RST INSTRUMENTS LTD.

Vibrating Wire Piezometer
Model VW2100
Instruction Manual

RST Instruments Ltd.
11545 Kingston St.,
Maple Ridge, B.C. Canada   V2X 0Z5
Tel: (604) 540-1100
Fax: (604) 540-1005
Email: info@rstinstruments.com
Website: www.rstinstruments.com

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Product: Vibrating Wire Piezometer Model VW2100
                             Installation Manual

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1 INTRODUCTION

The RST Vibrating Wire Piezometer is a stable, robust pressure transducer, designed to allow very accurate remote measurements of piezometric levels and borehole pressures over long periods of time and through all conditions. The VW pressure transducer output is a frequency signal which is unaffected by line impedance and/or contact resistance of the conductor. This allows for the accurate transmission of the frequency signal over very long distances. These types of VW sensors can be installed in boreholes (models VW2100-1), or driven into soft ground (model VW2100-DP).

A standard integral thermistor is included within each transducer, which measures the temperature of the transducer and its surroundings. This temperature information is used to provide temperature correction to the output pressure readings.

A gauge calibration factor and temperature correction factor are supplied with each manufactured gauge based on the factory calibrations which are carried out for each sensor, immediately following manufacture.

A portable Vibrating Wire readout unit, such as the RST model VW2106, is used to display the frequency of the vibrating wire which is proportional to the pressure being applied to the VW transducer diaphragm.

Additionally, the VW2106 readout unit will display the transducer temperature directly, in degrees Celsius.

Complete datalogging systems are available from RST to provide automated data collection from VW transducers. Consult RST for more information, if required.

2 RST VW PIEZOMETER CONSTRUCTION

The RST VW piezometer is a Vibrating Wire diaphragm pressure sensor. Pressure applied to the transducer diaphragm will cause a change in the Vibrating Wire tension, resulting in a change to the resonant frequency, which is directly proportional to the pressure change.

The Vibrating Wire sensors are made of two small diameter cylindrical parts joined by a length of steel tubing. The diaphragm is welded to the front cylinder. . A high strength steel wire (the Vibrating Wire) is clamped to the center of the diaphragm, then is run through the first cylinder, and then clamped to the base of the second cylinder which is the end block. The Vibrating Wire is clamped to the diaphragm and end block by low temperature hydraulic swaging which virtually welds the parts together without affecting the elastic properties of the wire. All parts of the sensor, other than the actual Vibrating Wire are machined from a high-grade stainless steel, selected for its low yield and high corrosion resistance.

The Vibrating Wire is set to a pre-determined tension during the manufacture. The instrument housing is evacuated and sealed using electron beam welding to ensure a perfect seal and a long working life. An O-ring placed behind the diaphragm seals the back of the assembly within the housing. A coil/magnet assembly is built into every VW transducer which is used in conjunction with the RST readout box, to pluck the Vibrating Wire and measure the VW's vibration period.

2.1 MODEL VW2100

The model VW2100 VW piezometer is designed to be embedded in earth fills and concrete, or inserted into boreholes and pipes as small as 19mm (3/4 inch) diameter. These VW piezometers consists of a small diameter cylindrical housing containing a pressure transducer and thermistor. One end is fitted with an insert that holds a micrometric high air or low air entry filter. The opposite end contains the cable entry, sealed with an epoxy compound. All parts are made of stainless steel.

The entry filter is set in the front end of the housing and sealed with an O-ring. With the filter in place, the diaphragm is protected from solid particles, and senses only the fluid pressure to be measured. The filter housing is easily removable for calibration of the transducer

The filter assembly can also be replaced with a pipe thread adapter fitting to use the gauge as a pressure transducer (Model VW2100-PT).

2.2   MODEL **VW2100-DP**

The model VW2100-DP Vibrating Wire piezometer is designed to be driven into unconsolidated fine grain material such as sand, silt or clay. The external housing is a thick walled cylinder fitted with a pointed shoe at one end, and male thread adapter at the cable entry, which fits standard "EX" drill rods. Three port holes above the point are equipped with micrometric filters. The data cable passes through the threaded end, and can be fed up through the drill rods to the surface. The cable entry is sealed with an epoxy compound. Both high and low air entry filters are available.

3 VIBRATING WIRE PRINCIPLE

The sensing element of the Vibrating Wire piezometer is a high strength steel wire attached to the diaphragm, (see section 2 for details). The VW is excited by two coil/magnets set around the connecting over tube. In operation, external pressure on the diaphragm will move the diaphragm a very small amount, which changes the tension on the Vibrating Wire. This tension change is directly proportional to the resonant, or natural, frequency at which the VW will vibrate.

The VW2106 Readout Unit generates plucking voltages to the coil/magnet in a spectrum of frequencies, spanning the natural frequency of the vibrating wire. This plucking allows the VW to find it's current natural frequency related to the pressure it is currently experiencing.   In turn, the oscillation of the VW generates AC voltage in the coil. This output signal is amplified by the 2106 Readout Unit, which also discriminates against harmonic frequencies, to determine the resonant frequency of the wire. The VW2106 Readout measures 100 cycles of vibration with a precise quartz oscillator, and displays a value proportional to the frequency squared, which is called B Units ($Frequency^2$ x 10^{-3}).The relationship between the B Unit readings and the pressure being exerted on the instrument diaphragm is expressed by the following equation:

$$P = CF (Li – Lc)$$

where:

P	=	Corrected Pressure Reading.
CF	=	Linear Calibration Factor – in kPa per B Unit digit. The CF is a unique value for each manufactured VW sensor and is determined by the initial laboratory calibration.
Li	=	Initial B Unit Reading at zero applied pressure on the diaphragm. The Li is a unique value for each manufactured VW sensor and is determined by the initial laboratory calibration.
Lc	=	Current B Unit Reading under the currently applied pressure on the diaphragm

The Vibrating Wire technology offers the unique advantage of frequency output signal virtually unaffected by line impedance, or contact resistance. Cable lengths of up to 1.5 km can be used without signal deterioration.

4 CALIBRATION

All RST VW piezometers are individually calibrated in the laboratory before shipment. Each VW piezometer is calibrated over its full working pressure range. A Linear Calibration Factor (CF) is established by using the calibration data points to do a linear regression. In addition, the calibration data is also fitted to a polynomial regression which provides slightly more accurate data output over the full reading range. Both formulas are provided on the instrument Calibration Record sheet for use as appropriate. It is also noted that RST dataloggers are set-up to use either formula to calculate the instrument output in engineering units.

As part of the calibration procedure, all VW Piezometers are tested to 150% of the standard working range to prove their function at overpressure. In addition, the sensor calibration is carried out over a temperature range of -20⁰ C to +80⁰ C which proves their function at a wide temperature range and provides the input data for the Temperature Correction Factor for each sensor.

A Calibration Record sheet is provided with each VW sensor for use in calculating the applied loads on the VW sensors. The following general information is contained in the Calibration Record sheet. Refer to Appendix A for an example of a Calibration Record sheet.

- Model Number:

- Serial Number:

- Manufacturing Number:

- Pressure Range:

- Work Order Number:

- Cable Length:

- Cable Meter Markings:

- Cable Color Code:

- Cable Type:

- Thermistor Type and Linear Calibration Factor (CF)

- Temperature Correction Factor (Tk)

- Polynomial Gauge Factors (A, B and C)Barometric Pressure at time of Calibration

- Temperature at time of Calibration

- Calibration Data Table

- Linear and Polynomial Formulas

- Calibration Certification

4.1   FIELD CALIBRATION CHECK

The following procedure can be used in the field to verify the validity of a VW Piezometer calibration, as supplied on the instrument Calibration Record sheet.

1. For standard Model VW2100 Piezometers, saturate the filter stone and ensure the space between the instrument diaphragm and the filter stone is totally filled with water. Refer to Appendix B for more detailed information on the saturation of VW2100 Piezometers with Casagrande style filter assemblies and VW2100-DP Piezometers.

2. Lower the piezometer to depth in a a vertical, water filled borehole using the cable markings to accurately control and set the depth. To ensure adequate accuracy of this field calibration check, it would be best to have a minimum emersion depth of about 10 meters.

3. Allow 20 to 30 minutes for the VW piezometer to come to complete thermal equilibrium in the hole. Using a 2106 Readout Unit, record the B unit and temperature readings at that depth.

4. Raise the VW piezometer a known amount, while keeping it fully submerged. If the temperature readings is noted to be changing, allow the instrument to come to the new thermal equilibrium (up to 30 minutes, if required).

5. Record the new B Unit and temperature readings at the higher elevation. Calculate the instrument Calibration Factor (CF) (kPa per B Unit) from this information, given the change in pressure head and B Unit readings.

6. Compare this field calibration to the CF value provided on the Calibration Record sheet. The two values should agree within ± 0.5%. Repeat this calibration check as necessary to confirm the sensor is in proper working condition.

7. If the Calibration Record sheet CF value cannot be confirmed by this field calibration test, the piezometer should not be installed. The instrument will need to be inspected and undergo a full shop function test and re-calibration before being returned to service.

- Note of Caution Regarding the Above Field Calibration Check Procedure:

  If the diameter of the water filled borehole is too small, the volume of water that the VW Piezometer cable displaces, when raised or lowered into position, could potentially raise or lower the borehole water level. This effect could seriously impact the accuracy of the above detailed Field Calibration Check. Noted that this potential effect will be further dependent on the available permeability of the borehole to absorb small amounts of volume change.

  To avoid this potential problem, it is recommended that the water filled borehole used for Field Calibration Checks be large enough in diameter, so that the potential error caused by cable volume displacement, will be insignificant in the calculation of the pressure change. A good rule of thumb is to use a borehole diameter that is a minimum of 10 times greater than the wire diameter. In addition, a borehole with a moderate degree of permeability would be much preferred to a "tight" borehole.

5   READING PROCEDURES

5.1   VW INSTRUMENT READINGS

The Operator must become familiar with the function and operation of the VW2106 Vibrating Wire Readout Unit prior to taking any VW instrument readings. Failure to do this could potentially result in damage to the VW2106 Vibrating Wire Readout unit and/or the VW sensors that are connected to it.

The Operator is strongly encouraged to review the instruction manual for the VW2106 Readout unit before proceeding.

5.2   INITIAL INSPECTION AND CHECK READINGS

A full inspection of all received VW instrumentation equipment is required immediately upon receipt at site, to ensure that the VW instruments have not been damaged in anyway during shipment and are fully functional, and ready for use.

Test readings should be taken of each VW instrument and compared to the VW instrument reading information provided on the Calibration Record sheet. If any discrepancies are noted, they need to be fully investigated and satisfactorily resolved before the VW instrument is released for field installation and service. The Operator doing the inspection and initial test readings must be familiar with the VW instrument operation and the contents of this instruction manual (VW Piezometer, Model VW2100, Instruction Manual, ELM0005K).

5.3   INITIAL READINGS

Vibrating Wire Piezometers differ from other types of pressure sensors in that they have a positive B-Unit reading without any external pressure being applied. This is because the Vibrating Wire, in the core of the sensor, is manufactured with an initial tension. VW Piezometers are therefore acutely sensitive to pressure changes right at the zero point, because there is no zero point hysteresis to overcome. The determination of VW instrument Initial Readings at the "zero point" is very important for the accuracy of the subsequent readings.

Before installing the VW piezometer, it is necessary to take initial zero readings with no applied load. The initial zero reading should be taken with either the filter stone removed or with the stone installed and completely saturated (Section 4.1 and Appendix B). The temperature reading from the internal thermistor must also be recorded. And for piezometers with a total range lower than 250 psi, the barometric pressure must also be recorded. These values are needed to be able to apply the correct Correction Factors for changes in temperature and/or barometric pressure, which will impact the reading accuracy of the VW Piezometers though their intended range.

Generally, initial zero readings are obtained immediately prior to installation with no external pressure being applied and at a constant ambient temperature and barometric pressure.

The following checks are required to obtain accurate initial zero readings:

- Has the temperature of the VW piezometer body reached full thermal equilibrium? Variations in temperature across the mass of the piezometer body may result in a temperature reading which is not consistent with the entire Vibrating Wire instrument. This inconsistency will result in an error to the calculated pressure being read by the VW sensor. Allow 20 to 30 minutes for the temperature of the VW Piezometer to equilibrate. If required, sources of temperature fluctuation, such as water flow, may have to be eliminated.

- Is the filter stone saturated? If the filter stone is only partially saturated, then surface tension effects within the pore spaces of the filter could affect the zero readings. This can be a particular problem at low pressures (less than 5 psi). If there is any question regarding the adequate saturation of the filter stone, the filter stone should be removed to allow direct atmospheric connection with the transducer diaphragm.

- <u>Be sure to record the VW piezometer temperature and the barometric pressure at the same time the B-Unit zero readings are taken</u>.

5.4   PRESSURE EQUATION (USING THE VW2106 READOUT)

The VW2106 VW Readout Unit displays VW piezometer readings in Frequency units called B-Units which equal $F^2 \times 10^{-3}$, where F = Frequency in Hertz.

The B-Unit values represent the absolute pressure and must be corrected for temperature and barometric pressure changes.

B-Unit ($F^2 \times 10^{-3}$) changes from the Initial Zero Reading are converted to the actual pressure changes using the below equations which include corrections for temperature and barometric pressure changes.

Linear Equation; $\quad\quad\quad\quad\quad$ $P \ = \ CF(L_i - L_c) \ - \ T_K(T_i - T_c) \ + \ F(B_i - B_c)$

Where:

$\quad\quad$ **P** $\quad\quad\quad\quad$ = **C**orrected Pressure; in kPa

$\quad\quad$ **CF** $\quad\quad\quad$ = Calibration Factor; in kPa / B-Unit (From the VW Piezometer Calibration Record sheet for each individual sensor)

$\quad\quad$ **L_i L_c** $\quad\quad$ = Initial and Current B-Unit reading ($F^2 \times 10^{-3}$)

$\quad\quad$ **T_K** $\quad\quad\quad$ = Temperature Correction Factor; in kPa / degree C Rise (From the VW Piezometer Calibration Record sheet in each individual sensor)

$\quad\quad$ **T_i T_c** $\quad\quad$ = initial and current temperature readings; in (ºC)

$\quad\quad$ **F** $\quad\quad\quad\quad$ **=** Barometric Pressure Constant = 0.1 kPa / Millibar

$\quad\quad$ **B_i B_c** $\quad\quad$ = Initial and Current Barometric pressure readings; in Millibars

Example for a 350 kPa Range Piezometer::

$\quad\quad$ **CF** $\quad\quad\quad$ = 0.11594 kPa / B-Unit

$\quad\quad$ **L_i** $\quad\quad\quad\quad$ = 8776 B-Units

$\quad\quad$ **L_c** $\quad\quad\quad\quad$ = 7200 B-Units

$\quad\quad$ **T_K** $\quad\quad\quad$ = - 0.03413 kPa / ºC

$\quad\quad$ **T_i** $\quad\quad\quad\quad$ = 22.9 ºC

$\quad\quad$ **T_c** $\quad\quad\quad\quad$ = 5.0ºC

$\quad\quad$ **F** $\quad\quad\quad\quad$ =0.1 kPa / Millbar

$\quad\quad$ **B_i** $\quad\quad\quad\quad$ = 1003.1 mbar

$\quad\quad$ **B_c** $\quad\quad\quad\quad$ = 995 mbar

$\quad\quad$ **P** $\quad\quad\quad\quad$ = [(0.11594) x (8776 - 7200)] - [(-0.03413) x (22.9 – 5.0)]

$\quad\quad\quad\quad\quad\quad\quad\quad$ + [0.1 x (1003.1 – 995)]

$\quad\quad$ **P** $\quad\quad\quad\quad$ = [182.72] - [-0.61] + [0.81] = **184.14 kPa**

Second Order Polynomial Equation; $P = \mathcal{A}(L_c)^2 + \mathcal{B}(L_c) + C + T_K(T_c - T_i) - F(B_c - B_i)$

Where:

P	= **C**orrected Pressure; in kPa
$\mathcal{A}$	= Polynomial Gauge Factor A; Second Order Polynomial Expression derived from the VW Piezometer Calibration data, for each individual sensor
$\mathcal{B}$	= Polynomial Gauge Factor B; Second Order Polynomial Expression derived from the VW Piezometer Calibration data, for each individual sensor
C	= Polynomial Gauge Factor C; Second Order Polynomial Expression derived from the VW Piezometer Calibration Record sheet in each individual sensor
L_c	= Current B-Unit reading ($F^2 \times 10^{-3}$)
T_K	= Temperature Correction Factor; in kPa / degree C Rise (From the VW Piezometer Calibration Record sheet in each individual sensor)
T_i T_c	= initial and current temperature readings; in (ºC)
F	**=** Barometric Pressure Constant = 0.1 kPa / Millibar
B_i B_c	= Initial and Current Barometric pressure readings; in Millibars

Example for a 350 kPa Range Piezometer::

$\mathcal{A}$	= - 4.1484E-07 - Dimensionless
$\mathcal{B}$	= - 0.10991 - Dimensionless
C	= 996.58 - Dimensionless
L_c	= 7200 B-Units
T_K	= -0.03413 kPa / ºC
T_i	= 22.9 ºC
T_c	= 5.0ºC
F	=0.1 kPa / Millbar
B_i	= 1003.1 mbar
B_c	= 995 mbar

P	$= \left[(\text{-4.1484 E-07}) \times (7200)^2 \right] + \left[\text{-0.10991} \times 7200 \right] + \left[996.58 \right] +$ $\left[\text{-0.03413} \times (5.0 - 22.9) \right] - \left[0.1 \times (995 - 1003.1) \right]$
P	$= \left[\text{-21.51} \right] + \left[\text{-791.35} \right] + \left[996.58 \right] + \left[0.61 \right] - \left[\text{-0.81} \right] =$ **185.14 kPa**

Note
Barometric compensation is *not* required with vented and differential pressure transducers.

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6 INSTALLATION

Vibrating Wire piezometers can be installed in various ways to suit the individual application. Specific guidelines for the installation of piezometers have been developed by various agencies and technical specialists. A list of references is given in Appendix E.

The following instructions summarize the generally accepted practice for:

- filter saturation,

- cable identification,

- piezometers installed in clay fill, granular material or boreholes,

- cable routing.

It is not recommended that VW piezometers be installed in wells or standpipes where an electrical pump and/or a power supply cable is present or nearby. Electrical interference from these sources can cause unstable readings. Ground fault currents from this type of equipment can easily damage the sensitive low voltage VW Piezometers. If for some reason, installation under these conditions is unavoidable, additional steps must be performed at the site to ensure complete isolation and adequate grounding of the instrumentation circuits. Care is also required to ensure that the instrument shield wire is well grounded, but isolated from sources of external electrical interference.

In situations where Vibrating Wire piezometers and packers are used at the same time in standpipes or wells, special care must be taken to avoid damaging or cutting the cable jacket with the packer equipment or tools. Any cuts in the cable jacket will allow water entry which will potentially result in damage or failure of the VW sensor.

6.1 FILTER SATURATION

Two types of filters are available; high air entry ceramic or low air entry sintered stainless steel filters.

These filters are intended to protect the delicate diaphragm area of the VW piezometer, while allowing the transmission of external pressures. The filters and bottom cavity of the piezometer body must be saturated to allow the accurate transmission of hydraulic pressures to the VW diaphragm. Filter saturation provides the following reading advantages:

- In a saturated environment, there is no fluid movement, only pressure transmission. This reduces the possibility of the filter becoming clogged with debris, due to oscillating water movement, .

- Decreased response times due to pressure changes, which means increased sensor sensitivity,

- In unsaturated soils, this will ensure hydraulic continuity between the pore water and the piezometer diaphragm, which will provide the highest accuracy of pressure measurement.

6.1.1 LOW AIR ENTRY SINTERED STAINLESS STEEL FILTERS

For accurate reading results, total saturation of the filter is necessary. For the low air entry filters, which are the standard filter type supplied, saturation will start to occur as the piezometer is lowered into the water. Water will be forced into the filter, compressing the air in the space between the filter stone and the pressure sensitive diaphragm. After a period of time, this air will dissolve into the water until the space below the diaphragm and within the filter is entirely saturated. This could take up to several days, which could mean slightly inaccurate initial reading results the first few days.

The following procedure will speed up the filter saturation process and will allow accurate readings to be taken immediately:

- Turn the VW piezometer upside down and remove the end filter assembly, which is held in place with an internal O-ring,

- Submerge the inverted piezometer in bucket of flat water (water which has been sitting for a day), This will fill the space above the piezometer diaphragm with water,

- While keeping the piezometer submerged, slowly replace the filter housing onto the inverted piezometer end, allowing the water to be forced out through the filter sinter.   Noted that with a low pressure range piezometer (0,1 mPa or less) it is recommended that VW readings be taken with a VW Readout box while the filter housing is being pushed slowly into place, so as to ensure that the sensor does not over-range due to this operation,

- To maintain the filter saturation prior to installation, the VW piezometer should be stored in the bucket of water until ready to install downhole.

- Noted that a VW piezometer cannot be allowed to freeze when fully saturated, otherwise damage will occur to the transducer diaphragm, which will invalidate the transducer function and calibration.

- During the installation, the VW piezometers should be handled as gently as possible to keep the water in the filter sinter and the bottom chamber until being submerged in the borehole.

If the VW2100 piezometer must undergo multiple removals and reinstallations of the filter housing, the O-ring, which provides the friction fit, may become worn and the filter housing may become loose. If this is noted to be occurring, the O-ring should be replaced immediately.

If problems are experienced with salts, or other precipitates, clogging the stainless sinter filter, coarser screen housings are also available for use on VW piezometers,   Unlike the standard stainless sinter filters, screens are less likely to become clogged by precipitates, and other debris, found in some water sources.

Noted that salts, and other dissolved solids, can be deposited within a stainless sintered filter, if the filter is allowed to dry out completely. To prevent filter clogging, it is recommended that the filter be thoroughly rinsed out with clean distilled water, prior to drying.

6.1.2 HIGH AIR ENTRY CERAMIC FILTERS

The ceramic filter on a high air entry piezometer is also removable for de-airing. Because of the high air entry characteristics of the filter, proper de-airing is particularly important for this type of filter assembly in order to ensure that accurate readings can be taken. High air entry filters are available with different air entry values, which will require different procedures. It is therefore very important to know which type of high air entry filter is installed.

One Bar High Air Entry Filters

1. Remove the filter housing from the piezometer body by carefully twisting and pulling on the filter housing assembly. Remove the filter housing slowly, so as not to cause a vacuum pressure on the piezometer diaphragm.

2. Boil the filter assembly in de-aired water for 30 minutes to force all air out of the filter and to saturate the filter material. When finished, place the filter into de-aired water.

3. Re-assemble the filter housing into the piezometer body under the surface of a bucket of de-aired water, while keeping the piezometer oriented with the diaphragm pointing upward. Must be certain that no air is trapped in the transducer cavity.

4. VW readings must be taken with a VW Readout box while the filter housing is being pushed slowly into place, Allow any over-range pressures to fully dissipate before pushing the filter on any further.

5. To maintain the saturation, a VW piezometer, with installed High Air Entry Filter, must be stored in de-aired water until the unit is installed.

6. Noted that a VW piezometer cannot be allowed to freeze when fully saturated, otherwise damage will occur to the transducer diaphragm, which will invalidate the transducer function and calibration

Two Bar (or Higher) High Air Entry Filters

The proper procedure for de-airing and saturating two bar (or higher) high air entry filters is complex and difficult to do properly. It should be done either at the factory or by carefully following the below instructions:

1. Place the assembled piezometer, with the filter housing facing downward, at the bottom of a vacuum chamber. The vacuum chamber is to have an inlet port at the bottom to allow later introduction of de-aired water into the chamber.

2. Close the valve for the de-aired water inlet and evacuate the chamber. The piezometer should be monitored with a VW Readout box while the chamber is being evacuated.

3. When the maximum vacuum has been achieved in the vacuum chamber, the piezometer is read by the VW Readout Box, until it has also reached the same maximum vacuum pressure.

4. At this point, the de-aired water inlet valve is opened to allow de-aired water to enter the bottom of the chamber and reach an elevation of about 50mm above the top of the piezometer high air entry filter.

5. Close the de-aired water inlet valve when the de-aired water has reached the required height.

6. Release the vacuum, allowing the vacuum chamber to return back to atmospheric pressure.

7. Observe the transducer output on the VW Readout Box. It will take as long as 24 hours for the filter to completely saturate (for a 5 bar high entry filter) and for the piezometer pressure to rise back to zero. The saturation of the high entry filter is considered to be completed at this point.

7. After saturation, the transducer must be kept in a sealed container of de-aired water until ready for installation. If de-aired at the factory, a special plastic cap is applied to the piezometer tip to maintain the saturation level. The plastic cap must be removed immediately before installation.

8.   Noted that a VW piezometer cannot be allowed to freeze when fully saturated, otherwise damage will occur to the transducer diaphragm, which will invalidate the transducer function and calibration

6.2   INSTALLATION IN FILL

6.2.1 COMPACTED CLAY

Excavate a vertical trench, or recess, about 50 cm deep in the clay material. Form a horizontal cylindrical hole in the sidewall of the excavated trench, near the bottom. The hole diameter should be slightly smaller than the piezometer body, so that when the piezometer is inserted in the hole, it will have a snug fit.

Push the piezometer into the hole in the trench side and into the host clay material. If necessary, to ensure continuity with the saturated high air entry filter and the pore water, smear the filter ceramic with a thin paste of the saturated clay material.

Before back-filling the trench, the cable must be placed with the utmost care to avoid any damage due to kinking or stretching. Loop the cable and route it out of the trench, making sure it rests on a bed of hand placed and lightly compacted screened clay.   Make sure that the cable does not come into direct contact with itself or other cables in the same area. Always maintain a few cm of compacted clay material between any two cables.

Backfill the trench with screened clay containing no particles larger than 3mm in dimension. The backfill should have a water content and density equal to that of the surrounding material.

Make sure that the cable is well protected from any potential damage caused by any angular fill material, the compacting equipment and any settlement that might occur due to construction work or subsequent fill placement.

6.2.2 GRANULAR MATERIALS

Excavate a vertical trench, or recess, about 50 cm deep in the granular material. Place the piezometer horizontally in the center of the trench, or recess, excavated for this purpose. Loop the cable and backfill the bottom 10 cm of the trench around the piezometer with screened granular material, not exceeding 3mm in dimension. Above that level, the trench can be backfilled in 10 cm lift with the same granular material that was excavated. The granular backfill should contain the same moisture content and should be compacted to the same density as the surrounding fill.   Care must be exercised to not subject the piezometer instrument to damage during the compaction work

In rock fill (particle sizes greater than 10mm), the large interstitial voids will not allow fine backfill materials around the piezometer to stay in place. The fine filter materials will migrate into the rock fill, eventually leaving the piezometer body in direct contact with the angular rock fill material. In this case, it will be necessary to place a graded filter zone around the piezometer to ensure that the filter materials will not be moved. Fine grained clean sand, grading to pea gravel, or larger, will be required around the piezometer instrument. The particle size of the backfill will have to increase in size outwards toward the rock fill. The sand placed around the piezometer instrument and cable should range in size from 0.5 to 3mm in diameter and should not be angular.

Noted that when attempting to place a fine grained zoned backfill around a piezometer, within courser fill materials, it may be necessary, or advisable, to use geotextile filter fabric layers and/or envelopes to provide hard boundaries. This practice will ensure that fine grained backfill materials, used within a graded filter, will not become mobilized and wash away.

6.3   INSTALLATION IN BOREHOLES

6.3.1 SAND/BENTONITE METHOD

The method used to install a piezometer in a borehole depends on the technical requirements for the instrument, the drilling method that was employed, the particular downhole conditions and the materials which the installation must be carried out in. The general method described below will have general applicability to most installations. However, the Field Engineer must be aware of the unique conditions which may be present in the subject borehole which will make downhole installations a major challenge. Conditions such as artesian pressures, squeezing ground, shear zones, and borehole wall instabilities will impact the piezometric instrumentation method chosen and installation techniques required. For a description of other potential instrumentation methods, please consult the references listed in Appendix E.

General Installation Methodology:

The drill casing is drilled 30 cm below the required piezometer installation elevation. If the piezometer is intended to measure the pore water pressure at a specific horizon, it may be necessary to drill hole to 90 cm below the required piezometer elevation to provide room for the placement of a bentonite bottom seal.

After the drilling is completed to the required depth,   the drill cuttings, and other downhole debris, must be removed from inside the drill casing. The borehole is washed to bottom, inside the drill casing, until the water emerging runs clear.

If the borehole walls are stable enough to remain open, the drill casing can be withdrawn, a certain distance above the hole bottom, to allow the piezometer installation to proceed in the open length of the borehole. This is the desired method because the work will able to proceed in much easier fashion.

If the borehole walls are considered to be unstable, and caving or collapse is likely, the piezometer installation will have to proceed with multiple small withdrawals of the drill casing to minimize the risk of losing the installation. This method is described below and it will be obvious why longer drill rod or casing pulls will be more desirable, if possible.

In general, boreholes in bedrock are more stable than boreholes in soil. And boreholes in cohesive soils are more stable than boreholes in less cohesive, granular soils.

Installation Procedures – (Bentonite Plug Method):

Bentonite Chips are recommended for downhole backfill work because they are a made from solid bentonite which will not hydrate as quickly when exposed to water as will Bentonite Pellets which are a manufacture product. Bentonite Pellets will become sticky very quickly when exposed to water and can easily clump together, bridging inside the casing, well above the target zone. Use of either of these Bentonite product for downhole seals should be limited to holes which are less that 20 meters, due to the difficulty involved with this method.

If required, place a 60 cm bentonite seal at the bottom of the borehole to seal the hole bottom. Raise the drill casing 15 cm and start placing the bentonite chips in 15 cm increments until the bentonite level is 30 cm below the required piezometer elevation. Pull the drill casing as the bentonite is set in place. Be very careful not to bridge or plug the drill casing with the bentonite. This is accomplished by making sure the bentonite level is at all times below the casing bottom and by slowly dropping the bentonite chips one at a time down the hole. Trying to feed the bentonite chips too rapidly will result in bridging of the chips in the drill casing or borehole. If bridging occurs, it will make it extremely difficult to complete the downhole installations. Once the bentonite chips are in place, tamping is not required because the natural swelling of the chips will provide an adequate seal to the borehole walls.

Prior to setting filter sand in place for the piezometer zone, lower a cylindrical weight down the drill casing to ensure that the hole is clear.of any obstructions, down to the top of the bentonite plug. If necessary, rinse the borehole with clean water to remove any obstructions or debris.

In the same general manner, place 30 cm of fine, clean sand, in 15 cm increments by dropping from surface. The drill casing will also have to be pulled as the sand back-filling proceeds. When compete, lower the piezometer into the hole and take the initial reading as described above.

Pull the drill casing 15 cm and backfill the hole around the piezometer with fine clean sand. Repeat until the sand and drill casing is 30 cm above the top of the piezometer. Then take a second reading on the piezometer.

Lift the casing in 15 cm increments and backfill with bentonite chips until a minimum four foot seal has been placed. During the bentonite chip placement, keep the piezometer cable taut to prevent the bentonite chips from holding up and adhering to the wall of the drill casing. Drop the bentonite chips into the hole one at a time to avoid bridging.

If more than one piezometer is to be installed in the drillhole, the intervening distance between the top of the first piezometer zone and the bottom of the next piezometer zone can be backfill with either cement grout or cement/bentonite grout delivered by tremie method. The second piezometer can then be constructed in the same general manner as described above..

Noted that when pulling the drill casing, it cannot be rotated, as this will likely result in damage to the installed piezometers. Once all the drill casing has been removed from the hole, the borehole collar should be topped off with grout and a protective steel collar casing.

6.3.2 FULLY GROUTED METHOD

The fully grouted method of piezometer installation involves the installation of the VW piezometers directly within a cement-bentonite grout mixture. This method has now become widely accepted based on the technical theory and on extensive field testing and application. It provides an simple and accurate method to obtain precision piezometric monitoring results. For a more detailed discussion of this method, the user is encouraged to read Mikkelson & Green (2003) and Contreras et al (2008) (Appendix E – References).

The general method described below, was taken from the two above technical papers and outlines the basic concepts and methodology of the Fully Grouted Method:

When using the fully grouted method, it is very important that proper filter saturation is performed. This ensures that there are no air filled voids in the filter and that cement-bentonite grout will not be able to plug the filter stone. Best practice is to install the piezometers upside down with the filter tips facing upwards which will ensure that the water stays inside the filter stone. The piezometer can be inverted and tied off to its own cable. Or, it can be inverted and taped onto a PVC pipe which can be used as either a downhole carrier pipe or as a tremie pipe for grout delivery .

The design of a bentonite-cement mixture is intended to approximate the strength and deformation characteristics of the surrounding soil or rock (rather than the surrounding permeability). The strength of the grout can be controlled by adjusting the Water-Cement ratio which is easy to control in the field. . The water and cement are mixed first, prior to adding any bentonite. This ensures that the water-cement ratio stays fixed and the strength/modulus of the mix is more predictable. Any type of bentonite drilling mud can be combined with Type I or II Portland Cement to make the mix. The quantity of bentonite powder will vary depending on the grade of the bentonite, the mixing agitation, the water pH and the water temperature. As the bentonite solids content increases, the mix density increases and the permeability decreases.

The final mix point has to be carefully monitored to ensure that the completed grout remains pumpable. Although the grout mix has a target bentonite content, it may be cut short or extra bentonite may be added to attain the required pumping viscosity. In the end, the low permeability cement bentonite grout will provide adequate permeability for the VW piezometer diaphragm to react any pressure changes occurring at the location. A number of installation methods have been identified using the fully-grouted method:

- Install piezometers one by one from the borehole bottom to the collar over multiple days. Use a single PVC plastic tremie pipe, which is reduced in length, as each successive installation is competed to the hole collar.

- Attach the multiple piezometers to a PVC plastic tremie pipe and install to depth in the borehole. Use the PVC plastic tremie pipe to grout the entire hole in one stage and leave it in place. Note that you need to ensure that the piezometers being grouted into the borehole will not be over ranged by the grout column being placed. VW piezometers can be over pressured to 200% of the full scale range. However, in practice, it is recommended that 150% of FS not be exceeded to ensure an adequate safety buffer.

- For deep holes with lower range piezometers, multiple grouted in PVC plastic tremie pipes may be required. If multiple PVC tremie pipes are used, they should have their annulus fully grouted to ensure that no internal to external pressure communication can occur, in the event that one or both of the PCV pipes should break..

- Install piezometers attached to a PVC plastic tremie pipe inside a casing or hollow stem auger. Leave in place while casing or auger stem is pulled out. Downhole grouting may be carried out before the casing or auger stem is pulled or following. This method is well suited to boreholes with wall stability issues.

- Complete drilling and then grout the hole with casing or hollow stem auger still in hole. Next, pull the casing or auger stem and top up the hole collar with grout. Install piezometers in the borehole, from the bottom to the top.   Add weighs to each piezometer, as required, to overcome viscous resistance of the grout while lowering the piezometer.

- Attach piezometers directly to outside of inclinometer casing and grout in place. Piezometers should be placed midway between the casing couplings.

- Attach directly to the outside of corrugated polyethylene settlement pipe (Sondex) or similarly attach to magnet/reed switch casing between the magnet sensors so that pore water pressure and settlement can be measured along the same borehole.

- Install a series of Vibrating Wire piezometers inside a length of perforated 2-inch PVC plastic pipe. The piezometer filter housings will be located in close proximity to one or more of the perforation holes and will therefore be able to monitor the external pressures when fully grouted in-place. This technique is useful in deep installations inside of drill casing or hollow stem augers to prevent cable and/or sensor damage when rotation is required during casing extraction. Later tremie grouting outside the PVC pipe, will result in the piezometers being fully grouted in-place.

6.4   PIEZOMETERS DRIVEN IN SOFT GROUND

RST Model VW2100-DP is designed to be pushed into place from the surface in soft soil materials. For deeper installations where driving from the surface would not be possible, the piezometer may be pushed into place from the bottom of a pre-drilled borehole.

The model VW2100-DP piezometer comes with an adapter fitting which can be connected to AW, CPT, 1"NPT or 1-1/4"NPT threaded pipe or drill rod for pushing.

The drive rods are larger in diameter than the VW2100-DP and form an effective seal above the piezometer. The drive rods are left in the ground with the piezometers, and can only be retrieved when and if, the piezometer is recovered. Should other rods need to be adapted to push the VW2100-DP piezometer in place, it is important to ensure that the first 1.5 meters of these rod have a diameter which is larger than the outside diameter of the VW2100 piezometer housing.

Installation:

1. For accurate results, total saturation of the VW2100-DP filter is necessary. Refer to Appendix C which outlines the steps required to saturate a Drive Point piezometer filter.

2. Prepare the rods to be used downhole. Lay a sufficient number of rods for the push side by side, alternating between male threaded end and female threaded end..

3. The piezometer cable is threaded through the rods leaving a 0.5 meter loop of extra cable laying flat on the ground at each rod end.

4. Leave an 8 meter length of free cable extending beyond the lower extremity of the first rod (assuming 3 meter rod lengths). This should provide sufficient slack to allow easy manipulation of the rods as they are screwed together and pushed into the drillhole.

5. Pull back the spare cable and Screw the lower rod onto the piezometer body. Use a pipe sealing compound or Teflon tape on the threads to form a permanent seal preventing pore-water from flowing into the rod string, thus causing delay response

6. In sequence, add on the required number of rod to reach the push point.

7. When ready to push, connect the VW Readout Box to the VW2100-DP and start monitoring the readings prior to pushing.

8. Push the piezometer into place while monitor any pressure build-up at the tip. Should the pressure exceed the VW working pressure range, stop the driving and wait until the pressure dissipates.

9. Complete the installation and ensure the cable leads are protected.

6.5   CABLE IDENTIFICATION

The VW cables are identified with a VW serial number tag that is attached to the cable jacket at the readout end. If the cable must be cut, this VW serial number tag must be removed and reattached at the new cable end. As an added identification feature, the large cable rolls used in the manufacture of all RST VW sensors have meterage numbers marked on the cable, every meter. The start and end point of the numbering sequence is unique to each sensor and is recorded on the instrument calibration sheet for later reference. Inspection of the cable meterage numbers can therefore be easily be used to verify the ID of an installed VW sensor.

If the VW cable is cut and needs to be repaired, or the cable must be lengthened with a cable splice, RST recommends the use of an RST ELSPLICE4 Electrical Cable Splice Kit For VW Cable. Any cable splice that will be exposed to any moisture should be protected in this manner to eliminate the potential of water egress, short circuiting and conductor corrosion.

6.6   CABLE ROUTING

6.6.1   TRANSITION FROM VERTICAL BOREHOLE TO HORIZONTAL TRENCH

The VW sensor cable should be routed along a curved path as it goes from a vertical to a horizontal position. At the collar of the borehole, prepare a large radius circular transition path within a cushion of screened sand/5% bentonite mix hand compacted to the surrounding fill density. Embed the cable along this transition pathway and bury it in place. This will ensure that the cable will not be stretched or kinked by uneven loading.

6.6.2   HORIZONTAL CABLE RUNS

Two methods are currently used to protect horizontal cable runs from damage. The first method is embedment within selected materials on the surface of the fill. The second method is embedment within an excavated trench within the fill. The second method is the most commonly used because once the trench is backfilled and compacted, the surface can be used for access.   Only the trench method is discussed below.

All surface cable installations require continuous surveillance and protection from traffic and earth moving equipment which must move around on the fill surface. For a description of this method, refer to Clements (1982) (Reference A-6) in Appendix E.

Some of the more important considerations that must be given to horizontal cable runs are:

- The trench dimensions should be 300 mm wider than the width required for the cable layout and a minimum 600 mm deep. A 100 – 150 mm bedding layer of 1 mm minus sand is then placed along the trench bottom. If required, bentonite can be added to the sand to form an impervious section or plug.

- The cable is then covered with a 150 mm lift of 10 mm minus select material.

- Completely backfill the trench with selected material and compact with light hand operated equipment.

- Avoid traversing transition zones in the fill where large differential settlements could occur and create excessive strain in the cable. If cables must traverse these zones, install them with additional length for cable snaking, which will allow slack for settlement to occur, rather than creating excessive cable strain.

- Avoid cable splices, but if required, only use an RST ELSPLICE4 Electrical Cable Splice Kit For VW Cable.. This will ensure a strong and waterproof splice.

- Spend time on the design of the cable layout in the trench, in an attempt to avoid overlaying or crossing of the cable runs one on top of the other. If overlaying and crossing cannot be avoided, the cables must be separated by a 50mm blanket of compacted fine grained soil.

- Use horizontal or vertical snaking of the cable within trenches to provide a certain amount of potential slack to avoid overstressing the cables during backfilling and the subsequent fill placement. For most materials, a pitch of 1.8m with an amplitude of 0.4 m will be suitable. In very wet clays, which could be subject to settlement, increase the amplitude from 0.4 m to between 0.6 m and 1.0 m.

- During the cable routing work, read the instruments at regular intervals to ensure their continued proper function. This is especially important prior to backfilling any of the trenches.

6.7 LIGHTNING PROTECTION

All RST Model 2100 Vibrating Wire Piezometers have highly reliable surge/lightning protection incorporated into the sensor circuitry. This surge protection is adequate for most applications. However, to be effectively isolated in all situations, the entire instrumentation system needs to be considered. This is of particular concern when multiple instruments are connected by wire into a large area network. In this cases, the network could be subject to transient and/or induced currents which could damage sensors and/or data acquisition equipment.

In cases where there may be additional risks of surge damage to the network and/or data loss, the following suggestions for additional surge protection, are provided:

- If a VW piezometer is connected to a terminal box or multiplexer on surface, components such as plasma surge arrestors (spark gaps) could be installed in the terminal box/multiplexer to provide an increased measure of transient protection. Terminal boxes and multiplexers available from RST provide built-in locations for the installation of these surge protection devices.

- Lightning arrestor boards and enclosures are available from RST that install at the exit point of an instrument cable from a drillhole or a structure. The enclosure can be easily accessed and opened, so that in the event that the protection board (Surge 4C) is damaged by a surge event, the user may easily service the components, or replace the board. A connection is made between this enclosure and earth ground to facilitate the passing of transients away from the VW instrument.

Additional information is available from RST on surge protection schemes and other alternatives

Additional sources of information on protecting instruments, junction boxes and data logging systems against power surges, transients and electromagnetic pulses are listed in references A-7, A-8 and A-9 in Appendix E.

7 TROUBLESHOOTING

Maintenance and troubleshooting of Vibrating Wire Piezometers is confined to periodic checks of cable connections and maintenance of terminals. The transducers themselves are sealed and are not user serviceable. The following are typical problems with suggested remedial actions.

- **VW Piezometer Fails to Give a Reading**

    1. Check the resistance of the VW coils by connecting an ohmmeter across the gauge terminals (red and black wires). Nominal resistance is approximately 180Ω (±5%), plus cable resistance at approximately 15Ω per 300 m of 22 AWG wire. If the resistance is very high or infinite, the cable is probably broken or cut. If the resistance is very low, the gauge conductors may be shorted.

    2. Check the VW Readout with another VW piezometer to confirm that the VW Readout is working.

    3. The VW piezometer may have been over-ranged or physically damaged. Inspect the diaphragm and housing for any obvious damage. Contact RST Instruments, if necessary.

- **VW Piezometer Reading Unstable**

    1. Connect the blue shield drain wire on the VW Readout to the shield wire of the VW instrument. In the absence of a shield wire on the VW instrument, the blue shield drain wire can be connected to the black or green wires from the VW instrument. If this does not result in more stable readings, proceed to the next item,

    2. Isolate the VW Readout from sources of ground by placing it on a piece of wood or similar non-conductive material. If this does not result in more stable readings, proceed to the next item,

    3. Check for sources of nearby electrical noise such as motors, generators, antennas or electrical cables. Move the VW piezometer cables as far away from and sources of electrical noise as possible. It the noise cannot be eliminated, Filtering and shielding equipment is likely required. Contact RST for technical advice.

4. The VW piezometer housing may be shorted to the shield. Check the resistance between the shield drain wire and the Piezometer housing. The resistance should very high.

5. The VW piezometer may have been over-ranged or physically damaged. Inspect the diaphragm and housing for any obvious damage. Contact RST Instruments, if necessary.

- **Thermistor Reading is Too Low**

    1. If the calculated temperature from the thermistor resistance reading is unrealistically low, it is very likely that there is an open circuit or poor connection in the thermistor wiring which is resulting in excessive resistance.

    2. Check all connections, terminals and plugs for any damage or corrosion that could cause excessive in-line resistance

    3. If cable damage or a cut is located, a splice must be performed to return the function of the wire connection to normal. It is recommended that an RST ELSPLICE4 Electrical Cable Splice Kit For VW Cable be used to ensure proper strength of the splice and waterproofing.

- **Thermistor Reading is Too High**

    1. If the calculated temperature from the thermistor resistance reading is unrealistically high, it is very likely that there is a short circuit in the thermistor wiring which is resulting in a lower resistance reading.

    2.   Check all connections, terminals and plugs for any damage or current leakage that could explain a partial short that could result in a reduced circuit resistance. If a short or partial short is located in the cable, the cable must be repaired with a splice. It is recommended that an RST ELSPLICE4 Electrical Cable Splice Kit For VW Cable be used to ensure proper strength of the splice and waterproofing.

    3. If no obvious sources of shorting are found, it is possible that water may have penetrated into the interior of the piezometer. If this is concluded to be the case, there are no remedial actions available.

8 SPECIFICATIONS

PERFORMANCE:	
Models:	VW2100
Measuring range:	170, 340, 690, 1700, 3400, 6900 kPa (Note 1) 25, 50, 100, 250, 500, 1000 psi (Note 1)
Resolution:	0.025% Full Scale
Accuracy:	0.1% Full Scale
Maximum overload:	2 x Full Scale
Diaphragm displacement:	< 0.001 cc at Full Scale

1. Custom ranges available upon request

Model:	VW2100	VW2100-HP	VW2100-DP	VW2100-L	VW2100-LV	VW2100-M	VW2100-MM
Description:	Standard model for general applications	High pressure version of standard model	Drive point model with CPT adapter	Low Pressure, unvented	Low Pressure, vented	Miniature version	Micro-Miniature version
Material:	Hermetically sealed stainless steel housing						
Outside Diameter:	19 mm (0.75 in.)	19 mm (0.75 in.)	33 mm (1.31")	25 mm (1.0")	25 mm (1.0")	17.5 mm (0.68")	11.1 mm (0.43")
Length:	133 mm (5.23 in.)	133 mm (5.23 in.)	432 mm (17.0")	133 mm (5.23")	133 mm (5.23")	133 mm (5.23")	165 mm (6.5")
Filters:	Standard - 50 micron sintered stainless steel filter Optional - High Air Entry alumina ceramic filter. Available in 1, 3 and 5 Bar versions						

THERMISTOR AND ELECTRICAL CABLE:	
Temperature Range:	-40 to 65ºC (-40 to + 150ºF)
Accuracy:	$\pm$ 0.2ºC ($\pm$ 0.4ºF)
Thermistor Time Constant:	n/a
Electrical Cable:	Standard: 2 pair RST 4 Conductor, AWG 22, red polyurethane jacket, shielded and water blocked Optional: 2 pair, Gel Filled 4 conductor, AWG 24, shielded

Wiring Code:	Standard: 2 pair RST
	 VW Gauge: Red – Black
	  Thermistor: Green – White
	
	Optional: 2 Pair, Gel Filled
	 VW Gauge: Blue - White
	   Thermistor: Orange – White

CALIBRATION AND IDENTIFICATION

Etched on Housing:	Serial number and psi range
Calibration chart:	Calibration factor
	Temperature correction factor
	Barometric pressure at time of factory calibration
	Temperature at time of factory calibration
	Electrical cable type and length

9 RESISTANCE VS. TEMPERATURE RELATIONSHIP

3000 Ohm NTC Thermistors

Ohms	Temp º C	Ohms	Temp º C	Ohms	Temp ºC	Ohms	Temp º C	Ohms	Temp º C
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
77.99K	-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	-35	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	282.4	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	56.92	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	53	250.9	93	83.6	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
								55.6	150

Temperature calculated using:

Steinhart-Hart Linearization

$$T_C = \frac{1}{C_0 + C_1(\ln R) + C_3(\ln R)^3} - 273.15$$

3000 Ohm @ 25C NTC Thermistor

C_0 = **0.0014051**
C_1 = **0.0002369**
C_3 = **0.0000001019**
lnR = **Natural Log of Resistance**
T_c = **Temperature in ^{o}C**

Appendix A - VW Pressure Transducer Calibration

Calibration Record

rst — innovation in geotechnical instrumentation

RST Instruments Ltd., 11545 Kingston St., Maple Ridge, British Columbia, Canada V2X 0Z5
Tel: 604 540 1100 • Fax: 604 540 1005 • Toll Free: 1 800 665 5599 (North America only)
e-mail: info@rstinstruments.com • Website: www.rstinstruments.com

Vibrating Wire Piezometer

Customer:	RST Instruments Ltd.
Model:	VW2100-0.35
Serial Number:	**VW24285**
Mfg Number:	1237447
Range:	350.0 kPa
Temperature:	22.9 °C
Barometric Pressure:	1003.1 millibars
Work Order Number:	Q025090
Cable Length:	10 meters
Cable Markings:	100022 m - 100031 m
Cable Colour Code:	Red / Black (Coil) Green / White (Thermistor)
Cable Type:	EL380004HDL
Thermistor Type:	3 kΩ

Applied Pressure (kPa)	First Reading (B units)	Second Reading (B units)	Average Reading (B units)	Calculated Linear (kPa)	Linearity Error (% FS)	Polynomial Error (% FS)
0.0	8776	8776	8776	0.5	0.15	0.01
70.0	8178	8178	8178	69.9	-0.04	-0.01
140.0	7577	7577	7577	139.5	-0.13	-0.01
209.9	6973	6973	6973	209.6	-0.09	0.02
279.9	6368	6367	6368	279.8	-0.03	0.00
349.9	5759	5758	5759	350.4	0.14	0.00
				Max. Error (%):	0.15	0.02

Linear Calibration Factor:	C.F.=	0.11594 kPa/B unit
Regression Zero:	At Calibration =	8780.6 B unit
Temperature Correction Factor:	Tk =	-0.03413 kPa/°C rise

Polynomial Gage Factors (kPa)   A: $-4.1484E-07$ B: -0.10991 C: 996.58

Pressure is calculated with the following equations:
Linear: $P(kPa) = C.F.(Li-Lc) - [Tk(Ti-Tc)] + [0.10(Bi-Bc)]$
Polynomial: $P(kPa) = A(Lc)^2 + BLc + C + Tk(Tc-Ti) - [0.10(Bc-Bi)]$

	Date (dd/mm/yy)	VW Readout Pos. B (Li)	Temp °C (Ti)	Baro (Bi)
Shipped Zero Readings:	18-Dec-12	8775	18.9	1014.0

Li, Lc = initial (at installation) and current readings
Ti, Tc = initial (at installation) and current temperature, in °C
Bi, Bc = initial (at installation) and current barometric pressure readings, in millibars
B units = B scale output of VW 2102, VW 2104, VW 2106 and DT 2011 readouts
B units = Hz^2 / 1000   ie: 1700Hz = 2890 B units

Technician: Benson Yu   Date: 18-Dec-12

This instrument has been calibrated using standards traceable to the NIST in compliance with ANSI Z540-1

Document Number.: ELL0130K

Recycled
MIG0106B

Appendix B – Vibrating Wire Piezometer with Casagrande Style Filter Assembly

Saturation Instructions:

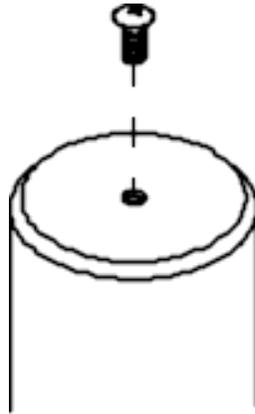1. Remove the sealing screw from the bottom end of the piezometer.

Figure 1 - **Removing the Sealing Screw**

2. Fill a bucket full of water.
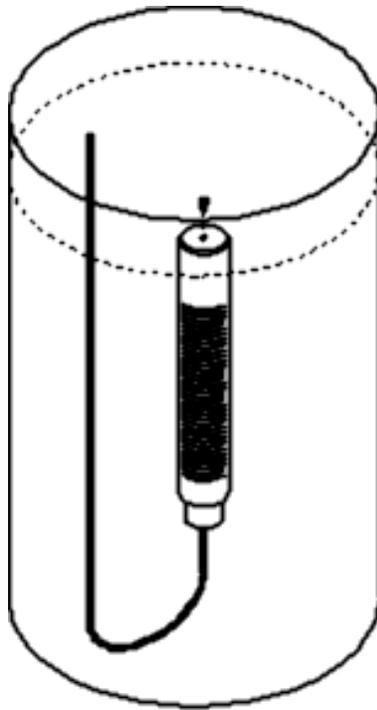3. Immerse the piezometer in the bucket of water so the sealing screw is pointing upwards.

Figure 2 - **Immersing the Piezometer**

4. Allow the air within the piezometer to escape. Gently tap and move the piezometer around underwater.
5. Replace the sealing screw underwater after all the air has been removed from the piezometer.
6. Note that with a low pressure range piezometer (<10psi), readings must be taken with a readout box while carefully pushing the filter housing on, so as not to over-range the sensor.
7. To maintain saturation, the unit should be stored under water until installation.

Appendix C – VW2100-DP "Drive-point" Piezometer

Pre-Operation Instructions:
1. Remove the protective plastic bag from the piezometer. Avoid touching the ceramic filter element, as oil from fingers may affect the permeability of the filter material.
2. Fill a bucket full of water.
3. Unscrew the drive point of the piezometer, so that water can flow freely into the piezometer housing.
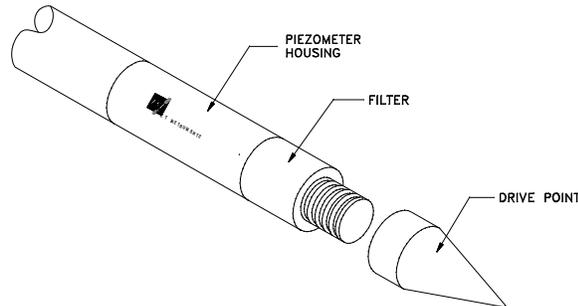

Figure 3 – Unscrew the drive point

4. Immerse the piezometer upside-down in the bucket of water, as shown in Figure 4, and ensure that all air is removed from the inside of the piezometer housing.
5. While the piezometer is still immersed in the water, thread the drive point back on. The drive point should be tightened snuggly by hand only. The filter should be slightly compressed by this process.
6. Note that with low pressure range piezometers (<10psi), readings must be taken with a readout box, while carefully pushing the filter housing on, so as not to over-range the sensor.
7. Remove the piezometer from the water and slide the wires through the adapter pipe. If the piezometer is not being installed immediately, the unit should be kept under water to maintain saturation.
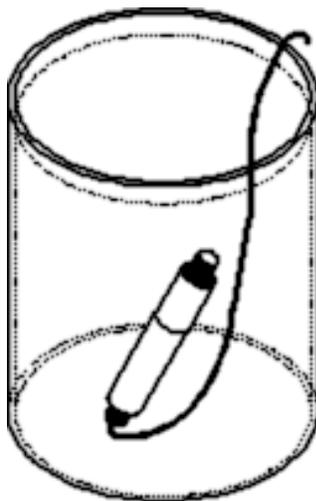8. Thread the adapter pipe onto the VW2100-DP piezometer. Install the piezometer.

Figure 4 - Immerse the piezometer in water.

Appendix D – Non Linearity and the use of a Second Order Polynomial to Improve the Accuracy of the Calculated Pressure

Most Vibrating Wire Pressure Transducers are sufficiently linear (approximately ± 0.2% FS) that the use of a Linear Equation and a Linear Calibration Factor will satisfy most normal output requirements. However, it must be noted that the accuracy of the calibration data used to establish the Linear Calibration Factor, is dictated by the accuracy of the calibration procedure and apparatus, which is always approximately ±0.1% FS.

The level of reading accuracy for a VW Pressure Transducer can be improved, especially when the transducer output is non-linear, by the use of a Second Order Polynomial Expression which gives a better fit to the real pressures, than the straight line Linear Equation.

The Second Order Polynomial Expression has the following form:

$$P \text{ (pressure)} = A \,(Lc)^2 + B \,Lc + C \qquad\qquad (\text{ Refer to Page 11})$$

Where, Lc is the Vibrating Wire reading (in B Units) and A, B, C are the polynomial coefficients determined by the individual instrument calibration procedure.

Appendix A shows a sample calibration sheet for a Vibrating Wire transducer which has a comparatively low non-linearity. In this case, there will only be a very small difference between the pressure value calculated by the Linear Equation and by the Second Order Polynomial Expression.

In contrast, it is noted that the Second Order Polynomial Expression method will provide more accurate pressure values for VW transducers which have a high non-linearity (greater than ± 0.2% FS). The VW calibration sheet contains a column labeled "Linearity Error (% Full Scale)". This column displays the calculated linear error percentage for the calibration steps. If the average of these percentage values (usually 6) exceed ± 0.2 %, it would be advisable to carry out all pressure calculations using the Second Order Polynomial Expression.

The Linearity Error (% Full Scale) is calculated as follows::

$$= ((\text{VW}_{\text{ Calculated Pressure}} - \text{{}_{\text{Applied Pressure}}}) \,/\, {}_{\text{Full Scale Pressure}}) \,^{*}\, {}_{100 \text{ Percent}}$$

The Second Order Polynomial Expression will provide a calculated pressure which is more accurate to the actual pressure monitored and will contain less error. However, it should be noted that where the accuracy of absolute pressure measurement is not required, such as monitoring relative water level changes, it makes little difference whether the Linear Equation or the Second Order Polynomial Expression is used.

Appendix E - References

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