Piezometers in depth

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Presentation contents

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- ISO-TC182-WG2
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Presentation contents

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Presentation contents

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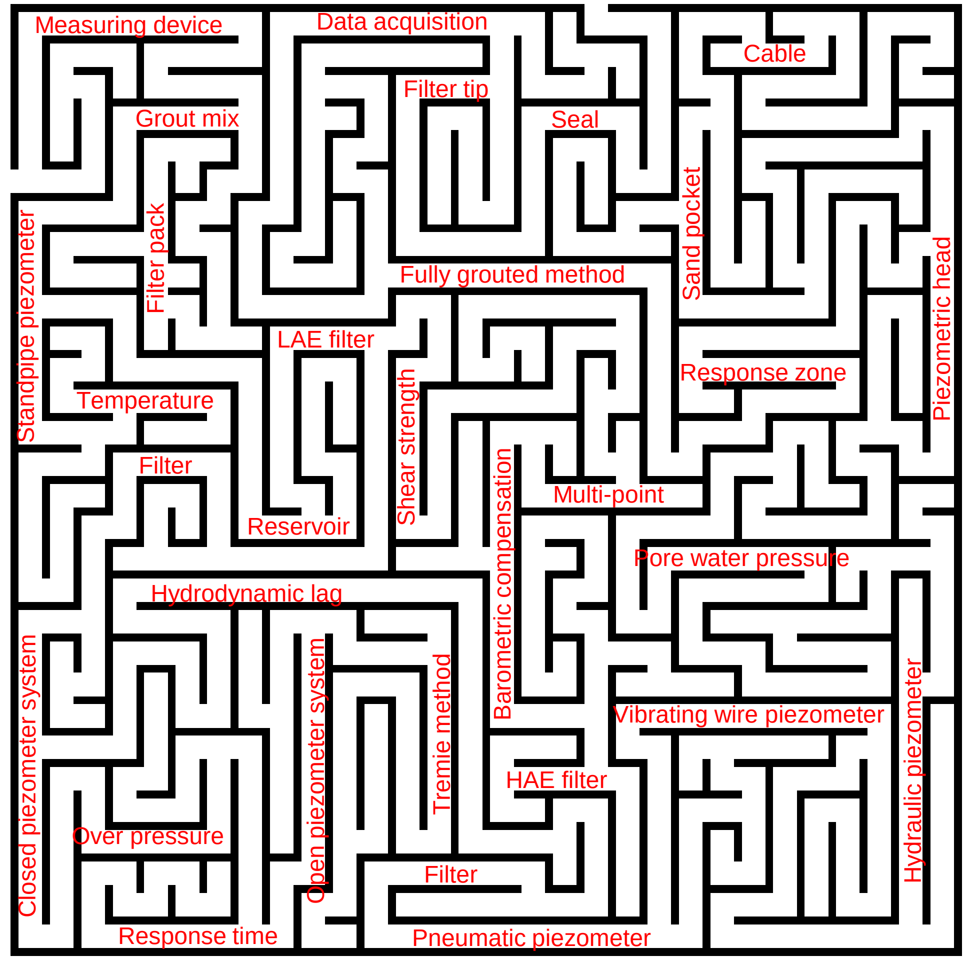
- Pressure range slope monitoring
- Pressure range surcharging
- Data reduction

Considerations

There are many considerations for piezometers

It sometimes feels like a maze of things to think about e.g.

- **Piezometer type**
- **Pressure range**
- **Filter**
- **Grout**
- **Seal type**
- **Barometric compensation**
- **Response time**



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Responsibilities

- **Engineer**
  1.) To identify the need (why) for monitoring
  2.) To identify what (i.e. PWP) & where (e.g. dam body) to monitor
  3.) To make the specification for the instrumentation
  4.) To analyse & understand the data from the instrumentation
  4.) To use the data from the instrumentation
- **I & M Contractor**
  1.) To install instruments to the Engineer's specification
  2.) To provide data to the Engineer's specification
- **Manufacturer/supplier**
  1.) To provide the I & M Contractor with hardware to meet Engineer's specification

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Overview

- **PWP – Probably <u>the</u> most monitored parameter (measurand)**
- **Piezometer – A <u>system</u> for monitoring <u>pressure (different types)</u>**
- **Very wide range of applications (embankments,dams, tunnels etc)**
- **Wide range of hardware (measuring devices) electric, fibre optic, hydraulic, pneumatic)**
- **Installation - Traditional & fully grouted method**

There are also common misunderstandings

- **Zero pressure reading**
- **Barometric compensation**
- **Pressure range selection**
- **Filter types**
- **System performance versus sensor (accuracy, resolution etc)**

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- **Piezometer ˌpʌɪɪˈzɒmɪtə**

From Greek *piezein "press or squeeze"* and *metron* "measure"

- ***Noun 19th Century***

an instrument for measuring the pressure of a liquid or gas, or something related to pressure (such as the compressibility of liquid)

- **Device**

invented in 1822 by Hans Christian Oersted (1777-1851) to measure the compression coefficient of water

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Geotechnical history

U. S. Army Engineer Waterways Experiment Station TECHNICAL REPORT NO. 6-654 Report I August 1964

“Piezometer tubes have been used for at least 38 years (so since 1926) to measure uplift pressure at the foundation of a dam.

Beginning in 1925 at American Falls Dam in Idaho systems of vertical wells have been placed across the contacts of the bases of concrete dams with the foundation rock.

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Casagrande

“The start of it all”

In the 1940’s Arthur Casagrande developed a “piezometer” to measure pore pressure used for the analysis of the compression of clays. It consisted of:

- **Bottom rubber plug**
- **Porous point – 1.5” OD x 1.0” ID x 2 ft (later to be known as a piezometer tip)**
- **Rubber bush**
- **Saran tube standpipe 0.5” OD**

He combined it in a borehole with

- **Filter sand around the porous point**
- **Bentonite seal to measure a specific zone**

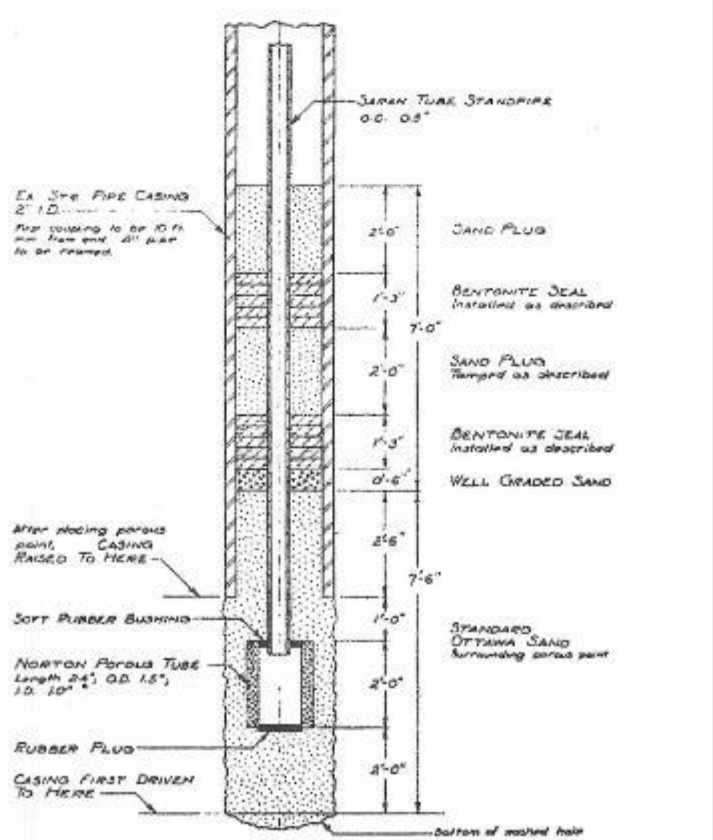

Fig. 19.—Diagram, in Distorted Scale, Showing Details of Piezometer Installation.

“The system which became a product”

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<u>Over 90 years</u> later things have changed but not so much!

We have finally <u>defined</u> a "piezometer" in an ISO standard

2020 ISO 18674-4 Measurement of pore water pressure:

Piezometers

- **Full definition of terms (no ambiguity)**
- **Difference between piezometer types (closed or open)**
- **Explaining the different measuring devices (hardware)**
- **Defining of all components (no ambiguity)**
- **Comparing performance (which best to use)**
- **Installation construction (guidance & quality control)**
- **Installation documentation (quality control)**

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The measurand

Piezometers measure <u>pressure</u> - nothing else

Expressed as:

SI Units - Pascal (kPa, MPa)

Imperial units - Pounds per square inch (PSI)

Used to measure either:-

- **i) Pore water pressure (positive & negative)**
- **ii) Piezometric level (head of water)**

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The measurand

- **PWP =** **pressure of the water in the voids of the ground or a fill**

For rocks, the associated term is joint pressure

- **Controls the strength & stability of soils**

  - Terzaghi's Effective stress ($\sigma' = \sigma - u$)

- **Added load (surcharge) = increase in pore pressure which can lead to "excess pore pressure" & instability**

- **Dissipation – dependent on permeability (cohesive slow)**

To allow the Engineer to:-

- **Calculate effective stress in soils**
- **Monitor changes in effective stress within soils**
- **Avoid excess pore water pressure**
- **Control stability**
- **Control heave**
- **Calculate active & passive loads**
- **Determine uplift pressures**
- **Determine effectiveness of dewatering**
- **Measure seepage rates (piping)**

The soil mechanics part of piezometers

From the measurand

APPLICATION	ELEMENT	MEASURAND	COMPUTATION
Dam	Foundation	Pressure	Uplift pressure Shear strength Seepage
	Embankment	Pressure	Pore pressure Shear strength Permeability
	Abutments	Pressure	Pore pressure Shear strength Groundwater level
	Reservoir	Pressure	Water level
Deep excavation	Base	Pressure	Uplift pressure Pore pressure
	Behind retaining wall	Pressure	Groundwater level Active pressure

From the measurand

APPLICATION	ELEMENT	MEASURAND	COMPUTATION
	Cuttings	Pressure	Pore pressure Shear strength Load
Ground Improvement & Stabilisation	Embankments	Pressure	Pore pressure Shear strength Load
	Cuttings	Pressure	Pore pressure Shear strength Load
Deep excavation	Drains	Pressure	Pore pressure
	Surcharging	Pressure	Pore pressure Shear strength

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From the measurand

APPLICATION	ELEMENT	MEASURAND	COMPUTATION
Dewatering	Groundwater	Pressure	Groundwater level
Hydrogeology	Groundwater	Pressure	Groundwater level
Underground structures	Foundation	Pressure	Pore pressure Uplift pressure
	Surrounding strata	Pressure	Pore pressure Load
Tunnel	Groundwater	Pressure	Groundwater level
	Surrounding strata	Pressure	Pore pressure Load

System or hardware?

Ques: What is the difference between a piezometer (as you probably know it) or a pressure transducer?

Ans 1: A piezometer is a <u>system</u>

Ans 2: A piezometer is a <u>sensor/instrument</u> = measuring device/component

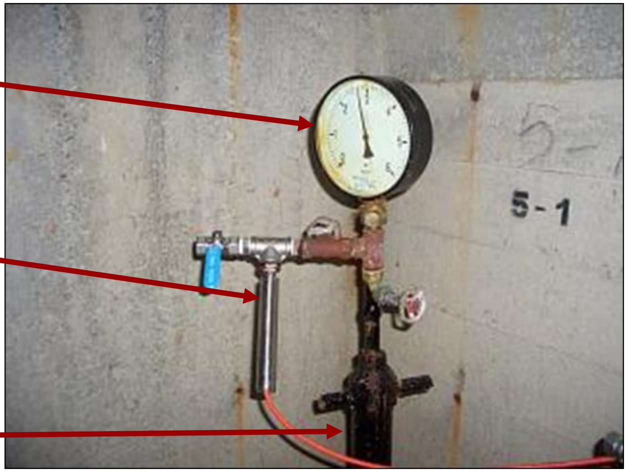
Ans 3: A piezometer (sensor) is typically buried in the ground & non retrievable

Ans 4: A pressure transducer is typically retrievable and integrated

System or hardware?

However a piezometer is a system <u>and</u> an instrument – confused?

1. **Bourdon gauge (measuring device)**
2. **VW pressure transducer (measuring device)**
3. **Vertical pipe (to access pressure)**



They are all are individual components but combined = <u>Piezometer system</u>

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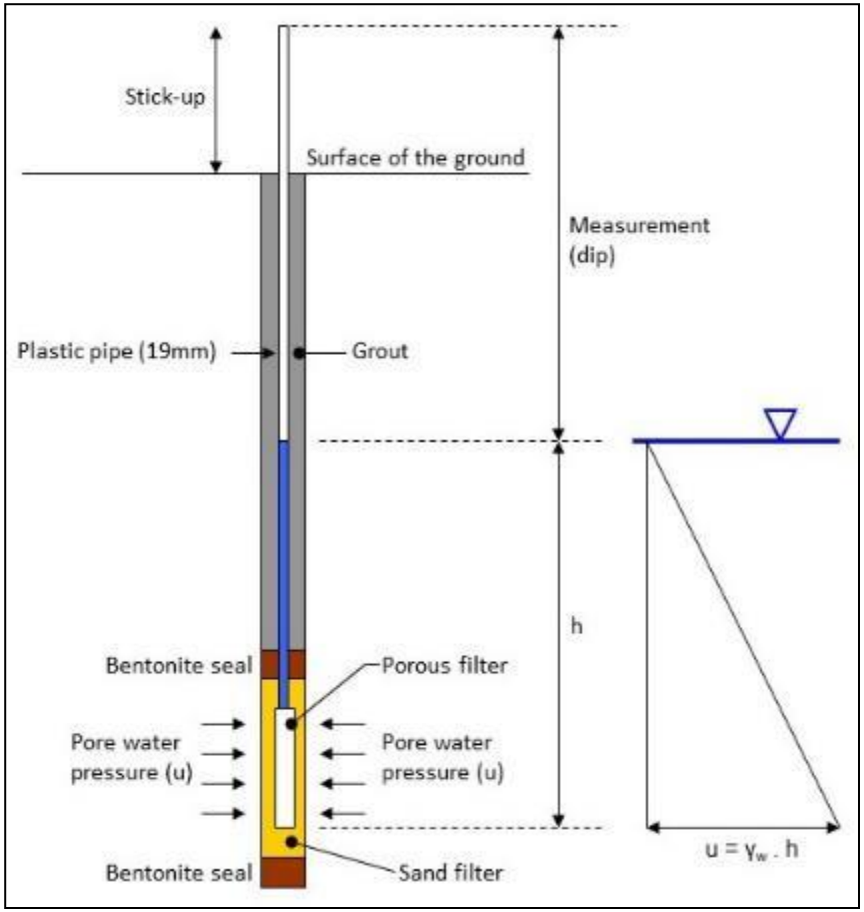
System types

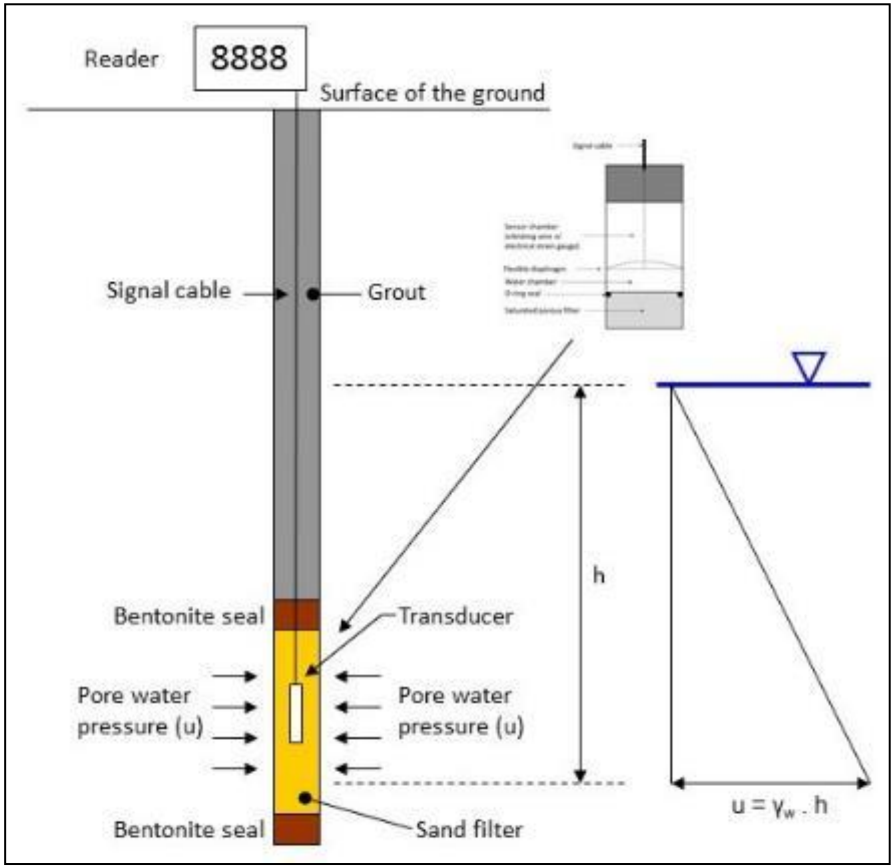
Open piezometer



Water is in direct contact with the atmosphere

- **Piezometer pipe used to access PWP/water level**
- **Measuring instrument/device**
  - **i) Water level meter**
  - **ii) Pressure transducer within pipe**

Closed piezometer



Water is not in direct contact with the atmosphere

- **The measuring device is typically a diaphragm transducer buried within the soil**
- **The deflection of the diaphragm is a function of the pore pressure**
- **The deflection is measured by means of electric, pneumatic, fibre optic or hydraulic piezometers**

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Why needed?

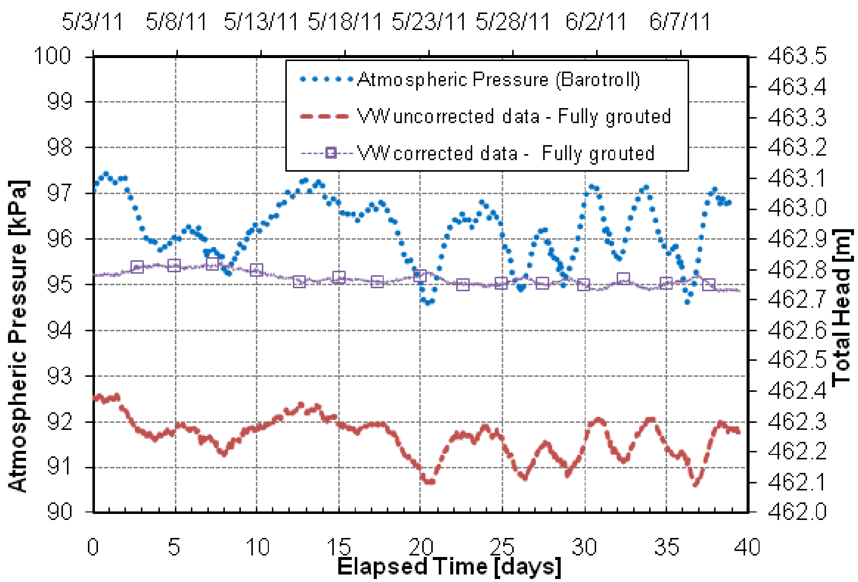
Barometric compensation

- **A standard VW piezometer is sealed during manufacture**
- **Variations in barometric pressure act only on the exposed side of the diaphragm**
- **The effects can be significant on low pressure piezometers**

For example, a piezometer subjected to a 10 millibar change in barometric pressure will modify the reading by 0.1m H_2O, even though the actual water pressure head remains the same.

Barometric compensation

When needed?



If in doubt - measure it

- **Open piezometers?**
- **Shallow closed piezometers?**
- **Closed piezometers?**
- **Research has found that barometric pressure affects are greater than originally thought**
- **F-G-M needs compensation for accurate measurement**
- **Correlation with atmospheric changes is a good check for correct sensor functionality even if data not understood**

Barometric pressure can be obtained by:-

- Barometer within the data logger
- Weather station on site
- Local weather station
- Internet

Vented VW piezometers are available but have maintenance issues to ensure condensation/dust does not block the vent tube

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Barometric compensation

Vented VW piezometer

(maintenance needed)

In-built barometer

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Which system?

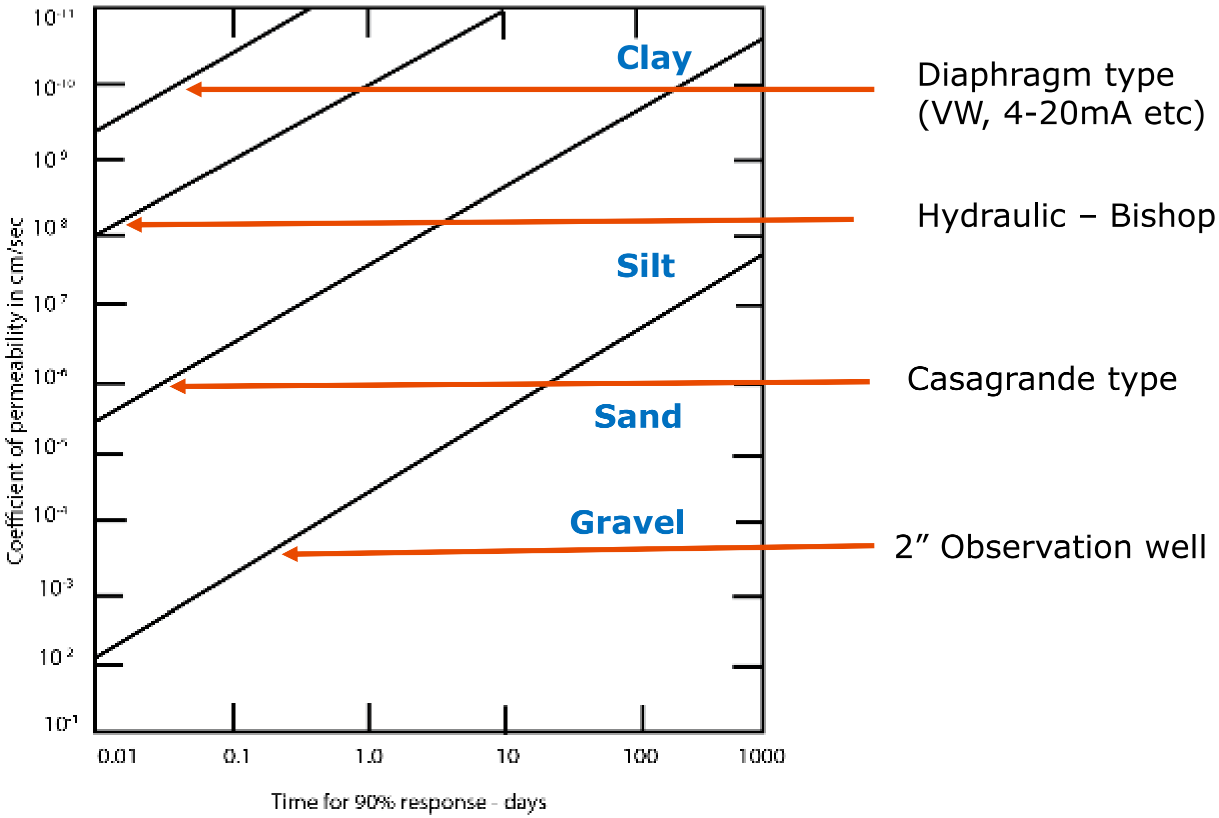
Choosing the type of piezometer depends on:

- **Manual or automatic readings**
- **Performance (range, resolution, accuracy, precision)**
- **Cable lengths**
- **Duration of the measurements**
- **Engineer’s preference**

Hydrodynamic Lag

Which system?

Also known as Response Time



Time span between a change of pore water pressure in the ground and the associated change in the measurement.

Primarily a function of:-

- **Piezometer geometry**
- **Ground permeability**
- **Installation type**
- **Not a function of the sensor**

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Which sensor & range?

1. Pressure range selection

Sensors should be chosen based on:-

- **The range of pressure expected**
- **Avoiding over pressure especially during grouting**

2. Pressure considerations

For the most accurate readings:-

- **The lowest appropriate range that can still withstand the pressure during installation (including any grouting)**

The Engineers responsibility

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Pressure solutions

- **When the pressure is known, select the range so that it doesn't exceed 75% of the maximum pressure (including during grouting)**
- **When the expected pressure is unknown it can be approximated based on the installation depth**
- **Monitor pressure during installation and grouting**

The Engineers responsibility

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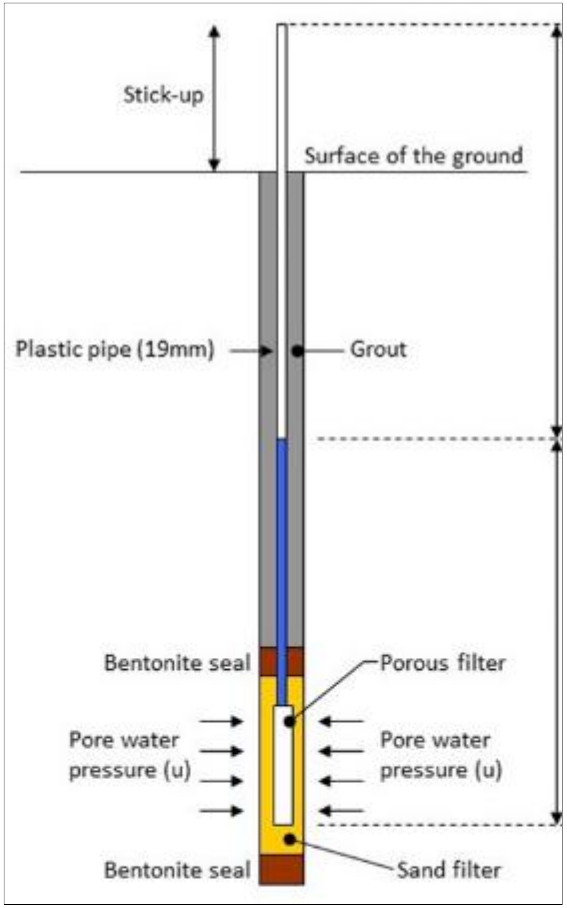
System or hardware?

Instrument models typically defined by manufacturers:-

- **Standpipe/Casagrande piezometers**
- **Vibrating wire piezometers**
- **Strain gauge piezometers**
- **Pneumatic piezometers**
- **Hydraulic piezometers**
- **Flushable hydraulic piezometers (negative pressure)**
- **Fibre-optic piezometers**

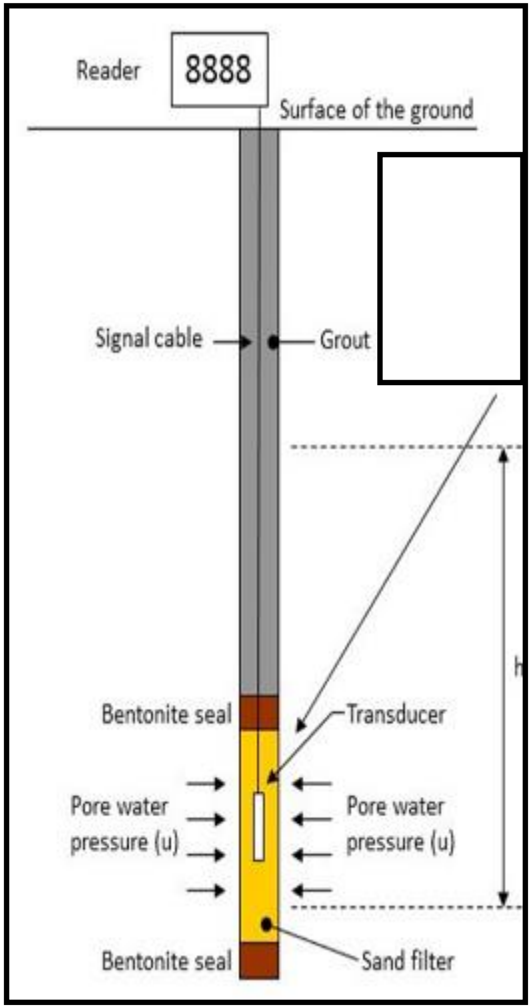
Standpipe piezometers (Casagrande)

Product hardware



Vibrating wire piezometers

Product hardware



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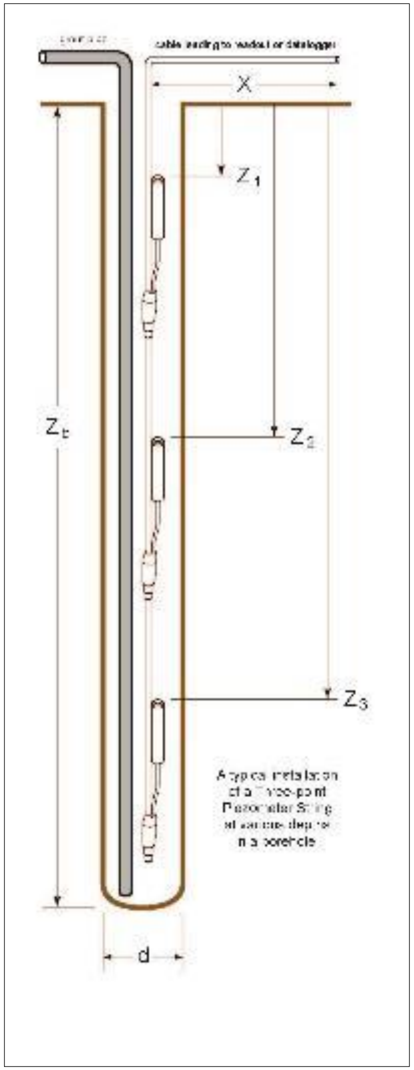
Multi-point VW piezometers (F-G-M)

Product hardware



Multi-point piezometers comprise of several piezometers connected together on a common cable which allows multiple piezometers to be simply and reliably installed in a single borehole.

The piezometer string and grout pipe are placed in the borehole and cement-Bentonite grout is pumped until the borehole is filled. This is known as the “fully grouted method” and is gaining popularity for VW piezometer installation.

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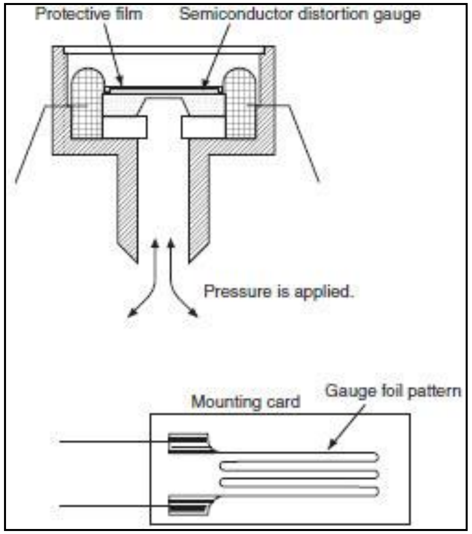
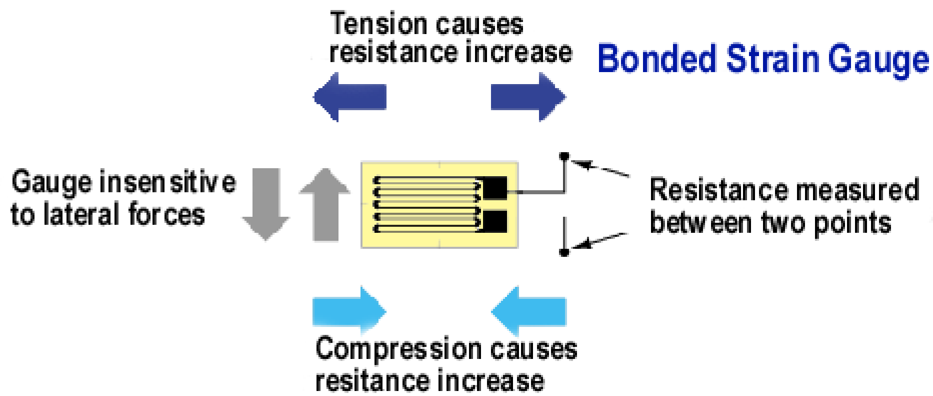
Strain gauge piezometers

Product hardware





- Typically comprising of a series of Foil Strain Gauges fixed to the internal side of a diaphragm

- Pressure applied to the diaphragm results in a resistance change of the Wheatstone Bridge in the strain gauge arrays

- This unbalance produces an output signal which is directly proportional to the applied pressure

- An electronic board converts this signal into 4-20 mA

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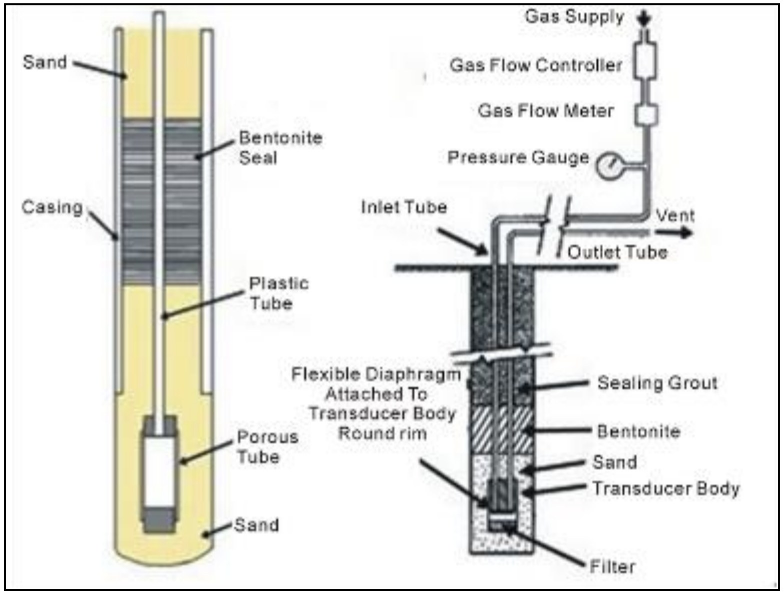
Pneumatic piezometers

Product hardware



- **The piezometer tip contains a flexible diaphragm/valve**
- **Water pressure acts on one side of the diaphragm and a gas pressure fed from the readout acts on the other**
- **By using gas pressure from the readout the gas pressure is made to equal the water pressure, and the readout shows the reading on its pressure gauge**

Use Flow or Non-flow method

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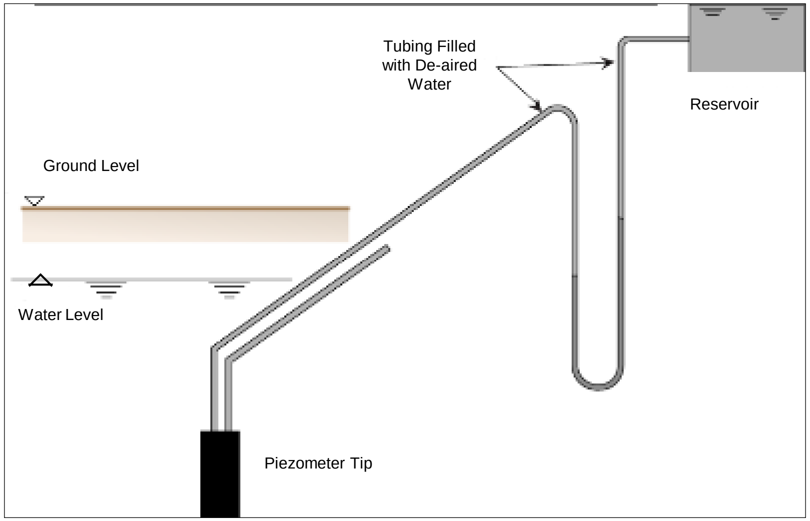
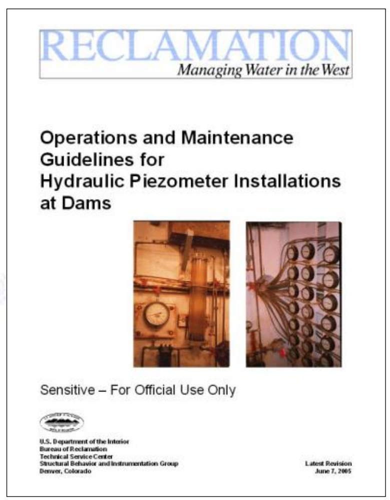
Hydraulic piezometers





RECLAMATION
Managing Water in the West

Operations and Maintenance Guidelines for Hydraulic Piezometer Installations at Dams

Sensitive – For Official Use Only

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Structural Behavior and Instrumentation Group
Denver, Colorado

Latest Revision
June 7, 2005

Product hardware

Consists of

- **A porous ceramic piezometer tip**
- **Twin tubing filled with de-aired water**
- **The pore water pressure at the tip is transmitted through the filter element to the water in the closed system.**
- **Readout – either a Bourdon gauge, U-tube manometer or pressure transducer**

Whilst not used very much nowadays there are many thousands installed worldwide so you need to be aware of their existence (see HAE filters later)

Cable (VW)

Product hardware




- **Typically 22 AWG (4 x 0.34 mm² conductors)**
- **PVC, PUR or LSZH (low smoke zero halogen) sheath**
- **Heavy Duty (flexible)**
- **SWA (Steel Wire Armoured)**

Filter tip type (LAE/HAE)

LAE (low air entry) filter

Filter tip (typically sintered stainless steel) with comparatively large pores (~50 micron) giving a lower resistance to the passage of air readily allowing the passage of both air and water. This often causes confusion as LAE means **'low RESISTANCE to air entry'.**

HAE (high air entry) filter

Filter tip (typically ceramic) with comparatively small pores (~1-3 micron) giving a higher resistance to the passage of air than to the passage of water; the use of HAE filters is required in unsaturated soils, or when negative pore water pressures are to be measured. This often causes confusion as HAE means "**high RESISTANCE to air entry**".

For further explanation see page 141, Chapter 9 in the "Red Book"

Mis-information occurs in literature and included in specifications

1μ ≠ 1 bar = 3 bar & very difficult to saturate

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Filter type (LAE/HAE)

The history

HAE filters came into being ~1955 because of the need to monitor pore <u>water (not gas)</u> pressures in the cores of clay core embankment dams and were originally used with hydraulic piezometers (Bishop).

Alan Bishop at Imperial College recognized the need for:

1. Intimate contact between filter and soil
2. COMPLETE saturation of the filter
3. Best possible de-airing of liquid in tubing
4. Ability to flush air/gas that passes through the filter by diffusion
5. Best possible tubing,to minimize air/gas entering

USING HAE FILTERS IN THE FULLY GROUTED METHOD CAN BE PROBLEMATICAL.

SHOULD THEY EVER BE USED WITH DIAPHRAGM PIEZOMETERS?

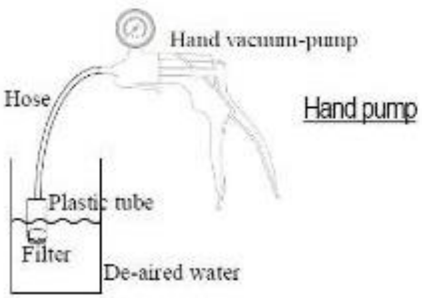
(MORE INFORMATION IN FULLY GROUTED SECTION & UNEXPECTED DATA)

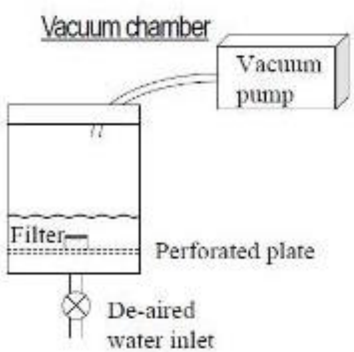
Filter type HAE

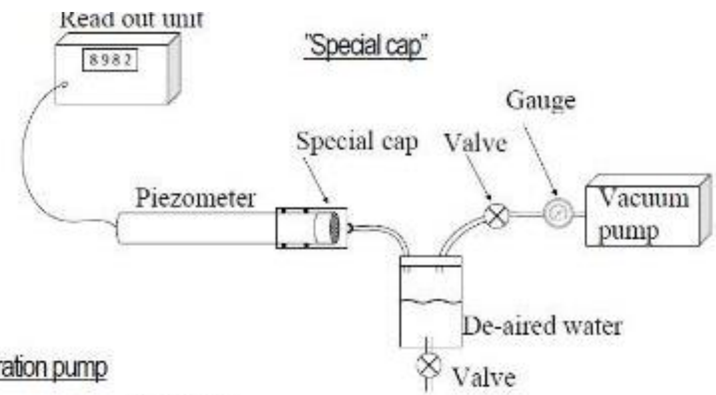
Saturation methods

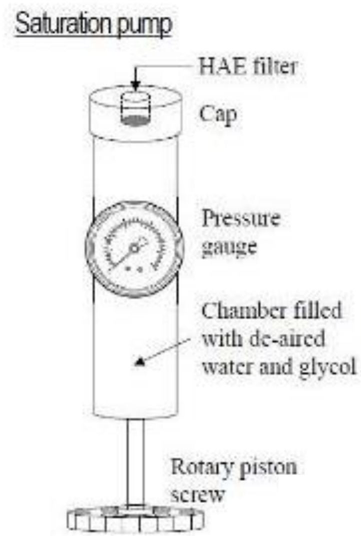
Boiling

- 5 different saturation methods for HAE filters







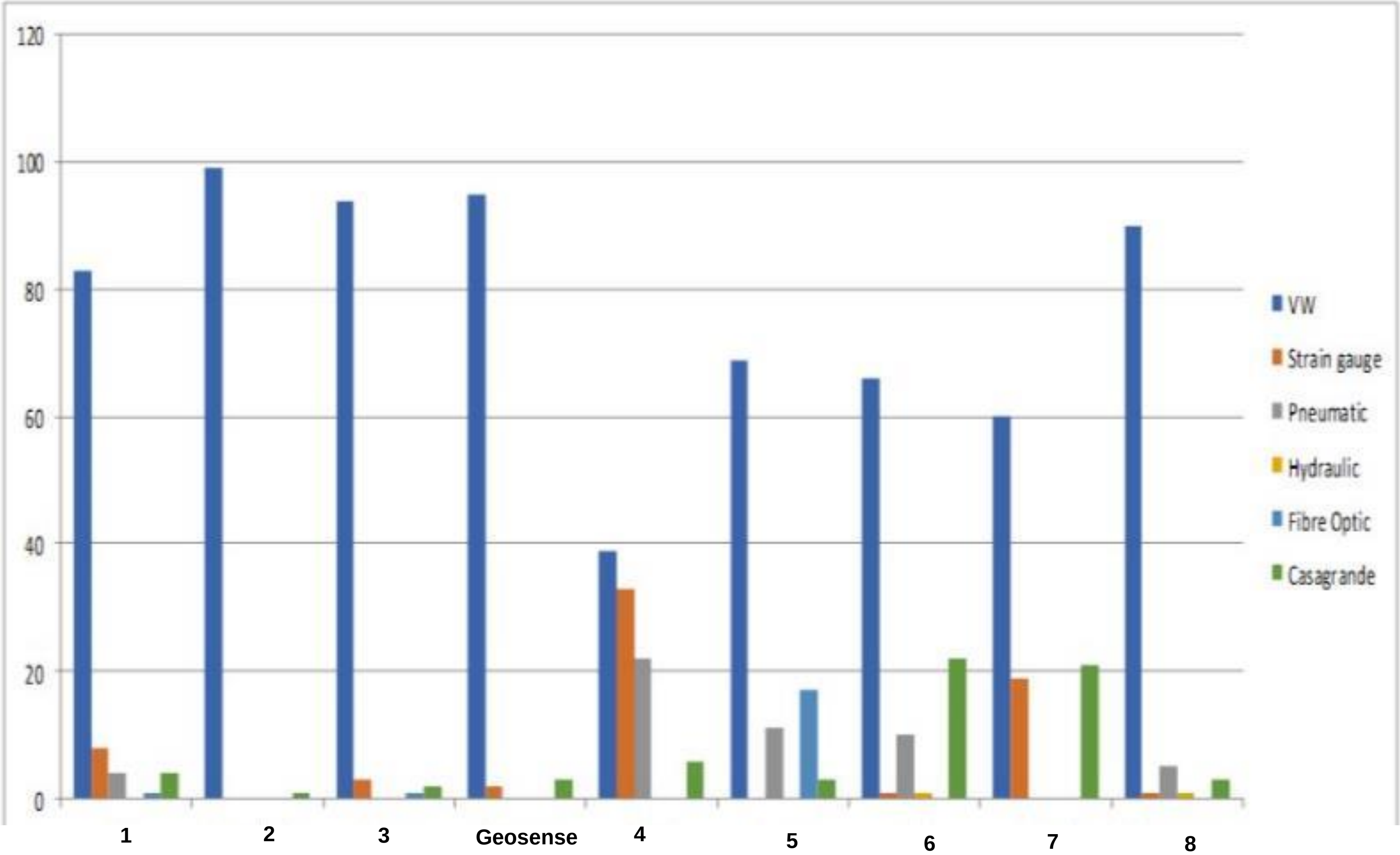


Portable readouts (Manual)

Stand-alone data loggers (Automatic)

Large multi-channel data loggers (Automatic)

VW most used technology



Percentage of different types of piezometers made by worldwide manufacturers

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Why vibrating wire?

- **Proven rugged, reliable & simple technology**

  (particularly suitable for construction environments)
- **Cable (long cable lengths, easily spliced/repaired)**
- **Wide range of models to suit applications**

  (Standard, Heavy Duty, Drive-in, Miniature, High Temperature)
- **Easy to troubleshoot & data log**
- **Excellent long term stability**

  (No drift from calibration or site zero pressure reading)
- **Relatively low cost**

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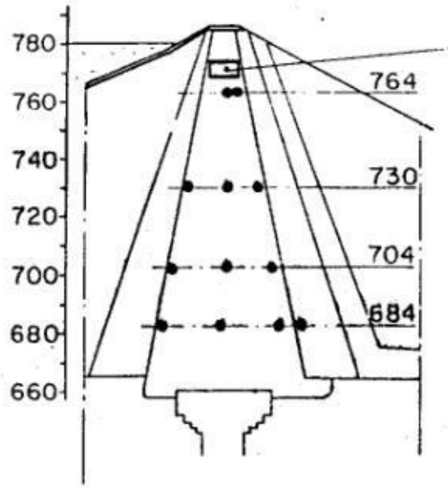
Long term stability

Why vibrating wire?

SECTION ALONG DAM AXIS

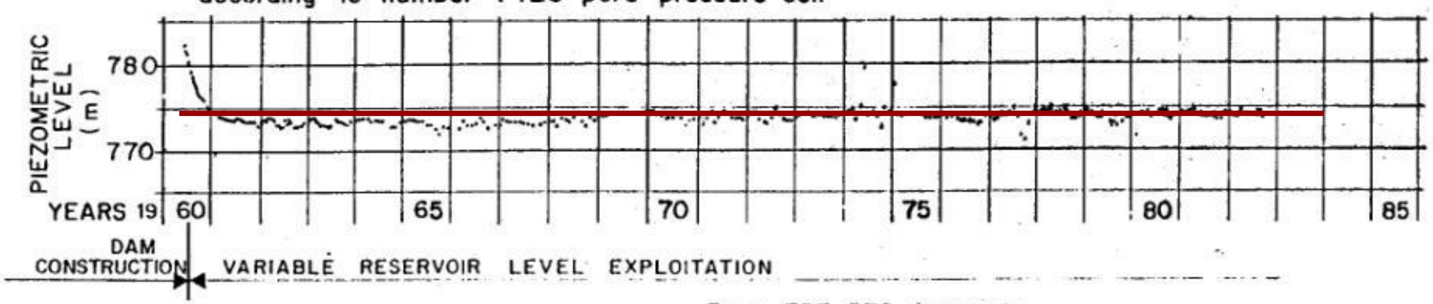
FIG 5



Symposium on Reliability of Geotechnical Instrumentation NRC/TRB/January 1985

"Some facts about long-term stability of VW instruments – Bordes & DeBreuille

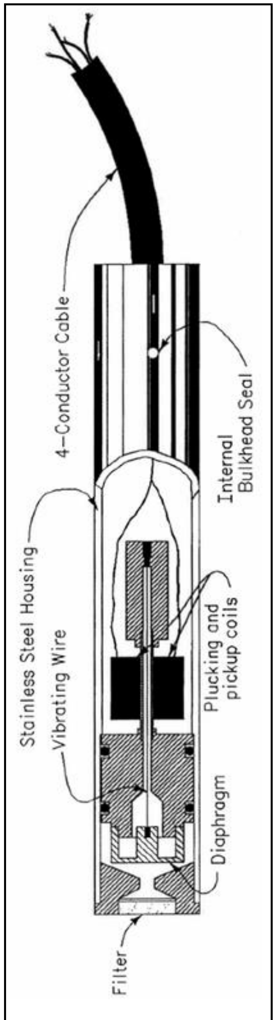
Piezometric level corresponding to an identical computed reservoir level reading, according to number T420 pore pressure cell



From EDF-DTG documents

Since vibrating wire instruments represent the majority of "piezometers" installed we are now going to concentrate on this technology.

How does VW work



- **A VW piezometer comprises of a tensioned wire with a magnetic coil located next to it (electric guitar)**
- **An excitation pulse from the readout makes it vibrate at its natural frequency**
- **As the diaphragm deflects under pressure the wire changes length thus changing the frequency**
- **Each instrument is <u>calibrated</u> for various frequencies against known pressures**

Signal output

The signal generated by a vibrating wire piezometer is a <u>frequency rather than voltage or current</u> (making it suitable for very long cable length ~5km)

Frequency - the unit of which is **Hertz (Hz)**

Linear Digits (B unit)

The frequency is not linear to the applied change in length of the wire. To overcome this the frequency is squared, thereby rendering it linear, but a large number. To reduce its size, it is divided by 1000.

The expression $\mathbf{Hz^2 \times 10^{-3}}$ is the most commonly adopted as a 'linear' output often referred to as **B Units**

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Calibration sheet

- **Individual sensor calibration certificates**
- **Linear versus polynomial accuracy**

Applied pressure		**Readings [digit]**			**Calculated Pressure**		**Error % FS (Non – linearity)**	
psi	kPa	1 up	1 down	avg.[digit]	lin.[kPa]	polyn.[kPa]	linear	polynomial
0.000	0.000	9532.1	9531.4	9531.8	-4.29	0.45	-0.06%	0.01%
200.145	1380.000	8802.7	8804.8	8803.8	1379.96	1379.01	0.00%	-0.01%
400.290	2760.000	8075.4	8076.1	8075.7	2764.16	2760.37	0.06%	0.01%
600.435	4140.000	7348.8	7351.1	7350.0	4144.13	4140.36	0.06%	0.01%
800.580	5520.000	6624.8	6627.0	6625.9	5520.82	5519.90	0.01%	0.00%
1000.725	6900.000	5901.7	5904.4	5903.1	6895.17	6899.91	-0.07%	0.00%

Note: Digits are $Hz^2 \times 10^{-3}$ units

More information about this in data reduction section

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Engineering Units

Calibration factors

Linear factor (k)

kPa per digit	psi per digit	mH_2O per digit
-0.851619245	-0.123513	-0.086841

Polynomial factors

	kPa	psi	mH_2O
A	3.70856E-07	5.37862E-08	3.7817E-08
B	-0.857125321	-0.124311	-0.087402
C	*	*	*

Thermal factor (T)

kPa per °C	psi per °C	mH_2O per °C
-0.286768474	-0.041590787	-0.029242

* Determined on site

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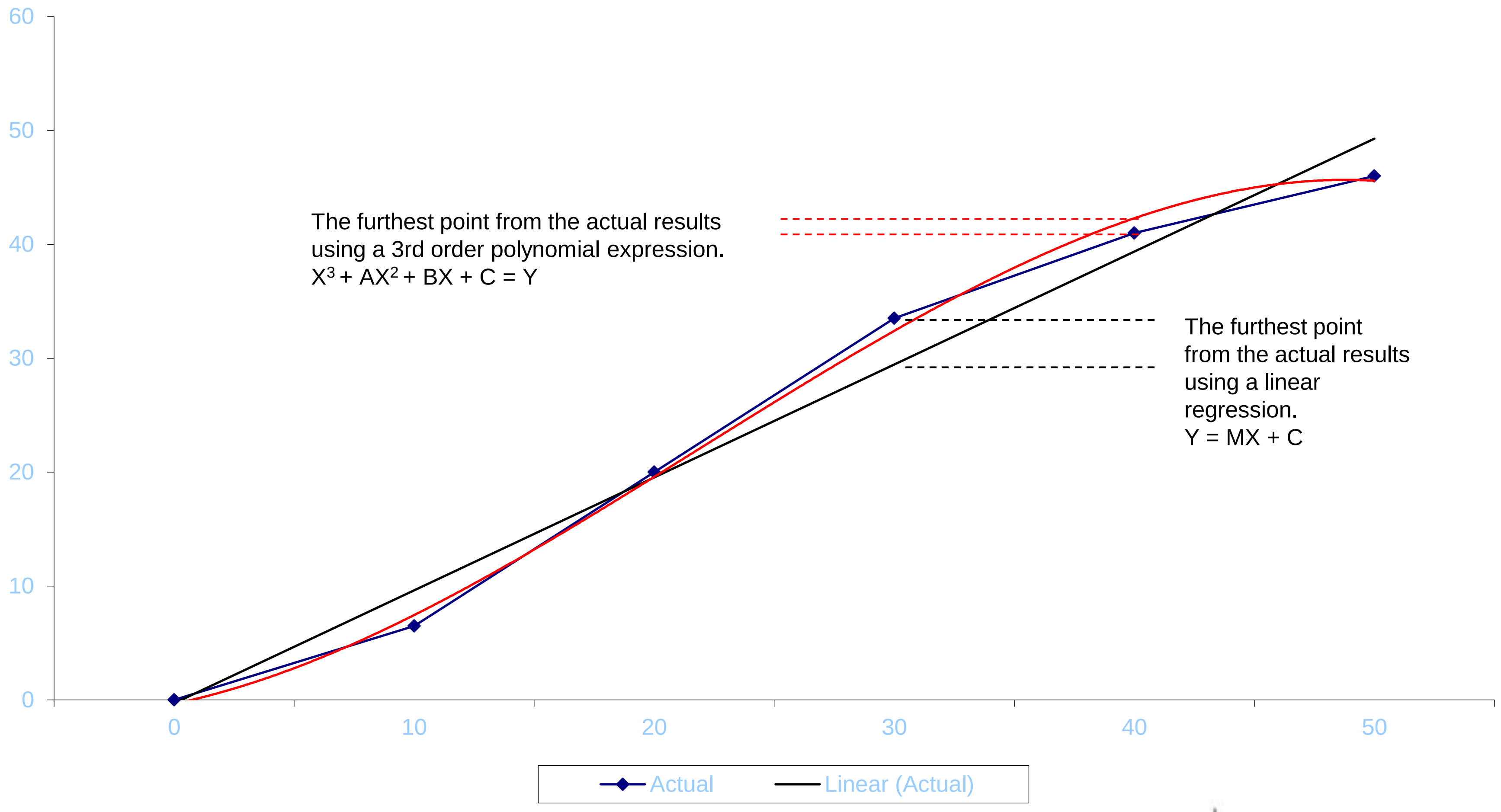
The mathematics

Polynomial regression



Specification

DESCRIPTION	PRESSURE RANGE	OVER PRESSURE RANGE	RESOLUTION	ACCURACY	NON LINEARITY	CALIBRATION TEMP RANGE
Standard pressure	**-100, 350, 500, 700 kPa 1, 2, 3.5 MPa**	**1.5**	**0.025% FS**	**± 0.1% FS**	**<0.5% FS**	**-20 to + 80 °C**
Low pressure	**70, 173 kPa**	**1.5**	**0.025% FS**	**± 0.1% FS**	**<0.5% FS**	**-20 to + 80 °C**
High pressure	**-100, 350, 500, 700 kPa 1, 2, 3.5, 5, 7 10, 20 MPa**	**1.5**	**0.025% FS**	**± 0.1% FS**	**<0.5% FS**	**-20 to + 80 °C**

Specification

1. Pressure range
The maximum pressure that the piezometer is designed for

2. Over range
The maximum pressure that may be applied continuously without causing damage and maintaining set point (zero) repeatability. **Sensor should never be operating in this range.**

3.Resolution
The smallest increment that is capable of being read from an instrument. Resolution is normally described as a percentage of full scale (%FS). If the range is 25mm and the smallest readable amount is 0.00625mm; then (0.00625/25) = 0.00025%

Or another easy way to describe this is the difference of a ruler marked in centimetres and one marked in in centimetres and millimetres. The resolution of the first one is one centimetre. The resolution of the second one is one millimetre.

NOTE: RESOLUTION IS READOUT DEPENDENT

GEOSENSE

Specification

4. Accuracy

The degree of closeness of the measurement of a quantity to that quantity's actual (true) value. It is measured for instruments by means of calibration against another instrument whose accuracy is verified and traceable to an acceptable international standard e.g. UKAS.

Within the geotechnical and structural monitoring industry it is standard practice to define accuracy by both linear and Polynomial factors, the latter of which is determined mathematically by a least squares regression analysis.

Typically accuracy is expressed as the following:-

± % FS - means that the measured value is within ± % FS of the full scale

Specification

5. Non-linearity (see polynomial slide)
To make sensors easier to use we can characterise their behaviour as **linear** even though their output is **not exactly linear**. Non-linearity is the percentage of variation from the measured value of the device to the calculated linear value with respect to the full scale of the sensor. This is often specified as linearity on datasheets but **non-linearity and linearity can be taken as the same thing**. It is often termed linearity as it is the linearity of the sensor that we are trying to ascertain but the value given is actually the % of non-linearity.

6. Calibration range
During calibration VW piezometers are typically calibrated over a temperature range of –20ºC to + 80ºC to prove their function over a wide temperature range and provide the input data for any temperature compensation that may be required.

7. Operating range
As under normal conditions they are monitoring water, their practical operating temperature range will above 0ºC.

GEOSENSE

Key fact - Zero pressure

- **At zero pressure VW <u>reads</u> a frequency value**
- **All subsequent readings are relative to this**
- **Taken prior to installation (stabilised condition)**

NOTE: MOST COMMON ERROR MADE

i.e. NOT TAKEN

IS THAT A PROBLEM – YES IT IS

(see later in data reduction)

GEOSENSE

Key fact - Site zero

Site Zero Reading

Key fact – VW read frequency at zero pressure

Geosense elevation 581ft (177m) ASL

AP ~ 1014 mbar at SL

Barometric pressures change with altitude by approximately 1.2kPa per 100 metres

Calibrations at room temp 20°C

(see later in data reduction)

GEOSENSE

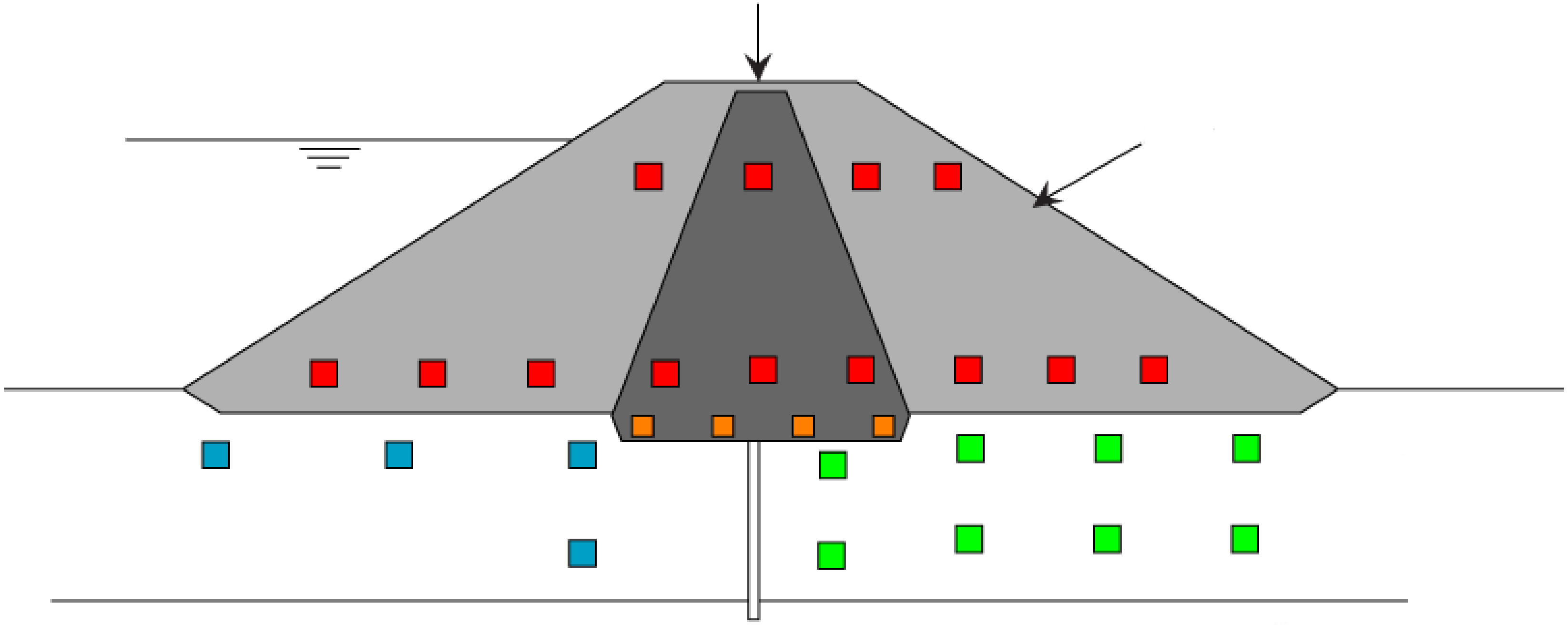
1. Taking "Zero pressure" reading
2. Compare with calibration sheet

The following slides illustrate some typical applications for piezometers

What, where, why?

Earth/rock fill dams

Used mainly to control fill placement, monitor pore water pressures, up lift pressures and to indicate seepage rates



Earth/rock fill dams

Where and what we monitor

Dam body
Monitor pore pressures during and after construction

Control fill placement in core

Monitor integrity of the core

Upstream foundation
Monitor up-lift pressures

Downstream foundation
Monitor up-lift pressures
Monitor pore pressure

Contact zone
Monitor contact pore pressures

Why we monitor

Excess pore pressure generated whilst placing fill can cause instability within the embankment. Measurements can be used to control the filing operations so as to avoid potential failure

For long term safety monitoring of pore pressures within the embankment

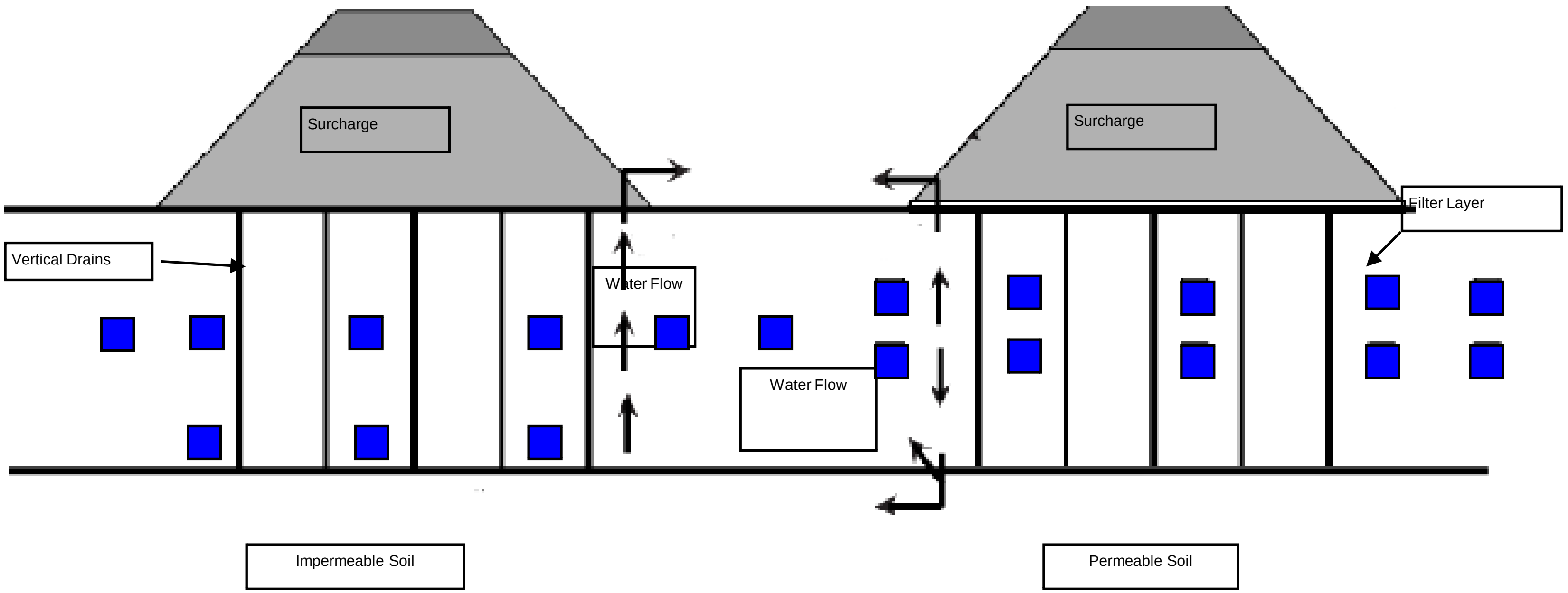
To determine changes in the effective stress within the foundation which affects stability, during and after construction

To determine changes in the effective stress within the foundation which affects stability, during and after construction

Changes in pore pressure within the foundation can indicate a failure of the cut-off wall

Excess pore pressure at the contact zone can cause both leakage and instability

Embankment constructed for consolidation (surcharge)



Embankment constructed for consolidation (surcharge)

Where and what we monitor

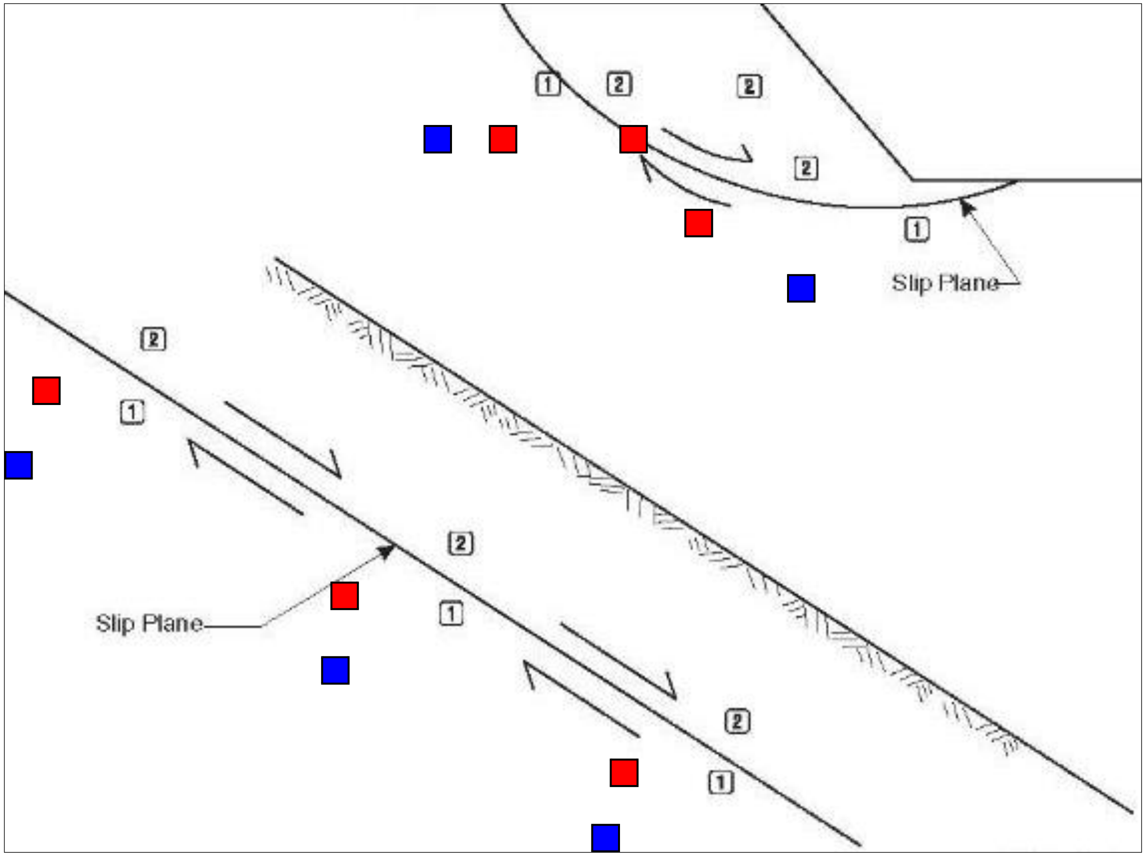
- **Embankment sub-soil**

  Pore-water pressure

Why we monitor

- Excess pore pressure generated whilst placing fill can cause instability within the embankment sub-strata.
- Measurements can be used to control the filing operations so as to avoid potential failure of the sub-strata and to monitor the effectiveness of the drainage system.

Slope stability



Slope stability

- **Increased pore pressure is main mechanism of failure**
- **Reduces shear strength**
- **Monitoring provides indication of changes in slope instability**

Where and what we monitor

Below potential shear zone

Monitor pore-water pressure

Above potential shear zone

Monitor groundwater level

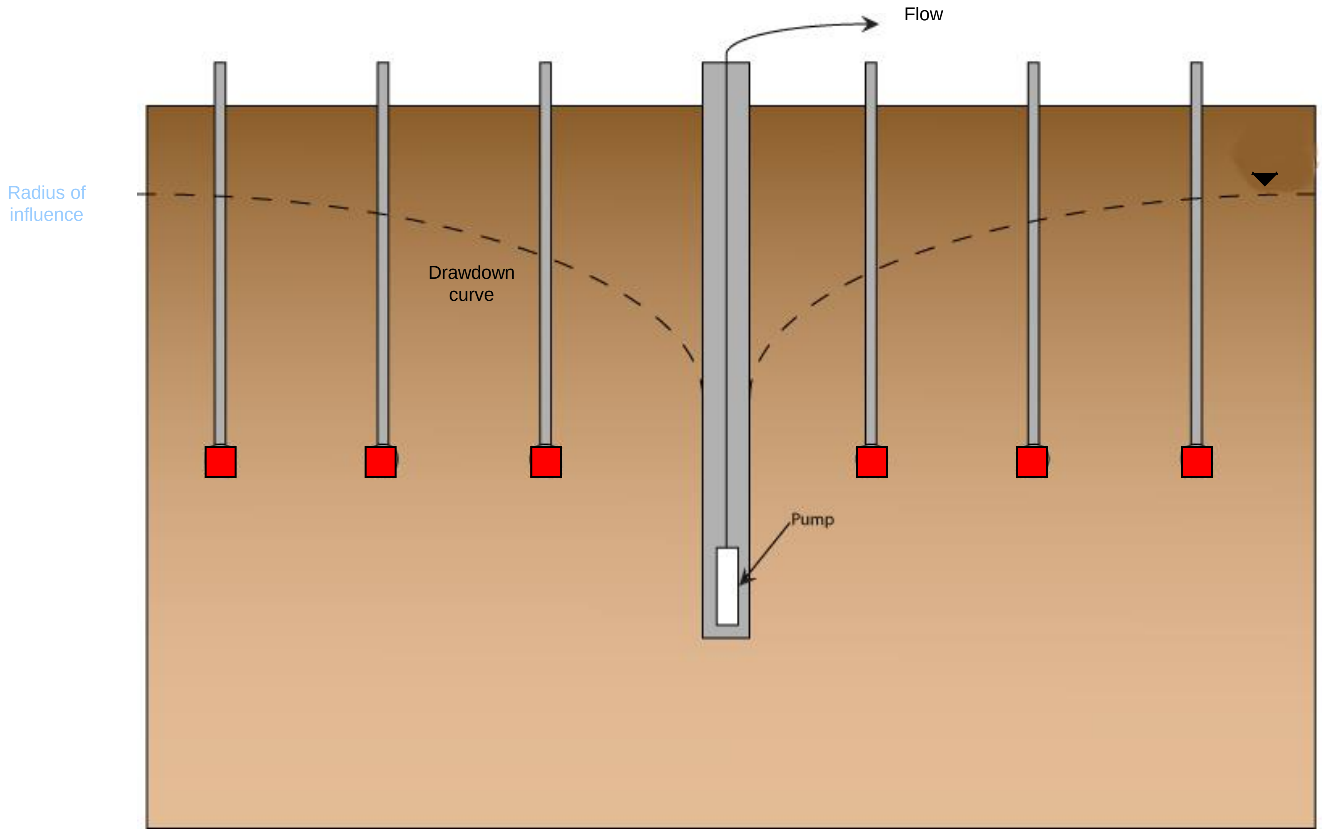
Why we monitor

To allow calculation of shear strength

Increase in pore-water pressure decreases the shear strength of the soil. A reduction in shear strength can lead to failure of a slope.

Groundwater levels add to the mass of the soil and if this becomes too high it can overcome the shear strength of the soil and lead to failure of the slope.

Pumping tests



- Excavation is to be carried out below the water table in non-cohesive soils
- Dewatering ensures stability of the excavation

Pumping tests

- **Determine pumping rate required to dewater the soil**
- **Measure the flow and drawdown to identify the radius of influence which is used to design a dewatering system**
- **Can be used to determine in-situ permeability**

Where and what we monitor

- **Monitor groundwater levels below in an array around the pumping well**

Why we monitor

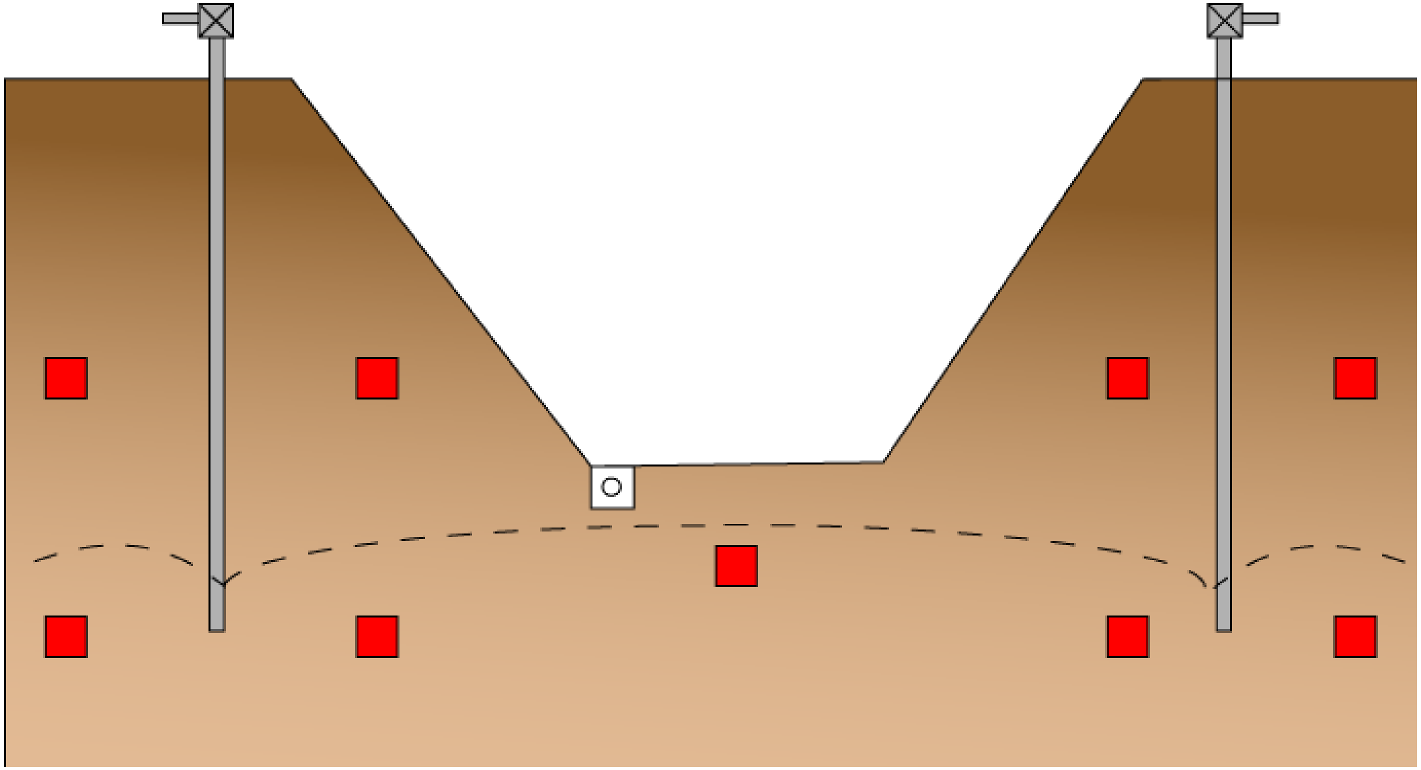
If the volume of water pumped out of the well is higher than the recharge value of the soil then the soil will become dewatered.

The point at which no drawdown occurs is known as the radius of Influence. Knowing this radius of influence and the shape of the drawdown curve enables a dewatering scheme to be accurately designed.

Data can also be used to determine the in-situ permeability.

GEOSENSE

Dewatering systems



Dewatering

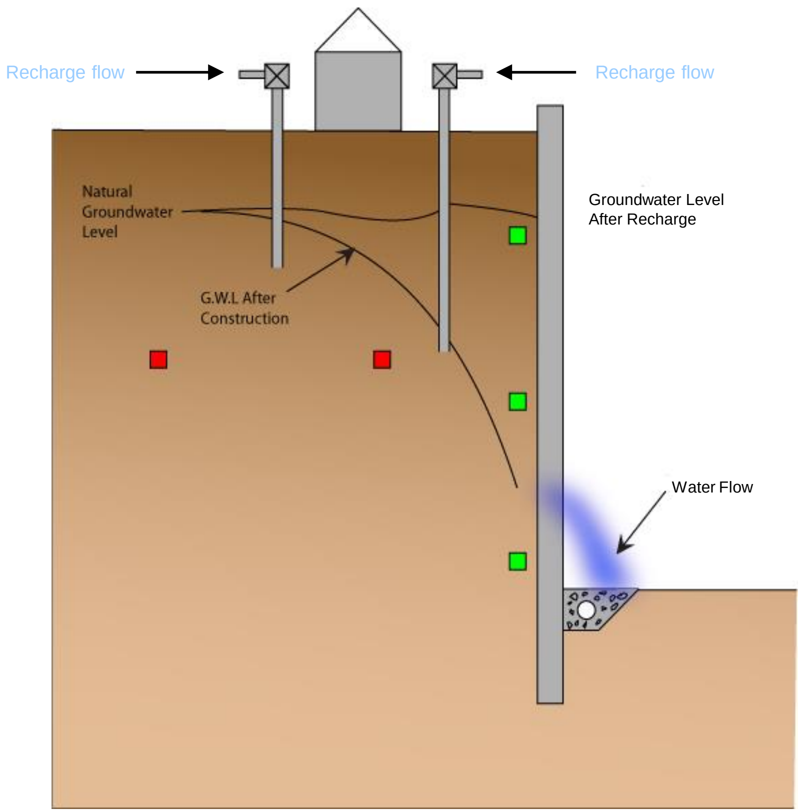
Where and what we monitor

- Monitor groundwater levels below, in and around the excavation and the wells

Why we monitor

In order to carry out excavation in saturated non-cohesive soils the groundwater level must be reduced to a level that is below the intended excavation level .

Groundwater re-charge



- **Subsequent consolidation of the soil as the water is removed can cause damage**
- **To minimise settlement, water from the dewatering wells is pumped back into the soil (recharge)**
- **Monitor groundwater levels and determine the effectiveness of recharge**
- **Can also be used to monitor the passive loads being applied to the wall.**

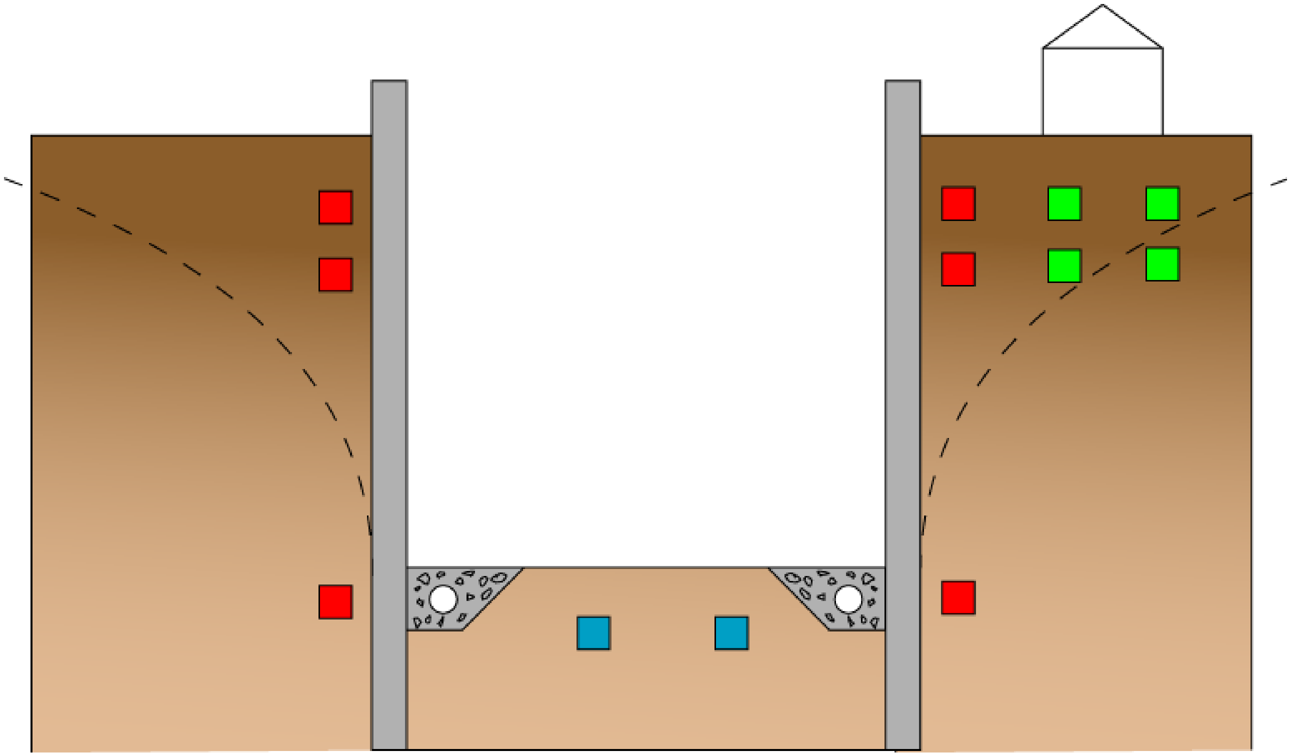
GEOSENSE

Groundwatrer re-charge

Where and what we monitor	Why we monitor
Monitor groundwater levels around the excavation	If the recharge rate is too high the groundwater level will not be low enough to allow stable excavation. If too low, settlement may occur.
Monitor groundwater level on the outside of the wall	If the groundwater level is too high then the loading on the retaining structure may increase to an unsafe level.

GEOSENSE

Deep excavation



Deep excavation

Where and what we monitor

- **Under the base of the excavation**

  Pore-water pressure and/or groundwater level

- **Behind the wall**

  Pore-water pressure and/or groundwater level

- **The outside of the wall & underneath adjacent buildings**

  Groundwater level

Why we monitor

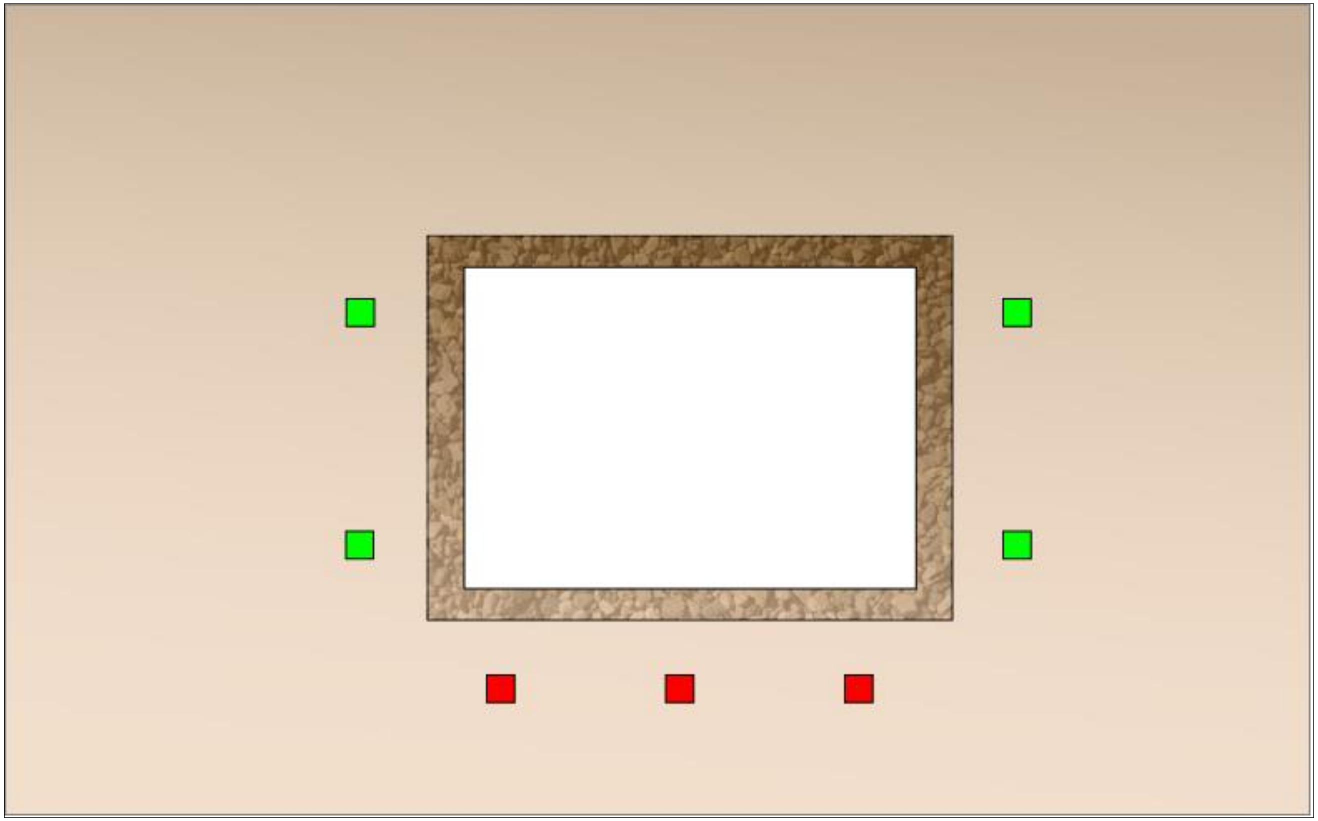
If the pore-water pressure is too high in the base of the excavation heave can occur causing instability of the excavation

Pore-water pressure is used to calculate active pressure behind the wall and then the subsequent load in order to ensure its stability as excavation progresses

Groundwater level is used to confirm the effectiveness of the dewatering system (where applicable) and the predict settlement underneath adjacent structures

GEOSENSE

Underground structures



Underground structures

Where and what we monitor

Beneath the structure

Groundwater pressure

Around the structure

Groundwater pressure

Why we monitor

To determine uplift pressures to ensure the stability of the buried structure

To determine pressures acting on the buried structure to determine any joint movement and structural integrity

GEOSENSE

Now that we have seen the applications it is time to look at the various considerations during installation

Pre-Installation

1. Storage

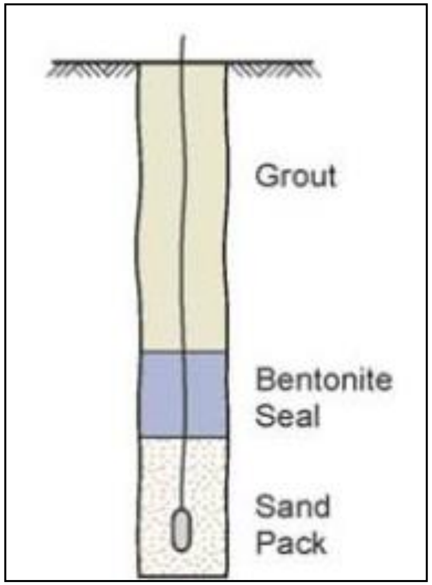
- Store in an environment that is protected from direct sunlight
- Dry environment to prevent moisture migrating along exposed conductors
- Free from rodents as they have been known to damage connecting cables

2. Installation key considerations

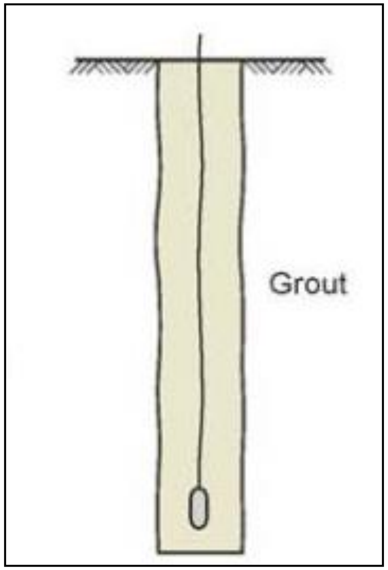
- **Intended elevation and/or depth of Piezometer**
- **Borehole or surface installation**
- **Filter type & zone**
- **Seal type**
- **Cable management (deep installations)**
- **Cable marking**
- **Site Zero Pressure reading**

Drilled boreholes

Installation



Filter + seal



Grout = filter + seal

Traditional Method

Sand pocket to create response zone around piezometer tip, with a conventional Bentonite seal to separate sand and grout

Fully Grouted Method

No sand pocket required as grout is pumped (Tremied) in from the bottom of the borehole upwards

Fully grouted now seems to be the preferred/accepted method

GEOSENSE

Traditional Method

Installation

FILTER PACK

- Quartz material (sand/glass) typically 1-2*mm with uniform grading

  * may vary with local standards

- Placement method will depend on depth:
  - Pouring continuously in small quantities to avoid bridging
  - Washing in
  - Placed within filter sock (placement/location guaranteed)

SEAL

- Material that has a permeability suitable for hydraulic separation of two aquifers e.g. Bentonite pellets
- Should be a plug of at least one meter length in a confining layer

FOR FULLY GROUTED THE GROUT IS BOTH THE FILTER & THE SEAL

GEOSENSE

Grouting

Installation

- Grout is used as either a seal, a void filler or combination of both
- Permeability of grout main issue for piezometer installation
- Often causes much discussion and disagreement
- Often omitted from instrumentation specifications and/or left to the installer/supplier to determine
- The grout specification **should be provided by the Engineer** and designed according to the surrounding soil conditions
- Need to control the water-cement ratio – key for F-G-M
- Mix water and cement first and then add bentonite
- The Marsh funnel number should be ~55 seconds

The Engineers responsibility

GEOSENSE

Piezometer orientation

Installation

It is important to install piezometers facing up when:-

- Installed in the Fully Grouted Method
- Installed in soil which may become unsaturated
- Marginal soils which will have fluctuating saturation levels

This is to prevent the filter tip from becoming unsaturated

GEOSENSE

Grout mix

The emphasis is on controlling the water-cement ratio. This is accomplished by mixing the cement with the water first. Bentonite is added to achieve a stable mix with the desired consistency.

In situ-soil	K_{soil} [m/s]	K_{grout} [m/s]	Mix ratio C/W/B	$q_{u,grout}$ [kPa]
Sand	10^{-6}	7.2×10^{-8}	1/6.55/1	100
Clayey sand	10^{-7}	3.1×10^{-8}	1/4/0.67	240
Clay	10^{-9}	2×10^{-8}	1/2.5/0.4	690
Clay	10^{-10}	1×10^{-9}	1/2/0.36	1720

References

- **Grouted-in installation of piezometers in boreholes**
– Gordon T. McKenna, Canadian Geotechnical Journal 1995

- **Piezometers in Fully Grouted Boreholes. International Symposium on Geomechanics, Oslo, Norway, September 2003**
- Mikkelsen, P.E. and Green, E.G. 2003.

- **The use of the fully-grouted method for piezometer installation, Part 1 and Part 2. Geotechnical News 26(2): 30-37**
- Contreras, I.A., Grosser, A.T., Ver Strate, R.H. 2008.

- **In Support of the Fully-grouted Method for Piezometer Installation**
– Daniel S. Weber | Geotechnical News (BiTech Publishers) June 2009

- **Field Performance of fully grouted piezometers**
– Lucia Simeoni, Fabio De Polo, Giovanni Caloni, Giorgio Pezzetti

- **Instrumenting and Monitoring a Slow Moving Landslide**
- Matthew Schafer, Renato Macciotta, Michael Hendry & Derek Martin

- **Update of the fully grouted method for piezometer installation**
- Contreras, Grosser & Ver Strate
http://www.bitech.ca/pdf/GeoTechNews/2012/GIN%203002.pdf (Includes references to other publications)

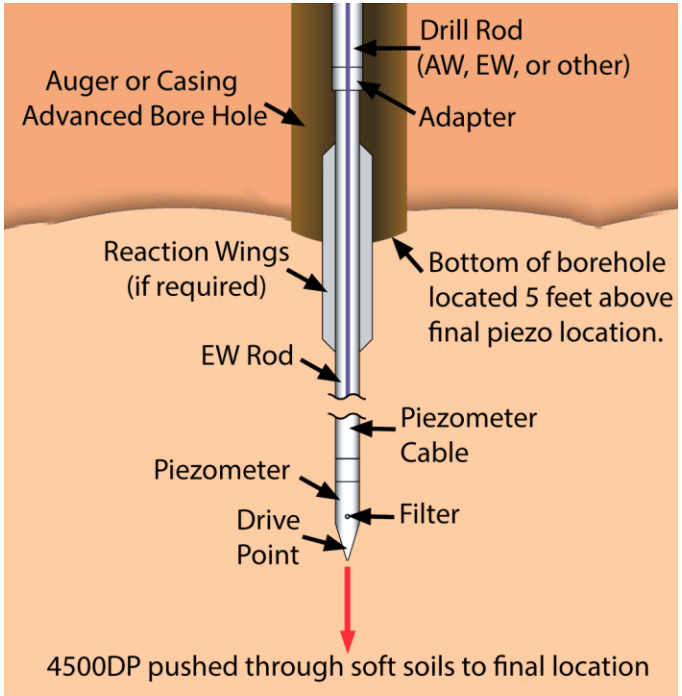
GEOSENSE

Installation

Push-in

Push-in adaptor for BSP pipe or CPT rods

Push-in adaptor for Drill Rods



- **Avoid over pressure**
- **Monitor pressure**

Deep installations >50m = Major challenges

Installation

The main considerations are:

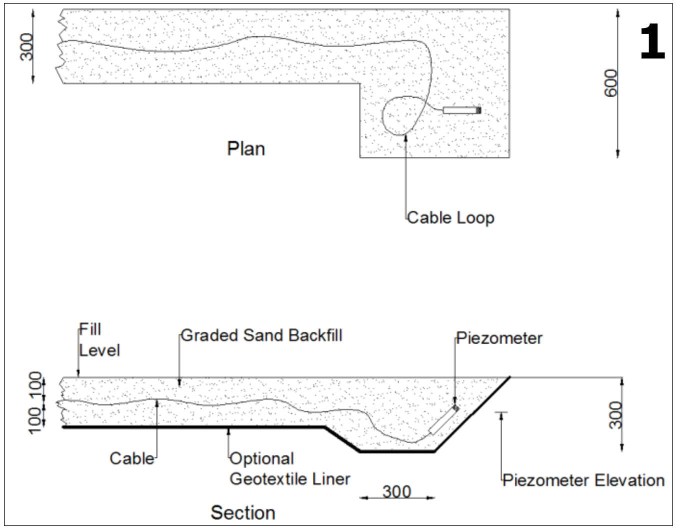
- Borehole construction
- The piezometer response zone
- The piezometer seal
- The sensor type
- Cable management

The deeper the installation the greater these challenges become

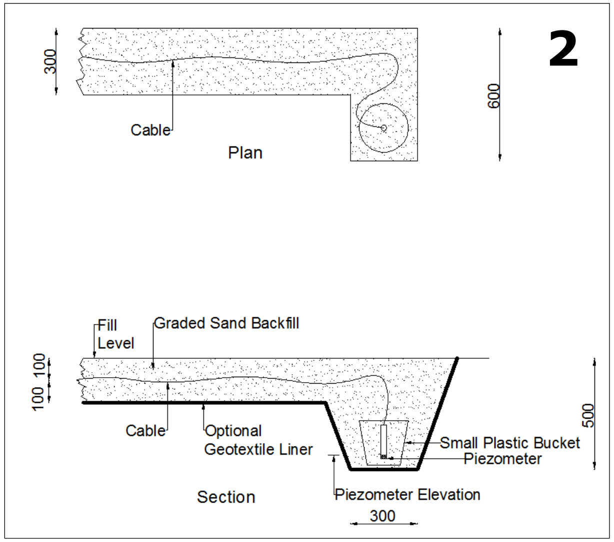
More details can be found in the Geosense Knowledge Article on the USB

GEOSENSE

Trenches & pockets



1. In a pocket in a permeable material

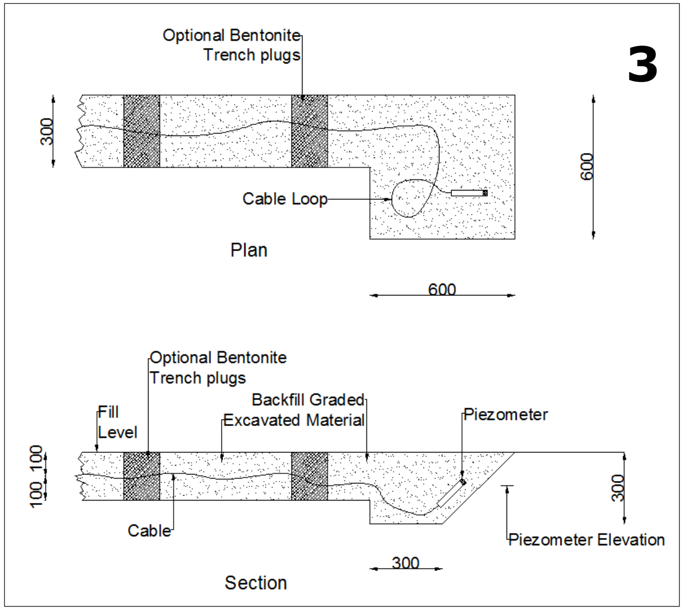


2. In a pot in a pocket in a permeable material

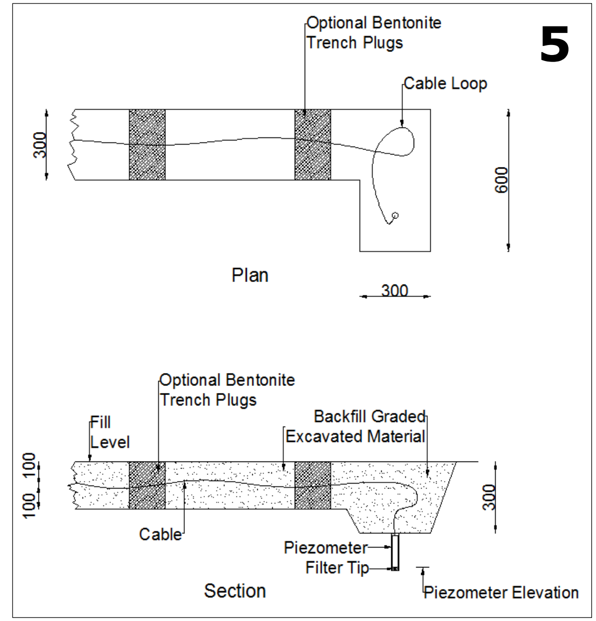
GEOSENSE

Trenches & pockets

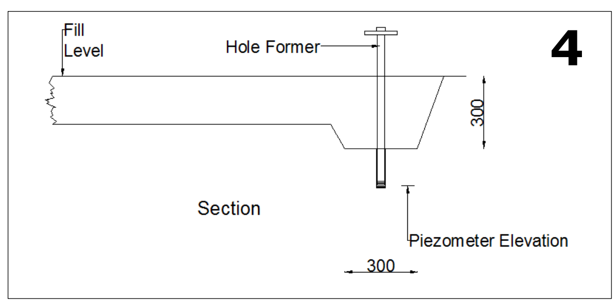
Installation



3. In a pocket in an impervious material



5. Piezometer pushed into an impervious material



4. Forming hole in impervious material

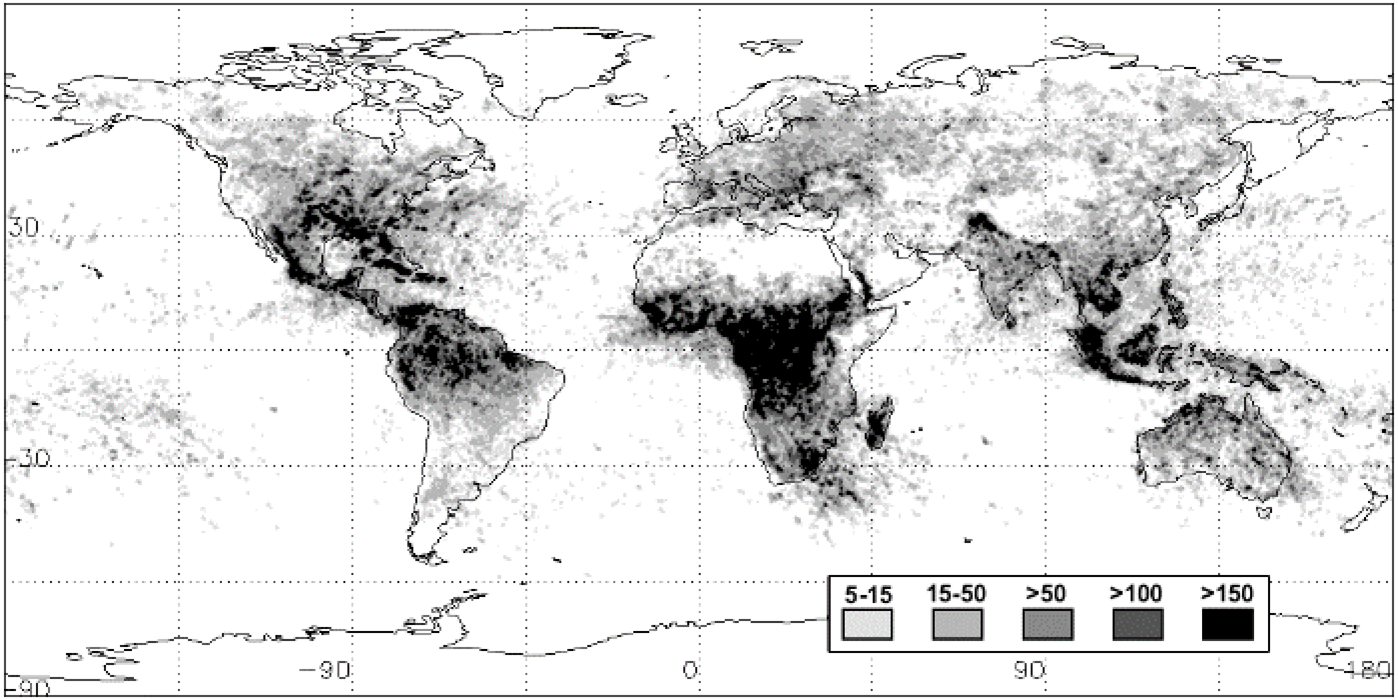
Trenches & pockets

Installation

GEOSENSE

Where Does Lightning Strike ?

Lightening protection

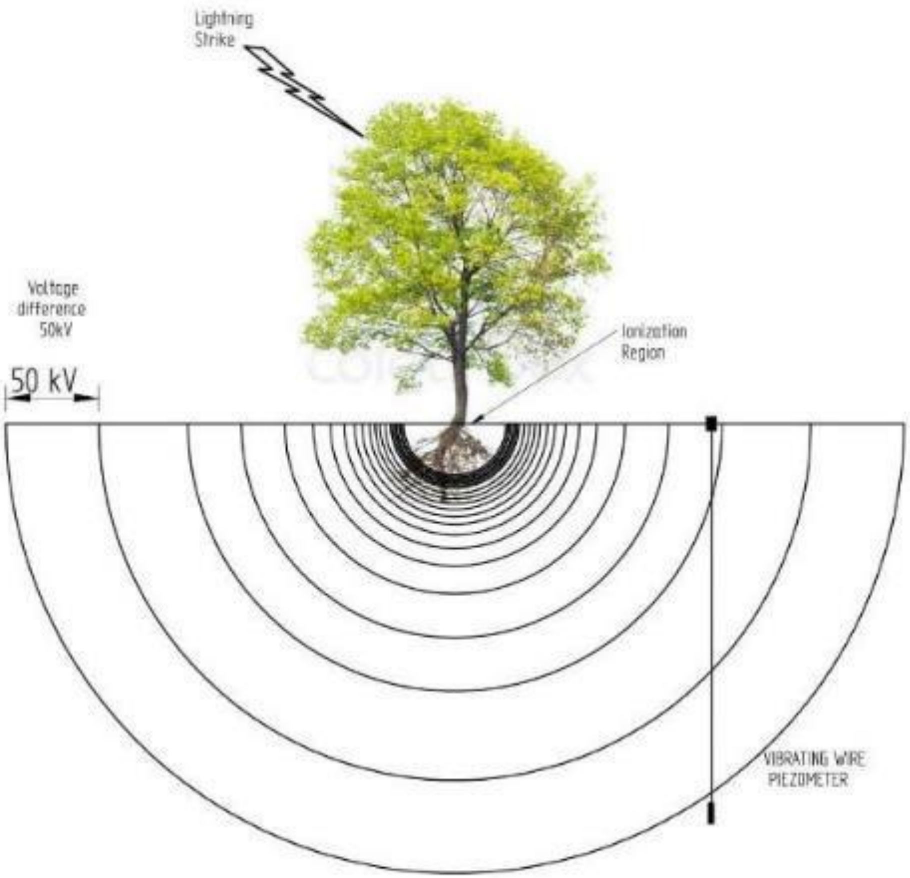


(GDT)

- VW piezometers have gas discharge tube (GDT) protection built-in
- GDT's can take single 10,000 A shots, but let 600V transients through & won't fire at 110 VAC power fault

Affect of a lightning Strike

Lightening protection



Nearby (not direct strike) generates huge differences in electrical potential

Linear Calculation

Data reduction

- The simplest calculation to convert ‘raw’ data to engineering units
- It can be easily carried out using a simple calculator
- It assumes that the reading is in Linear Digits ($Hz^2/1000$)
- If necessary the reading should be converted to Linear Digits prior to application of the calibration factors

Pressure (kPa) = Linear Factor (k) for kPa x (Current Reading - Zero Pressure Reading)

GEOSENSE

Linear calculation

Frequency units (Hz) to Metres of Water (mH_2O)

Site Zero Reading in **Hz** = **3155.9**

Site Zero Reading in Linear Digits ($Hz^2/1000$) = 9959.7 (calculated)

Calibration Factor for **mH_2O** (K) = - 0.009356

Current Reading in **Hz** = **2977.5**

Current Reading in Linear Digits ($Hz^2/1000$) = 8865.5 (calculated)

Equation

Water Pressure = K for mH_2O x (Current Reading - Zero Reading)

Water Pressure = -0.009356 x (8865.5 – 9959.7)

Water Pressure = **10.24 mH_2O**

Polynomial Calculation

Data reduction

- More precise as it accommodates any slight deviation from a perfect linear correlation
- The "C" Constant for the site must be calculated using a "Site Zero Pressure" Reading
- Once the Site "C" Constant is established the polynomial formula can be used to convert Raw Data to Engineering Units

Linear Digits ($Hz^2/1000$) to mH_2O

Polynomial Calibration Factors for mH_2O

A = **- 5.0632E-08**

B = **- 0.008537**

Site Zero in Linear Digits = 9959.7

Site C = (- (- 5.0632E-08 x $(9959.7)^2$) - (- 0.008537 x 9959.7)

= 5.02247 + 85.0260 = **90.0484**

Current Reading in Linear Digits = 8865.5

Pressure in mH_2O = [A x $(\text{Reading})^2$] + [B x Reading] + Site C

= [- 5.0632E-08 x $(8865.5)^2$] + [- 0.008537 x 8865.5] + 90.0484

= - 3.9795 – 75.6848 + 90.0484

Pressure = 10.38 mH_2O

Example calculation spreadsheet

Data reduction

Disclaimer: The following spread sheet is provided in good faith as an aid for data reduction but it is the sole responsibility of the user to check that the calculations are suitable for their own use.

VW PIEZOMETER INPUT CALCULATION SHEET V1.1

Installed Depth Below Existing Ground Level (m):	
Existing Ground Level (m Above Sea Level):	
Serial Number:	
Linear Calibration Factor (k):	kPa per digit
Site Zero Pressure/Base Reading (H^2/1000):	
Site Zero Temp (°C):	
Site Zero Baro (mbar):	

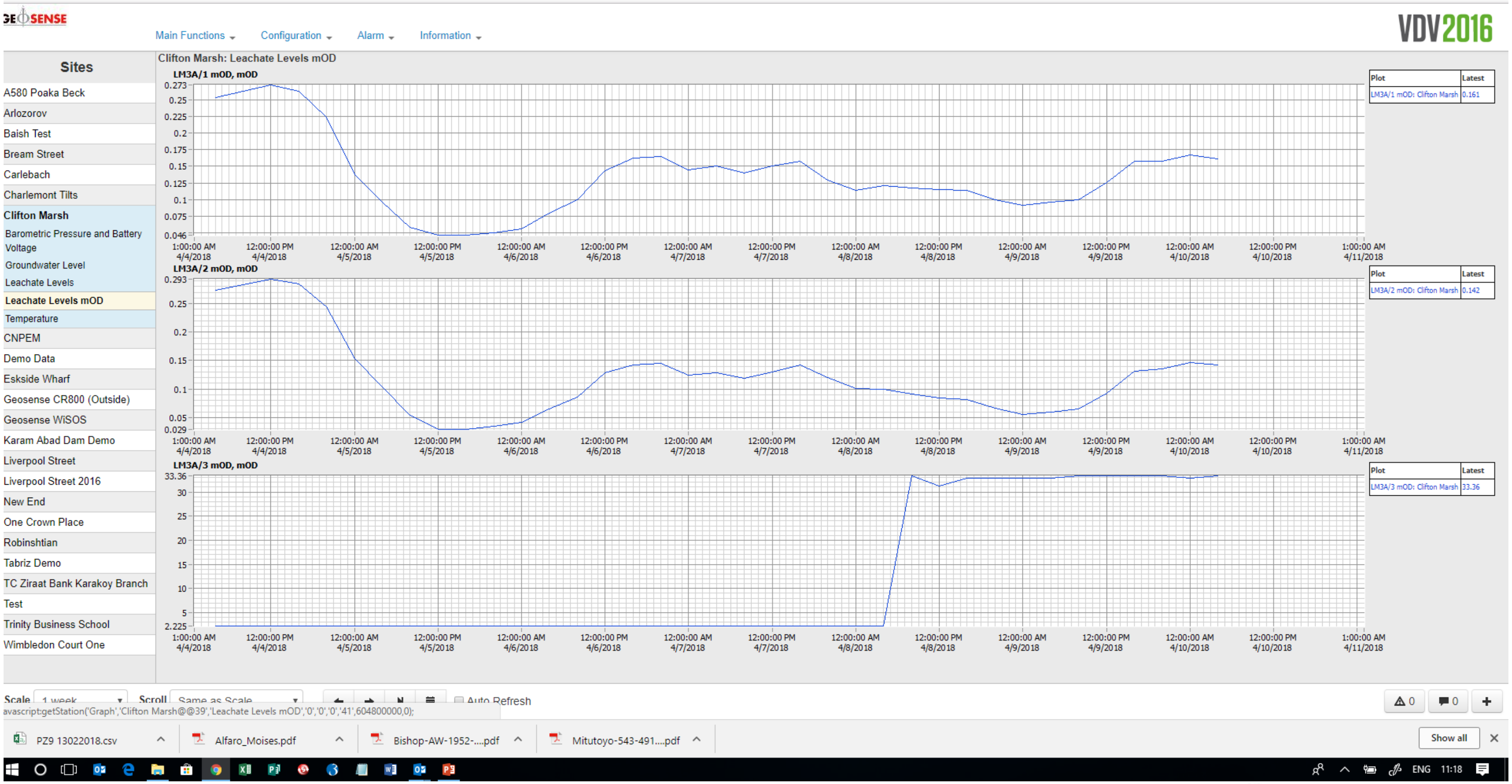
Project Name:	
Borehole Reference:	
Calibrated Pressure Range (kPa):	
Initial Borehole Water Level (m):	
Thermal Factor:	
Barometric Compensation?:	Yes

Date	Time	Digits (Hz2/1000)	Temperature (°C)	Barometric Pressure (mbar)	Pressure (kPa)	Barometric Corrected Pressure (kPa)	Water Level (m Above Sea Level)	Remarks
20/05/2014	14:00:00	9786.0	20.0	970.0	0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	
					0.00	0.00	0.00	

Input Sheet | Graph (no Baro) | Graph (Baro) | VW Conversion Sheet

Data visualisation

Data reduction



GEOSENSE

Unexpected readings

If you have unexpected readings you will need to try to understand the problem:

1. Is it really unexpected – what were you expecting?
2. Was the zero pressure reading taken
3. Have you looked at the raw data?
4. Is it really incorrect data?
5. Are the readings consistent – no major change in frequency?
6. Is the barometric reading fluctuating?
7. Is it sensor failure?
8. How to Trouble shoot sensor?

Unexpected readings

No “Zero pressure” reading

Calibration Factors	Channel 1
Sensorname	
Model	VWP-3000
Serial	343725
Baro	991.3035
TempatCal	20
LinFactor	-0.02
ConstA	-8.44E-08
ConstB	-0.01868
ConstC	1829.199
ConstT	0.032432
Sweepmin	800
Sweepmax	3500
Range	2700
Thermistor	3K
ZeroRdg	
ZeroT	

Date/time	Vbatt	Temp.	Channel 1 ()	(°C)		CH1 Raw (Digits)
21/07/2017 10:19	5	35.2	-178.8	26.8		8940.1
21/07/2017 11:19	5.1	31.5	-178.8	26.8		8941.3
21/07/2017 12:19	5	32.6	-178.8	26.8		8941.9
21/07/2017 13:19	5	28.8	-178.9	26.8		8943.1
21/07/2017 14:19	5.1	27.3	-178.9	26.8		8944.9
21/07/2017 15:19	5	26.9	-178.8	26.8		8942.5

GEOSENSE

Unexpected readings

No input of calibration factors

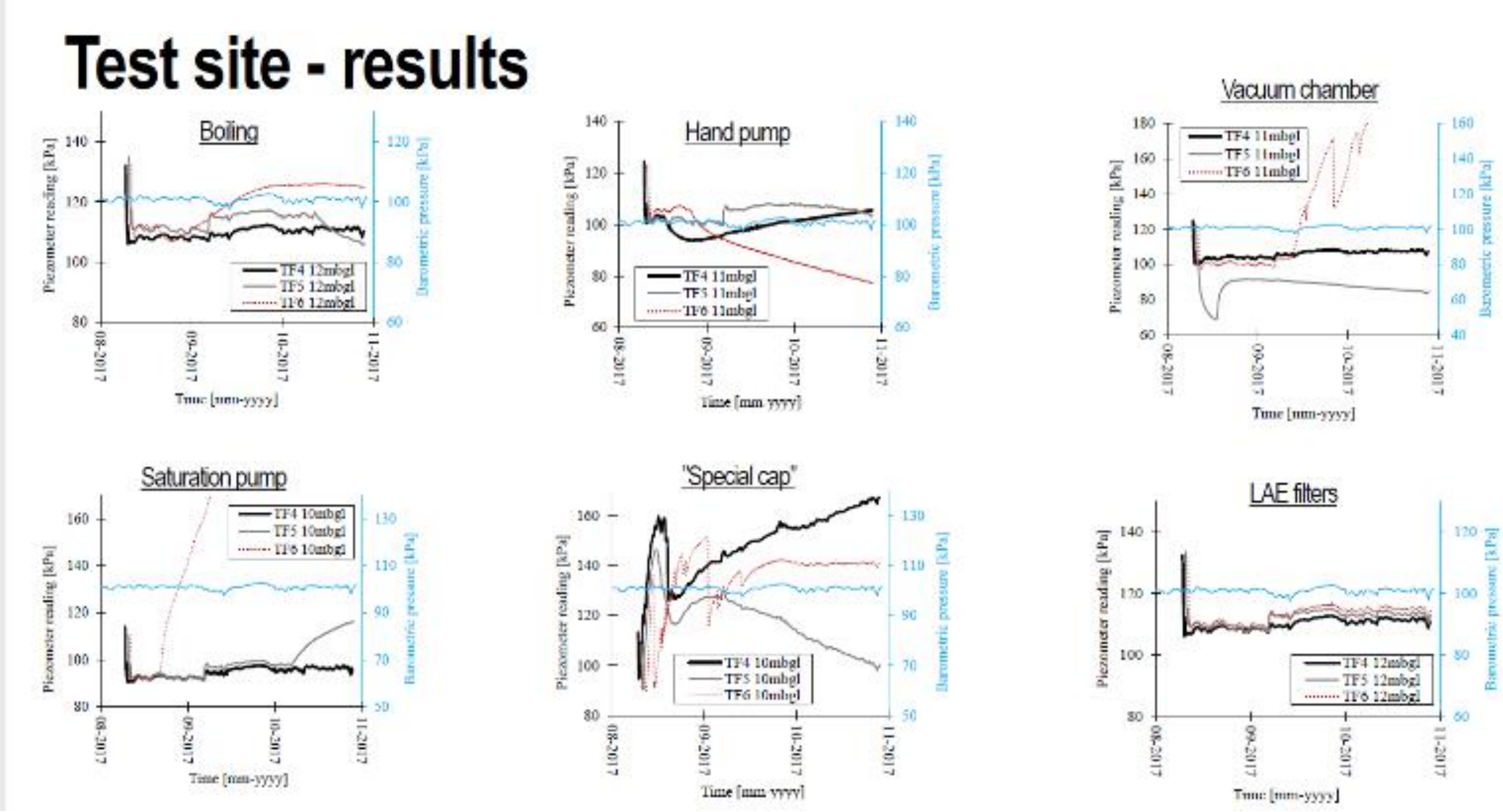
Calibration Factors	Channel 1
Sensorname	
Model	
Serial	
Baro	
TempatCal	
LinFactor	
ConstA	
ConstB	
ConstC	
ConstT	
Sweepmin	
Sweepmax	
Range	
Thermistor	3K
ZeroRdg	
ZeroT	

Date/time	Vbatt	Temp.	Channel 1 ()	(°C)	CH1 Raw (Digits)
23/07/2017 17:57	5.7	28.3	8920.4	26.7	8920.4
23/07/2017 18:57	5.6	25.2	8928.1	26.7	8928.1
23/07/2017 19:57	5.6	23.9	8927.5	26.7	8927.5
23/07/2017 20:57	5.6	23.3	8925.8	26.7	8925.8
23/07/2017 21:57	5.6	23.2	8926.4	26.7	8926.4
23/07/2017 22:57	5.6	23.2	8928.1	26.7	8928.1
23/07/2017 23:57	5.6	23.1	8929.9	26.7	8929.9

LAE v HAE filter in F-G-M

Unexpected readings

(FMGM 2018 paper)



Not a sensor problem as responding to atmospheric changes. What does it mean? Currently not explainable. Grout issue?

Sensor failure?

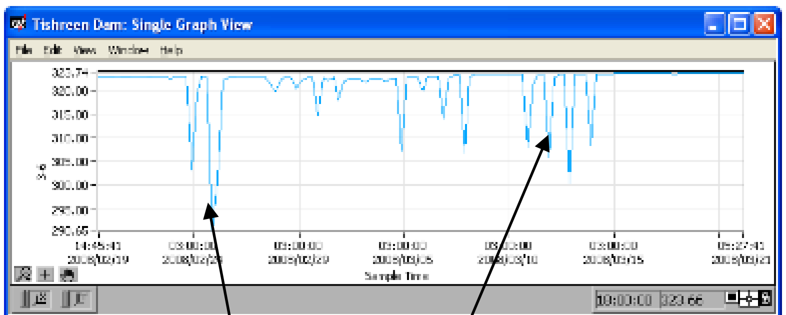
Unexpected readings

- **For VW sensors very rare**
- **VW actually work under water**
- **Cable damage more likely**

GEOSENSE

EMI – Electro-magnetic interference – “spikes”

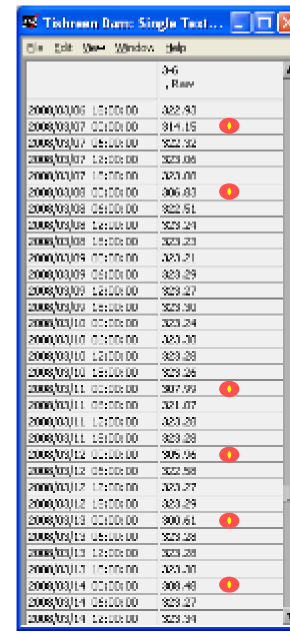
VW sensors are relatively immune to EMI but sometimes can cause problems



Graphical view of “Spikes”

“Spikes” occur at same time

“midnight”



	3-6 , Raw
2008/03/06 18:00:00	322.93
2008/03/07 00:00:00	314.15
2008/03/07 06:00:00	322.92
2008/03/07 12:00:00	323.06
2008/03/07 18:00:00	323.00
2008/03/08 00:00:00	306.83
2008/03/08 06:00:00	322.51
2008/03/08 12:00:00	323.24
2008/03/08 18:00:00	323.23
2008/03/09 00:00:00	323.21
2008/03/09 06:00:00	323.29
2008/03/09 12:00:00	323.27
2008/03/09 18:00:00	323.30
2008/03/10 00:00:00	323.24
2008/03/10 06:00:00	323.30
2008/03/10 12:00:00	323.28
2008/03/10 18:00:00	323.26
2008/03/11 00:00:00	307.99
2008/03/11 06:00:00	321.07
2008/03/11 12:00:00	323.28
2008/03/11 18:00:00	323.28
2008/03/12 00:00:00	305.96
2008/03/12 06:00:00	322.58
2008/03/12 12:00:00	323.27
2008/03/12 18:00:00	323.29
2008/03/13 00:00:00	300.61
2008/03/13 06:00:00	323.28
2008/03/13 12:00:00	323.28
2008/03/13 18:00:00	323.30
2008/03/14 00:00:00	308.48
2008/03/14 06:00:00	323.27
2008/03/14 12:00:00	323.34

Coincidence? No - turbines turned on at this time

Don’t be afraid to remove spikes

Unexpected readings

Always look at “raw” not manipulated data

TIMESTAMP	RECORD	BATTERY	VW 2	Therm 2	VW 3	Therm 3	VW 7	Therm 7	VW 8	Therm 8		VW 2	Therm 2	VW 3	Therm 3
											Unit Type	Pressure		Pressure	
											Input Units	kPa		kPa	
											Output Units	kPa		kPa	
											Offset	0.00E+00		0.00E+00	
											Cal A =	-1.12E-06		-1.04E-06	
											Zero B =	-1.82E-01		-1.70E-01	
											Cal C =	1.78E+03		1.67E+03	
											Temp CF	Disabled		Disabled	
											Temp Initial	Disabled		Disabled	
											Linked Channel	Disabled		Disabled	
											Sensor	[illegible]	[illegible]	[illegible]	[illegible]
UNITS->		Volts	kPa	deg C	kPa	deg C	kPa	deg C	kPa	deg C		B Units	Ohms	B Units	Ohms
27/02/2017 10:26	95	3.56	85.970856	9.7	113.615623	9.69						8837.160156	6059.978516	8715.219727	6061.461914
27/02/2017 11:26	96	3.56	80.779617	9.69	108.506516	9.68						8862.929688	6062.946289	8742.389648	6063.688965
27/02/2017 12:26	97	3.56	79.894981	9.68	107.590569	9.68						8867.320313	6065.916992	8747.259766	6065.916992
27/02/2017 13:26	98	3.57	79.60495	9.67	107.31028	9.67						8868.759766	6068.146484	8748.75	6068.88916
27/02/2017 14:26	99	3.57	79.522308	9.66	107.238831	9.66						8869.169922	6069.632813	8749.129883	6071.119629
27/02/2017 15:26	100	3.57	80.066368	9.65	107.767258	9.65						8866.469727	6072.605957	8746.320313	6073.350098
27/02/2017 16:26	101	3.57	79.822571	9.65	107.539688	9.64						8867.679688	6074.093262	8747.530273	6075.581543
27/02/2017 17:26	102	3.57	79.494171	9.64	107.244522	9.64						8869.30957	6076.325684	8749.099609	6077.813477
27/02/2017 18:26	103	3.57	79.157494	9.63	106.924736	9.63						8870.980469	6078.557129	8750.799805	6080.045898
27/02/2017 19:26	104	3.57	78.837143	9.63	106.62001	9.62						8872.570313	6080.791016	8752.419922	6082.280273
27/02/2017 20:26	105	3.56	78.571297	9.62	106.343567	9.61						8873.889648	6083.025391	8753.889648	6084.514648
27/02/2017 21:26	106	3.56	78.371758	9.61	106.155472	9.61						8874.879883	6085.260742	8754.889648	6086.750488
27/02/2017 22:26	107	3.56	78.20253	9.61	105.976738	9.6						8875.719727	6086.750488	8755.839844	6088.987305
27/02/2017 23:26	108	3.57	78.025223	9.6	105.799843	9.59						8876.599609	6088.987305	8756.780273	6090.479004
28/02/2017 00:26	109	3.56	77.928406	9.59	105.702118	9.59						8877.080078	6091.225098	8757.299805	6092.716797
28/02/2017 01:26	110	3.55	77.833748	9.59	105.609909	9.58						8877.549805	6092.716797	8757.790039	6094.955566
28/02/2017 02:26	111	3.56	77.813484	9.58	105.59668	9.57						8877.650391	6094.208984	8757.860352	6097.194824
28/02/2017 03:26	112	3.56	77.785339	9.57	105.570412	9.56						8877.790039	6095.70166	8758	6098.688965
28/02/2017 04:26	113	3.56	77.736931	9.57	105.527061	9.56						8878.030273	6097.941895	8758.230469	6100.928711
28/02/2017 05:26	114	3.55	77.767235	9.56	105.547813	9.55						8877.879883	6100.181641	8758.120117	6102.423828
28/02/2017 06:26	115	3.55	77.767235	9.56	105.561043	9.54						8877.879883	6100.928711	8758.049805	6104.665527
28/02/2017 07:26	116	3.55	77.785339	9.55	105.583633	9.54						8877.790039	6102.423828	8757.929688	6106.160645
28/02/2017 08:26	117	3.55	77.809547	9.54	105.606232	9.53						8877.669922	6104.665527	8757.80957	6108.404785
28/02/2017 09:26	118	3.55	77.805412	9.54	105.60054	9.53						8877.69043	6106.160645	8757.839844	6109.900879
28/02/2017 10:26	119	3.56	77.809547	9.53	105.615601	9.52						8877.669922	6107.65625	8757.759766	6112.145996
28/02/2017 11:26	120	3.56	77.801476	9.53	105.60054	9.51						8877.709961	6109.152344	8757.839844	6113.643066
28/02/2017 12:26	121	3.56	77.833748	9.52	105.6325	9.51						8877.549805	6110.649414	8757.669922	6115.140625
28/02/2017 13:26	122	3.56	77.801476	9.52	105.606232	9.5						8877.709961	6112.145996	8757.80957	6116.638672
28/02/2017 14:26	123	3.57	77.781403	9.51	105.579781	9.5						8877.80957	6113.643066	8757.950195	6118.136719
28/02/2017 15:26	124	3.57	77.767235	9.51	105.566734	9.49						8877.879883	6115.140625	8758.019531	6119.635254
28/02/2017 16:26	125	3.56	77.787308	9.5	105.593002	9.49						[illegible]	[illegible]	[illegible]	[illegible]

GEOSENSE

Unexpected readings

Localtime	Freq(578m) Hz	Therm3 ohm	Freq(475m) Hz	Therm2 ohm	Freq(243.5m) Hz	Therm1 ohm	Pressure (243.5 m) mH2O (polynomial)	Pressure (475 m) mH2O (polynomial)	Pressure (578 m) mH2O (polynomial)
2017-04-19 19:49:08	2584.120117	7074.700195	2697.198975	8468.610352	2645.461914	7726.209961	247.6200103	517.0459446	593.7792916
2017-04-19 19:54:11	2584.082031	7074.689941	2697.175049	8458.169922	2645.461914	7725.890137	247.6200103	517.0712803	593.8180219
2017-04-19 19:59:14	2584.058105	7074.629883	2697.159912	8459.929688	2645.461914	7725.72998	247.6200103	517.087309	593.8423521
2017-04-19 20:04:16	2584.041992	7074.470215	2697.149902	8464.200195	2645.460938	7725.740234	247.6206506	517.0979085	593.8587376
2017-04-19 20:09:17	2584.030029	7074.430176	2697.139893	8462.370117	2645.461914	7726.100098	247.6200103	517.108508	593.8709026
2017-04-19 20:14:20	2584.019043	7074.839844	2697.133057	8462.030273	2645.461914	7726.189941	247.6200103	517.1157467	593.8820744
2017-04-19 20:19:23	2584.01001	7074.399902	2697.126953	8464.080078	2645.461914	7725.700195	247.6200103	517.1222097	593.8912601
2017-04-19 20:24:24	2584.001953	7074.910156	2697.120117	8464.650391	2645.461914	7725.77002	247.6200103	517.1294483	593.8994527
2017-04-19 20:29:25	2583.996094	7074.859863	2697.115967	8469.200195	2645.460938	7726.140137	247.6206506	517.1338432	593.905411
2017-04-19 20:34:27	2583.98999	7074.410156	2697.110107	8471.230469	2645.459961	7725.799805	247.621291	517.1400477	593.9116175
2017-04-19 20:39:28	2583.985107	7074.799805	2697.105957	8473.009766	2645.461914	7726.089844	247.6200103	517.1444426	593.9165827
2017-04-19 20:44:32	2583.97998	7074.720215	2697.102051	8476.25	2645.459961	7725.680176	247.621291	517.1485789	593.9217961
2017-04-19 20:49:34	2583.975098	7074.910156	2697.0979	8478.169922	2645.460938	7725.870117	247.6206506	517.1529737	593.9267613
2017-04-19 20:54:36	2583.970947	7075.060059	2697.094971	8481.099609	2645.459961	7725.740234	247.621291	517.156076	593.9309817
2017-04-19 20:59:37	2583.967041	7075.129883	2697.091064	8480.799805	2645.459961	7725.810059	247.621291	517.1602123	593.9349538
2017-04-19 21:04:39	2583.962891	7075.129883	2697.087891	8481.929688	2645.460938	7725.740234	247.6206506	517.163573	593.9391742

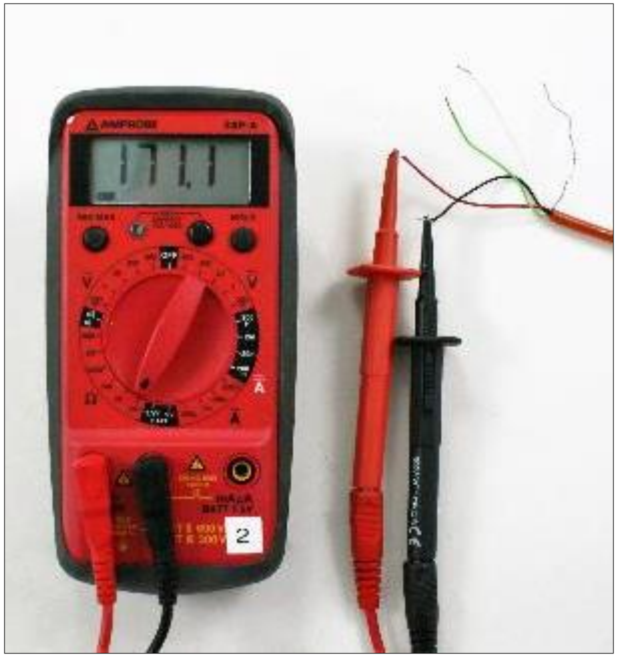
GEOSENSE

Cable damage

Troubleshooting

Where damage to a sensor or cable is suspected simple resistance checks can be taken to identify the possible cause of the problem.

Resistance checks can be made with most types of multi-meter which are readily available in the market.



RESISTANCE OF THE COILS

STEP 1
Set the range to 200Ω or Ω if using a multi-meter which has automatic ranging.

STEP 2
Connect the VW+ (red) conductor to the red lead on the multi-meter and the VW- (black) to the black lead on the multi-meter.

The correct reading should be **180Ω ±10%**

IF THE VALUES ARE OUT OF THESE RANGES THEN THERE IS A FAULT IN THE COILS

IF THE VALUES ARE 50% THEN THERE IS A PROBLEM WITH <u>ONE</u> OF THE COILS

GEOSENSE

Cable damage

Troubleshooting

RESISTANCE OF THE THERMISTOR

STEP 1
Set the range to 20kO or O if using a multi-meter which has automatic ranging.

STEP 2
Connect the T+ (green) conductor to the red lead on the multi-meter and the T- (white) to the black lead on the multi-meter.

The readings will be dependent on the temperature as below:-

10°C ~ 5.971kΩ (5971Ω)
15°C ~ 4.714kΩ (4714Ω)
20°C ~ 3.478kΩ (3478Ω)
25°C ~ 3.000kΩ (3000Ω)

SEE THERMISTOR LOOK UP TABLE

IF THESE VALUES DIFFER THEN THERE IS A PROBLEM WITH THE THERMISTOR OR IT'S CONDUCTORS

GEOSENSE

Thermistor look up table

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
201.1K	-50	16.60K	-10	2417	30	525.4	70	153.2	110
187.3K	-49	15.72K	-9	2317	31	507.8	71	149.0	111
174.5K	-48	14.90K	-8	2221	32	490.9	72	145.0	112
162.7K	-47	14.12K	-7	2130	33	474.7	73	141.1	113
151.7K	-46	13.39K	-6	2042	34	459.0	74	137.2	114
141.6K	-45	12.70K	-5	1959	35	444.0	75	133.6	115
132.2K	-44	12.05K	-4	1880	36	429.5	76	130.0	116
123.5K	-43	11.44K	-3	1805	37	415.6	77	126.5	117
115.4K	-42	10.86K	-2	1733	38	402.2	78	123.2	118
107.9K	-41	10.31K	-1	1664	39	389.3	79	119.9	119
101.0K	-40	9796	0	1598	40	376.9	80	116.8	120
94.48K	-39	9310	1	1535	41	364.9	81	113.8	121
88.46K	-38	8851	2	1475	42	353.4	82	110.8	122
82.87K	-37	8417	3	1418	43	342.2	83	107.9	123
77.66K	-36	8006	4	1363	44	331.5	84	105.2	124
72.81K	-35	7618	5	1310	45	321.2	85	102.5	125
68.30K	-34	7252	6	1260	46	311.3	86	99.9	126
64.09K	-33	6905	7	1212	47	301.7	87	97.3	127
60.17K	-32	6576	8	1167	48	292.4	88	94.9	128
56.51K	-31	6265	9	1123	49	283.5	89	92.5	129
53.10K	-30	5971	10	1081	50	274.9	90	90.2	130
49.91K	-29	5692	11	1040	51	266.6	91	87.9	131
46.94K	-28	5427	12	1002	52	258.6	92	85.7	132
44.16K	-27	5177	13	965.0	53	250.9	93	83.6	133
41.56K	-26	4939	14	929.6	54	243.4	94	81.6	134
39.13K	-25	4714	15	895.8	55	236.2	95	79.6	135
36.86K	-24	4500	16	863.3	56	229.3	96	77.6	136
34.73K	-23	4297	17	832.2	57	222.6	97	75.8	137
32.74K	-22	4105	18	802.3	58	216.1	98	73.9	138
30.87K	-21	3922	19	773.7	59	209.8	99	72.2	139
29.13K	-20	3748	20	746.3	60	203.8	100	70.4	140
27.49K	-19	3583	21	719.9	61	197.9	101	68.8	141
25.95K	-18	3426	22	694.7	62	192.2	102	67.1	142
24.51K	-17	3277	23	670.4	63	186.8	103	65.5	143
23.16K	-16	3135	24	647.1	64	181.5	104	64.0	144
21.89K	-15	3000	25	624.7	65	176.4	105	62.5	145
20.70K	-14	2872	26	603.3	66	171.4	106	61.1	146
19.58K	-13	2750	27	582.6	67	166.7	107	59.6	147
18.52K	-12	2633	28	562.8	68	162.0	108	58.3	148
17.53K	-11	2523	29	543.7	69	157.6	109	56.8	149

Cable damage

Troubleshooting

RESISTANCE OF ALL INDIVIDUAL CONDUCTORS

STEP 1
Set the range to 20kΩ or Ω if using a multi-meter which has automatic ranging.

STEP 2
All conductors should be checked by connecting to the red and black leads on the multi-meter as follows:-

Red & screen

Black & screen

Green & screen

White & screen

A value of O.L (Open Loop) means that there is a high/infinite resistance = OK

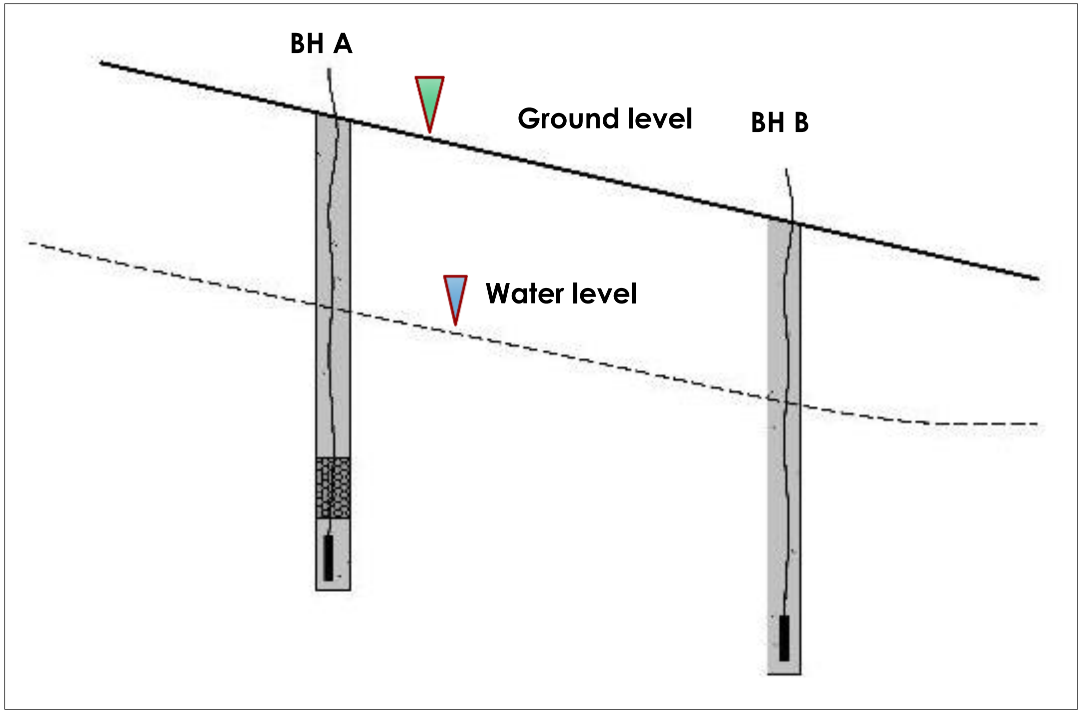
If any are less than this then it is likely that there has been cable damage.

GEOSENSE

Specifying pressure range

Pressure range

Slope monitoring



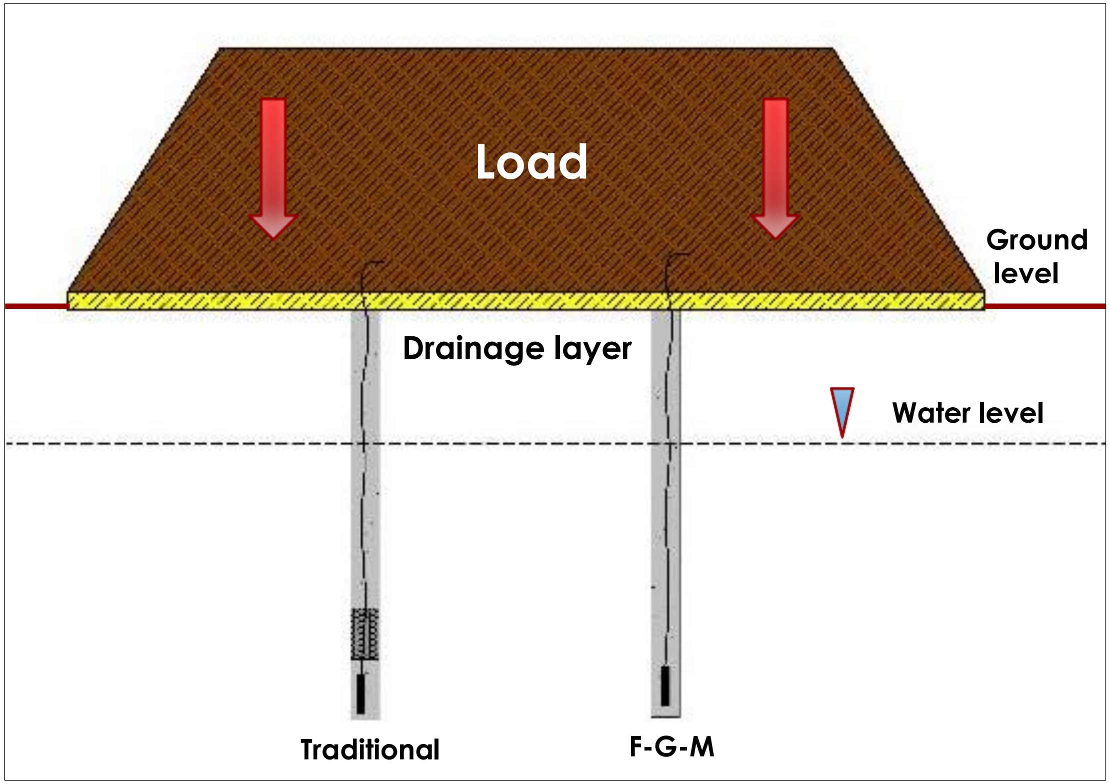
Considerations

- Depth to piezometer
- Depth to groundwater
- Grout pressure
- Pressure range required

Specifying pressure range

Pressure range

Surcharging



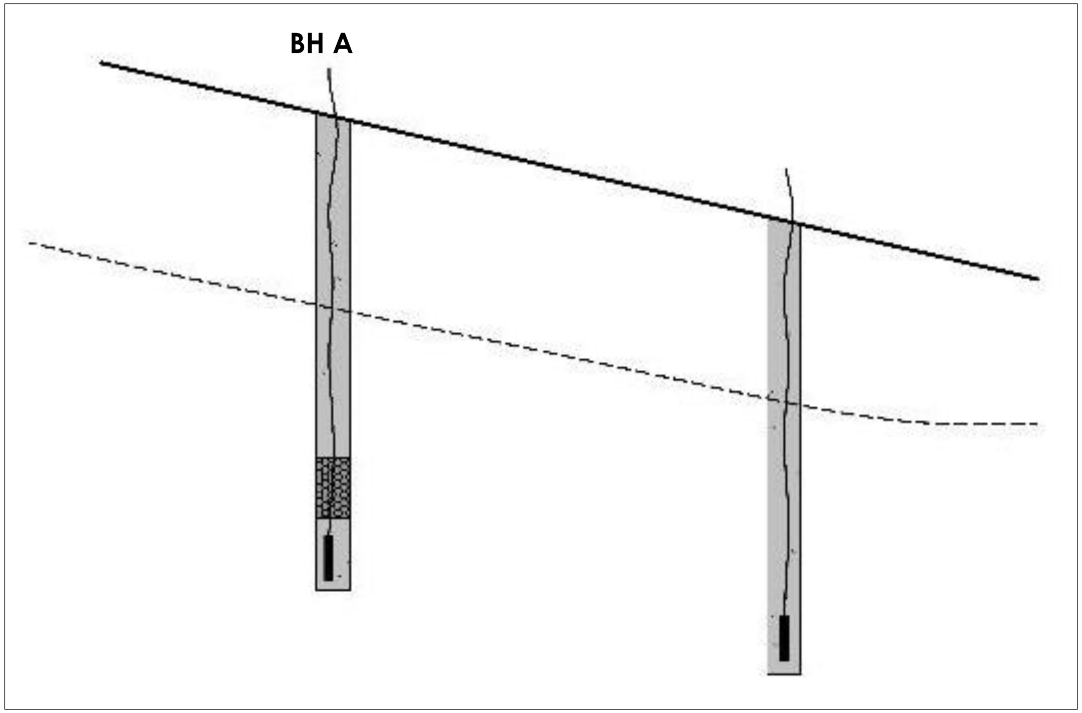
Considerations

- Depth to piezometer
- Depth to groundwater
- Grout pressure
- Pressure range required

GEOSENSE

Data reduction exercise

Calculation



For BH A calculate:-

- **Depth to piezometer**
- **Current pressure**
- **Elevation of groundwater**

The end

Thank you,

Danke, Dank u, Merci, Gracias, Grazie, Dziękuję, σας ευχαριστώ, Takk ,Tack, Tak, Kiitos, شكرا, благодаря, Hvala, Děkuji, Aitäh, გმადლობთ, Köszönöm, þakka þér, Paldies, Ačiū, Obrigado, Mulţumesc, спасибо, хвала, ďakujem, Hvala, Teşekkür ederim, Спасибі, آپ کا شکریہ, शुक्रिया