
**Geotechnical investigation and
testing — Geotechnical monitoring by
field instrumentation —**

**Part 4:
Measurement of pore water pressure:
Piezometers**

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

Partie 4: Mesure de la pression interstitielle: Piézomètres



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation —

Part 4:

Measurement of pore water pressure: Piezometers

IMPORTANT — The electronic file of this document contains colours which are considered to be useful for the correct understanding of the document. Users should therefore consider printing this document using a colour printer.

1 Scope

This document specifies the measurement of pore water pressures and piezometric levels in saturated ground by means of piezometers installed for geotechnical monitoring. General rules of performance monitoring of the ground, of structures interacting with the ground, of geotechnical fills and of geotechnical works are presented in ISO 18674-1.

If applied in conjunction with ISO 18674-5, 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 (e.g. quay walls, dikes, excavation walls, foundations, dams, tunnels, slopes, embankments, etc.);
- 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, installed as part of the geotechnical investigation and testing in accordance with References [4] and [5]. 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 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 22475-1, *Geotechnical investigation and testing — Sampling by drilling and excavation 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 the following apply.

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

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1

piezometer

field instrument system for measuring *pore water pressure* (3.2) or *piezometric level* (3.4) where the *measuring point* (3.15) is confined within the ground or geotechnical fill so that the measurement responds to the fluid pressure around the measuring zone/point and not to fluid pressures at other elevations

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

Note 2 to entry: The system is either an *open piezometer system* (3.6) or a *closed piezometer system* (3.7).

3.1.1

intake zone

zone confined by *seals* (3.1.6), between which water in the ground can flow to the measuring device, thus defining the *measuring point* (3.15)

Note 1 to entry: See [Figure 1](#).

Note 2 to entry: It is assumed that a hydrostatic *pore water pressure* (3.2) distribution is established along the intake zone.

Note 3 to entry: The constant of proportionality between flow into or out of a *piezometer* (3.1) and the change of pore water pressure is called the intake factor *F*.

3.1.2

reservoir

space between the ground and the *measuring device* (3.1.7), occupied by a fluid, which allows the *pore water pressure* (3.2) to act on the sensing element of the measuring device

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

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

3.1.3

filter

permeable section of a *piezometer* (3.1) defining the *intake zone* (3.1.1), which allows water to enter and at the same time restricts soil particles entering the standpipe or *measuring device* (3.1.7)

Note 1 to entry: The filter can be a combination of elements, such as a sand pocket, a perforated pipe, a geotextile sleeve, a filter tip (3.1.4) and grout backfill in specific cases.

3.1.4

filter tip

filter (3.1.3) element which is a common part of a *closed piezometer system* (3.7)

Note 1 to entry: Filter tips are formed of a material with purpose-designed pore diameters, i.e. *HAE filter* (3.1.4.1) or *LAE filter* (3.1.4.2).

3.1.4.1

high air entry filter

HAE filter

filter tip (3.1.4) 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 µm and 3 µm.

Note 2 to entry: HAE filter tips are used when it is intended to keep gas out of the *measuring device* (3.1.7).

Note 3 to entry: In unsaturated soil or when negative *pore water pressures* (3.2) 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 filter

LAE filter

filter tip (3.1.4) 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 µm and 50 µm.

3.1.5

filter pack

permeable material, placed around a slotted section of an open *piezometer* (3.1) or around the *filter tip* (3.1.4), allowing water to reach the *measuring device* (3.1.7)

3.1.6

seal

layer in a borehole, made with a material that has a permeability suitable for hydraulical separation of two *aquifers* (3.10)

Note 1 to entry: Seals are generally used to confine an *intake zone* (3.1.1).

3.1.7

measuring device

part of the *piezometer* (3.1) system used to measure the *piezometric level* (3.4) in an *open system* (3.6) or the *pore water pressure* (3.2) in a *closed system* (3.7)

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

Note 2 to entry: For a *closed piezometer system* (3.7), the measuring device is typically a diaphragm pressure transducer (see 7b in Figure 1 b)). The diaphragm separates a *reservoir* (3.1.2) and an inner chamber in the transducer. The deflection of the diaphragm is a function of the *pore water pressure* (3.2) (see Figure 3).

Note 3 to entry: For closed piezometer 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* (3.6) or during the installation procedure of *piezometers* (3.1).

3.1.7.2

electric piezometer

piezometer (3.1) where the *measuring device* (3.1.7) has a diaphragm and the deflection of the diaphragm due to *pore water pressure* (3.2) 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 (3.1) where the *pressure measuring device* (3.1.7) 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 (3.1) where the *pressure measuring device* (3.1.7) 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* (3.2)

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, relative to the atmospheric pressure

Note 1 to entry: The pore water pressure is the difference between the total stress and the effective stress in saturated ground (see References [6] and [7]).

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 [8] and [Annex F](#)). Instruments that directly measure negative pore pressures are sometimes termed 'tensiometers', but are not within the scope of this document (see ISO 11276).

Note 5 to entry: Measurements of the pore water pressure can be affected by changes of the atmospheric pressure (see [5.4.1](#) and [Annex A](#)).

3.3

pressure head

ψ

ratio u/γ_w of the *pore water pressure* *u* (3.2) and the specific weight of water γ_w above a point

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

3.4

piezometric level

z_w

elevation to which water will rise in an *open standpipe piezometer* (3.6.1) and 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 (3.3):
 $z_w = z + u/\gamma_w$

Note 2 to entry: See [Figure 1](#).

3.5

groundwater table

water table

elevation at which *pore water pressure* *u* (3.2) is zero

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 system

open piezometer system

field instrument system in which the fluid is in direct contact with the atmosphere and the *piezometric level* (3.4) at the *measuring point* (3.15) is measured

3.6.1

open standpipe piezometer

open piezometer system (3.6), consisting of a pipe (installed in the ground) which, at its upper end, is open to the atmosphere and with a perforated section, located in the *intake zone* (3.1.1)

Note 1 to entry: See [Figure 1 a](#)).

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

3.6.2

Casagrande piezometer

open standpipe piezometer (3.6.1) with one or two comparatively small inner diameter pipes and a porous *filter tip* (3.1.4) at the *measuring point* (3.15)

Note 1 to entry: See 5.2.2.4, [Figure 2](#) and Reference [9].

3.6.3

monitoring well

open standpipe piezometer (3.6.1) with a large inner diameter of the pipe (typically ≥ 100 mm)

Note 1 to entry: A monitoring well can be used as *standpipe piezometer* (3.1), if the *response time* (3.9) 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* (3.1.1) is unconfined

Note 1 to entry: Observation wells are often incorrectly termed *open standpipe piezometers* (3.6.1). Observation wells do not classify as *piezometers* (3.1) as they do not have *seals* (3.1.6).

Note 2 to entry: See 5.2.2.3.2.

3.7

closed system

closed piezometer system

measuring system in which the *reservoir* (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* (3.1.7)

Note 1 to entry: See [Figure 1 b](#)).

Note 2 to entry: Examples for pressure measuring devices, used in closed systems, are electric transducers, fibre optic transducers and pressure valves.

3.7.1

diaphragm piezometer

closed system (3.7) with a *filter tip* (3.1.4), a small *reservoir* (3.1.2) and diaphragm which separates the pore water from the measuring system

Note 1 to entry: The deflection of the diaphragm is measured and the signal is transported through a cable to an accessible location.

Note 2 to entry: Possible diaphragm piezometers are *electric piezometers* (3.1.7.2) or *fibre optic piezometers* (3.1.7.3).

Note 3 to entry: The pressure is measured adjacent to the filter tip.

3.7.2

closed hydraulic twin-tube piezometer

closed system (3.7) with a porous ceramic *filter tip* (3.1.4) located within an *intake zone* (3.1.1) 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 (3.7) where a moveable *measuring device* (3.1.7) is inserted into a pipe which is equipped with one or more measuring ports, each located at an *intake zone* (3.1.1)

3.8

multi-level piezometer

system with several *measuring points* (3.15) permanently installed at different elevations in the ground, where each measuring point has its own *intake zone* (3.1.1)

3.9

hydrodynamic time lag response time

time span between a change of the *pore water pressure* (3.2) 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* (3.1) (essentially the size of the *reservoir* (3.1.2)), the permeability of the ground and the installation procedure (see Annex D).

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

3.10

aquifer

body of permeable rock or soil mass suitable for containing and transmitting groundwater

3.11

unconfined aquifer

aquifer (3.10) in which the groundwater surface forms the upper boundary

3.12

confined aquifer

aquifer (3.10) which is bounded above and below by *aquicludes* (3.14)

3.13

confining layer aquitard

a low permeability layer of rock or soil that restricts groundwater flow and separates *aquifers* (3.10)

3.14

aquiclude

body of soil or rock with extremely low transmissivity, which effectively prevents the flow of water through the ground

3.15

measuring point

point in the ground where the *pore water pressure* (3.2) is referenced to

4 Symbols and abbreviated terms

Symbol	Name	Unit
A	cross-sectional area of the standpipe	m ²
d	borehole diameter / diameter of intake zone	m
D	diameter of a standpipe	m
F	intake factor	—
FS	full scale	—
GWT	groundwater table	—
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	—
t	time	s
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/m ³
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. An advantage of open systems is the possibility that automatic measurements can be checked against manual measurements. Open piezometers may not have a suitable response time in low permeability soils.

Table 1 (continued)

No.	Type	Sub-type	Feature
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 loading conditions and the hydrodynamic time lag of the system.

NOTE 1 The choice between open or closed system is crucial and can be a decisive factor on success or failure of the measurement. For example, in undrained conditions, an open system will not correctly follow the true changes of pore water pressure (see [Annex D](#)).

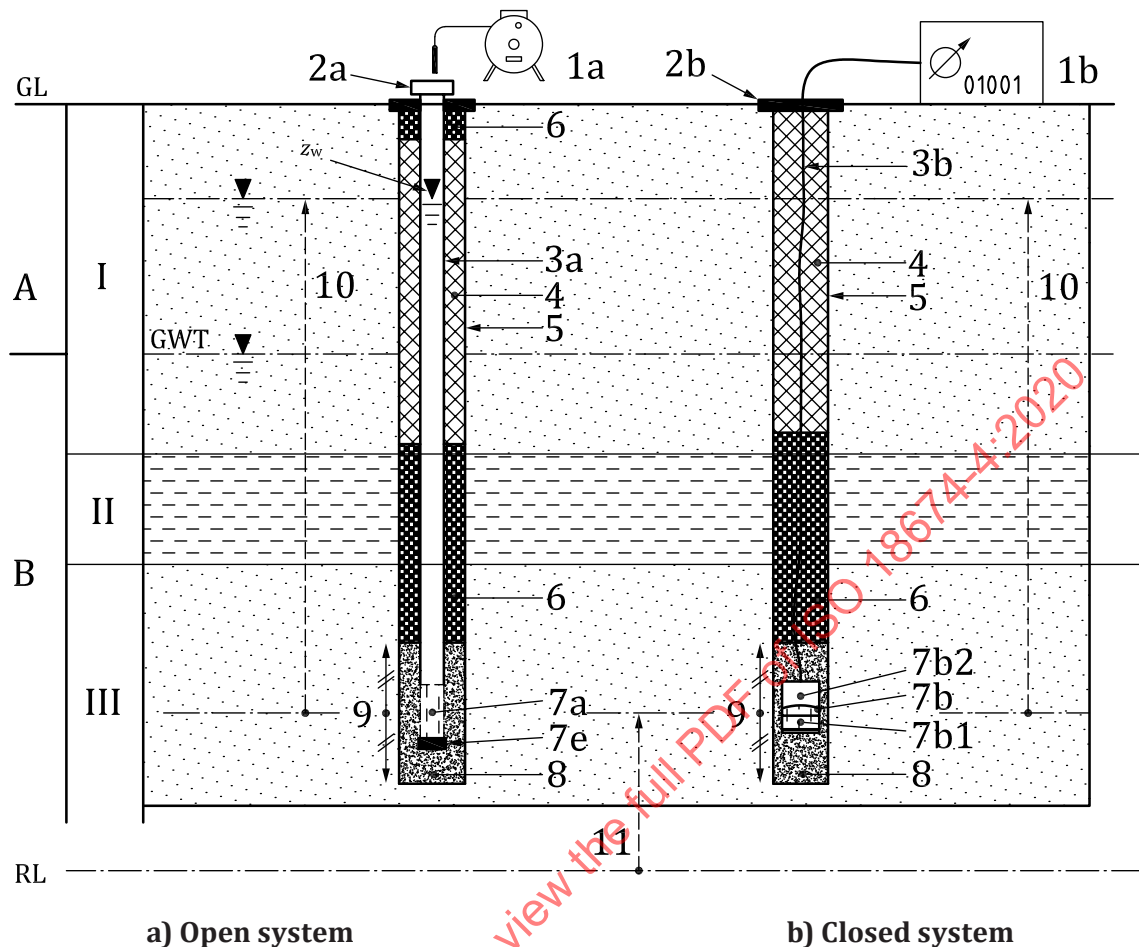
NOTE 2 Climatic conditions play also an important role when choosing between an open and a closed system. For example, when there is a risk of freezing conditions, a closed system is preferred.

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 consequences of diverse electrochemical potential e.g. galvanic effects, shall be prevented.

NOTE Differences in electrochemical potential can cause modified pore water pressures. This effect emanates from gases generated by electric currents created by using different metals or alloys in the piezometer tip and/or filter material.

**Key**

GL	Ground Level	A	zone above GWT	B	zone below GWT
I	unconfined aquifer	II	aquiclude or aquitard	III	confined aquifer
z_w	piezometric level in III	GWT	groundwater table in I	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	reservoir with filter tip
7b2	inner chamber of transducer	7e	end cap	8	filter pack
9	intake zone	10	pressure head	11	elevation of measuring point relative to RL

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 1 a\)](#).

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 is placed 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). When a pressure transducer is used to determine the piezometric level, compensation for atmospheric variations should be considered (see [5.4](#)).

5.2.1.5 In case of artesian conditions and an overflow of the standpipe, 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 Types of open piezometer systems

5.2.2.1 General

Open piezometer systems can be of the following types:

- Open standpipe piezometer
- Monitoring well
- Casagrande piezometer

5.2.2.2 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 The minimum inner diameter is related to self-de-airing of 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 3 When used in highly permeable ground with large and rapid water variations, the openings in the perforated or slotted pipe need to 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 1 m above the filter pack to confine the intake zone and to avoid rain water directly entering the piezometer system;

NOTE 4 When using clay pellets to form a seal, it is good practice to have at least 1 m of the seal below the groundwater level in order to allow the pellets to swell. When this is not possible, it is good practice to use a grout mixture as the seal.

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

5.2.2.3 Monitoring well

5.2.2.3.1 A monitoring well (see 3.6.3) with appropriate seals may be used as an open standpipe piezometer (see 5.2.2.2) as long as the response time is acceptable for purpose.

5.2.2.3.2 Monitoring wells should be clearly distinguished from observation wells. As the groundwater regime cannot be known a priori, the use of observation wells is strongly discouraged.

NOTE Observation wells (see 3.6.4) do not classify as piezometers as they do not have seals and thus can create connections between different aquifers and disturb the groundwater regime. The use of observation wells is limited to the measurement of the groundwater level in the uppermost layer of the ground in which, from the groundwater table, the water pressure increases uniformly with depth.

5.2.2.4 Casagrande piezometer

5.2.2.4.1 A Casagrande piezometer shall include the following components:

- a low air entry filter made from appropriate materials such as quartz sand, ceramic material, sintered metal or porous plastic, placed in a borehole;
- one or two standpipes of a comparatively small inner diameter attached to the filter coming up to the surface.

NOTE 1 See Figure 2.

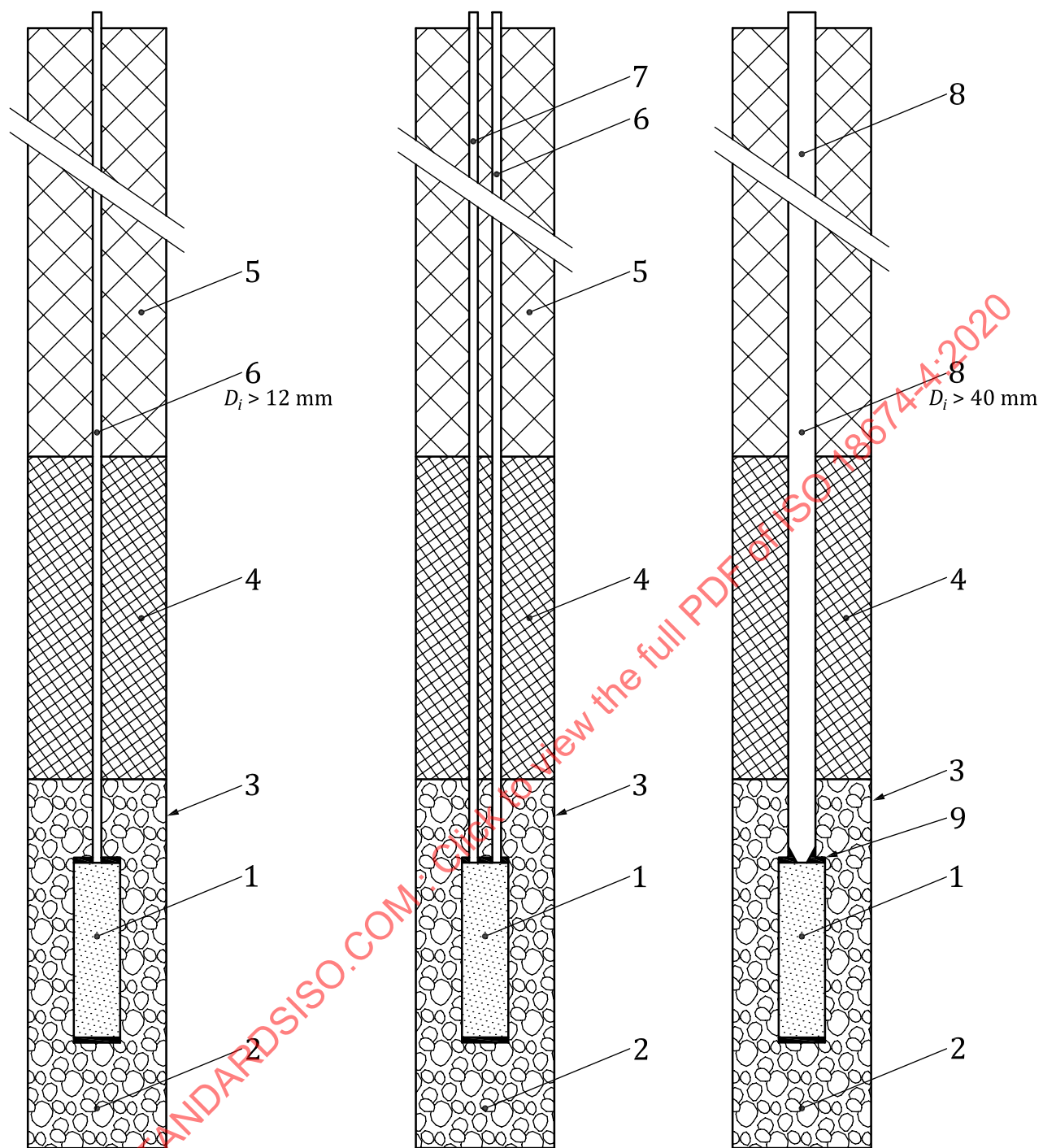
NOTE 2 A typical inner diameter of the standpipes is 12 mm. Smaller inner diameters can be used, but it is possible that they are not self-de-airing.

5.2.2.4.2 With dual pipes the piezometer can be flushed to remove air and/or soil particles out of the system.

NOTE 1 With dual pipes (see Figure 2 b)), the diameter of the pipes can be smaller than 12 mm.

NOTE 2 The use of a larger diameter pipe (see Figure 2 c)) allows the installation of a pressure measuring device within the standpipe. The device can be retrieved and replaced.

NOTE 3 Using a special tip connection (see 9 in Figure 2 c)), a Casagrande piezometer can be converted to a closed piezometer system. The pipe(s) can be closed by a device which includes a pressure transducer and a suitable solution to seal the casing(s).



a) Single standpipe
(with common D_i)

b) Double standpipes
(with small D_i)

c) Single standpipe
(with large D_i)

Key

- | | | |
|-----------------------------|-----------------------|---|
| 1 porous filter | 4 seal | 7 second pipe allowing flushing |
| 2 filter pack (filter sand) | 5 backfill | 8 larger diameter pipe allowing installation of pressure transducer |
| 3 borehole wall | 6 small diameter pipe | 9 filter tip connection (optional) |

Figure 2 — Casagrande piezometer, showing different connections to the surface

5.3 Closed piezometer systems

5.3.1 General

5.3.1.1 Closed piezometer systems shall include the components shown in [Table 2](#). The components of the system are a function of the installation method.

Table 2 — Piezometer components as a function of the installation method

Installation method	Piezometer component			
	Filter tip at the measuring point	Filter pack around the filter tip	Seal above the filter	Measuring device
traditional	+	+	+	+
fully grouted	+	+ ^a		+
push-in ^b	+	-	+	+
embedded	+	+	-	+
Key				
+ essential				
- absent				
^a The grout acts as a filter pack and as a seal, see 6.1.3 .				
^b The filter tip is pushed into the ground and is in direct contact with the ground, see 6.1.3 .				
EXAMPLE For traditionally installed closed systems, see Figure 1 b).				
NOTE The water pressure at the pressure measuring device is not necessarily in equilibrium with the atmospheric pressure.				

5.3.1.2 The measuring point is the location of the diaphragm, adjacent to the filter tip.

NOTE When a filter pack is present around the filter tip, the pressure measured at the diaphragm is influenced by the intake zone and does not necessarily represent the pressure at the measuring point in the ground.

5.3.1.3 Pressure measuring devices, or components thereof, shall be located either directly near the filter tip or at the ground surface. The device located near the filter tip can be either a diaphragm pressure transducer (see [Figure 3](#)) or a pressure valve (see [Figure 4](#)). Measuring devices at the ground surface can be pressure gauges (see [Figure 5](#)), readout units and/or control panels.

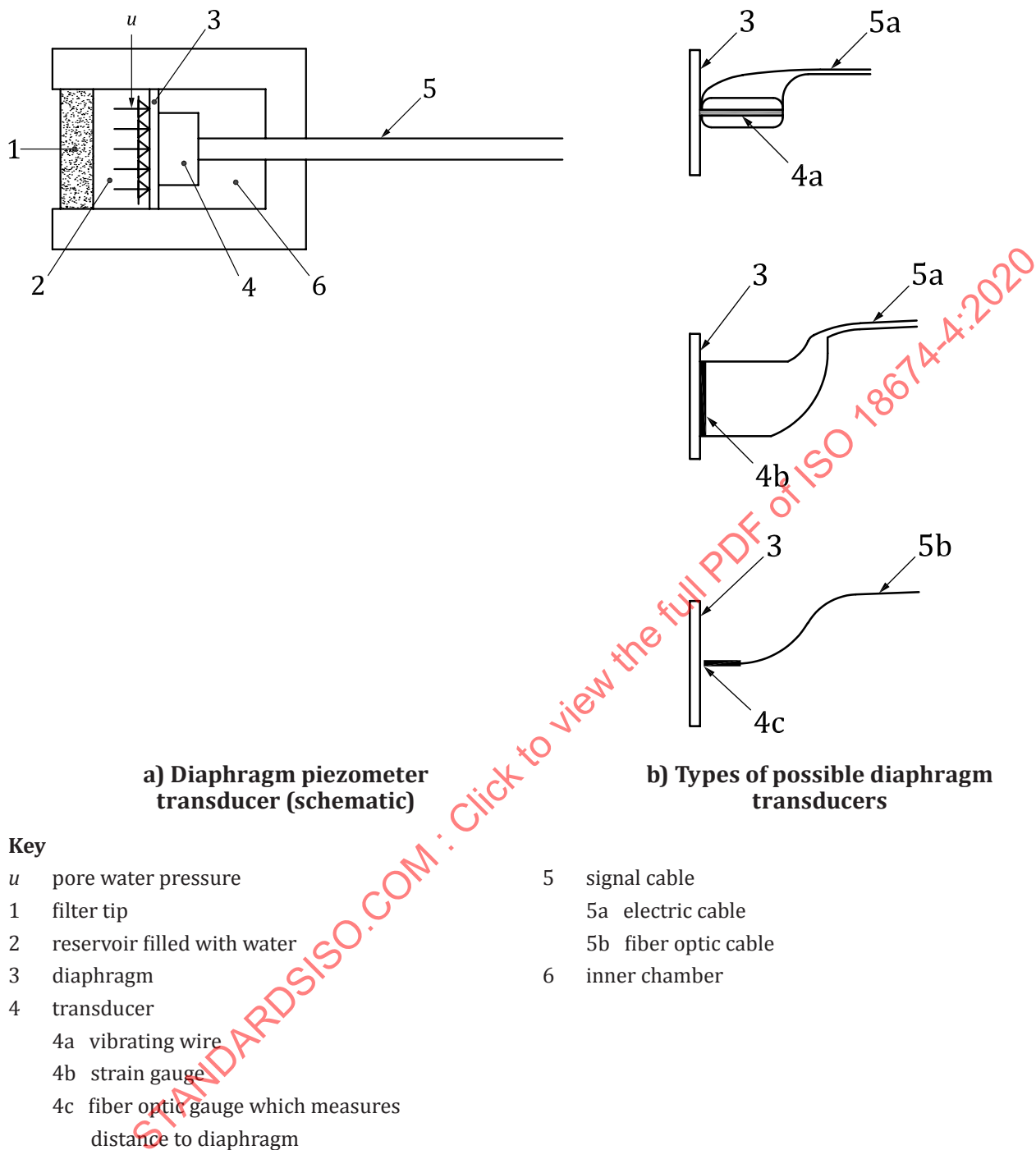
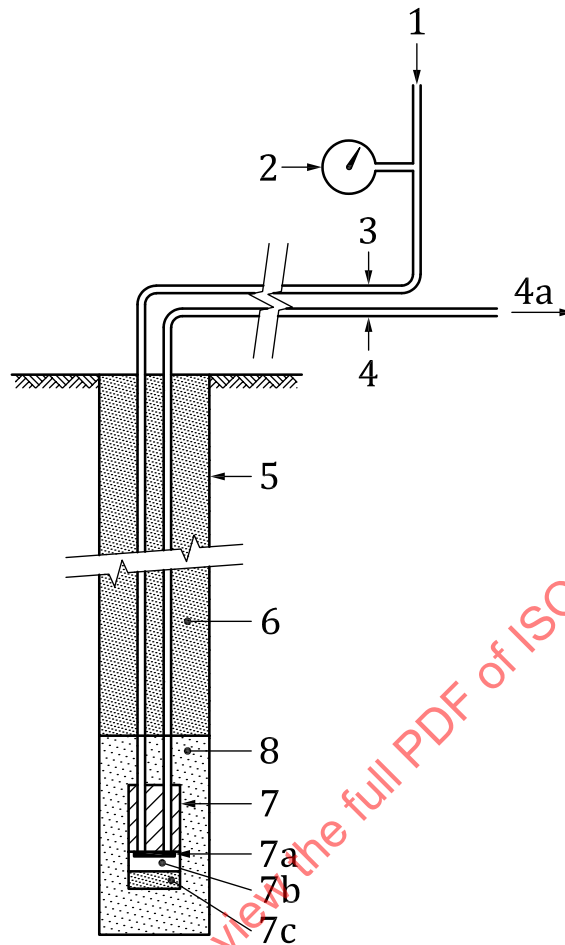


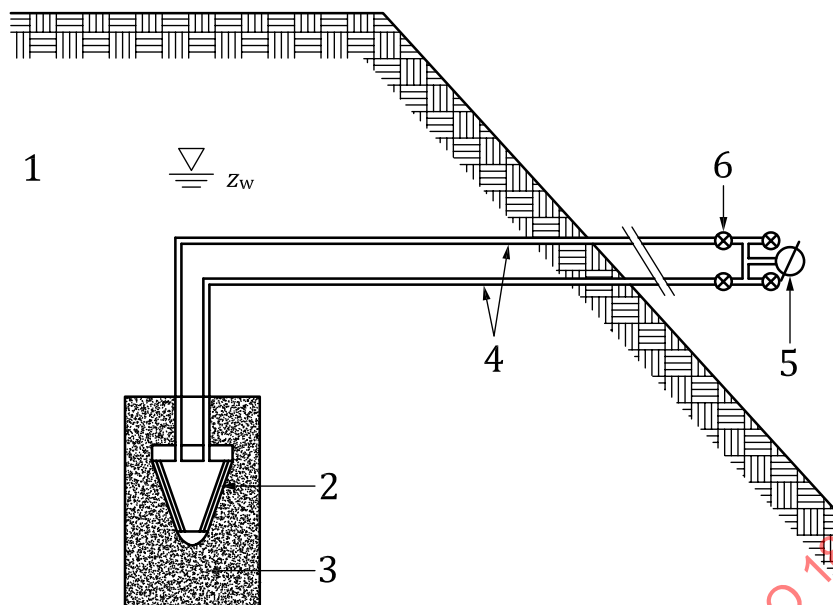
Figure 3 — Diaphragm pressure transducers of different types of closed piezometer systems

**Key**

- 1 gas supply
- 2 pressure gauge
- 3 inlet tube
- 4 outlet tube
- 4a vent to atmosphere
- 5 borehole wall
- 6 seal
- 7 body of pressure measuring device
- 7a pressure valve (flexible membrane)
- 7b reservoir filled with water
- 7c filter tip (LAE)
- 8 filter pack

NOTE This figure is sourced from Reference [10].

Figure 4 — Pneumatic piezometer (schematic)

**Key**

- z_w piezometric level
 1 ground
 2 filter tip (LAE)
 3 filter pack
 4 twin hydraulic tube
 5 pressure gauge
 6 valve

Figure 5 — Hydraulic piezometer (schematic)

5.3.2 Types of closed piezometer systems

5.3.2.1 General

Closed piezometer systems can be of the following types:

- Piezometers with diaphragm pressure transducers
- Piezometers with pneumatically activated pressure valve
- Hydraulic twin-tube piezometer

5.3.2.2 Piezometers with diaphragm pressure transducers

The piezometer shall include a pressure transducer with a deformable diaphragm, separating two chambers: a water-filled reservoir incorporating a filter tip as the intake for the pore water (7b1 in [Figure 1](#)) and an inner chamber of the transducer (7b2 in [Figure 1](#)) incorporating connections to an outside read-out.

EXAMPLE Electric (including vibrating wire) and fibre optic pressure transducers.

NOTE 1 See [Figure 3](#), [3.1.7.2](#) and [3.1.7.3](#).

NOTE 2 Vibrating wire, current loop and fibre optic transducers are frequently used when the measuring signal has to be transmitted via cables over long distances without measurable loss in the quality of the signal.

5.3.2.3 Piezometers with pneumatically activated pressure valve

The piezometer shall include a diaphragm valve in the measuring device.

NOTE 1 Pneumatic piezometers are generally considered reliable in the long-term.

NOTE 2 See [Figure 4](#) and [3.1.7.4](#).

NOTE 3 Pneumatic systems measure the pore water pressure in relation to the atmospheric pressure at the ground surface (see [5.4](#)) as the return tube is open to the atmosphere.

5.3.2.4 Hydraulic twin-tube piezometer

5.3.2.4.1 Hydraulic twin-tube piezometers shall consist of a low or high air entry filter with two tubes fitted to the filter body.

NOTE See [Figure 5](#).

5.3.2.4.2 The hydraulic tubes shall not be allowed to rise above the elevation of the level of the minimal hydraulic head. They should be made from polythene-coated nylon to avoid leakage and covered by a protection to avoid mechanical damage.

5.3.2.4.3 After installation and when otherwise required during operation, water shall be flushed through the tubes such that trapped air is purged from the system.

NOTE 1 Connecting pressure gauges to both hydraulic tubes can be used to identify if there is any air in the piezometer. A discrepancy in the pressure gauge readings is indicative of air, which can have developed in the system.

NOTE 2 The long-term stability of the system is supported by the exclusion of mechanical and electric components.

5.4 Absolute versus relative measurements and atmospheric compensation

5.4.1 When selecting a pore water pressure measuring device and when taking the measurements, absolute pressure, gauge pressure and relative pressure shall be distinguished from each other.

NOTE 1 See [Figure 6](#).

NOTE 2 Absolute pressure is zero-referenced to vacuum. Gauge pressure is zero-referenced against ambient atmospheric pressure, so it is equal to absolute pressure minus atmospheric pressure at the reference time. Relative pressure is referenced to atmospheric pressure.

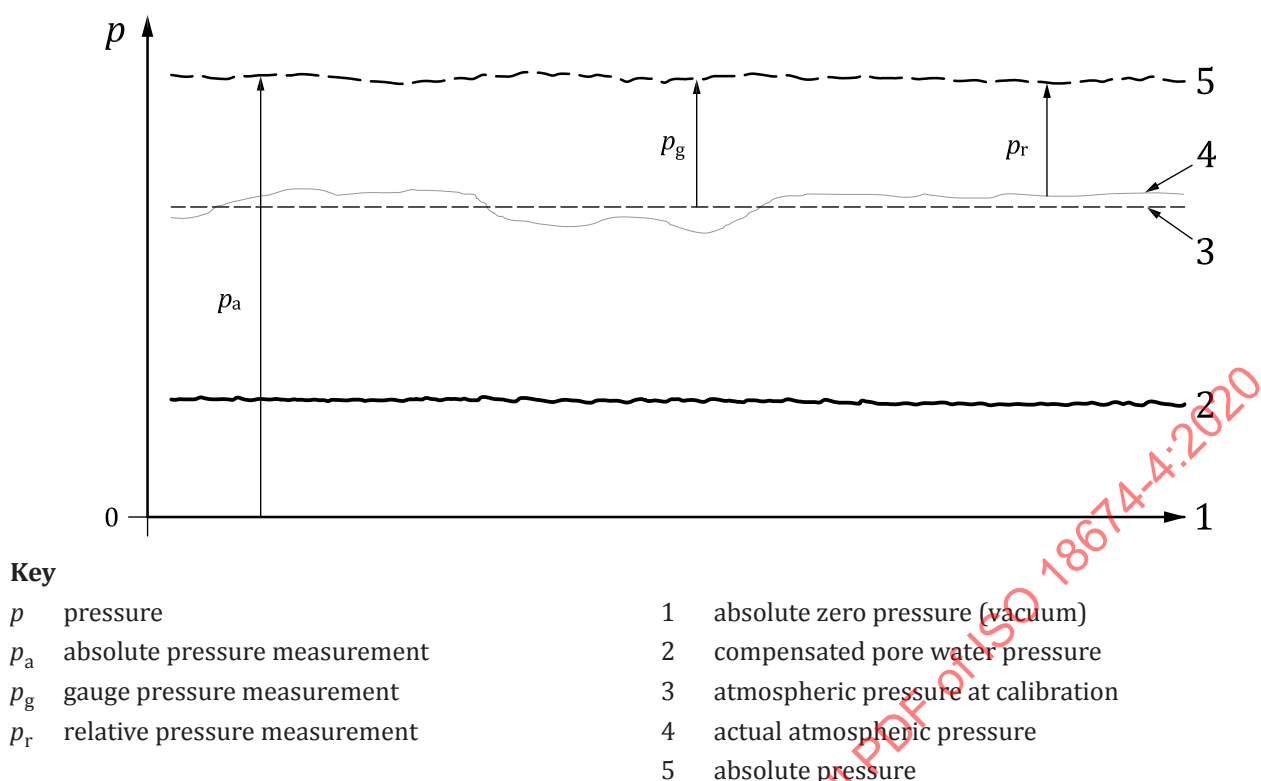


Figure 6 — Absolute gauge and relative pressure measurements

5.4.2 For the measurement of absolute or gauge pressure, the inner chamber (7b2 in [Figure 1](#)) of the measuring device shall be hermetically sealed.

NOTE 1 For gauge pressure measurements the pressure chamber of the sensor is typically sealed at 100 kPa or at the atmospheric pressure on the production date. In these cases, measured pressure can be below 0 kPa.

NOTE 2 The pressure in the hermetically sealed inner chamber can be tailored by the manufacturer if required, e.g. when installing piezometers at high altitude.

NOTE 3 When compensation for atmospheric pressure is required, piezometers which are sealed at atmospheric pressure only need to be compensated for the deviation of the atmospheric pressure at the measurement point from the atmospheric pressure indicated in the factory calibration report.

5.4.3 For the measurement of differential pressure, at least two measuring devices with hermetically sealed inner chambers (7b2 in [Figure 1](#)) are required.

NOTE When one device measures the atmospheric pressure and another device measures the pore water pressure at the same time, atmospheric compensation can be calculated by subtracting both values; see [Annex A](#).

5.4.4 For the measurement of relative pressure, the inner chamber of the measuring device shall be connected to the atmosphere.

NOTE Commonly, a venting tube is used for the connection of the inner chamber to the atmosphere. That tube can have a comparatively small inner diameter (e.g. integrated in the electric cable). Especially for long-term measurements, it is susceptible to blockage and risk of damage to the sensor by condensed water, remains of insect activity etc. A moisture trap can be used to reduce this risk. Alternatively, differential pressure measurements can be considered for atmospheric compensation.

5.4.5 The influence of the atmospheric pressure shall be considered. If influenced by the atmospheric pressure, pore water pressure shall be evaluated taking into account the barometric efficiency and reported as pressure relative to the atmospheric pressure.

NOTE See Reference [11].

5.5 Requirements for filters

5.5.1 Filters in open piezometer systems

5.5.1.1 The filter of an open piezometer system shall consist of a filter pack around a perforated or slotted section of pipe. The filter pack determines the intake zone of the piezometer and shall extend at least half a meter above and half a meter below the perforated or slotted section.

5.5.1.2 The criteria of the filter pack are that it should consist of a uniformly graded granular material, which is sufficiently coarse to allow water intake into or out of the piezometer and that it should prevent soil particles entering the slotted or perforated section. The slotted or perforated section may be covered by a geotextile sleeve to avoid soil ingress.

5.5.2 Filters in closed piezometer systems

5.5.2.1 In the context of this standard, piezometers should be placed in saturated ground conditions. The choice of the filter shall be made considering the characteristics of the ground, the expected piezometric pressure, the type of piezometer to be installed and the method of installation (see [Table 3](#)).

5.5.2.2 A HAE filter tip and the corresponding reservoir shall be saturated with de-aired water prior to installation (see [6.1.3.1](#)) and shall be placed in saturated conditions. The reservoir of an LAE filter should be filled with de-aired water, to avoid air entrapment in the inner chamber.

5.5.2.3 In ground that can temporarily lose saturation, attention shall be given to the choice of filter.

NOTE 1 Piezometers with HAE filters can measure suction, as long as they remain saturated. Working life can be extended with means to re-saturate the piezometer (see [Annex F](#)).

NOTE 2 LAE filters will not record representative pore water pressures in desaturated ground, but can partly resaturate naturally when the ground is resaturated. This can lead to slower response time. Placing the piezometer with the filter pointing upwards can delay desaturation of the piezometer in this case.

5.5.2.4 When intended to measure negative pore water pressure (suction), the requirements stated in [Annex F](#) shall be considered.

5.5.2.5 When placed within a borehole and in a filter pack, the filter tip may be placed upside down, to avoid air bubbles entering and remaining in the filter tip.

Table 3 — Requirements of filter type and saturation for closed piezometers in different applications

Application	Method of installation	Saturated soil or rock	
		Type of filter	Need for saturation
Positive pore water pressures	push-in	LAE	preferred
	in a borehole, within a sealed filter pack	LAE	preferred
	in a borehole, fully grouted	LAE	preferred
	placed in fill	HAE	required

Table 3 (continued)

Application	Method of installation	Saturated soil or rock	
		Type of filter	Need for saturation
negative pore water pressures	push in or in a fully grouted borehole	HAE	required

5.6 Measuring range and accuracy

The information in [Table 4](#) should be taken into consideration when selecting piezometers.

NOTE 1 The measuring range and accuracy of piezometer systems depend, amongst other factors, on the installation method, the depth at which the piezometer is placed, the hydraulic pressure on the piezometer (including during installation), the atmospheric compensation, the hydrodynamic time lag and the applied measuring device.

NOTE 2 When determining the piezometric level, the accuracy with which the reference point (top of piezometer or ground level) and/or the level of the measuring device is determined, has a significant impact.

NOTE 3 [Annex B](#) provides an overview of the various piezometer types in some geo-engineering applications.

Table 4 — Types, common measuring ranges of piezometer measuring devices

Type of Piezometer	Open system		Closed system			
	manual	automatic	electric	fibre optic	pneumatic	twin-tube hydraulic
common measuring range	0 m to 30 m	0 kPa to 100 kPa 0 MPa to 3 MPa	0 kPa to 100 kPa 0 MPa to 3 MPa	0 kPa to 100 kPa 0 MPa to 3 MPa	0 MPa to 2 MPa	0,06 MPa to 5 MPa
common measuring accuracy	0,01 m	0,2 ÷ 0,5 % FS	0,2 ÷ 0,5 % FS	0,2 ÷ 0,5 % FS	0,5 ÷ 1 % FS	0,5 % FS

6 Installation and measuring procedure

6.1 Installation

6.1.1 General

6.1.1.1 The installation of the piezometer shall be according to the monitoring plan and shall be described in a method statement.

6.1.1.2 In stratified ground, the variation of groundwater potential with depth shall be considered when choosing the installation level and filter length.

6.1.1.3 The installation of piezometers shall not permanently affect the groundwater flow and quality. Any hydraulic connections opened up between different layers during installation shall be closed by means of suitable seals. The height of the seal and the seal material depend on the thickness and permeability of the layer to be sealed. The seal shall be more than 1,0 m in length.

NOTE 1 It is good practice to extend the seal at least 2 m into a thick aquiclude. For aquicludes less than 2 m thick it is good practice to extend the seal at least 0,5 m above and below the aquiclude.

NOTE 2 Swelling clay (e.g. pellets, beads, granules) or grout is commonly used for sealing.

NOTE 3 Most bentonite swelling clay will not swell completely in salt water. Only activated bentonite is capable to have enough swelling capacity in salt water.

NOTE 4 Grout is commonly placed by means of a tremie pipe, inserted in the annular space or an injection device inserted in the casing. The sealing process proceeds from the bottom up over the grouted section.

6.1.1.4 In rock, particular care shall be exercised when installing filter zones and seals.

NOTE In rock, water circulates predominately in discontinuities and abrupt pressure changes can occur between adjacent discontinuities. If borings with filter zones link such discontinuities, the groundwater regime can be substantially altered. It can be advisable to carry out water pressure tests in short sections, determining the shut-in pressure and the local permeability.

6.1.1.5 If the piezometer is to be installed in a borehole, drilling shall be carried out and documented in accordance with ISO 22475-1.

6.1.1.6 The diameter of the borehole shall be large enough to accommodate the piezometer system including the filter pack and the seal.

6.1.1.7 When installing piezometers in boreholes, separate boreholes should preferably be drilled for each groundwater layer and for each piezometer. Nevertheless, several piezometers may be installed in one borehole at different levels by applying state of the art methods and experienced installation staff.

6.1.1.8 When installing a piezometer in a borehole and the borehole extends deeper than the intake zone, a seal may also be required below the filter pack.

6.1.1.9 When drilling for piezometers, additives should be avoided. If additives are used, the type and amount of the additive shall be documented.

NOTE Examples of additives are bentonite, polymers or even fresh water in salt water conditions.

6.1.1.10 Appropriate measures shall be taken to avoid any risk to the piezometer due to contamination, flooding, traffic or frost. Measures to protect the installation during the observation period shall be carried out.

6.1.1.11 The installation of the piezometer, including the position and elevation of the measuring point and the materials and positions of filters and seals, shall be documented (see [8.1](#)).

6.1.2 Installation of open piezometer systems

6.1.2.1 Open piezometers should be installed in boreholes. In soft ground, they may also be installed by ramming, pushing, water-jetting or after predrilling. When selecting the installation method consideration shall be given to the disturbance of the ground.

6.1.2.2 Joints of standpipes shall be watertight.

6.1.2.3 Penetration of surface water into an open standpipe piezometer shall be prevented.

EXAMPLE Seal around the top of the standpipe, raising the standpipe above the surface, vented cap on top of the standpipe.

6.1.2.4 Over the height of the seal, complete backfilling of the annulus between borehole wall and standpipe shall be established.

6.1.2.5 The gravel or sand of a filter pack shall be placed continuously in small quantities to avoid bridging.

6.1.2.6 In Artesian situations and when, for whatever reason, the top of a standpipe is placed below the ground surface, the pressure head might rise above the top of the standpipe. The top of the pipe may then be equipped with a selectively permeable membrane to avoid a runoff of water from the pipe whilst still allowing degassing of the system.

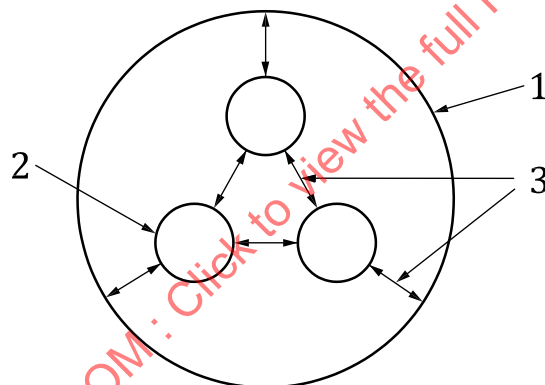
NOTE Gore-Tex® is an example of a suitable selectively permeable membrane available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

6.1.2.7 When pressure transducers are installed in an open system they shall be securely fixed in position. The diaphragm of the transducer shall be placed below the lowest piezometric level.

6.1.2.8 If, irrespective of 6.1.1.7, more than one standpipe piezometer is to be installed in a single borehole, it shall be proven that the equipment and the procedure allow for correct measurements in all layers. The spacing between the standpipes and their distance from the borehole wall or casing should be greater than 25 mm.

EXAMPLE A maximum of three standpipes of Ø 50 mm placed in a Ø178 mm borehole (see Reference [7]).

NOTE See Figure 7.



Key

- 1 borehole wall or casing
- 2 standpipe
- 3 distance > 25 mm

Figure 7 — Permissible geometric configuration for three open standpipe piezometers in a single borehole (cross section)

6.1.2.9 In order to ensure filter stability, the thickness and gradation of the filter pack shall be designed as a function of the gradation of the surrounding ground and the purpose of the measurements. The openings of the perforated section of the standpipe shall be chosen as a function of the filter pack.

NOTE Filter packs are commonly used in open systems to prevent soil particles from entering the filter and clogging the filter.

6.1.2.10 The top of the piezometer standpipe may terminate above or below the ground level. Protective measures shall be taken to avoid damage to and water ingress in the piezometer (see Annex C).

6.1.3 Installation of closed piezometer systems

6.1.3.1 Prior to and during the installation, the filter shall be saturated and the instrument shall be function checked.

NOTE 1 The presence of gas or air in a piezometer adversely affects the measurement of pore water pressure.

NOTE 2 Common de-airing methods are boiling or vacuum boiling.

6.1.3.2 Any contamination of the filter and insufficient saturation during storage and transportation shall be avoided.

EXAMPLE Contamination by oily or greasy substances; touching with bare fingers.

6.1.3.3 When selecting the installation method, consideration shall be given to ensure a good contact between the measuring device and the ground. Closed piezometers may be installed in boreholes by using a filter pack and a seal, or by using the fully grouted method. When using the fully grouted method, installation shall be done in accordance with [Annex E](#). In sufficiently soft ground, closed piezometers may also be installed by pushing, driving down or pushing after pre-drilling.

NOTE 1 If it is intended to install a push-in piezometer after pre-drilling, pre-drilling is commonly terminated 0,5 m above the installation depth, depending on the soil type. At least a 1 m thick seal above the filter is good practice.

NOTE 2 When driving down the piezometer to installation depth it is not good practice to use sonic drilling systems in soft soils.

NOTE 3 Twin-tube hydraulic piezometers are usually installed in trenches. Installation in boreholes limits the possibilities of measuring negative pore water pressures (see [Annex F](#)).

6.1.3.4 If, irrespective of [6.1.1.7](#), more than one piezometer is to be installed in a single borehole, multi-level piezometer systems or the fully grouted method (see [Annex E](#)) should be considered as an installation option because it simplifies the installation procedure significantly.

6.1.3.5 When applying the fully grouted method, the borehole diameter shall be as small as possible.

NOTE Larger borehole diameters imply longer flow paths from the intake zone to the measuring device (or the inverse) and thus an increase of the response time of the piezometer.

6.1.3.6 When installing piezometers by pushing them into the ground, piezometers shall be selected which have purpose-made push-in tips fitted beneath the filter.

6.1.3.7 The string of extension pipes, which is commonly used for the installation of push-in piezometers, may be left in the ground to act as a seal. In case the string is retracted, the developing cavity shall be filled with a slurry which, after setting, should have a lower permeability than the surrounding soil.

NOTE 1 If it is intended to reuse a push-in piezometer (e.g. after short-term measuring operations), the pipes can be left in the ground until the entire piezometer is subsequently retracted.

NOTE 2 When recovering the push-in rods prior to the measurements, the slurry for filling up the developing cavity is commonly fed through the push-in rods. The bottom part of the string (e.g. a pipe of 1 m length) is often left in the ground as an additional sealing element.

NOTE 3 An adaptor between the push-in piezometer and the push-in rods avoids heave of the filter tip.

6.1.3.8 For push-in piezometers in low-permeable soils, pushing can generate considerable local excess pore water pressure. It shall be ensured that the measuring device is not being damaged due to overloading, by checking the measurements during installation (ideally continuously).

NOTE 1 Excess pore water pressure during pushing can be reduced by lowering the rate of pushing.

NOTE 2 Overloading of the pressure transducer can also be avoided by using a transducer which is inserted after installation of the filter.

6.1.3.9 If, during the course of the monitoring project, gas might develop and become trapped in the piezometer system (e.g. due to bacteria present in the ground or due to electrochemical effects), a piezometer with a system for removing the gas shall be used.

EXAMPLE 1 Use of a degassing tube or twin-tube hydraulic piezometer. In the latter case, it is possible to calibrate the sensor after installation.

EXAMPLE 2 Use of a retrievable measuring system.

NOTE Self de-airing can be possible when installing a piezometer with an LAE filter facing upwards.

6.1.3.10 In twin-tube hydraulic systems, considerations shall be given and documented to protect the system against frost and thermal variations. Tubes and filter shall be flushed for gas bubbles before connecting the readout device to the system.

6.1.3.11 All pipes, tubes and cables in closed systems shall be protected from mechanical damage between the measuring point and the readout device, e.g. by routing them in excavated and refilled trenches.

6.1.4 Checks before, during and after installation

6.1.4.1 General

6.1.4.1.1 Before installation, the functionality of the measuring device shall be checked by performing the tests suggested by the manufacturer.

6.1.4.1.2 Each instrument and the connector (if applicable), shall be indelibly marked. A record of installation shall be prepared for each piezometer. The levels of filter pack, seal and backfill shall be measured and recorded during placement.

6.1.4.2 Checking of open piezometer systems

6.1.4.2.1 For an open standpipe piezometer, the standpipe shall be flushed with clear water after installation. Flushing shall be continued until the up-coming water is clear.

NOTE Using air to flush the piezometer by use of an air-lift system can lead to oxidation at the filter level when the groundwater has a high iron content.

6.1.4.2.2 The function of open standpipe piezometers shall be tested prior to commissioning, by raising or lowering the water level in the open standpipe. This shall be done after a stable water level is reached in the piezometer. The functioning may be assessed by verifying (visually or by measuring the fall/rise rate) that the water level in the piezometer changes and stabilizes in a time frame congruent with the instrument/soil properties. The date and result of the function test shall be included in the installation report.

6.1.4.2.3 When performing long term measurements (>1 years), the function test for an open piezometer shall be repeated every year.

NOTE In high permeable soils (sand and gravel), an open piezometer normally responds immediately and returns within minutes to hours to the piezometric level at the installation depth. In less permeable soils (silt, clay), this can take up to days or weeks. The time lag needs to be smaller than the time needed for changes in piezometric level to take place.

6.1.4.3 Checking of closed piezometer systems

6.1.4.3.1 Measurements shall be carried out and the results recorded during and immediately after installation.

NOTE It is possible to check the sensor calibration at the site, either by making 3 manual measurements with the sensor at different elevations in a water filled container or borehole, or precisely with a calibrated device connected to the piezometer tip.

6.1.4.3.2 In pneumatic systems, the gas pressure shall be applied to the supply tube after installation and the stabilisation process monitored until a constant pressure is obtained at the specified flow. The process should be repeated after releasing the air pressure in the supply tube for control purposes. The pressure should be plotted against time to check if the piezometer is functioning.

6.1.5 Maintenance

6.1.5.1 Function checks for open systems shall be performed according to [6.1.4.2](#) and for closed systems according to [6.1.4.3](#). The results shall be compared with the earlier checks.

6.1.5.2 When clogging is suspected, open piezometers and hydraulic twin-tube piezometers should be flushed with clean water. For hydraulic twin-tube piezometers, the water should be de-aired.

6.1.5.3 If the results of the function checks of open piezometers differ considerably from the earlier checks, the following measures shall be taken:

- check that the standpipe is not blocked, to verify that no sludge has accumulated in the standpipe;
- if sludge has accumulated, attempt to remove the sludge (e.g. by flushing);
- verify that the piezometer has been repaired successfully by undertaking an additional function check according to [6.1.4.2](#).

If the repair is not successful, the piezometer results shall be ignored and the piezometer may be decommissioned.

6.2 Carrying out the measurement

6.2.1 Instrumentation check and calibration

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

6.2.1.2 In open systems, only the measuring device can be calibrated. When a pressure transducer is used, its measurements shall be verified at least once a year. When a water level meter is used, it shall be calibrated every year.

NOTE Verification of pressure transducers can be done by manual measurements or calibration checks of the pressure sensor. When making manual measurements, ideally the manual measurement is made without or before removing the pressure transducer. In a small diameter borehole, this might not be possible. Depending on the permeability of the soil, this might result in a deviation of the measured water level.

6.2.1.3 In open systems, the elevation of the top of the pipe should be checked when there is a risk of variation of that elevation.

6.2.1.4 In closed systems, subsequent calibration checks are only possible with retrievable measuring devices.

6.2.2 Measurement

The measurements shall be carried out, for open piezometers in accordance with [A.1.1](#) and for closed piezometers in accordance with [A.2.1](#), both in conjunction with the requirements of ISO 18674-1:2015, Clause 7.

7 Data processing and evaluation

7.1 Processing and evaluation of the measuring data shall be carried out, for open piezometers in accordance with [A.1.2](#) and for closed piezometers in accordance with [A.2.2](#).

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

- type of piezometer (open; closed) and sub-type according to [5.2.2](#) and [5.3.2](#);
- type of filter tip (LAE; HAE);
- type of measurements (manual; automatic): frequency of measurement, frequency of logging and frequency of data communication.

EXAMPLE See [Annex G](#).

7.3 When evaluating the measurements, installation effects of the measuring system shall be considered. Such effects can be associated with the installation method (traditional; fully grouted; push-in; embedded; see [Table 2](#)), flushing medium (change of water density), excess pore water pressure, clogging and leakage between aquifers.

8 Reporting

8.1 Installation report

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

8.2 Monitoring report

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

Annex A (normative)

Measuring and evaluation procedure

A.1 Open piezometers

A.1.1 Measuring procedure

A.1.1.1 Manual measurement

For manual measurements in open piezometer systems, the vertical distance between the reference point and the water level in the standpipe shall be measured.

NOTE 1 The reference point is usually the top of the standpipe or the ground level.

NOTE 2 Commonly a water level meter is used for the measurement.

The reference point shall be defined and documented.

The repeatability of the measurement shall be better than ± 5 mm.

NOTE 3 The accuracy by which the level of the reference point is determined, has an important effect on the accuracy of the determined piezometric level.

The possibility of changes in the level of the reference point shall be considered.

EXAMPLE Settlement of the ground, damage to, and replacement of, the top of the standpipe.

A.1.1.2 Automatic measurement

For automatic measurements of open piezometer systems, an appropriate measuring device shall be installed.

EXAMPLE Pressure transducer installed inside the standpipe at a level well below the deepest piezometric level to be expected

The level of the measuring device shall be maintained and documented.

Pressure transducer measurements should be carried out together with barometric pressure measurements.

Manual measurements as per [A.1.1.1](#) shall be considered to verify automatic measurements.

NOTE 1 When the difference between manual readings and automatic measurements exceeds a predefined value, further analysis is needed to determine the reason for the deviation.

NOTE 2 When executing a manual verification measurement, the water level is best measured before removing the pressure transducer, as the removal of the pressure transducer can have an effect on the water level in the standpipe. This effect increases for small diameter pipes.

A.1.2 Evaluation procedure

A.1.2.1 Piezometric level

A.1.2.1.1 Manual measurement

The piezometric level z_w shall be determined according to [Formula \(A.1\)](#).

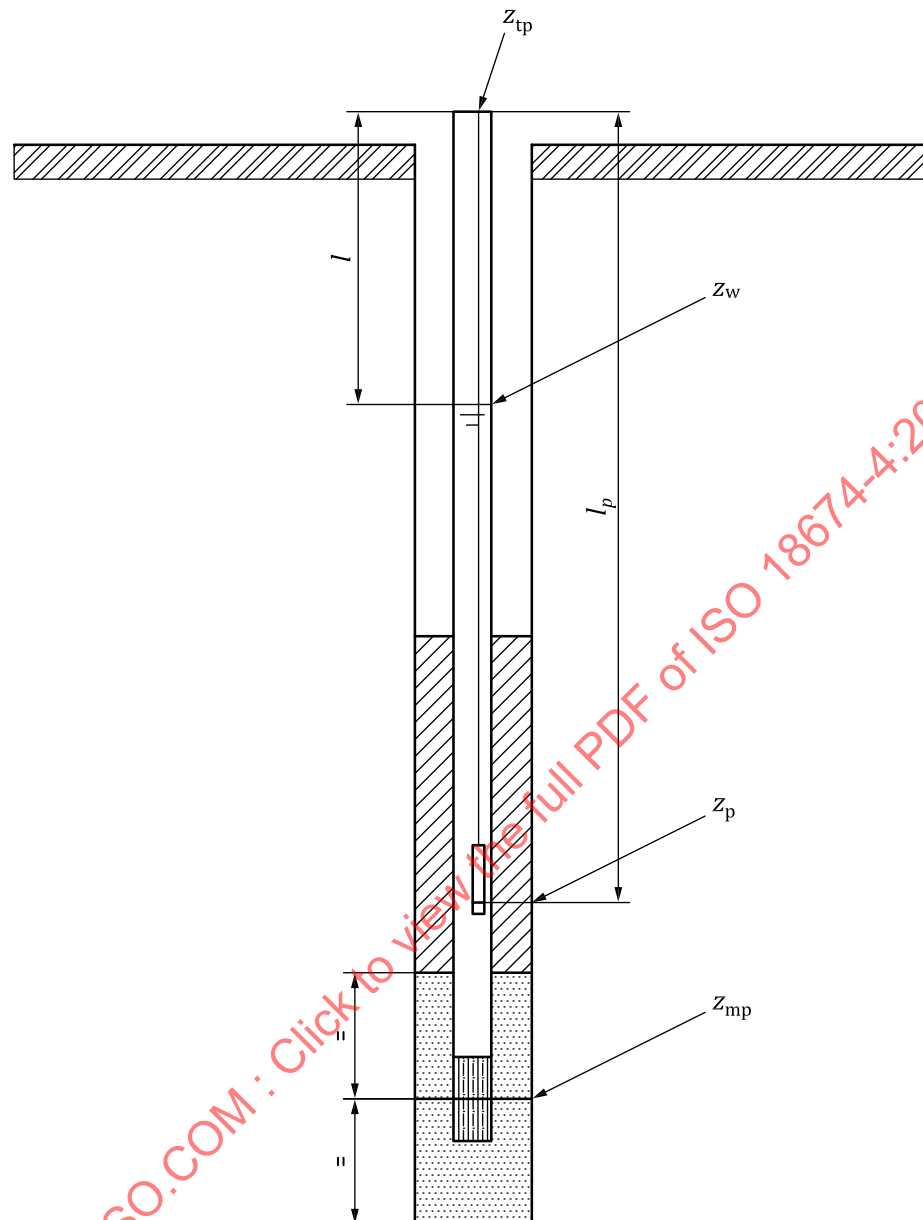
$$z_w = z_{tp} - l \quad (A.1)$$

where (see [Figure A.1](#))

z_{tp} is the level of the reference point at the top of the standpipe;

l is the measured vertical distance between the reference point and the water level inside the standpipe.

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**Key**

- l measured distance between reference point and water level inside the standpipe
- l_p suspension length of the pressure transducer
- z_{mp} geometric height of the measuring point
- z_p level of the pressure transducer
- z_w piezometric level

Figure A.1 — The evaluation procedure of an open piezometer system

A.1.2.1.2 Automatic measurement

When a pressure transducer is used, the piezometric level z_w shall be determined according to [Formula \(A.2\)](#).

$$z_w = z_p + p_w / \gamma_w \quad (\text{A.2})$$

where

z_p is the level of the pressure transducer (see [Figure A.1](#));

p_w is the water pressure measured by the pressure transducer;

γ_w is the density of water.

The level of the pressure transducer z_p shall be determined according to [Formula \(A.3\)](#).

$$z_p = z_{tp} - l_p \quad (\text{A.3})$$

where (see [Figure A.1](#))

z_{tp} is the level of the reference point at the top of the standpipe;

l_p is the suspension length of the pressure transducer.

NOTE 1 It is good practice to verify the suspension length of the pressure transducer l_p by a manual measurement of the groundwater depth. Sometimes corrections to l_p are applied after this check. The accuracy of the manual measurement is important when interpreting this check. In situations where the water level is fluctuating rapidly, it is also important to take into account the time difference between manual and automatic readings.

Depending on the type of pressure transducer, absolute pressure, gauge pressure or relative pressure is measured (see [5.4](#)).

NOTE 2 See [Figure 6](#).

When the pressure transducer measures absolute pressure (i.e. when the pressure transducer is hermetically sealed at vacuum pressure), the water pressure at the sensor p_w shall be determined according to [Formula \(A.4\)](#).

$$p_w = p_{abs} - p_{atm} \quad (\text{A.4})$$

where

p_{abs} is the absolute pressure;

p_{atm} is the atmospheric pressure in the proximity of the piezometer.

When the pressure transducer measures gauge pressure (i.e. when a pressure transducer is hermetically sealed at ambient air pressure), the water pressure at the sensor p_w shall be determined according to [Formula \(A.5\)](#).

$$p_w = p_{ga} - (p_{atm} - p_{ref}) \quad (\text{A.5})$$

where

p_{ga} is the gauge pressure;

p_{atm} is the atmospheric pressure in the proximity of the piezometer;

p_{ref} is the ambient reference pressure at which the sensor was sealed.

When the pressure transducer measures relative pressure (i.e. when using a venting tube), the water pressure p_w is measured directly by the pressure transducer.

A.1.2.2 Pore water pressure and pressure head

The pore water pressure u at the location of the measuring point shall be determined according to [Formula \(A.6\)](#):

$$u = \gamma_w (z_w - z_{mp}) \quad (A.6)$$

where

z_w is the piezometric level;

z_{mp} is the level of the measuring point;

γ_w is the density of the water.

The pressure head ψ shall be determined according to [Formula \(A.7\)](#).

$$\psi = u/\gamma_w = z_w - z_{mp} \quad (A.7)$$

A.2 Closed piezometers

A.2.1 Measuring procedure

A.2.1.1 Manual measurement

Manual measurements, although not common, can be made by means of a portable read-out unit.

For closed hydraulic twin-tube piezometers, pressure gauges can be used at a remote location (see [Figure 5](#)) and their readings recorded manually. The measurements shall be adjusted for the elevation differences between the filter tip and the gauges.

A.2.1.2 Automatic measurement

A specific measuring and logging device shall be used, depending on the type of closed piezometer.

Pressure transducer measurements should be carried out together with barometric pressure measurements. The measured values shall be corrected by the atmospheric pressure when required.

NOTE 1 For relative measurements, due to the risk of clogging of the venting tube, it is good practice to measure atmospheric pressure at the ground surface to verify that the venting tube is still working.

NOTE 2 For closed piezometer systems, the influence of atmospheric variation diminishes in the ground. It is therefore sometimes not necessary or even wanted to compensate the measurement for atmospheric variation. It is good practice to measure with absolute pressure transducers and to measure the atmospheric pressure at the ground surface to verify this.

When temperature compensation is required, the measurement of the temperature should be made close to the measuring device.

Measurements with pneumatic piezometers shall be performed by introducing gas pressure into the supply tube and gradually increasing the gas pressure until the diaphragm valve in the piezometer is displaced and gas is detected in the return tube. Two methods of measurement can be adopted:

1. The gas pressure in the supply tube is slowly reduced to a pre-defined, steady flow rate and the corresponding supply pressure is recorded.
2. The gas supply is turned off and the gas in the supply tube is allowed to escape past the diaphragm valve until the water pressure equals the gas pressure and the diaphragm valve is closed by the water pressure. The gas pressure in the supply tube is then recorded.

A.2.2 Evaluation procedure

A.2.2.1 Pore water pressure and pressure head

When evaluating the readings of a closed piezometer with an electric pressure transducer it shall be observed which type of pressure transducer was used in the measurements.

NOTE 1 Transducers are available for absolute pressure, gauge pressure or relative pressure.

NOTE 2 See [5.4](#) and [Figure 6](#).

When the pressure transducer measures absolute pressure (i.e. when the pressure transducer is hermetically sealed at vacuum pressure), the pore water pressure u may be determined according to [Formula \(A.8\)](#).

$$u = p_{\text{abs}} - p_{\text{atm}} \quad (\text{A.8})$$

where

p_{abs} is the absolute pressure;

p_{atm} is the atmospheric pressure in the proximity of the piezometer.

When the pressure transducer measures gauge pressure (i.e. when a pressure transducer is hermetically sealed at ambient air pressure), the pore water pressure u may be determined according to [Formula \(A.9\)](#).

$$u = p_{\text{ga}} - (p_{\text{atm}} - p_{\text{ref}}) \quad (\text{A.9})$$

where

p_{ga} is the gauge pressure;

p_{atm} is the atmospheric pressure in the proximity of the piezometer;

p_{ref} is the constant ambient reference pressure at which the sensor was sealed.

When the pressure transducer measures relative pressure (i.e. when using a venting tube, or in case of a pneumatic piezometer), the pore water pressure u is assumed to be measured directly by the pressure transducer.

NOTE 3 See [A.2.1.2](#), NOTE 2.

The pressure head ψ above the measuring point shall be determined as u/γ_w .

If applicable, the evaluation shall include corrections for temperature changes. Changes of the water density and tides should be considered in marine areas.

A.2.2.2 Piezometric level

The piezometric level z_w at the measuring point may be determined according to [Formula \(A.10\)](#).

$$z_w = z_p + \psi = z_p + u/\gamma_w \quad (\text{A.10})$$

where

z_p is the elevation of the pressure transducer;

ψ is the pressure head;

u is the pore water pressure, measured by the pressure transducer (see [A.2.2.1](#));

γ_w is the unit weight of water.

The elevation of the pressure transducer z_p shall be determined during installation.

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Annex B (informative)

Geo-engineering applications

The type of piezometer to be used depends on the type of ground, in particular its hydraulic conductivity, the geo-engineering application and the installation. [Table B.1](#) provides an overview of the various piezometer types to be considered in some common geo-engineering applications. The classification as shown in [Table B.1](#) can assist in the instrument selection. In the case that a geo-engineering application is not explicitly considered in [Table B.1](#), the closest application can be considered for the selection.

Table B.1 — Guide for the selection of piezometer types in geo-engineering applications

Application		Open piezometer system		Closed piezometer system		
		Open standpipe	Casagrande	Diaphragm	Pneumatic	Hydraulic twin-tube
Note about automation:		Manual or automatic	Essentially manual	Essentially automatic	Essentially manual	Essentially manual
In high permeable soils (e.g. $k > 10^{-5}$ m/s)	Determination of piezometric level	+	+	+/-	+	+
	Follow up of piezometric level variations, slow variations such as seasonal changes	+	+	+	+	+
	Follow up of piezometric level variations, relatively fast variations such as tidal influence	+	+/-	+	+/-	+/-
	Follow up of piezometric level variations, potentially fast variations such as monitoring of work effects or drainage	+	+/-	+	+/-	+/-
	Piezometric level variation due to pumping test	+	+/-	+	+/-	+/-

Table B.1 (continued)

Application		Open piezometer system		Closed piezometer system		
		Open standpipe	Casagrande	Diaphragm	Pneumatic	Hydraulic twin-tube
Note about automation:		Manual or automatic	Essentially manual	Essentially automatic	Essentially manual	Essentially manual
In low permeable soils (e.g. $k < 10^{-5}$ m/s)	Determination of piezometric level	–	+/-	+	+	+
	Determination of pore water pressure	–	+/-	+	+	+
	Follow up of pore water pressure during consolidation, potentially slow variations	–	+/-	+	+	+
	Follow up of pore water pressure variations, potentially fast variations such as work effects	–	–	+	–	–
	Determination of suction due to excavation	–	–	+/-	–	+
	Dynamic variations in pore water pressure	–	–	+	–	–
Key + likely to be suitable +/- possibly suitable – likely to be unsuitable						

Annex C **(informative)**

Protection of piezometers at the ground level

C.1 General

The top of piezometer standpipes (open systems) and all pipes, cables and connections coming out of the piezometer at the ground level need to be protected against damage of equipment and water infill.

C.2 Open systems

C.2.1 When the top of the standpipe is located above ground level, an example of a protection system is given in [Figure C.1](#). In this case, all the on-site remaining cables and connections coming out of the standpipe are to be fixed correctly inside the protective casing.

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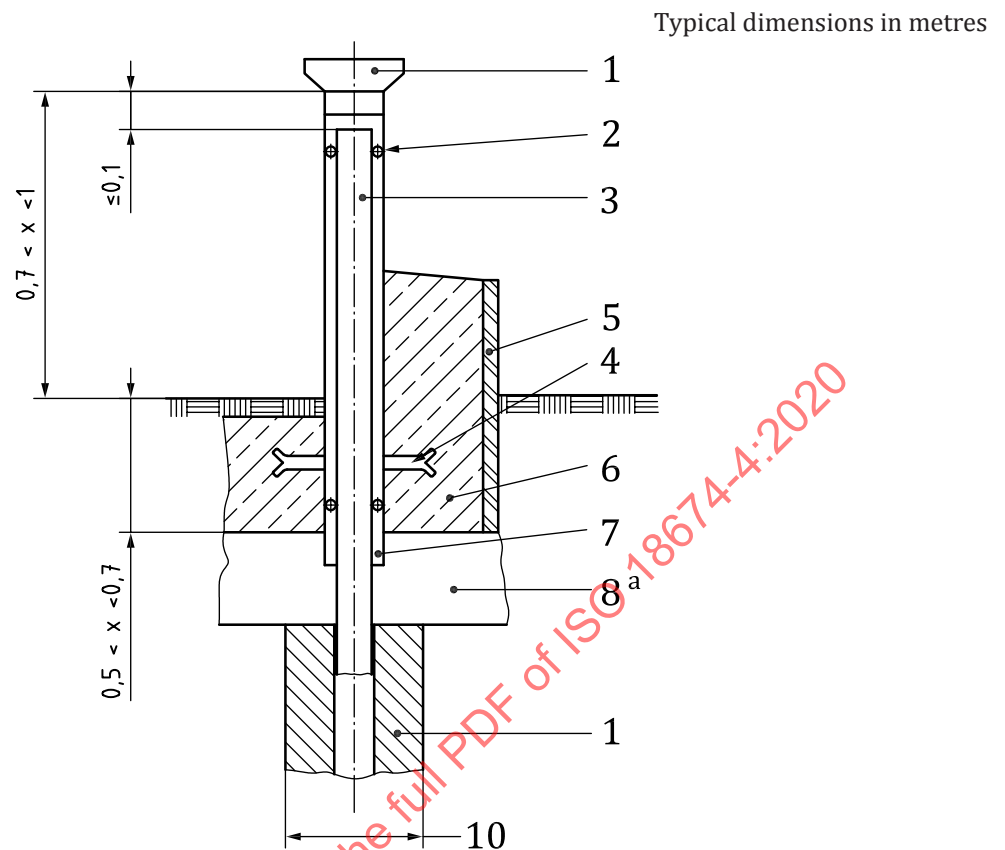


Figure C.1 — Example of protection system of an open piezometer above ground level

C.2.2 When the top of the standpipe is located below ground level, an example of a protection system is given in [Figure C.2](#). In this case, all the on-site remaining cables and connections coming out of the standpipe are to be fixed correctly inside the protection system below the traffic cap.

C.2.3 The cover needs to be compatible with withstanding traffic.

C.2.4 It needs to be ensured that any surface water penetrating the box can drain away (e.g. by inserting a drainage pipe in the concrete foundations).

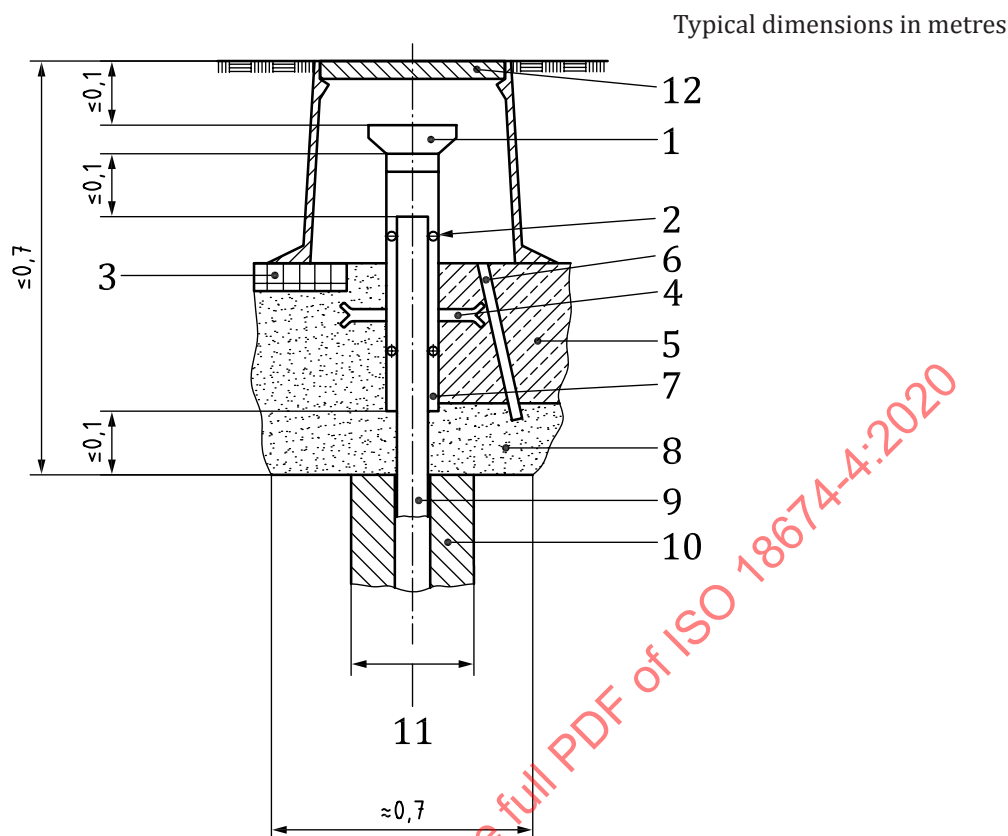


Figure C.2 — Example of protection system of an open piezometer below ground level

C.3 Closed systems

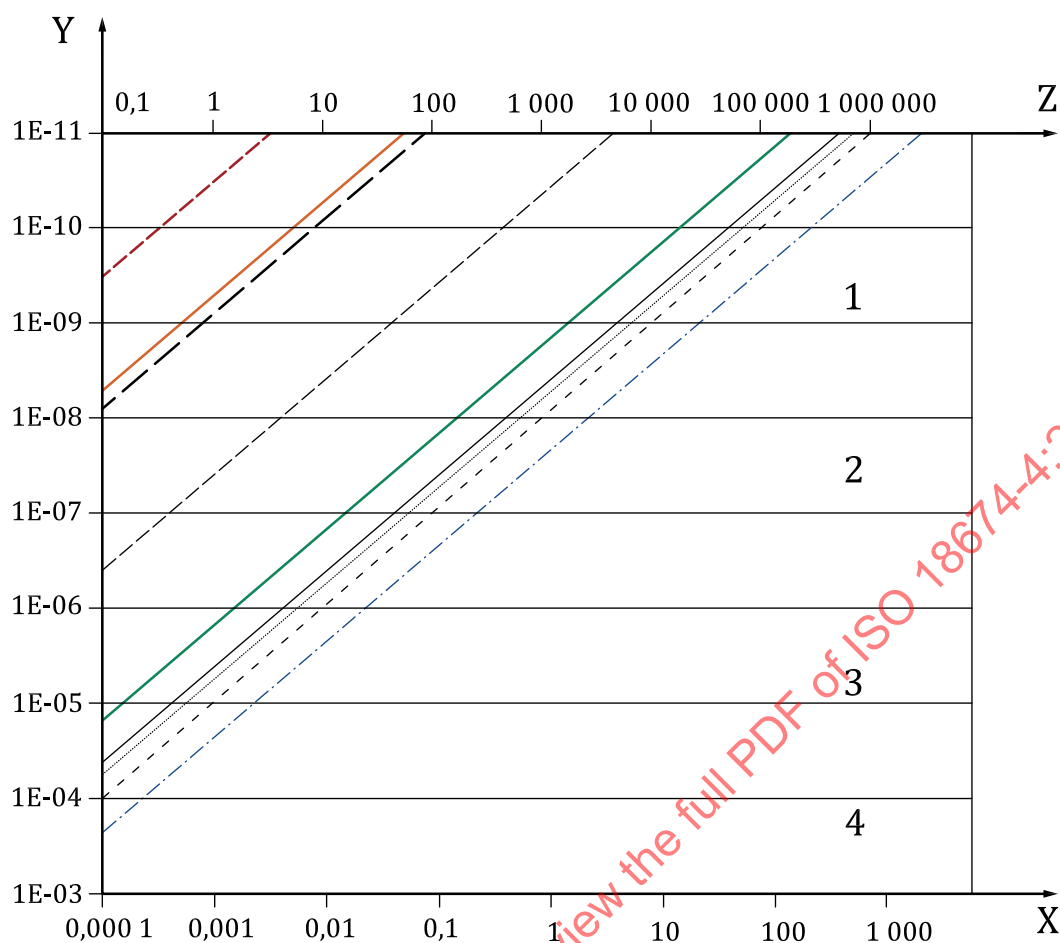
All pipes and cables connecting the piezometer and the readout device in closed groundwater systems need to be protected against mechanical damage (e.g. in excavated trenches refilled with sand) and water infill. Any extension pipes left in the ground until subsequent retraction of the piezometers need to be clearly marked on the site and also protected against damage.

Annex D (informative)

Response time for pore water pressure measurements

D.1 When measuring changes of the pore water pressure by means of a piezometer, the time span between a change of the pore water pressure in the ground and the associated change in the measurement is called the hydrodynamic time lag or the response time of the piezometer. The response time depends primarily on the permeability of the ground, on the type and dimensions of the piezometer and on the rate of the pressure change occurring in the ground. In order to reduce the response time and increase the sensitivity of the installation to rapid pressure changes, the volume of water which must flow into the instrument to equalise the pressure should be reduced to a minimum whilst the intake zone should be as large as possible.

D.2 [Figure D.1](#) shows approximate response times for various types of piezometers and soils, installed with the traditional method.

**Key**

X response time (days)

Y coefficient of permeability (m/s)

Z response time (min)

1 clay

2 silt

3 sand

4 gravel

--- diaphragm piezometer, laboratory conditions (see Reference [12])

— fully grouted diaphragm piezometer (see Reference [13])

--- closed hydraulic piezometer (Bishop)

.... closed hydraulic piezometer (Bishop) with 300 m tubing

— casagrande $\varnothing$ 1 cm; filter length 0,6 m; $\varnothing$ borehole 8 cm— open standpipe piezometer $\varnothing$ 2,5 cm, filter length 2 m, $\varnothing$ borehole 8 cm.... open standpipe piezometer $\varnothing$ 2,5cm, filter length 1 m, $\varnothing$ borehole 15 cm--- open standpipe piezometer $\varnothing$ 2,5 cm, filter length 1 m, $\varnothing$ borehole 8 cm- . - . open standpipe piezometer $\varnothing$ 5 cm, filter length 1 m, $\varnothing$ borehole 15 cm

NOTE This figure is based on References [12], [13], [14], [15] and [16].

Figure D.1 — Approximate response times for various types of piezometers in dependency of the hydraulic conductivity of the ground

D.3 In fully grouted installation (see [Annex E](#)), the response time depends on the permeability of the grout, the permeability of the soil, the dimensions of the borehole and the type of piezometer, and varies between a few seconds and several minutes.

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Annex E (normative)

Fully grouted piezometer installation

E.1 For closed systems, a distinction should be made between the installation of the measuring device in a sand pocket with a bentonite (or grout) sealing (traditional installation) and the placement of the measuring device in a fully grouted borehole (fully grouted installation).

NOTE Examples of the fully grouted installation method can be found in References [13], [16], [17], [18], [19], [20] and [21].

E.2 The grout mix shall be designed before installation. The important variables to consider are the permeability, viscosity and strength of the grout.

E.3 The grout shall act as a filter so as not to adversely affect the horizontal flow of water to the piezometer and as a seal so to prevent significant vertical flow along the borehole.

NOTE 1 This can be achieved if permeability of the grout is no more than 100 to 1 000 times the permeability of the ground (this includes grouts that are less permeable than the ground) (see References [17] and [22]).

NOTE 2 When the grout is less permeable than the ground, response time is increased.

NOTE 3 The permeability can decrease by orders of magnitude in the months after installation.

E.4 The viscosity of the grout shall allow it to be pumped but avoid excessive penetration of the grout into the surrounding ground.

NOTE 1 In soils with a high permeability the viscosity of the grout is more important than the permeability.

NOTE 2 A marsh funnel can be used to measure viscosity (see Reference [22]).

E.5 The cement and the water should be mixed first as the water / cement ratio determines the permeability (as well as the strength and stiffness of the mix). Bentonite shall be used to control viscosity and to avoid excessive bleed.

NOTE 1 Typical grout mixes are shown in Table E.1.

NOTE 2 It is considered best if the strength and the stiffness of the grout are similar to the surrounding ground.

NOTE 3 There exist many types of bentonites. The viscosity of the grout will depend on the quantity and type of bentonite which is used.

E.6 Cement without additives shall be used.

Table E.1 — Typical grout mixes (ratios in weight) and order of magnitude of hydraulic conductivity and uniaxial compressive strength

Cement	Water	Bentonite	Hydraulic conductivity [m/s] at 28 days	$q_{u,grout}$ [kPa]
1	6	1	$\sim 5 \times 10^{-8}$ to 1×10^{-7}	100
1	4	0,7	$\sim 2 \times 10^{-8}$ to 5×10^{-8}	200
1	2,5	0,4	$\sim 10^{-8}$	700
1	2	0,36	$\sim 10^{-9}$	1 500

E.7 High air entry porous filters shall not be used with the fully grouted method unless there is a means of removing air from the piezometer.

E.8 The grout should be delivered to the bottom of the borehole, using a tremie pipe, which may be moved upwards as the grouting proceeds. The tremie nozzle shall be kept below the grout surface during grouting.

E.9 When using the fully grouted method, care should be taken to not overstress the transducer, due to grout weight and pumping pressure. This can be checked by making frequent measurements of the pressure recorded by the transducer during installation.

Annex F (normative)

Measuring negative pore water pressure (soil suction)

F.1 It should be realised that all kinds of electric (including vibrating wire) and fibre optic piezometers have the potential to measure negative pore water pressures (i.e. soil suctions). It is only the measurement range that is limited. It is not possible to measure negative pore water pressures with pneumatic piezometers.

F.2 To successfully measure soil suctions all parts of the piezometer system (e.g. the backfill material, the porous filter and the fluid reservoir) shall remain saturated at all times and the water in the piezometer shall be in continuous contact with the water in the soil at all times.

NOTE 1 Sand is not suitable for use as a backfill material when negative pore water pressures are being measured because it desaturates when very low values of negative pore pressure are applied and continuity is therefore lost between the water in the piezometer and the water in the soil.

NOTE 2 Cement grout mixed with a water/cement ratio between 0,5 and 1,5 will remain saturated to soil suctions up to 200 kPa. Small amounts of bentonite (up to 10 % by weight of the cement) are sometimes added to restrict bleed. The grout is pumped to the bottom of the borehole through a tremie hose to avoid the formation of air bubbles.

F.3 If air forms inside the piezometer it shall be removed and saturation of the device shall be restored.

NOTE Air can be removed by flushing water into a flushable piezometer or by removing the piezometer and resaturating it.

F.4 To maximise the range of the measurements, the pressure measuring device should be located at the same elevation as the measuring point.

NOTE Measuring soil suctions greater than 100 kPa requires special measures and special equipment, see Reference [8].

Annex G (informative)

Measuring examples

G.1 General

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

1. Open (standpipe) piezometer (see [G.2](#))
2. Closed piezometer: diaphragm piezometer (VW sensor) (see [G.3](#))
3. Closed piezometer: pneumatic piezometer (see [G.4](#)).

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

G.2 Open standpipe piezometer

a	Owner of the project	De Vlaamse Waterweg, Government of Flanders, Belgium.
b	Name and location of the project	Design of measures to improve stability of an instable slope, Dendermonde, Belgium.
c	Name of the company carrying out the monitoring project	Geotechnics Department, Government of Flanders, Belgium.
d	Monitoring project	Measurement of piezometric levels above and below of a Tertiary clay layer.
e	Type of ground	Compacted sand.
f	Instrumentation	Double open standpipe piezometers in three boreholes (see Figure G.1 for the location of the boreholes).
g	Installation	Drilling of 168 mm Ø Boreholes B6, B9 and B14. Insertion of two standpipes, Ø _{inner} 57 mm, in each borehole. Length of the pipes varied between 7,5 m and 19,5 m, with a perforated section of 2,0 m at their lower ends. The perforated sections are centrally installed in the borehole and surrounded by a 3 m high sand pocket. A bentonite seal of 4 m to 6 m is placed between the two filters, and a bentonite seal of 1,5 m height placed above the top of the highest filter pack.
h	Commissioning of the monitoring	After verification of the well functioning of the piezometers.
i	Measurements	Both manual and automatic measurements were performed (see Figures G.2 and G.3). For the automatic measurements retrievable absolute pressure transducers were used.

- | | | |
|---|---|--|
| j | Measuring uncertainty | 0,35 kPa for the piezometer sensors. Overall accuracy of water level estimated to be around 5 cm to 10 cm. |
| k | Principal results of the monitoring project | The measurements were used to optimize a groundwater flow model and to calculate the pore water pressure in and underneath the Tertiary clay layer. |
| l | Assessment and evaluation | Continuous logging and the verification of the automatic measurements by occasional manual measurements substantiated the understanding of the tidal influence onto the pore pressures acting in the different aquifers. It contributed significantly to the optimisation of the groundwater flow model. |

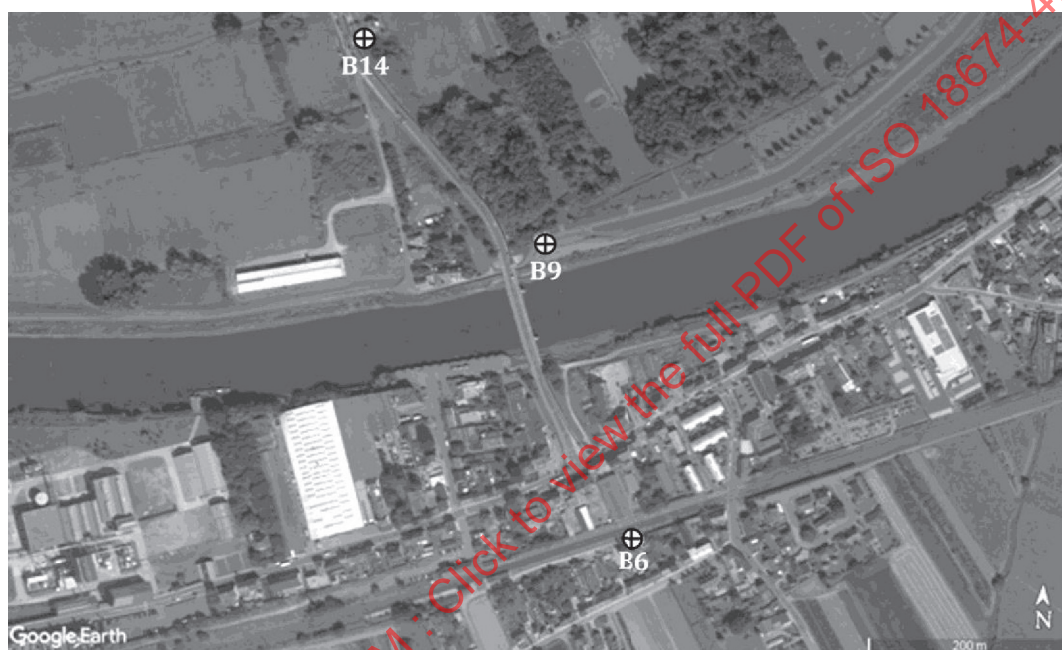


Figure G.1 — Location of the open standpipe piezometer boreholes B6, B9 and B14

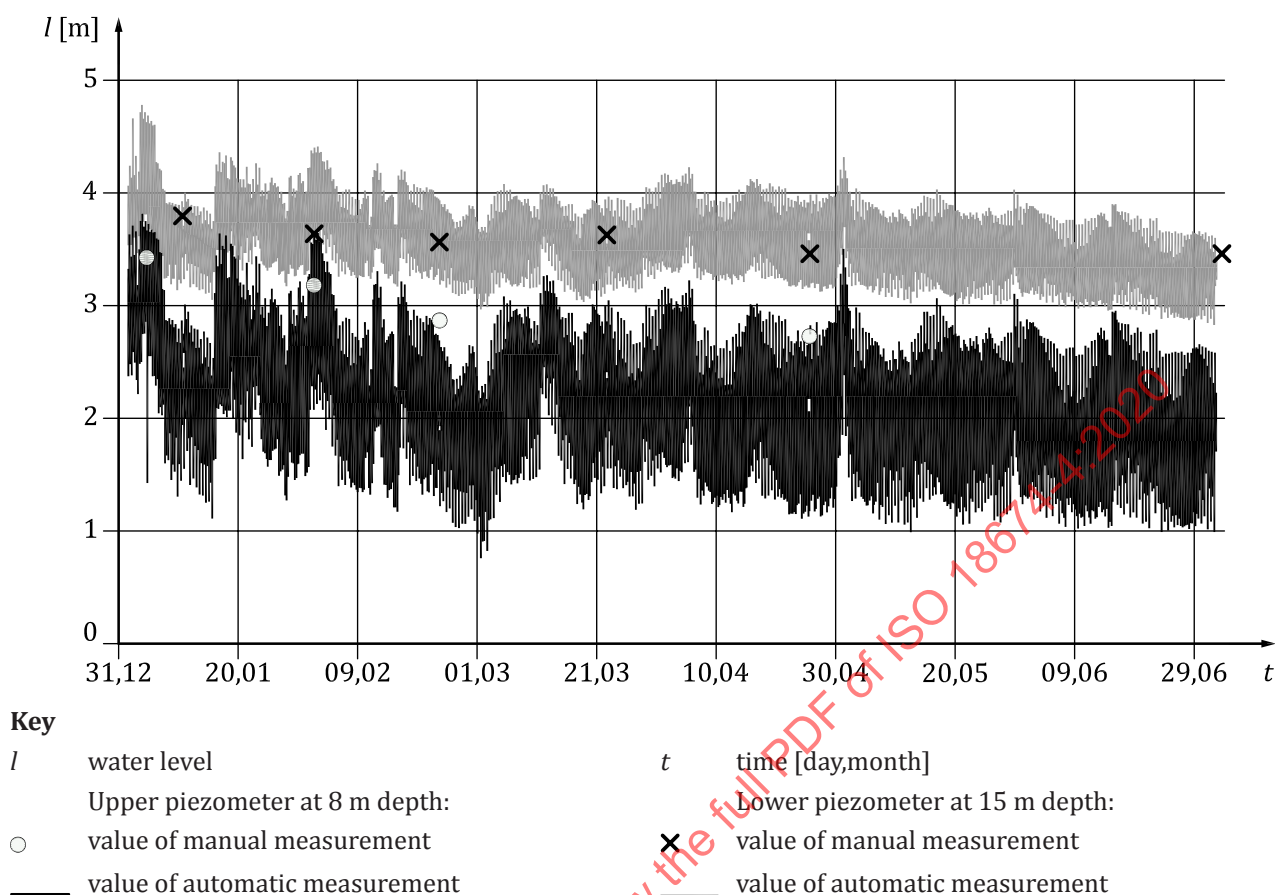
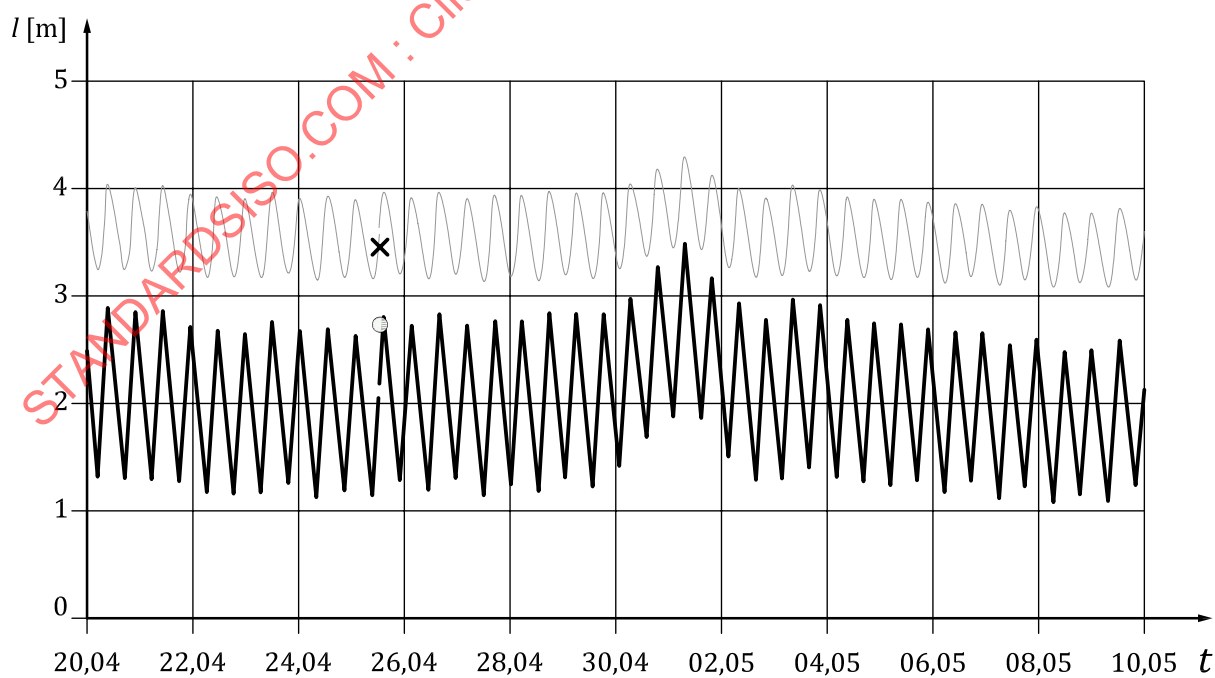


Figure G.2 — Open standpipe piezometer P9 — Tidal influence: comparison between automatic and manual measurements



NOTE See Key to [Figure G.2](#).

Figure G.3 — Open standpipe piezometer — Tidal influence: detail of [Figure G.2](#)