Monitor
with
Confidence

VW2100 Vibrating Wire Piezometer Instruction Manual

Document Number: ELM0005 O

Release Date: June 20, 2018

RST INSTRUMENTS LTD.
11545 Kingston St.,
Maple Ridge, BC
CANADA V2X 0Z5

SALES + SERVICE + MANUFACTURING:
604 540 1100 | info@rstinstruments.com
TOLL FREE (USA & Canada) | 1-800-665-5599

www.rstinstruments.com

Table of Contents

1 Introduction 4

1.1 Model VW2100 5

1.2 Model VW2100-DP 5

2 Vibrating Wire Principle 5

3 Calibration 6

3.1 Field Calibration Check 7

4 Reading Procedures 8

4.1 VW Instrument Readings 8

4.2 Initial Inspection and Check Readings 8

4.3 Initial Readings 8

4.4 Pressure Equation (Using the VW2106 Readout) 9

4.4.1 Linear Equation 10

4.4.2 Second Order Polynomial Equation 11

5 Installation 12

5.1 Filter Saturation 12

5.2 Low Air Entry Sintered Stainless-Steel Filters 13

5.3 High Air Entry Ceramic Filters 14

5.3.1 One Bar High Air Entry Filters 14

5.3.2 Two Bar (or Higher) High Air Entry Filters 15

5.4 Installation in Full 15

5.4.1 Compacted Clay 15

5.4.2 Granular Materials 16

5.5 Installation in Boreholes 17

5.5.1 Sand/Bentonite Method 17

5.5.2 Fully Grouted Method 19

5.6 Piezometers Drive In Soft Ground 20

5.6.1 Installation 21

5.7 Cable Identification 21

5.8 Cable Routing 22

5.8.1 Transition from Vertical Borehole to Horizontal Trench 22

5.8.2 Horizontal Cable Runs 22

5.9 Lightning Protection 23

6 Troubleshooting 23

6.1 VW Piezometer Fails to Give a Reading 24

6.2 VW Piezometer Reading Unstable 24

6.3 Thermistor Reading is Too Low 24

6.4 Thermistor Reading is Too High 25

7 Specifications 25

8 Service and Repair 26

Appendix A : VW2100 Calibration Sheet 27

APPENDIX B : CASAGRANDE STYLE FILTER ASSEMBLY 28
APPENDIX C : VW2100-DP (DRIVE POINT) PIEZOMETER..29
APPENDIX D : USING THE SECOND ORDER POLYNOMIAL TO IMPROVE THE ACCURACY OF THE CALCULATED PRESSURE 30
APPENDIX E : THERMISTOR TEMPERATURE DERIVATION 31
APPENDIX F REFERENCES..32

LIST OF FIGURES

Figure 1-1 Vibrating Wire Piezometer (0.7 MPa)..4
Figure E-1 Thermistor Resistance versus Temperature..31

LIST OF EQUATIONS

Equation E-1 Convert Thermistor Resistance to Temperature..31

LIST OF TABLES

Table 7-1 General Specifications for All Models..25
Table 7-2 Specifications for Individual Models..26

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 extended periods of time and through all conditions. The vibrating wire 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 vibrating wire sensors can be installed in boreholes or driven into soft ground.

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 VW2106 Readout Unit, is used to display the frequency of the vibrating wire which is proportional to the pressure being applied to the vibrating wire transducer diaphragm. Additionally, the VW2106 readout unit will display the transducer temperature directly in degrees Celsius.

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

FIGURE 1-1 VIBRATING WIRE PIEZOMETER (0.7 MPA)

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.

1.1 MODEL VW2100

The RST VW2100 Vibrating Wire Piezometer is designed to be embedded in earth fills and concrete, or inserted into boreholes and pipes as small as 19 mm (3/4 inch) in diameter. The VW2100 piezometer 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 to use the gauge as a pressure transducer (Model VW2100-PT).

1.2 MODEL VW2100-DP

The RST 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. The opposite end is fitted with a 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.

2 VIBRATING WIRE PRINCIPLE

The sensing element of the Vibrating Wire piezometer is a high strength steel wire attached to the diaphragm. The vibrating wire 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 vibrating wire 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 vibrating wire to find its current natural frequency related to the pressure it is currently experiencing. In turn, the oscillation of the vibrating wire generates AC voltage in the coil. This output signal is amplified by the VW2106 Readout Unit, which also discriminates against harmonic frequencies, to determine the resonant frequency of the wire.

The VW2106 Readout Unit 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 B Unit readings and the pressure being exerted on the diaphragm is expressed by the following equation:

$$P = CF (L_0 - L)$$

where:

P = Corrected Pressure Reading

CF = Linear Calibration Factor in kPa \ B Unit digit. The CF is a unique value for each manufactured VW sensor, as determined by the initial laboratory calibration

L_0 = Initial B Unit Reading at zero applied pressure on the diaphragm. The L_0 is a unique value for each manufactured VW sensor and is determined by initial laboratory calibration

L = 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. Up to 1.5 km of cable length can be used without signal deterioration.

3 CALIBRATION

All RST vibrating wire piezometers are individually calibrated in the laboratory before shipment. Each vibrating wire 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 data loggers are set up to use either formula to calculate the instrument output in engineering units.

As part of the calibration procedure, all vibrating wire piezometers are tested to 150% of the standard working range to prove their function at overpressure. The sensor calibration is carried out over a temperature range of -20º C to +80º 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 vibrating wire sensor for use in calculating the applied loads on the vibrating wire sensors. The following general information is contained in the Calibration Record sheet:

- Model, Serial, and Manufacturing Numbers;
- Pressure Range;
- Temperature and Barometric Pressure at time of Calibration;

- Work Order Number;
- Cable Information (Length, Meter Markings, Color Code, and Type);
- Thermistor Type;
- Linear Calibration Factor (CF);
- Temperature Correction Factor (Tk);
- Polynomial Gauge Factors (A, B, and C);
- Calibration Data Table;
- Linear and Polynomial Formulas;
- Zero Reading, Temperature, and Barometric Pressure at time of Shipment;
- Calibration Certification.

Refer to Appendix A for an example of a Calibration Record sheet.

3.1 FIELD CALIBRATION CHECK

The following procedure can be used in the field to verify the validity of a vibrating wire piezometer calibration as supplied on the Calibration Record sheet.

Note that VW2100 piezometers will require the filter stone to be saturated prior to calibration. Place the VW2100 piezometer in water to saturate the filter stone. Ensure the entire space between the instrument diaphragm and the filter stone is filled with water. Refer to Appendix B for more detailed information on the saturation of VW2100 piezometers with Casagrande style filters, and VW2100-DP piezometers.

1. Lower the piezometer to depth in a vertical, water filled borehole using the cable markings to accurately control and set the depth. A minimum emersion depth of 10 m is recommended to ensure adequate accuracy of the field calibration check.

2. Allow 20 to 30 minutes for the piezometer to come to complete thermal equilibrium in the borehole. Record the B unit and temperature readings at that depth using an RST VW2106 readout unit.

3. Raise the piezometer a known amount while keeping it fully submerged. If the temperature reading is changing, allow the instrument to come to the new thermal equilibrium. This may take another 20 to 30 minutes.

4. 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.

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

It is not recommended to install the piezometer if the calibration record sheet CF value cannot be confirmed by the field calibration test. The instrument will need to be inspected and undergo a full shop function test and re-calibrated before being returned to service. Contact RST for further information.

If the diameter of the water filled borehole is too small, the volume of water that the vibrating wire piezometer cable displaces, when raised or lowered into position, could potentially raise, or lower the borehole water level. This effect may seriously impact the accuracy of the above detailed Field Calibration Check. Note 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. It is recommended to use a borehole diameter that is a minimum of 10 times greater than the wire diameter. A borehole with a moderate degree of permeability would be preferred to a “tight” borehole.

4 READING PROCEDURES

4.1 VW INSTRUMENT READINGS

It is strongly recommended that the instruction manual for the RST VW2106 Readout Unit be read thoroughly before proceeding. Failure to become familiar with the function and operation of the VW2106 Readout could potentially result in damage to the VW2106 Readout unit and/or the vibrating wire sensors that are connected to it.

4.2 INITIAL INSPECTION AND CHECK READINGS

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

Test readings should be taken of each vibrating wire instrument and compared to the vibrating wire instrument reading information provided on the Calibration Record sheet. Any discrepancies should fully be investigated and satisfactorily resolved before the vibrating wire instrument is released for field installation and service.

The individual performing the inspection and initial test readings must be familiar with the vibrating wire instrument operation and contents of this instruction manual.

4.3 INITIAL READINGS

Vibrating wire piezometers differ from other types of pressure sensors as the core of the vibrating wire sensor is manufactured with an initial tension. The piezometers have a positive B-Unit reading without any external pressure being applied. Vibrating wire piezometers are acutely sensitive to pressure changes at zero point as there is no zero-point hysteresis to overcome. The determination of vibrating wire instrument initial readings at the “zero point” is extremely important for the accuracy of the subsequent readings.

It is necessary to take the initial zero reading with no applied load before installing the vibrating wire piezometer. The initial zero reading should be taken with either the filter stone removed or with the stone installed and completely saturated (Refer to Section 5.1 and Appendix B).

The temperature reading from the internal thermistor must also be recorded. The barometric pressure for piezometers with a total range lower than 2 MPa must also be recorded. These values are needed to apply the correct correction factors for changes in temperature and/or barometric pressure, which will impact the reading accuracy of the vibrating wire piezometers through their intended range.

Initial zero readings are generally obtained immediately prior to installation with no external pressure and a constant ambient temperature and barometric pressure.

NOTE: BE SURE TO RECORD THE VIBRATING WIRE PIEZOMETER TEMPERATURE AND BAROMETRIC PRESSURE AT THE SAME TIME THE B-UNIT ZERO READINGS ARE TAKEN.

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

- Has the temperature of the vibrating wire 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 vibrating wire sensor. Allow 20 to 30 minutes for the temperature of the vibrating wire piezometer to equilibrate. Sources of temperature fluctuation, such as water flow, may have to be eliminated.
- Is the filter stone saturated?
  - Surface tension effects within the pore spaces of the filter could affect the zero readings if the filter stone is only partially saturated. This can be a problem particularly at low pressures (less than 350 kPa). Remove the filter stone to allow direct atmospheric connection with the transducer diaphragm if there is any question regarding the adequate saturation of the filter stone.

4.4 PRESSURE EQUATION (USING THE VW2106 READOUT)

The VW2106 Readout Unit displays vibrating wire piezometer readings in frequency units called B-Units, which equal Frequency^2 x 10^-3, where frequency is in Hertz.

The B-Unit values represent absolute pressure and must be corrected for changes in temperature and barometric pressure. B-Unit changes from the initial zero reading are converted to the actual pressure changes using equations in sections 4.4.1 and 4.4.2, which include corrections for temperature and barometric pressure changes.

4.4.1 Linear Equation

$P = CF(L_0 - L) - Tk(T_0 - T) + (S_0 - S)$

Where:

P = Corrected Pressure in kPa

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

L_0 , L = Initial and Current B-Unit reading (Frequency^2 x 10^-3)

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

T_0 , T = Initial and current temperature readings in (ºC)

F = Barometric Pressure Constant = 0.1 kPa / Millibar

S_0 , S = Initial and Current Barometric pressure readings; in Millibars

4.4.1.1 Example for a 350 kPa Range Piezometer

CF = 0.11594 kPa / B-Unit

L_i = 8776 B-Units

L = 7200 B-Units

T_K = - 0.03413 kPa / ºC

T_i = 22.9 ºC

T = 5.0ºC

F = 0.1 kPa / Millibar

S_i = 1003.1 mbar

S = 995 mbar

P = [(0.11594) x (8776 - 7200)] - [(-0.03413) x (22.9 - 5.0)] + [0.1 x (1003.1 - 995)]

= [182.72] - [-0.61] + [0.81]

= 184.14 kPa

NOTE: BAROMETRIC COMPENSATION IS NOT REQUIRED WITH VENTED AND DIFFERENTIAL PRESSURE TRANSDUCERS.

4.4.2 Second Order Polynomial Equation

$P = A(L)^2 + B(L) + C - Tk (T_0 - T) + F (S_0 - S)$

Where:

P = Corrected Pressure in kPa

A = Polynomial Gauge Factor A (Second Order Polynomial Expression derived from the VW Piezometer Calibration data, for each individual sensor)

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 data, for each individual sensor)

NOTE: POLYNOMIAL GAUGE FACTOR C MUST BE CALCULATED USING THE SITE ZERO READINGS, AS PER THE EQUATION BELOW.

$$C = - [A(L_0)^2 + B(L_0)]$$

L_0 , L = Initial and Current B-Unit reading (Frequency^2 x 10^-3)

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

T_0, T = Initial and current temperature readings in (ºC)

F = Barometric Pressure Constant = 0.1 kPa / Millibar

S_0, S = Initial and Current Barometric pressure readings in Millibars

4.4.2.1 Example for a 350 kPa Range Piezometer

A = - 4.1484E-07 kPa / (B-Units ^{2})

B = - 0.10991 kPa / B-Units

C = 996.58 kPa / B-Units

L = 7200 B-Units

T_K = -0.03413 kPa / ºC

T_0 = 22.9 ºC

T = 5.0ºC

F = 0.1 kPa / Millibar

S_0 = 1003.1 mbar

S = 995 mbar

P = [(-4.1484 E-07) x $(7200)^2$] + [-0.10991 x 7200] + [996.58]

+ [-0.03413 x (5.0 - 22.9)] - [0.1 x (995 - 1003.1)]

= [-21.51] + [-791.35] + [996.58] + [0.61] - [-0.81]

= 185.14 kPa

5 INSTALLATION

Vibrating wire piezometers can be installed in various ways to suit the individual application. Specific guidelines for piezometer installation have been developed by various agencies and technical specialists. Appendix F provides a list of references.

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 vibrating wire 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 vibrating wire piezometers. Additional steps must be performed on site to ensure complete isolation and adequate grounding of the instrumentation circuits if installation under these conditions is unavoidable. The instrument shield wire should be 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 can potentially result in damage or failure of the vibrating wire sensor.

5.1 FILTER SATURATION

High air entry ceramic or low air entry sintered stainless steel filters are available. The filters are intended to protect the delicate diaphragm area of the vibrating wire 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 vibrating wire diaphragm. Filter saturation provides the following reading advantages:

- There is no fluid movement in a saturated environment - 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;
- Ensure hydraulic continuity between the pore water and the piezometer diaphragm in unsaturated soils, which will provide the highest accuracy of pressure measurement.

5.2 LOW AIR ENTRY SINTERED STAINLESS-STEEL FILTERS

Total saturation of the filter is necessary for accurate reading results. For the standard filter supplied, the low air entry filter, 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. Given enough time, this air will dissolve into the water until the space below the diaphragm and within the filter is entirely saturated. This could take multiple days, which could mean slightly inaccurate reading results the first few days.

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

- Turn the vibrating wire piezometer upside down. Remove the end filter assembly, which is held in place with an internal O-ring.
- Submerge the inverted piezometer in a bucket of flat water (water which has been sitting for 24 hours). 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.
    - Note that with a low-pressure range piezometer (less than 350 kPa), it is recommended that vibrating wire readings be taken with a VW2106 Readout Unit while the filter housing is being pushed slowly into place, to ensure that the sensor does not over-range due to this operation.
- The vibrating wire piezometer should be stored in the bucket of water until ready to install downhole to maintain the filter saturation prior to installation.
- During the installation, the vibrating wire piezometers should be handled as gently as possible to keep the water in the filter sinter and the bottom chamber until submerging in the borehole.

CAUTION: VIBRATING WIRE PIEZOMETERS CANNOT BE ALLOWED TO FREEZE WHEN FULLY SATURATED, OTHERWISE DAMAGE WILL OCCUR TO THE TRANSDUCER DIAPHRAGM, WHICH WILL INVALIDATE THE TRANSDUCER FUNCTION AND CALIBRATION.

The O-ring providing the friction fit may become worn and the filter housing may become loose if the vibrating wire piezometer must undergo multiple removals and reinstallations of the filter housing. Replace the O-ring immediately if the filter housing is loose.

Coarser screen housings are available for use on vibrating wire piezometers if salts or other precipitates are clogging the stainless sinter filter. Screens are less likely to become clogged by precipitates and other debris found in some water sources.

Note that salts and other dissolved solids can be deposited within a stainless sintered filter if the filter is allowed to dry out completely. Thoroughly rinse out the filter with clean distilled water prior to drying to prevent filter clogging.

5.3 HIGH AIR ENTRY CERAMIC FILTERS

The ceramic filter on high air entry piezometers 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.

5.3.1 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 to avoid causing 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. Place the filter into de-aired water when boiling is completed.
3. Re-assemble the filter housing into the piezometer body under the surface of de-aired water, while keeping the piezometer oriented with the diaphragm pointing upward. Take care to ensure that no air is trapped in the transducer cavity.
4. Vibrating wire readings must be taken with a VW2106 readout unit 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. The vibrating wire piezometer with a high air entry filter installed must be stored in de-aired water until the unit is installed.

CAUTION: VIBRATING WIRE PIEZOMETERS CANNOT BE ALLOWED TO FREEZE WHEN FULLY SATURATED, OTHERWISE DAMAGE WILL OCCUR TO THE TRANSDUCER DIAPHRAGM, WHICH WILL INVALIDATE THE TRANSDUCER FUNCTION AND CALIBRATION.

5.3.2 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 complete properly. It is recommended that it be performed either at the factory or by carefully following the instructions below:

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 later allow 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 VW2106 readout unit while the chamber is being evacuated.
3. When the maximum vacuum has been achieved in the vacuum chamber, use the VW2106 readout unit to read the piezometer until it has also reached the same maximum vacuum pressure.
4. Open the de-aired water inlet valve to allow de-aired water to enter the bottom of the chamber and reach an elevation of approximately 50 mm 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 chamber to return to atmospheric pressure.
7. Observe the transducer output on the VW2106 readout unit. Up to 24 hours ma be required for the (5 bar high entry) filter to completely saturate and for the piezometer pressure to return to zero. The saturation of the high entry filter is considered to be completed at this point.
8. 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.

CAUTION: VIBRATING WIRE PIEZOMETERS CANNOT BE ALLOWED TO FREEZE WHEN FULLY SATURATED, OTHERWISE DAMAGE WILL OCCUR TO THE TRANSDUCER DIAPHRAGM, WHICH WILL INVALIDATE THE TRANSDUCER FUNCTION AND CALIBRATION.

5.4 INSTALLATION IN FULL

5.4.1 Compacted Clay

1. Excavate a vertical trench or recess approximately 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 to ensure a snug fit when the piezometer is inserted in the hole.

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

3 Place the cable with the utmost care to avoid any damage due to kinking or stretching. Look the cable and route it out of the trench. Mak sure it rests on a bed of hand placed and lightly compacted screened clay. Ensure that the cable does not come into direct contact with itself or other cables in the area. Always maintain a few centimeters of compacted clay material between any two cables.

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

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

5.4.2 Granular Materials

1 Excavate a vertical trench or recess about 50 cm deep in the granular material.

2 Place the piezometer horizontally in the center of the trench or recess.

3 Loop the cable and backfill the bottom 10 cm of the trench around the piezometer with screened granular material not exceeding 3 mm in dimension.

4 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 be compacted to the same density as the surrounding fill. Care must be exercised to not subject the piezometer instrument to damage during compaction work.

5 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. 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.

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

5.5 INSTALLATION IN BOREHOLES

5.5.1 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 that may be present in the subject borehole, which could 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. Refer to Appendix F for references of descriptions of other potential instrumentation methods.

5.5.1.1 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.

The piezometer installation will have to proceed with multiple small withdrawals of the drill casing to minimize the risk of losing the installation if the borehole walls are considered to be unstable or likely to cave or collapse. 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. Boreholes in cohesive soils are also more stable than boreholes in less cohesive, granular soils.

5.5.1.2 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 compared to bentonite pellets, which are a manufactured 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 bentonite products for downhole seals should be limited to holes which are less that 20 meters, due to the difficulty involved with this method.

CAUTION: DO NOT ROTATE THE DRILL CASING. THE DRILL CASING CANNOT BE ROTATED WHEN BEING PULLED. ROTATING THE DRILL CASING WILL LIKELY RESULT IN DAMAGE TO THE INSTALLED PIEZOMETERS.

1. Place a 60 cm bentonite seal at the bottom of the borehole to seal (if required).

2. Raise the drill casing 15 cm and start placing the bentonite chips until the bentonite level is 30 cm below the required piezometer elevation.

3. 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 ensuring 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. Feeding the bentonite chips in too rapidly will result in bridging of the chips in the drill casing or borehole. Bridging will make completing downhole installations extremely difficult.

    - Tamping is not required because the natural swelling of the chips will provide an adequate seal to the borehole walls once the bentonite chips are in place.

4. Lower a cylindrical weight down the drill casing to the top of the bentonite plug to ensure the hole is clear of any obstructions prior to setting filter sand in place for the piezometer zone.

5. Rinse the borehole with clean water to remove any obstructions or debris.

6. 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.

7. Lower the piezometer into the hole and take the initial readings, as described in Section 4.3.

8. Raise the drill casing 15 cm and backfill the hole around the piezometer with fine, clean sand. Repeat until the sand is 30 cm above the top of the piezometer.

9. Take a second reading on the piezometer.

10. Lift the casing in 15 cm increments and backfill with bentonite chips until a minimum four-foot seal has been placed. Keep the piezometer cable taut to prevent the bentonite chips from adhering to the wall of the drill casing during the bentonite chip placement. 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 drill hole, the intervening distance between the top of the first piezometer zone and the bottom of the next piezometer zone can be backfilled 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.

11. Top off the borehole collar with grout and a protective steel collar casing once all the drill casing has been removed from the hole.

5.5.2 Fully Grouted Method

The fully grouted method of piezometer installation involves the installation of the vibrating wire 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. Refer to Mikkelson & Green (2003) and Contreras et al. (2008) in Appendix F for a more details on this method.

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. The 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 vibrating wire piezometer diaphragm to react to 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. Vibrating wire 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, if one or both 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 weights to each piezometer as required, to overcome viscous resistance of the grout while lowering the piezometer.
- Attach piezometers directly to the outside of the 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.

5.6 PIEZOMETERS DRIVE IN SOFT GROUND

RST Model VW2100-DP is designed to be pushed into place from the surface in soft soil. 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.

5.6.1 Installation

1 Total saturation of the VW2100-DP filter is necessary for accurate results. 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 and female threaded ends.

3 Thread the piezometer cable through the rods leaving a 0.5 m 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 drill hole.

5 Pull back the spare cable. 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 Add on the required number of rod in sequence to reach the push point.

7 Connect the VW2106 readout unit to the VW2100-DP and start monitoring the readings prior to pushing.

8 Push the piezometer into place while monitoring any pressure build-up at the tip. Stop the driving and wait until the pressure dissipates should the pressure exceed the working pressure range.

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

5.7 CABLE IDENTIFICATION

The vibrating wire cables are identified with a 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 vibrating wire sensors have meterage numbers marked on the cable at 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 used to verify the ID of an installed vibrating wire sensor.

If the vibrating wire 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 Vibrating Wire 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.

5.8 CABLE ROUTING

5.8.1 Transition from Vertical Borehole to Horizontal Trench

The vibrating wire 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 to ensure the cable will not be stretched or kinked by uneven loading.

5.8.2 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 in an excavated trench in 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. The trench method is discussed below. Refer to Clements (1982) in Appendix F for a description of this method.

All surface cable installations require continuous surveillance and protection from traffic and earth moving equipment which must move around on the fill surface.

Note that 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. Bentonite can be added to the sand to form an impervious section or plug if required.

1. Cover cable completely with a 150 mm lift of 10 mm minus select material.
2. Completely backfill the trench with selected material. Compact it with light hand operated equipment.
3. 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.
4. Avoid cable splices. Only use an RST ELSPLICE4 Electrical Cable Splice Kit for Vibrating Wire Cables if splicing is required. The kit will ensure a strong and waterproof splice.
5. Spend time on the design of the cable layout in the trench. Avoid overlaying or crossing the cable runs on top of each other. If overlaying and crossing cannot be avoided, the cables must be separated by a 50 mm blanket of compacted fine-grained soil.
6. 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 1.8 m 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.

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

5.9 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. The entire instrumentation system needs to be considered to be effectively isolated in all situations, especially when multiple instruments are connected by wires into a large area network. 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 vibrating wire 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 drill hole or 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 ground to facilitate the passing of transients away from the vibrating wire instrument.

Additional information on surge protection alternatives is available from RST. Additional sources of information on protecting instruments, junction boxes, and data logging systems against power surges, transients, and electromagnetic pulses are listed in available in Appendix F.

6 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.

6.1 VW Piezometer Fails to Give a Reading

1. Check the resistance of the vibrating wire 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 possibly broken or cut. If the resistance is very low, the gauge conductors may be shorted.

2. Check the VW2106 Readout Unit with another vibrating wire piezometer to confirm that the VW2106 Readout Unit is working.

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

6.2 VW Piezometer Reading Unstable

1. Connect the blue shield drain wire on the vibrating wire readout to the shield wire of the vibrating wire instrument. In the absence of a shield wire on the vibrating wire instrument, the blue shield drain wire can be connected to the black or green wires from the vibrating wire instrument. If this does not result in more stable readings, proceed to step 2 below.

2. Isolate the vibrating wire readout from ground sources by placing it on a piece of wood or similar non-conductive material. If this does not result in more stable readings, proceed to step 3 below.

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

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

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

6.3 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 Vibrating Wire Cables be used to ensure a strong and waterproof splice.

6.4 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 Vibrating Wire Cables be used to ensure a strong and waterproof splice.

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

7 SPECIFICATIONS

TABLE 7-1 GENERAL SPECIFICATIONS FOR ALL MODELS

Specification	Value
Range	0.07, 0.175, 0.35, 0.7, 1, 2, 3, 5, 7.5, 10 MPa
Over-range	1.5 x FS
Temperature Range	-20°C to 80°C
Resolution	<0.025% FS
Accuracy	±0.1% FS
Non-Linearity	<0.05% FS
Zero Stability	0.02% FS/year
Thermal Zero Shift	< 0.05% FS/°C
Frequency Range	1200-3550 Hz
Coil Resistance	180 Ω
Diaphragm Displacement	<0.001 cc @ FS
Thermistor Type	NTC 3k Ω @ 25°C
Filter	50 micron sintered stainless steel (High air entry alumina ceramic filter available for 1, 3 and 5 MPa versions)

TABLE 7-2 SPECIFICATIONS FOR INDIVIDUAL MODELS

Model	Description	Pressure Range	Dimensions
VW2100	Standard model for general applications	0.35, 0.7, 1, 2, 3 MPa	19mm ϕ x 130mm
VW2100-HD	Heavy-duty piezometer for direct burial in fills and large dam embankments	0.35, 0.7, 1, 2, 3, 5, 7.5, 10 MPa	25.4mm ϕ x 130mm
VW2100-XHD	Extra heavy-duty piezometer for direct burial in fills and large dam embankments	1, 2, 3, 5, 7.5 ,10 MPa	38.1mm ϕ x 130mm
VW2100-DPC	Drive point with CPT thread	0.07, 0.175, 0.35, 0.7, 1, 2, 3, 5, 7.5 MPa	33mm ϕ x 130mm
VW2100-DPC-CT	Drive point model with drop-off shoe	0.07, 0.175, 0.35, 0.7, 1, 2, 3 MPa	50.8mm ϕ (tip) 33.4 ϕ (body) x 130mm
VW2100-DPE	Drive point model with extension rod (31.8mm ϕ x 127mm)		
VW2100-L	Low pressure, unvented	70, 175 kPa	25mm ϕ x 133mm
VW2100-LV	Low pressure, vented	70, 175 kPa	25mm ϕ x 133mm
VW2100-M	Miniature version	0.35, 0.7, 1, 2, 3 MPa	17.5mm ϕ x 133mm
VW2100-MM	Micro-miniature version	0.35, 0.7 MPa	11.1mm ϕ x 165mm
VW2190	Heavy duty piezometer with bladder for brine environment	0.07, 0.175, 0.35, 0.7, 1, 2, 3, 5, 7.5 MPa	42mm ϕ x 319mm
VW2191	Heavy duty piezometer with bladder for acidic environment and secondary corrosive protection	0.07, 0.175, 0.35, 0.7, 1, 2, 3, 5, 7.5 MPa	42mm ϕ x 319mm

8 SERVICE AND REPAIR

The product contains no user-serviceable parts. Contact RST for product service or repair not covered in this manual.

Appendix A : VW2100 CALIBRATION SHEET

Vibrating Wire Piezometer

Customer:		RST Instruments Ltd.
Model:		VW2100-0.35
Serial Number:		**VW21345**
Mfg Number:		P101940
Range:		350.0 kPa
Temperature:		23.0 °C
Barometric Pressure:		1024.4 millibars
Work Order Number:		54049
Cable Length:		50 meters
Cable Markings:		802296 m - 802345 m
Cable Colour Code:	Red / Black (Coil)	Green / White (Thermistor)
Cable Type:		EL380004
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)	Calculated Polynomial (kPa)	Polynomial Error (% FS)
0.000	8507	8508	8507	-0.004	0.00	0.006	0.00
70.000	7718	7719	7718	70.057	0.02	70.055	0.02
140.000	6932	6933	6932	139.851	-0.04	139.843	-0.04
210.000	6141	6142	6141	210.090	0.03	210.081	0.02
280.000	5353	5354	5353	280.062	0.02	280.060	0.02
350.000	4566	4567	4566	349.945	-0.02	349.956	-0.01
				Max. Error (%):	0.04		0.04

Linear Calibration Factor: CF = **8.8797E-02 kPa/B unit**

Temperature Correction Factor: Tk = **-9.4569E-02 kPa/°C rise**

Polynomial Gage Factors:

A = 5.1074E-09 kPa/(B unit)² **B = -8.8864E-02 kPa/B unit** **C = ________ kPa**

Pressure is calculated with the following equations:

Linear: $P = CF(L_0 - L) - Tk(T_0 - T) + (S_0 - S)$

Polynomial: $P = A(L^2) + B(L) + C - Tk(T_0 - T) + (S_0 - S)$

Users must establish site zero readings for calculation purposes

Polynomial $C = - [A(L_0^2) + B(L_0)]$

L_0, L = initial (installation) and current readings, in B units
T_0, T = initial (installation) and current temperature, in °C
S_0, S = initial (installation) and current barometric pressure readings, in kPa
B units = B scale output of VW 2102, VW 2104, VW 2106 and DT 2011 readouts
B units = $Hz^2/1000$ ie: 1700 Hz = 2890 B units

	Date (dd/mm/yy)	VW Reading (B units)	Temperature (°C)	Baro (mbar)
Shipped Zero Readings:	25-Apr-18	8505	21.8	1008.8

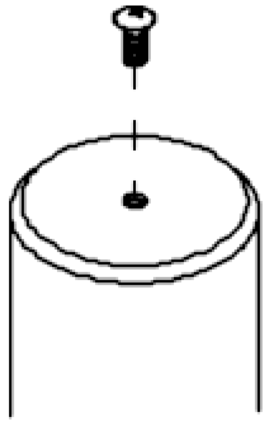
This instrument has been calibrated using standards traceable to the NIST in compliance with ANSI Z540-1

Technician: E. Gilboe Date: 25-Apr-18

Appendix B : CASAGRANDE STYLE FILTER ASSEMBLY

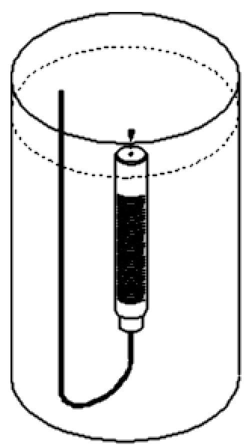
Saturation Instructions:

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



2 Fill a bucket full of water.

3 Immerse the piezometer in the bucket of water so the sealing screw is pointing upwards.



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 (70 kPa), 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.

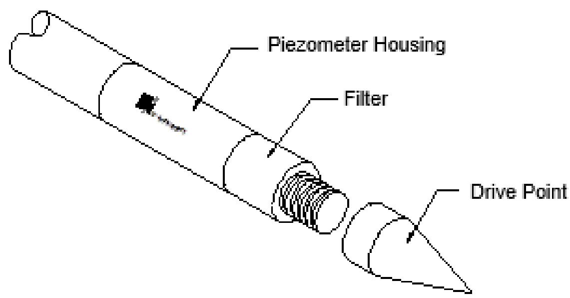
Appendix C : VW2100-DP (DRIVE POINT) PIEZOMETER

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 with water.

3 Unscrew the drive point of the piezometer, so that water can flow freely into the piezometer housing.



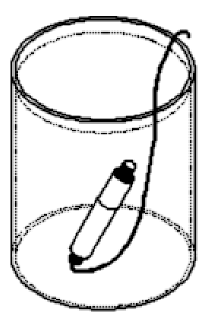
4 Immerse the piezometer upside-down in the bucket of water and ensure that all air is removed from the inside of the piezometer housing.

5 While the piezometer is still immersed in the water, thread the drive point back on. The drive point should be hand-tightened. The filter should be slightly compressed by this process.

6 Note that with low pressure range piezometers (<70 kPa), 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. The unit should be kept under water to maintain saturation if the piezometer is not being installed immediately.

8 Thread the adapter pipe onto the VW2100-DP piezometer. Install the piezometer.



Appendix D : Using the Second Order Polynomial to Improve the Accuracy of the Calculated Pressure

Most Vibrating Wire Pressure Transducers are sufficiently linear (<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 <0.1% FS.

The level of accuracy for a Vibrating Wire Pressure Transducer can be improved, especially when the transducer output is non-linear, by using the Second Order Polynomial Expression, which is better suited to the real pressures than the Linear Equation.

The Second Order Polynomial Expression has the following form:

$$P \text{ (pressure)} = A(L)^2 + B(L) + C$$

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

Appendix A shows a sample calibration sheet for a Vibrating Wire pressure 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 vibrating wire 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) exceeds 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:

LE = [(Calculated Pressure – Applied Pressure) / Full Scale Pressure] * 100%

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 : Thermistor Temperature Derivation

Thermistor Type: YSI 44005, Dale 41C3001 B3, Alpha #13A3001 B3
Resistance to Temperature Equation:

$$T = \frac{1}{A + B(LnR) + C(LnR)^3} - 273.2$$

Equation E-1 Convert Thermistor Resistance to Temperature

where:

T	=	Temperature in °C
LnR	=	Natural Log of Thermistor Resistance
A	=	1.4051×10^{-3} (coefficient calculated over the -50 to +150°C span)
B	=	2.369×10^{-4}
C	=	1.019×10^{-7}

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
201.1K	-50	16.60K	-10	2417	+30	525.4	+70	153.2	+110
187.3K	-49	15.72K	-9	2317	31	507.8	71	149.0	111
174.5K	-48	14.90K	-8	2221	32	490.9	72	145.0	112
162.7K	-47	14.12K	-7	2130	33	474.7	73	141.11	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

Figure E-1 Thermistor Resistance versus Temperature

Appendix F REFERENCES

A-1 Terzaghi, K and Peck, R.B.; “Soil Mechanics in Engineering Practice”, John Wiley and Sons, Inc., 1967. (Article 68 of Chapter 12 provides a survey of tip types and recommendations on installation procedure.)

A-2 U.S. Department of the Interior, Bureau of Reclamation; “Earth Manual”, U.S. Government Printing Office, Washington 1974. (Designations E-27 and E-28 in the Appendix give detailed guidance on piezometer installations in dam foundations.)

A-3 Bishop, A.W., Vaughan, P.R., and Green, G.E. (1969); Report on specialty session, “Pore Measurements in the Field and in the Laboratory”, Proc. 7th, Int. Conf. Soil Mech. and Found. Eng. 3, 427. (A review of recent practice and instrumentation, related principally to earth structures.)

A-4 “Suggested Methods for Determining In-Situ Permeability, Groundwater Pressure and Flow”; Int. Soc. for Rock Mechanics, committee on Field Tests (Draft report, 1974; Final report in course of preparation.)

A-5 Hanna, T.H.; “Foundation Instrumentation”, Trans. Tech. Publications, Ohio, USA, 1973. (Chapter 3 describes different types of piezometer tip, methods of installation, methods of recording and the protection of piezometer.)

A-6 Clements, D.J., and A.C. Durney (1982); “Instrumentation Developments”, Proceedings of the Autumn Conference on the British National Committee on Large Dams (BNCOLD) Keele University, Institution of Civil Engineers, London, pp. A5-55.

A-7 General Electric (1976); Transient voltage suppression manual, G.E. Semiconductor products Department, Syracuse, New York.

A-8 Baker, C. (1978); “Surge Protection for Instrumentation”, proceedings of the Tempcon Conference, London. Available from Measurement Technology, Inc., 7541 Gary Road, Manassas, Virginia, 22110, U.S.A.

A-9 Baker, C., (1980); “Protecting Electronic Circuits from Lightening and Transients”. Available from Measurement Technology, Inc., 7541 Gary Road, Manassas, Virginia, 22110, U.S.A.

A-10 Corps of Engineers (1984); “Publications Relating to Geotechnical Activities”, USACE DAENECE-G, September 27th.

A-11 McKenna, G.T. (1995); “Grouted-In Installation of Piezometers in Boreholes”, Canadian Geotechnical Journal, Vol.32(2), pp. 355-263.

A-11 Mikkelsen, P.E. and Green, G.E. (2003); “Piezometers in fully grouted boreholes”. Field Measurements in Geomechanics, -Myrvoll(ed.). Swets & Zeitlinger, Lisse, ISBN 90 5809 602 5.

A-12 Contreras, I.A., Grosser. A.T., Ver Strate, R.H. (2008); `The Use of the Fully-Grouted Method for Piezometer Installations``, Geotechnical Instrumentation News, Episode 55

A-13 Contreras, I.A., Grosser. A.T., Ver Strate, R.H. (2011); `Practical Aspects of the Fully-Grouted Method for Piezometer Installations``, Proc 8th International Symposium on Field Measurements in Geomechanics, Berlin.

A-14 Simeoni, L., De Polo, F., Caloni, G., Pezzetti, G. (2011); Field Performance of Fully Grouted Piezometers`, Proc 8th International Symposium on Field Measurements in Geomechanics, Berlin.

A-15 Contreras, I.A., Grosser. A.T., Ver Strate, R.H. (2012); `Update of the Fully-Grouted Method for Piezometer Installation``, Geotechnical Instrumentation News, Episode 70