INTERNATIONAL STANDARD

ISO 18674-1

First edition
2015-05-15

Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation —

Part 1: **General rules**

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

Partie 1: Règles générales

Reference number
ISO 18674-1:2015(E)

Contents

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 meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

ISO 18674-1 was prepared by European Committee for Standardization (CEN) in collaboration with ISO/TC 182, *Geotechnics*, Subcommittee SC 01, *Geotechnical investigation and testing*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

ISO 18674 consists of the following parts, under the general title *Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation:*

— *Part 1: General rules*

The following parts are under preparation:

— *Part 2: Displacement measurements along a line: Extensometers*

The following parts are planned:

— *Part 3: Displacement measurements across a line: Inclinometers*

— *Part 4: Piezometers*

— *Part 5: Total pressure cells*

— *Part 6: Hydraulic settlement gauges*

— *Part 7: Strain gauges*

— *Part 8: Load cells*

— *Part 9: Geodetic monitoring instruments*

— *Part 10: Vibration monitoring instruments*

NOTE For further information on geotechnical monitoring by field instrumentation, see References [1] to [7].

Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation —

Part 1: General rules

1 Scope

This part of ISO 18674 lays out the general rules for the performance monitoring of the ground, of structures interacting with the ground, of geotechnical fills, and of geotechnical works.

NOTE ISO 18674 fulfils the requirements for general rules for the performance monitoring of the ground, of structures interacting with the ground, of geotechnical fills, and of geotechnical works as part of the geotechnical investigation and testing according to EN 1997-1[8] and EN 1997-2[9].

Specifically, this part of ISO 18674 applies to field instrumentation and measurements carried out

— in connection with site investigations of soils and rocks,

— in connection with Observational Design procedures,

— in connection with the performance of geotechnical structures before, during, and after construction,

— for ground behaviour evaluation, e.g. unstable slopes, consolidation etc.,

— for the proof or follow-up of a new equilibrium within the ground, after disturbance of its natural state by construction measures (e.g. foundation loads, excavation of soil, tunnelling),

— for the proof or follow-up of the stability, serviceability, and safety of structures and operations which might be influenced by geotechnical construction,

— for perpetuation of evidence, and

— for the evaluation and control of geotechnical works.

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 14688-1, *Geotechnical investigation and testing — Identification and classification of soil — Part 1: Identification and description*

ISO 14689-1, *Geotechnical investigation and testing — Identification and classification of rock — Part 1: Identification and description*

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

ISO/IEC Guide 99:2007, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

3 Terms and symbols

3.1 Terms

For the purposes of this document, the terms and definitions given in ISO/IEC Guide 99:2007 and the following apply.

3.1.1
geotechnical monitoring
observation of the ground behaviour and/or performance of geotechnical structures before, during, and/or after construction

Note 1 to entry: Geotechnical monitoring is an integral part of the Observational Design procedure (see EN 1997–1: 2004).

Note 2 to entry: Geotechnical monitoring is based on field observation, including construction site inspection.

3.1.2
field instrument
measuring tool to assist geotechnical monitoring

Note 1 to entry: Monitoring by field instruments comprises the measurement of physical parameters, in particular, the change of the parameter values.

3.1.3
geotechnical key parameter
physical parameter indicative of the geotechnical issue under consideration and subject to geotechnical monitoring

EXAMPLE Displacement (absolute or relative), strain, inclination, stress, pore pressure, earth pressure, force, velocity, acceleration, temperature.

3.1.4
geotechnical monitoring project
entirety of aspects and processes which, in a specific project, are relevant for geotechnical monitoring

Note 1 to entry: Includes planning, risk assessment, specifying, procurement, delivery, and installation of a project-specific monitoring system and collecting, processing, evaluating, and reporting of the monitoring data.

3.1.5
geotechnical monitoring concept
preliminary plan for the measurement of geotechnical key parameters developed within the conceptual design phase, identifying specific objectives such as risk mitigation to be addressed by monitoring, thereby considering type of measurement, measuring locations, and schedule(s) for carrying out the measurement

3.1.6
geotechnical monitoring plan
advancement of the monitoring concept within the specification design phase

3.1.7
geotechnical monitoring system
hardware and software to provide field data

Note 1 to entry: Includes instruments signal, transmission (e.g. electric cables), data acquisition, and auxiliary units.

Note 2 to entry: The performance (e.g. the accuracy, stability, precision) of the geotechnical monitoring system will not necessarily be identical to the performances of the system components.

3.1.8
geotechnical monitoring programme
entirety of those components of a monitoring project which can be systematically planned, consisting of a monitoring plan and monitoring system

3.1.9
commissioning
demonstration and acceptance of the correct functioning of an installed monitoring system

Note 1 to entry: The commissioning criteria are commonly defined in the monitoring plan.

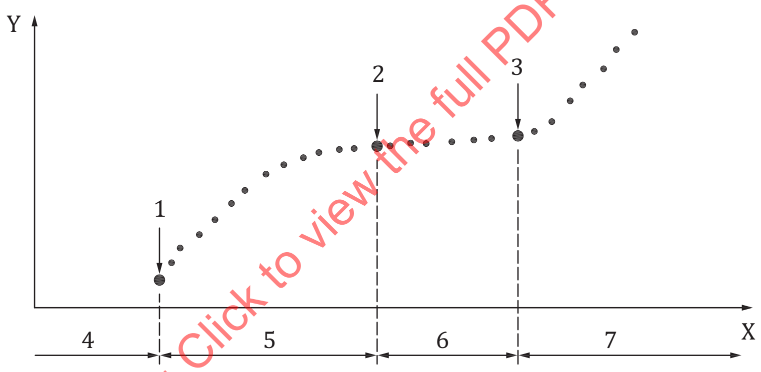
3.1.10
instrument data sheet
manufacturer's document containing instrument technical specifications

3.1.11
initial measurement
first measurement after installation (see Figure 1)

3.1.12
zero measurement
measurement carried out after stabilization of installation effects (see Figure 1)

Note 1 to entry: The zero measurement is often taken as reference for subsequent measurements, as it is commonly related to local space and time coordinates.

Note 2 to entry: The zero measurement is commonly carried out with increased measuring effort, e.g. repetition of measurements, to provide a reliable datum for subsequent measurements.



Key
1 initial measurement
2 zero measurement
3 reference measurement
4 installation period
5 stabilization period
6 period of baseline measurements
7 construction period
X time
Y reading

Figure 1 — Definition of distinct measuring points during a geotechnical monitoring project in the period up to and including the construction phase

3.1.13
baseline measurements
measurements carried out, subsequent to the zero measurement, over a period of time before any construction starts, to help in the definition of changes that occur from causes other than construction

EXAMPLE Seasonal changes in groundwater levels, tidal and moisture content changes, climatic changes such as temperature, and incidence of sunlight.

3.1.14
reference measurement
measurement which serves as reference base for previous and subsequent measurements

Note 1 to entry: The reference measurement is also known as datum measurement.

Note 2 to entry: A new reference measurement is often used for a new construction phase.

Note 3 to entry: The reference measurement is often derived from several measurements.

3.1.15
value change measurement
difference between a measurement and the reference measurement

3.1.16
point measurement
measurement of a physical parameter at a point

EXAMPLE Displacement of a measuring point; force of an anchor at its head; stress state in the ground; porewater pressure in an embankment; water discharge rate at the downstream toe of a dam.

3.1.17
line measurement
measurement of a physical parameter along a line

EXAMPLE Inclinometer measuring survey of a borehole.

3.2 Symbols

For the purpose of this document, the symbols of Table 1 apply.

Table 1 — Symbols

Symbol	Name	Unit
d	borehole diameter	m
i	number of measurement, measurement direction, or measuring point	-
l	distance	m
u, v, w	displacement component in x-, y-, z- direction, respectively	m
u	porewater pressure	Pa
x, y, z	local coordinates	m
z_w	piezometric level	m
α	angle, inclination	Degree or mm/m
ε_n	strain normal to measuring plane	-
$\varepsilon_x\ \varepsilon_y\ \varepsilon_z$	normal strain with reference to borehole coordinates	-
$\gamma_{xy}\ \gamma_{yz}\ \gamma_{zx}$	shear strain with reference to borehole coordinates	-
$\sigma_1\ \sigma_2\ \sigma_3$	principal stress	Pa
σ_n	normal stress with reference to measuring plane	Pa
$\sigma_x\ \sigma_y\ \sigma_z$	normal stress components with reference to borehole coordinates	Pa
$\tau_{xy}\ \tau_{yz}\ \tau_{zx}$	shear stress components with reference to borehole coordinates	Pa

NOTE Symbols with more than one meaning (e.g. u) are distinguishable in the context of their use.

4 Principal requirements

4.1 Geotechnical monitoring in connection with geotechnical design

Geotechnical monitoring shall be designed, implemented, and evaluated in connection with the geotechnical design.

NOTE Figure C.1 shows the position of geotechnical monitoring in connection with the design and the construction of geotechnical structures; see also "observational method" in EN 1997–1: 2004, 2.7.

4.2 Geotechnical monitoring in connection with specific questions

Each geotechnical monitoring project shall be based on at least one specific question that is to be answered. The question shall be formulated at the start of the monitoring project and actualized throughout the project with the aid of information from the measurements.

NOTE Monitoring of construction procedures and long-term monitoring of existing safety-sensitive structures are included.

4.3 Requirements of a geotechnical monitoring project

4.3.1 In a geotechnical monitoring project, all items as defined in 3.1.4 shall be considered in the sequence described in 4.3.2 to 4.3.7.

4.3.2 Within the initiation and preliminary design phase, reference shall be made to the geotechnical issue to be addressed. The key parameters shall be identified and their expected range estimated. The accuracy and the uncertainty with which the key parameters are to be measured and their geotechnically tolerable limits shall be specified.

4.3.3 Within the conceptual design phase, a concept shall be developed on how to measure the key parameters of the geotechnical issue under consideration.

NOTE Aspects for consideration are the principal type of the instruments, frequency of measurements, redundancy in the system, the anticipated operation time of the monitoring system, and potential risks associated with monitoring.

4.3.4 Within the specification design phase, the monitoring concept shall be refined and transferred into a comprehensive monitoring programme. Aspects which shall be considered are the instrument selection based on instrument data sheets (Annex A) together with expected field performance and the specification of the instrument installation procedure.

NOTE 1 The monitoring plan includes the specification of the measuring procedure, the location of the monitoring points, the monitoring schedule, and the type of data collection (manual reading or data logging with or without remote data access).

NOTE 2 The measuring procedure might encompass the measuring principle (physical base of the measurement, e.g. vibrating wire principle) and of the measuring method (e.g. compensation method, digital/analogue method).

NOTE 3 Field instruments comprise a large variety of sensors with different measuring principles which all have their specific advantages and disadvantages depending on the type of application. Examples of sensors with different measuring principles are vibrating wire, current-loop, inductive, capacitive, resistance strain gauge, and fibre-optical sensors.

4.3.5 Within the installation and data collection phases, it shall be ensured that

— the instrument system is installed as early as possible prior to construction for baseline measurements (see Figure 1),

— the installation is carried out in such a way as to achieve good conformance of the measuring instruments, NOTE Good conformance is associated with only insignificant, if any, alterations of the measured values by the presence of the instrument

— the instruments are operated and handled in accordance with the manufacturer's instructions, and

— the monitoring system is routinely inspected and adequately protected from site works.

4.3.6 Within the data processing, evaluation, and reporting phase, attention shall be paid to the fact that the monitoring data are often affected by instrument, installation, and environmental effects (see 5.3). In the evaluation process, plausibility checks of the monitoring data shall be carried out. Checking shall include instrument, as well as geotechnical aspects (see 8.5).

4.3.7 The monitoring results shall be evaluated in respect to the geotechnical issue under consideration.

4.4 Geodetic measurements

For the support, evaluation, and control of geotechnical measurements, reference shall be made to geodetic measurements if applicable.

NOTE 1 See ISO 18674-9.

NOTE 2 For comparison of geotechnical and geodetic measurements, see Table C.1.

4.5 Safety requirements

National and site safety regulations shall be followed.

EXAMPLES Regulations for:

— personal health and safety equipment;

— clean air if working in confined spaces;

— ensuring the safety of the measuring system and its components.

5 Requirements of a geotechnical monitoring system

5.1 General

5.1.1 Geotechnical monitoring systems are subject to specific conditions, which shall be accounted for in the monitoring programme and evaluation of the monitoring data. These conditions include the following:

— mechanical, hydro-mechanical, or thermo-mechanical interaction between critical components of the geotechnical measuring system (e.g. sensors, measuring lines) and the surrounding medium in which the components are embedded;

— environmental conditions (e.g. aggressive groundwater and gases; high ground pressure; electro-magnetic disturbance) which might affect the embedded components;

— vulnerability of the data communication of the monitoring system (e.g. long measuring lines, often passing through construction zones).

5.1.2 The sign conventions and units shall be clearly stated and adhered to.

5.1.3 Requirements 5.2 to 5.6 shall be documented.

NOTE Manufacturers' documentation, e.g. instrument data sheets (see Annex A), is to provide a basis to make an informed choice of the instruments.

5.2 Robustness

5.2.1 The components of the system shall be robust enough to effectively perform their individual functions over the design lifetime of the system, despite environmental and construction conditions.

NOTE This requirement relates to the material used (e.g. quality of the measuring cable, corrosion resistance of sensors), the type of construction of the installed units, and to the safety of the entire monitoring system, e.g. towards over-voltage (lightning protection), disturbance from the construction site, and vandalism.

5.2.2 Failure in data communication, e.g. of cables, radio links, is a potential problem. When planning geotechnical monitoring systems, these risks should be managed.

EXAMPLE In automatic monitoring systems, provision for communication failure alarms and low power levels.

5.2.3 Where damage is likely then, in addition to protection provisions, the need to replace or repair equipment should be anticipated. Provisions such as these shall be included in the monitoring plan.

5.3 Influencing factors

5.3.1 For the evaluation of geotechnical measurements, all relevant factors which influence the sensor signal shall be addressed. Conceptually, discrimination shall be made between direct and indirect influences onto the measured physical quantity.

NOTE 1 Direct influences are related to the object being monitored. Indirect influences are related to the monitoring system.

NOTE 2 Common factors that can influence the monitoring system are changes of the temperature and atmospheric pressure.

NOTE 3 The monitoring system might also be influenced by factors such as high voltage lines, electro-magnetic disturbance, and ground vibrations.

5.3.2 Provisions shall be made to discriminate between the respective effects of the influencing factors onto the monitoring object and monitoring system.

EXAMPLES Choice of temperature-compensated displacement transducer; pressure-compensated piezometer; extensometer rods with a material of low thermal expansion coefficient; provision of zero stress strain gauges; temperature correction of convergence tape measurements (see ISO 18674-2).

5.4 Redundancy

Geotechnical measurements should include redundancy to ensure the continued functioning of the system despite possible component malfunction. A redundancy in the measuring data should be used for the identification of erroneous readings and for data corrections.

EXAMPLES (in order of increasing degree of redundancy):

— multiple readings;

— installation of more sensors than theoretically required, e.g. more than 3 sensors in 2-D stress monitoring;

— duplication of sensors of the same measuring principle;

— application of different measuring principles for one and the same quantity (“diversification”).

5.5 Stability of sensor signal

As a re-calibration (see 5.6) of permanently embedded sensors is hardly possible, attention shall be given to the stability of the measuring signal of sensors and to the redundancy of the monitoring system.

It should be ensured that the signal could be expected to be sufficiently stable over the time span of the monitoring project.

NOTE Safety-sensitive geotechnical structures such as tunnels and dams often require long-term monitoring.

5.6 Function check and calibration

Function checks and/or instrument calibrations shall be carried out and documented at the following stages of the monitoring project.

— Prior to shipment; these shall be the responsibility of the manufacturer and are to be documented in calibration certificates.

— Before installation (*pre-installation acceptance tests)*; these shall be documented in a certificate. If possible, this also includes checking of the zero point and scale of the system components.

— After installation (*post-installation acceptance tests)*.

NOTE Pre-installation and post-installation acceptance tests are part of the commissioning.

— During service life; the accessible components of the monitoring systems shall be re-calibrated at specified intervals. The interval between any two re-calibrations shall be addressed in the monitoring programme, considering also the recommendations of the manufacturer, the usage, and the environment. If possible, a calibration should be carried out if reasonable doubts exist on the reliability or accuracy of an instrument component. Additional re-calibrations may become necessary in specific measuring applications.

NOTE See ISO 18674-2.

6 Location of measuring points and geotechnical parameters

6.1 Location of measuring points

6.1.1 The measuring points can be located at free surfaces, at the interface between any two media, or inside of a medium.

6.1.2 Measuring points in the ground are to be installed in boreholes. The measurement of these points should be related to the local coordinates of the borehole under consideration (see Annex B).

NOTE 1 Boreholes provide the possibility to install sensors within the measuring object and allow the access to the measuring points.

NOTE 2 The term "borehole" implies other sub-surface installations, such as push-in installations, trial pits, shafts, and adits.

6.2 Measurement and monitoring of geotechnical parameters

6.2.1 Geotechnical monitoring shall be based on the measurement of geotechnical key parameters.

NOTE For examples of geotechnical key parameters and their measurement, see Table D.1 and Annex E.

6.2.2 Geotechnical monitoring measures values of a parameter from which changes can be determined by comparison to those of the zero or reference measurement (see 3.1.12 and 3.1.14).

NOTE For examples of parameter changes and their measurement, see Table D.2 and Annex E.

7 Carrying out the measurements

7.1 The measurements should be ideally carried out by the same person, or group of persons, over the entire monitoring project. If the responsibility for taking the measurements is transferred from one person, or group of persons, to another, an overlap should be ensured whereby both persons are in attendance for a measurement or group of measurements. The measuring personnel should be familiarized with the purpose of the monitoring project, including the expected ground reaction in response to construction.

7.2 The schedule of the measurements shall be specified in the monitoring plan. The schedule can be adjusted to the progress of the construction and to any new insights gained in course of the monitoring project. The reasons and justifications for any changes to the schedule shall be documented.

7.3 In conjunction with taking the readings of the geotechnical key parameters, the date and time shall be recorded and documented for each measuring series. If applicable, the temperature of the measuring location shall also be recorded.

NOTE 1 It is good practice to also record and document the site conditions and/or construction activities.

NOTE 2 Date and time are commonly needed to correlate the measurements with construction stages.

NOTE 3 Temperature measurements are the base for identifying influencing factors (see 5.3) and for corrections of the measuring signal.

NOTE 4 Other data might also be needed for specific measuring tasks, such as barometric pressure for piezometer measurements.

7.4 While carrying out the measurements, any observation which might be of importance in the evaluation of the measurements shall be documented, such as the following:

— changes of the groundwater conditions (e.g. new wet spots or drying out of springs);

— indications of de-stressing, excessive deformation, or over-stressing of ground support elements such as soil or rock nails, sheet piles, anchors, steel arches, wedges;

— movements of the ground (e.g. opening of discontinuities, activation of shear planes, displacements of rock blocks);

— development of over- and underprofiles, loosening zones, fault zones in underground construction;

— occurrence of cracks (width, length, relative movement), e.g. in diaphragm walls or shotcrete linings.

7.5 While taking the readings, or immediately after a measuring series, the measured data shall be checked on its plausibility. In the case of unexpected or contradicting data, the measurements shall be repeated immediately.

8 Data processing and verification

8.1 Preliminary rapid data processing shall be carried out in order to detect any changes that require immediate action.

8.2 Data processing shall comprise the transformation of the measured values (e.g. values indicated on a dial gauge; frequency of electrical sensor signal) via calibration factors into the relevant engineering units. If systematic errors of the measurement can be identified and not adjusting the data would result in the measurements falling outside the required accuracy, data processing shall include the adjustment of the measuring results. Where such adjustments are applied, they shall be reported.

NOTE A measurement result is generally expressed as a single measured quantity value and a measurement uncertainty. If the measurement uncertainty is considered to be negligible for some purpose, the measurement result can be expressed as a single measured quantity value (ISO/IEC Guide 99:2007).

8.3 All measuring results should be presented in tables and/or graphs. The minimum requirements are as follows:

a) For each measuring survey:

— project specification;

— number of measuring survey, in increasing numerical order with each follow-up measurement;

— date and time of survey;

— specification of reference survey (commonly reference measurement).

b) For each measuring point:

— unique identifier, e.g. a number;

— location (relative or absolute);

— measuring result.

c) For each type of measurement:

— measuring uncertainty, if applicable.

8.4 All measuring values shall be laid down in a documented standard protocol and should be readable independently of the measuring software.

8.5 In the case of unexpected measuring results, immediate data processing and evaluation shall be carried out. Unexpected measuring results (including false alarms) might be caused by one or a combination of the following three principal factors:

1) insufficient functionality of the instruments;

2) improper installation, improper operation, or insufficient maintenance;

3) inadequate or incorrect geotechnical model such as unexpected ground behaviour.

For the identification of the cause(s) 1) to 3), the potentially influencing factors should be separated as clearly as possible for the reasons given in 5.1.1.

8.6 The measured results shall be evaluated and discussed with respect to their reliability and the effectiveness of the measuring project (see 4.1).

9 Reporting

9.1 Installation report

9.1.1 The installation report should be submitted immediately after commissioning of the monitoring system.

9.1.2 The installation report shall encompass the following information, if applicable:

a) owner of the geotechnical project;

b) name and location of the geotechnical project;

c) name of the company carrying out the monitoring project;

d) name and number of the monitoring project;

e) specification and calibration sheets (see 5.6);

f) installation details, including installation and initial measurements within the instrument stabilization period (see Figure 1) ;

g) record on the commissioning of the monitoring system;

h) boreholes for the installation of instruments:

   — drilling head sheet according to ISO 22475-1

   — characterization and description of the soil after ISO 14688-1 and rock after ISO 14689-1;

i) location and date of submission of the report;

j) name and signature of the person responsible for the monitoring project.

9.2 Monitoring report

9.2.1 A monitoring report shall cover all the relevant aspects of the monitoring project, particularly the monitoring results.

NOTE 1 A monitoring report provides the base for answering the geotechnical question formulated at the onset of the monitoring project and for geotechnical solutions in the sense of EN 1997–1: 2004.

NOTE 2 In many circumstances, a one-page summary report of important information is useful.

NOTE 3 The close-out report is a specific case of a monitoring report, details of which are usually defined in the monitoring plan.

9.2.2 Each monitoring report shall include the following, if applicable:

a) an executive summary;

b) the geotechnical questions to be addressed by the monitoring project (see 4.2);

c) the monitoring procedures with reference to this standard, in particular concept, implementation, and evaluation of the monitoring project according to 4.3.1;

d) principal results of the monitoring project;

e) statement whether the accuracy and uncertainty specified in 4.3.2 is met;

f) assessment and evaluation of the measuring results;

g) facts and observations which might be important for the judgement of the measuring results in context with the geology, geotechnical design, and construction activities of the site and maintenance of the monitoring system;

h) location and date of submission of the report;

i) name and signature of the person(s) responsible for the monitoring project.

Detailed monitoring documents should be attached. This, in particular, applies to the following:

— the installation report according to 9.1;

— list of the measuring values;
— date, location (e.g. borehole number), and number of measurements;
— ambient conditions (e.g. temperature);
— tabular and graphic presentation of the monitoring results;
— monitoring results in relation to construction stages;
— particular events and observations made during the measurement.

Annex A
(normative)

Minimum requirements on content of instrument data sheets

Reference is made to ISO/IEC Guide 99:2007.

A. Metrology

Mandatory:	Measurement principle
	Range
	Accuracy
	Repeatability
	Stability
Optional:	Resolution
	Hysteresis
	Over range
	Dead band

B. Electrical

Mandatory:	Power supply
	Output
	Sensitivity
Optional:	Warm-up time

C. Environmental

Mandatory:	Material
	Temperature range
	IP-Class according to IEC 60529
Optional:	ATEX - Class (see Reference [7])

D. Others

Optional:	Suggested field of application

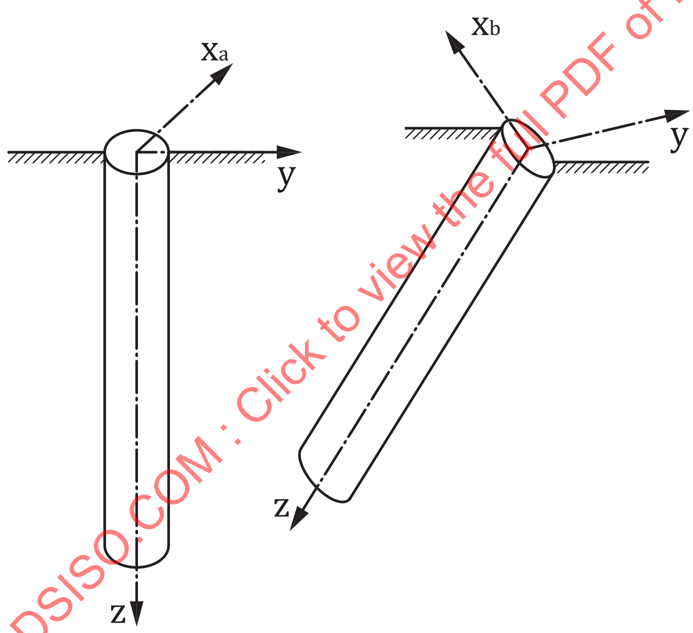
Annex B
(normative)

Geotechnical measurements in boreholes

B.1 Geotechnical measurements in boreholes should be related to a local coordinate system of the borehole under consideration. Pertinent transformation equations are to be employed for the transformation of the measured values into a global coordinate system.

NOTE For a complete definition of a coordinate system, the following information is required: Origin, orientation and sense of direction of the axes and units of the coordinates (e.g. scale).

B.2 A right-hand rectangular coordinate system should be selected. In case that the origin of the coordinate system is located in the collar of the borehole then the coordinate axes x, y, and z should be defined according to Figure B.1



Key

a North or local direction

b top

Figure B.1 — Local coordinate system for vertical boreholes (left) and horizontal or inclined boreholes (right)

B.3 In the general 3-D case, displacements of a point in the ground which is accessed by a borehole shall be determined by means of the three independent displacement components u, v, and w.

NOTE 1 Table B.1 compiles measuring procedures and borehole instruments that can be employed for the measurement of the respective displacement components.

NOTE 2 For technical reasons, it, hereby, is necessary to distinguish between vertical boreholes and horizontal/inclined boreholes. For displacement measurements, it can be employed

— along the borehole axis: borehole extensometers, and

— across the borehole axis: inclinometer and/or deflectometer.

Table B.1 — Parameters and borehole instruments for displacement measurements

Borehole coordinate		Displacement component	Reference to borehole axis	Measured parameter	Instrument which can be employed
Axis	**Direction (+)**				
A	**Vertical boreholes**				
x	Direction 1 (global or local)	*u*	across	Change in inclination of borehole axis	Vertical inclinometer (see ISO 18674-3)
y	Direction 2 (global or local)	*v*	across	Change in inclination of borehole axis	Vertical inclinometer (see ISO 18674-3)
z	Borehole toe	*w*	along	Change in distance between two points of borehole axis	Extensometer (see ISO 18674-2)
B	**Horizontal and inclined boreholes**				
x	top	*u*	across	Change in inclination of borehole axis	Horizontal inclinometer (see ISO 18674-3)
y	horizontal	*v*	across	Change in orientation of borehole axis	Deflectometer (see ISO 18674-3)
z	Borehole toe [a]	w	along	Change in distance between two points of borehole axis	Extensometer (see ISO 18674-2)
a alternatively: Initial orientation at the borehole axis in the borehole collar, particularly suitable for curved boreholes.					

B.4 In the general 3-D case, stresses acting in a point of the ground which is accessed by a borehole shall be determined by six independent stress components.

NOTE 1 With reference to the borehole coordinate system x, y, z, they are the normal stress components σ_x, σ_y, and σ_z, and the shear stress components τ_{xy}, τ_{xz}, and τ_{yz}. Transformation equations are commonly employed to express the monitored stress components in terms of changes of the principal stresses $\Delta\sigma_1$, $\Delta\sigma_2$, and $\Delta\sigma_3$ with respect to magnitude and orientation.

NOTE 2 Table B.2 compiles borehole instruments that can be employed for stress monitoring in soil and rock. It is to be distinguished between direct and indirect stress measuring procedures. In the direct procedure, a stress quantity is measured; in the indirect procedures, a strain quantity. In the latter case, the measured strain is transferred into stress via a presumably correct stress-strain relationship.

NOTE 3 The effective stress cannot be measured directly but can be derived from combined total stress and porewater pressure measurements.

Table B.2 — Parameters and borehole instruments for stress monitoring

Instrument Measuring procedure		Measured parameter [a]	Target parameter [b]	Remarks
Direct	Total pressure cell (TPC)	σ_n	$\Delta\sigma_1$ $\Delta\sigma_2$	Total stress change measurement in soil and soft rock (see ISO 18674-5)
	Piezometer	u	Δu	Necessary for the determination of effective stresses (see ISO 18674-4)
Indirect	Stressmeter (stiff inclusion strain cell) Deformation gauge	Δd_i	$\Delta\sigma_1$ $\Delta\sigma_2$	Stress change measurement in rock

a Parameter measured in the field.

b In borehole stress measurements, the target parameters are commonly the changes of the principal stresses in terms of magnitude and orientation.

Annex C
(informative)

Field measurements in connection with the design and construction of geotechnical structures

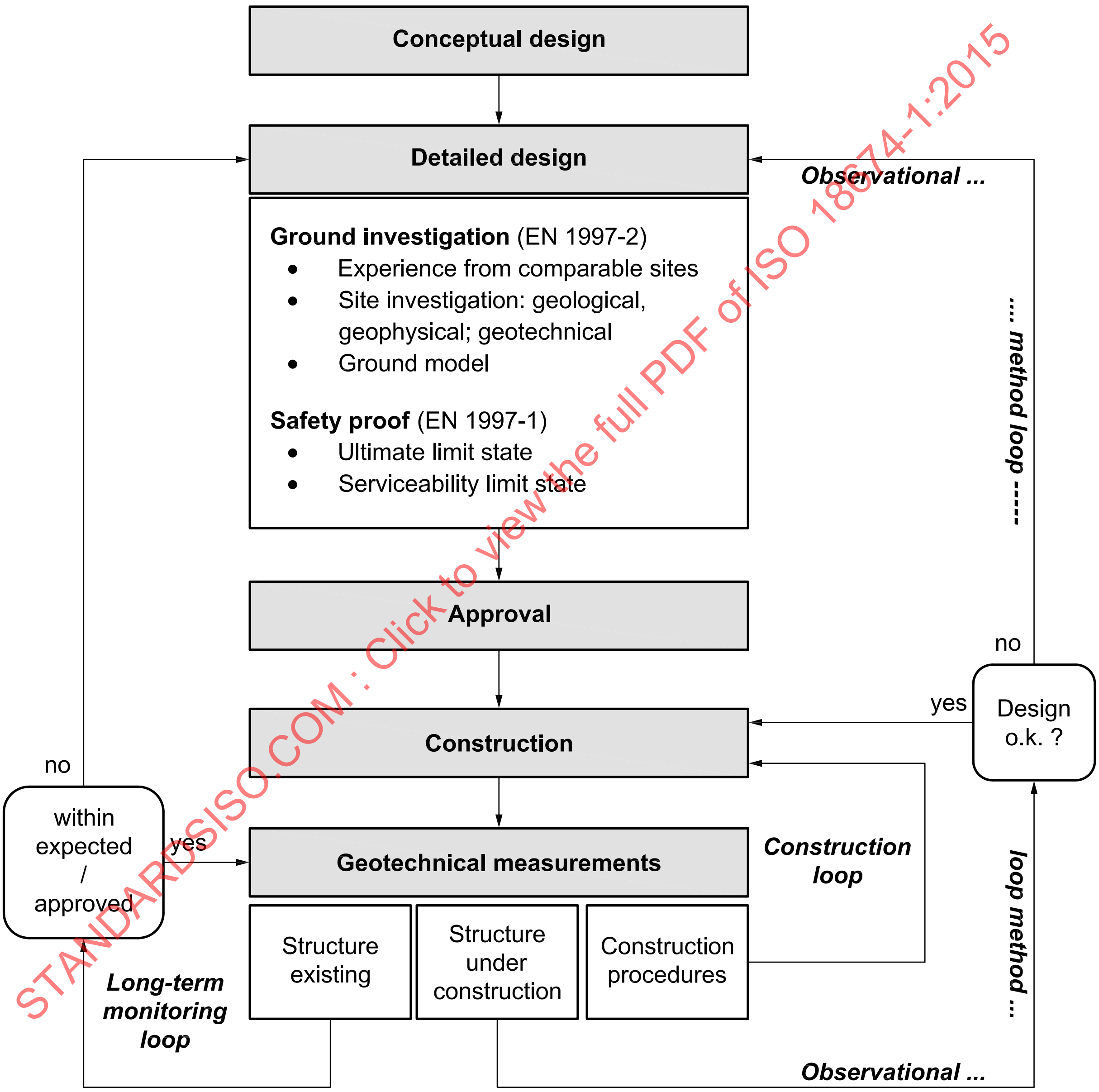


Figure C.1 — Position of geotechnical field measurements in connection with the design and construction of geotechnical structures

Table C.1 — Geotechnical and geodetic measurements

Measuring value (parameter)	Geotechnical measurements	Geodetic measurements
Measuring value (generally)	All kinds of parameters	Location of measuring points in space and time
Measuring values (specific) — displacement of measuring points incl. special cases such as vertical displacement component (= settlement or heave) and deduced parameters such as tilt and strain — velocity — acceleration (vibration) — pressure stress force — flow	by means of (e.g.): — extensometer (ISO 18674-2), inclinometer and deflectometer (ISO 18674-3); liquid level gauge; pendulum (normal and inverse); tiltmeter strain gauge — accelerometer; geophone — accelerometer — total pressure cell (ISO 18674-5); piezometer, stress/strain cell; anchor load cell — flowmeter; measuring weir	— total station levelling instrument electronic distance meter, laser scanner GNSS (Differential GPS) radar interferometry (InSar; terrestrial or satellite) — — } not subject in geodetic measurements
Locality of measuring points	— at visible surface — in borehole — embedded (e.g. in earth fill dam)	at visible surface
Further features and requirements	See Clause 5	Common in every construction project

Annex D
(informative)

Measurement and monitoring of geotechnical key parameters

D.1 Geotechnical key parameters and their measurement

Table D.1 — Geotechnical key parameters and examples of measuring instruments

Parameter	Common unit	Detail / example	Instruments (example) (see also Annex E)
Location	m	Longitude, latitude, elevation of a measuring point (commonly related to global coordinate system = absolute measurement)	— total station — levelling instrument — GNSS (Differential GPS)
Distance	m	distance between two measuring points	— tape extensometer
Inclination	Degree	inclination of a measuring line (e.g. along the axis of a borehole)	— borehole inclinometer — chain of electro-level sensors
Orientation	Degree	orientation of a measuring line (e.g. azimuth deviation of an anchor borehole)	— borehole deflectometer — gyro
Force	kN	Section forces of structural elements (e.g. anchors, pillars, struts, steel sets)	— load cell — strain gauged steel bar
Stress	kPa	soft soil, fill, concrete and in contact surfaces (e.g. foundation plane)	— total pressure cell (TPC)
	MPa	in stiff soil and rock	— hydraulic fracturing equipment — strain cells (overcoring)
Pressure	kPa	— porewater pressure — fluid pressure	— piezometer (absolute or atmospheric) — pressure gauge
Temperature	°C	parameter, commonly affecting geotechnical measuring systems	— thermo-electrical resistance measurement
Flow rate	l/s	rate of water flow	— measuring weir; flowmeter
Velocity	m/s	speed of particles	— geophone
Acceleration	m/s^2	Vibrations due to: — earthquake — blasting	— servo accelerometer

D.2 Monitoring of geotechnical key parameters (value change measurements)

Table D.2 — Geotechnical keyparameters and examples of monitoring instruments

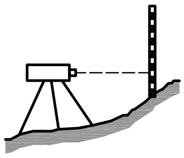
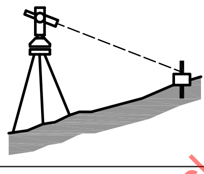
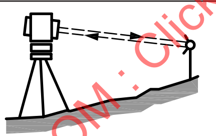
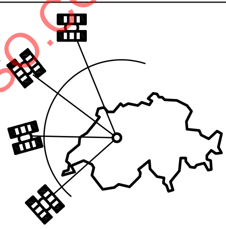
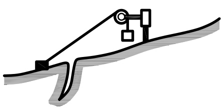
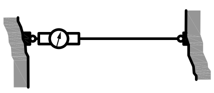
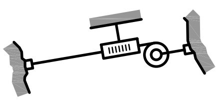
Key parameter			Monitoring procedure/instruments (example) (see also Annex E)
Measurement at a point	Change in location: Displacement of a point (general 3-D case; absolute and/or relative)		geodetic methods (see Table C.1)
	vertical component only: — settlement — heave		for vertical component by means of: — levelling instrument — liquid level system — hydro-static settlement gauge
	horizontal components only: — horizontal displacement		for horizontal components by means of: — pendulum (normal or inverse)
	Change in location: Displacement of a discontinuity (relative only) — normal to discontinuity (in the sense of opening and closure) — along a discontinuity (two independentdirections)		crackmeter — 1-D crackmeter — 3-D crackmeter
	Change of force magnitude		— anchor load cell — strain-gauged structural element
	Stress change	for soil, concrete and fill	— total pressure cell
		for rock	— borehole stressmeter (stiff inclusion) — borehole deformation gauge
	Porewater pressure change		— piezometer
	Change of flow rate		— weir monitor
Measurement with respect to a line	Change in distance (extension / shortening) (measurement along a line):		— extensometer — strain gauge — convergence tape
	Change in inclination (tilt) (in a vertical plane) (measurement across a line):		— inclinometer — tiltmeter
	Change in orientation (in horizontal plane) (measurement across a line):		— deflectometer — compass probe

Annex E
(informative)

Types of instruments and monitoring methods commonly used

Table E.1 provides a list of instruments with a brief description and a sketch of the measuring principle, the measuring range, and the measuring uncertainty which are common in geo-engineering applications. The list assists in the selection of monitoring systems. It furthermore allows a general comparison of monitoring systems that are offered by manufacturers.

Table E.1 — Types of instruments and monitoring methods commonly used

I Displacements on the surface			
Instruments Measurand	Scheme (Sketch)	Measuring range	Measurement uncertainty (indicative/typical range)
Level Precision level Δz		Very large	2 mm/0,5 mm (depending on the arrangement of measuring points)
Total station Δx, Δy, Δz Δl indirectly		Very large	1 mm ... 5 mm (depending on measured distance)
Electronic distance meter Δl		Very large	0,5 mm ... 3 mm (depending on measured distance)
GPS Global Positioning System Δx, Δy, Δz		Very large	20 mm (with four satellites and a receiver placed on base point)
Invar wire tensioned by weight Δl		3m (very large if wire is added, depends on local conditions)	10 mm (depending on length of wire)
Distance meter with invar wire Δl		100 mm	0,1 mm
Convergence device with steel tape Δl		50 mm (dial gauge)	1 mm