Czech Metrology Institute

Okružní 31, 638 00 Brno

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Executive summary for the EC (not part of this legislation)

Tendon assemblies for prestressed concrete and rock anchors are subject to national metrological regulation – initial verification and follow-up verification at the specified intervals when they are put into use and during subsequent use. The subject of this regulation is to lay down metrological and technical requirements for these measuring instruments, including the testing methods for the initial verification and follow-up verification of these measuring instruments already put into use.

The requirements imposed on these measuring instruments when in use are based on the document ETAG 013 from June 2002.

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PUBLIC DECREE

As the authority with substantive and territorial jurisdiction in the matter of laying down metrological and technical requirements for specified measuring instruments and stipulating test methods for type approval and verification of specified measuring instruments pursuant to § 14(1) of Act No 505/1990, on metrology, as amended, and in accordance with the provisions of § 172 et seq. of Act No 500/2004, the Code of Administrative Procedure (hereinafter the AC), the Czech Metrology Institute (CMI) commenced ex officio proceedings on 26. 2. 2016 pursuant to § 46 of the CAP, and, based on supporting documents, issues the following:

I.

DRAFT GENERAL MEASURE

number: 0111-OOP-C070-18

laying down metrological and technical requirements for specified measuring instruments, including requirements for verification of the following specified instruments:

“tendon assemblies for prestressed concrete and rock anchors”

1 Basic definitions

The terms and definitions pursuant to VIM and VIML[1] as well as the terms and definitions specified in the following shall apply for the purposes of this general measure:

1.1
tendon assembly
device which serves to prestress building structures and rock anchors using inserted reinforcement

1.2
stressing jack
hydraulic cylinder with piston which serves to exert prestressing force

1.3
hydraulic unit
device which serves as a source of hydraulic pressure for the stressing jack

1.4
force measuring instrument
the part of a tendon assembly which serves to measure tensioning force

1.5
pressure gauge
deformation or electromechanical pressure gauge used to measure the oil pressure in the stressing jack

1.6
reference load cell
load cell which serves to verify a tendon assembly

1.7
reference pressure gauge
pressure gauge which serves to calibrate the working pressure gauges of a tendon assembly

1.8
tendon assembly confidence interval, E_{NS}
The limits of the confidence interval are given by the sum of the relative error of the force indication and the relative expanded uncertainty of the tendon assembly.

1.9
interpolated force value, F_a
force value calculated according to the polynomial of the first, second or third degree

1.10
force indicated on tendon assembly scale, F_i
the force value indicated on the scale of the tendon assembly (if the tendon assembly is equipped with such a scale) or the force value determined from the diagram or equation

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[1] TNI 01 0115 International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM) and International Vocabulary of Legal Metrology (VIML) are part of the technical harmonisation compendium ‘Terminology in the field of metrology’, which is publicly available at www.unmz.cz.

1.11
force indicated on tendon assembly scale, F_i

the force value indicated on the scale of the tendon assembly (if the tendon assembly is equipped with such a scale) or the force value determined from the diagram or equation

1.12
force on one piston of a multi-cylinder tendon assembly, F_j

the force value which one piston of the tendon assembly's press puts on the corresponding reference load cell in each load level set

1.13
nominal test force value, F_N

the greatest force value of the tendon assembly's measurement range

1.14
force value indicated on tendon assembly scale, F_{NS}

the force value indicated on the scale of the tendon assembly or the force value calculated from the pressure of the oil in the hydraulic press cylinder.

1.15
zero variable value before loading, I_0

indication value of the variable quantity (actual force or oil pressure) before a measurement series when the tendon assembly is unloaded, indicated in units of force or pressure

1.16
zero variable value after loading, I_f

indication value of the variable quantity (actual force or oil pressure) after a measurement series when the tendon assembly is unloaded, indicated in units of force or pressure

1.17
tendon assembly sensitivity coefficient, S

The sensitivity coefficient is the ratio between the force value and the oil pressure in the tendon assembly at the reference measurement point. These are usually the nominal force and oil pressure values.

1.18
expanded tendon assembly uncertainty, U_{NS}

the value of the error in force or oil pressure read out at each load level for probability P = 0.95

1.19
expanded relative uncertainty of tendon assembly, W_{NS}

the relative value of the error in force or oil pressure calculated at each load level for probability P = 0.95

1.20
interpolated value of variable quantity, F_a

force or pressure value calculated according to the polynomial of the first, second or third degree

1.21
value of variable quantity, X_i (X_1 to X_n)

the values of the oil pressure in the cylinder of the tendon assembly (at a constant actual force) or the value of the actual force (at constant oil pressure in the cylinder of the tendon assembly), measured when verifying the tendon assembly

1.22
greatest value of the variable quantity at the measurement point, X_{max}

the greatest value of the variable quantity at the measurement point in question

1.23
the smallest value of the variable quantity at the measurement point, X_{min}

the smallest value of the variable quantity at the measurement point in quantity

1.24
mean value of the variable quantity, X_r

the value of the variable quantity (force or pressure), calculated as the arithmetic average of the values measured with the reference load cells or pressure gauge at each load level

1.25
mean value of variable specification at nominal force, X_N

mean value of variable at nominal force. Specified in units of force or pressure.

1.26
relative value of the tendon assembly's resolution, a

relative value of the smallest specification on the tendon assembly's force scale which can be indicated on the scale. It is specified in % of the measured value (hereinafter in % MV).

1.27
relative repeatability error, b

a relative value determined as the proportion of the difference of the greatest values of variable specifications ascertained when verifying the tendon assembly divided by their mean value. Expressed in % MV.

1.28
relative interpolation error, f_a

the relative value of the difference between the mean value of variable X_r and value X_a, calculated from the polynomial of the 1st, 2nd or 3rd degree. Expressed in % MV.

1.29
relative zero value error, f_0

the relative value of the difference between the values measured on the scale of the tendon assembly or reference load cell in relation to the nominal value. Expressed in % MV.

1.30
relative tendon assembly error in reverse operation, h

the relative value of the difference in the variable quantity (force or oil pressure) during loading and unloading of the tendon assembly at the same load level, in relation to the value during loading

1.31
number of tendon assembly cylinders, m
the number of cylinders which are connected in parallel for the purpose of increasing stress force

1.32
number of measurement series, n
the number of identical load cycles when verifying the tendon assembly

1.33
pressure value in a single cylinder of the tendon assembly, p_i
oil pressure value in a single cylinder of the tendon assembly at the applicable load level

1.34
nominal pressure of tendon assembly, p_N
the oil pressure in the cylinder of a stressing jack which must build up in order to reach the nominal force F_N (usually the highest oil pressure value at which a test of a device for measuring the force of a tendon assembly is carried out). Specified in units of force or pressure.

1.35
average pressure value in all tendon assembly cylinders, p_r
the average oil pressure value calculated from partial pressures in all tendon assembly cylinders. Calculated for each load level.

1.36
relative error of force measuring instrument, q
the relative value of the difference in force read on the tendon assembly's scale and the actual force, in relation to actual force

1.37
resolution capacity of tendon assembly, r
the smallest value which the tendon assembly's scale is capable of indicating, specified in units of force or oil pressure

1.38
standard uncertainty of interpolation, u_a
the value of the standard uncertainty of interpolation is determined as the difference in force or oil pressure values calculated from the interpolation scale and the actual values. Specified in units of force or oil pressure.

1.39
standard uncertainty of repeatability, u_b
the value of the standard uncertainty of repeatability is determined as the standard deviation of the arithmetic average of the measured values of the variable quantity (force or oil pressure)

1.40
combined uncertainty of the tendon assembly, u_c
The combined uncertainty of the tendon assembly is determined as the square root of the sum of the squares of the standard uncertainties of repeatability, resolution of the reference force and interpolation.

1.41
standard uncertainty of zero value, u_0

The value of the standard uncertainty of the zero value is determined as the arithmetic average of the differences in the variable quantity after unloading and before loading the tendon assembly. Specified in units of force or pressure.

1.42
standard uncertainty of reference load cell, u_{EF}

The standard uncertainty of the reference load cell is calculated from the data specified on the calibration sheet for the reference load cells, from the environmental conditions and from their properties.

1.43
standard uncertainty of reference load cell calibration, $u_{F,cal}$

The standard uncertainty of the calibration of the reference load cell is calculated from the data specified on the calibration sheet for the reference load cells.

1.44
standard uncertainty of tendon assembly resolution, u_r

The standard uncertainty of the resolution of the scale on the tendon assembly's indication device. Specified in units of oil pressure or force.

1.45
relative standard uncertainty of interpolation, w_a

The value of the relative standard uncertainty of interpolation is determined as the difference in force or oil pressure values calculated from the interpolation scale and the actual values. It is in relation to the actual force value. Expressed in % MV.

1.46
relative standard uncertainty of repeatability, w_b

The value of the relative standard uncertainty of repeatability is determined as the standard deviation of the arithmetic average of the measured values of the variable quantity (force or oil pressure) in relation to the measured value at the applicable calibration point. Expressed in % MV.

1.47
relative standard uncertainty of calibration of reference load cell, $w_{F,cal}$

The relative standard uncertainty of calibration of the reference load cell is calculated from the data specified on its calibration sheet. Expressed in % MV.

1.48
relative standard uncertainty of reference load cell, w_{EF}

The relative standard uncertainty of the reference load cell is calculated from the data specified on the calibration sheet for the reference load cells, from partial relative uncertainty of environmental influence and from the load cells' properties. Expressed in % MV.

1.49
relative standard uncertainty of zero value, w_0

The value of the relative standard uncertainty of the zero value is determined as the arithmetic average of the differences in the variable quantity after unloading and before loading the tendon assembly, in relation to the value of the variable at nominal force. Expressed in % MV.

1.50
relative standard uncertainty of tendon assembly resolution, w_r

The relative standard uncertainty of the resolution of the scale on the tendon assembly's indication device. Expressed in % MV.

1.51
relative uncertainty of interpolation of reference load cell, w_{ap}

the relative uncertainty of interpolation of the reference load cell when calibrating the measuring instrument of the tendon assembly. It is determined from the calibration sheets of the reference load cells. Expressed in % MV.

1.52
relative error of reference load cell caused by signal drift, w_{drift}

the relative standard uncertainty of the change in time of a reference load cell's signal since the last calibration. Expressed in % MV.

1.53
relative error of reference load cell caused by differences in temperature, w_{temp}

The relative standard uncertainty of the reference load cell caused by a temperature which was different when the tendon assembly was verified and when it was calibrated. Expressed in % MV.

1.54
force-pressure diagram

the dependence of the force acting on the roving or anchor on the oil pressure in the stressing jack cylinder

1.55
measurement series

each measurement cycle at 8 to 15 measurement points when loading the stressing jack and the reference load cell from the zero position to nominal force and subsequently unloading them to the unloaded state

2 Metrological requirements

2.1 Requirements for tendon assemblies

The metrological requirements on tendon assemblies are based on the document ETAG 013[2] and are specified in Table 1.

Table 1 – Metrological parameters of tendon assemblies

Maximum permissible relative expansion of uncertainty of the tendon	Maximum value of relative permissible error of tendon assembly for:				Maximum relative expanded uncertainty of reference load cell
	tensioning force indication	tensioning force repeatability	tensioning force interpolation	resolution of the tendon assembly's force indicator	

[2] ETAG 013 Post-tensioning kits for prestressing of structures. This document is available to the public at www.oiml.org.

assembly W_{NS}	q	b	f_a	a	W_{EF}
% MV					
2	±2	1	±1	1	0.4

3 Technical requirements

Technical requirements for tendon assemblies are divided into the following parts:

a) stressing jack;
b) hydraulic unit;
c) connection hose;
d) measuring systems;
e) frame load plates.

3.1 Stressing jack

The stressing jack serves to exert and measure force when prestressing supporting elements in prestressed concrete structures and rock anchors. The design of the stressing jack must enable the safe testing of force measuring instruments (pressure and piston movement). The body of the stressing jack must bear a table with the basic identification information. The stressing jack may be with one hydraulic cylinder or several.

Length measuring instruments which are part of certain stressing jacks are calibrated as length measuring instruments according to separate accredited calibration procedures. Their calibration is not part of this general measure.

3.2 Hydraulic unit

The hydraulic unit serves to supply pressure oil for the stressing jack. It contains a pump with drive, control and measuring circuits. It also contains a cooling system for cooling the oil. The hydraulic unit's pump must be dimensioned so that it is able to deliver a quantity of oil at the pressure needed to exert the nominal force of the stressing jack. Hydraulic unit regulation systems must enable the setting of the speed of increasing or decreasing the oil pressure in order to enable reliable indication of oil pressure and test force values. The hydraulic unit cabinet must bear a table with the basic identification information.

3.3 Connection hose

The connection hose must be dimensioned for the maximum possible pressure and maximum quantity of oil transported. The length of the hoses must conform to spatial requirements. The hoses must be marked with identifying information.

3.4 Oil pressure measuring systems

The oil pressure measuring system is mechanical or electromechanical. A mechanical measurement system is made up of a deformation pressure gauge. The deformation pressure gauge must have an accuracy of 1 % or better. An electromechanical system is designed on the basis of tensometric or piezoelectric oil pressure sensors and the associated amplifiers. The uncertainty of the pressure sensors and amplifiers must be better than 0.2 %. The pressure sensors and amplifiers must be unambiguously identifiable by the manufacturer's marks, model and serial number.

3.5 Frame load plates

The load plates are separate components of the load frame. They serve as adaptable elements for placing force between the reference load cells, the frame and the stressing jack. The load plates must be made of material of suitable quality and workmanship. The bearing surfaces of the plates must be level and smooth so as not to damage the bearing surfaces of the reference load cells or tendon assemblies. The measuring part of the reference load cell must be loaded by way of a ball joint. The plates must be dimensioned for the required load strength so as to prevent undesired deformation to the reference load cells which would have an adverse effect on the measured values.

4 Measuring instrument markings

4.1 Markings on tendon assemblies

The stressing jack and hydraulic unit must bear an easily accessible manufacturer's identification table with the marking:

a) name of manufacturer or commercial company;
b) tendon assembly model;
c) year of manufacture;
d) serial number;
e) nominal force;
f) nominal oil pressure.

The oil pressure sensors on the stressing jack (if installed) must bear the following information:

g) name of manufacturer or commercial company;
h) sensor model;
i) serial number;
j) nominal pressure.

All data, specifications, information, etc. required in the articles of this measure must be specified in the user manual.

4.2 Official mark placement

The tendon assembly must have easily accessible places to put the official marks. All measuring systems must have official marks in order to prevent any tampering with system elements that could cause changes to the measuring instrument's metrological properties.

5 Type approval of the measuring instrument

5.1 General information

The type approval of the measuring instrument is not relevant.

6 Initial verification

6.1 General information

The process of the initial verification of the tendon assembly encompasses:

a) visual inspection;
b) function test – a test of the measuring instrument's prestressing force.

6.2 Visual inspection

The purpose of the visual inspection of the tendon assembly shall be to check that:

a) the tendon assembly submitted for verification has all functional parts and that these parts are not mechanically damaged;

b) the measuring systems and their components are suitable in terms of functionality and integrity:
   - the stressing jack does not have a damaged piston gasket and sealing and the bearing surfaces and anchor elements are not damaged;
   - the pressure gauges measuring the oil pressure in the stressing jack cylinders have the necessary accuracy, are not damaged, do not bear signs of external intervention and operate smoothly;
   - the electronic indicator has the necessary accuracy (in the case of an electromechanical system for measuring prestressing force);
   - the hydraulic unit has the necessary performance, does not bear signs of damage, the hydraulic part is well-sealed and the electrical part is free of external defects;
   - the connection hoses are correctly dimensioned for the oil quantity and oil pressure and are not damaged;
   - the tendon assembly has been installed on the load frame according to the manufacturer's instructions.

6.3 Function test

6.3.1 Test equipment

The function test makes use of a reference load cell or set of load cells (depending on the type of tendon assembly and the size of the nominal force), a load frame, components for exerting force, a stressing jack, a tendon assembly measuring system, hydraulic unit and connection hose.

6.3.1.1 General information

Tendon assembly verification consists of the following parts:

a) assessment of the technical condition of the tendon assembly;
b) calibration of the prestressing force measuring system.

6.3.1.2 Tools and equipment required

The following measuring instruments and equipment are required for verifying tendon assemblies:

a) reference load cells

   The test of the tendon assemblies' force measuring instruments requires reference load cells with a relative expanded uncertainty less than the value specified in Table 1 of this general measure. The design of the reference load cell must be suitable for the verified type of tendon assembly.

b) stenter frame

   The stenter frame serves to exert the test force from the stressing jack on the reference load cell. It must meet the technical conditions for the verification of the applicable tendon assemblies and must be sufficiently dimensioned so as not to affect the measurement results caused by uneven deformation during measuring. It is also necessary to ensure that the force and deformation influences of the frame on the verified assembly do not differ too greatly from the conditions during the actual prestressing. The stenter frame must be designed so as not to cause non-axial loading of the reference load cells or to otherwise negatively influence the results of the tendon assembly measuring instrument test.

c) pressure gauges for tendon assembly calibration

The tendon assembly must be fitted with pressure gauges of a suitable design and corresponding precision class. Tendon assembly verification can be carried out with a reference pressure gauge which is not part of the tendon assembly. In this case, the tendon assembly must be supplemented by additional pressure gauges of the required precision class with valid calibration sheets. It will then be necessary to correct the uncertainty of the tendon assembly by the calibration uncertainty of these pressure gauges.

Components of the stenter frame include other auxiliary devices which serve to manipulate the stressing jack and reference load cell and fit them into the frame. Base plates for exerting force on the reference load cell, stressing jack and clamping parts are also part of the frame.

d) thermometer for measuring the ambient temperature

Thermometers serve to measure the temperature of the environment during measuring, for measuring the temperature of the reference load cells and for measuring the oil temperature. The maximum permissible error of thermometers for measuring the ambient temperature and load cells is ±0.6 °C.

6.3.2 Performance of the function test

The tendon assembly is fitted with a built-in reference load cell (or load cells) for the test of the prestressing force measuring system. Setup and connection are checked and the hydraulic unit is turned on. The system is left at rest for 30 minutes to allow the operation and electronic measuring system of the force gauges to stabilise. The zero value of the force and oil pressure are then detached and a load cycle is conducted from an unloaded state to the nominal force value of the tendon assembly (usually the upper limit of the measurement range). The force is maintained at this value for a period of 3 minutes. The smoothness of the increase in load force and the behaviour of the stressing jack are checked during loading. If there is a delay at nominal force, then the stability of maintaining the set force is to be checked. If this function test is carried out without problems, then the test of the tendon assembly’s load cell equipment is conducted according to point 6.3.3.

6.3.3 Test of the tendon assembly’s force measuring instrument

This test is conducted by one of two measurement procedures. Each procedure begins with three preliminary loadings from the unloaded state to the nominal force value of the tendon assembly and then by unloading it to the unloaded state. The delay at zero force value and nominal value is greater than 90 seconds. The value of the force and pressure in the unloaded state and at nominal prestressing force value is recorded during this process. Once the preliminary loading has been completed, the actual measuring cycle is carried out.

With tendon assemblies having one hydraulic cylinder, at least three measurement series are conducted under loading with removal of actual force and pressure values at the force calibration points with subsequent unloading from the upper limit of the measurement range to the unloaded state. The measurement series must contain at least eight load levels.

With tendon assemblies having two or more cylinders, the reference load cell is placed beneath each piston of the tendon assembly. Preliminary loading to the maximum loading force with subsequent complete unloading is carried out three times. The delay upon preliminary loading at zero value must be longer than 30 seconds. Two measurement series are then carried out under loading with removal of the actual force values beneath each cylinder of the stressing jack and the oil pressure values in each cylinder of the stressing jack or average oil pressure in all cylinders. The measurement is carried out at each load level up to nominal force. It is then unloaded to the unloaded state. If the tendon assembly allows, then two measurement series are to follow during loading and unloading (series 3 and 4) while removing the actual force and oil pressure values at the measurement points. If the tendon assembly does not allow a test to be carried out in reverse operation, then one measurement series is to follow under unloading only.

Each measurement series must contain at least eight points on the tendon assembly’s force scale. The individual measurement errors may not be greater than the values specified in Table 1.

6.4 Evaluation of the test of tendon assemblies with one cylinder

The values measured during the accuracy test are recorded and evaluated.

6.4.1 Mean value of the variable quantity

The mean value of the variable quantity is calculated from the values removed in the first, second and final measurement series (X_1 to X_n) during loading. The calculation is conducted according to the equation:

$$X_r = \frac{1}{n}\sum_{i=1}^{n} X_i \qquad (1)$$

6.4.2 Tendon assembly sensitivity coefficient

The sensitivity coefficient of the tendon assembly is determined as a proportion of the actual force and the corresponding oil pressure at the value of the upper limit of the tendon assembly's measurement range. The calculation is conducted according to the equation:

$$S = \frac{F_N}{p_N} \qquad (2)$$

If the force is the constant quantity during the measurement, then the maximum force of the measured range (in units of force) is set for F_N and the mean pressure value X_r (in units of pressure) is set for p_N. If oil pressure is the constant quantity during the measurement, then the mean value X_r (in units of force) is set for the force value F_N and the corresponding pressure value is set for p_N (in units of pressure).

6.4.3 Relative error of force measuring instrument

The relative error of the force measuring instrument q is determined as the difference between the force value F_i measured by the tendon assembly and the corresponding mean actual force value F_r. The value F_i is the force indicated by the tendon assembly (if the tendon assembly has a readout in units of force) or the force is calculated from the pressure values by means of the sensitivity coefficient. This error is only indicated if the sensitivity coefficient is the output value of the tendon assembly measuring instrument test or if the tendon assembly has a scale in units of force. In the case of tendon assemblies with a scale in units of pressure with readout of force-pressure values in the table and diagram, then this error is not indicated. The relative error q is specified in per cent of the measured value (% MV) and is determined according to the equation:

$$q = \frac{F_i - F_r}{F_r} \times 100 \qquad (3)$$

in which F_i .... is the force indicated by the tendon assembly (kN, MN)

F_r .... is the actual force value measured by the reference load cell (kN, MN).

6.4.4 Relative repeatability error of the force measuring instrument

The relative repeatability error b is determined from the values measured during the test of the tendon assembly. It is expressed in % MV and determined from the equation:

$$b = \frac{X_{\max} - X_{\min}}{X_r} \times 100 \qquad (4)$$

in which b ...... is the relative repeatability error of the tendon assembly (% MV),

X_{max} . is the maximum force or oil pressure value indicated by the tendon assembly (depending on which quantity is variable) for the load level in question (kPa, MPa, bar or kN, MN),

X_{min} . is the minimum force or oil pressure value indicated by the tendon assembly (depending on which quantity is variable) for the load level in question (kPa, MPa, bar or kN, MN).

X_r ..... value of the variable quantity (force or pressure), calculated as the arithmetic average of the values measured with the reference load cells or pressure gauge at each load level (kPa, MPa, bar or kN, MN).

6.4.5 Relative resolution error of indicator device

The relative resolution error of indicator device a is determined from the indicator's resolution value r and the force value F for each measurement point. It is specified in % MV and determined from the following equation:

$$a = \frac{r}{F_i} \times 100 \tag{5}$$

in which a . . is the relative resolution error (% MV),

r . . . is the resolution value of the tendon assembly's scale (kN, MN),

F_i . . is the value of the load level (kN, MN).

6.4.6 Relative interpolation error of the force measuring instrument

The relative interpolation error f_a is determined for each measured value of force as the difference between the force value measured by the tendon assembly and the value calculated from the polynomial of the first, second or third degree or read from the diagram. The relative interpolation error f_a is expressed in % MV. It is calculated from the equation:

$$f_a = \frac{F_a - F_r}{F_r} \times 100 \tag{6}$$

in which f_a ..... is the relative interpolation error (% MV),

F_r .... is the calculated mean value of the actual force (oil pressure is the constant quantity) (kN, MN),

F_a .... is the force value calculated according to the polynomial of the first, second or third degree (kN, MN).

6.5 Test of tendon assemblies with stressing jack with multiple cylinders

Proceed accordingly when verifying tendon assemblies with a stressing jack with multiple cylinders. The test is conducted at constant oil pressure at the load level. The values measured during the test are recorded and evaluated. This procedure applies to tendon assemblies with m measuring cylinders, in which each cylinder has an electromechanical pressure gauge and pressure oil intake of its own. The test force is measured with a separate load cell for each measuring piston of the stressing jack. The reference load cells must be conducted to a measuring system with m components. The measured force values must be removed from all reference load cells at the same moment in time.

6.5.1 Mean oil pressure value in the cylinders of the stressing jack

The oil pressure in each cylinder is measured with a separate electromechanical pressure gauge. The mean pressure value is calculated from the pressure values measured and serves as the constant value for measuring the actual forces which the pistons of the tendon assembly exert upon the reference load cells.

$$p_r = \frac{1}{m} \times \sum_{i=1}^{m} p_i \qquad (7)$$

6.5.2 Value of the test force of the tendon assembly at load level for the measurement series

The total force development by the tendon assembly at the load level in question is calculated from the values measured by the reference load cells. The calculation is conducted according to the equation:

$$F_i = \sum_{j=1}^{m} F_j \qquad (8)$$

6.5.3 Mean value of the test force of the tendon assembly at load level

The average value of the tendon assembly's prestressing force is determined from the values measured by the reference load cells at the point in question. The calculation is conducted according to the equation:

$$F_r = \frac{1}{n} \times \sum_{i=1}^{n} F_i \qquad (9)$$

6.5.4 Tendon assembly sensitivity coefficient

The sensitivity coefficient of the tendon assembly is determined as a proportion of the actual force and the corresponding oil pressure at the point on the tendon assembly's measurement range which serves to set the characteristics. The calculation is conducted according to the equation:

$$S = \frac{F_r}{p_r} \qquad (10)$$

6.5.5 Force indicated by tendon assembly

The force indicated by the tendon assembly is determined by two methods. In tendon assemblies equipped with a scale in units of force, this value of force is read on the scale. In tendon assemblies equipped with a pressure gauge with a scale in units of pressure, the force is calculated from the equation:

$$F_{NS} = S \times p_r \qquad (11)$$

6.5.6 Relative error of force measuring instrument

The relative error of the force measuring instrument q is determined as the difference between the force value F_i measured by the tendon assembly and the corresponding actual force value F_r. The value F_i is the force indicated by the tendon assembly (if the tendon assembly has a readout in units of force) or the force is calculated from the pressure values by means of the sensitivity coefficient. This error is only indicated if the sensitivity coefficient is the output value of the verification of the tendon assembly or if the tendon assembly has a scale in units of force. In the case of tendon assemblies with a scale in units of pressure with readout of force-pressure values in the table and diagram, then this error is not indicated. The relative error q is specified in per cent of the measured value (% MV) and is determined according to the equation:

$$q = \frac{F_i - F_r}{F_r} \times 100 \qquad (12)$$

in which F_i .... is the force indicated by the tendon assembly (kN, MN),

F_r .... is the actual force of the tendon assembly measured by the reference load cells (kN, MN).

6.5.7 Relative repeatability error of the force measuring instrument

The relative repeatability error *b* is determined from the values measured during the test of the tendon assembly. It is calculated from the equation:

$$b = \frac{X_{max} - X_{min}}{X_r} \times 100 \quad (13)$$

in which b ...... is the relative repeatability error of the tendon assembly (% MV)

X_{max} . is the maximum value of force indicated by the tendon assembly at the load level (kN, MN),

X_{min} . is the minimum value of force indicated by the tendon assembly at the load level (kN, MN),

X_r .... is the mean value of the variable quantity (force) at the load level in question (kN, MN).

6.5.8 Relative resolution error of indicator device

The relative resolution error of indicator device *a* is determined from the indicator's resolution value *r* and the force value F_r for each load level. It is specified in % MV and determined from the following equation:

$$a = \frac{r}{F_r} \times 100 \quad (14)$$

6.5.9 Relative error of the zero value of the tendon assembly's force measuring instrument

The relative error of the error value f_0 is determined as the average of the difference in values of the variable quantity measured prior to loading and after unloading. This test is only carried out if the tendon assembly enables controlled continuous unloading all the way to a completely unloaded state. The error value f_0 is expressed in % MV. It is calculated from the equation:

$$f_0 = \left| \frac{I_f - I_0}{X_N} \right| \times 100 \quad (15)$$

in which f_0 .... is the relative error of the zero value (% MV),

I_f ..... is the specification of the tendon assembly after unloading (kN, MN),

I_0 ..... is the specification of the tendon assembly prior to loading (kN, MN),

X_N ... is the specification of the tendon assembly at nominal force (kN, MN).

6.5.10 Relative error of force measuring instrument in reverse operation

The relative reverse operation error *h* is determined as the average of the difference in variable quantity values measured during loading and unloading. The values measured in the third and fourth measurement series are used for the calculation (X_3, X'_3, X_4, X'_4). Expressed in % MV. It is calculated according to the equation:

$$h = \left| \frac{(X'_3 - X_3) + (X'_4 - X_4)}{X_3 + X_4} \right| \times 100 \quad (16)$$

in which h ...... is the relative reverse operation error of the tendon assembly (% MH),

X'_3 .. is the value of force measured during unloading after the third measurement series (kN, MN),

X_3 .... is the value of force measured during loading in the third measurement series (kN, MN),

X'_4 .. is the value of force measured during unloading after the fourth measurement series (kN, MN),

X_4 .... is the value of force measured during loading in the fourth measurement series (kN, MN).

6.6 Measurement uncertainty calculation

6.6.1 Source of uncertainties during measurement

The standard measurement uncertainties are determined according to the information specified in Table 2.

Table 2 – Sources of standard uncertainties

Source of uncertainty	Distribution and type of standard uncertainty	Standard uncertainty	Relative standard uncertainty
Repeatability of measured values	Normal distribution Uncertainty type A	$u_b = \sqrt{\dfrac{\sum_{i=1}^{n}\left(F_i - F_r\right)^2}{n \times (n-1)}}$	$w_b = \dfrac{100}{\lvert F_{st} \rvert} \times \sqrt{\dfrac{\sum\left(F_i - F_r\right)^2}{n \times (n-1)}}$
Interpolation	Isosceles triangle distribution Uncertainty type B	$u_a = \dfrac{f_a}{100} \times F_a$	$w_a = f_a$
Zero value	Right-angle distribution Uncertainty type B	$u_0 = \dfrac{f_0}{\sqrt{3}} \times \dfrac{F_N}{100}$	$w_0 = \dfrac{f_0}{\sqrt{3}}$
Resolution capacity of tendon assembly	Right-angle distribution Uncertainty type B	$u_r = \dfrac{r}{\sqrt{6}}$	$w_r = \dfrac{a}{\sqrt{6}}$
Force gauge	Normal distribution Uncertainty type A	$u_{F,cal} = \dfrac{W_{EF,cal}}{2} \times \dfrac{F_i}{100}$	$w_{F,cal} = \dfrac{W_{F,cal}}{2}$
Pressure gauge	Normal distribution Uncertainty type A	$u_{Ep} = \dfrac{U_{Ep}}{2}$	$w_{Ep} = \dfrac{W_{Ep}}{2}$
Working pressure gauge of tendon assembly	Normal distribution Uncertainty type A	$u_{pp} = \dfrac{U_{pp}}{2}$	$w_{pp} = \dfrac{W_{pp}}{2}$

6.6.2 Combined uncertainty

The relative combined uncertainty is calculated as the square root of the sum of the squares of the standard uncertainties.

The standard uncertainty of reference load cells is determined from the equation:

$$w_{EF} = \sqrt{w_{F,cal}^2 + w_{temp}^2 + w_{drift}^2 + w_{ap}^2} \quad (17)$$

in which $w_{F,cal}$ is the relative standard uncertainty of the reference load cell calculated from the data from its calibration sheet (% MV),

w_{temp} relative standard uncertainty of the reference load cell caused by a temperature which was different when the tendon assembly was verified from when it was calibrated (% MV),

w_{drift} relative standard uncertainty of the change in time of reference load cells' signal since the last calibration (% MV),

w_{ap} relative uncertainty of interpolation of the reference load cell when calibrating the measuring instrument of the tendon assembly. It is determined from the calibration sheets of the reference load cells (% MV).

For single-cylinder tendon assembly

$$u_c = \sqrt{u_b^2 + u_r^2 + u_{EF}^2} \quad (18)$$

$$w_c = \sqrt{w_b^2 + w_r^2 + w_{EF}^2} \quad (19)$$

For multi-cylinder tendon assembly

$$u_c = \sqrt{u_b^2 + u_r^2 + u_0^2 + u_a^2 + w_{EF}^2} \quad (20)$$

$$w_c = \sqrt{w_b^2 + w_r^2 + w_0^2 + w_a^2 + w_{EF}^2} \quad (21)$$

6.6.3 Relative expanded measurement uncertainty

The relative expanded measurement uncertainty of a tendon assembly is obtained by multiplying the combined uncertainty of the measurement coefficient of expansion k. For tendon assemblies, the probability is assumed to be P = 0.95. This results in a coefficient of expansion k = 2. The relative expanded uncertainty of the tendon assembly is calculated from the equation:

$$U_{NS} = 2 \times u_c \quad (22)$$

$$W_{NS} = 2 \times w_c \quad (23)$$

The resulting expanded uncertainty value is specified with an accuracy of two digits.

6.6.4 Tendon assembly confidence interval

The boundaries of the tendon assembly confidence interval E_{NS} are given by the sum of the relative indication error and the relative expanded measurement uncertainty. It is specified in % MV and determined from the following equation:

$$E_{NS} = q \pm W_{NS} \quad (24)$$

The confidence interval is specified in the tendon assembly's verification sheet.

7 Follow-up verification

7.1 General information

The process of the follow-up verification of the tendon assembly encompasses the following tests:

a) visual inspection;
b) force measuring instrument test.

7.2 Visual inspection

The visual inspection in the follow-up verification is carried out according to Article 6.2.

7.3 Function tests

7.3.1 Test equipment

The equipment pursuant to Article 6.3.1 is used for the tests.

7.3.2 Performance of the function test

The function test is performed according to Article 6.3.2.
In case of any faults, the measuring instrument shall be disqualified from further tests.

7.3.3 Test of the tendon assembly's force measuring instrument

The test of the measuring instrument's accuracy is performed according to Article 6.3.3.
The measurement errors may not be greater than the values specified in Table 1.

7.4 Evaluation of force measuring instrument test

The test is evaluated by conducting the procedure specified in Articles 6.4 and 6.5.

8 Measuring instrument examination

When examining measuring instruments pursuant to § 11a of the Metrology Act at the request of a person who may be affected by an incorrect measuring instrument, please proceed according to Chapter 7.

9 Notified standards

For the purposes of specifying the metrological and technical requirements for measuring instruments and specifying the testing methods for their type approval and verification arising from this general measure, the CMI shall provide notification of the Czech technical standards, other technical standards or technical documents of international or foreign organisations, or other technical documents containing more detailed technical requirements (hereinafter notified standards). The CMI shall publish a list of these notified standards attached to the relevant measures, together with the general measure, in a manner accessible to the public (on www.cmi.cz).

Compliance with notified standards or parts thereof is considered, to the extent and under the conditions stipulated by a general measure, to be compliance with the requirements stipulated by this measure to which these standards or parts thereof apply.

Compliance with notified standards is one way of demonstrating compliance with the requirements. These requirements may also be met by using another technical solution guaranteeing an equivalent or higher level of protection of legitimate interests.

II.

G R O U N D S

The CMI issues, pursuant to § 14(1)(j) of the Metrology Act, for the implementation § 6(2), § 9(1) and (9) as well as § 11a(3) of the Metrology Act, this general measure, stipulating metrological and technical requirements for specified measuring instruments and requirements for verification of these specified measuring instruments – ‘tendon assemblies for prestressed concrete and rock anchors’.

Decree No 345/2002 laying down measurement instruments for mandatory validation and measurement instruments subject to type approval, as amended, classifies the measuring instruments under item 2.4.1 in the annex to the Second List of Specified Measurement Instruments of the specified type as measurement instruments subject to type approval and mandatory validation.

This legislation (general measure) will be notified in accordance with Directive (EU) 2015/1535 of the European Parliament and of the Council of 9 September 2015, laying down a procedure for the provision of information in the field of technical regulations and of rules on Information Society services.

III.

I N S T R U C T I O N S

In accordance with § 172(l) APC, in conjunction with § 39(l) APC, the CMI has stipulated a time limit for comments of 30 days as of the date of posting on the official notice board. Comments submitted after this time will not be considered.

The persons concerned are hereby invited to comment on this draft general measure. In light of the provisions of § 172(4) of the APC, comments shall be submitted in written form.

In accordance with the provisions of § 174(l) APC in conjunction with § 37(l) APC, it must be clear who is making the comments, which general measure they address, how it contradicts legislation or how the general measure is inaccurate, and the signature of the person making the comment must be included.

The supporting documents for this draft measure of a general nature may be consulted at the Czech Metrological Institute, Department of Legal Metrology, Okružní 31, 638 00 Brno, upon appointment by telephone.

This general measure shall be posted for 15 days.

...…………………………..............

RNDr. Pavel Klenovský

Director-General

Person responsible for accuracy: Mgr. Tomáš Hendrych

Posted on:

Signature of the authorised person confirming posting: ....

Removed on:

Signature of the authorised person confirming removal: ....