VW Piezometer

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Introduction

Applications

The VW piezometer is sealed in boreholes and embedded in fills to measure pore-water pressures. It can also be placed in standpipes and wells to measure water levels. Typical applications include:

- Monitoring dewatering schemes for excavations and underground openings.
- Monitoring ground improvement techniques such as vertical drains, sand drains, and dynamic compaction.
- Monitoring pore pressures to determine safe rates of fill or excavation.
- Investigating the stability of natural and cut slopes.
- Monitoring the performance of earthfill dams and embankments.
- Monitoring seepage and ground water movement in embankments, land fill dikes, and dams.
- Monitoring water levels in wells, standpipes, lakes, reservoirs, and rivers.

Theory of Operation

The VW piezometer converts water pressure to a frequency signal via a diaphragm and a tensioned steel wire. The piezometer is designed so that a change in pressure on the diaphragm causes a change in tension of the wire.

When excited by a magnetic coil, the wire vibrates at its natural frequency. The vibration of the wire in the proximity of the magnetic coil generates a frequency signal that is transmitted to the readout device. The readout device processes the signal and displays a reading.

Calibration factors, which establish a relationship between pressure applied to the diaphragm and the frequency signal returned to the readout device, are used to convert Hz readings to engineering units.

Installation

Installation Tips

Here are some installation tips.

Sensor Care

- Handle the piezometer with care.
- If you are working in cold weather, do not allow a water-filled piezometer or a saturated filter to freeze.

Cable Care

- Store cable where it is dry and safe from rodents and traffic.
- Handle cable carefully. Don't lay the cable across roads with traffic. Avoid dragging cable over rocks and sharp surfaces. Do not pull hard on the cable, since this may damage the conductors. Avoid making small radius bends in the cable for the same reason.
- Mark cables carefully for positive identification later.
- Protect the ends of signal cables so that water cannot enter the cable jacket. Cables should be terminated above ground level at a waterproof box or with waterproof connectors.

Backfilling the Borehole

- In traditional borehole installations, a sand intake zone is formed around the piezometer and a bentonite seal is placed above the sand zone. We now favor the grout-in method of installation, where the entire borehole is filled with a bentonite cement grout, eliminating the need for a sand zone. We believe this method to be suitable for nearly all saturated soils and offer grout-in instructions in this manual. For the theory behind the method, visit see technotes on the Slope Indicator website. ”
- If drill casing is used to hold the borehole open, it must be pulled out as backfill is placed. Use care when pulling casing so that you do not twist and damage the signal cable.

Obtaining Initial Readings

Drilling a borehole and backfilling it temporarily changes the pore-water pressure in the ground, so readings that are taken immediately after installation will not be good datum readings.

Recovery of the natural pore-water pressure may take a few hours to a few weeks, depending on the permeability of the soil. Recovery is signalled by stable readings over a period of a few days. A datum reading can then be obtained.

Saturating Filters

Standard Filters: Most VW piezometers are supplied with filters that have a pore size of 50 to 60 microns. These filters pass both air and water, so they do not require elaborate saturation procedures. Pull off the filter, fill the piezometer with water, and replace the filter.

High Air Entry Filters: Sometimes specifications call for high-air-entry filters. Such filters have very fine pores and the surface tension of the water in the pores prevents the entry of air. High-air entry filters were originally used with hydraulic piezometers to monitor negative pore-water pressures in clay-core dams. The hydraulic piezometer was capable of saturating the filter in-situ to maintain the filter's ability to resist the entry of air.

Diaphragm piezometers, such as the VW piezometer, can be supplied with high-air entry filters, but because there is no mechanism for saturating the filter in-situ, the filter will become ineffective for measuring negative pore-pressures if the soil becomes unsaturated. Although we believe that high air entry filters are not appropriate for VW sensors, you can find instructions on saturating such filters at www.slopeindicator.com. Go to Support - Tech Notes - Piezometers.

Bentonite-Cement Grout as a High Air Entry Filter: There is some evidence that VW piezometers, when directly embedded in a bentonite-cement grout, are capable of measuring negative pore-water pressures. The grout, which is largely water, acts as a hydrated high-air entry filter. The VW piezometers themselves are equipped with the standard filter.

Borehole Installation (Traditional Method)

The instructions below assume that the piezometer will be installed at the bottom of the borehole.

1. Drill the borehole below the required depth of the piezometer. Flush the borehole with water or biodegradable drilling mud.

2. Form a sand intake zone: tremie wet sand to the bottom of the borehole. You must pull drill casing slightly to keep it above the level of the sand. When the sand reaches the required depth of the piezometer, lower the piezometer into the borehole. Tremie sand around the piezometer, again pulling the casing to keep it above the level of the sand. Continue until at least six inches (150 mm) of sand has been placed above the piezometer.

   Note: If you know that the water table will drop below the elevation of the piezometer, install the piezometer with its filter tip pointing upwards. This allows easy re-entry of water.

   Note: Sometimes the piezometer is placed in a sand-filled canvas bag. The bag then serves as a sand intake zone.

3. Place a bentonite seal above the intake zone, using bentonite chips. A typical seal is at least 1 foot thick, but refer to project specifications for the required length. Again, be sure to pull the casing up above the level of the bentonite. Drop chips in slowly to ensure proper placement of the seal and to avoid bridging.

   The bentonite seal typically requires 2 to 3 hours to set up, but refer to your bentonite instructions for exact times. Keep the borehole filled with water to fully hydrate the bentonite and prevent it from drawing water from the surrounding soil.

4. Backfill with a bentonite-cement grout.

5. Readings taken immediately after installation will be high, but will decrease as the grout cures. A datum reading can be taken hours to days after installation, depending on the permeability of the soil. Take readings periodically to determine when recovery has occurred (pressure readings have stabilized).

6. Terminate the installation as specified. It is important to terminate the cable above ground level in a waterproof enclosure or with a waterproof connector. Protect the installation from construction traffic and mark its location with a stake.

Borehole Installation (Grout-In Method)

This method is faster and easier than the traditional method. It also provides a way to install multiple piezometers in one borehole or piezometers with inclinometer casing.

1. Drill the borehole below the required depth of the piezometer. Flush the borehole with water or biodegradable drilling mud.
2. Prepare the piezometer: Submerse the piezometer in a bucket of clean water, pull off the filter to allow air to escape from the piezometer, then replace the filter. Hold the piezometer with filter end up to prevent water from draining out.
3. Tie the piezometer to its own signal cable, so that you can lower it, filter-end up, into the borehole. You may need to add weight (a bag of sand, etc). If the piezometer is installed with inclinometer casing, tape it, filter-end up, to the casing.
4. Back-fill the borehole with grout. Use either of the mixtures below as a starting point for your grout mix. Mix cement with water first, and then add the bentonite. Adjust the amount of bentonite to produce a grout with the consistency of heavy cream. If the grout is too thin, the solids and the water will separate. If the grout is too thick, it will be difficult to pump.

Grout Mix for Hard and Medium Soils		
Materials	Weight	Ratio by Weight
Portland cement	94 lb (1 bag)	1
Bentonite	25 lb (as required)	0.3
Water	30 gallons	2.5
Grout Mix for Soft Soils		
Materials	Weight	Ratio by Weight
Portland cement	94 lb (1 bag	1
Bentonite	39 lb (as required)	0.4
Water	75 gallons	6.6

5. Readings taken immediately after installation will be high, but will decrease as the grout cures. Datum readings can be taken hours to days after installation, depending on the permeability of the soil. The lag time caused by the grout itself is measured in minutes.
6. Terminate the installation as specified. It is important to terminate the cable above ground level in a waterproof enclosure or with a waterproof connector. Protect the installation from construction traffic and mark its location with a stake.

Push-In Installation

Push-in installation requires the push-in model of the VW piezometer. The piezometer has a right-hand EW drill rod thread. Also required is a disposable adapter which threads onto the piezometer and has a left-hand thread for connection to the drill rod. Normally, the piezometer is pushed a short distance into the ground at the bottom of a borehole. We do not recommend that the piezometer be driven in from the surface.

It is important that signal cable is not twisted during installation or when drill rod is removed. Also, it is important to avoid over-pressuring the piezometer as it is pushed in.

1. Slip the disposable adapter onto the signal cable and thread it onto the piezometer.
2. Drill the borehole and flush with water or biodegradable drilling mud.
3. Attach coupling pin to bottom drill rod. Feed signal cable through drill rod. Screw drill rod into adapter on piezometer. Add other sections of drill rod as required.
4. Connect signal cable to indicator so that you can take readings as the piezometer is pushed in.
5. Lower piezometer to bottom of borehole. If additional rods are added, prevent bottom rod from turning (because signal cable will get twisted).
6. Push piezometer into the soil, checking readings frequently to make sure that pressures do not exceed the ranges shown on the calibration sheet. It may be necessary to halt or slow the process to allow pressure to dissipate.
7. Detach drill rod and backfill borehole as specified.
8. Piezometer readings will not be valid at this stage because of excess pore-water pressure created when the piezometer is pushed in. If a bentonite seal has been placed, it may cause the opposite effect. Recovery time depends on the permeability of the surrounding soil and the size of the seal. Take readings periodically to determine when recovery has occurred, and then obtain your datum reading.
9. Terminate as specified. It is important to terminate the cable above ground level in a waterproof enclosure or with a waterproof connector. Protect the installation from construction traffic and mark its location with a stake.

Embankment Installation

1. Check project specifications for the required procedure.
2. In clays or other cohesive materials, form a hole for the piezometer, then place the piezometer in the hole slowly to avoid over-pressuring the diaphragm. To avoid sharp bends in the cable, a horizontal hole is preferred. Place a bentonite seal to isolate the piezometer from the cable trench.
3. Protect signal cables with hand-compacted layers of fine embankment materials on top and bottom. Use lightweight power tamping or rubber-tired equipment to compact materials placed immediately above this protective layer of fines. Avoid using heavy vibratory rollers or sheepsfoot rollers until there at least 18 inches (0.5 meters) of fill has been placed above the cables.
4. Avoid making tight bends in the cable. If the cable path changes direction, use extra cable at the turn. Avoid crossing cables. If cables must cross, place a layer of fine fill material between the cables.
5. Build water stops as specified.
6. Mark the location of the piezometer with a stake and devise some protection for the signal cable to prevent any possibility of water entry.
7. Terminate as specified. It is important to terminate the cable above ground level in a waterproof enclosure or with a waterproof connector. Protect the installation from construction traffic and mark its location with a stake.

Installation in a Monitoring Well

VW piezometers can be installed in wells to monitor water levels. Keep in mind that the piezometer is a sealed unit and is sensitive to any pressure on its diaphragm. Thus when installed in a well that is open to atmosphere, the piezometer reading is affected by changes in atmospheric pressure as well as changes in water level.

When accuracy better than ±150 mm (±6”) head of water is required, atmospheric pressure must be monitored and the reading must be adjusted for changes in atmospheric pressure.

Atmospheric pressure should be monitored by an on-site recording barometer or by a second piezometer that is dedicated to monitoring atmospheric pressure.

Installation

1. Lower the piezometer into the well and position it at the specified depth or just below the maximum expected drawdown. If turbulence is expected, use a centralizer to keep the piezometer stable.
2. Secure the signal cable above ground level.

Taking Readings

Introduction

These instructions tell how to read the VW piezometer with Slope Indicator's portable readouts.

Instructions for reading VW sensors with a Campbell Scientific CR10 can be found at www.slopeindicator.com. Go to Support - Tech Notes and click on the link titled "CR10-VW Sensors."

Reading with the VW Data Recorder

1. Connect signal cable from the sensor to the data recorder:

Binding Posts	Wire Colors	
VW	Orange	Red
VW	White & Orange	Black
TEMP	Blue	White
TEMP	White & Blue	Green
SHIELD	Shield	Shield

2. Choose Hz + RTD or Hz + Thermistor.
3. Select the 1400-3500 Hz range.
4. The recorder displays the VW reading in Hz and a temperature reading in degrees C.

Reading with the VWP Indicator

1. Connect signal cable from the sensor to the VW indicator's jumper cable (part# 52611950), as shown below.

Clips	Wire Colors		Function
Red	Orange	Red	VW
Red	White & Orange	Black	VW
Black	Blue	White	TEMP
Black	White & Blue	Green	TEMP

2. Read the VW sensor: Select the 1.4-3.5 kHz range with the Sweep key. Select Hz with the Data key.
3. Read the temperature sensor: Select °C with the Data key. Note that the VWP Indicator reads RTDs only and cannot read thermistors.

Reading with the DataMate MP

The DataMate MP allows you to choose engineering units for your readings. However, for ease of data reduction, we recommend that you record readings in Hz. See the DataMate MP manual for directions on programming.

Manual Mode

1. Connect the DataMate to the sensor (see connection table below).
2. Switch on. Press ✔ (Manual Mode).
3. Scroll through the list to find “Vibrating Wire Hz.”
4. Press ↵ to excite the sensor and display the VW reading in Hz and a temperature reading in degrees C. Note that this provides readings only for RTDs, not thermistors. A separate setting can be used to read thermistors.

Connections

The DataMate jumper cable has a universal connector that connects directly to a universal terminal box or to signal cables that are terminated with a universal connector. A bare-wire adapter (BWA) is also supplied with the DataMate. It allows connection to wires of the signal cable as shown below:

Terminals on BWA or Terminal Box	Wire Colors		Function
5	Blue	White	RTD
6	White & Orange	Black	VW
7	White & Blue	Green	RTD
8	Orange	Red	VW
10	Shield	Shield	Shield

Data Reduction

Overview

Readings from your VW piezometer are typically in Hz, rather than in units of pressure. To convert the Hz reading to units of pressure, you must apply factors listed on the sensor calibration record.

There are a number of corrections that you can make to the pressure reading. Your application determines whether these corrections are required or not. We list these corrections later in this chapter.

Sensor Calibration Record

Each VW piezometer has a unique calibration. Use the sensor serial number to match the sensor with its calibration record.

Conversion Factors

ABC Factors: Your calibration record may list these as "manual" ABC factors. They are used to convert Hz readings to various engineering units. They can be used in programmable readouts, such as the DataMate MP, or they can be used in spreadsheets. Keep in mind that it is always a good idea to record unprocessed readings (Hz and °C). Processing on your PC is almost always preferable to processing in the readout or data logger.

IDA ABC Factors: These factors are used to program "retired" readouts, such as the VS DataMate and the IDA system. These readouts can be programmed to provide readings in Hz and °C.

Temperature Factors

These two factors can be used to calculate a correction for temperature effects. The factors are applied to the temperature reading that you obtain from the sensor's built-in thermistor or RTD. Older calibration records list a temperature coefficient.

Temperature Offset

The temperature offset shows the difference between a reading taken with the piezometer's built-in thermistor or RTD and a reading taken with an NIST-traceable temperature sensor.

If you are interested in absolute temperature values, add the offset to your temperature readings.

Converting Hz Readings to Units of Pressure

1. Choose a unit of pressure from the ABC factors listed on the sensor calibration record.
2. Apply the factors as follows.Apply the factors as follows:

   Pressure Reading = $Ax^2 + Bx + C$

   Where x is the Hz reading and A, B, and C are factors listed on the sensor calibration record

Finding Changes in Pressure

Subtract the initial reading from the current reading. A positive value indicates increased pressure. A negative reading indicates decreased pressure.

$\Delta Pressure = Pressure_{current} - Pressure_{initial}$

Barometric Correction

Geography and weather patterns control variations in atmospheric pressure. In some locations, pressure varies little, except when there are storms. In other locations, normal weather may bring barometric pressure changes as large as 34 mb (0.5 psi) during a day, and 68 mb (1 psi) during a year.

Is this correction required?

Is your piezometer sealed in a borehole to measure pore-water pressure? In this case, the only pressure acting on the piezometer's diaphragm is the water pressure at that depth, so a barometric correction should not be applied. Even if you later found a relation between barometric pressure and pore-water pressure, you would probably not apply a correction.

Are you measuring the water level in a standpipe or well that is open to atmosphere? In this case, the pressure seen at the piezometer is the combined pressure of water and the air above the surface of the water. If the barometric pressure drops, the piezometer will report decreased pressure, even if the water level remains unchanged. If you want to eliminate measurement uncertainty introduced by barometric pressure, you must apply a correction.

You can use a barometer or a second piezometer to measure atmospheric pressure. This is explained on the next page.

Using a barometer reading to calculate a barometric correction

1. Obtain barometer reading on site at the time of reading the piezometer. The barometer should provide station pressure, i.e. the actual pressure of the atmosphere, with no adjustment for elevation above sea level. Off-site reports from weather stations are not adequate for this purpose.

2. Subtract the barometer reading from 1 atm (1013.2 mb or 29.92 inches of mercury). This is the barometric correction value in millibar or in Hg.

   Barometric Correction = 1 atm - barometer reading.

3. Convert the barometric correction value to psi or bar.

Starting Unit	Multiplier	Resulting Unit
millibar	0.001	bar
	0.014503	psi
Inch Hg	0.03386	bar
	0.49115	psi

4. Add the barometric correction to the pressure reading.

   Corrected Pressure = Pressure Reading + Barometric Correction

Using a VW piezometer as a barometer

The VW piezometer is calibrated to report 0 psi at 1 atm. Thus, to make the piezometer report the same as a barometer, we would have to add 1 atm to the piezometer reading. A barometric correction would then be calculated as follows:.

Barometric Correction = atm - (atm + piezometer reading).

1. Thus a correction can be calculated by simply changing the sign of the piezometer reading.

   Barometric Correction = -1 x piezometer reading

2. Add the barometric correction to the pressure reading.

   Corrected Pressure = Pressure Reading + Barometric Correction

Elevation Correction

Barometric pressure drops about 0.5 psi for every 1000 feet of elevation. The piezometer, which reads zero at sea level, will now read a negative pressure.

Is this correction required?

If you are correcting for barometric pressure changes as described in the previous section, no elevation correction is required.

If you are monitoring changes in pore-water pressure or water levels, no elevation correction is required. You can think of elevation as a kind of offset that is eliminated when you calculate changes. Note that variations in atmospheric pressure will still affect readings from standpipes open to atmosphere.

If you require absolute pore-water pressure or absolute water levels, you should apply the elevation correction. Again, variations in atmospheric pressure will still affect readings from standpipes open to atmosphere.

Calculating the Elevation Correction

1. The equation below works with meters of elevation:

$$\text{Elevation Correction} = \text{Conversion Factor} \times \left[1 - \left(1 - \frac{\text{Elevation in meters}}{44307.69231}\right)^{5.5328}\right]$$

For a correction in this unit:	Use this conversion factor:
bar	1.0132
kPa	101.33
psi	14.696

2. Add the elevation correction to the pressure reading.

   Corrected Pressure = Pressure Reading + Elevation Correction

Temperature Effects

Temperature can affect the response of the piezometer, and a correction for temperature effects can optionally be calculated.

Is a correction needed?

If your piezometer is sealed in a borehole or buried in fill, there is probably no reason to correct for temperature variations, since they will be very small.

If your piezometer is suspended in a shallow standpipe or well, it may be subject to wide changes in temperature as the seasons change. In this case, a temperature correction might be useful.

Note that the temperature corrections are useful only when there is enough time for all the parts of the piezometer to reach temperature equilibrium. If the water temperature changes faster than that, then it is better not to correct.

Temperature factors after July 2002

1. Find the temperature factors on the sensor calibration record. There are three factors: m, b, (both in PSI) and TempOffset. You can convert m and b to other units, if necessary.

To convert from psi to:	Multiply m and b factors by:
kPa	6.895
bar	0.06895
meters of water	0.7037 (water at 15.5 °C)

2. Calculate the temperature correction:

   Temperature Correction = m x (Temperature Reading - TempOffset) + b

   Where m, b, and TempOffset are values listed on the calibration sheet and TemperatureReading is the current reading in degrees C obtained from the piezometer's built-in thermistor or RTD.

3. Apply the temperature correction:

   Corrected Pressure = Pressure + Temperature Correction

Temperature coefficient before July 2002

1. Older calibration records show a temperature coefficient that should be applied to a change in temperature readings from the RTD or thermistor.

   Temperature Correction = Temp Coefficient (T_0 - T_1)
   Where Temp Coefficient is converted to the required unit, T_1 is the current temperature reading, and T_0 is the initial temperature reading.

2. Add the temperature correction to the pressure reading.

   Corrected Pressure = Pressure + Temperature Correction

Acceptance Tests

Introduction

The main purpose of an acceptance test is to provide reasonable assurance that a sensor is functioning properly. Unless you have access to sophisticated test facilities and calibration equipment, acceptance tests should not be expected to achieve the accuracy and precision of the calibration data provided on the sensor calibration record. Thus when you evaluate the results of an acceptance test, look for obvious non-conformance rather than an exact match between your data and the data on the calibration record.

Quick Zero Check

1. Ideally, this test would be conducted in a draft-free room where the piezometer can be kept at a constant temperature. At minimum, the piezometer should be placed in a location that is out of direct sunlight and allowed to reach thermal equilibrium with the surface it is resting on and the surrounding air. This takes about an hour. Do not handle the piezometer during this time or during the test.

2. Connect the signal cable to readout and obtain a frequency reading. Check that you have obtained a repeatable reading.

3. Apply calibration factors to convert the frequency to a pressure reading in psi.

4. If your local elevation is above sea level, the pressure reading that you obtain will most likely be negative because the sensor calibration is referenced to one standard atmosphere (sea level). To calculate a correction for your elevation, allowing 0.5 psi for every 1,000 feet of elevation above sea level (1.15 mb per 10 m). Add the correction to your reading. For example, if you are at 5,000 feet, you would add a correction of 2.5 psi to the pressure reading.

5. The piezometer is working satisfactorily if the difference between the corrected pressure and zero is within 2 percent of the full scale of the piezometer (2 psi for a 100 psi piezometer).

6. To make a more precise check, you would correct for the true altitude, the barometric pressure, and the temperature.

Down Hole Pressure Check

This test is conducted in a water-filled borehole or standpipe piezometer. You will need the sensor calibration record.

1. Mark signal cable at two depths, one at a shallow depth and the other as deep as possible (within the range of the piezometer). Measure from the location of the diaphragm: 0.9 inch from the tip of the borehole piezometer; 4.4 inches from the tip of the push-in piezometer, and 2 inches from the tip of the embankment piezometer.
2. Pull the filter off the piezometer, fill it with clean water, and replace the filter. Hold the filter end up until the piezometer is placed in the water.
3. Lower the piezometer to the shallowest mark on the signal cable. Clamp the cable in position and wait at least 30 minutes for the piezometer to adjust to the temperature of the water. Connect the piezometer signal cable to the readout device. Check that you can obtain repeatable readings. Record the frequency reading and the temperature reading at the shallow depth.
4. Lower the piezometer until the other mark on the signal cable is lined up with the same reference used for the shallow position. Allow the piezometer to adjust to temperature at that depth. Check that you have repeatable readings, then record the frequency reading, and the temperature reading.
5. Convert both readings to units of pressure by applying calibration factors.
6. Subtract the shallow pressure from the deep pressure. We do this to avoid having to correcting for altitude.
7. Convert both pressure values to feet or meters of liquid head and compare to the distance between the two marks made on the signal cable.
8. There are many variables that can degrade the accuracy of this test, including positioning errors, the specific gravity of water at each depth, temperature of the piezometer at each depth, etc. You can correct for these, but the real purpose of the test is to verify that the piezometer gives you roughly the reading that you would expect.

Diagnostics

Introduction

Perform the tests below to diagnose what is wrong with your piezometer. Unfortunately, after the instrument has been installed, there is often no remedial action possible.

No Reading

Set your handheld multimeter to a low-ohm range (5k ohm).

- Measure the resistance between the two VW wires (orange and white-and-orange). A normal reading should be about 300 ohms. If the reading is very high or infinite, the coil is damaged (or the cable is severed). If the reading is very low, the cable may have been crushed and a short has developed.
- Measure the resistance between the temperature sensor wires (blue and white). Thermistors should read about 3000 ohms. RTDs should reading about 2000 ohms. If the reading is very high or infinite, the temperature device is damaged (or the cable is severed). If the reading is very low, the cable may have been crushed and a short has developed.

Unstable Reading

Set your handheld multimeter to a high range (10 or 20 M ohm).

- Measure the resistance between a VW wire and a Temp wire. The reading should be infinite or out of range.
- Measure the resistance between any of the colored wires and the drain (shield) wire. The reading should be infinite or out of range.
- Measure the resistance between the shield wires of two installed VW sensors. Wires must be disconnected from data logger or terminal box to make this test. The reading should be very high or infinite. A lower reading indicates the presence of a ground loop.
- Other sources of unstable readings are electrical noise from nearby power lines, radio transmitters, or motors. Also, over ranged or shocked instruments can exhibit this problem.