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Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation —

Part 2: Measurement of displacements along a line: Extensometers

Reconnaissance et essais géotechniques — Mesures géotechniques — Partie 2: Mesure de déplacement le long d'une ligne par extensomètre

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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The committee responsible for this document is ISO/TC 182, *Geotechnics*.

A list of all part in the ISO 18674 series, published under the general title *Geotechnical investigation and testing – Geotechnical monitoring by field instrumentation*, can be found on the ISO website.

Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation —

Part 2: Measurement of displacements along a line: Extensometers

1 Scope

This document specifies the measurement of displacements along a line by means of extensometers carried out for geotechnical monitoring. General rules of performance monitoring of the ground, of structures interacting with the ground, of geotechnical fills and of geotechnical works are presented in ISO 18674-1.

If applied in conjunction with ISO 18674-3, this document allows the determination of displacements acting in any direction.

This document is applicable to:

— monitoring the behaviour of soils, fills and rocks;

— checking geotechnical designs in connection with the Observational Design procedure;

— deriving geotechnical key parameters (e.g. from results of pile load tests or trial tunnelling);

— evaluating stability ahead of, during or after construction (e.g. stability of natural slopes, slope cuts, embankments, excavation walls, foundations, dams, refuse dumps, tunnels).

NOTE This document fulfils the requirements for the performance monitoring of the ground, of structures interacting with the ground and of geotechnical works by the means of extensometers as part of the geotechnical investigation and testing in accordance with References [5] and [6].

2 Normative references

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

ISO 18674-1:2015, *Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation — Part 1: General rules*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 18674-1 and the following apply.

3.1
extensometer <geotechnical>
field instrument for monitoring changes of distance between two or more measuring points located along a measuring line

Note 1 to entry: Monitoring of such changes allows the determination of displacements of measuring points acting in the direction of the measuring line.

Note 2 to entry: At a measuring point, the movements of the medium (e.g. soil, rock, concrete and steel structures) being investigated are transferred to the measuring point by devices such as anchors, rings or bolts (see 5.1.6).

Note 3 to entry: In the ground, the measuring points are typically installed in boreholes. The measuring line then coincides with the axis of the borehole.

3.2
in-place extensometer
permanently installed extensometer, essentially consisting of anchor(s), connecting element(s) and at least one measuring head

Note 1 to entry: Each connecting element is affixed to an anchor and free to move along the measuring line.

Note 2 to entry: Measuring heads are commonly located at one end of the measuring line. When carrying out the measurements, they function as reference measuring points.

Note 3 to entry: For in-place extensometers in boreholes, see Reference [7].

Note 4 to entry: See Figure 1.

3.3
rod extensometer
in-place extensometer where the connecting element is a rod

Note 1 to entry: Common rod materials are steel or fibreglass.

Note 2 to entry: See Figure 1 a).

3.4
wire extensometer
in-place extensometer where the connecting element is a wire

Note 1 to entry: See Figure 1 b).

3.5
single extensometer
in-place extensometer with one anchor only

Note 1 to entry: See Figure 1 b).

3.6
multiple-point extensometer
in-place extensometer with more than one anchor

Note 1 to entry: Up to six anchor points are common in geo-engineering practice.

Note 2 to entry: See Figure 1 a).

3.7
chain extensometer
in-place extensometer formed of a series of single extensometer elements

Note 1 to entry: See Figure 1 c).

3.8
probe extensometer
extensometer where the connecting element is a moveable unit

Note 1 to entry: Probe extensometers can be developed as *single-point probe extensometer* (3.9) or *double-point probe extensometer* (3.10).

Note 2 to entry: See Figure 2.

3.9
single-point probe extensometer
extensometer, essentially consisting of a measuring probe and a guiding tube with measuring marks and in which, at the measuring position, only one measuring mark interacts with the probe

Note 1 to entry: The connecting element is the unit consisting of a measuring cable and a probe. The measured value is the distance between the measuring mark and the reference mark at the head of the guiding tube.

Note 2 to entry: Because of its design, function and usual geotechnical application, the single-point probe extensometer is commonly designated as a “magnetic extensometer,” a “magnet settlement probe” or an “inductance probe.”

Note 3 to entry: See Figure 2 a).

3.10
double-point probe extensometer
extensometer, essentially consisting of a measuring probe and a guiding tube with measuring marks and in which, at the measuring position, two measuring marks interact with the probe

Note 1 to entry: The connecting element is the measuring probe. The measured value is the distance between the two measuring marks which are in interaction with the probe.

Note 2 to entry: Because of its design and function, the double-point probe extensometer is commonly designated as an “incremental extensometer” or a “sliding micrometer.”

Note 3 to entry: See Figure 2 b).

3.11
gauge length
L
nominal distance between the contact points of the double-point extensometer probe

Note 1 to entry: *L* is commonly 1,0 m.

Note 2 to entry: *L* is commonly verified in a calibration of the probe prior to the measurement.

3.12
tape extensometer
extensometer for distance measurements between two accessible measuring points by means of a measuring tape, essentially consisting of a device for tensioning of the tape with a reproducible pulling force, two end pieces for connecting the device to *bolts* (3.13) and of a read-out unit

Note 1 to entry: Traditionally, tape extensometers were used in tunnelling. By means of follow-up measurements, the change of the distances of two tunnel wall measuring points (in tunnelling, termed “convergence”) is determined. For this reason, tape extensometers are commonly designated as “convergence tapes.”

Note 2 to entry: See Figure 3.

3.13
convergence bolts
measuring bolts fitting to the type of tape extensometer used

4 Symbols

Symbol	Name	Unit
d	depth of borehole	m
d_i	distance between measuring point i and measuring head	m
F	subscript for follow-up measurement	—
h	height of measuring head above sea level	m
i	number of a measuring point	—

Symbol	Name	Unit
K_T	temperature correction term	—
L	gauge length of a double-point probe extensometer	m
L_i	length of the connecting element between measuring head and measuring point *i*	m
l	distance between measuring points	m
l_M	length of a measuring ring for probe extensometer	m
n	total number of measuring points along a measuring line	—
P	pulling force of wire extensometer	kN
R	subscript for reference measurement	—
s	displacement reading	m
T	temperature	°C
t	elapsed time	s
u, v, w	displacement component in x-, y-, z-direction, respectively	m
$w_{i\ rel}$	displacement component of measuring point *i* in z-direction relative to the measuring head	m
w_0	absolute displacement component of the measuring head in z-direction	m
w_i	absolute displacement component of measuring point *i* in z-direction	m
Δw_i	relative displacement between adjacent measuring points *i and i*-1 in z-direction	m
x, y, z	local coordinates of measuring points on a guide tube or in a borehole	m
α_T	coefficient of linear thermal expansion	K^{-1}
ε_z	strain in direction of the z coordinate	—

5 Instruments

5.1 General

5.1.1 The following types of extensometer in-place, probe and tape should be distinguished from each other (see Table 1 and Figures 1 to 3).

Table 1 — Extensometer types

Extensometer			Feature	Automatic data acquisition
No.	**Type**	**Subtype**		
1	in-place (see 5.2)	Single-point/multiple-point in-place extensometer rod/wire extensometer	all instrument components are permanently installed in the ground or at accessible surfaces	possible
2	probe (see 5.3)	single-point/double-point probe extensometer	measuring unit sequentially moved into measuring positions	not common
3	tape (see 5.4)	steel/wire tape extensometer		

5.1.2 Changes of the distances between measuring points shall be monitored by comparison of the measured values with those of the reference measurement. Displacements of the measuring points along the measuring line shall be deduced in accordance with Annex A.

5.1.3 An increase of the distance between two measuring points (=extension) shall be assigned a positive value.

5.1.4 The point onto which the extensometer measurements are related shall be denoted the “reference point.”

5.1.5 For absolute measurements, the coordinates of the reference point shall be independently determined or assumed and verified as fixed.

NOTE If the reference point is assumed to be at the deepest anchor, surveying of the measuring head can serve as a check.

5.1.6 Extensometer measuring points shall be marked by devices such as anchors, rings or bolts. The measuring points of these devices shall be specified as follows:

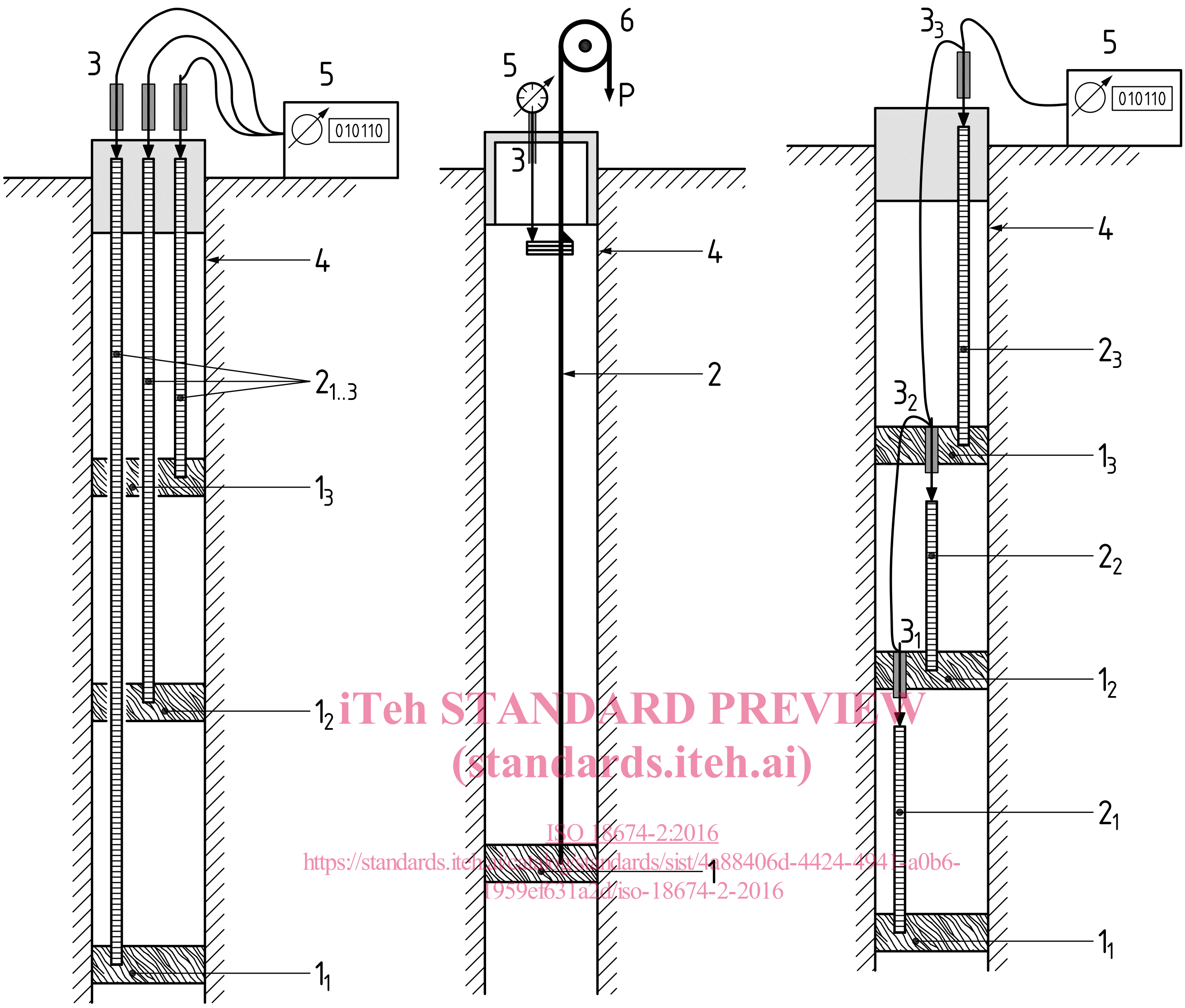
— for anchors, the centre of an anchor;

— for rings, the centre of a ring;

— for bolts, the centre of a contact butt (for screwed couplings) or the centre of an eye (for eye/hook couplings).

5.1.7 It shall be secured that the device, marking a measuring point, is set in such a way that it is solidly connected to the medium so that any movement of the medium at the measuring point is fully transferred to the device.

5.1.8 Instruments shall not significantly affect the conditions of the medium under investigation and, in turn, shall not be significantly affected in their functionality by the medium (in accordance with ISO 18674-1:2015, 5.1 and 5.2).



a) Rod extensometer **b) Wire extensometer** **c) Chain extensometer**

Key

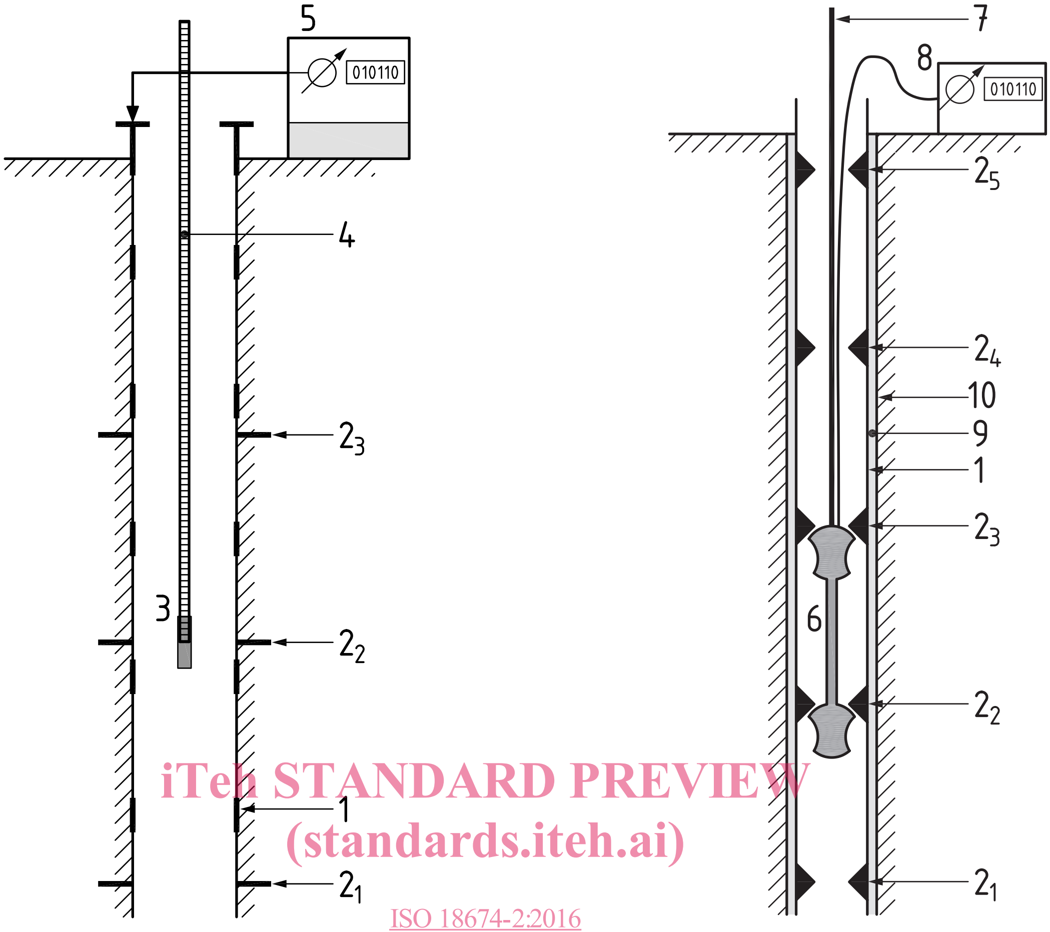
1 anchor
$1_{1..3}$ anchors 1 to 3
2 connecting element (wire)
$2_{1..3}$ connecting elements 1 to 3
3 measuring head
$3_{1..3}$ local measuring heads 1 to 3
4 borehole wall
5 read-out device
6 pulling device
P tension force

EXAMPLE 1 For subfigure a), triple-point rod extensometer with electrical displacement transducers.

EXAMPLE 2 For subfigure b), single-point wire extensometer with dial gauge read-out.

EXAMPLE 3 For subfigure c), triple-point chain extensometer with electrical displacement transducers.

Figure 1 — Examples of in-place extensometer types



a) Single-point probe extensometer

b) Double-point probe extensometer

Key

1 measuring tube

$2_{1..3}$ anchor plates 1 to 3 (with external measuring rings)

$2_{1..5}$ measuring rings 1 to 5

3 probe (in measuring position with anchor Plate No.2)

4 measuring tape

5 measuring head with reference mark

6 probe (in measuring position with rings No. 2 and 3)

7 setting rods (or pulling rope)

8 read-out unit

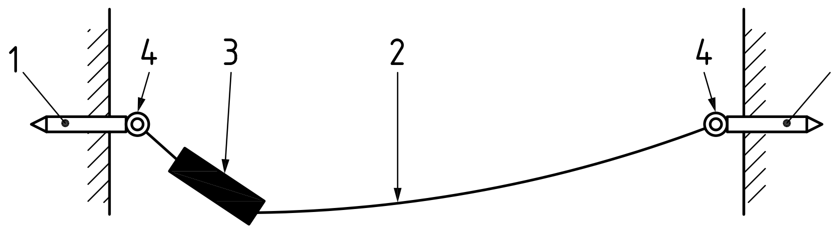
9 backfill

10 borehole wall

EXAMPLE 1 For subfigure a), magnetic probe extensometer in telescopic tubing.

EXAMPLE 2 For subfigure b), sliding micrometer.

Figure 2 — Examples of probe extensometer types



Key

1 convergence bolt

2 measuring tape (or measuring wire)

3 device for tensioning of tape (or wire) and read-out

4 coupling element

Figure 3 — Principal sketch of a tape extensometer

5.2 In-place extensometer

5.2.1 Measuring points

The measuring points should be similar in their function to those common in rock nailing and anchoring works.

EXAMPLES Wedge, straddle packer, spring-activated clamp, cement- or resin-grouted borehole packer, anchor grouting with non-shrinking cement.

NOTE The movement of a measuring point is also transferred to the attached connecting element.

5.2.2 Connecting elements

5.2.2.1 For rod extensometers, a string of interconnected steel rods or a continuous glass fibre-reinforced resin rod should be used, and for wire extensometers, steel wires should be used.

5.2.2.2 The selection of the material and that of the cross sectional area of the connecting elements should be guided by the measuring task, environmental conditions, measuring accuracy and the length of the measuring section (see Table 2).

5.2.2.3 If a connecting element can be disconnected temporarily from its fixing device at the measuring point, it shall be established that the coupling tolerance does not exceed the intended measuring accuracy of the system.

EXAMPLE Screw couplings or bayonet locks of the connecting element at the anchors.

NOTE Movements across the borehole axis or closure of the borehole can block the connecting element and can affect the functionality of the extensometer. The functionality of an extensometer can be checked by intermittently uncoupling a connecting element.

5.2.2.4 The coefficient of thermal expansion of the connecting elements shall be specified. Temperature variations within the system should be taken into account.

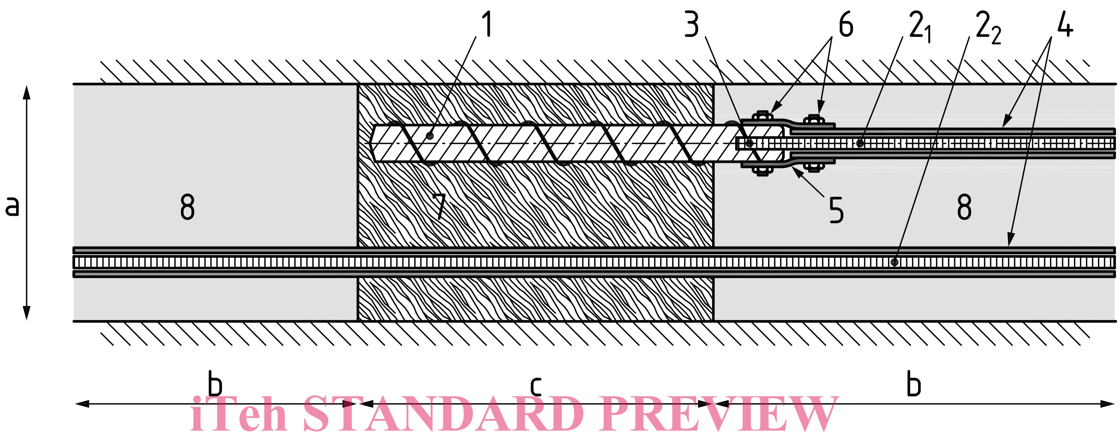
NOTE Temperature-induced changes of the length of the connecting elements can have a substantial influence on the accuracy of an extensometer system. The measurement of thermal gradients by a series of temperature sensors along the extensometer can be useful in developing a suitable correction for temperature changes (see measuring example in D.2).

5.2.2.5 The free movement of the connecting elements against each other and the backfill shall be ensured by placing the connecting elements inside protective tubes.

EXAMPLE See Figure 4.

5.2.2.6 Friction between connecting elements and protection shall not affect the measurement.

5.2.2.7 For wire extensometers, the connecting elements shall be tensioned prior to the measurement. A constant tensioning force shall be applied. The calibration of the read-out device shall have been made with regard to the specified tension force. In the case that the tensioning force is changed, the measured values shall be corrected accordingly.



Key

1 anchor

2_1 connecting element attached to (1)

2_2 connecting element to adjacent anchor (not shown)

3 coupling anchor/connecting element

4 protective tube

5 rubber sleeve

6 clamp

7 grout

8 borehole backfill

a borehole diameter

b filled borehole section

c grouted section of anchor ≥30 cm

Figure 4 — Example of a cement-grouted anchor of a multiple-point borehole rod extensometer with the connecting element attached to the anchor and a passing connecting element

5.2.3 Measuring head and read-out device

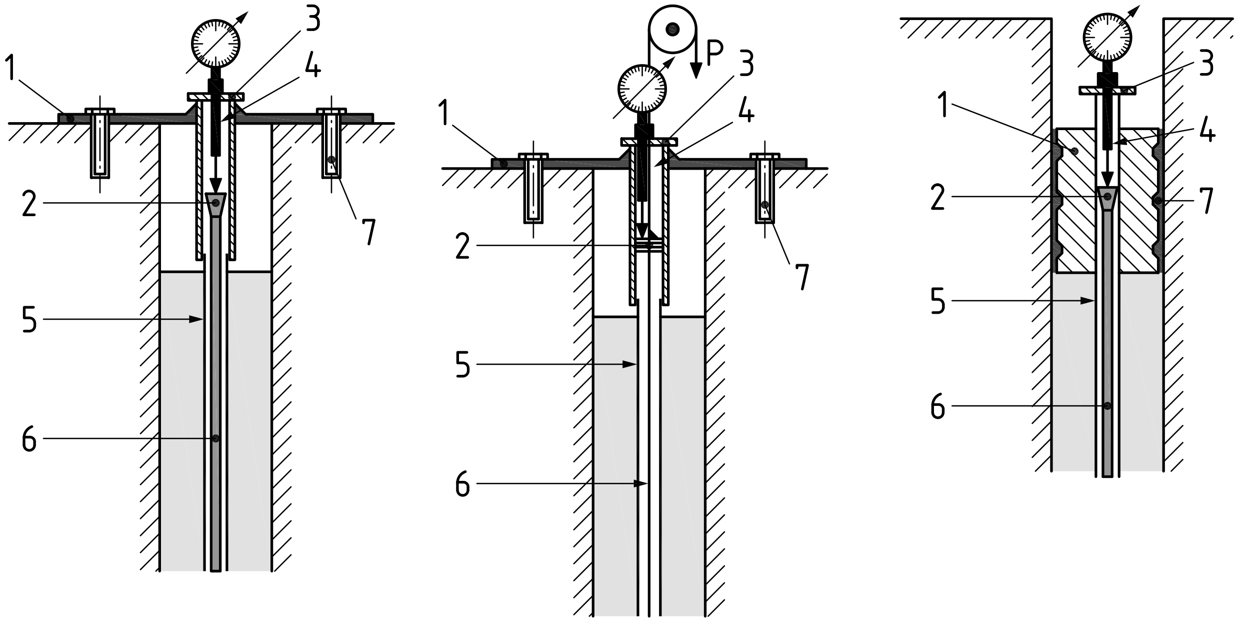
5.2.3.1 The connecting elements terminate at the measuring head. The axial distance between the measuring butt of the measuring head and the measuring butt of the connecting element shall be measured.

EXAMPLE See Figures 1 and 5.

NOTE Common distance meters are mechanical dial gauges, electric displacement transducers, vibrating wire displacement transducers and topographic levels.

5.2.3.2 In certain applications, it may be necessary to shorten, or to extend, the connecting elements (including the protection tubes) in the course of the monitoring project. If such a situation is likely to occur, provisions should be made in the monitoring plan and the extensometer system designed accordingly.

EXAMPLE Shortening, respectively extension, of the connection element is required when the measuring range of the distance meter is exceeded.



Key

1 head unit (head plate or recessed head)
2 measuring butt at connecting element
3 measuring butt of head plate
4 displacement sensor
5 protection tube
6 connecting element (rod; wire)
7 fixation of head unit (dowelling; cementation)

Figure 5 — Types of in-place extensometer measuring head layouts (schematic)

5.3 Probe extensometer

5.3.1 Measuring points and guide tube

5.3.1.1 Each measuring point should be marked by a ring which is embedded in, or attached to, the medium. The ring may be a part of the guide tube [see Figure 6 b)].

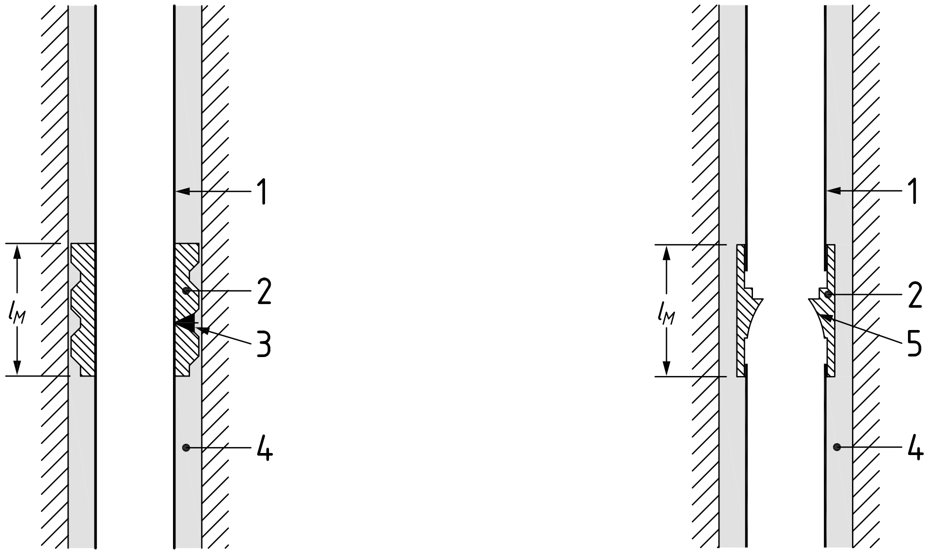
5.3.1.2 The guide tube shall not affect the movement of the measuring rings.

5.3.1.3 For single-point probe extensometers [see Figure 2 a) and PrEx1 in Table 2], the measuring points can be set at any location along the measuring line.

5.3.1.4 For double-point probe extensometers [see Figure 2 b) and PrEx 2-1 and PrEx 2-2 in Table 2], measuring rings shall be used which are compatible with the type of probe used. The measuring points shall be equally spaced according to the gauge length (see 3.11), with a tolerance depending on the measuring range of the probe (see Table 2).

5.3.1.5 Hydraulic pressures or ground pressures which may develop during the installation and throughout the measuring period shall be considered in the selection of the guide tube.

5.3.1.6 Ground excavation procedures may require temporary or permanent cutting or interruption of guide tubes. It is permissible to continue the probe extensometer survey in the remaining parts of the guide tubes.



a) Continuous guide tube, inductive measurement

b) Discontinuous guide tube, mechanical measurement

Key

1 guide tube

2 precision measuring ring of length l_M

3 setting screw

4 backfill (mortar)

5 mechanical high-precision coupling

Figure 6 — Possible measuring ring fixations for probe extensometers

5.3.2 Probe

5.3.2.1 The extensometer device shall allow a controlled positioning of the probe in the measuring points. Reading of the measured value shall be made with the probe at rest.

5.3.2.2 At a measuring location of a single-point probe extensometer, the probe shall uniquely interact with one measuring point. The measured value shall be the distance between the measuring point and the reference mark of the measuring head.

NOTE A tension-resistant graduated measuring cable is commonly used for the measurement of that distance.

5.3.2.3 At a measuring location of a double-point probe extensometer, the probe shall uniquely interact with two adjacent measuring points. The measured value should be the difference between the base length *L* of the probe and the distance between the two measuring points.

NOTE For a measuring line, the number of double-point probe extensometer measuring points is *n*-1, where *n* is the total number of measuring rings installed.

