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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

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.

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
$w_\mathrm{i\,rel}$	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.

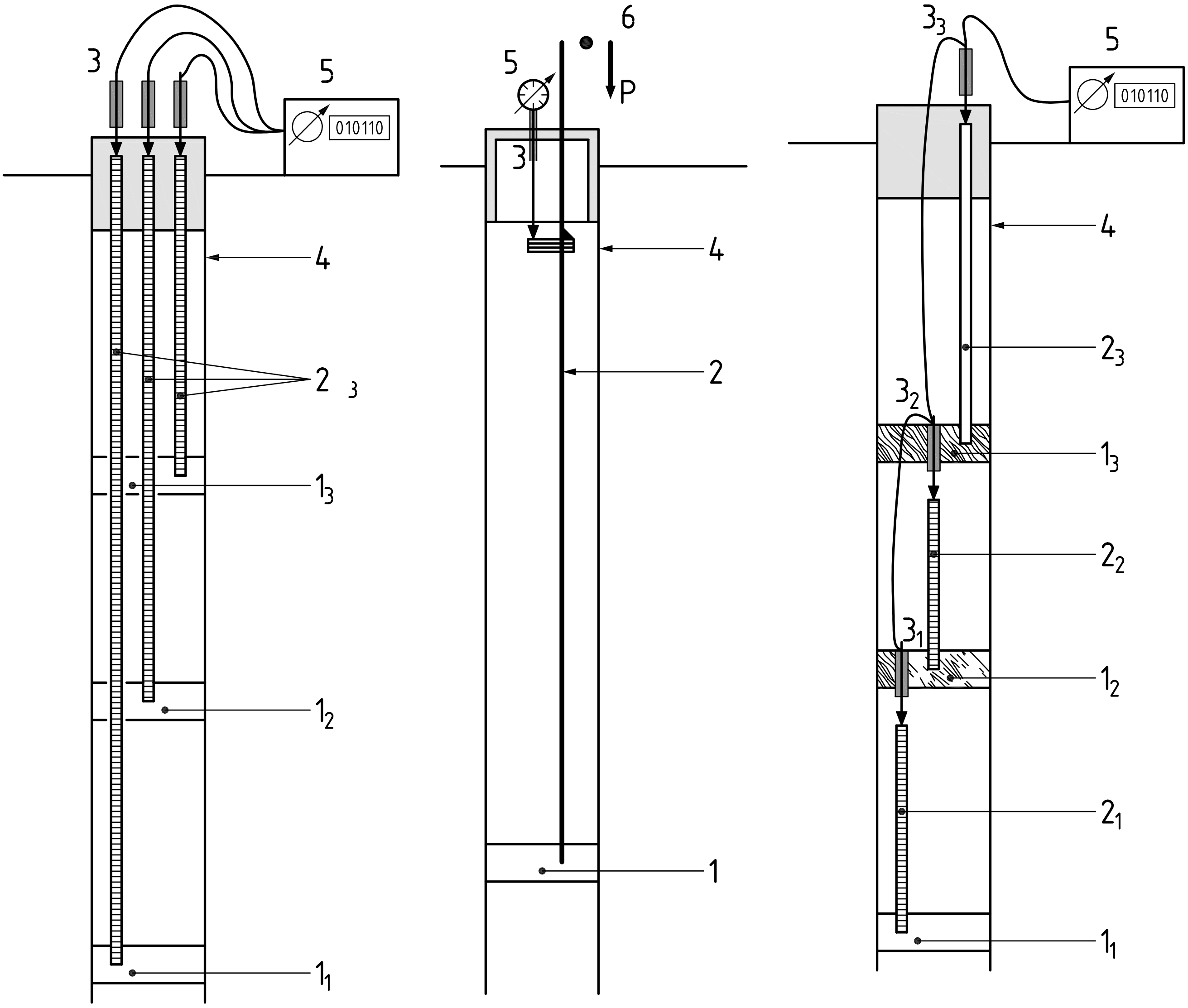
NOTE If the reference point is assumed to be at the deepest anchor, surveying of the measuring head can serve as a check.

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

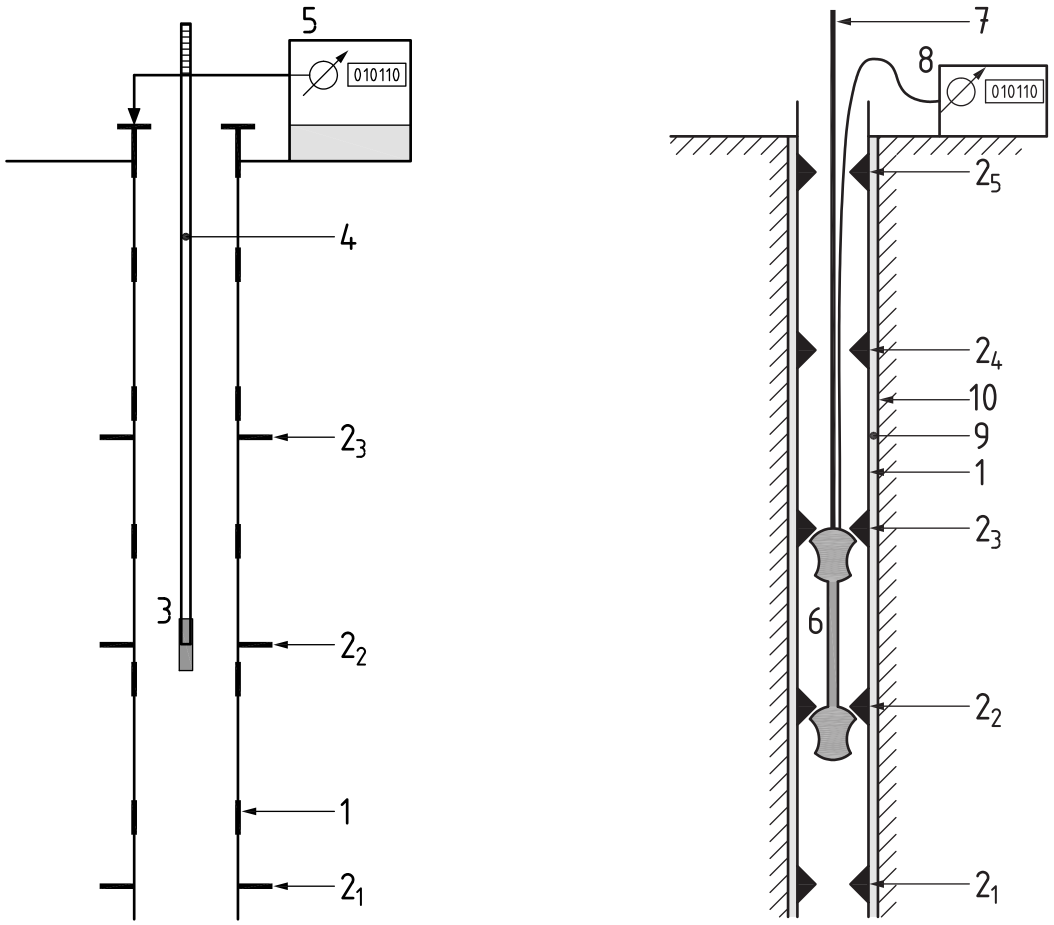
1	anchor
$1_{1..3}$	anchors 1 to 3
2	connecting element (wire)
$2_{1..3}$	connecting elements 1 to 3
3	measuring head
$3_{1..3}$	local measuring heads 1 to 3
4	borehole wall
5	read-out device
6	pulling device
P	tension force

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**

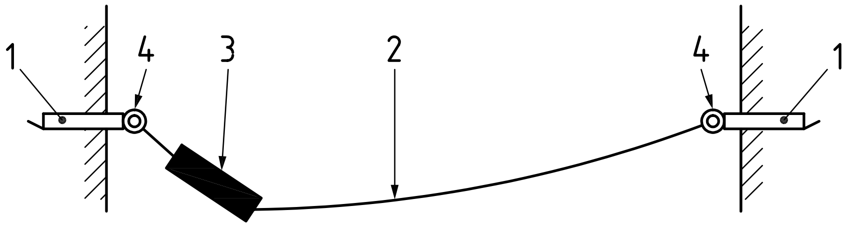
Key

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.

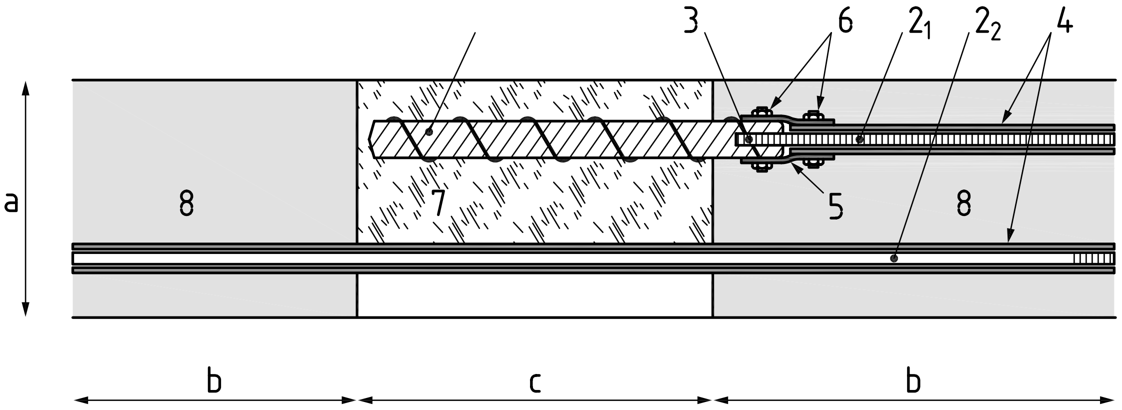
NOTE Temperature-induced changes of the length of the connecting elements can have a substantial influence on the accuracy of an extensometer system. The measurement of thermal gradients by a series of temperature sensors along the extensometer can be useful in developing a suitable correction for temperature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

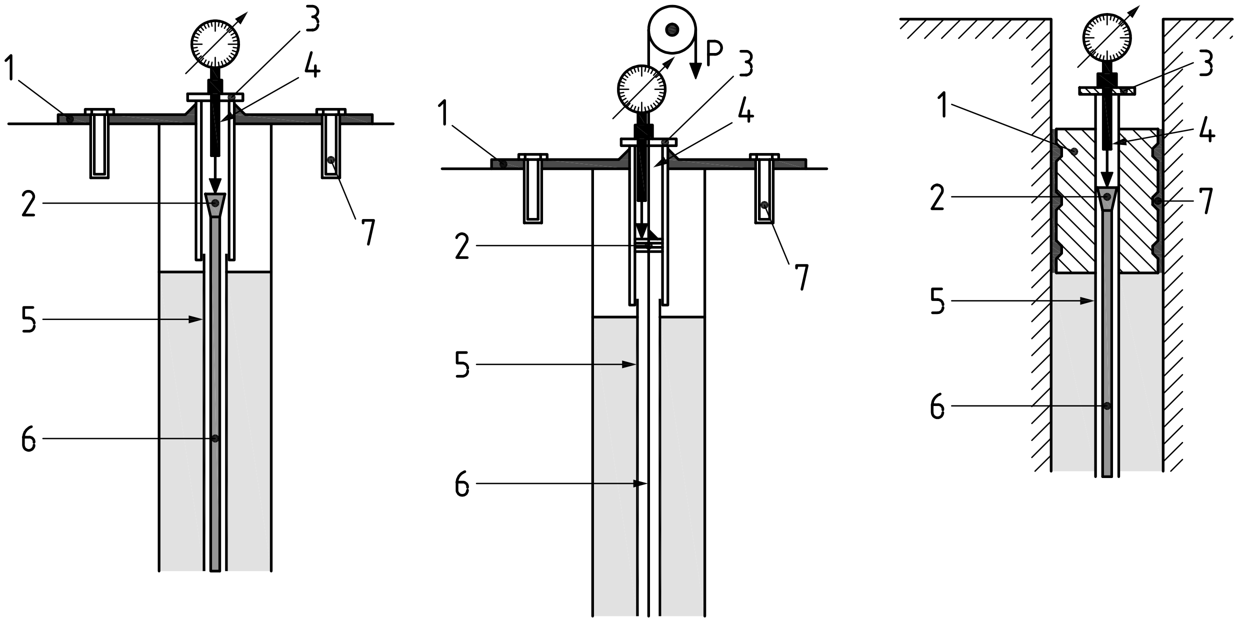
5.2.3.1 The connecting elements terminate at the measuring head. The axial distance between the measuring butt of the measuring head and the measuring butt of the connecting element shall be measured.

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

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)].

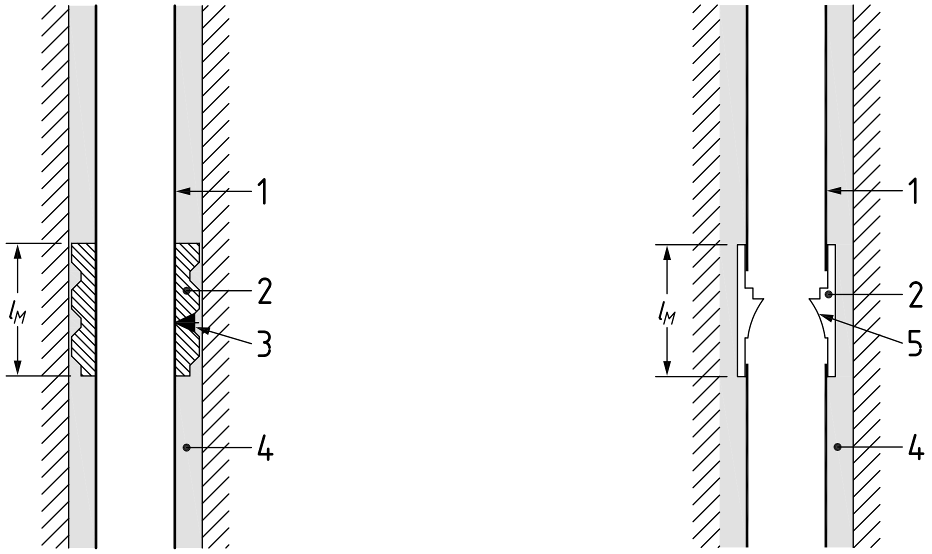
5.3.1.2 The guide tube shall not affect the movement of the measuring rings.

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.

5.5 Tape extensometer (convergence tape)

NOTE Convergence measurements can also be performed by optical geodetic methods.

5.4.1 For tape extensometer measurements, the following components are required (see Figure 3):

— convergence bolts;

— tensioning and read-out devices (convergence device);

— measuring tape or measuring wire;

— coupling elements to the convergence bolts.

5.4.2 Convergence bolts of the measuring systems CV 1 and CV 2 (see Table 3) shall be equipped with a contact butt for the coupling elements. The contact butt should consist of a durable and corrosion-resistant material (e.g. stainless steel or galvanized steel). The contact butts and coupling elements should be protected from dirt and against damage.

5.4.3 Convergence bolts may be equipped with survey targets to allow geodetic measurements.

5.4.4 The convergence measuring system shall be equipped with a device for assuring a constant and reproducible pulling force of the measuring tape or wire.

5.4.5 The coefficient of linear thermal expansion of the measuring tape or measuring wire shall be specified by the instrumentation manufacturer and documented (see 8.1).

5.6 Measuring range and accuracy

Measuring range and accuracy of extensometers depend, amongst other factors, on the measuring length. Table 2 provides information which should be taken into consideration when selecting extensometers.

NOTE Annex C provides an overview of the various extensometer types in some common geo-engineering applications. Examples of the various types of extensometers and typical applications are presented in Annex D.

Table 2 — Types, common measuring lengths, ranges and accuracies of extensometers

Extensometer type		In-place extensometer		Probe extensometer			Tape extensometer (convergence tape)		
Technical feature		Rod	Wire	1-point	2-point (L = 1,0 m)		Cardan joint with measuring butt		Hook and eye
					Non-mechanical	Mechanical	Invar wire	Steel tape (punched or graduated)	
Designation (abbreviated)		Ex-rod	Ex-wire	PrEx 1	PrEx 2-1	PrEx 2-2	CV 1	CV 2	CV 3
1	common (extreme) lengths of measuring lines [m]	30 (300)	10 (300)	30 (200)	30 (150)	30 (150)	15 (100)	15 (20)	15 (30)
2	common measuring range of extensometer sensor [mm]	±50	±250	±1 000 or ± 10 % of tube length	±20 per metre	±10 to ± 50 per metre	±50	±20[a]	±50[a]
3	typical accuracy of installed extensometer [mm][b] over a measuring length of … [m]	±0,2 30	±2 10	±5 30	±0,3 30	±0,05 to ± 0,5 30	±0,05 15	±0,1 15	±0,5 15

[a] Measuring range, adjustable to higher values.

[b] For relative displacements.

6 Installation and measuring procedures

6.1 Installation

6.1.1 Surface components

Extensometer components mounted to accessible surfaces shall be protected from direct sunlight, aggressive environment, construction works, fly rocks from blasting and vandalism.

NOTE Protection can be achieved by sun-shade covers, lockable protective covers, recessed measuring heads or covered extensometer shafts.

6.1.2 Installation in boreholes and in fill

6.1.2.1 Knowledge of the ground profile is required for the installation of extensometers in the ground.

NOTE Drilling of extensometer boreholes with sample recovery, providing direct information on the ground conditions, allows a better placement of the anchors and enables a better interpretation of the measuring results.

6.1.2.2 In soft ground and in fill, a single-point extensometer may be installed by sounding techniques such as CPT or dynamic probing (in accordance with ISO 22476-1 and ISO 22476-2).

6.1.2.3 Extensometer boreholes should be back-filled with a suitable material.

NOTE 1 One of the purposes of backfilling is to re-establish separations between different aquifers in accordance with ISO 22475-1:2006, 5.5.4.

NOTE 2 Common backfill materials are low-strength cement-based mortar and cement-bentonite suspensions (see Annex B).

6.1.2.4 The composition of the backfill material shall be documented and its properties considered in the relation to the surrounding medium.

6.1.2.5 The axial stiffness of an extensometer, including its protective tubes and cured backfill, shall not exceed the stiffness of the medium.

NOTE 1 This requirement is particularly relevant for settlements in soil, fill and soft rock.

NOTE 2 The following mitigating measures are considered acceptable:

a) for in-place borehole extensometers, selection of low-strength backfill (see Annex B) in combination with spot fixation of the anchors such as mechanical clamps, bladder-type hydraulic anchors or cement-activated packer anchors;

b) for embedment extensometers, selection and installation of telescoping tubing or corrugated guide tubes;

c) for probe extensometers, selection and installation of telescoping tubing, corrugated guide tubes and/or selection of low-strength backfill.

6.1.2.6 Sufficient time should be allowed for the backfill to cure so that anchor fixity and stability is observed prior to the zero and baseline measurements being undertaken in accordance with ISO 18674-1:2015, Figure 1.

6.1.3 In-place extensometer

When selecting and installing in-place extensometers, attention shall be paid to the following.

a) Friction between connecting elements and protection tubes can be reduced by using spacers.

b) The extensometer assembly should be installed in the borehole without twisting the rods.

c) The protective tubing shall withstand the pressures from the ground, groundwater, grouting and back-filling operations.

   NOTE For very long vertical extensometers (e.g. 100 m), common installation practice is sequential back-filling over a limited height. The next back-filling step is then carried out after curing of the previous stage.

d) For multiple-point extensometers, the connecting elements shall be uniquely identified at the measuring head.

e) Adjustments of the length of the connecting elements must be recorded and considered in the evaluation procedure.

NOTE Adjustments are common if the measuring range is likely to be exceeded.

6.1.4 Probe extensometer

When selecting and installing the measuring tubes of the probe extensometer, attention shall be paid to the following.

a) Possibility that the measuring tube may float in a water-filled borehole.

   NOTE Floating of the measuring tube can be avoided by measures, or a combination of measures, such as filling the tube with water, loading the bottom by dead weight and initial cement grouting the toe of the tube.

b) Possibility of excessive external pressure, which may lead to a collapse of the measuring tube.

c) Difficulty of recovering the drilling casing without undue influence on the measuring tube.

   NOTE An installation rod inside the measuring tube can assist to keep the tube stretched during the recovery of the drilling casing.

d) For double-point probe extensometer systems, the measuring rings are to be firmly and durably connected to the medium. For that purpose, the entire annulus between the measuring tube and the borehole wall can be back-filled with a suitable material (see 6.1.2.3 and 6.1.2.4).

e) In cast-in-place concrete piles, the measuring tube shall be fixed to the reinforcement cage prior to the placement of the cage and the concrete. Special attention shall be paid during lifting and lowering the cage to prevent any damage to the tubes.

NOTE High-precision double-point extensometers of the Type PrEx 2–2 (see Table 2) are often installed in concrete piles to assist in determining the distribution of skin friction along the pile, e.g. in pile load testing.

6.1.5 Tape extensometer

When installing the measuring bolts of a tape extensometer, attention shall be paid to the following.

a) The bolts should be placed in holes and fixed with cement- or resin-based material or by mechanical expansion anchors.

b) The bolts may be temporarily secured at the steel mesh or, if permissible, welded onto steel arches or reinforcement bars.

6.2 Carrying out the measurement

6.2.1 Instrumentation check and calibration

6.2.1.1 For general function checks and calibrations, refer to ISO 18674-1:2015, 5.6.

6.2.1.2 For in-place extensometers, portable measuring instruments (such as dial gauges and read-out devices) and electric displacement transducers (where accessible) shall be regularly calibrated. If not specified by the manufacturer, the maximal interval shall be two years.

6.2.1.3 Single-point probe extensometers shall be function checked at least once a year. It shall be confirmed that the measuring cable does not change its length (stretching or shrinking) in course of the monitoring project.

6.2.1.4 Double-point probe extensometers shall be calibrated at least once a year. Before and after each series of measurements, they shall be checked against a known reference. Differences between the reference and the measurement shall be recorded and accounted for in the data processing.

6.2.1.5 Convergence instruments shall be checked against a known reference before and after each series of measurements. Differences between the reference and the measurement shall be recorded and accounted for in the data processing.

6.2.2 Measurement

The measurements shall be carried out in accordance with Annex A, in conjunction with the requirements of ISO 18674-1:2015, Clause 7.

7 Data processing and evaluation

7.1 The evaluation of the measuring data shall be carried out in accordance with Annex A.

7.2 The evaluated results shall be presented in tables and/or graphics. A record of the following data is required in addition to the requirements of ISO 18674-1:2015, Clause 8:

a) For each measuring survey:
   1) identification of the measuring line;
   2) definition of reference point and its displacement condition.

b) For each measuring point:
   1) measuring depth;
   2) for in-place extensometer and single-point probe extensometer:
      i) relative displacement component $w_{\mathrm{i\ rel}}$ related to the reference point in accordance with Formulae (A.1) and (A.2) in dependency of the time, and/or
      ii) absolute displacement component w_{i} in accordance with Formula (A.3) in dependency of the time;

      NOTE In addition to the above, section-wise longitudinal strain ε_{zi} in accordance with Formula (A.5) can also be presented.

   3) for double-point probe extensometer:
      i) section-wise longitudinal strain between adjacent measuring points ("differential displacements") in accordance with Formula (A.8), and/or
      ii) relative and, if applicable, also absolute displacements along the measuring line ("integrated longitudinal displacement") relative to the reference point in accordance with Formula (A.9);
   4) for tape extensometer:
      change of the measuring value Δs (negative sign: convergence; positive sign: divergence) in accordance with Formulae (A.10) to (A.12) in dependency of time.

7.3 Time-dependent deformations, such as velocity and acceleration, can be presented in semi-logarithmic graphs.

8 Reporting

8.1 Installation report

The installation report shall be in accordance with ISO 18674-1:2015, 9.1.

8.2 Monitoring report

The monitoring report shall be in accordance with ISO 18674-1:2015, 9.2.

Annex A
(normative)

Measuring and evaluation procedure

A.1 In-place extensometer

A.1.1 Measuring procedure

In-place extensometer measurements imply the measurement of the distance changes between a measuring point *i* and the measuring head (see Figure A.1). The head should be considered as the reference point or as measuring point 0. The measurement is obtained by means of a connecting element (rod or wire) which is firmly attached to the anchor of the measuring point *i* and which should extend into the measuring head. At the head, any changes of the position of the connecting element shall be monitored by a displacement transducer (e.g. mechanical dial gauge; electric sensor). For a multiple-point extensometer, there are connecting elements of different lengths L_i [see Figures 1 a) and A.2].

NOTE The distance between a measuring point *i* and the measuring head is about equal, however not identical, to the length L_i of the connecting element. The distance can be subject to changes (which, in fact, is the measuring purpose proper) whereas the length of the connecting element is considered to be constant (L_i = const.). Confirming that the length of the connecting element remains constant throughout the monitoring project is of some practical concern as the extensometer can be subject to temperature changes and mechanical distortions, e.g. by shear across the measuring line (see 5.2.2.3 and 5.2.2.4).

A.1.2 Evaluation procedure

A.1.2.1 Relative displacement

The change of the extensometer measuring value Δs_i in the period between reference and follow-up measurements is as follows (see Figure A.1):

$$\Delta s_i = s_{i,\mathrm{F}} - s_{i,\mathrm{R}} \tag{A.1}$$

where

$\varnothing s_i$ is the change of the measuring value of the measuring point *i*;

$s_{i,\mathrm{R}}$ is the displacement reading for measuring point i of the reference measurement;

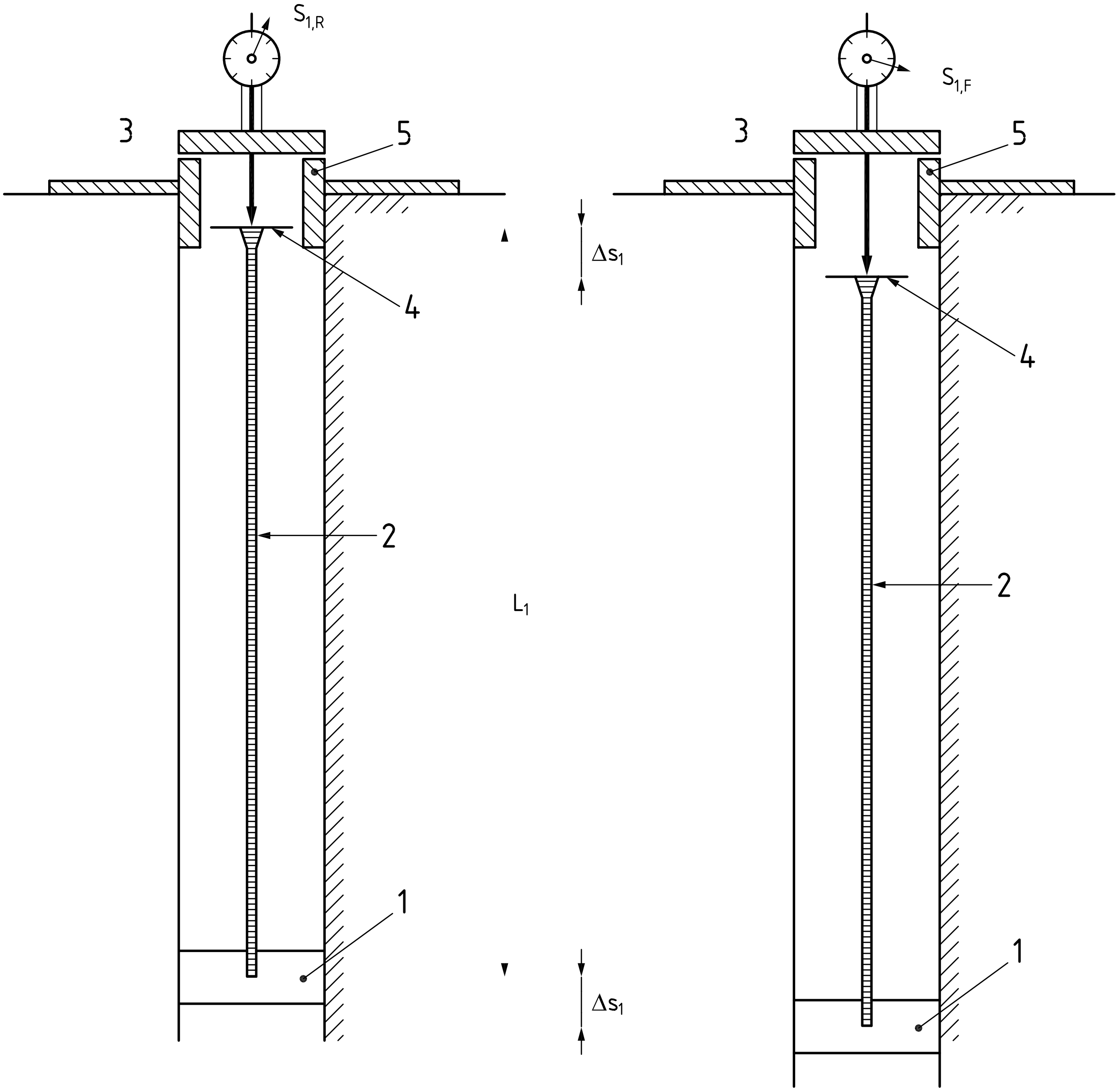
$s_{i,\mathrm{F}}$ is the displacement reading for measuring point *i* of the follow-up measurement.

Δs_i is identical to the distance change between the measuring point *i* and the measuring head, and thus is the displacement $w_{i\,\mathrm{rel}}$ of the measuring point *i* relative to the measuring head:

$$\Delta s_i = w_{i\,\mathrm{rel}} \tag{A.2}$$

where

$w_{i\,\mathrm{rel}}$ is the displacement component of measuring point *i* in direction of the measuring line relative to the measuring head.



a) Reference measurement (subscript R) **b) Follow-up measurement** (subscript F)

Key

1	measuring point 1 (anchor)	4	measuring butt of the connecting element
2	connecting element (rod)	5	measuring butt of the measuring head
3	measuring head with read-out device (dial gauge)	Δs_i	change of the measuring value of the measuring point 1

EXAMPLE Table of measured and evaluated values.

Measuring point no. i	Length L_i of rod m	Measured value mm		Δs_i [see Formula (A.1)] mm
		$s_{i,R}$	$s_{i,F}$	
1	10	2,35	2,56	0,21

Figure A.1 — Measuring and evaluation procedure of a single rod extensometer with $w_0 = 0$

A.1.2.2 Absolute displacement

The *absolute displacement* w_i of a measuring point *i* in direction of the measuring line is as follows:

$$w_i = w_{i\,\mathrm{rel}} + w_0 \tag{A.3}$$

where

$w_{i\,\mathrm{rel}}$ see Formula (A.2);

w_0 is the absolute displacement component of the measuring head in direction of the measuring line.

For the determination of w_0, see 5.1.5.

A.1.2.3 Segmental strain

For multiple-point extensometers, the term Δs_i (see A.1.2.1) relates to the measuring head and not to one of the adjacent measuring points (see Figure A.2). The relative displacement Δw_i between adjacent measuring points in direction of the measuring line is as follows:

$$\Delta w_i = \Delta s_i - \Delta s_{i-1} \tag{A.4}$$

where

Δs_i is the change of the measuring value of the measuring point *i*;

$\Delta s_{i\text{-}1}$ is the change of the measuring value of the measuring point *i*-1.

The segmental strain $\varepsilon_{\mathrm{z}\,i}$ of the measuring point *i* in the direction of the measuring line can be calculated if Δw_i is referred to the distance Δl_i between the measuring points *i* and *i*-1 as follows:

$$\varepsilon_{\mathrm{z}i} = \Delta w_i \,/\, \Delta l_i \tag{A.5}$$

and

$$\Delta l_i = L_i - L_{i-1} \tag{A.6}$$

where

L_i is the length of the connecting element between measuring head and measuring point *i*;

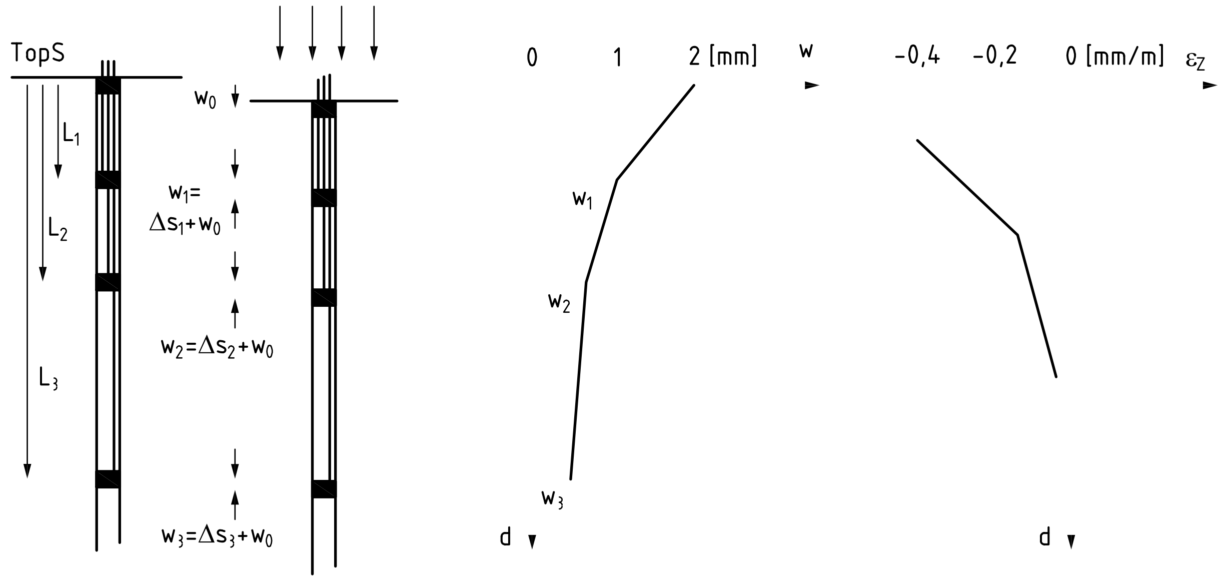
$\mathrm{L}_{i\text{-}1}$ is the length of the connecting element between measuring head and measuring point *i*-1.

NOTE $\varepsilon_{\mathrm{z}i}$ allows a unified evaluation and interpretation of the extensometer measurement, irrespectively of different distances between the measuring points.

A.1.2.4 Temperature correction

If temperature changes along the measuring line are expected, then provisions for temperature measurements shall be made and the effects of these changes on the measurement considered.

NOTE Temperature changes can occur due to curing of concrete, sunlight on the structure, ambient or medium temperature changes, etc.



EXAMPLE Table of measured and evaluated values.

Measuring point i	Length L_i of rod m	Measured value mm		Δs_i mm [see Formula (A.1)]	w_i mm (see Formula (A.2), (A.3)]	Δw_i mm [see Formula (A.4)]	Spacing Δl_i between adjacent measuring points m	ε_z mm/m [see Formula (A.5)]
		$s_{i,\mathrm{R}}$	$s_{i,\mathrm{F}}$					
0	-	-	-	-	2,0[a]			
						-1,0	2,5	-0,40
1	L_1 = 2,5	3,00	2,00	-1,00	1,0			
						-0,4	2,5	-0,16
2	L_2 = 5,0	5,50	4,10	-1,40	0,6			
						-0,2	5,0	-0,04
3	L_3 =10,0	1,35	-0,25	-1,60	0,4			

[a] Geodetic measurement.

Figure A.2 — Measuring and evaluation procedure of a triple borehole rod extensometer, as demonstrated by the example of the ground settlements beneath a strip foundation

A.2 Probe extensometer

A.2.1 Measuring procedure

The probe is inserted into the guide tube and shall sequentially be moved to the respective measuring points i via a cable or a string of setting rods. In each measuring position, the probe shall interact with either one measuring point i (single-point probe extensometer) or two adjacent measuring points i and i+1 (double-point probe extensometer).

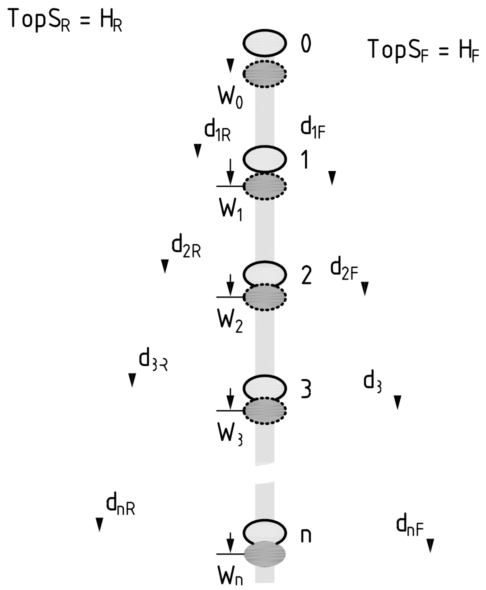
A.2.2 Evaluation procedure

A.2.2.1 The evaluation of the measurements of a single-point probe extensometer can be in accordance with Formulae (A.1) to (A.6). The measuring line can be oriented in any direction and can have any inclination.

A.2.2.2 In the common case of a vertical measuring line and a single-point probe extensometer, the settlements w_i of a measuring point *i* may be calculated as follows (see Figure A.3):

$$w_i = \mathrm{d}_{i,\mathrm{F}} - \mathrm{d}_{i,\mathrm{R}} - w_0 \tag{A.7}$$

where



w_i is the vertical displacement (=settlement) of measuring point *i* at the time of the follow-up measurement in relation to the reference measurement;

$\mathrm{d}_{i,\mathrm{F}}$ is the distance between measuring point *i* and measuring head at the follow-up measurement;

$\mathrm{d}_{i,\mathrm{R}}$ is the distance between measuring point *i* and measuring head at the reference measurement;

w_0 is the settlement of the measuring head in the time span between reference and follow-up measurements.

a) Reference measurement (subscript R) **b) Follow-up measurement** (subscript F)

Key

TopS	topographic surface	H	height of topographic surface above sea level
0	measuring head	d_i	distance of measuring point *i* from measuring head
1 … n	Number of measuring points (subscript *i*)	w_i	settlement of measuring point *i*

Figure A.3 — Measurements with a vertical single-point probe extensometer

A.2.2.3 The evaluation of double-point probe extensometer readings shall be in accordance with Formulae (A.8) and (A.9) as follows (see Figure A.4):

(a) Evaluation of segmental relative displacements

$$\Delta w_i = l_{i,\mathrm{F}} - l_{i,\mathrm{R}} \tag{A.8}$$

where

Δw_i is the relative displacement between the adjacent measuring points *i* and *i*-1;

$l_{i,\mathrm{F}}$ is the distance between the measuring points *i* and *i*-1 in the follow-up measurement;

$l_{i,\mathrm{R}}$ is the distance between the measuring points *i* and *i*-1 in the reference measurement.

NOTE Usually, the measured value is the difference between the distance of adjacent measuring points and the base length *L* of the probe (see 5.3.2.3). When determining Δw_i in accordance with Formula (A.8), the term *L* is eliminated, as it is a constant throughout the reference and follow-up measurements.

(b) Evaluation of absolute displacements

The distance change between a measuring point *i* and a reference point shall be calculated as the sum of the relative displacements Δw_i of all measuring increments located between the measuring point and the reference point. For the determination of the absolute displacement, the displacement component w_0 of the reference point shall be added as follows (see Figure A.4):

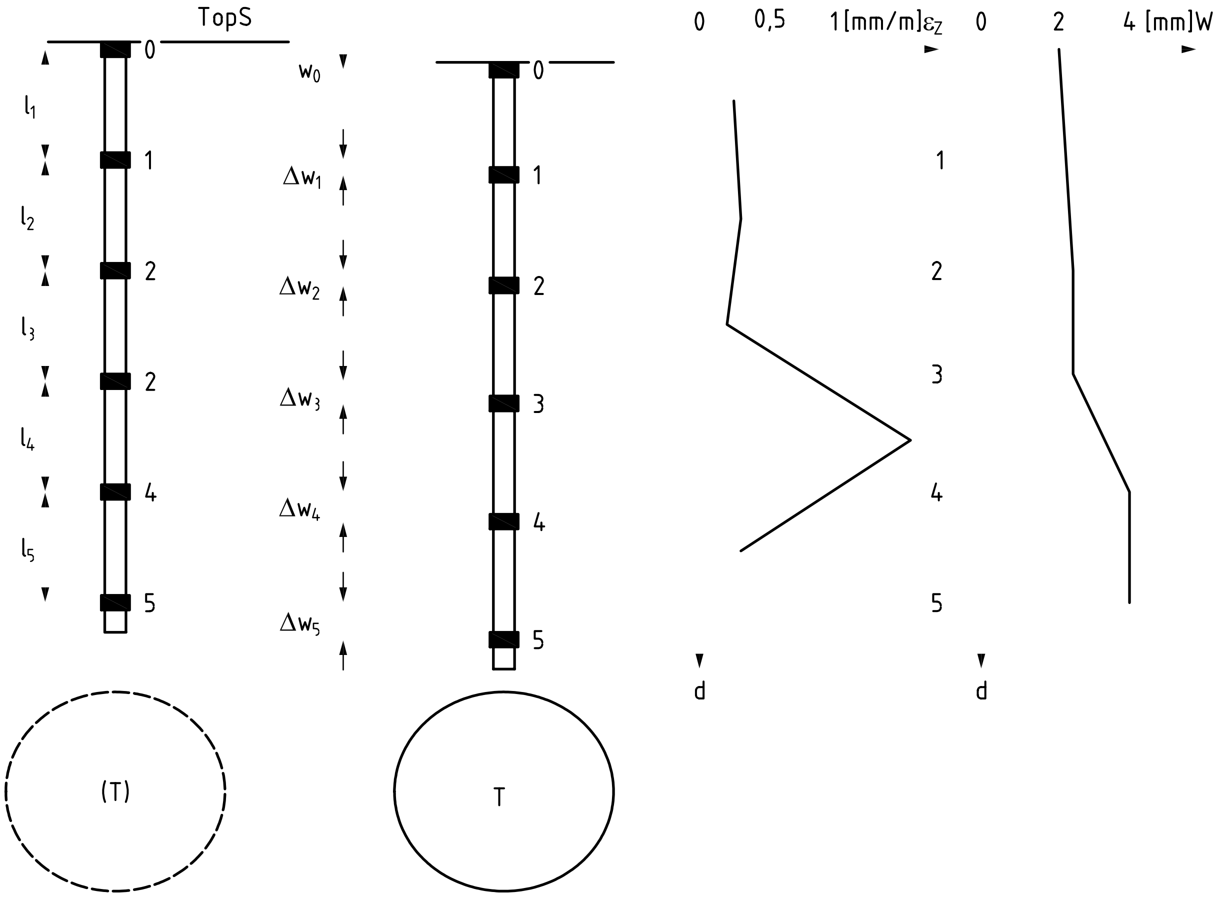
$$w_i = \Delta w_i + \Delta w_{i-1} + \Delta w_{i-2} + \ldots. + \Delta w_1 + w_0 = \Sigma \Delta w_i + w_0 \tag{A.9}$$

where

w_i is the absolute displacement component of measuring point *i* in direction of the measuring line;

Δw_i is the relative displacement of the adjacent measuring points *i* and *i*-1;

w_0 is the absolute displacement component of the reference point in direction of the measuring line.



a) Reference measurement prior to tunnelling (dashed tunnel contour)

b) Follow-up measurement after tunnelling (solid tunnel contour)

c) incremental strain ε_z versus depth d

d) absolute vertical displacements *w* versus depth d

Key

0	reference point (Measuring Ring 0	d	depth
TopS	topographic surface	T	tunnel
1...5	measuring ring number		

EXAMPLE Table of measured and evaluated values.

Measuring point no. *i*	Measured value mm		Δw_i mm [see Formula (A.8)]	Δz mm/m [see Formula (A.5) and (A.6)][a]	w_i mm [see Formula (A.9)]
	$l_{i,R}$	$l_{i,F}$			
0					2,0[b]
	1,25	1,45	0,20	0,20	
1					2,2
	-0,30	-0,05	0,25	0,25	
2					2,5
	2,85	3,01	0,16	0,16	
3					2,6
	-0,55	0,88	1,43	1,43	
4					4,0
	-1,88	-1,54	0,34	0,34	
5					4,4

[a] Measuring base $L = 1{,}00$ m.

[b] w_0 = geodetic measurement.

Figure A.4 — Measuring and evaluation procedure of a double-point probe extensometer, as demonstrated by the example of ground settlements in the roof of a shallow tunnel

A.3 Tape extensometer

A.3.1 Measuring procedure

The purpose of tape extensometer measurements is the determination of the relative displacement between two measuring points. The measurement shall be carried out by a measuring device (see 5.4.4) which allows the tensioning of a measuring tape or wire with a defined and repeatable pulling force. The device and the measuring tape or wire shall be connected via coupling elements to two measuring points marked by convergence bolts (see 5.4.2). The distance between the measuring points shall not be greater than 30 m.

A.3.2 Evaluation procedure

A.3.2.1 For the evaluation of the tape extensometer measurements, Formula (A.1) shall be applied in the following sense:

$$\Delta s = s_F - s_R \qquad \text{(A.10)}$$

where

Δs is the change of the distance between the two measuring points;

s_R s_F is the measured values for reference and follow-up measurement, respectively.

A.3.2.2 Influences from any changes of the ambient temperature between reference and follow-up measurements should be considered in accordance with Formulae (A.11) and (A.12):

$$\Delta s = (s_F + K_T) - s_R \tag{A.11}$$

where

K_T is the temperature correction term in accordance with Formula (A.12).

$$K_T = \alpha_T \cdot l \cdot \Delta T \tag{A.12}$$

where

α_T is the coefficient of linear thermal expansion of the tape (or wire);

l is the distance between the two measuring points;

$\Delta T = T_F - T_R$ is the temperature change between reference and follow-up measurements.

Annex B
(informative)

Backfill materials

B.1 Common backfill materials are low-strength cement-based mortar and cement-bentonite suspensions.

EXAMPLE See Table B.1.

Table B.1 — Examples of typical cement-bentonite grout mixes

Applications		**Soils**			**Rocks**
		Soft	**Medium**	**Hard**	
Material [ratio by weight]	Water (water-cement ratio)	~6,6	~3,0	~2,5	1,0 > ~0,6
	Ordinary Portland cement	1,0	1,0	1,0	1,0
	Bentonite	~0,4	~0,35	~0,3	~0,05 > ~0,05
28 day compressive strength [kPa]		~30	~300	~700	~1 000 < ~7 000

NOTE 1 Partially adapted from Reference [8] for inclinometer boreholes.

NOTE 2 Additional mixes are reviewed in the literature, see Reference [9].

NOTE 3 Local experience and practice assist in the selection of an appropriate backfill material.

NOTE 4 The quantities specified in Table B.1 are based on the procedure where the cement is added to the water first, and subsequently the bentonite is added to the cement/water mix. This is because the strength and stiffness of the grout are determined by the initial water/cement ratio.

NOTE 5 To facilitate pumping in long backfilling tubes of comparatively small diameter (length > 15 m; inner diameter = 16 mm), it is advisable to add a fluidiser to the suspension.

B.2 All constituents are to be added to the water slowly and the mix be stirred continuously so as to prevent the formation of any lumps.

B.3 Sufficient bentonite is added to provide a creamy mix, which is pumpable.

NOTE Bentonite is added primarily to restrict “bleed” (sedimentation of the solids, leaving ponded water at the surface). The amount of bentonite required to provide this depends on the ambient temperature and the acidity of the water (so will be variable).

Annex C
(informative)

Geo-engineering applications

Table C.1 provides an overview of the various extensometer types in some common geo-engineering applications. The classification, as shown in Table C.1, may assist in the instrument selection. In the case that a geo-engineering application is not included in Table C.1, the closest application can be considered for the selection.

Table C.1 — Guide for the selection of extensometer types in geo-engineering applications

Column	Application	Extensometer (abbreviated designation)[a]							
		Ex-rod	Ex-wire	PrEx 1	PrEx 2-1	PrEx 2-2	CV 1	CV 2	CV 3
A	Shallow foundation in soil	+	-	-	+	±	-	-	-
B	Shallow foundation in rock	+	-	-	±	+	-	-	-
C	Pile and pile-raft foundation, including pile load testing	+	-	-	±	+	-	-	-
D	Excavation adjacent to settlement-sensitive structures (including cut and cover tunnels)	+	-	+	±	+	+	±	±
E	Swelling of the ground	±	-	-	+	+	-	-	-
F	Loosening and natural movements of the ground (karst, abandoned mine workings)	±	±	+	+	±	-	-	-
G	Earth dams and embankments	±	-	+	±	-	-	-	±
H	Embankment on soft soil	±	-	+	±	-	-	-	-
I	Small-scale slope movements	+	-	-	+	±	-	±	±
J	Large-scale slope movements	±	+	±	-	-	-	-	±
K	Near-surface tunnelling	+	-	-	+	+	-	±	-
L	Deep tunnelling and cavern excavation	+	-	-	+	+	±	±	±
M	Underground repositories	+	-	-	±	+	+	±	-
N	Structural health monitoring (tunnels; structures)	±	-	-	±	+	+	±	-
O	Plate load test in rock	+	-	-	-	-	+	+	-

Key

for geo-engineering applications

+	likely to be suitable
±	possibly suitable
-	likely to be unsuitable

[a] See Table 3.

Annex D
(informative)

Measuring examples

D.1 General

NOTE Examples of the various types of extensometers and typical applications are presented as follows:

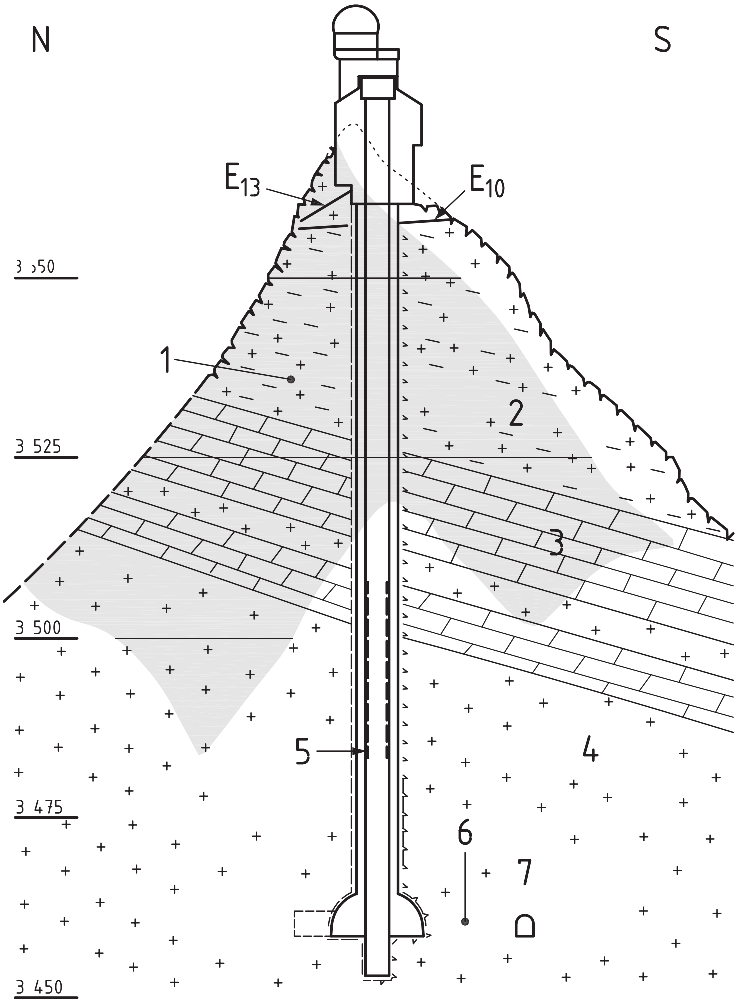
1. In-place multiple-point extensometer (D.2)
2. Retrievable chain extensometer in pile load test (D.3)
3. In-place chain extensometer with reverse head in tunnelling (D.4)
4. Single-point probe extensometer in embankment construction (D.5)
5. Double-point probe extensometer in near-surface tunnelling (D.6).

Each example contains information that is typically included in a report in accordance with ISO 18674-1:2015, Clause 9.

D.2 In-place multiple-point extensometer

a	Owner of the geotechnical project	Jungfrau-Bahngesellschaft AG, Interlaken, Switzerland
b	Name and location of the geotechnical project	Enlargement of the “Sphinx” observation platform (see Figure D.1) and construction of new access and construction shafts (see Figure D.2) 3500 m above sea level
c	Name of the company carrying out the monitoring project	Geotest AG, Zollikofen, and B+S AG, Bern, Switzerland
d	Monitoring project	Perpetuation of evidence of the integrity of the “Sphinx” rock pinnacle in connection with the shaft construction. The pinnacle is subject to permafrost.
e	Instrumentation	In-place multiple-point rod extensometers: Four extensometers E1 ... E4 at the shaft base and four extensometers E10 ... E13 at the shaft top, supplemented by temperature sensors placed along the extensometers (see Figure D.2)
f	Instrumentation details	Packer anchors $\varnothing_{\text{outer}}$ = 100 to 145 mm; stainless steel rods Ø = 14 mm with protective sleeves $\varnothing_{\text{outer}}$ = 20 mm; electric displacement transducers (potentiometers), data logger, overvoltage (surge) protection of the entire monitoring system
g	Boreholes for the installation of instruments	Rotary drilling with continuous core recovery (Category A sampling), borehole Ø = 136 mm
h	Installation details	Installation and stabilization periods controlled by climatic and local weather conditions due to frequent temperature changes with melting ice and freezing water

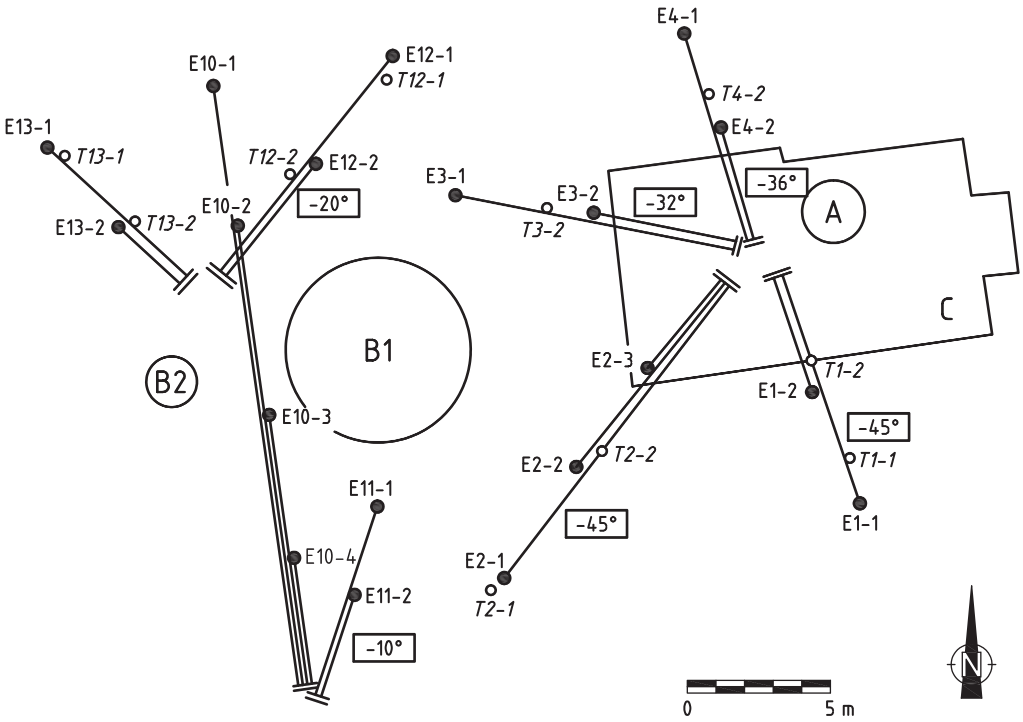
i	Measuring uncertainty	±0,05 mm
j	Commissioning of the monitoring system	After stabilization period. Supply of installation report including instrumentation specifications and calibration sheets
k	Principal results of the monitoring project	In baseline measurement (see left of Figure D.3), identification of temperature-induced reversible ground displacements. With commencement of construction (see right of Figure D.3): Irreversible displacements of some 3 mm, particularly at the top of the “Sphinx.”
l	Assessment and evaluation of the measuring results	Continuous automated logging allowed identifying the strong effects of temperature on the displacement measurements.
m	Hints on facts and observations which may be important for the judgement of the measuring results in context with the geology, geotechnical design and construction activities of the site	Based on the monitoring results, the “Sphinx” foundation slab was increased with regard to dimension and reinforcement.
n	Location and date of submission of the report	Steiner, W., Graber, U. Keusen, H.-R. (1996). Construction in rock at 3550 m elevation (Jungfraujoch, Switzerland). - Proc. Eurock ‘96, Rotterdam (Balkema), pp. 543 – 550.



Key

1	zone of permafrost	6	cross cut
2	chlorite sericite gneiss	7	pedestrian tunnel
3	limestone (malm)	E_{XY}	in-place extensometer with extensometer number
4	granitic gneiss	Numbers	elevation above sea level [m]
5	lift shaft		

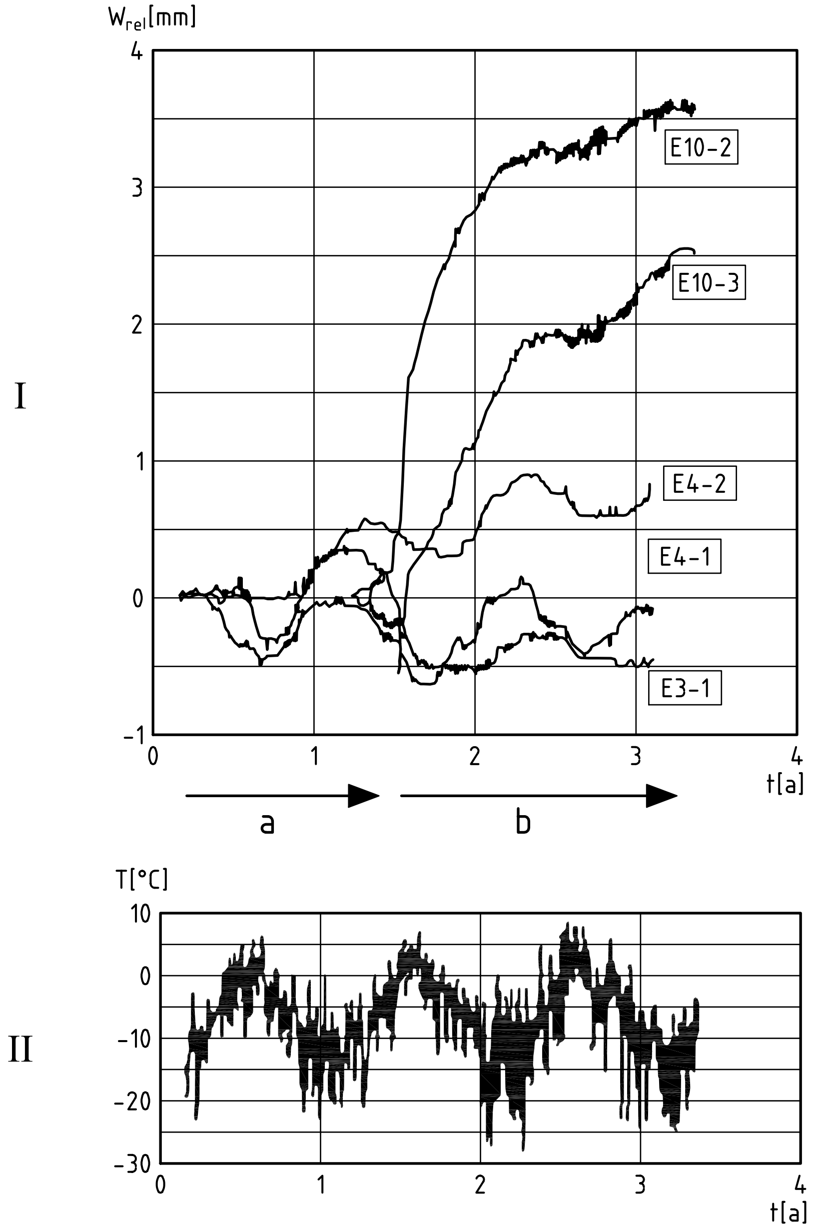
Figure D.1 — Geologic section of the “Sphinx” pinnacle with the new 120 m high vertical elevator shaft to the viewing platform at the top



Key

●	$E_{X\text{-}Y}$ extensometer with number of anchor point
○	$T_{X\text{-}Y}$ temperature sensor with number
−45°	inclination of extensometer (negative = down-dipping from head)
A	existing elevator shaft
B1	new elevator shaft
B2	ancillary construction shaft
C	underground chamber for access to the base of the existing Shaft A

Figure D.2 — Plan of the extensometer location



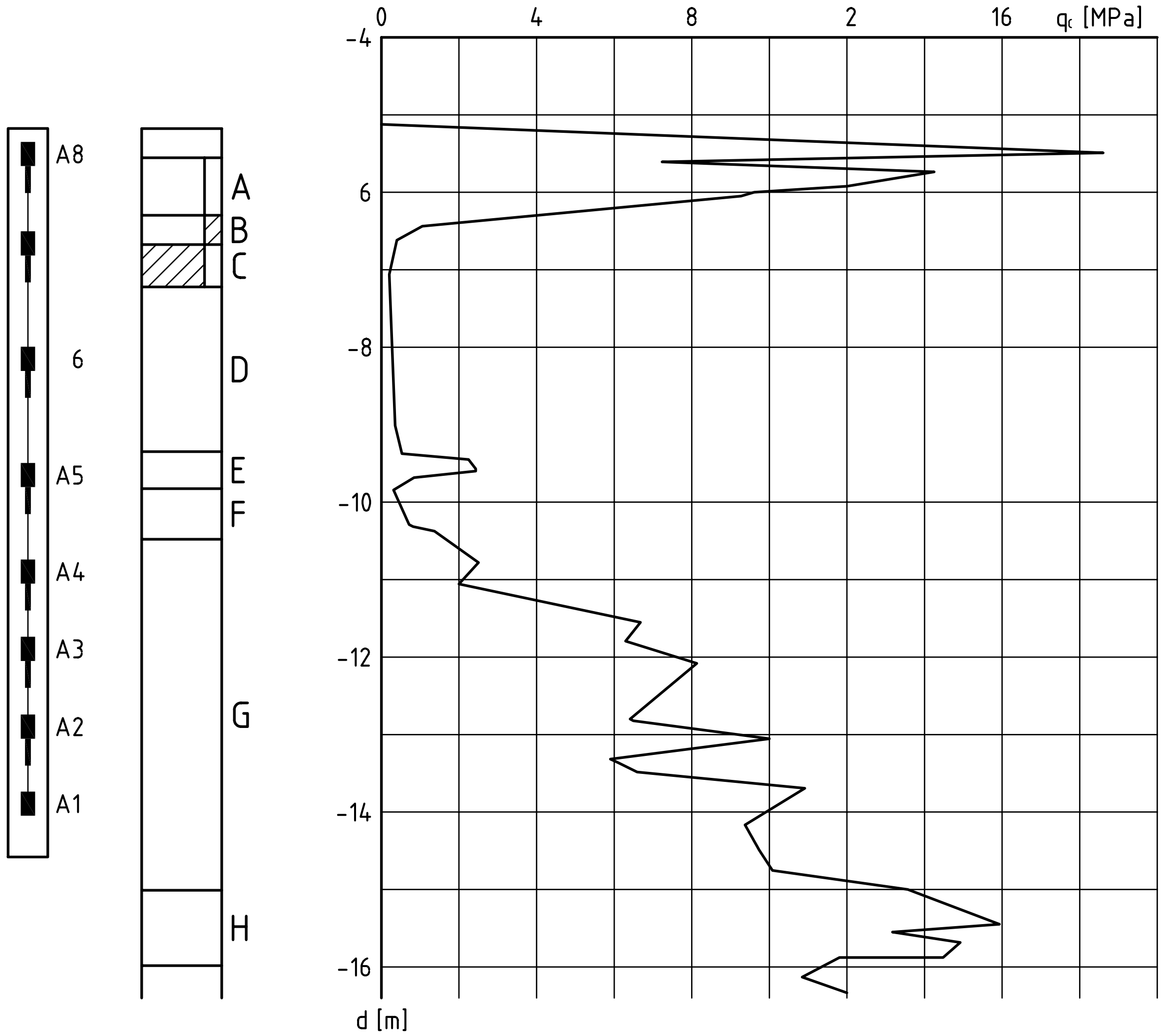
Key

I	diagram of relative displacements w_{rel} as a function of time
II	diagram of air temperature T as a function of time
E X-Y	extensometer with number of anchor points
w_{rel}	relative displacement [mm]
t	time elapsed since installation [year]
T	air temperature [°C]
a	period of baseline measurements
b	construction period

Figure D.3 — Examples of monitored rock displacements

D.3 Retrievable chain extensometer in pile load test

a	Owner of the geotechnical project	Voorbij Funderingstechniek b.v.
b	Name and location of the geotechnical project	Pile testing site
c	Name of the company carrying out the monitoring project	Fugro Geoservices b.v.
d	Monitoring project	Instrumentation and test loading of concrete piles in line with EC7. The ground consisted of Holocene sediments overlying Pleistocene sands [see Figure D.4 b)] and was sounded by CPT [see Figure D.4 c)].
e	Instrumentation	Retrievable extensometers, Fugro Geoservices b.v. automated pile loading equipment
f	Boreholes for the installation of instruments	Polyethylene tubing in pile, Ø = 50 mm
g	Instrumentation details	Retrievable extensometer [see Figure D.4 a)], consisting of a chain of seven single point extensometers with bottom anchor as reference (in total 8 anchors, pneumatically activated). Connecting elements of fibreglass. Vibrating wire displacement transducers.
h	Installation details	The extensometer chain was assembled at the surface and lowered as a complete string into the measuring tube of the pile. Subsequently, the anchors were activated. Activation was carried out sequentially to ensure that each sensor was within the anticipated measuring range (bottom sensors = 6 mm, upper sensors = 12,5 mm).
i	Commissioning of the monitoring system	N.A.
j	Measurements	Automated measurements with readings recorded every minute during the test. Test was carried out in eight load cycles, lasting for some 3 days in total (see Figure D.5).
k	Measuring uncertainty	General error is 0,03 %FS for the sensors.
l	Principal results of the monitoring project	After the test the strain per section was calculated and compared to the results of the load cell. The maximum compression of the piles was in the order of 4,5 mm over a length of 13 m.
m	Assessment and evaluation of the measuring results	Substantial portions of the loads are transferred in depths between about 10,8 and 13,5 m into the sandy ground by skin friction (see Figure D.6).

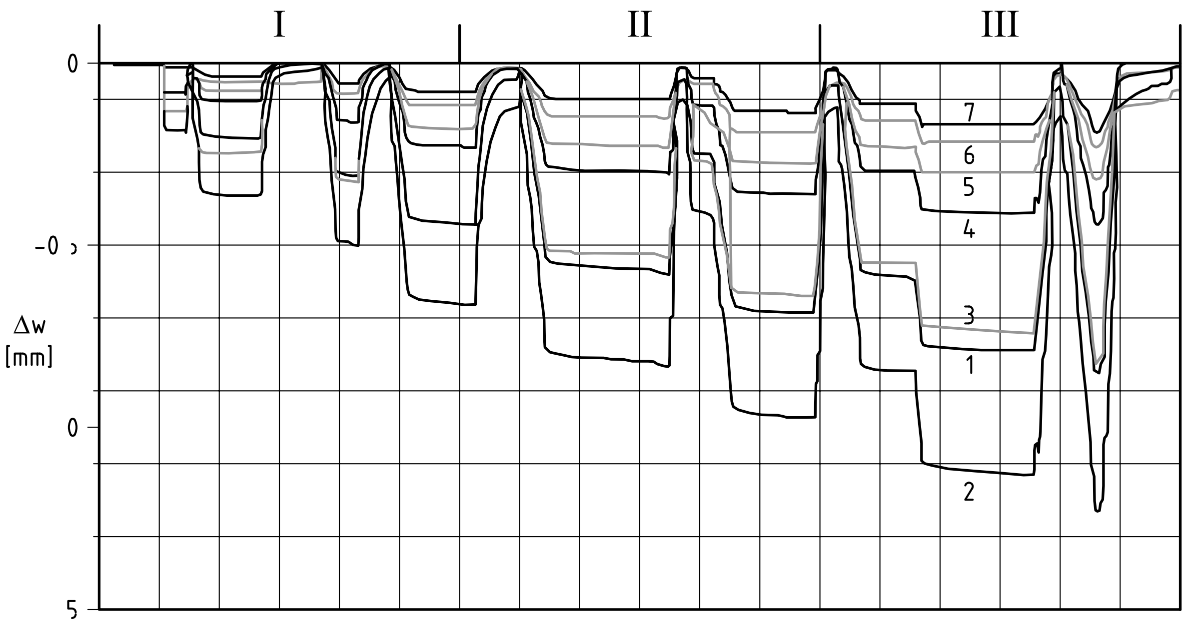


a) b) c)

Key

a	retrievable chain extensometer
A1 ... A8	location and number of anchor points
b	soil profile (simplified)
c	cone penetration resistance record
qc	cone penetration resistance [MPa]
d	depth w. r. t. NAP (New Amsterdam Level) [m]
A	sand to sand, gravelly
B	sand, dense / sand, clayey
C	clay, silty / silt
D	peat, organic
E	sand, slightly silty to silty
F	sand, silty to silt
G	sand, slightly silty to silty
H	sand, slightly silty to silty

Figure D.4 — Ground profile of the test site



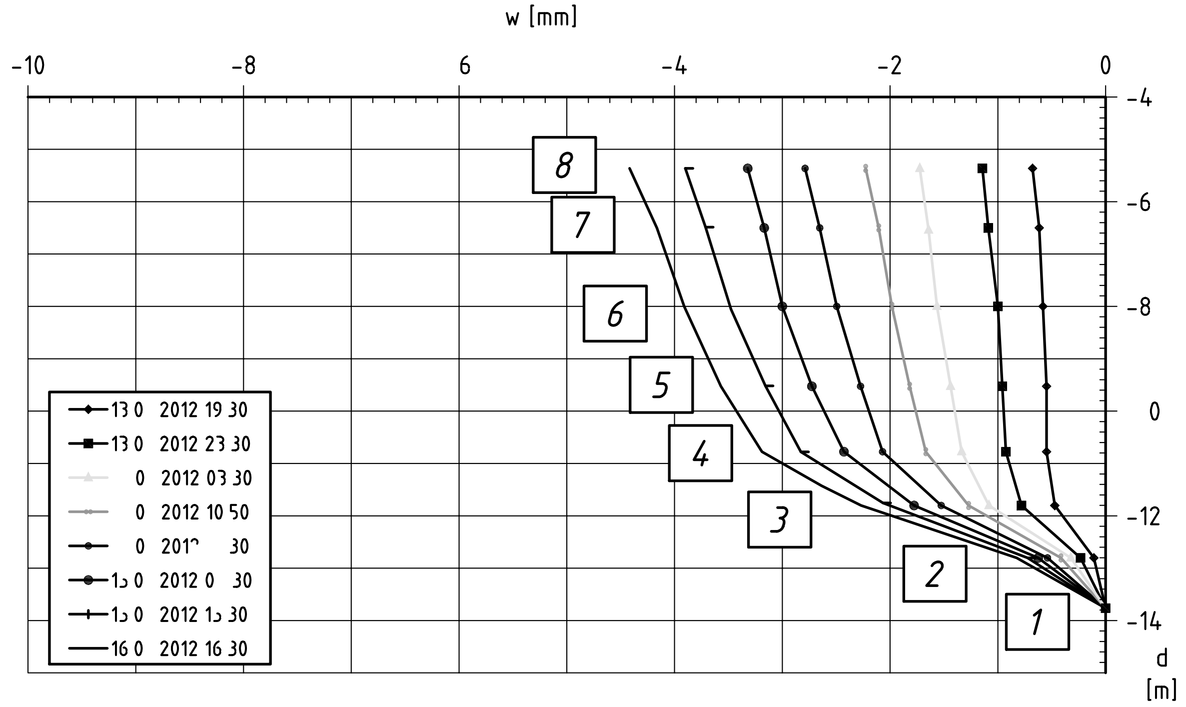
Key

Δw relative axial displacement between adjacent anchor points n and n+1

1 ... 7 anchor point time-displacement record

NOTE 1 = relative displacement between anchor points A1 and A2.

Figure D.5 — Record of pile load test phases



Key

w axial displacement relative to the bottom anchor No. 1 (assumed to be a fix point)

1 ... 8 anchor point level

d depth w. r. t. NAP [m]

Figure D.6 — Cumulated displacements at the load phase maximums

D.4 In-place chain extensometer with reverse head

a	Owner of the geotechnical project	AlpTransit Gotthard Ltd, Switzerland
b	Name and location of the geotechnical project	Ceneri base tunnel, Switzerland
c	Name of the company carrying out the monitoring project	Solexperts AG, Switzerland and Engineering Joint Venture: Consorzio d’ingegneri ITC ITECSA-Toscano, Switzerland
d	Monitoring project	Horizontal displacements of the ground acting in the direction of an advancing tunnel face: Top heading at the northern tunnel portal of the Ceneri base tunnel, Vigana (Camorino)
e	Instrumentation	Three in-place chain extensometers E_1 ... E_3 (see Figures D.7) and D.8), type Solexperts Modular-Reverse-Head-Extensometer (M-RHX), seven anchor points per extensometer
f	Boreholes for the installation of instruments:	Three sub-horizontal boreholes, each approx. 38 m long, 101 mm diameter
g	Instrumentation details	Steel anchors with integrated potentiometric displacement transducers. Measuring range 100 mm (85 mm extension, 15 mm shortening). Anchor length 120 mm per element. Location of anchors at 3,0 m, 8,0 m, 11,0 m, 18,0 m, 23,0 m, 27,0 m and 32,0 m borehole depth. Integrated water-tight data logger. Location at 37 m borehole depth (=deepest part of the chain extensometer). Sequential removal of anchors and sensors of the chain elements in line with the ongoing tunnel excavation. From the actual tunnel face, connection to the data logger by means of an electric cable.
h	Installation details	Sub-horizontal extensometer boreholes, slightly down-dipping. Emplacement of instruments in boreholes with a pre-installed injection tube attached. Cement/bentonite grout as borehole refill.
i	Commissioning of the monitoring system	Installation and commissioning within a time span of 26 days.
j	Measurements	Logging of the displacement values every 30 minutes during the tunnel excavation. Read-out of the data logger at least once a day by a laptop.
k	Measuring uncertainty	±0,02 mm
l	Principal results of the monitoring project	Successful control of the auxiliary construction measures (jet grouting, back anchorage). The measured ground displacements (see Figure D.9) turned out to be within the predicted range. This contributed in the validation of the tunnel design.

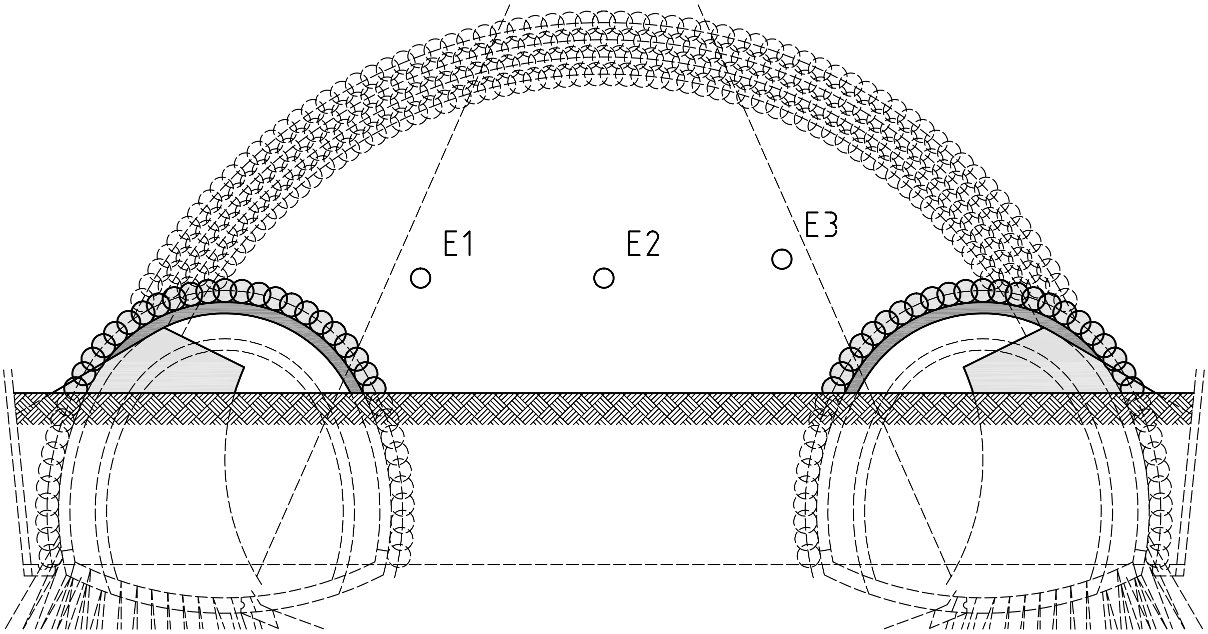
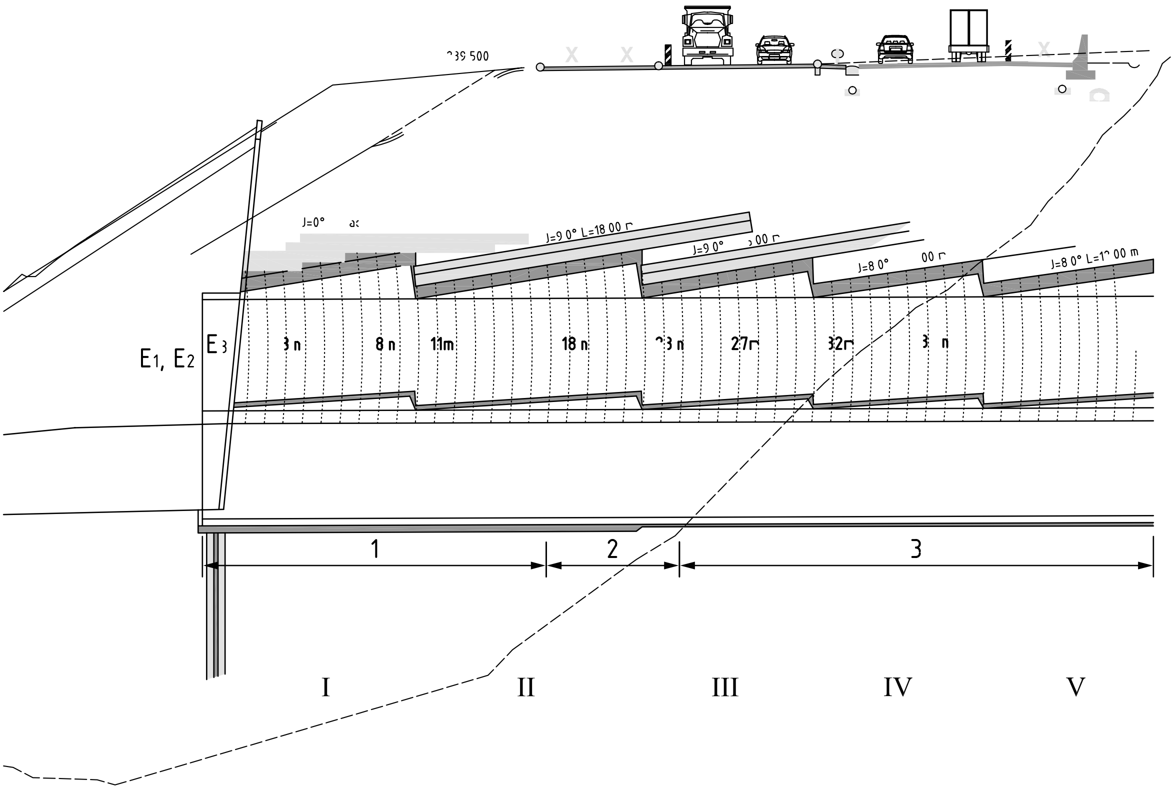


Figure D.7 — Front view of the Ceneri Base tunnel: Position of three sub-horizontal in-place chain extensometers E_1, E_2, E_3 in the top heading prior to excavation

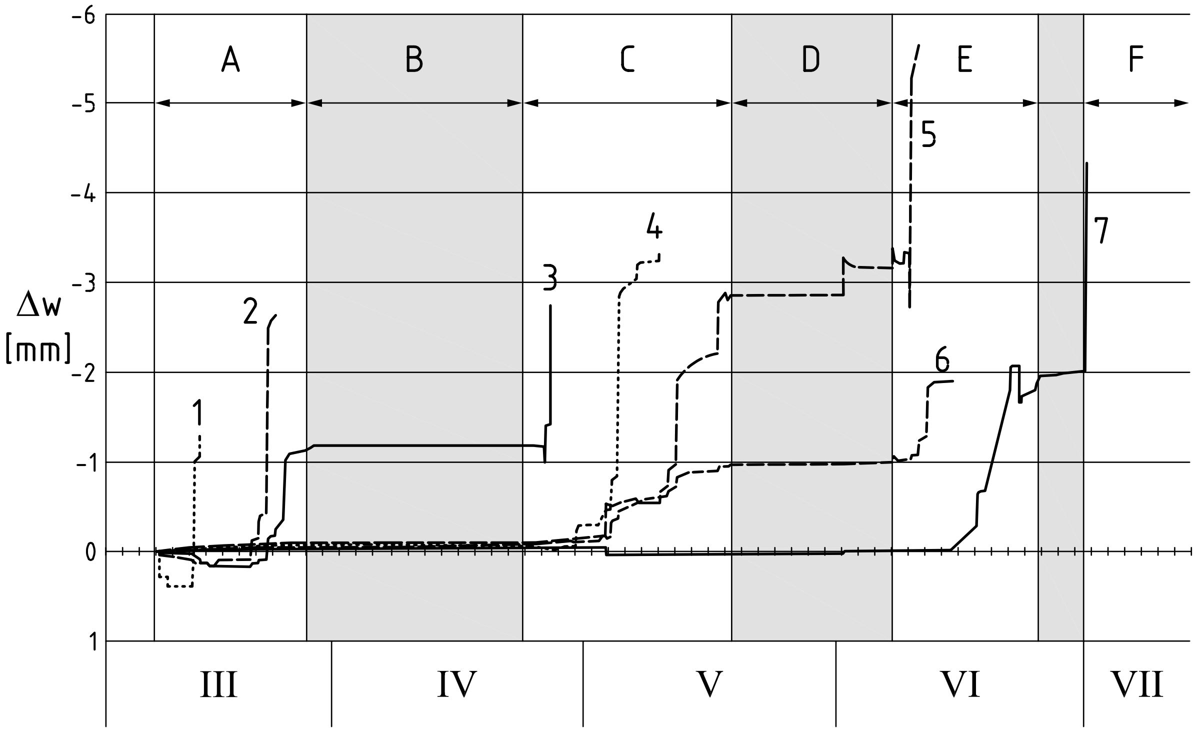


Key

1	Granular material
2	Weathered rock
3	Rock
I	Stage 1
II	Stage 2
III	Stage 3
IV	Stage 4
V	Stage 5

Figure D.8 — Side view of the top heading of the Ceneri Base tunnel with the location of the in-place chain extensometers E_1, E_2, E_3 and anchor points indicated

NOTE The top heading is excavated in the protection of a jet-grouted arch (see Figure D7). Jet-grouting is sequentially carried out in tune with the associated excavation stages whereby each sequence covers an advance of some 10 to 12 m (see Figure D.8). The three extensometers are installed over a length of some 37 m, thus providing displacement data for up to three to four sequences. Measured are the displacements of the ground towards the tunnel face (see Figure D.9). The two bench tunnels (see Figure D.7) are already excavated ahead of the main construction.



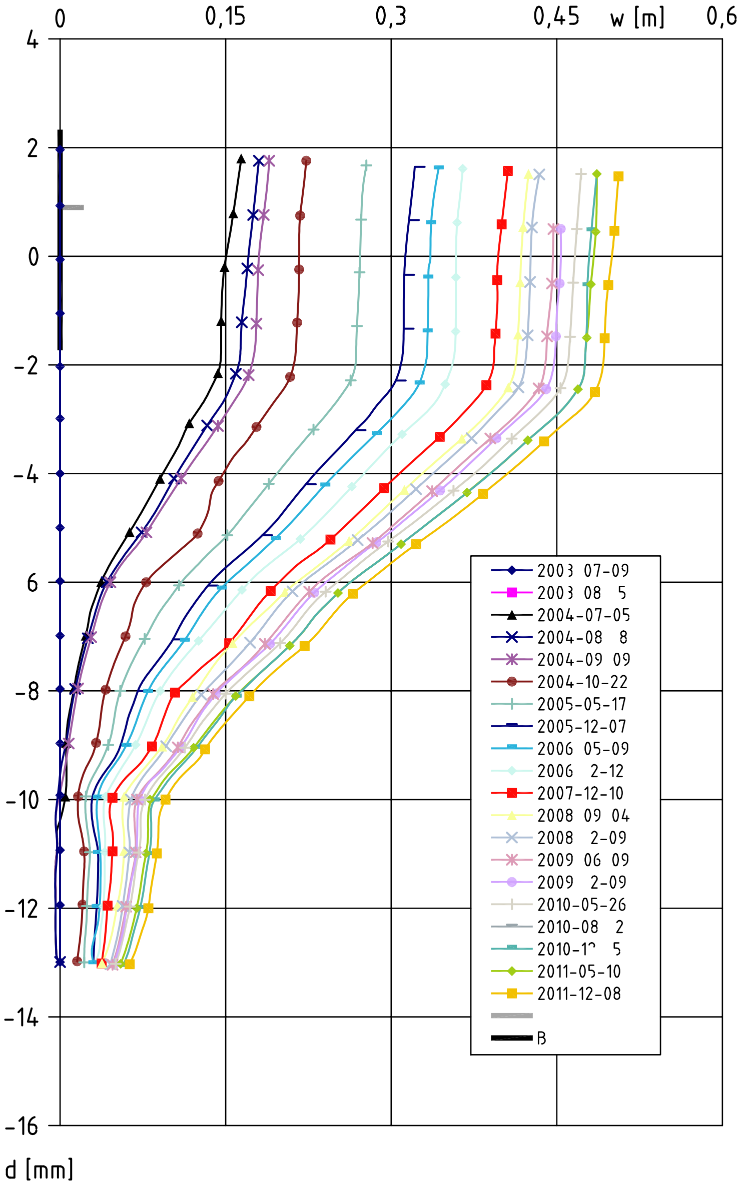
Key

A Excavation stage 1
B Jetting stage 2
C Excavation stage 2
III March
IV April
D Jetting stage 3
E Excavation stage 3
F Excavation stage 4
VI June
VII July
Δw relative displacement of the ground towards the tunnel face
1 ... 7 chain extensometer segments:
(1) = 3,0 to 8,0 m;
(2) = 8,0 to 11,0 m;
(3) = 11,0 to 18,0 m;
(4) = 18,0 to 23,0 m;
(5) = 23,0 to 27,0 m;
(6) = 27,0 to 32,0 m;
(7) = 32,0 to 37,0 m.

Figure D.9 — Measured relative displacements Δw of the ground in direction to the tunnel face in response to jet grouting and tunnel excavation phases

D.5 Single-point probe extensometer in embankment construction

a	Owner of the geotechnical project	The Technical Department of Municipality of Kristianstad, Sweden
b	Name and location of the geotechnical project	Embankment dam on very soft soil, Kristianstad, Sweden
c	Name of the company carrying out the monitoring project	FmGeo AB in cooperation with Tyréns AB, Sweden
d	Monitoring project	Monitoring of vertical displacement in 15 boreholes (and of horizontal displacement in 9 tubes; not shown in this measuring example).
e	Instrumentation	Single-point probe extensometers (Bellow Hose) supplemented by geodetic levelling of the measuring head
f	Boreholes for the installation of instruments:	Casing ($\varnothing_{\text{outer}} = 35$ mm)
g	Instrumentation details	Flexible plastic hose ($\varnothing_{\text{outer}} = 25$ mm); measuring rings spaced at 1,00 m distance.
h	Installation details	The bellow hose was installed in the casing with an inner rod. The tube was stretched and fixed in about 24 hours before the inner rod was withdrawn. About 2-3 m of the casing was left. The top of the upper casing was taken as reference level.
i	Commissioning of the monitoring system	After a stabilization period of two weeks, two reference measurements were performed within a one-week interval.
j	Measurements	About two follow-up measurements per annum
k	Measuring uncertainty	±2 mm
l	Principal results of the monitoring project	Larger settlements and longer time for consolidation than expected (see Figure D.10).
m	Assessment and evaluation of the measuring results	Consideration of alternative methods to further increase the height of the dam. The origin plan was to wait until the settlements have eased and fill up the dam to compensate for the settlements.



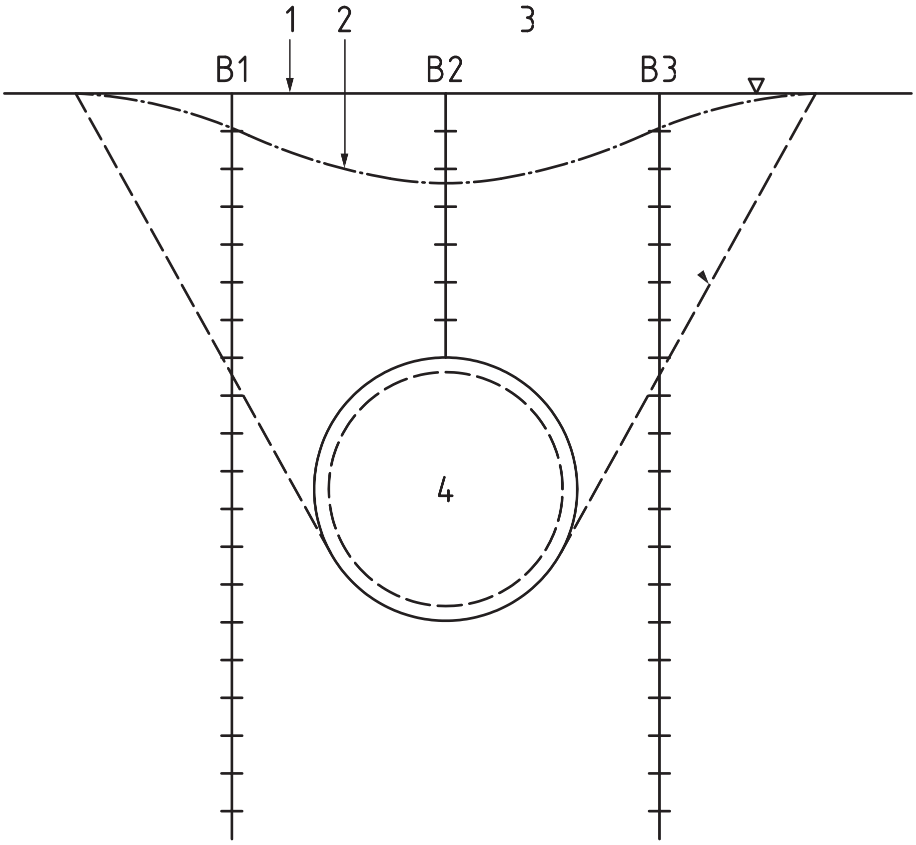
Key

A	ground level
B	casing
d	depth w. r. t sea level
w	vertical displacement (settlement)

Figure D.10 — Single-point probe extensometer measurements beneath an embankment dam on soft ground

D.6 Double-point probe extensometer in near-surface tunnelling

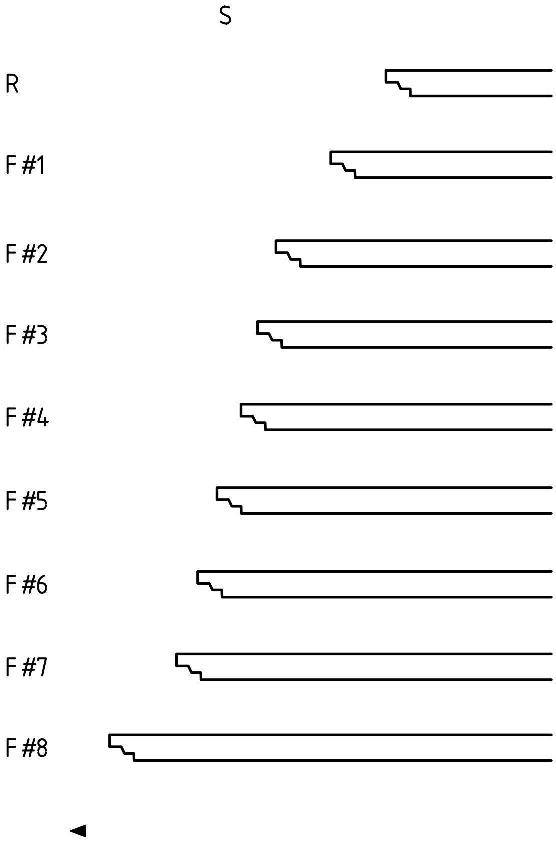
a	Owner of the geotechnical project	German Railways Corp. (Deutsche Bahn AG), Berlin
b	Name and location of the geotechnical project	Construction of a near-surface tunnel for new regional railways, Line S4 in the City of Dortmund
c	Name of the company carrying out the monitoring project	ELE, Geotechnical Consultants, Essen, Germany
d	Monitoring project	Ground displacements in course of shotcrete tunnelling for validation of settlement trough theory. Quality control of tunnel construction.
e	Instrumentation	Double-point probe extensometer in three vertical boreholes B1 to B3 (see Figure D.11) in line with levelling of the topographic surface.
f	Boreholes for the installation of instruments	Rotary drilling with continuous core recovery (Category A sampling). Borehole Ø = 101 mm. Double-tube core barrel T6S.
g	Instrumentation details	Extensometer probe ($\varnothing_{\text{outer}}$ = 46 mm), Type PrEx 2-1 (see Table 2). PVC measuring tubings ($\varnothing_{\text{outer}}$ = 76 mm); measuring rings ($\varnothing_{\text{outer}}$ = 86 mm) spaced at 1,00 m distance.
h	Installation details	Backfilling of annulus between borehole wall and casing/ring assembly by low-strength mortar.
i	Commissioning of the monitoring system	Immediately after zero measurement, when top heading of the tunnel was still remote from measuring section. No baseline measurements required.
j	Measurements	Eight follow-up measurements in tune with the tunnel advancing and crossing the measuring section (see Figure D.12).
k	Measuring uncertainty	±0,01 mm/m with regard to sectional (“differential”) displacements ±0,10 mm with regard to overall (“integrated”) displacements
l	Principal results of the monitoring project	Delineation of significant ground displacements ahead of tunnelling. When tunnelling passes the measuring section, development of an inhomogeneous loosening zone in the roof strata (see segmental strain plot, top left of Figure D.13) and, to a minor degree, also in the ground of the sidewalls (see bottom left of Figure D.13). The resulting settlements in the ground and at the surface (see right, top and bottom of Figure D.13) differ substantially from the anticipated trough theory.
m	Assessment and evaluation of the measuring results	Reliable and detailed picture of the ground displacements. Makes, for the case considered, adjustment of the settlement trough theory necessary.



Key

1	topographic surface
2	settlement trough (anticipated)
3	limiting line of ground loosening (anticipated)
4	tunnel
B1, B2, B3	borehole with number, equipped with double-point probe extensometer casings

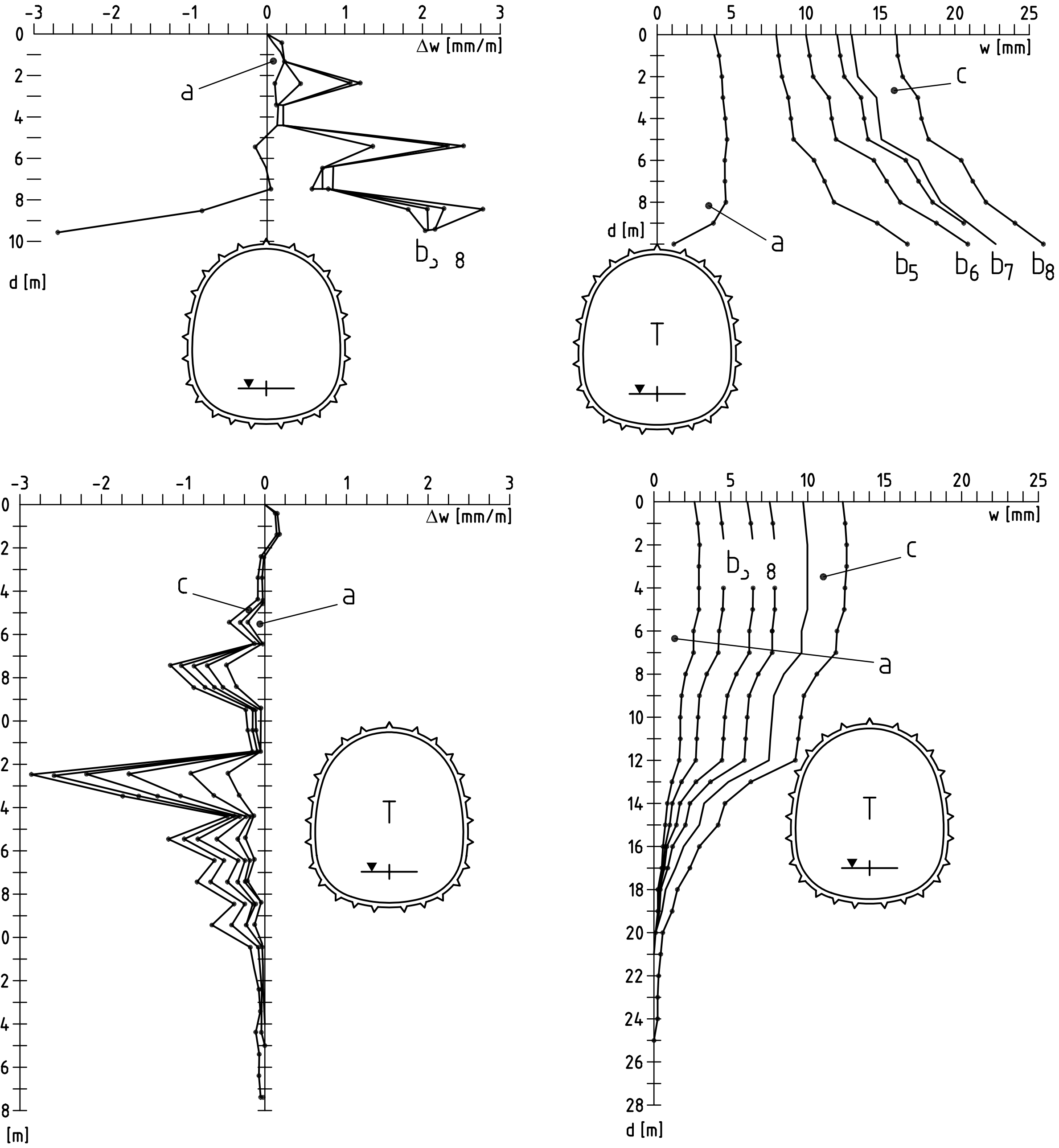
Figure D.11 — Double-point probe extensometer measuring section



Key

T.A.	direction of tunnel advance
M.S.	measuring section
R	reference measurement
F #1 ... F #8	follow-up measurement with number

Figure D.12 — Monitoring scheme in context with the tunnel advance



Left: Segmental strain plots **Right: Absolute displacement plots**

Key

a displacements ahead of tunnelling (shaded; Follow-up Measurement #4)

b displacements at the stage of tunnelling in measuring section (Follow-up Measurements # 5 ...8)

c displacements after completion of tunnelling (shaded; Follow-up Measurements > #8)

d depth below topographic surface (coinciding with No. of measuring ring)

T tunnel

Figure D.13 — Displacements monitored in the roof strata (top) and in one of the sidewalls (bottom)

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