SLOVENSKI STANDARD
oSIST prEN ISO 18674-4:2019

01-oktober-2019

Geotehnično preiskovanje in preskušanje - Geotehnične meritve - 4. del: Meritve tlaka vode v porah: piezometri (ISO/DIS 18674-4:2019)

Geotechnical investigation and testing - Geotechnical monitoring by field instrumentation - Part 4: Measurement of pore water pressure: Piezometers (ISO/DIS 18674-4:2019)

Geotechnische Erkundung und Untersuchung - Geotechnische Messungen - Teil 4: Porenwasserdruckmessungen: Piezometer (ISO/DIS 18674-4:2019)

Reconnaissance et essais géotechniques - Surveillance géotechnique par instrumentation in situ - Partie 4: Titre manque (ISO/DIS 18674-4:2019)

Ta slovenski standard je istoveten z: **prEN ISO 18674-4**

ICS:

13.080.05	Preiskava tal na splošno	Examination of soils in general
17.100	Merjenje sile, teže in tlaka	Measurement of force, weight and pressure
93.020	Zemeljska dela. Izkopavanja. Gradnja temeljev. Dela pod zemljo	Earthworks. Excavations. Foundation construction. Underground works

oSIST prEN ISO 18674-4:2019 **en**

DRAFT INTERNATIONAL STANDARD
ISO/DIS 18674-4

ISO/TC **182** Secretariat: **BSI**

Voting begins on: **2019-07-17** Voting terminates on: **2019-10-09**

Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation —

Part 4: Measurement of pore water pressure: Piezometers

ICS: 13.080.20; 93.020

This document is circulated as received from the committee secretariat.

ISO/CEN PARALLEL PROCESSING

Reference number
ISO/DIS 18674-4:2019(E)

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Website: www.iso.org

Published in Switzerland

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Foreword

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

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Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation — Part 4: Measurement of pore water pressure: Piezometers

1 Scope

This document specifies the measurement of pore water pressures and piezometric levels in saturated ground by means of piezometers 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 18674-1:2015.

If applied in conjunction with ISO 18674-5, the procedures described in this document allow the determination of effective stresses acting in the ground.

This document is applicable to:

— monitoring of water pressures acting on and in geotechnical structures prior to, during and after construction (e.g. quay walls, dikes, excavation walls, foundations, dams, tunnels, slopes. embankments, …);

— monitoring of consolidation processes of soil and fill (e.g. beneath foundations and in embankments);

— evaluating stability and serviceability of geotechnical structures;

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

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 piezometers as part of the geotechnical investigation and testing in accordance with References [1] and [2]. This document relates to measuring devices, which are installed in the ground. For pore water pressure measurements carried out in connection with cone penetration tests, see ISO 22476-1.

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.

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

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

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

EN ISO 22475-1:2006, *Geotechnical investigation and testing – Sampling by drilling and excavation methods and groundwater measurements – Part 1: Technical principles for execution*

ISO 22476-1:2012 + Cor.1:2013, *Geotechnical investigation and testing – Field testing – Part 1: Electrical cone and piezocone penetration test*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 18674-1:2015 and the following apply.

3.1
piezometer
field instrument system for measuring pore water pressure (see 3.2) or piezometric level (see 3.4) where the measuring point is confined within the ground so that the measurement responds to the fluid pressure around the measuring zone/point and not to fluid pressures at any other elevations

Note 1 to entry: The system consists of a sealed reservoir filled with fluid (see 3.1.2), a filter (see 3.1.3) and a measuring device (see 3.1.7).

Note 2 to entry: The system is either of an open type (see 3.6) or of a closed type (see 3.7).

3.1.1
intake zone
zone confined by seals, between which water in the ground can flow to the measuring device, thus defining the measuring point

Note 1 to entry: See Figure 1.

Note 2 to entry: It is assumed that a hydrostatic pore water pressure distribution is established along the intake zone

3.1.1.1
intake factor
constant of proportionality between flow into or out of a piezometer and the change of pore water pressure

Note 1 to entry: The intake factor is to be considered when designing piezometers using filter packs (see 3.1.5).

Note 2 to entry: See Annex D

3.1.2
reservoir
space between the ground and the measuring device (see 3.1.7), occupied by a fluid, which allows the pore water pressure to act on the sensing element of the measuring device

Note 1 to entry: The pores within the filter (see 3.1.3) are an integral part of the reservoir.

Note 2 to entry: In open piezometer systems (see 3.6), the water-filled part of the standpipe is part of the reservoir.

3.1.3
filter
permeable section of a piezometer defining the intake zone (see 3.1.1). It allows water to enter and at the same time restricts soil particles entering the standpipe or measuring device

Note 1 to entry: The filter can be a combination of elements, such as sand pocket, perforated pipe, geotextile sleeve, filter tip and grout backfill in specific cases.

3.1.4
filter tip
filter element which is a common part of a closed piezometer system

Note 1 to entry: Filter tips are formed of a material with purpose-designed pore diameters (see 3.1.4.1 and 3.2.4.2)

3.1.4.1
high air entry (HAE) filter
filter tip with comparatively small pores giving a higher resistance to the passage of air than to the passage of water

Note 1 to entry: Commonly, high air entry filter tips have pore diameters of between 1 and 3 micron.

Note 2 to entry: HAE filter tips are used when intending to keep gas out of the measuring device.

Note 3 to entry: In unsaturated soil or when negative pore water pressures are to be measured (i.e. suction; see Annex F), the pressure of the gaseous phase is always higher than that of the pore water. The required pore diameter of the HAE filter tip depends on the difference between the pore air pressure and the pore water pressure

3.1.4.2
low air entry (LAE) filter
filter tip with comparatively large pores giving a lower resistance to the passage of air readily allowing the passage of both air and water

Note 1 to entry: Commonly, low air entry filter tips have pore diameters of between 20 and 50 micron.

3.1.5
filter pack
permeable material, placed around a slotted section of an open piezometer or around the filter tip, allowing water to reach the measuring device

3.1.6
seal
layer in a borehole, made with a material that has a permeability suitable for hydraulical separation of two aquifers

Note 1 to entry: Seals are generally used to confine an intake zone.

3.1.7
measuring device
part of the piezometer system used to measure the piezometric level in an open system or the pore water pressure in a closed system

Note 1 to entry: For open piezometer systems (see 3.6), the measuring device is commonly a water level meter (see 3.1.7.1) for manual measurements or a pressure transducer for automatic measurements.

Note 2 to entry: For closed piezometers systems (see 3.7), the measuring device typically is a diaphragm pressure transducer (see 7 in Figure 1b). The diaphragm separates inner and outer chambers of the transducer where the deflection of the diaphragm is a function of the pore water pressure (see Figure 3).

Note 3 to entry: For closed piezometers systems, the measuring device is often synonymously termed a piezometer in a narrow sense.

3.1.7.1
water level meter
measuring device with a marked length measuring tape and a tip that activates a signal (light, sound) when it comes into contact with water

Note 1 to entry: A water level meter is commonly used for manual measurements in open systems or during the installation procedure of piezometers.

3.1.7.2
electric piezometer
piezometer where the measuring device has a diaphragm and the deflection of the diaphragm due to pore water pressure is measured by an electric sensor

Note 1 to entry: Electric piezometers are commonly based on strain gauge, piezo-electric, vibrating wire or capacitive sensors. Data acquisition devices exist which accommodate all types of electric piezometers.

Note 2 to entry: See Figure 3.

3.1.7.3
fibre optic piezometer
piezometer where the pressure measuring device has a diaphragm and the deflection of the diaphragm is measured by an optical sensor

Note 1 to entry: Fibre optic piezometers do not require electrical connection between read-out unit and sensor.

Note 2 to entry: Fibre optic piezometers require a dedicated read-out unit.

3.1.7.4
pneumatic piezometer
piezometer where the pressure measuring device has a valve which is opened pneumatically by a gas pressure, which is applied from the outside via gas-filled tubes and closed by the pore water pressure

Note 1 to entry: See Figure 4.

3.2
pore water pressure
u
pressure of the water in the voids of the ground or a fill

Note 1 to entry: The pore water pressure is the difference between the total stress and the effective stress in saturated ground (see References [3] and [6]).

Note 2 to entry: For rocks, the associated term is joint water pressure.

Note 3 to entry: The state of soil or fill where the pores are completely filled with water is referred to as "saturated".

Note 4 to entry: Pore water pressure measurements can yield positive or negative values (see Reference [4] and Annex F). Instruments that directly measure negative pore pressures are sometimes termed 'tensiometers', but are not within the scope of this standard.

Note 5 to entry: Changes of the pore water pressure can be affected by changes of the barometric pressure.

3.3
pressure head
ψ
ratio u/γ_w of the pore water pressure u and the specific weight of water γ_w, above a point

Note 1 to entry: For an open piezometer system (see 3.6), it is proportional to the elevation difference between the piezometric level (see 3.4) and the level of the measuring point (see 3.15 and Figure 1).

3.4
piezometric level
z_w
elevation to which water will rise in an open standpipe piezometer (see 3.6.1); it is the elevation at which the pressure of the water in the ground is equal to that of the ambient atmosphere

Note 1 to entry: The piezometric level z_w is the sum of the geometric elevation z and the pressure head ψ (see 3.3): $z_w = z + u/\gamma_w$.

Note 2 to entry: See Figure 1.

3.5
groundwater table
elevation below which pores are completely filled with groundwater, producing a "saturated condition"

Note 1 to entry: See Figure 1.

Note 2 to entry: An equivalent term is phreatic surface.

Note 3 to entry: The groundwater level is the level of the groundwater table at a geographical coordinate.

3.6
open (piezometer) system
field instrument system in which the fluid is in direct contact with the atmosphere and the piezometric level (see 3.4) at the measuring point is measured

3.6.1
open standpipe piezometer
open piezometer system, consisting of a pipe (placed in a borehole) which, at its upper end, is open to the atmosphere and with a perforated section, located in the intake zone

Note 1 to entry: See Figure 1a) and Figure 2.

Note 2 to entry: Typical inner diameters of the pipe are from 19mm to 60mm.

3.6.2
Casagrande piezometer
open standpipe piezometer with one or two comparatively small inner diameter pipes and a porous filter tip at the measuring point

Note 1 to entry: See 5.2.2.3, Figure 2 and Reference [5].

3.6.3
monitoring well
open standpipe piezometer with a large inner diameter of the pipe (typically ≥ 100mm)

Note 1 to entry: A monitoring well may be used as standpipe piezometer, if the response time is satisfactory (see Annex D).

Note 2 to entry: A monitoring well is often used for taking samples of the groundwater or for performing pumping tests.

3.6.4
observation well
open pipe within a borehole, where the intake zone is unconfined

Note 1 to entry: Observation wells are often incorrectly termed open standpipe piezometers. Observational wells do not classify as piezometers as they do not have seals.

Note 2 to entry: See 5.2.2.2.2.

3.7
closed (piezometer) system
measuring system in which the reservoir (see 3.1.2) is not in direct contact with the atmosphere and in which the pressure in the fluid is measured by a pressure measuring device

Note 1 to entry: See Figure 1 b) and Figures 3 to 5.

Note 2 to entry: Examples for pressure measuring devices, used in closed systems, are electric transducers, fibre optic transducers and pressure valves (see 3.1.7.2 till 3.1.7.4).

3.7.1
diaphragm piezometer
closed system with a filter tip, a small reservoir and diaphragm which separates the pore water from the measuring system; the deflection of the diaphragm is measured and the signal is transported through a cable to an accessible location

Note 1 to entry: Possible diaphragm piezometers are electric piezometers (see 3.1.7.2) or fibre optic piezometers (see 3.1.7.3).

Note 2 to entry: The pressure is measured adjacent to the filter tip

3.7.2
closed hydraulic twin-tube piezometer
closed system with a porous ceramic filter tip located within an intake zone and connected to a remote location via twin fluid filled tubes

Note 1 to entry: The pressure measurement takes place at the remote location and not at the filter tip. The measurements need to be adjusted for elevation differences between the filter tip and the remote location.

3.7.3
probe piezometer
closed system where a moveable measuring device is inserted into a pipe which is equipped with one or more measuring ports, each located at an intake zone

3.8
multi-level piezometer
system with several measuring points permanently installed at different elevations in the ground, where each measuring point has its own intake zone

3.9
hydrodynamic time lag
time span between a change of the pore water pressure in the ground and the associated change in the measurement

Note 1 to entry: The time lag depends primarily on the type and dimensions of the piezometer (essentially the size of the reservoir), the permeability of the ground and the installation procedure (see Annex D).

Note 2 to entry: An equivalent term is response time. The term "slow response time" of the piezometer is synonymous with a long hydrodynamic time lag.

3.10
aquifer
major sources of groundwater, concentrated in bodies of permeable rock and/or sediment

3.11
unconfined aquifer
aquifer which has no confining layer between it and the surface

3.12
confined aquifer
aquifer which is overlain by a confining layer; the piezometric level may differ from the groundwater table

3.13
confining layer
layer of rock or soil that restricts groundwater flow

3.14
aquiclude
confining layer which separate two aquifers

3.15
measuring point
point in the ground where the pore water pressure is referenced to.

4 Symbols

Symbol	Name	Unit
A	cross-sectional area of the standpipe	m²
d	borehole diameter / diameter of intake zone	m
D	diameter of a standpipe	m
F	intake factor	-
GWT	groundwater table	m
HAE	high air entry	-
k_s	hydraulic conductivity of soil	m/s
k_g	hydraulic conductivity of grout	m/s
L	length of intake zone	m
LAE	low air entry	-
p	pressure	kPa
q_u	unconfined compressive strength	Pa
RL	reference level	m
t	time	
u	pore water pressure	kPa

z	geometric height	m
z_{mp}	geometric height of the measuring point	m
z_w	piezometric level	m
γ_w	unit weight of water	kN/m³
ψ	pressure head	m

5 Instruments

5.1 General

5.1.1 Open piezometer systems and closed piezometer systems should be distinguished from each other (see Table 1 and Figure 1).

Table 1 — Piezometer types

No.	Type	Sub-type	Feature
1	Open piezometer system (see 5.2)	• Open standpipe piezometer • Monitoring well • Casagrande piezometer	A filter and reservoir, installed in the ground and open to the atmosphere. The measuring device is retrievable. Readings can be manual or automatic. A main advantage of open systems is the possibility to check the automatic measurements with manual measurements. Open piezometers may not have a suitable response time in low permeable soils.
2	Closed piezometer system (see 5.3)	• electric, fibre optic or probe piezometer • pneumatic piezometer • twin-tube piezometer	A filter, a reservoir and a pressure transducer are installed in the ground and are closed from the atmosphere. Retrievable pressure transducers are possible using special systems. Closed systems commonly have a shorter time lag than open systems.

5.1.2 The choice between open or closed systems should be made according to the monitoring plan (see ISO 18674-1:2015, 4.3) and in consideration of the hydrodynamic time lag of the system (see Annex D).

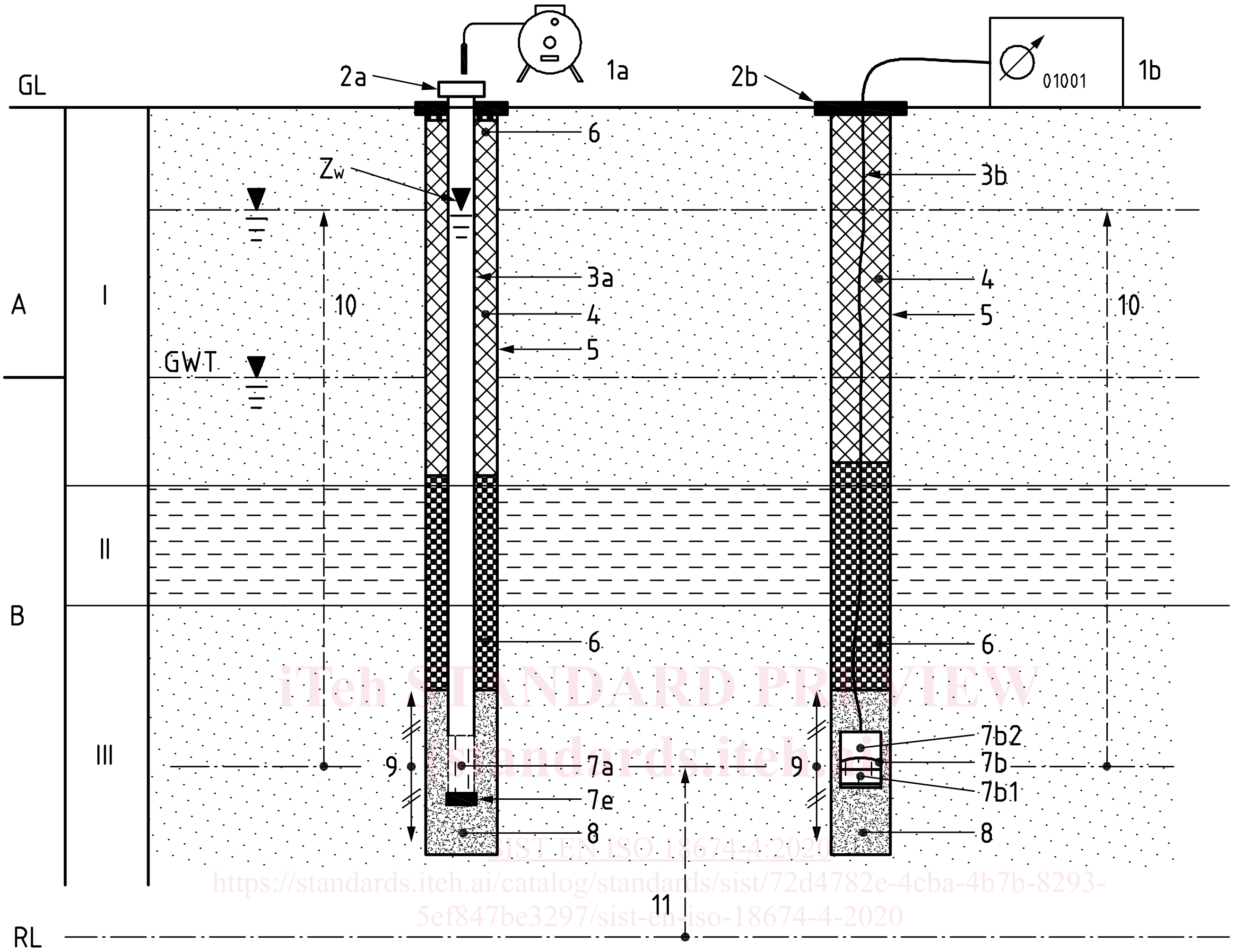
NOTE Climatic conditions play also an important role when choosing between an open and a closed system. For example, when there is a risk of freezing conditions, a closed system is preferred.

5.1.3 The intake zone of the filter should be limited to an adequately short vertical section of the aquifer.

NOTE Pore water pressures can vary with depth or in stratified aquifers or when vertical groundwater flow is present.

5.1.4 All components and equipment intended for installation in the ground shall be sufficiently resistant to mechanical loading and chemical attack by constituents in the groundwater. Any reactions between the materials used and the ground, in particular the formation of galvanic effects, shall be prevented.

NOTE Galvanic effects may cause modified pore water pressure. This effect emanates from gases generated by electric currents from galvanic cell created by using different metals or alloys in the piezometer tip.



a) open system b) closed system

Key

GL	Ground level	A	unsaturated zone	B	saturated zone
I	unconfined aquifer	II	aquiclude	III	confined aquifer
z_w	piezometric level	GWT	groundwater table	RL	reference level (e. g. sea level)
1a	water level meter	1b	readout unit with barometer	2a	vented top cap with base plate
2b	base plate	3a	standpipe	3b	signal cable
4	backfill	5	borehole wall	6	seal
7a	perforated or slotted section	7b	pressure measuring device	7b1	inner chamber with filter tip
7b2	outer chamber	7e	end cap	8	filter pack
9	intake zone	10	pressure head	11	elevation of measuring point

Figure 1 – Types of piezometer systems

5.2 Open piezometer systems

5.2.1 General

5.2.1.1 An open piezometer system shall include the following components: a filter around the measuring point, a seal above the filter and an open pipe which extends from the filter through the seal up to the ground surface.

EXAMPLE See Figure 1a).

NOTE 1 The water pressure at the piezometric level is in equilibrium with the atmospheric pressure.

NOTE 2 If the borehole extends deeper than the intake zone, a seal may be required below the filter. It is also good practice to include a seal below the filter if horizontal flow is required (e.g. for performing rising or falling head tests).

5.2.1.2 The measuring point of an open piezometer is defined as the midpoint of the intake zone.

NOTE 1 The piezometric level, measured at the measuring point of an open piezometer is influenced by the intake zone. A hydrostatic pressure distribution is assumed over the height of the intake zone.

NOTE 2 For an open piezometer, the measuring point is not related to the position of the measuring device. For example, when using a pressure transducer in an open piezometer, the measuring point remains the centre of the intake zone, which is usually not the position of the pressure transducer.

5.2.1.3 The top cap of the standpipe shall be equipped with a vent to permit unrestricted variations of the water level inside the pipe.

5.2.1.4 Measurements can be conducted either by determining the piezometric level (e.g. by a water level meter) or by measuring the water pressure in the standpipe at a specified depth below the piezometric level (e.g. by using a pressure transducer).

NOTE When a pressure transducer is used to determine the piezometric level, compensation for atmospheric variations needs to be considered (see 5.4).

5.2.1.5 Piezometric levels above the ground level will overflow the standpipe and are termed 'Artesian'. In that case the standpipe can be extended to a level above the highest piezometric level or the open system can be converted to a closed system (see 5.3), e.g. by sealing a pressure gauge onto the top end of the standpipe.

5.2.2 Types of open piezometer systems

Open piezometer systems can be of the following types:

— Open standpipe piezometer

— Monitoring well

— Casagrande piezometer

5.2.2.1 Open standpipe piezometer

An open standpipe piezometer shall include the following components:

— a straight pipe with a minimum inner diameter of 12 mm;

NOTE 1 That minimum inner diameter is commonly required for self-de-airing open standpipe systems.

NOTE 2 Main considerations in the selection of the inner diameter are the ground conditions and the hydrodynamic time lag. Larger diameter pipes have longer hydrodynamic time lags.

— a slotted or perforated section of the lower part of the standpipe;

NOTE When used in highly permeable ground with large and rapid water variations, the openings in the perforated or slotted pipe must be sufficiently large to minimise flow resistance.

— a filter pack around the slotted or perforated section of the standpipe according to 5.5.1.1 and 5.5.1.2;

— a sealing plug of at least one meter length in a confining layer. The location and length of the plug should be adjusted to the local ground conditions.

NOTE 1 When no confining layer is present, the sealing plug is still required to confine the intake zone and to avoid rain water directly entering the piezometer system.

NOTE 2 When using clay pellets as a seal, at least 1m of the sealing plug has to be below the groundwater level in order to allow the pellets to swell. When this is not possible, a grout mixture should be used as a plug.