INTERNATIONAL STANDARD

ISO 18674-3

First edition
2017-10

Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation —

Part 3: Measurement of displacements across a line: Inclinometers

Reconnaissance et essais géotechniques — Surveillance géotechnique par instrumentation in situ —

Partie 3: Mesurages des déplacements perpendiculairement à une ligne par inclinomètre

Reference number
ISO 18674-3:2017(E)

ISO copyright office
Ch. de Blandonnet 8 • CP 401
CH-1214 Vernier, Geneva, Switzerland
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
copyright@iso.org
www.iso.org

Contents

Page

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 182, *Geotechnics.*

A list of all parts in the ISO 18674 series can be found on the ISO website.

Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation —

Part 3: Measurement of displacements across a line: Inclinometers

1 Scope

This document specifies the measurement of displacements across a line by means of inclinometers 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.

This document also refers to deflectometers (see Annex B) to supplement inclinometers for the determination of horizontal displacements across horizontal measuring lines.

NOTE In general, there are two independent displacement components acting across measuring lines. Inclinometers allow the determination of the two components for vertical measuring lines. For horizontal lines, inclinometers are limited to the determination of the vertical component only.

If applied in conjunction with ISO 18674-2, this document allows the determination of displacements acting in any direction.

This document is applicable to:

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

— monitoring of geotechnical structures prior to, during and after construction (e.g. natural slopes, slope cuts, embankments, excavation walls, foundations, dams, refuse dumps, tunnels);

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

— identification and monitoring of active shear planes in the ground.

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 inclinometers as part of the geotechnical investigation and testing in accordance with References [1] and [2].

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 18674-2:2016, *Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation — Part 2: Measurement of displacements along a line: Extensometers*

ISO 22475-1:2006, *Geotechnical investigation and testing — Sampling methods and groundwater measurements — Part 1: Technical principles for execution*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 18674-1 and ISO 18674-2 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
inclinometer
system for monitoring displacements across a measuring line by means of inclination measurements in the field

Note 1 to entry: The system essentially consists of an instrument with one or more *tilt sensors* (3.2), a guide tube, a means to measure the position of the instrument in the guide tube and a read-out device.

Note 2 to entry: Data from inclinometers require evaluation, which can be done using proprietary software or spreadsheets.

3.2
tilt sensor
gravity-activated electric sensor for inclination measurements

3.3
probe inclinometer
system comprising a probe with one or more built-in *tilt sensors* (3.2) for step-by-step measurements of the inclination on a measuring line

Note 1 to entry: Also known as a traversing inclinometer.

Note 2 to entry: Vertical probe inclinometers measure displacements in horizontal directions.

Note 3 to entry: Horizontal probe inclinometers measure displacements in vertical directions (settlements or heave).

Note 4 to entry: An alternative to horizontal probe inclinometers is a hydrostatic probe system.

Note 5 to entry: See also Reference [3].

3.4
in-place inclinometer
IPI
inclinometer system comprising a single element, or a series of elements, with one or more built-in *tilt sensors* (3.2) in each element, for measurement of the inclination at specific locations on a measuring line without removing the instrument

Note 1 to entry: In-place inclinometers exist which can measure at all inclinations, but when in near-horizontal position, deflections from the azimuth cannot be measured.

3.5
uniaxial inclinometer
system for inclination measurements in a single plane

Note 1 to entry: Common for horizontal measuring lines.

3.6
biaxial inclinometer
system for inclination measurements in two planes 90° to each other

Note 1 to entry: Common for vertical measuring lines.

3.7
inclinometer casing
guide tube appropriate to the inclinometer system being used

Note 1 to entry: Commonly, the inner side of inclinometer casings have four longitudinal keyways. Commercially available casings differ with regard to material, dimension, type of coupling, number of keyways etc. (see 5.4).

Note 2 to entry: The corners of casings with square section can be considered as keyways.

3.8
gauge length
L
distance between adjacent contact points of the instrument

Note 1 to entry: For *probe inclinometers* (3.3), *L* is commonly 0,5 m or 1,0 m.

3.9
base length
distance between adjacent measuring points used in the evaluation procedure

Note 1 to entry: For *probe inclinometers* (3.3), the base length is equal to the *gauge length* (3.8).

4 Symbols

Symbol	Name	Unit
A	measuring plane of the probe which coincides with the plane of the guide wheels	—
a	lateral displacement component in Plane A	m
B	measuring plane of the inclinometer probe normal to Plane A	—
b	lateral displacement component in Plane B	m
d	depth, distance	m
F	subscript for follow-up measurement	—
h	height with respect to sea level	m
i	number of a measuring point	—
L	gauge length of an inclinometer or deflectometer probe	m
l	distance between measuring points	m
n	total number of measuring points along a measuring line	—
R	subscript for reference measurement	—
t	elapsed time	s
t_F	date and time of a follow-up measurement	—
t_R	date and time of a reference measurement	—
u, v, w	displacement component in x-, y- and z-direction, respectively	m
x, y, z	local coordinates of a guiding tube or borehole	m
α	tilt angle of the probe axis in Plane A	° (degree)
β	tilt angle of the probe axis in Plane B	° (degree)
ψ	angle between guide tube coordinate x and plane A of the inclinometer	° (degree)
θ, ρ	auxiliary quantities	° (degree)

5 Instruments

5.1 General

5.1.1 Probe and in-place inclinometers should be distinguished from each other (see Table 1 and Figures 1, 2 and A.1).

Table 1 — Inclinometer types

No.	Type	Sub-type	Principal measuring procedure	Automatic data acquisition
1	Probe (see 5.2)	Inclinometer — Vertical inclinometer — Horizontal inclinometer	Probe moved inside a guide tube from one measuring point to the next (see Figures 1 and A.1). Repeated measurements within the measuring period.	Not common
2	In-place (see 5.3)	In-place inclinometer (IPI) — Vertical inclinometer — Horizontal inclinometer — Combined	Instrument inserted into a guide tube and held in measuring position throughout the measuring period	Common

NOTE A combined IPI is a series of elements in which some elements act as vertical and some act as horizontal inclinometers.

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

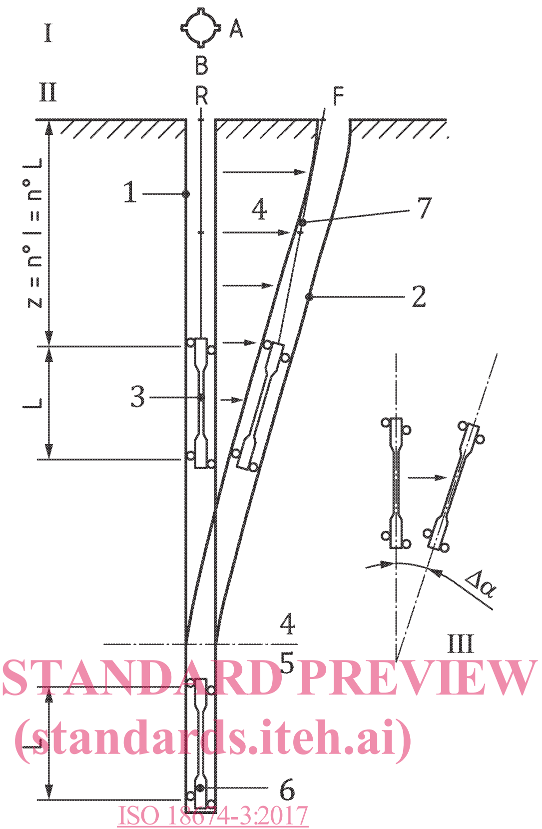
5.1.3 The point to which the measurements are related shall be denoted the “reference point”.

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

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

5.1.5 The sensing element shall consist of a housing with either one (uniaxial configuration) or two (biaxial configuration) built-in tilt sensors. In the case of a biaxial configuration, the tilt sensors shall be installed with axes perpendicular (90°) to each other.

5.1.6 The installation planes of the tilt sensors shall be denoted as the instrument Planes A and B, whereby Plane A shall coincide with the plane of the guide wheel assemblies (see 5.2.5). The planes shall be durably marked onto the inclinometer housing, e.g. by the mark “A+” showing the positive A direction.



Key

1	undeformed inclinometer casing	I	top view of inclinometer casing
2	deformed inclinometer casing	II	side view
3	inclination measuring element	III	detail of inclinometer element in R- and F- positions
4	area of the ground subject to displacements	A	A+ direction
5	undeformed deeper ground for base fixity	B	B+ direction
6	reference point (here, the axis of the bottom wheel is set at the lowest measuring position)	L	gauge length
7	depth measuring device	R	initial position of inclinometer casing at the reference measurement
Δα	change of inclination	F	position of inclinometer casing at a value change measurement

Figure 1 — Measuring concept for inclinometers (schematic)

5.2 Probe inclinometers

5.2.1 Inclinometer probes shall be moved incrementally along the measuring line, whereby each increment shall not exceed the gauge length *L* of the probe.

5.2.2 The depth measuring device shall have permanent and wear-resistant depth measuring marks. The spacing of the marks should be equal to the gauge length *L* of the probe.

5.2.3 The length of the depth measuring device and the spacing between the marks shall be checked throughout the measuring project. Changes shall be recorded.

NOTE 1 Monitoring displacements by probe inclinometers requires good repeatability of the probe's positioning at the respective measuring points (see 6.5.2.3 and 7.4).

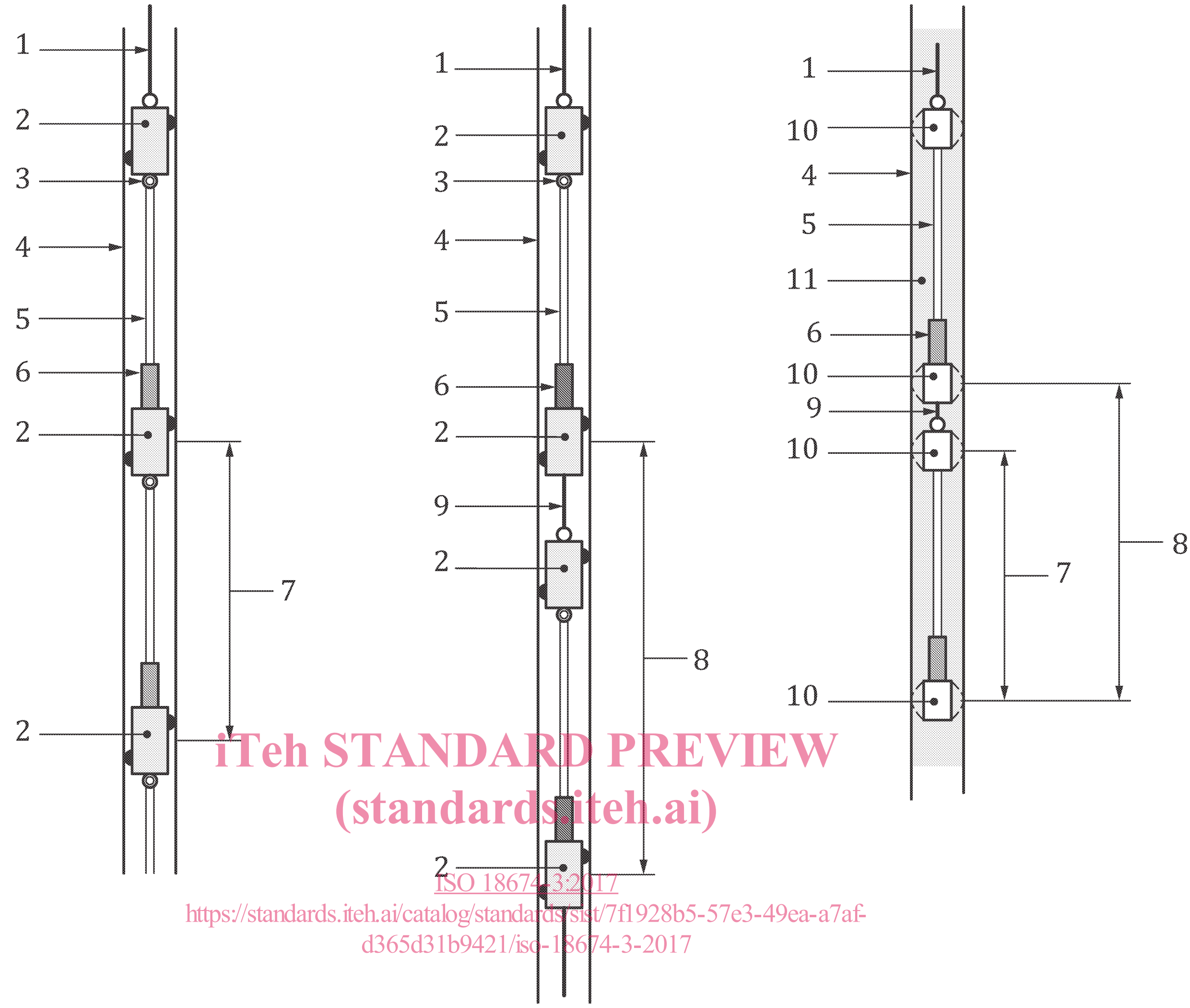
NOTE 2 The use of a cable gate or a suspension pulley can help to ensure good positioning.

5.2.4 Inclinometer casing shall be used as guide tubes (see 5.4).

5.2.5 The inclinometer probe shall be equipped with two spring-loaded guide wheel assemblies. The width of the guide wheels shall fit the keyways of the inclinometer casings. The force of the springs should ensure a central positioning of the probe in the casing, even for extended monitoring periods with repeated measuring runs.

5.3 In-place inclinometers

5.3.1 The principal setup of in-place inclinometers should be as in Figure 2.



a) IPI with wheel assembly and continuous string of sensors

b) IPI with wheel assembly and discontinuous string of sensors

c) IPI without wheel assembly and discontinuous string of sensors

Key

1 top suspension
2 wheel assembly
3 universal joint
4 guide tube
5 connecting element
6 sensor
7 gauge length, *L*
8 base length
9 intermediate suspension
10 expanding joint or skid
11 embedment material

Figure 2 — Principal setup and components of in-place inclinometers (IPIs)

5.3.2 It shall be ensured that the lengths of the connecting elements remain constant throughout the measuring project (no elongation, no shrinkage).

5.3.3 For a continuous string of measuring elements [see Figure 2 a)], the flexibility of the measuring elements shall be negligible.

NOTE This requirement applies in particular to horizontal strings (see Reference [4]).

5.3.4 For a discontinuous string of measuring elements [see Figure 2 b) and c)], engineering judgement shall be used to integrate angular changes into displacements.

5.3.5 Gauge lengths should not exceed 2 m. Within an installation, they can be varied to adjust to local conditions.

NOTE Shorter lengths will commonly lead to better results.

5.3.6 The long-term reliability of the sensor signals should be considered. Intermittent removal of the instrument for re-calibration should be avoided and is only permissible if especially justified and documented.

NOTE An approach to checking the long-term reliability is to make measurements in two adjacent guide tubes; one for the IPI and one for a probe inclinometer ("diversification"; in accordance with ISO 18674-1:2015, 5.4).

5.4 Inclinometer casing

5.4.1 The section of the casing shall be selected against the background of the specific measurement requirements and the expected ground movements across the measuring line (see also 6.3.1.1).

5.4.2 The material of the casing shall fulfil the following requirements:

— be neutral to groundwater and other soil components;

— be durable during complete measuring period;

— be robust for installation;

— be flexible for bending.

NOTE 1 Acrylonitrile butadiene styrene (ABS) is a common inclinometer casing material.

NOTE 2 Metal casings, especially aluminium casings, can corrode, for example, by short-circuiting between ground layers with different electric potentials or by aggressive groundwater.

5.4.3 If the inclinometer casing has internal keyways, the spiralling of the keyways shall be less than 0,25°/m. The string of casings should be assembled so that the keyways are continued over the joints.

5.4.4 When selecting the casing, the flexibility of the assembled string, including the backfill material (see 6.3.2.5 and Annex C), should be considered with respect to the site conditions.

5.4.5 If using telescopic couplings, the design of the couplings, their telescopic travel and the method of fixing should be such as to allow the string of casings to readily compress or extend in the direction of the measuring line by an amount equal to the ground compression or extension.

NOTE 1 Telescopic couplings can have major detrimental effects on the accuracy of measurements and on the tracking and depth positioning control of the probe.

NOTE 2 The addition of external corrugated sleeving to flush-coupled casing can eliminate damage caused by ground settlement. However, there is no need to extend the sleeving into the undeformed deeper ground (see Figure 1).

5.4.6 Prior to installation, the casings should be stored in a safe and secure place, laid horizontally and supported to avoid deformations due to self weight. They should also be protected from direct sunlight.

5.5 Measuring range, accuracy and repeatability

5.5.1 Table 2 provides some order of magnitude information regarding accuracy and repeatability of inclinometers. Inclinometer measurements shall be in accordance with Table 2.

Table 2 — Requirements of inclinometer measurements

Type	Line	Issue	Inclinometer	
			Vertical	Horizontal
Probe	1	Accuracy of the instrument (probe or IPI element)	±0,02 % full scale (e.g. ±0,1 mm/m for ±30° range)	
	2	*Repeatability (precision) of a complete survey along a measuring line:* Difference between the cumulated displacements of a measuring point relative to a reference point 30 m apart, when repeatedly carrying out the survey under repeatability conditions (see 5.5.2)	±2 mm	±10 mm
In-place	3	*Repeatability (precision) of a string of IPI elements, measuring range ±10°, spaced at 2 m:* Difference between the cumulated displacements of a measuring point relative to a reference point 30 m apart, when repeatedly carrying out the survey under repeatability conditions (see 5.5.2)	±2 mm	±2 mm
Probe and in-place	4	*Stability of sensor signal:* Difference after a 24 h period under repeatability conditions	±0,1 mm/m	

5.5.2 The repeatability of a measuring value (see Lines No. 2 and 3 in Table 2) should be established within the reference measurement (see 6.5.2.5).

NOTE 1 Repeatability conditions comprise, i.e.

— identical observer;

— identical measurement procedure;

— identical instruments;

— identical influencing quantities.

NOTE 2 The values are specified for measurements in the A-axis. The B-axis measurements are commonly less accurate. Achieving the specified values for the secondary axis (B-axis) requires dedicated measurements with the wheels in the corresponding keyways.

6 Installation and measuring procedure

6.1 General

Particular attention should be paid to the selection of suitable guide tubes and their installation as they are critical for the quality of the measurements.

6.2 Installation of guide tubes at accessible surfaces and in concrete

6.2.1 When installing guide tubes at the surface of above-ground engineered structures, attention should be paid to a durable fixation. An exposure of the tubes to environmental impacts such as direct sunlight should be avoided, e.g. by protective covers.

6.2.2 When installing guide tubes in reinforced concrete, the tubes can be either placed inside a void former that is pre-installed before the concreting or fixed directly to the reinforcement. If the guide tubes

