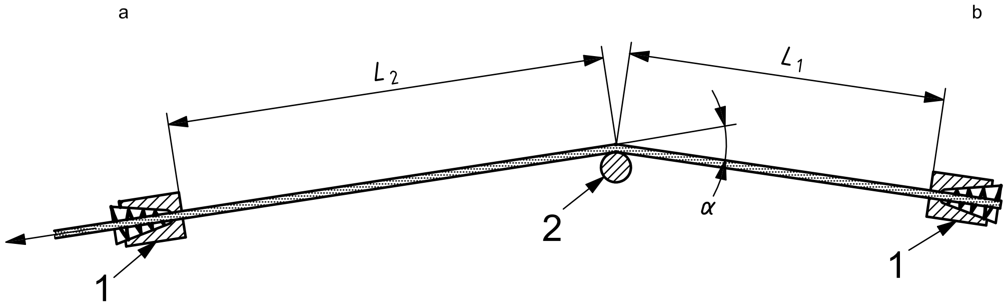
The dimensions of the test device shown in Figure 5 shall be as follows:

L_1: (700 ± 50) mm;

L_2: ⩾ 750 mm;

α: 20° ± 0,5°.

The axis of the mandrel shall be perpendicular to the plane formed between the active and the passive anchorage sides and the centre of the mandrel.



Key

1 anchorage

2 central mandrel

a Active side.

b Passive side.

Figure 5 — Main dimensions of the deflected tensile test device

11.3.3 Anchorages

The longitudinal axis of both ends of the test piece shall be perpendicular to the plane of bearings for the anchorages. An inadequate geometrical position may cause incorrect test results.

The anchorages shall fulfil the following requirements:

— uniaxial tensile tests with the anchorages (wedges and dies) used in the deflected tensile tests shall provide at least 95 % of the maximum force in the uniaxial tensile test carried out in accordance with Clause 5;

— axial displacement of the centre wire in relation to the outer wires of the strand shall be less than 0,5 mm at 90 % of the maximum force in the uniaxial tensile test;

— displacement of the wedges in the anchorage body shall be less than the values given in Table 6;

— the contact between the conical part of the die and wedges shall be secured during the test;

— the toothed part of the wedges shall have a minimum length of 2,5 times the strand diameter.

Table 6 — Displacement of wedges

Percentage of maximum force	Admissible maximum displacement[a] mm
from 0 % to rupture	5
from 50 % to rupture	2,5

[a] Bedding-in of the wedges prior to the beginning of the test shall be disregarded.

11.3.4 Mandrel

The mandrel shall be made of tool steel in accordance with ISO 4957. The chemical composition, microstructure and heat treatment shall be such that it is ductile and has a high wear resistance.

The surface hardness shall be 58 HRC to 62 HRC measured in accordance with ISO 6508-1.

The surface finish of the fresh mandrel groove shall have a roughness, *Ra*, of maximum 1,6 µm. *Ra* is defined in ISO 4287.

The dimensions of the mandrel (see Figure 6) are given in Table 7.

Table 7 — Dimensions of the mandrel

Parameter	**Strand diameter** (mm)		
	12,5 to 13,0	15 to 16	17 to 18
Nominal mandrel diameter, d_a (mm)	40	49	59
Angle of the groove flanks	60° ± 12′	60° ± 12′	60° ± 12′
Radius at the base of the groove, R (mm)	2 ± 0,2	2 ± 0,2	2 ± 0,2
Depth of the groove, G (mm)	7,6	9,5	12
Groove width, C, at nominal mandrel diameter, d_a (mm)	14,4	17,9	21,9
Inner diameter, d_i, of the groove (mm)	24,7 ± 0,1	29,9 ± 0,1	34,9 ± 0,1
Diameter with 2 cylinders in the groove, d_b (mm)	57,0 ± 0,1	72,0 ± 0,1	81,0 ± 0,1
Diameter of the gauge cylinder, d_e (mm)	14	18	20

The mandrel shall be rigidly fixed in such a way that any rotation or other movement is impossible.

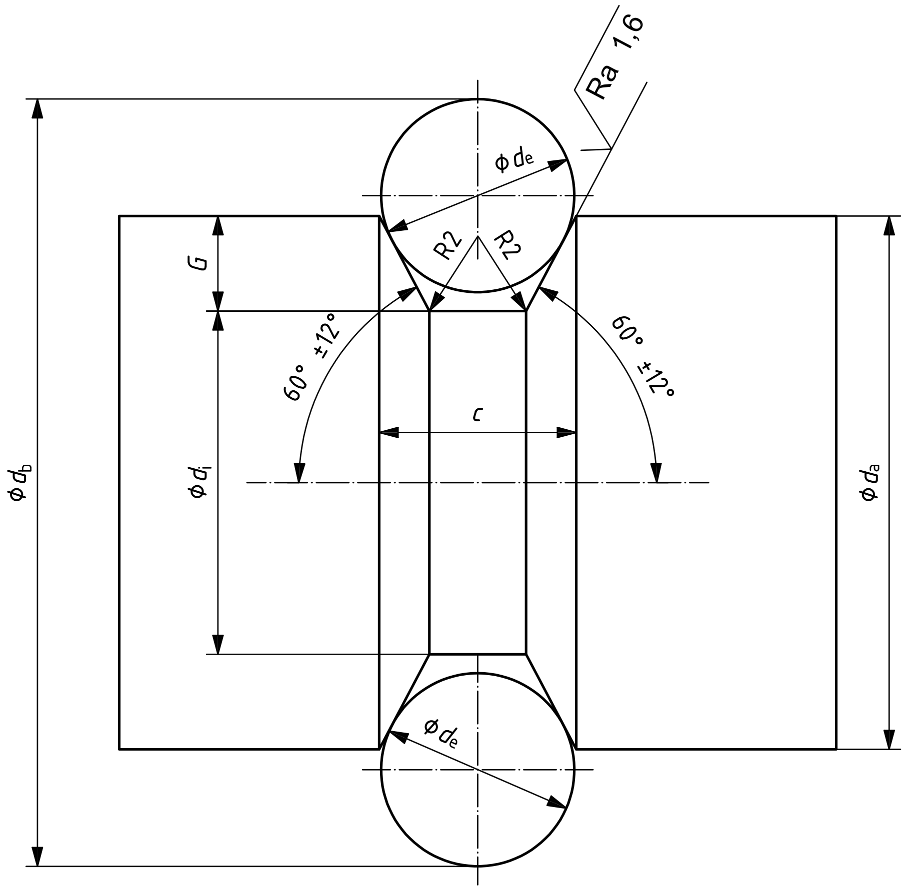


Figure 6 — Mandrel

11.3.5 Loading device

The loading equipment, preferably using a force cell, shall be calibrated in accordance with ISO 7500-1. Accuracy shall be at least ±1 % of the indicated force for forces ⩾10 % of the total force range.

The loading rate shall be adjustable. This rate shall be controlled during the test so that, when the force rises to 50 % of the anticipated breaking force, the rate shall be in the range 30 MPa·s^{-1} to 60 MPa·s^{-1} (or in the strain rate range of 15×10^{-5} s^{-1} to 30×10^{-5} s^{-1} if the test is strain-controlled). This rate shall then be maintained until fracture occurs.

11.4 Test procedure

The surface of the mandrel groove shall be carefully cleaned (see 10.4.1) before starting any test. If the strand is slightly curved, the test piece shall be laid into the groove in such a way that the curvature is in the same direction as the deflection during the test.

Proper alignment of the test piece shall be verified after installation in the anchorages and before application of any force. During loading, the grip efficiency of the anchorages shall be checked to verify that there is no slip between the strand and the anchorage grips.

The loading rate shall conform to 11.3.5.

A test shall be considered as invalid if the rupture of one or more wires of the strand does not occur at the contact with the mandrel.

The value of $F_{a,i}$ for a valid test shall be recorded with the accuracy indicated in 11.3.5. The corresponding value D_i shall be calculated from $F_{a,i}$ as follows and shall be reported:

$$D_i = (1 - F_{a,i} / \bar{F}_m) \times 100 \text{ in } \% \tag{4}$$

The D-value shall be calculated as the average of the five D_i values.

12 Chemical analysis

In general, the chemical composition is determined by spectrometric methods.

In case of dispute about analytical methods, the chemical composition shall be determined by an appropriate reference method specified in one of the relevant International Standards.

NOTE The list of the relevant International Standards for the determination of the chemical composition is given in the Bibliography.

13 Measurement of the geometrical characteristics

13.1 Test piece

The general provisions given in Clause 4 apply.

The length of the test piece shall be sufficient to carry out the measurements in accordance with 13.3.

13.2 Test equipment

The geometrical characteristics shall be measured with an instrument of a resolution of at least the following:

— 0,01 mm for the height of ribs (for bars or quenched and tempered wire) and the depth of indentations (for indented cold-drawn wire and strand);

— 0,05 mm for the gap between the ribs or indentations of two adjacent rib or indentation rows;

— 0,5 mm for the measurement of the distance between ribs or indentations when determining the rib or indentation spacing (see 13.3.1.3 and 13.3.2.3), the length of indentations (see 13.3.2.4) or of the lay length for strands (see 13.3.3);

— one degree for the inclination between the rib or indentation and the longitudinal axis of the wire or bar.

13.3 Test procedures

13.3.1 Rib measurements

13.3.1.1 Height at the highest point (a_{max})

The rib height at the highest point (a_{max}) shall be determined by measuring the height of n ($n \geqslant 5$) individual ribs in each row at their highest point and calculating the mean of all obtained individual values.

13.3.1.2 Rib height at a given position

The rib height at a given position, e.g. at the quarter-point or at the mid-point or at the three-quarters point, respectively designated $a_{1/4}$, a_m and $a_{3/4}$, shall be determined by measuring the height of n ($n \geqslant 3$) individual ribs in each row and calculating the mean of all obtained individual values.

13.3.1.3 Rib spacing (c)

The rib spacing (c) shall be determined from the length of the measured distance divided by the number of rib gaps.

The measured distance is deemed to be the interval between the centre of a rib and the centre of another rib on the same row of the product determined in a straight line and parallel to the longitudinal axis of the product. The measured distance shall include at least 10 rib gaps.

13.3.1.4 Part of the circumference without ribs ($\sum e_i$)

The part of the circumference without ribs ($\sum e_i$) shall be determined as the sum of the average gap (e) between ribs of two adjacent rib rows, for each rib row. The average gap (e) shall be determined from at least 3 measurements.

13.3.1.5 Rib inclination angle (β)

The rib inclination angle (β) shall be determined as the mean of the individual angles measured for each row of ribs with the same angle.

13.3.1.6 Width of transverse rib (b)

The width of transverse rib (b), see Figure 8, section M-M, shall be determined as the mean of three measurements on each row, at the mid-point of the rib, made normal to the axis of the rib.

13.3.2 Indentation measurements

13.3.2.1 General

Measurements on indented strand shall be made on each individual wire from the test piece. Prior to measurement, the individual wires shall be separated from the strand and straightened without change to the wire surface. Single-wire test pieces which are not straightened in the production process shall be straightened, prior to measurement, without a change to the wire surface.

13.3.2.2 Depth at the deepest point (a_{max})

The indentation depth at the deepest point (a_{max}) shall be determined by measuring the depth of n ($n \geqslant 5$) individual indentations in each row at their deepest point and calculating the mean of the individual values obtained.

13.3.2.3 Indentation spacing (c)

The indentation spacing (c) shall be determined from the length of the measured distance divided by the number of protrusions between indentations included in it.

The measured distance is deemed to be the interval between the side of an indentation and the corresponding side of another indentation on the same row of the product, determined along a line crossing the indentations in their centres and parallel to the longitudinal axis of the product, at the surface level of the wire. The measured distance shall include at least 10 protrusions between indentations.

13.3.2.4 Length of indentation (l)

The length of indentation (l) shall be determined as the mean of three measurements on each row made parallel to the longitudinal axis of the wire along a line crossing the indentation in its centre, at the surface level of the wire.

13.3.2.5 Part of the circumference without indentations ($\sum e_i$)

The part of the circumference without indentations ($\sum e_i$) shall be determined as the sum of the average gap (e) between indentations of two adjacent indentation rows, for each indentation row. The average gap (e) shall be determined from at least 3 measurements.

13.3.2.6 Indentation angle (β)

The indentation angle (β) shall be determined as the mean of the individual angles measured for each indentation row.

13.3.3 Lay length of strand (P)

The lay length of strand (P) shall be determined as the distance between two consecutive corresponding points of the same wire.

It is recommended that this distance be measured on paper onto which an impression of the strand is made by rubbing.

13.3.4 Straightness

The bow height (h_b) which indicates the straightness of the product shall be determined by measuring in the plane of the bow the distance between the prestressing steel and the line joining the ends of a rule of 1 m long in contact with the prestressing steel lying on a flat horizontal surface with a flatness tolerance of 1 mm/m (see Figure 7).

Distance in metres

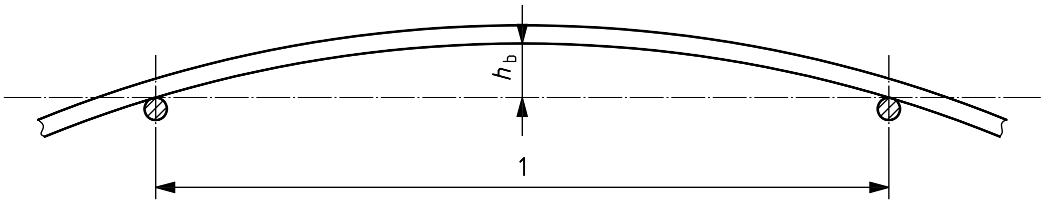


Figure 7 — Measurement of bow height

14 Determination of the relative rib area (f_R)

14.1 General

The determination of the relative rib area (f_R) for ribbed prestressing steel shall be carried out using the results of measurements made in accordance with 13.3.1.

14.2 Calculation of f_R

14.2.1 Relative rib area

The relative rib area is defined by the following formula:

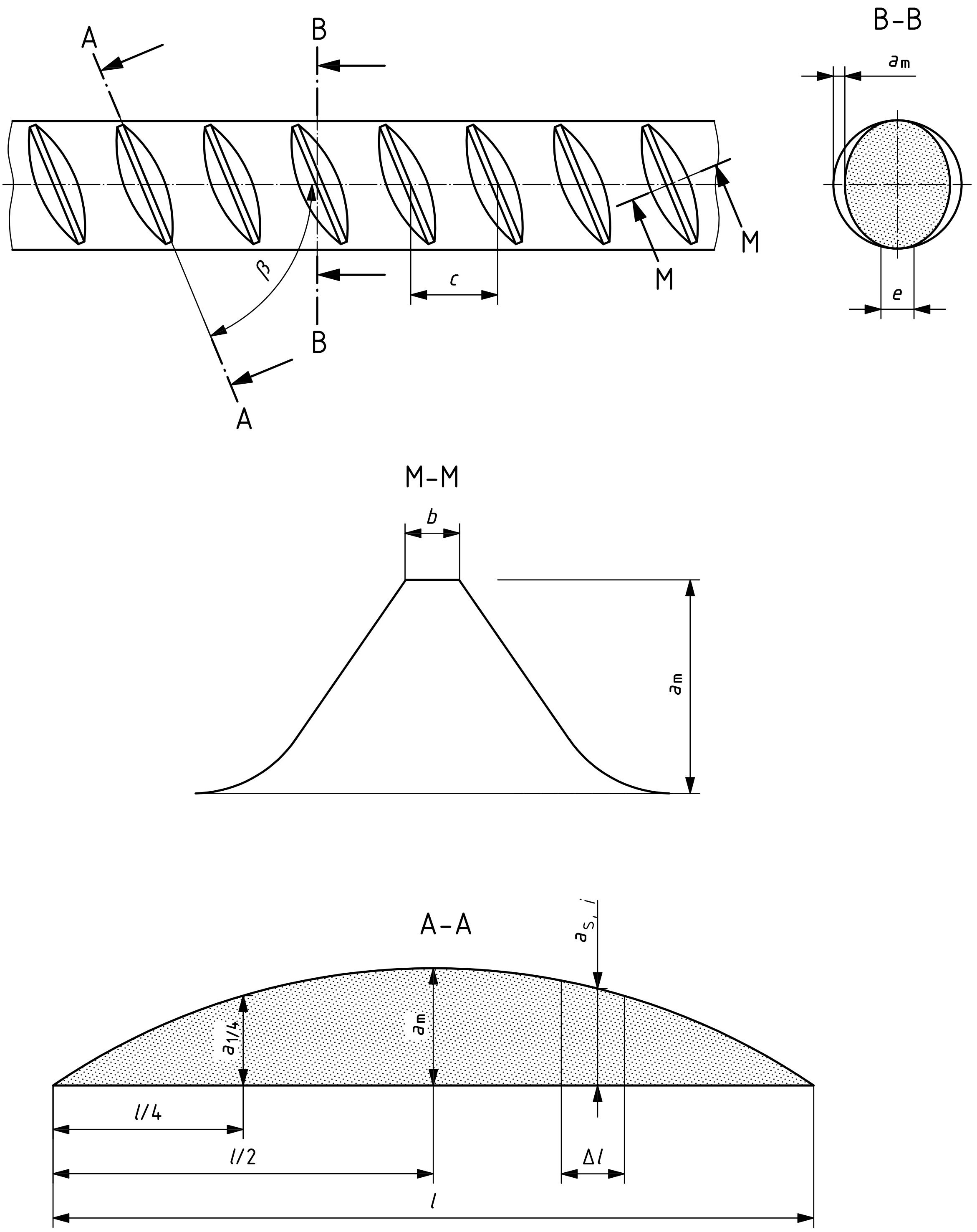
$$f_R = \frac{1}{\pi d} \sum_{i=1}^{n} \frac{\frac{1}{m} \sum_{j=1}^{m} F_{R,i,j} \sin \beta_{i,j}}{c_i} \tag{5}$$

where

n is the number of rows of transverse ribs on the circumference;

m is the number of different transverse rib inclinations per row.

$F_R = \sum_{i=1}^{p} (a_{s,i} \Delta l)$ is the area of the longitudinal section of one rib (see Figure 8) where $a_{s,i}$ is the average height of a portion i of a rib subdivided into p parts of length Δl.



NOTE Section A-A is a flattened representation of a transverse rib.

Figure 8 — Determination of the area of the longitudinal section, F_R

14.2.2 Simplified formulae

Where the general formulae given in 14.2.1 are not strictly applied by using special devices, a simplified formula may be used.

Examples of simplified formulae are as follows:

a) Trapezium formula:

$$f_R = (a_{1/4} + a_m + a_{3/4})(\pi d - \sum e_i)\frac{1}{4\pi dc} \tag{6}$$

b) Simpson's rule formula:

$$f_R = (2a_{1/4} + a_m + 2a_{3/4})(\pi d - \sum e_i)\frac{1}{6\pi dc} \tag{7}$$

c) Parabola formula:

$$f_R = \frac{2a_m}{3\pi dc}(\pi d - \sum e_i) \tag{8}$$

d) Empirical formula:

$$f_R = \lambda \frac{a_m}{c} \tag{9}$$

where λ is an empirical factor that may be shown to relate f_R to a particular wire profile.

The values $a_{1/4}$, a_m, $a_{3/4}$ shall be determined in accordance with 13.3.1.2. $\sum e_i$ shall be determined as indicated in 13.3.1.4.

14.2.3 Formula used for the calculation of f_R

The formula used for the calculation of f_R shall be in accordance with the product standard and be stated in the test report.

15 Determination of deviation from nominal mass per metre

15.1 Test piece

In addition to the general provisions given in Clause 4, the test pieces shall have square-cut ends.

15.2 Accuracy of measurement

The length and mass of the test piece shall be measured with an accuracy of at least ±0,5 %.

15.3 Test procedure

The percentage deviation from nominal mass per metre shall be determined from the difference between the actual mass per metre of the test piece, deduced from its mass and length, and the nominal mass per metre as given by the relevant product standard.

16 Test report

The test report shall include the following information:

a) a reference to this part of ISO 15630, i.e. ISO 15630-3:2010;

b) the identification of the test piece (including the nominal diameter of the bar, wire or strand);

c) the free length of the test piece;

d) the type of test carried out and the relevant test results;

e) the relevant product standard, if applicable;

f) any complementary useful information concerning the test piece, test equipment and procedure.

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