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Development of international standards for geotechnical monitoring under ISO

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SUMMARY: International standards for monitoring under ISO have been under development since 2010 and the intentions were presented during FMGM 2011 in Berlin and progress was reported at FMGM 2015 in Sydney. The base standard on general rules was published in 2015, Part 2 the standard on extensometers in 2016 and in 2017 the third part on inclinometers. These three standards have been published as ISO Standards in English and French worldwide. In Europe the standards have been published under EN_ISO 18674 and a German language version has also been published. The standards on measurements of pore-water pressures with piezometers (Part 4) and on stress change measurements with total pressure cells (Part 5) are under development and will be submitted to enquiry during 2018.

KEYWORDS: monitoring, standards, general rules, extensometers, inclinometers.

1 INTRODUCTION

1.1 Review of development of geotechnical monitoring standards

The development of international standards for monitoring started in 2000 under CEN TC-341 Geotechnical measurements in particular as a task group of working group CEN TC-341/WG1. The development of these standards was always in parallel, under the Vienna agreement, between ISO and CEN, however due to the voting process under ISO, where a majority for work under CEN was not achieved by the ISO members voting outside CEN. Therefore the development had to be transferred under the auspices of ISO TC-182. The working group ISO TC182/WG2 Geotechnical monitoring has been formed in 2015. Essentially all the persons working under CEN have now been working under ISO. The active members of the working group are listed as co-authors of this paper. The development of international standards for monitoring has been reported during previous meetings of FMGM initially in Berlin (Bock, 2011) and then in Sydney (Steiner et al., 2015). Several standards have been published and the present state of publication and development will be reported herein.

1.2 Development of standards under ISO Directives.

The development of standards under ISO is regulated by ISO Directives and foresees the development of standards under strict rules and enquiry of the standard drafts during development and vote.

Table1: Stages and Documents during the development of ISO standards

Stage	Document	Abbreviation	Remarks
Preliminary Stage	Preliminary work item	PWI	Stage may be omitted
Proposal stage	New work item proposal	NP	
Preparatory stage	Working drafts(s)	WD	
Committee stage	Committee drafts(s)	CD	Stage may be omitted
Enquiry stage	Enquiry draft	ISO/DIS	Draft International Standard
Approval stage	Final draft International standard	FDIS	Final Draft International Standard
Publication stage	International Standard	ISO	

Working drafts are developed by the working group and then submitted to the main committee, here ISO TC-182, which decides if the draft shall be submitted to enquiry as Committee draft (CD) or as enquiry draft (ISO/DIS). The committee draft is then circulated to the member bodies for normally

8 weeks. The enquiry draft is circulated by 12 weeks. The comments are then sent to the working group for consideration. A final draft is then prepared with deadlines fixed. The final draft is circulated for 8 weeks until it is voted. A two-thirds majority of the voting P- members is required for accepting a final draft and not more than a quarter of the votes are negative.

The formal and structured procedure of development allows that the developed standards become highly accepted in the profession. The developed standards form a reliable basis for geotechnical monitoring as a worldwide consensus has been reached.

2 STATE OF THE STANDARDS

2.1 Published standards

Until 2017 three standards on Geotechnical Monitoring have been published, namely:

Part 1: ISO 18674-1 “General rules”, 31 p.; 2015
Part 2: ISO 18674-2 “Measurement of displacements along a line: Extensometers”, 45 p., 2016
Part 3: ISO 18674-3 “Measurement of displacements across a line: Inclinometers”, 38 p. 2017

The table of content of these standards and the main issues treated will be presented in following sections.

2.2 Standards under preparation

Part 4 on piezometers and Part 5 on total pressure cells (TPC) are in a further stage of development and will be submitted for inquiry during 2018 to ISO TC-182.
The development of Part 4 the standard on piezometers proves to be particularly demanding, as there are many different types of piezometers available that can be used in different situations. Different open types of piezometer are used, as are many typed of closed systems. Various types of installation exist, like placed in boreholes, driven or pushed. The types of placement, either traditionally in sand pockets or with the fully grouted method are also addressed. The issues will be addressed in section 5.

2.3 Work involved in developing the standards

From 2010 until March 2018 the group has met during 18 meetings to develop the standards. The last meeting of CEN TC-341/WG1/TG2 was held April 23 and 24, 2015 in Ghent, Belgium. Since the change to ISO TC-182/WG2 five meetings of ISO TC182/WG2 were held in different European cities and countries. The last meeting took place in Aarhus, Denmark, March 6 and 7, 2018.

2.4 Planned standards

The following parts of standards are planned:

- Part 6 Hydraulic settlement gauges
- Part 7 Strain gauges
- Part 8 Load cells
- Part 9 Geodetic monitoring instruments
- Part 10 Vibration monitoring instruments

In the immediate future, the group will focus on Part 9 geodetic measurements as these are quite often used in practice. With respect to Part 10 on vibration monitoring the needs for observations of seismic motions, structural vibrations and monitoring has to be addressed. These contacts have to be made via ISO TC-182 and CEN TC-341 to other ISO and CEN committees.

3 CONTENTS OF THE PUBLISHED STANDARDS

3.1 General Rules: ISO 18674-1

EN ISO 18674-1 contains 31 pages. Its structure is reflected in the table of contents as shown in Table 2. The contents are essentially self-explanatory as a standard is a condensed set of rules. A detailed discussion would lead to a repetition of the standard. Important points are that geotechnical monitoring is part of geotechnical design. Each monitoring project has to be designed. Terms and definitions have been established.

Some key issues will be discussed that are considered important for a monitoring project. These are the different types of measurement based on the installation and operation phases of a monitoring project.

Table 2. Contents of ISO 18674-1: General rules

Foreword		
1	Scope	
2	Normative references	
3	Terms and symbols	
4	Principal requirements	
	4.1	Geotechnical monitoring in connection with geotechnical design
	4.2	Geotechnical monitoring in connection with specific questions
	4.3	Requirements of a geotechnical monitoring project
	4.4	Geodetic measurements
	4.5	Safety requirements
5	Requirements of a geotechnical monitoring system	
	5.1	General
	5.2	Robustness
	5.3	Influencing factors
	5.4	Redundancy
	5.5	Stability of sensor signals
	5.6	Function check and calibration
6	Location of measuring points and geotechnical parameters	
	6.1	Location of measuring points
	6.2	Measurement and monitoring of geotechnical parameters
7	Carrying out of the measurement	
8	Data processing and verification	
9	Reporting	
	9.1	Installation report
	9.2	Monitoring report
Annex A (normative)	Minimum requirements on content of instrument data sheets	
Annex B (normative)	Geotechnical measurements in boreholes	
Annex C (informative)	Field measurements in connection with the design and construction of geotechnical structures	
Annex D (informative)	Measurement and monitoring of geotechnical key parameters	
	D.1	Geotechnical key parameters and their measurement
	D.2	Monitoring of geotechnical key parameters (value change measurements)
Annex E (informative)	Types of instruments and monitoring methods commonly used	
Bibliography		

3.1.1 Some basic definitions of a monitoring system

In the standard geotechnical monitoring is linked to geotechnical design. In particular geotechnical monitoring shall be linked to at least one specific question that is to be answered; naturally there may be several questions to be answered. The key issue is that questions are formulated at the initiation of a project and actualized during the project.
It is important to identify geotechnical key parameters that shall be measured. The changes of these key parameters from the zero or reference measurements are made.
In this context very important definitions are the different measurements that have to be taken during a geotechnical monitoring project from installation to construction period, the following measurements have been defined (Figure 1):

- Initial measurement (1)
- Zero measurement (2)
- Reference measurement (3)

The time periods between these key time points are: before the initial measurement is the period of installation of the measuring system, this is followed by the stabilization period before the zero measurements. Then the period of baseline measurements follows until the reference measurement is taken.

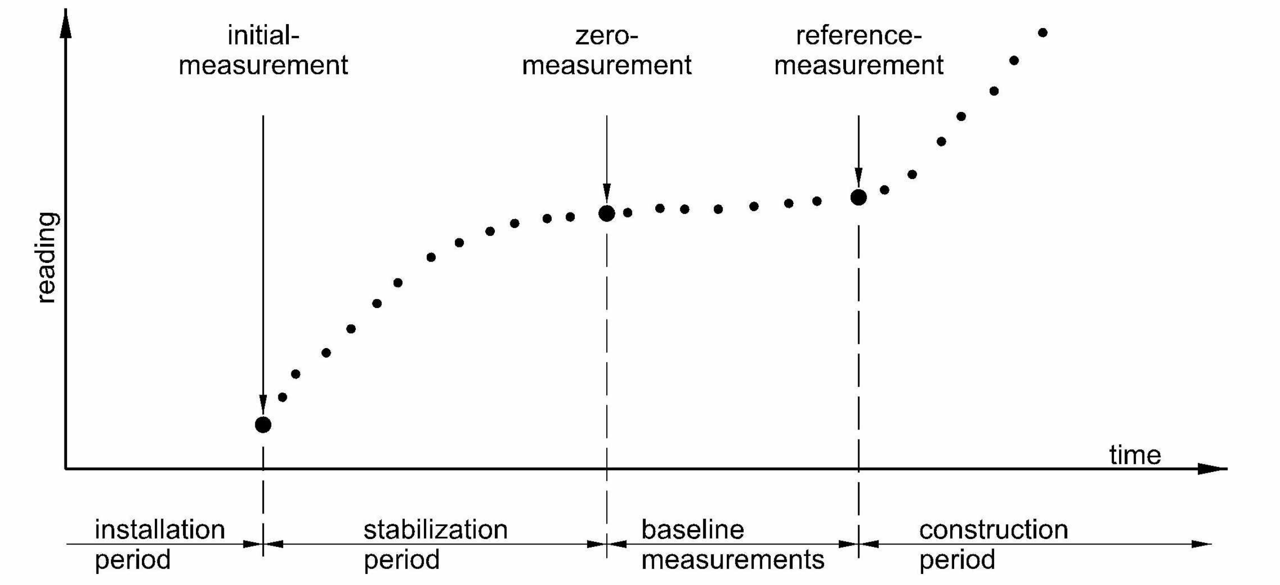

Figure 1: Definitions for readings and installations during monitoring projects according to ISO 18674-1

3.1.2 Requirements for a monitoring project

The requirements of a geotechnical monitoring project are prescribed. During the different design phases from

- Initiation phase
- preliminary design phase
- conceptual design phase
- specification design phase (of the monitoring system)
- Installation

- Data collection phase
- Data processing, evaluation and reporting phase

Different aspect in the design of the monitoring project shall be addressed.

Geotechnical measurements shall be supplemented by geodetic measurements, if applicable, to support and verify them.

A geotechnical monitoring system has to fulfill several severe requirements, as there are complex interactions between the ground and the monitoring system. The system is vulnerable as the communication lines are often located in construction zones. The components of the monitoring system have to be robust in order to function under the mostly severe environmental and construction conditions. The geotechnical measurements are influenced by direct and indirect factors. Direct factors are related to the construction or the object. Indirect factors are temperature and atmospheric pressures, but also high voltage lines, electro-magnetic fields and ground vibrations.
A monitoring system should include redundancy, such that with the failure of one component not the entire system fails.

3.1.3 Particular requirements

In Annex A the "Minimum requirements on content of instrument data sheets" are prescribed. It is important that for an instrument or sensor a certain number of data are furnished by the supplier.

In order to facilitate communication a definition of the general and local coordinate system (in boreholes) is provided normative in Annex B. A right-hand rectangular coordinate system is defined with the origin of the coordinate system in the collar of the borehole and the z-coordinate follows the axis of the borehole.

The use of field measurements in connection with design and constructions of geotechnical structures and the relation to geodetic measurements (Table 3) is given in Annex C.

Table 3. Geotechnical and geodetic measurements

Measuring value	Geotechnical Measurements	Geodetic measurements
Measuring value (generally)	All kinds of parameters	Location of measuring points in space and time
Measuring value (specific) • Displacement of measuring points, horizontal or vertical	by means of (e.g.) • Extensometers • Inclinometers or deflectometers • Liquid level gauge • Pendulum (normal and inverse) • Tiltmeter	• Total station leveling instrument with electronic distance meter Laser scanner GNSS
• Pressure • Pore pressure	Total pressure Pore pressure	No geodetic measurements
• Velocity • Acceleration	Geophone accelerometer	No geodetic measurements

In Annex D "Measurement and monitoring of geotechnical key parameters" the link between key parameters and different measurement methods is presented. In Annex E types of instruments and monitoring methods are presented with a concise description and sketches.

3.2 Extensometers: ISO 18674-2: Measurements of displacement along a line

The table of contents is given in Table 4. Different types of extensometers with different applicability exist and their applicability is described and defined (Table 5).

Table 4. Content of ISO 18674-2 Extensometers

Foreword
1 Scope
2 Normative references
3 Terms and definitions
4 Symbols
5 Instruments
 5.1 General
 5.2 In-place extensometer
  5.2.1 Measuring points
  5.2.2 Connecting elements
  5.2.3 Measuring head and read-out device
 5.3 Probe extensometer
  5.3.1 Measuring points and guide tube
  5.3.2 Probe
 5.4 Tape extensometer (convergence tape)
 5.5 Measuring range and accuracy
6 Installation and measuring procedures
 6.1 Installation
  6.1.1 Surface components
  6.1.2 Installation in boreholes and in fill
  6.1.3 In-place extensometer
  6.1.4 Probe extensometer
  6.1.5 Tape extensometer
 6.2 Carrying out the measurement
  6.2.1 Instrumentation check and calibration
  6.2.2 Measurement
7 Data processing and evaluation
8 Reporting
 8.1 Installation report
 8.2 Monitoring report
Annex A (normative) Measuring and evaluation procedure
Annex B (informative) Backfill materials.
Annex C (informative) Geo-engineering applications.
Annex D (informative) Measuring examples
Bibliography

Table 5. Types of extensometers

Extensometer Type	Extensometer Subtype	Feature	Automatic data acquisition
In-place	Single-point/multiple point in-place extensometer Rod/ wire extensometer	All instruments component permanently installed in ground or at accessible surfaces	possible
Probe	Single-point/ double point probe extensometer	Measuring unit sequentially moved into measuring position	Not common
Tape	Steel/ wire tape extensometer		

The requirements for details of the instruments are given in for each type of extensometer with several points treated in detail in the standard; the headings are shown in Table 6.

Table 6: Details of extensometers treated in ISO 18674-2

Type	In-Place Extensometer	Probe extensometer	Tape extensometer
Points	Measuring points	Measuring points and guide tube	Convergence Bolts
Connection	Connecting elements	Probe	Tape or wire
Read-out	Measuring head and read-out device		Couplings

The measuring range and accuracy are presented in detail. The installation and measuring procedures are discussed in similar detail as the types of extensometers. In Annex A the measuring and evaluation procedures are presented for the three main types of extensometers.

The backfill materials that should be used for installing extensometers are presented in Annex B. An informative guide for the selection of extensometers is presented in Annex C.

In Annex D of ISO 18674-2 five examples of the typical application of various types of extensometers are presented:

1. In-place multiple-point extensometer combined with temperature measurements
2. Retrievable chain extensometer in pile load test
3. In-place chain extensometer with reverse head in tunneling for evaluating face stability
4. Single-point probe extensometer in embankment construction for monitoring settlement on soft ground.
5. Double-point probe extensometer in near-surface tunneling for evaluation of settlement

Each case has its particular merits and shows the use of different extensometer types.

3.3 Inclinometers: ISO 18674-3 Measurement of displacements across a line.

The standard ISO 18674-3 treats (Table 7) in the main body probe inclinometers and in-place inclinometers and in a normative Annex B deflectometers. A deflectometer may become necessary, if the lateral deviation of a horizontal guide tube needs to be measured. Lateral displacements may only be measured by an inclinometer that has a minimal inclination, say of about 30°.

The contents are arranged in the same manner as for extensometers and follow the same structure.

Table 7. Content of ISO 18674-3: Inclinometer

Foreword
1 Scope
2 Normative references
3 Terms and definitions
4 Symbols
5 Instruments
5.1 General
5.2 Probe inclinometers
5.3 In-place inclinometers
5.4 Inclinometer casing
5.5 Measuring range, accuracy and repeatability
6 Installation and measuring procedure
6.1 General
6.2 Installation of guide tubes at accessible surfaces and in concrete
6.3 Installation of guide tubes in boreholes
6.3.1 Drilling of boreholes
6.3.2 Installation of guide tubes
6.3.3 Securing borehole measuring locations
6.4 Installation of in-place inclinometers
6.5 Carrying out the measurement
6.5.1 Instrumentation check and calibration
6.5.2 Measurement
7 Data processing and evaluation
8 Reporting
8.1 Installation report
8.2 Monitoring report
Annex A (normative) **Measuring and evaluation procedure**
Annex B (normative) **Deflectometers**
Annex C (informative) **Backfill materials**
Annex D (informative) **Geo-engineering applications**
Annex E (informative) **Measuring examples**
Bibliography

The annexes deal with normative matter that would make the main body difficult to read or is informative. Annex A treats the *Measuring and evaluation procedures* of inclinometers and gives definitions how the coordinate system shall be arranged. As mentioned above *Deflectometers* are described in Annex B in detail, with the components of the instruments, the installation and measuring procedure, the measuring and evaluation procedures.

In Annex C Backfill materials are described, besides the mostly used cement-bentonite grout mixes, also granular backfill material for exceptional geotechnical circumstances such as strongly fractured rock or high permeable soil are described. The use of a geotextile hose could be useful to prevent the loss of backfill material.

In Annex D the use of inclinometers or deflectometers in vertical or horizontal guide tubes for different applications are presented.

Examples of typical applications of the various types of inclinometers and deflectometers are presented with four case histories:

1. vertical inclinometer: Displacement measurements in a natural slope subject to creep;
2. horizontal inclinometer: Monitoring of settlements at the base of a refuse dump;
3. in-place deflectometer: Measurement of horizontal ground displacements ahead of tunnelling;
4. vertical inclinometer: Displacement measurements in retaining walls of urban excavation.

4 STANDARDS UNDER DEVELOPMENT

4.1 Development of a standard on piezometers

The development of the standard on pore pressure measurements with piezometers proves to be particularly challenging. There is a large variety of measuring methods, which is a consequence of different geologic and subsoil conditions and different geotechnical requirements. In a first step one has to distinguish between open and closed systems. For these systems many subtypes exist.

For open systems:

- Standpipe piezometer installed in boreholes
- Small diameter pipe systems with Quartz filter, often called Casagrande piezometers.
- Larger diameter Monitoring wells with seals that might also be used for a pumping test
- Driven piezometers
- Pushed-in piezometers

Closed systems:

- Closed systems with a diaphragm but different transducers and transmission of the signal:
  - Electric active measurements with
    - Strain gauges
    - Piezo resistivity
    - Vibrating wire
  - Passive measurement with fibre optics
- Pneumatic piezometers
- Hydraulic twin-tube piezometers
- Closed push-in systems

The installation procedures will also be treated and discussed. The nearly most important issue in piezometer installation is the placement of piezometer in boreholes either traditionally with filter packs and sealing with grout or bentonite pellets or the fully grouted method that has advantages but the limits of the method are not yet well known.

The enquiry draft of Part 4 should be ready before the end of 2018.

4.2 Standard for measuring stress changes in the ground with total stress cells

The standard is ready for submission to main committee and enquiry in 2018.

5 CONCLUSIONS

International Standards have been and are developed under ISO TC-182 Geotechnical Engineering, the International Standard Organization, that provide a frame-work and rules for planning, installing and operating monitoring systems in geotechnical and civil engineering practice. These new standards support engineering design and engineering judgment.

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