



ENCARDIO RITE

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Over 50 years of excellence through ingenuity

USERS' MANUAL

VIBRATING WIRE PIEZOMETER

MODEL EPP-30V, EPP-40V, EPP-50V & EPP-60V



**ГЕОТЕХ
ГРУП**
МОНИТОРИНГ



EPP-50V



EPP-60V



EPP-40V



EPP-30V

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1 INTRODUCTION

Pressure experienced by water contained in pores of earth materials, concrete structures or rock is generally called pore water pressure. In any instrumentation scheme for geotechnical or geo-structural study associated with large civil engineering structures like tall buildings, dams, underground tunnels etc., measurement of pore water pressure (also known as piezometric level) plays an important part.

The study of pore pressure has following main purposes:

- Effect of water in pores of soil or rock is to reduce load bearing capacity of soil or rock. Effect is more pronounced with higher pore water pressure leading eventually in some cases to total failure of load bearing capacity of the soil.
- To determine level and flow pattern of ground water
- Determine flow pattern of water in earth/rock fill & concrete dams and their foundations and to delineate the phreatic line.

1.1 Applications

Encardio-rite vibrating wire piezometer is the electrical piezometer of choice as its frequency output is immune to external noise, it is able to tolerate wet wiring common in geotechnical applications and it is capable of transmission of signals to long distances. It has applications in the measurement of positive or negative pore pressure in soil, concrete mass or rock including:

- Construction control, stability investigation and monitoring of earth dams, embankments, foundations, shallow underground works and surface excavations.
- Uplift and pore pressure gradients in foundations, embankments, abutments and fills.
- Hydrological investigation, ground water elevation study and water supply operations.
- Pore pressure studies in relation to waste and environmental applications
- Monitoring of pore pressure for soil improvement & stability and for slope stability

1.2 Vibrating wire piezometer Encardio-rite's range

- Encardio-rite model EPP-30V electron beam welded robust vibrating wire piezometer especially suitable for monitoring pore pressure in heavy structures like earth/rockfill dams and mass concrete during construction and for long term monitoring after construction is over.
- Encardio-rite model EPP-40V slim piezometer 19 mm diameter specially designed to monitor pore pressure in small diameter boreholes during construction activity.
- Encardio-rite model EPP-60V low pressure piezometer specially designed to monitor low pore pressures.
- Encardio-rite model EPP-50V piezometer for installing by pushing into soft soil.

1.3 Conventions used in this manual

WARNING! Warning messages calls attention to a procedure or practice that if not properly followed could possibly cause personal injury.

CAUTION: Caution messages calls attention to a procedure or practice that if not properly followed may result in loss of data or damage to equipment.

NOTE: Note contains important information and is set off from regular text to draw the users' attention.

1.4 How to use this manual

The users' manual is intended to provide sufficient information for making optimum use of vibrating wire piezometers in different applications.

To make the manual more useful we invite valuable comments and suggestions regarding any additions or enhancements. We also request to please let us know of any errors that are found while going through the manual.

NOTE: Installation personnel must have a background of good installation practices and knowledge of fundamentals of geotechnics. Novices may find it very difficult to carry on installation work. The intricacies involved in installation are such that even if a single essential but apparently minor requirement is ignored or overlooked, the most reliable of instruments will be rendered useless.

A lot of effort has been made in preparing this instruction manual. However best of instruction manuals cannot provide for each and every condition in field that may affect performance of the sensor. Also, blindly following the instruction manual will not guarantee success. Sometimes, depending upon field conditions, installation personnel will have to consciously depart from written text and use their knowledge and common sense to find solution to a particular problem.

Installation of a piezometer requires expertise. It is recommended that potential users themselves practice all the operations laid down in this manual by repeated installations.

NOTE: The sensor is normally used to monitor site conditions and will record even a minor change that may affect behaviour of structure being monitored. Some of these factors amongst others, are, seasonal weather changes, temperature, rain, barometric pressure, nearby landslides, earthquakes, traffic, construction activity around site including blasting, tides near sea coasts, fill levels, excavation, sequence of construction and changes in personnel etc. These factors must always be observed and recorded as they help in correlating data later on and also may give an early warning of potential danger or problems.

The manual is divided into a number of sections. Each section contains a specific type of information. Please refer to the "table of content" for the sections included in the manual.

2 VIBRATING WIRE PIEZOMETER

2.1 Operating principle

The vibrating wire piezometer consists of a magnetic, high tensile strength stretched wire, one end of which is anchored and the other end fixed to a diaphragm that deflects in some proportion to applied pressure. Any change in pressure, deflects the diaphragm proportionally and this in turn affects the tension in the stretched wire. Thus any change in pore pressure, directly affects the tension in the wire.

The wire is plucked by a coil magnet. Proportionate to the tension in the wire, it resonates at a frequency 'f', which can be determined as follows:

$$f = [\sigma g / \rho]^{1/2} / 2l \text{ Hz}$$

where	σ	=	tension of wire
	g	=	gravitational constant
	ρ	=	density of wire
	l	=	length of wire

The resonant frequency, with which wire vibrates, induces an alternating current in the coil magnet. The pore pressure is proportional to the square of the frequency and the Encardio-rite model EDI-54V readout logger is able to display this directly in engineering units.

2.2 General description

Piezometers are manufactured in various capacities. A thermistor is provided integrally in each piezometer to monitor temperature and if necessary, to make the temperature correction in the zero reading (see § 5).

A tri-polar plasma surge arrestor inside the transducer housing protects the vibrating wire pluck and read coils from electrical transients such as may be induced by direct or indirect lightning strikes.

2.2.1 Model EPP-30V electron beam welded heavy duty piezometer

The vibrating wire and coil magnet assembly is enclosed in a stainless steel body (figure 2.1) which is electron beam welded to the diaphragm. This results in a vacuum of around 1/1000 Torr inside the sensor resulting in it becoming immune to effect of any ingress of water and other corrosive materials that may be present in the water. As piezometer is of stainless steel construction, it is not affected by normal chemical corrosion at locations in which it is used.



A low air entry value ceramic flat filter with a thickness of 3 mm and a grain size of 40-60 microns is normally provided. The water oozing through internal pores or seams in rock formations of dam foundations, mass concrete of structures, foundation soil of structures, reclaimed land soil etc. percolates through the filter to pressurise the diaphragm. A locking nut holds the filter in position. For filling up the cavity behind the filter with de-aired water before installation and for saturating the filter with water, a bent nose plier (commonly used for circlips) is used to remove and again assemble the locking nut.

Depending upon the application, filters with different porosity and air entry values are available.

The leads from the coil magnet are terminated on a glass to metal seal which is integrally electron beam welded to the stainless steel body of the piezometer. The two pins marked red and black are connected to the coil magnet. The other two pins are connected to a thermistor. A cable joint housing and cable gland is provided for the cable connection. For cable jointing, refer to Users' Manual 6002.11.

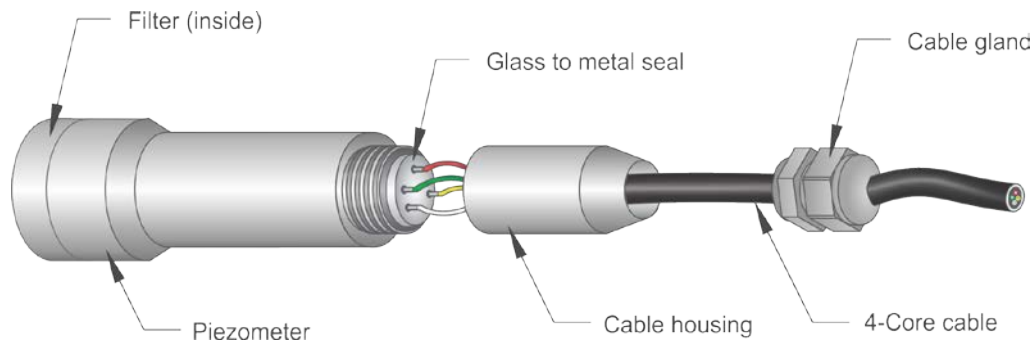


Figure 2-1 Model EPP-30V electron beam welded piezometer

Normally, the piezometer is supplied without any cable attached to it. Cable jointing with required length of appropriate cable can be easily done at site. However, if specifically requested, piezometers are supplied with requisite length of cable attached.

2.2.2 Model EPP-40V slim size piezometer

EPP-40V slim size 19 mm ϕ piezometer is mostly used for monitoring pore pressure in boreholes during construction operation. This sensor is electron beam welded with a vacuum of around 1/1000 Torr inside it. A low air entry value ceramic flat filter is provided with a grain size of 40-60 microns unless specified otherwise. Cable jointing through a glass to metal seal is just like as in model. However, if specifically requested, the piezometers are supplied with the requisite length of cable attached.



2.2.3 Model EPP-60V low pressure piezometer

EPP-60V low pressure sensor is specially designed to measure low water pressure. The basic pressure sensor, in a diameter of 30 mm, is conveniently designed to measure water level, and water pressure in boreholes. Pressure sensor is used for applications in which maximum hydrostatic head (height of water level above piezometer location) is less than 7 m over the sensor diaphragm.



2.2.4 Model EPP-50V push-in piezometer

EPP-50V push-in type vibrating wire piezometer is used for monitoring pore water pressure in soft soil/clay and landfills. It has a pointed cone at one end and drill rod threads (EW or M 28) at the other end. It is inserted into a borehole, threaded into a drill rod and then pushed into soft soil directly till the required depth. The cable is passed through the drill rod. Push-in piezometer is provided with a standard 1 m long polyurethane sheathed cable which can be extended at site as per requirement with a kit that is available from the factory. However, if specifically requested, the piezometers are supplied with the requisite length of cable attached.



2.3 Typical installations

Typical installation methods are described in section 4.

2.4 Zero Reading

In any Encardio-rite vibrating wire piezometer, tension in wire is set such that at no pressure on the diaphragm, the wire vibrates at an initial frequency as specified in the test certificate. This means that the piezometer has an initial frequency reading with no pressure exerted on its diaphragm. It is therefore necessary that an initial zero reading be accurately determined for each piezometer, as this reading will be used for subsequent data reduction. Generally, the initial reading prior to installation with no pressure applied is considered.

Special consideration should be given to the following:

- Make sure that piezometer temperature reaches thermal equilibrium. Temperature variation across body of piezometer results in temperature transients and consequently error in reading. Allow 20-25 minutes for piezometer temperature to stabilize. Take particular care that sunlight does not fall on any surface of piezometer. For borehole installations, to achieve thermal equilibrium the piezometer may be lowered down in the borehole and stopped just above the water table. It should remain at the same location and initialized once thermal stability is achieved.
- Check if filter is fully saturated with water. Reading will be seriously affected due to surface tension effects in pores of filter in case filter is not fully saturated. At low pressures below 0.5 kg/cm², the problem is more acute.
- In conducting any preliminary tests involving raising or lowering piezometer in a fluid filled borehole or at low pressures it is advisable to remove the filter.
- Check if temperature and barometric pressure are recorded at time of taking zero reading.
- For monitoring level in a standpipe, allow sufficient time for level to stabilize. Lowering piezometer and cable in a borehole may sufficiently displace water column and affect the water level reading, especially if diameter of borehole is proportionately small. Take an example in which the model EPP-30V piezometer is lowered by a 6 mm outside diameter cable, 10 m below water column in a 50 mm inside diameter casing. The water level will rise by around 22 cm and unless allowed to stabilize with time will give an erroneous reading.

2.5 Taking readings with model EDI-54V vibrating wire indicator

The model EDI-54V vibrating wire indicator (figure 2.3) is a microprocessor-based read-out unit for use with Encardio-rite's range of vibrating wire sensors. It can display the measured frequency in terms of time period, frequency, frequency squared or the value of measured parameter directly in proper engineering units. It uses a smartphone with Android OS as readout having a large display with a capacitive touch screen which makes it easy to read the VW sensor.

The EDI-54V vibrating wire indicator can store calibration coefficients from 10,000 vibrating wire sensors so that the value of the measured parameter from these sensors can be shown directly in proper engineering units. For transducers with built-in interchangeable thermistor, it can also display the temperature of the transducer directly in degree Centigrade.



Fig 2.3 – Vibrating wire indicator

The vibrating wire indicator has an internal non-volatile memory with sufficient capacity to store about 525,000 readings from any of the programmed sensors. Each reading is stamped with the date and time the measurement was taken.

Refer instruction manual WI-6002.112 of model EDI-54V for entering the transducer calibration coefficients. The gage factor of the model EPP-30V/40V/50V/60V vibrating wire piezometer is given in the test certificate provided with every supply. The initial reading IR will be the actual reading in digits from the vibrating wire piezometer after it is installed in the borehole/foundation and properly set in grout.

An internal 6 V 4 Ah rechargeable sealed maintenance-free battery is used to provide power to the vibrating wire indicator. A battery charger is provided to charge the internal battery, which operates, from 90 V to 270 V AC 50 or 60 Hz V AC mains. A fully discharged battery takes around 6 hours to get fully charged. The indicator uses a smartphone as a readout that has its own internal sealed rechargeable Li-ion maintenance battery as a power source. A separate battery charger/adaptor unit for the smartphone, operating from universal AC mains supply is supplied with each EDI-54V indicator unit.

The EDI-54V vibrating wire indicator is housed in an impact resistant plastic moulded housing with weatherproof connectors for making connections to the vibrating wire transducer and the battery charger.

For operating complete operating procedure please refer 'Doc. # WI 6002.112'

2.6 Sample test certificate for model EPP-30V piezometer

TEST CERTIFICATE DWT Traceable to standard no. : J082301 T8F 281 TC

Customer :
P.O.No. :
Instrument : Piezometer Date : 03.11.2011
Serial number : 15905 Temperature : 26°C
Capacity : 350 kPa Atm. Pressure : 100 kPa

Input pressure (kPa)	Up1 (Digit)	Observed value Down (Digit)	Up2 (Digit)	Average (Digit)	End Point Fit (kPa)	Poly Fit (kPa)
0.0	6065.8	6068.7	6068.7	6067.3	0.0	0.1
70.0	5816.2	5817.2	5815.5	5815.9	70.1	69.9
140.0	5563.7	5565.0	5563.3	5563.5	140.4	140.0
210.0	5312.9	5314.2	5312.4	5312.6	210.3	209.9
280.0	5060.0	5060.7	5060.6	5060.3	280.6	280.3
350.0	4811.2	4811.2	4811.3	4811.2	350.0	349.9
Error (%FS)					0.17	0.08

Digit : $f^2/1000$
Linear gage factor (G) : 2.7865E-01 kPa/digit
(Use gage factor with minus sign with our read out unit Model : EDI-51V)
Thermal factor(K) : -0.077 kPa/°C
Polynomial constants :
A= 9.3331E-07 B= -2.8863E-01 C= 1.7169E+03

Pressure "P" is calculated with the following equation:

Linear : $P(\text{kPa}) = G(R0 - R1) + K(T1 - T0) - (S1 - S0)$

Polynomial : $P(\text{kPa}) = A(R1)^2 + B(R1) + C + K(T1 - T0) - (S1 - S0)$

R1 = current reading & R0 is initial reading in digit.

S1 and T1 = current atmospheric pressure(kPa) and temperature (°C)

Readings at the time of shipment	Date	04.11.2011
f	Hz	2463.5
f ²	Digit	6069.0
Temperature	°C	27
Thermistor	Ohm	2680
Atm.pressure	kPa	100
Coil resistance	Ohm	133

(Zero conditions in the field must be established by recording the reading R0 (digit) along with temperature T0 (°C) and atmospheric pressure S0 (kPa) at the time of installation. If polynomial constants are used, determine value of 'C' as per § 6.2 of user's manual.)

Pin configuration/wiring code:

Red & black : Signal Green & white: Thermistor

Checked by

Tested by

2.7 Sample test certificate for model EPP-40V or model EPP-50V piezometer

TEST CERTIFICATE

DWT Traceable to standard no. : H090401 T8F 281 TC

Customer	:		
P.O.No.	:		
Instrument	:	Vibrating wire Piezometer	Date: 31.07.2009
Model	:	EPP-40V	Temperature: 31 °C
Serial number	:	04633	Atm. pressure: 0.099 MPa
Capacity	:	1.0 MPa	
Cable length	:		

Input pressure (MPa)	Up1 (Digit)	Down (Digit)	Up2 (Digit)	Average (Digit)	End Point Fit (MPa)	Poly Fit (MPa)	Non Conformance (% FS)
0.000	7439.5	7440.8	7440.8	7440.2	0.000	0.000	0.008
0.200	6665.0	6665.8	6665.8	6665.4	0.200	0.200	0.009
0.400	5888.4	5890.2	5898.9	5893.7	0.400	0.399	0.051
0.600	5112.6	5114.0	5122.9	5117.7	0.601	0.600	0.018
0.800	4339.6	4340.6	4349.0	4344.3	0.801	0.800	0.041
1.000	3574.9	3574.9	3575.2	3575.1	1.000	1.000	0.025

Non linearity (% FS)				0.10	Accuracy(% FS)	0.05
Digit	:	$f^2 / 1000$				
Linear gage factor (G)	:	2.5872E-04 MPa/digit				
		(Use gage factor with minus sign with our read out unit Model : EDI-51V)				
Thermal factor(K)	:	0.000 MPa/°C				
Polynomial constants	:	A = 1.6150E-10				
		B = -2.6042E-04				
		C = 1.9287E+00				

Pressure "P" is calculated with the following equation:

Linear , $P(\text{MPa}) = G(R0 - R1) + K(T1 - T0) - (S1 - S0)$

Polynomial , $P(\text{MPa}) = A(R1)^2 + B(R1) + C + K(T1 - T0) - (S1 - S0)$

R1 = current reading & R0 is initial reading in digit.

S1 and T1 = current atmospheric pressure(MPa) and temperature (°C)

(Zero conditions in the field must be established by recording the reading R0 (digit) along with temperature T0 (°C) and atmospheric pressure S0 (MPa) at the time of installation. If polynomial constants are used, determine value of 'C' as per § 6.2 of user's manual.)

Pin configuration/wiring code:

Red & blue : Signal Green & yellow : Thermistor

Checked by

Tested by

2.8 Sample calibration constants for model EPP-30V piezometer required to be used with EDI-54V Readout Unit

Calibration Constants for EDI-54V Data Loggers

The constants will be used to read the Sensor Output in engineering unit (MPa)

Sl.No.	Pressure Sensor Sl. No.	Polynomial Constants				Linear Constants		
		A5,A3,A1	A4	A2	A0	A5,A4,A3,A1	A2	A0
1	43995	0	1.8362E-15	-4.6259E-07	2.5110E+00	0	-4.4249E-07	2.8314E+00
2	44006	0	1.9630E-16	-4.2461E-07	2.6567E+00	0	-4.2309E-07	2.6543E+00
3	44007	0	-2.9337E-16	-4.0744E-07	2.5885E+00	0	-4.1132E-07	2.6019E+00
4	44020	0	-1.9308E-16	-4.2233E-07	2.6675E+00	0	-4.2498E-07	2.6776E+00
5	44050	0	4.0604E-16	-4.4961E-07	2.8401E+00	0	-4.4592E-07	2.8302E+00
6	44066	0	3.5270E-15	-4.3925E-07	2.6177E+00	0	-4.0173E-07	2.5213E+00
7	44148	0	4.9612E-16	-4.5513E-07	2.8694E+00	0	-4.5044E-07	2.8609E+00
8	44155	0	2.2529E-15	-4.2783E-07	2.5889E+00	0	-4.0411E-07	2.5281E+00
9	44169	0	-6.8315E-16	-3.9056E-07	2.5110E+00	0	-3.9862E-07	2.5358E+00
10	44175	0	-4.9131E-17	-4.1682E-07	2.6646E+00	0	-4.1791E-07	2.6691E+00
11	44186	0	-1.8561E-15	-3.8740E-07	2.5307E+00	0	-4.0856E-07	2.5914E+00
12	44192	0	-9.7324E-16	-3.9361E-07	2.5154E+00	0	-4.0469E-07	2.5459E+00
13	44222	0	6.4001E-16	-4.1122E-07	2.5154E+00	0	-4.0489E-07	2.5608E+00
14	44255	0	7.2646E-16	-4.3504E-07	2.7026E+00	0	-4.2797E-07	2.6870E+00

(Q.C.Division)

2.9 Sample calibration constants for model EPP-30V piezometer required to be used with ESDL-30 Datalogger

Calibration Constants for ESDL-30 Series Data Logger

The constants will be used to read the Sensor Output in engineering unit (MPa)

Sl.No.	Pressure Sensor Sl. No.	Polynomial Constants			Linear Constants		
		A2	A1	A0	A2	A1	A0
1	43995	1.8362E-15	-4.6259E-07	2.5110E+00	0	-4.4249E-07	2.8314E+00
2	44006	1.9630E-16	-4.2461E-07	2.6567E+00	0	-4.2309E-07	2.6543E+00
3	44007	-2.9337E-16	-4.0744E-07	2.5885E+00	0	-4.1132E-07	2.6019E+00
4	44020	-1.9308E-16	-4.2233E-07	2.6675E+00	0	-4.2498E-07	2.6776E+00
5	44050	4.0604E-16	-4.4961E-07	2.8401E+00	0	-4.4592E-07	2.8302E+00
6	44066	3.5270E-15	-4.3925E-07	2.6177E+00	0	-4.0173E-07	2.5213E+00
7	44148	4.9612E-16	-4.5513E-07	2.8694E+00	0	-4.5044E-07	2.8609E+00
8	44155	2.2529E-15	-4.2783E-07	2.5889E+00	0	-4.0411E-07	2.5281E+00
9	44169	-6.8315E-16	-3.9056E-07	2.5110E+00	0	-3.9862E-07	2.5358E+00
10	44175	-4.9131E-17	-4.1682E-07	2.6646E+00	0	-4.1791E-07	2.6691E+00
11	44186	-1.8561E-15	-3.8740E-07	2.5307E+00	0	-4.0856E-07	2.5914E+00
12	44192	-9.7324E-16	-3.9361E-07	2.5154E+00	0	-4.0469E-07	2.5459E+00
13	44222	6.4001E-16	-4.1122E-07	2.5154E+00	0	-4.0489E-07	2.5608E+00
14	44255	7.2646E-16	-4.3504E-07	2.7026E+00	0	-4.2797E-07	2.6870E+00

(Q.C.Division)

3 TOOLS & ACCESSORIES REQUIRED FOR INSTALLATION

Model EPP-30V, 40V and 60V piezometer has a glass to metal seal with four terminals for jointing the cable at site. Model EPP-50V is supplied with 1 m long cable attached and may be suitably extended at site. The following is a general list from which tools and accessories required by you may be chosen (also refer to users' manual on cable jointing WI-6002.11):

- 3.1 Soldering iron 25 watt
- 3.2 Rosin 63/37 solder wire RF-3C, 30 swg
- 3.3 Thread sealant (Loctite 577 or equivalent)
- 3.4 Cable jointing compound (Please refer to Encardio-rite user's manual "cable jointing of sensors" 6002.11 for options that can be used)
- 3.5 Acetone (commercial)
- 3.6 Spanner 20/22 and 26/28 and pliers 160 mm
- 3.7 Hacksaw with 150 mm blade
- 3.8 Cable Cutter
- 3.9 Surgical blade with holder
- 3.10 Wire stripper
- 3.11 Bent nose plier (internal)
- 3.12 Pouring funnel.
- 3.13 Stainless steel rod 5 mm ϕ , 150 mm length and Spatula
- 3.14 Rotary tin cutter
- 3.15 Fixture for jointing upto six piezometers (figure 3-1)
- 3.16 Toothbrush
- 3.17 Cloth for cleaning (lint less)
- 3.18 Geo-textile bag (150 mm x 250 mm) with integral tying lace to contain the piezometer
- 3.19 Digital multimeter
- 3.20 EDI-54V portable readout unit

4 INSTALLATION PROCEDURE

4.1 Preparation of sensor before installation

Following instructions are for model EPP-30V piezometer. Modify instructions for the other piezometers as per additional instructions given.

- 4.1.1 Remove cable joint housing from cable end of sensor. This gives access to the four pin terminal. Two of the terminals are marked with red and black colours. These are internally wired to the coil of the magnet assembly inside the sensor. The other two terminals are utilized for measurement of temperature using a thermistor. Clean the terminals with a toothbrush.

NOTE: Do not use any acetone for cleaning the terminals as it may damage the glass to metal seal. Acetone should be used to clean the other portions of the sensor.

- 4.1.2 Check working of the sensor as follows:

- For EPP-30V, the coil resistance measured by a digital multimeter between the red and black pins, should lie between 120-150 Ohm. For EPP-40V and EPP-50V, the coil resistance measured by a digital multimeter between the red and black pins, should lie between 130-170 Ohm. Determine resistance at room temperature from thermistor temperature resistance chart in § 5. This resistance should be approximately equal to that between pins marked green and white. For example, if room temperature is 25°C, the resistance would be 3,000 Ohm.
- The resistance between any lead and the protective armour should be > 500 M Ohm.
- Connect sensor to Encardio-rite model EDI-54V portable readout unit and switch it on. The display will show something like:

Freq: 2629.8 Hz

Where the actual figure will vary depending on the transducer connected to the indicator.

- For piezometer, initial reading (offset) in frequency as read on the portable readout unit should be stable.
- For model EPP-30V, check whether sensor is responding to changes in pressure. A crude but simple and effective method of checking whether sensor is responding to changes in pressure is as follows:
 - o Remove filter from piezometer by using a locking nut spanner.
 - o Press diaphragm with thumb and verify that frequency reading on indicator decreases.
 - o This change in reading ensures that deformation produced by pressure of thumb on diaphragm is transmitted to vibrating wire sensing element.

Note: This test is not possible for the model EPP-40V and EPP-50V piezometers.

- Shift readout unit display to frequency² mode. Each sensor is provided with a test certificate giving relationship between applied pressure and output. For model EPP-30V and EPP-40 V the zero reading in frequency² given in test certificate should not differ from current zero reading by more than 100 ($\times 10^3$) divisions and 250 ($\times 10^3$) divisions respectively after due regard to corrections made for difference in temperature, barometric pressure, height above sea level and actual cell position (whether standing up or lying down).
- For example in test certificate for model EPP-30V (see § 2.6), zero reading in frequency² at the time of dispatch is 6452.6 ($\times 10^3$ Hz²). In case temperature and barometric pressure is same at place and time of installation and sensor is placed lying down, reading in frequency² should be between 6,352.6 and 6,552.6 ($\times 10^3$ Hz²).

- 4.1.3 Connect required length of cable to model EPP-30V or EPP-40V piezometer as described in operating manual on cable jointing WI-6002.11 or extend cable of model EPP-50V as required.

NOTE: The cable should always be unreeled by turning cable drum so that cable is laid out on the flooring. Cables should never be unreeled by pulling on cable itself as the internal conductors can get damaged from excessive strain.

Cable should never be unwound from any one side of the drum. This can happen, for example, when the cable drum is kept on its side and the cable is taken out without rolling the drum.

- 4.1.4 Check working of the sensor again following the procedure described above.

NOTE: Add cable resistance when checking resistance between the leads after the cable jointing. For the model CS 0401 cable, the resistance is 26 Ohm/km and for the model CS 0406 cable, the resistance is 48 Ohm/km. (multiply by 2 for both leads). In case any other cable is used, make necessary addition in resistance value.

4.2 Saturating filters

- 4.2.1 Use a bent nose pliers to remove filter from piezometer and boil it in water in a large vessel for about 15 minutes. The filter will saturate with water. Let the water in vessel cool down to room temperature.

NOTE: In model EPP-30V, filter can be removed by opening the locking nut. In model EPP-40V, filter can be removed by pulling out the filter holder. In model EPP-50V, filter can be removed by unscrewing the conical top.

- 4.2.2 Dip piezometer head inside water and re-assemble filter. Make sure that water enclosed between diaphragm and filter does not leak out of sensor when it is tilted or turned around. Bag sensor in de-aired water until installation.

CAUTION: Make sure that de-aired water does not leak out of piezometer. If this happens, an air lock may develop behind filter resulting in erroneous reading of pore pressure. In case water leaks out, repeat process making sure that 'O' ring provided sits properly in its position and locking nut is properly tightened.

NOTE: Assembled piezometer should be bagged in de-aired water to maintain saturation until installation.

NOTE: Some users follow above procedure only in case of high air entry filters and do not find it necessary for low air entry filters as with time air between filter and diaphragm gets dissolved in the water. We however recommend above procedure.

4.3 Installing piezometer (model EPP-30V or EPP-40V slim size) in borehole/foundation

Installation of piezometer in a borehole is done with fully grouted method. Installing multiple piezometers in a borehole using the traditional method, which involves placement of sand pockets surrounding the piezometers, bentonite seals and grout columns to separate piezometers at different levels, is slow and complex. It also poses a risk of unintended communication between piezometers. Fully grouted method (refer to figure 4-1 and 4-2) is quick and easy and results in excellent zone isolation. Vibrating wire piezometers are the electrical piezometers of choice to implement this method as these require very little volume of water to register a change in pore water pressure, thus resulting in a fast response time.

- 4.3.1 Determine the installation depths of the multilevel piezometers. Connect the required length of cables - installation depth plus extra length of 1 to 2 m, to each piezometer. Check the working of the sensors again following the procedure described above.
- 4.3.2 At any elevation, locate by surveying exact position of borehole where borehole/foundation piezometers are to be installed.
- 4.3.3 Drill a 100 mm diameter hole to a depth of around 1 m below the elevation at which the piezometer is to be installed using Guargum as drilling mud. If necessary, use casing to prevent the sidewall of the borehole from collapsing. Wash the borehole clean up to the bottom by pumping in fresh water.
- 4.3.4 Attach bottom most piezometer to sacrificial grout pipe, approximately 300 to 500 mm from the end as shown in picture on net page. PVC pipe of 20 mm dia., bell ended or threaded, could be used as sacrificial grout pipe. Use nylon cable tie to attach piezometer to PVC pipe. Attach piezometer to pipe with its tip pointing upwards. This is to avoid leakage of de-aired water enclosed between diaphragm and filter and to minimize possibility of de-saturation.

NOTE: For long term monitoring, model EPP-30V is recommended. For EPP-40V smaller diameter borehole can be drilled. Outer diameter of EPP-40V is 19 mm.

- 4.3.5 Connect leads to EDI-54V and take the reading in frequency² (digits). This reading will form the 'initial reading' to be entered in the EDI-54V for the sensor set-up data. Shift to temperature mode and record the ambient temperature.
- 4.3.6 Lower the above assembly into the borehole. Attach the cable from the piezometer to the grout pipe at approximate intervals using nylon cable tie or BOPP tape, leaving some slack. Attach subsequent lengths of grout pipe following the same method as described above. Cable should be taped above the grout pipe at regular intervals. Hold the assembly at the borehole top such that there is gap between grout pipe and borehole bottom.
- 4.3.7 Take readings of piezometer after the complete assembly is lowered down the borehole, to check functioning. Normally, the reading should be in accordance to the height of the water column above the piezometer.

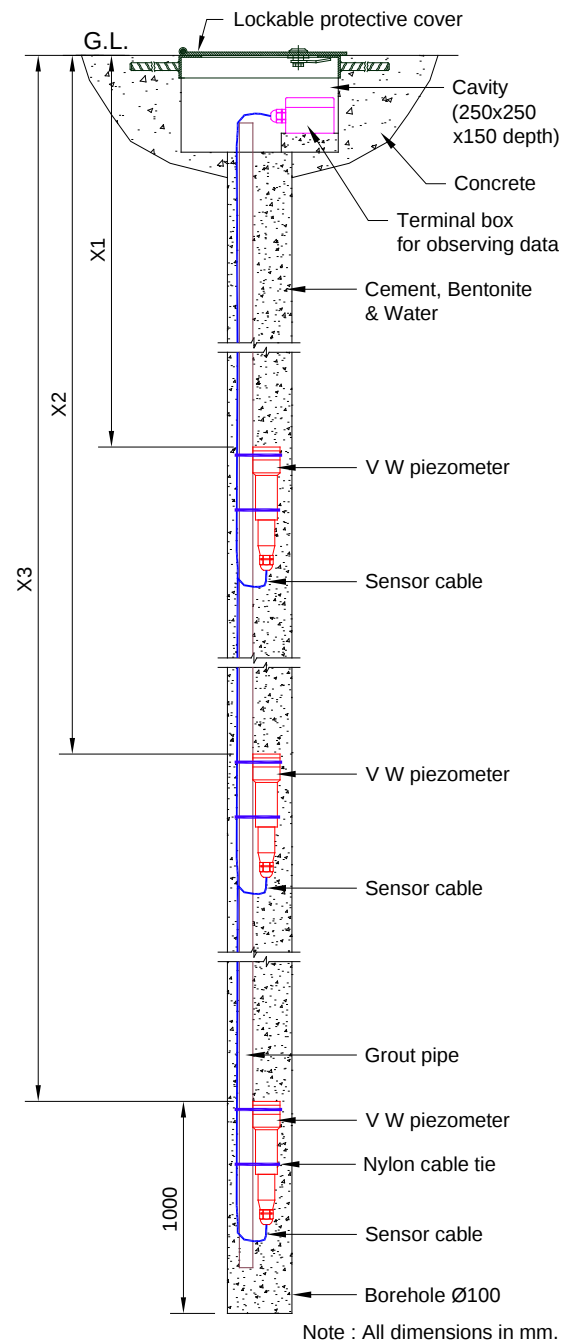


Figure 4-1

- 4.3.8 Prepare grout mix to be filled in the annular space between the piezometer assembly and borehole, as directed by project authorities. If no instructions are available, suggested grout mix is as follows:

Cement	50 kg
Bentonite	15 kg
Water	125 liters

NOTE: It is re-commended that the grout mix should be prepared in sufficient amount such that continuous grouting of the borehole can be carried out in order to avoid choking of the borehole and loss of instrumentation.

- 4.3.9 Mix cement in water first. Add bentonite in cement-water mix slowly, such that clumps are not formed. Continue adding bentonite until the watery mix turns to an oily/slimy consistency. Circulate/mix the grout for another five to ten minutes. Add more bentonite if required until the grout has consistency of cream. It should not be so thick that it is difficult to pump it into the borehole.

NOTE: Record initial reading and temperature with EDI-54V for permanent record before lowering piezometer in borehole. This will form the zero reading for the piezometer. Note barometric pressure at time of taking initial reading.

- 4.3.10 Pump grout in the annular space between borehole and piezometer assembly using the sacrificial grout pipe until it reaches the ground surface. If casing is used for preventing the borehole walls from collapsing, successively pull it out as the borehole is grouted.

NOTE: It is suggested that the maximum discharge head capacity of the grouting pump (Trash Pump) should be higher than the maximum depth of borehole. If no details are available, suggested grout pump is as follows:

Model	KTH-80X-BAB
Make	Keshin Ltd.
Mix Discharge head	27 m
Delivery Volume	1340 l/min

- 4.3.11 Leave the grout to settle down overnight or 12 hr. approximately. Next day, top up the settled grout to the ground surface.

- 4.3.12 Take readings of piezometers after the borehole is grouted. The piezometer readings will normally be more at this stage owing to the grout column above the piezometers, which is denser than water. The readings will decrease as the grout cures. Normally the grout will take two days to cure.

- 4.3.13 Make a 400 mm x 400 mm concrete platform on top and install 250 mm x 250 mm lockable protective cover. Terminate the cable end in a terminal box for observing data, located in the niche/cavity.

NOTE: For saline water applications, specially treated piezometers have to be procured. In these, the stainless steel diaphragm is protected with a thin layer (around 1 mm) of GE Silicones compound TSE 399. Wrap the remaining exposed cylindrical surface of the piezometer stainless steel body with a saline resistant tape like "33 super PVC 3M tape".



Figure 4.2 – installation by fully groutable method

Particular care should be taken to cover the joint between the piezometer and the cable joint housing.

NOTE: In case readings are to be taken with the portable EDI-54V at specified intervals, use a junction box with only one cable gland. However, in case cable has to be extended to a distant location, use a junction box with two cable glands.

NOTE: At certain locations like earth/rockfill or concrete dams, it is convenient not to have the junction box and route one continuous cable from the sensor to the observation room. In such a case the platform (clause 4.3.13) is not made.

NOTE: Note elevation at which piezometer is installed for future correlation of data and its analysis.

4.4 Installing piezometer in embankment – recommended piezometer model EPP-30V

4.4.1 Carefully mark the position where piezometer is to be installed. Place some sand/gravel to form a plain surface in the earth/rock fill or concrete dam.

4.4.2 Fill geo-textile bag with saturated sand (2-4 mm) and insert piezometer in it. Tie bag at top by pulling lace. Make assembly into a cylinder of around 75 mm ϕ .

4.4.3 Connect leads to EDI-54V and take reading in frequency² (digits). This reading will form the 'initial reading' to be entered in EDI-54V for sensor set-up data. Also record ambient temperature.

NOTE: Record initial reading and temperature with EDI-54V for permanent record. This will form the zero reading for the piezometer. Note barometric pressure at time of taking initial reading.

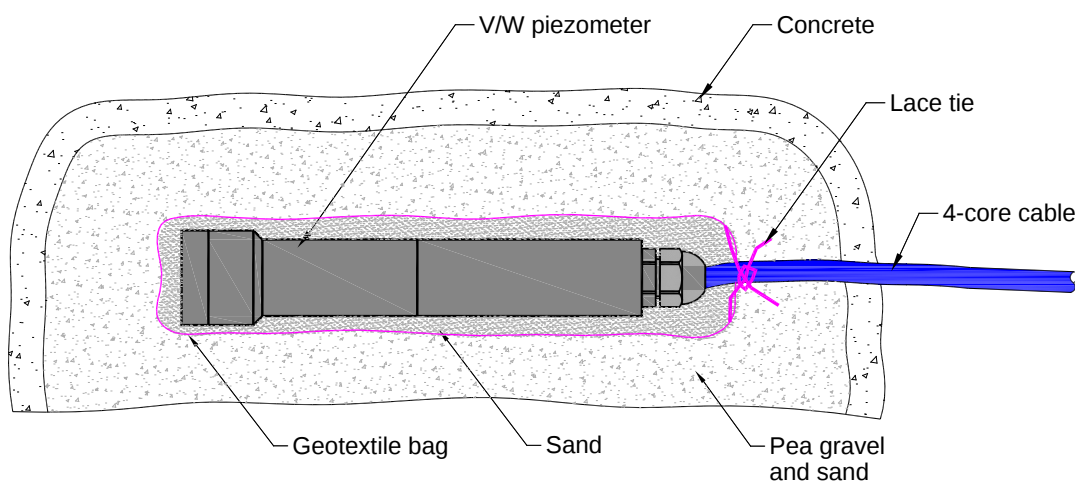


Figure 4-2

4.4.4 Place enough sand/ gravel to cover the sensor and the adjoining cable all around.

4.4.5 Cover sensor with enough back fill in case of earth/rock fill dam. In concrete dam pour concrete by hand shovel to embed sensor to depth of around 0.5 m before commencing normal operation.

4.5 Embedment of sensor and cable laying

4.5.1 General precautions in the mounting of the cable

Careful and skilled cabling is required in installation of piezometer as sensor/cable joint and a large part of cable is permanently embedded and no future access is available for any maintenance and corrective action.

The procedure for laying of cables differs with individual installations. In general, however, all installations have the following common requirement:

- Protect cable from damage by angular and sharp particles of material in which it is embedded.
- Cables may be spliced without affecting sensor reading; nevertheless splicing should be avoided wherever possible. If necessary, use special cable jointing kits available from factory.
- In earth/rock embankments and backfill, cable must be protected from stretching due to differential compaction of embankment. Cable must also be protected from damage by compaction equipment.

Precaution must be taken that cable is properly tagged, onward from point from which they come out of embankment. With the best possible precautions, mistakes may still occur. Tags may get lost due to cable getting accidentally cut. Encardio-rite uses the convention that looking from end of trench towards sensor, cable from most distant sensor is always at the left hand side and the offset trenches are to the right of the cable trench. In that order, the cable from the closest sensor is at the extreme right.

NOTE: A simple code for remembering this is “LL-SR”. Longer (cable) left, shorter (cable) right when viewing the sensors from the observation room.

CAUTION: All cables should be properly identified by tagging them every 5 m, onwards from the point from which they come out of the embankment. The tags should be of a non-corrosive material like stainless steel or plastics.

CAUTION: Follow the Encardio-rite convention that looking from the end of the trench towards the sensor, the cable from the most distant sensor is always at the left hand side and the cable from the closest sensor is at the extreme right.

As an Encardio-rite convention, cable from most distant sensor should be connected to extreme left socket in junction box. Succeeding cables from sensors are connected progressively towards the right in junction box.

In case of an earth dam before packing the trench with back fill, a plug approximately 100 mm thick, made of a mixture of 5% bentonite (by volume) exhibiting a free swell factor of approximately 600%, and 95% sand should be placed in the trench at intervals of approximately 10 m.

In case of concrete dam, to take care of any settlement and/or contraction of concrete due to temperature effects, cable should be zigzagged by providing a uniformly distributed slack of around 0.5 m in a 15 m length of each cable.

4.5.2 Earth and rock fill dam – recommended piezometer model EPP-30V

In an earth and rock fill dam, a number of piezometers and maybe other sensors are installed at selected elevations at different cross sections, as illustrated in figure 4-4. For example, nine piezometers and three soil pressure meters are installed at elevation 438 m.

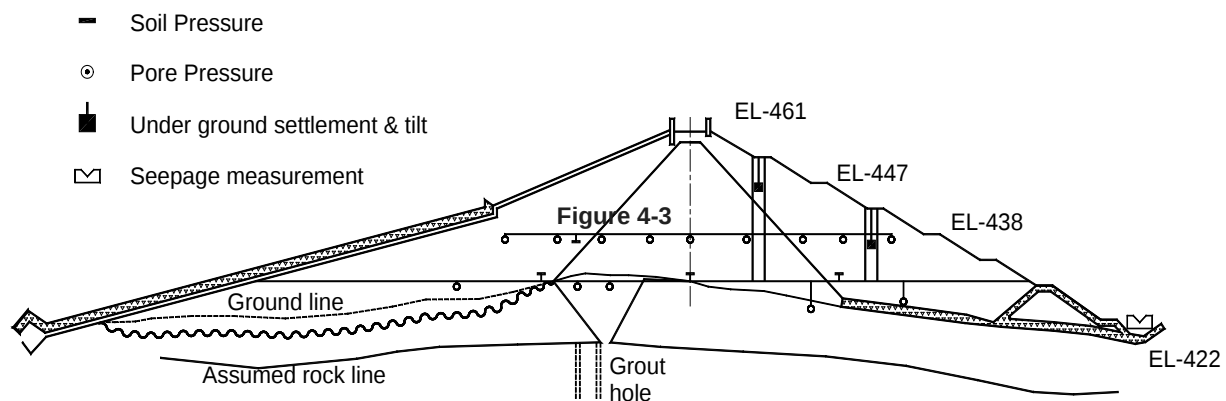


Figure 4-4 - Typical piezometer layout in earth and rockfill dam

Monitoring of readings from group of piezometers installed at different elevations help in determining the phreatic line and gives an indication on how it advances with time till steady state conditions are reached.

At any cross section, filling of dam is allowed to continue to an elevation of around 0.5 to 1 m higher than where piezometers are to be mounted. Positions where piezometers (whether foundation or embankment) are to be mounted are carefully marked. Offset trenches (around 1 m x 1 m) to reach correct required elevation are dug at these positions.

Material around sensor should be placed by hand shovel and compacted with a light duty pneumatic or petrol backfill tamper. First layer of material over sensor should be around 250 mm high and compacted properly. Similar layers of material should be put over this and compacted properly until at least 500 mm of material has been placed. Rubber tyre equipment can now cross this location, but no vibratory rollers should be permitted over the sensor until a compacted thickness of at least 1 m is laid.

In case foundation piezometers are to be installed, necessary boring is done to the required depth and installation of piezometer is done as per section § 4.3.

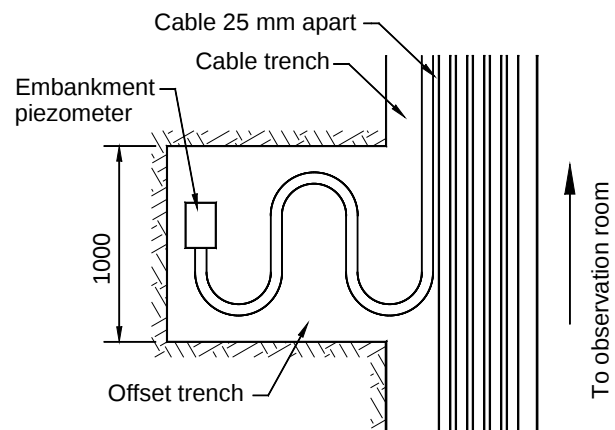


Figure 4-5 Installation in embankment

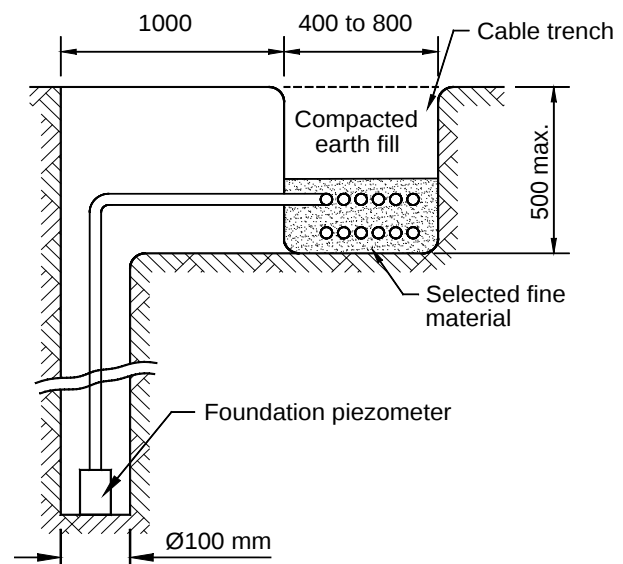


Figure 4-6 Installation in foundation

In case of installation of foundation piezometer in earth/rockfill or concrete dams, it is convenient not to have the junction box and route one continuous cable from the sensor to the observation room. In such a case the platform (clause 4.2.13) is not made instead cabling is done in cable trench.

Looking towards the sensors from the trench end side dig a cable trench around 400 - 800 mm wide and upto 500 mm deep suitable cable trench at the left hand side of the sensor locations to route cables from all the sensors at that elevation along the offset trenches, as shown in figure 4-5 and figure 4-6. Remove any sharp rocks to prevent the cable from accidentally getting damaged. Properly clean and level the trench with 50 mm (as specified by project) of well graded clean sand (2-4 mm) at the bottom of the trench along the path. Depth and width depends upon number of cables trench has to carry. Based upon cable layout design, the trench runs into abutment and then along abutment to downstream side or directly to downstream side towards observation room. These cable trenches carry the individual cables from piezometers to observation room.

Before laying cables, trench should be properly cleaned and levelled with 30 mm of fine sand at bottom of trench along the path. Any sharp rocks should be removed to prevent cable from accidentally getting damaged. Centre distance between successive cables should be kept at around 25 to 40 mm. A distance of 100 mm must be left free from sides of trench. To take care of any increase in length due to settlements cable should be zig zagged by providing a uniformly distributed slack of around 0.5 m in a 15 m length of each cable

NOTE: In embankments, sensor and cables may be embedded in a protective covering of sand or selected fine embankment material. Typical installation might, for example comprise positioning of a series of sensors and cables on a prepared layer consisting of not less than 100 mm of compacted selected fine material. In order to establish an acceptable grade without undue interference with construction operations, prepared layer may be located either in a trench or on an exposed ramp. In rockfill dams with earth fill cores, for example, it is frequently convenient to install sensors and cables in trenches in core and fine filter zones and in ramps in coarse filter and compacted rock fill shell zones. In an earth embankment it is convenient to install in a trench. By doing so, adequate degrees of compaction of backfill can be more easily obtained without damage to sensor or cable trench. As sensors and cables are covered and compacted, repeated readings should be taken to ensure that they continue to function properly.

NOTE: In instances in which more than one layer of cables must be placed in a given array, the cables should be separated from each other by a vertical interval of not less than 100 mm of hand compacted sand or selected fine embankment material.

NOTE: In case of an earth dam, before packing the trench with back fill, a plug approximately 100 mm thick, made of a mixture by volume of 5:95 bentonite and backfill exhibiting a free swell factor of approximately 600% should be placed in trench at intervals of approximately 10 m.

NOTE: In embankment dams vertical routing of signal cables from sensors should be avoided as far as possible. However, if vertical run of cables is unavoidable, they should be routed vertically only through the filter. Figure 4.7 schematically shows preferred method for vertical routing of instrumentation cables through the filter.

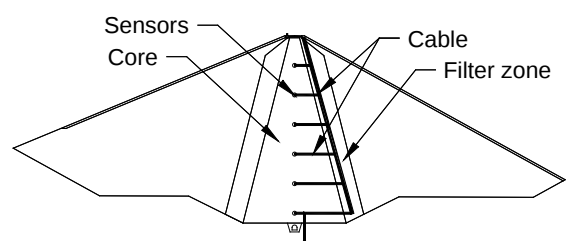


Fig. 4.7 - Section of Dam

4.5.3 Concrete dam – recommended piezometer model EPP-30V

As access galleries are available in concrete dams, the cable from the sensors is first routed to the gallery. These cables may be terminated in junction boxes inside the gallery. The data from the various sensors can then be taken or logged from the junction boxes with the help of a readout unit or data logger. Alternatively, if required, the signals from the junction boxes may be carried through multi core cables to any observation room outside the dam structure.

In a concrete dam, a number of piezometers along with other sensors are installed at selected elevations at different cross sections, as illustrated in figure 4-8 below. For example, three piezometers, five strain rosettes, five no stress strain containers, five stress meters and two temperature meters are installed at elevation 132 m. Cables from these sensors have to be taken to junction boxes to be mounted inside one of the cross galleries. The gallery may be above or below the elevation at which the sensors are to be installed. As a general practice, all the cables from sensors at any particular elevation are routed to a vertical shaft on the upstream side of the dam. The cables are then lowered or lifted through the vertical shaft to the gallery.

At any cross section, the filling of the dam is allowed to continue to an elevation of around 25 cm higher than where the sensors are to be mounted, leaving 0.5 m x 0.5 m x 25 cm deep trenches at the positions where the sensors are to be placed. Larger trench may be left in case the piezometer is to be installed along with other sensors, especially the strain rosette and the no stress strain meter that require more space. In case the latter are to be mounted along with the piezometer, refer to User's manual WI-6002.16.

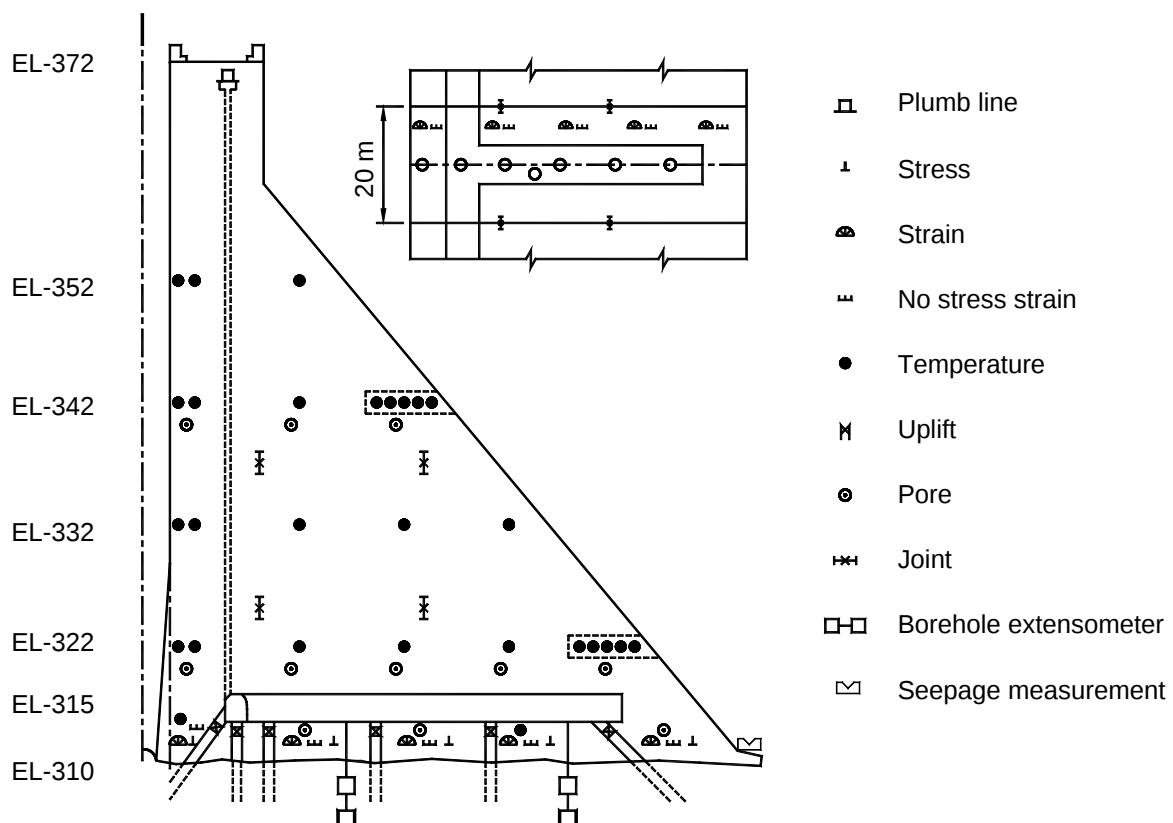


Figure 4-8

The cable from the sensors should be routed through a carefully marked channel trench ending into the vertical shaft and running parallel to the line of the sensors. The depth and width of the channel trench depends upon the number of cables the trench has to carry. In case all the cables at an elevation fit in one row, the depth of the channel can be around 10 cm. If more than one row is required to lay all the cables, the depth should be increased by 10 cm per row. Before laying the cables, the channel trench

should be properly cleaned and levelled. Any sharp rocks or objects should be removed to prevent the cable from accidentally getting damaged. The centre distance between successive cables should be kept at a distance of around 25 mm with the help of the wooden cable spacer and cable rake provided. To take care of settlement effects and temperature effects during concrete setting, the cable should be zigzagged by providing a uniformly distributed slack of around 0.5 m in a 15 m length of each cable. After laying the cable in any row, it should be covered with concrete by a hand shovel to a depth of around 10 cm and allowed to set. This is necessary to prevent any accidental damage to the cables.

To make doubly sure that some of the precautions in the laying of cable are definitely followed, they are being repeated in the following few paragraphs.

Precaution must be taken that the cables are properly tagged, onward from the point from which they come out of the dam into the vertical shaft. With the best possible precautions, mistakes may still occur. Tags may get lost due to the cable getting accidentally cut. Encardio-rite uses the convention that looking from the vertical shaft end towards the sensor, the cable from the most distant sensor is always at the left hand side and the offset trenches are to the right of the channel trench. In that order, the cable from the closest sensor is at the extreme right.

CAUTION: All cables should be properly identified by tagging them every 5 m or closer, onwards from the point from which they come out of the dam body into the vertical shaft. The tags should be of a non-corrosive material like stainless steel or plastics.

CAUTION: To take care of any of any settlement and/or contraction of concrete due to temperature effects, the cable should be zigzagged by providing a uniformly distributed slack of around 0.5 m in a 15 m length of each cable.

It is good practice to grout the cable in the vertical shaft at 2 m distances such that the left to right alignment is maintained. As an Encardio-rite convention, the cable from the most distant sensor at any elevation should be connected to the extreme left socket in the junction box. Succeeding cables from the sensors are connected progressively towards the right in the junction box.

4.6 Installation of model EPP-50V push-in piezometer in soft soil

- 4.6.1 For installation in soft soils the Encardio rite model EPP-50V push-in piezometer is recommended. It does not require any elaborate grout sealing below and above the piezometer as required for other piezometer models. The EPP-50V has a hard conical tip that allows the piezometer to be pushed in to the required depth from the ground surface or the base of a drilled borehole.
- 4.6.2 The EPP-50V has a conical tip at one end and drill rod threads at the other end. It is available in two different thread options, one with EW thread for use with EW drill rods and the other with M 28x1.5 thread for use with cone penetrometer rods. Just above the conical tip are three stainless steel disc filters arranged around the cylindrical housing of the piezometer which make intimate contact with the surrounding soil when the piezometer is driven inside soft soil.
- 4.6.3 The conical tip of the piezometer with the three stainless steel filter discs can be unscrewed from the EPP-50V body. Before installation the EPP-50V filters need to be deaired or saturated. To saturate the filters unscrew the conical tip and follow the saturation process as described in section 4.2. Reassemble the conical tip on the piezometer body under water after saturation.
- 4.6.4 The EPP-50V can be installed for two different situations, one where the piezometer is permanently left in place after installation and the other where the piezometer is to be retrieved after some time.

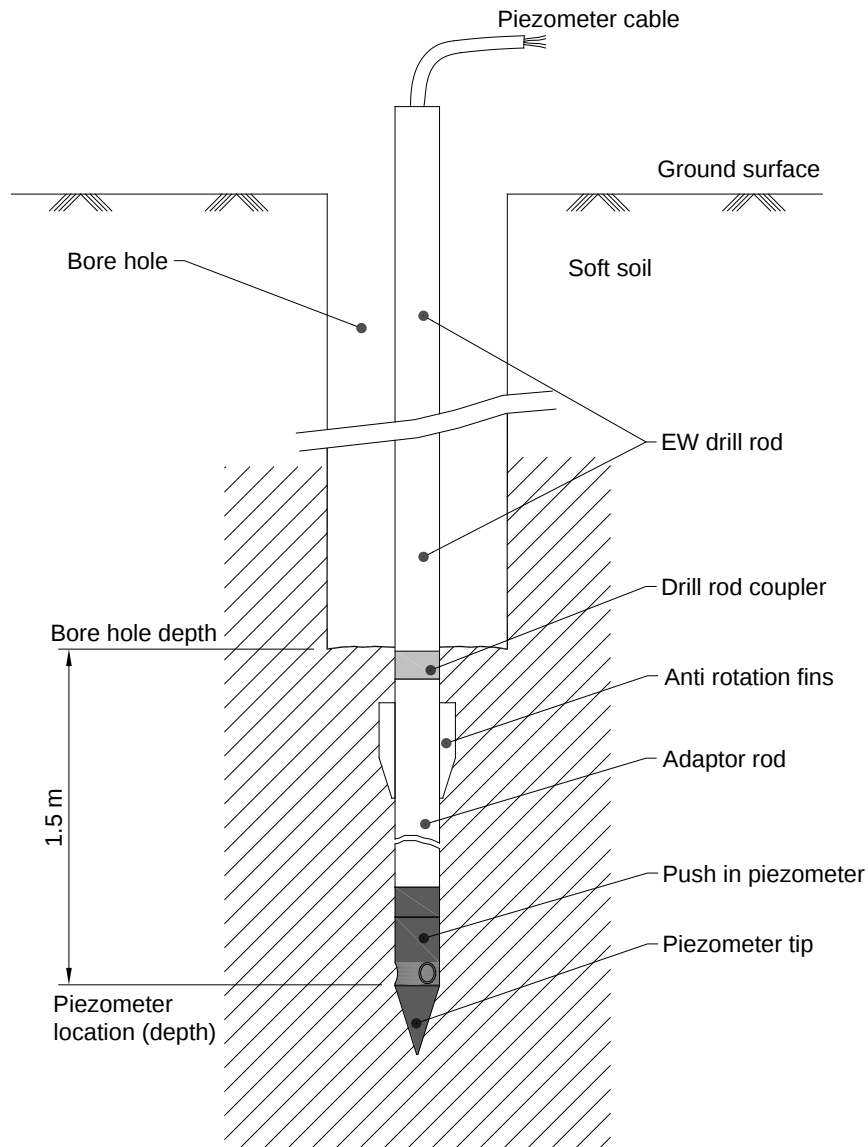


Figure 4.9

4.6.5 If the piezometer is to be retrieved after some time it can be directly screwed on to the end of the hollow drill rod. The piezometer cable should first be routed through the hole in the drill rod before fixing the piezometer to the drill rod. The drill rod with the piezometer should be pushed into the soil slowly using a constant pushing force. The drill rod should not be hammer driven or rotated while pushing in the piezometer as it can damage the piezometer.

4.6.6 To increase the piezometer tip installation depth a series of drill rods can be connected to increase the overall length of the rods. After the piezometer tip reaches the required depth the drill rods with the cable inside are left in place till the time the piezometer needs to be retrieved.

NOTE: Care must be taken to ensure the piezometer cable is properly guided through the drill rods and the piezometer or the piezometer cable is never allowed to rotate inside the drill rods. Precaution should also be taken to ensure that the drill rod edges do not cut into the cable sheathing while installing.

4.6.7 While pushing piezometer inside soil keep checking the pressure readings frequently on EDI-54V read-out. The pressure should not exceed the calibrated range of the piezometer. If necessary, stop the process for a while to allow the pressure to dissipate.

- 4.6.8 If the piezometer is to be installed at a greater depth, pushing in the piezometer along the whole depth may damage the piezometer. A recommended procedure is to make a bore hole using an auger or casing advanced boring with a diameter larger than 100 mm to a depth of around 1.5 metres less than the final piezometer tip depth. The drill rods with the piezometer will then only need to be pushed-in in the final 1.5 metres of soil. This ensures that the piezometer tip is isolated from top and bottom layers and correctly measures the pore pressure at its own depth.
- 4.6.9 After the piezometer's purpose is over it can be retrieved by pulling out the drill rods. The piezometer can then be used at another location.
- 4.6.10 For installations where the piezometer is to be permanently left in place and only the drill rods retrieved a special adaptor rod which is a modified drill rod of 1.5 m length and a left hand / right hand coupler is available. The piezometer is fixed at one end of the adaptor rod and at the other end with left hand thread a special left hand / right hand threaded coupler is fixed. The adaptor rod is optionally provided with anti-rotation fins. In practice the adaptor rod is fixed to the drill rods using the coupler. After the piezometer is installed at its predetermined depth the drill rod (or the series of drill rods) is rotated clockwise so that the coupler unscrews free of the adaptor rod. The anti-rotation fins of the adaptor rod prevent it from rotating while unscrewing the drill rods. The piezometer with the adaptor rod can be left in place while the drill rods with the coupler can be removed for reuse. In this method one adaptor rod is required for each push-in piezometer. The same coupler can be reused for different installation.

NOTE: Before fixing the piezometer to the adaptor rod ensure that the piezometer cable is pushed through the holes of the adaptor rod, coupling and the first drill rod in that sequence. Always keep the piezometer fixed while rotating the adaptor rod, coupling or the drill rods. If the piezometer is let to rotate the piezometer cable will get damaged.

NOTE: Great care should be taken while unscrewing the drill rods from the rod adaptor as the piezometer cable running inside the drill rods do not get damaged due to abrasion from the drill rod surface or edges.

5 TEMPERATURE MEASUREMENT

5.1 Thermistor - temperature resistance correlation

Thermistor type Dale 1C3001-B3

Temperature resistance equation

$$T = 1/[A + B(\ln R) + C(\ln R)^3] - 273.2 \text{ } ^\circ\text{C}$$

where T = temperature in $^\circ\text{C}$

LnR = Natural log of thermistor resistance

A = 1.4051×10^{-3}

B = 2.369×10^{-4}

C = 1.019×10^{-7}

Ohm	Temp. $^\circ\text{C}$	Ohm	Temp. $^\circ\text{C}$	Ohm	Temp. $^\circ\text{C}$
201.1k	-50	16.60K	-10	2417	+30
187.3K	-49	15.72K	-9	2317	31
174.5K	-48	14.90K	-8	2221	32
162.7K	-47	14.12K	-7	2130	33
151.7K	-46	13.39k	-6	2042	34
141.6K	-45	12.70K	-5	1959	35
132.2K	-44	12.05K	-4	1880	36
123.5K	-43	11.44K	-3	1805	37
115.4K	-12	10.86K	-2	1733	38
107.9K	-41	10.31K	-1	1664	39
101.0K	-40	9796	0	1598	40
94.48K	-39	9310	+1	1535	41
88.46K	-38	8851	2	1475	42
82.87K	-37	8417	3	1418	43
77.66K	-36	8006	4	1363	44
72.81K	-35	7618	5	1310	45
68.30K	-34	7252	6	1260	46
64.09K	-33	6905	7	1212	47
60.17K	-32	6576	8	1167	48
56.51K	-31	6265	9	1123	49
53.10K	-30	5971	10	1081	50
49.91K	-29	5692	11	1040	51
46.94K	-28	5427	12	1002	52
44.16K	-27	5177	13	965.0	53
41.56k	-26	4939	14	929.6	54
39.13K	-25	4714	15	895.8	55
36.86K	-24	4500	16	863.3	56
34.73K	-23	4297	17	832.2	57
32.74K	-22	4105	18	802.3	58
30.87K	-21	3922	19	773.7	59
29.13K	-20	3748	20	746.3	60
27.49K	-19	3583	21	719.9	61
25.95K	-18	3426	22	694.7	62
24.51K	-17	3277	23	670.4	63
23.16K	-16	3135	24	647.1	64
21.89K	-15	3000	25	624.7	65
20.70K	-14	2872	26	603.3	66
19.58K	-13	2750	27	582.6	67
18.52K	-12	2633	28	562.8	68
17.53K	-11	2523	29	525.4	70

5.2 Measurement of temperature

Thermistor for temperature measurement is integral with all Encardio-rite piezometers. The thermistor gives a varying resistance output related to the temperature (see § 5.1). The thermistor is connected between the green and white leads. The resistance can be measured with an Ohmmeter. The cable resistance may be subtracted from the Ohmmeter reading to get the correct thermistor resistance. However the effect is small and is usually ignored.

The Encardio-rite model EDI-54V readout unit gives the temperature from thermistor reading directly in °C.

5.3 Temperature correction

Each vibrating wire sensor is individually compensated for temperature zero drift. It is therefore relatively insensitive to temperature fluctuation and often the effect of temperature can be ignored. However in case a 'pressure - temperature variation' correlation is required, the correction for the temperature effect on the sensor can be made by making use of the temperature zero shift factor (K) provided in the Test certificate (see § 2.6 and § 2.7) and substituting it in the following equation:

$$P_{\text{correction}} = (\text{current temperature} - \text{initial temperature}) \times K$$

The temperature correction value is added to the pressure value read from the EDI-54V readout.

Encardio-rite gives the value of the factor 'K' by actually determining the zero shift by putting the complete cell in the thermal chamber.

6 OTHER CONSIDERATIONS/TROUBLE SHOOTING

6.1 Barometric pressure correction

The pressure transducer used in the Encardio-rite vibrating wire piezometer is evacuated and hermetically sealed and will respond to barometric pressure fluctuation. In fact all piezometers will respond to barometric pressure fluctuations unless they are manufactured in the gage pressure version and a capillary tube is provided in the cable that opens into the atmosphere.

Since the magnitude of barometric pressure fluctuations is of the order of +/- 0.3 kPa, correction is generally not required for sensors with a range of 0.2 MPa and higher. If a correction for these fluctuations is required then it is necessary to record the barometric pressure at the time of taking the reading. The initial barometric pressure corresponding to the zero reading is to be recorded at the time of installation (see § 2.5). The correction can be made by using the following equation:

$$P_{\text{correction}} = (\text{initial barometric pressure} - \text{current barometric pressure})$$

The pressure correction value is added to the pressure value read from the EDI-54V readout.

6.2 Polynomial linearity correction

Refer to § 2.6 - test certificate for EPP-30V and to § 2.7 – test certificate for EPP-40V/50V. Polynomial constants 'A', 'B', and 'C' in test certificate are determined at ambient barometric pressure and temperature at time of calibration. The value of constant 'C' given in test certificate would have been different had barometric pressure or temperature been different at time of calibration.

For example in § 2.6 - test certificate for EPP-30V, the initial average reading in digits in test certificate at time of calibration is 6442. This initial zero reading at time of installation would have slightly changed due to difference in barometric pressure/temperature or due to rough handling during transportation or installation. For example, let initial zero reading (§ 2.6) at time of installation be 6462 digits. The constant 'C' will then have to be reworked as follows by setting the pore pressure 'P' at zero in the polynomial equation:

$$P = A (R_1)^2 + B(R_1) + C \text{ MPa}$$

$$\text{or } 0 = -1.4257\text{E-}09 \times (6462)^2 - 2.2094\text{E-}04 \times (6462) + C$$

$$\text{or } C = 1.4277$$

Instead of C = 1.4826 given in the test certificate, use the value C = 1.4277 to get the pressure reading with polynomial linearity correction.

6.3 Use of piezometers in coastal areas

Use of piezometers in coastal areas has increased in the last few years. Some of the applications to which they are being put in use are as follows:

- Reclamation of land in high population density areas in coastal regions for building highways, multi-storied structures, port trusts or recreational facilities. This requires extensive instrumentation for measurement of horizontal displacement, vertical movement and pore pressure.
- At Vancouver, a highway along the coast is extended towards the seashore to increase the number of transportation lanes. Closer to home, reclamation of land is always going on at Mumbai.
- In many coastal areas, and occasionally inland, there is a danger that over pumping water from boreholes will cause saline water to replace the fresh water in the aquifer. Once this saline intrusion has occurred it is extremely difficult to remove the problem. Frequently, boreholes have

to be abandoned and other water sources sought, often at high cost. Aquifers can be complex and include several saline horizons at different depths. Such horizons can be detected by multilevel piezometers and water sampling systems together with conductivity/flow logging in boreholes.

Saline intrusion into the coastal aquifer of Kerala is a serious and increasing problem in this relatively densely populated rural area with many wells used for irrigation and domestic supply. A program of sampling has been established using multilevel piezometers to determine the characteristics of the groundwater regime that is strongly influenced by the local monsoon climate. A saline intrusion computer model helps in understanding the seasonal cyclic movement of the saline/freshwater interface and provides recommendations for safe abstraction.

Excessive pumping over many years caused serious draw downs in the alluvial coastal aquifer of the Valle de San Quintin at Baja California, Mexico. This resulted in the intrusion of seawater in this arid area. Alternative supplies are not available and the livelihood of the 50,000 local population is being put at risk. Pore pressure measurement and borehole conductivity/flow logging was undertaken to determine the extent of intrusion and then a computer model developed to aid remedial measures.

- In coastal areas, it is necessary to determine and implement a strategy to overcome salinity problems and to increase community understanding and involvement in finding and implementing a solution. Monitoring piezometer data and water sampling helps in determining the effect on salinity of climate, vegetation, and management of groundwater movement. At the Derriwong/Ootha area of the USA associated with an elevated saline groundwater table, a tree planting program has been implemented to recharge the area throughout the catchments. Using farm plans and government agency advice, changes in management and land use practices are being adopted (i.e. increased perennial pastures). More than 40 salt-tolerant pasture species are being used to assess suitability for land reclamation and rehabilitation. Over 20,000 seed have been planted and direct seeding of local tree species is underway.
- New ports are being built and extra capacity is being added to several existing ports. At the Kandla port in India, construction work on new berths for docking of cargo vessels is normally going on. These areas need a lot of instrumentation. At the Kandla port, the proposed material storage yard (cargo section) behind the eighth berth is 205 m long x 151 m wide. It was instrumented with 22 piezometers, 8 magnetic extensometer devices for settlement, 29 platform type settlement gages and inclinometer tubing at 8 locations for measurement of horizontal displacement. The land behind the eight berth was a normally consolidated area. When used as a cargo storage facility, the overburden pressure would obviously increase. This area was therefore consolidated resulting in a settlement of around 1 m in depth.

6.3.1 Saline corrosion

Use of sensors in saline water is one of the most difficult applications from the point of view of corrosion. Great care should be taken for corrosion protection in case a piezometer is used for such applications. This is a tricky application and precaution must be taken to protect both the body and the diaphragm of the sensor.

It should be remembered:

- Seawater corrosion or atmospheric corrosion in coastal areas is very different from other corrosions, like in industrial areas.
- Sensors used in geotechnical applications are generally of stainless steel construction. Stainless steels are normally passive, but when exposed to corrosive solutions whose oxygenating power is low, these steels become active. Oxygenating agents must be present and replenished

constantly to maintain passivity. Otherwise localized corrosion frequently results in pitting at the surface. It should be remembered that in case seawater in the vicinity of the piezometer is flowing, the pitting would be less than when it is stationary.

- The best material for use in case of seawater is Monel. Stainless steel 316L is also substantially used. However, this is not always possible in the case of sensors. To attain good linearity and hysteresis characteristics the diaphragm of the piezometer has to be a spring element. To achieve this, hardened AISI 420 or 17-4 PH is generally used.
- In seawater, galvanic couples with different types of stainless steels may result in severe corrosion of the metals forming the couple. It is preferable to use only those metals that are closely related in electrode potential. Galvanic couples may form at the intersection of the AISI 304 cable joint housing and the AISI 420 body of the piezometer.
- Welding of unstabilized grades of stainless steel can lead to localized attack in seawater by upsetting the condition of heat treatment necessary for good corrosion resistance. Welding can also result in localized depletion of nickel and chromium, thus enhancing the effect of sea water corrosion

6.3.2 Precautions to be taken

To substantially minimize the effect of saline corrosion, it is recommended to protect the outside body and the diaphragm of the piezometer from corrosion. The literature has a number of suggestions on how to do this.

- The stainless steel diaphragm should be protected with a thin layer (around 1 mm) of GE Silicones compound TSE 399. This will prevent pitting of the surface, the piezometer being used in still seawater. No solvent (like acetone) should be used to clean this area as it may affect the adhesion of the silicone rubber to the diaphragm.
- The weld area may also be protected with GE Silicones compound TSE 399 enclosed in a PVC retainer housing. In any case, wrap the other surface areas of the stainless steel body of the piezometer with a saline resistant tape like "33 super PVC 3M tape". Particular care should be taken to cover the joint between the piezometer and the cable joint housing.

An easier method is to use a heat shrinkable tube with an integral adhesive inner lining, to encapsulate and protect the complete piezometer body including the weld area from the ingress of seawater.

6.4 Trouble shooting

Piezometer is generally installed in a borehole or buried inside a structure. Once installed, the cell is usually inaccessible and remedial action is limited. Maintenance and trouble shooting is consequently confined to periodic checks of cable connection and functioning of the readout unit. Refer to the following list of problems and possible solutions should problems arise. For any additional help, consult factory.

6.4.1 Symptom: piezometer reading unstable

- Check the insulation resistance. The resistance between any lead and the protective armour should be > 500 m Ohm. If not, cut a meter or so from the end of cable and check again.
- Does the readout work with another piezometer? If not, the readout may have a low battery or be malfunctioning. Consult the manual of the readout unit for charging or trouble shooting instructions.
- Use another readout unit to take the reading.

- Check if there is a source of electrical noise nearby? General sources of electrical noise are motors, generators, transformers, arc welders and antennas. If so the problem could be reduced by shielding from the electrical noise.

6.4.2 Symptom: piezometer fails to read

- The cable may be cut or crushed? Check the nominal resistance between the two gage leads using an Ohmmeter. It should be within 120 - 150 Ohm. The correct value is given in the piezometer test certificate. For the model CS 0401 cable, the resistance is 26 Ohm/km and for the model CS 0406 cable, the resistance is 48 Ohm/km. (multiply by 2 for both leads). In case any other cable is used, make the necessary addition in the resistance value. If the resistance reads infinite or a very high value, a cut in the cable is suspected. If the resistance reads very low (<100 Ohm), a short in the cable is likely.
- Does the readout work with another piezometer? If not, the readout may have a low battery or be malfunctioning. Consult the manual of the readout unit for charging or trouble shooting instructions.
- Use another readout unit to take the reading.

7 APPENDIX-B: SAMPLE OBSERVATION SHEETS

7.1 Vibrating wire piezometer sample observation sheet and chart

Customer's name:

PO no.:

Project name:

Owners:

The Engineer:

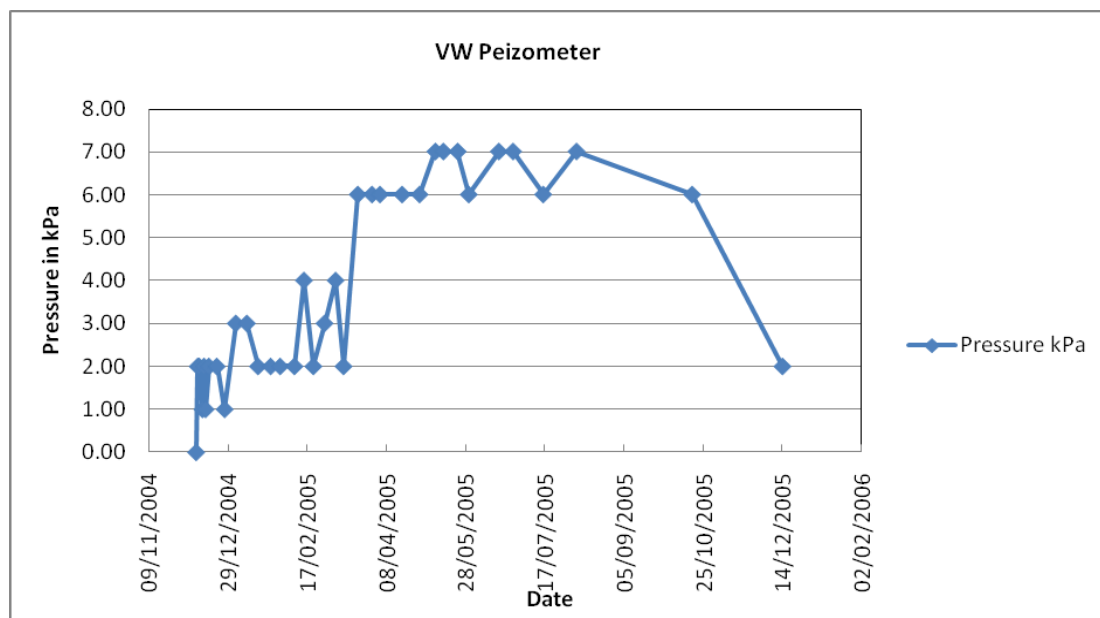
Site name:

Instrument type: Vibrating wire piezometer

Instrument model no. EPP-30V

Instrument tag no.: MZ3-PZ2

Reading no.	Date	Time	Date/Time	Pore-water pressure (kPa)	Temp, deg C
1 (initial)	01-Nov-09	14:00	01/11/2009 14:00	3.0	33.0
2	02-Nov-09	16:10	02/11/2009 16:10	2.0	33.0
3	03-Nov-09	15:10	03/11/2009 15:10	5.0	33.0
4	04-Nov-09	16:00	04/11/2009 16:00	6.0	33.0
5	05-Nov-09	16:12	05/11/2009 16:12	6.2	33.0
6	07-Nov-09	14:12	07/11/2009 14:12	5.8	33.0
7	08-Nov-09	14:12	08/11/2009 14:12	3.0	33.0
8	09-Nov-09	13:12	09/11/2009 13:12	3.0	33.0
9	10-Nov-09	13:01	10/11/2009 13:01	3.0	33.0
10	11-Nov-09	18:00	11/11/2009 18:00	3.0	33.0



8 WARRANTY

The Company warrants its products against defective workmanship or material for a period of 12 months from date of receipt or 13 months from date of dispatch from the factory, whichever is earlier. The warranty is however void in case the product shows evidence of being tampered with or shows evidence of damage due to excessive heat, moisture, corrosion, vibration or improper use, application, specifications or other operating conditions not in control of Encardio-Rite. The warranty is limited to free repair/replacement of the product/parts with manufacturing defects only and does not cover products/parts worn out due to normal wear and tear or damaged due to mishandling or improper installation. This includes fuses and batteries

If any of the products does not function or functions improperly, it should be returned freight prepaid to the factory for our evaluation. In case it is found defective, it will be replaced/repaired free of cost.

A range of technical/scientific instruments are manufactured by Encardio-rite, the improper use of which is potentially dangerous. Only qualified personnel should install or use the instruments. Installation personnel must have a background of good installation practices as intricacies involved in installation are such that even if a single essential but apparently minor requirement is ignored or overlooked, the most reliable of instruments will be rendered useless.

The warranty is limited to as stated herein. Encardio-rite is not responsible for any consequential damages experienced by the user. There are no other warranties, expressed or implied, including but not limited to the implied warranties of merchantability and of fitness for a particular purpose. Encardio-rite is not responsible for any direct, indirect, incidental, special or consequential damage or loss caused to other equipment or people that the purchaser may experience as a result of installation or use of the product. The buyer's sole remedy for any breach of this agreement or any warranty by Encardio-rite shall not exceed the purchase price paid by the purchaser to Encardio-rite. Under no circumstances will Encardio-rite reimburse the claimant for loss incurred in removing and/or reinstalling equipment.

A lot of effort has been made and precaution for accuracy taken in preparing instruction manuals and software. However best of instruction manuals and software cannot provide for each and every condition in field that may affect performance of the product. Encardio-rite neither assumes responsibility for any omissions or errors that may appear nor assumes liability for any damage or loss that results from use of Encardio-rite products in accordance with the information contained in the manuals or software.

Products described in Encardio-rite's catalogs are subject to modification and improvement as dictated by subsequent developments. Encardio-rite reserves the right to modify, change or improve products, to discontinue them or to add new ones without notice.