

Procedure For Using Piezometers to Monitor Water Pressure in a Rock Mass

This procedure is under the jurisdiction of the Materials Engineering and Research Laboratory, code 86-68180, Technical Service Center, Denver, Colorado. The procedure is issued under the fixed designation USBR 6515. The number immediately following the designation indicates the first year of acceptance or the year of last revision.

1. Scope

1.1 *Explanation.*-This designation covers the description, application, selection, installation, data collection, and data reduction for using piezometers to monitor water pressure in a rock mass.

1.2 *Application.*-The procedure contained in this designation applies to both hard rock and soft rock.

1.3 *Units.*-Stating the values in SI/metric (inch-pound) units is to be regarded as standard.

1.4 *Caveats.*-This designation does not purport to address all the safety issues associated with its use and may involve use of hazardous materials, equipment, and operations. The user has the responsibility to establish and adopt appropriate safety and health practices. Also, the user must comply with prevalent regulatory codes while using this procedure.

1.5 *Sources.*-This designation reflects the information available

from American Society for Testing and Materials, International Society of Rock Mechanics, Bureau of Reclamation, and other sources.

2. Applicable Documents

2.1 *USBR Procedures:*
[USBR 3000 Using Significant Digits in Calculating and Reporting Laboratory Data](#)

USBR 3910 Standard Terms and Symbols Relating to Rock Mechanics
[USBR 9300 Checking, Rounding, and Reporting of Laboratory Data](#)

2.2 *ASTM Documents:*
ASTM D4750 Standard Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)

ASTM D 5092 Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers

ASTM D 5093 Standard Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed-Inner Ring

2.3 *ISRM Suggested Methods: Suggested Methods for Pressure Monitoring Using Hydraulic Cells, "Rock Characterization Testing and Monitoring," ISRM Suggested Methods*, Brown, E.T. (ed.), Pergamon Press, 1981, pp 203-211

2.4 *Other Publications: Concrete Dam Instrumentation Manual*, Pressure Measuring Devices, Sections 2.3, 2.4, 2.5 and 2.6, Bureau of Reclamation, pp 20-36, 1987.

Embankment Dam Instrumentation Manual, Pressure Measuring Devices, Sections 27, 28, 29, 30, 31, 32, 33 and 34, Bureau of Reclamation, 1987, pp 17-56.

Dunnicliff, John, Measurement of Groundwater Pressure, Chapter 9, *Geotechnical Instrumentation for Monitoring Field Performance*, John Wiley and Sons, 1988, pp 117-164.

Drilling of Exploratory Holes, Observation Wells and Piezometers, Section 7-7, *Ground Water Manual*, U.S. Department of the Interior, Water and Power Resources Service, Denver, 1981, pp 201-204
Groundwater Data Acquisition Methods, Chapter 9, *Engineering Geology Field Manual*, Bureau of Reclamation, pp 167-183.

Instrument Installations, Designation E-27, Instructions for Installing and Reading Hydraulic-Type Twin Tube Piezometers in Earth Dams, and Designation E-28, Instructions for Installing and Reading Porous-Tube Piezometers, *Earth Manual*, Bureau of Reclamation, Denver, 1974, pp 650-699.

3. Summary of Method

3.1 *Select.*-Based on the evaluation of available geological information, carefully select the locations of boreholes and the collection zones for the boreholes where piezometers are to be installed.

3.2 *Drill.*-Carefully drill the boreholes straight with no drilling mud. If the boreholes cave use biodegradable drilling fluids. Drill the boreholes about 300 mm (12 in) below the proposed location of the piezometer tip. Wash the borehole clean of drill cuttings.

3.3 *Backfill.*-Backfill the bottom of the borehole with clean fine sand to a point about 150 mm (6 in) below the piezometer tip position.

3.4 *Place.*-Lower the piezometer into position and place clean fine sand around the piezometer to a point 150 millimeters (6 in) above the piezometer.

3.5 *Seal.*-Immediately above the sand packed zone, seal the borehole with either (1) alternating layers of bentonite and sand backfill, tamped in place for about 300 mm (12 in) followed by common backfill or (2) an impermeable bentonite-cement grout mix.

3.6 *Tamp.*-If multiple piezometers are to be placed in a single borehole, tamp the bentonite-sand plugs in place below and above the piezometers and also at intervals between the piezometer zones.

3.7 *Record.*-From the initial and subsequent recorded readings of piezometer data over a period of time, calculate and report water pressure variations.

4. Significance and Use

4.1 *Groundwater Presence.*-The presence of ground water or other liquids and the depth of water table or liquid level below the ground surface have considerable significance in geotechnical, geological, hydrological, waste-management planning/storage, and other design investigations and studies. These investigations or studies typically may include completion of observation wells, performing aquifer tests, and monitoring of the water or other liquid levels with the passage of time. Alternatively, frequently read piezometers can provide similar information at substantial cost and time savings.

4.2 *Stratum Characteristics.*-Observation wells have hydraulic connectivity vertically of different stratum and cannot yield the hydrologic characteristic of a single stratum.

4.3 *Pressures.*-Piezometers can monitor hydrostatic water pressure in a single stratum or a small stratum zone and yield pore pressure data of that single stratum.

4.4 *Strength.*-Piezometer data can be used to indirectly estimate the effective stress and thereby the index of rock mass strength.

4.5 *Absolute Pressures.*-A vibrating wire piezometer is the only device that can measure negative pore pressures (because it indicates absolute pressures).

5. Description of Terms Specific to This Designation

5.1 *Aquifer.*-A body of rock that is sufficiently permeable to conduct ground water or other liquid and to yield sufficient quantities of water or other liquid.

5.2 *Aquitard.*-A confined bed that retards but does not totally prevent the flow of water or other liquid to or from an adjacent aquifer.

5.3 *Aquiclude.*-A geological formation that confines the flow of water.

5.4 *Collection Zone.*-The aquifer zone that influences the flow of water or other liquid toward a piezometer and also the pressure exerted on the installed piezometer diaphragm.

5.5 *Piezometer.*-Any of several geotechnical instruments that are used for measuring the pore pressure in a soil or rock stratum.

5.6 *Other Terms.*-See USBR 3910.

6. Apparatus

6.1 *System Components.*-A piezometer system has three main components: (1) a piezometer, (2) a conductor cable, and (3) a readout box and several auxiliary components.

6.2 *Piezometer.*-A vibrating wire piezometer, commonly used by Reclamation, is shown on figure 1. Its stainless steel housing nests the different components of the piezometer such as (1) the filter, (2) the diaphragm, (3) the vibrating wire, (4) the plucking and pickup coils, (5) the internal bulkhead seal, and (6) the cable connectors. The vibrating wire converts the fluid pressures into equivalent frequency signals that are then recorded. The piezometer pressure range could be 0.034 to 34.5 MPa (5 to 5,000 lbf/in²) with an accuracy of ± 0.5 percent. The operating temperature range could be -29 to 65 °C (-20 to 150 °F). Also, vibrating wire piezometers can be used to measure fluid temperature (if thermistors are installed in the housing) and existing negative pore pressures.

6.2.1 The filter (figure 1) could be a standard 50-micrometer sintered stainless steel or a high entry 2-micrometer alumina.

6.2.1 Vibrating wire piezometers are hermetically sealed at the factory and their performance is not affected by use of long cable lengths. They have long-term stability in difficult environments.

6.2.3 Vibrating wire piezometers come in different models such as standard, drive point, small diameter, vibro/pneumatic, low pressure, pressure transducer, and auto resonant models.

Note 1.-Other types of piezometers, such as hydraulic cell piezometers,

twin tube piezometers, open stand pipe piezometers, pneumatic piezometers, electrical resistance piezometers, push-in piezometers, and heavy liquid piezometers are usually not used by Reclamation. Reclamation uses twin-tube piezometers and open stand pipe piezometers for monitoring pore pressures in embankment and concrete dams.

6.2.4 One end of the vibrating wire (figure 1) of the piezometer is connected to a sensitive stainless steel diaphragm, and the other end is connected to an internal block. In use, the changing water or other fluid pressure on the diaphragm causes the diaphragm to deflect. The deflection of the diaphragm changes the tension and thereby the frequency of vibration of the vibrating wire element. The square of the frequency of vibration is directly proportional to the pressure applied to the diaphragm.

A coil and magnet assembly, located close to the vibrating wire (figure 1) is used to both pluck the wire and sense the resultant vibration frequency. In use, a pulse of varying frequency is applied to the coil and magnet assembly, causing the wire to vibrate at its resultant frequency. This resultant frequency in the form of an induced signal is transmitted and recorded using the read-out box..

6.3 *Electrical Cable.*-A 4-conductor cable is a standard item for a vibrating wire piezometer (figure 1) Two of the conductors of the cable can be used with the built-in vibrating wire temperature gauge (thermistor) to measure temperature of water or

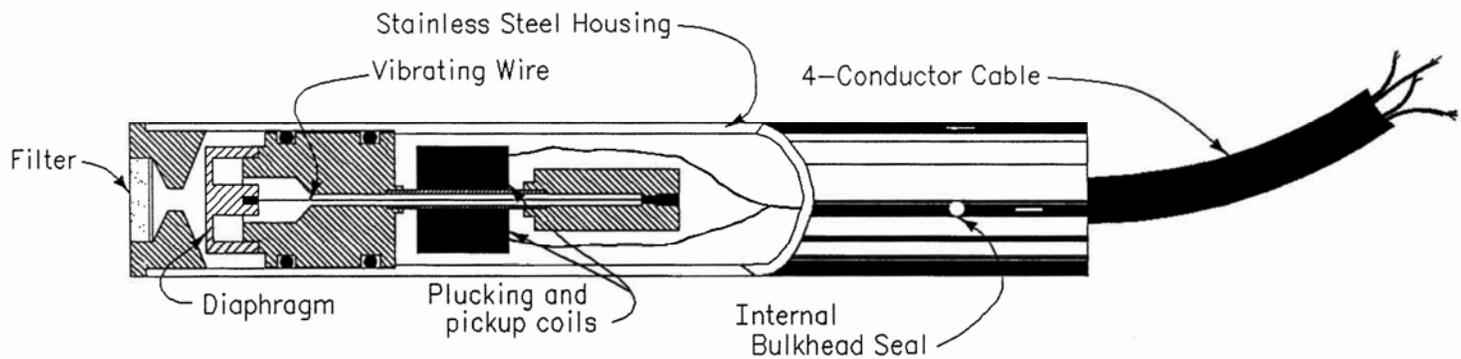


Figure 1. A vibrating wire piezometer.

any other liquid in the rock pores. The other two cables are used to read the frequency and thereby the pore pressure. The cable has a thick PVC outer jacket. The conductors in the cable are 6.4 millimeters (0.25 in) in diameter.

Note 2.-Because vibrating wire piezometers convert pore pressure into an equivalent frequency, the resistance changes of the conductor wires brought about by water or fluid penetration, temperature variations, and contact resistance do not affect the frequency output of the signals.

6.3.1 Direct Burial Cables.- Armored and gel-filled electrical cables that are used for direct burial of long conductor cables for remote sensing of piezometer readings.

6.4 Readout Box.-A portable vibrating wire readout box (figure 2) is battery operated, waterproof, and suitable for cold weather operations. Vibrating wire piezometers are read out by connecting them to the readout box using the input plug or patch cord provided with the readout box. The box is switched on and set to an appropriate display setting. The

gauge reading is displaced on a five-digit liquid crystal display. Both fluid temperature and pore pressure are read by switching to proper controls in the readout box.

6.5 Battery.-A sealed, gel-type 8-volt rechargeable battery with a battery life of 10 to 16 hours is used with the readout box. A battery charger requires 115 volts \pm 10 percent at 50 to 60 hertz. A 230-volt battery charger is optional.

6.6 Biodegradable Drill Fluid.- This fluid is composed of an organic polymer that self destructs through enzyme breakdown with time, reverting to water. This type of drilling fluid provides the necessary stabilization for the drilled hole and eases cutting removal during drilling. Upon reverting to water, this fluid leaves the borehole free of the organic polymer.

6.7 Lightning Protection.- Protection can be built into the body of the piezometer that protects the piezometer against low energy voltage spikes across the input loads to the plucking coil. Alternatively, a metal pipe or metal rod can be driven

into the ground for lightning protection at the surface, as close to the piezometer as possible.

7. Auxiliary Items

- Borehole drilling and viewing equipment
- Grout mixing and injection tools
- Wrenches
- Electrical connectors
- Couplings
- Casings
- Hand tools
- Bentonite
- Wire mesh screen
- Sand
- Cloth bags

8. Calibration and Standardization

8.1 *Manufacturer's Settings.*- Calibrate the piezometer in accordance with the recommendations obtained from the piezometer manufacturer. Calibration data are supplied by the manufacturer. Also, the manufacturer supplies the zero reading of the piezometer at a specific temperature and barometric pressure.

8.2 *Zero Readings.*-Zero readings of the piezometer at the site should coincide with the manufacturer's furnished zero readings within a few digits (not more than 20) after barometric and temperature corrections are made.

9. Conditioning

9.1 *Seal Swell.*-Before taking piezometer readings, allow sufficient time after the seal swell is complete

for pore pressures to equilibrate.

9.2 *Enzyme Breakdown.*-If biodegradable drill fluid is used during borehole drilling, allow sufficient time to elapse for enzyme breakdown (consult manufacturer's biodegradable drill fluid data) before taking piezometer readings.

10. Precautions

10.1 *Saturation.*-Check that the piezometer filter stone is fully saturated. Because of surface tensions caused by improper saturation, unsaturated filters can seriously affect the readings.

10.2 *Isolation.*-Check proper isolation of the collection zone.

10.3 *Leakage.*-Check that no electrical leakage occurs at splices and connections and that the cable is not severed or cut at any location.

10.4 *No Dirt.*-Protect tubing and cable ends from intrusion of dirt during installation. Use dust caps on all end fittings after installation.

10.5 *No Couplings.*-Minimize the use of tube couplings or avoid them altogether if possible.

10.6 *Straight Lines.*-Avoid zigzagging of piezometer tubes if used, and introduce some slack in the tubing.

10.7 *No Snags.*-Be sure to remove all burrs and sharp corners that may come in contact and damage the piezometer tubes or cables, if used.

10.8 *Seals.*-Check that the seals isolating the collection zone are effective and are not punctured or damaged.



Figure 2. - Vibrating wire readout box.

10.9 *Shock Resistance.*-In blasting zones, ensure use of shock resistant piezometers.

11. Specifications

11.1 *Location Selection.*-After thoroughly evaluating the geological data, select the location, orientation, length, and number of piezometer boreholes, and numbers and positions of piezometers in each borehole. A thorough evaluation of the construction or maintenance operation sequence and the geotechnical features of the host rock is essential to plan an intelligent and effective piezometric monitoring program. Important factors during this evaluation are: (1) estimates of directions and magnitudes of rock

discontinuities that are permeable in nature, (2) procedure, timing, and sequence of construction activities before, during, and after installing piezometers, and (3) the nature of other geotechnical instruments installed or likely to be installed in the vicinity of the piezometer.

11.2 *Selection of the Piezometer System.*-Select the best piezometer system consistent with the scope and objectivity of the piezometer program that has proper range and precision. The selected piezometer should have long-term reliability, excellent stability, high sensitivity, good repeatability, and robust, corrosion resistant construction. Vibrating wire piezometers have proven to provide best long term service.

11.3 *Time of Installation.*
To obtain a complete history of pore pressure variations, install piezometers at the very start of the construction activity for the project.

11.4 *Documentation of Field Work.*- Properly document the piezometer data on a real-time basis

12. Procedure

12.1 *Drilling Boreholes:*

12.1.1 Use a drilling method that is consistent with the existing geology and the availability of the type of drilling equipment. The Rotary method of drilling is recommended. Using percussion drilling has to be evaluated with caution due to issues that may result in a core hold with unsatisfactory parameters, such as diameter or alignment.

12.1.2 Check that the size of the borehole is consistent with the size of piezometer unit that is likely to be used (use manufacturer's recommended diameter for the boreholes or select the borehole diameter to be 50 mm [2 in] larger than the external diameter of the piezometer unit).

12.1.3 Verify the location and orientation and drill the boreholes to their designated depths. The depth of each borehole is to be at least 300 mm (12 in) deeper than the tip of the piezometer (tip of lowest piezometer in the same borehole).

12.1.4 Inspect the drilling operations from start to completion of the borehole. Keep notes on the drilling rates, drill casing installations (avoid using casings if possible; use biodegradable mud instead of the casing), detected geologic soft and permeable zones, cavings, pluggings of boreholes, or other drilling difficulties.

12.1.5 Log the cores recovered from the boreholes. It is important to record the rock lithology, joint orientation, degree of weathering, location of water bearing seams, and other pertinent information.

12.1.6 Clean and wash the borehole to remove the drill cuttings.

12.2 *Preinstallation Procedure for Vibrating Wire Piezometer:*

12.2.1 Record carefully the particular piezometer's identification number for future use.

12.2.2 Check the zero reading of the piezometer at the site by connecting the piezometer to the conductor cable, the conductor cable to the readout box, and the readout box to the recharged battery. Allow about 30 seconds for warming up before taking the zero reading.

12.2.3 The zero reading at the site should coincide with the factory reading within a few digits after correcting the reading for barometric and temperature variations from the factory conditions (supplied by the manufacturer). In case of large differences in zero reading (more than 20), have the piezometer repaired. Only use a properly calibrated piezometer.

12.2.4 Remove the sintered stainless steel filter (figure 1) from the piezometer housing and place it in a bath of boiling water. Boil the filter until all the air is purged.

12.2.5 Reassemble the piezometer while keeping it submerged in a cool water tank. The tank should be large enough to allow reassembly of the piezometer and enclosure of the piezometer in a sand bag (section 12.2.6) while keeping the piezometer completely submerged at all times.

12.2.6 Place a cloth bag in the tank and partially fill the cloth bag with well graded sand (grading to be recommended by the test engineer). Place the reassembled piezometer in the center of the bag and thoroughly pack the sand around the piezometer. When full and compacted, tie the top of the bag and wrap the entire bag

with a wire mesh screen (size of mesh screen to be recommended by the test engineer). The entire operation must be completed while keeping the piezometer completely saturated at all times until the piezometer is installed in the borehole.

12.2.7 Using the readout unit, obtain and record an initial reading on the piezometer while it is still in the water tank. This reading is the zero or initial reading for the particular piezometer.

12.3 *Piezometer Installation in Boreholes:*

12.3.1 In the cleaned and washed borehole, place well graded and saturated sand up to an elevation 150 mm (6 in) below the piezometer tip.

12.3.2 Using suitable tamping or compacting techniques, thoroughly compact the saturated sand.

12.3.3 Lower the cloth bagged piezometer into the borehole to the desired elevation and take a reading to ensure that the piezometer is operating properly.

12.3.4 If the piezometer is operating correctly, backfill the collection zone or influence zone with saturated, well graded sand up to about 150 mm (6 in) above the top of the piezometer. Compact the sand properly.

12.3.5 Place a bentonite pellet seal about 300 mm (12 in) thick over the compacted sand (see section 12.3.4).

12.3.6 If multiple piezometers are installed in the same borehole, repeat the steps in sections 12.2 and the steps in sections 12.3.1 through 12.3.5 for each piezometer unit.

12.3.7 Following compaction of upper bentonite seal, remove all slack in the electrical conducting cable(s) and backfill the rest of the borehole with a sand-bentonite mixture.

12.3.8 If a casing was used, then pull the casing as filling progresses or after backfilling is complete.

12.3.9 If a biodegradable drill fluid was used, then wait for complete biodegradation before taking piezometric readings.

12.4 *Monitoring Piezometer Readings:*

12.4.1 Determine the piezometer readings at intervals as recommended by the instrumentation engineer. Usually, more frequent readings are required in the beginning of a monitoring program.

12.4.2 Determine the temperature of the piezometer.

12.4.3 Determine the pore pressure and its variations with time using the equations shown in section 13.

Note 3.-Temperature and pore pressure readings are taken by switching channels to respective units on the read-out box.

12.5 *Report:* Write a report using guidelines stated in section 14.

13. Calculations

13.1 Pore Pressure Calculation:

13.1.1 The diaphragm deflection, Δ , is given by the following equation:

$$\Delta = k \omega^2 = \frac{N}{T^2} \quad (1)$$

where:

k = constant, manufacturer supplied or determined by calibration

ω = frequency, cycles/s

N = another constant, manufacturer supplied or determined by calibration

T = period of vibration, s

13.1.2 Because pore water pressure is proportional to diaphragm deflection, the relationship between the pore water pressure and the reading at the read-out unit is expressed by equation 2:

$$P = G (R_0 - R_1) \quad (2)$$

where:

P = pore water pressure, MPa (in lbf/in²)

G = gage constant, adjusted depending upon whether SI or inch-pound units are used

R_0 = initial zero reading at the read-out unit with zero pressure applied on the piezometer at the time of installation

R_1 = reading under actual site conditions of pore pressure

13.2 Temperature Correction:

13.2.1 Obtain the temperature correction using equation 3:

$$P_{(T_1)} = G(R_0 - R_1) - M(T_0 - T_1) \quad (4)$$

where:

$C_{(T_1)}$ = temperature correction in pore pressure, MPa (lbf/in²)

M = temperature correction factor supplied by the manufacturer (values of M depend upon the temperature measurements in °C or °F)

T_0 = initial temperature at the time of pore pressure measurement, °C (°F)

13.2.2 The corrected pore water pressure is given by equation 4:

$$C_{(T_1)} = - M (T_0 - T_1) \quad (3)$$

where:

$P_{(T_1)}$ = pore water pressure at temperature T_1 , MPa (lbf/in²)

Other symbols were defined previously.

13.3 Correction for Barometric Pressure:

13.3.1 Because the zero reading of the hermetically sealed piezometer was calibrated at the elevation of the manufacturer's factory, the elevation difference at the site has to be calculated with respect to the elevation at the factory.

PIEZOMETER CALIBRATION

	Date <u>10 March 83</u>
Model No. <u>4500S</u>	Temp. <u>64.4°</u>
Serial No. <u>255T-100</u>	Barometer <u>29.86</u>
Gauge Factor, G <u>0.0499</u>	Zero Rdg., R_0 <u>3273</u>
Temp. Coeff., C <u>0.043 KPa/°C or</u> <u>0.0025 (lb/in²)/°F</u>	Period. <u>5527</u>

$$\text{Pressure} = (L_0 - L_1) G$$

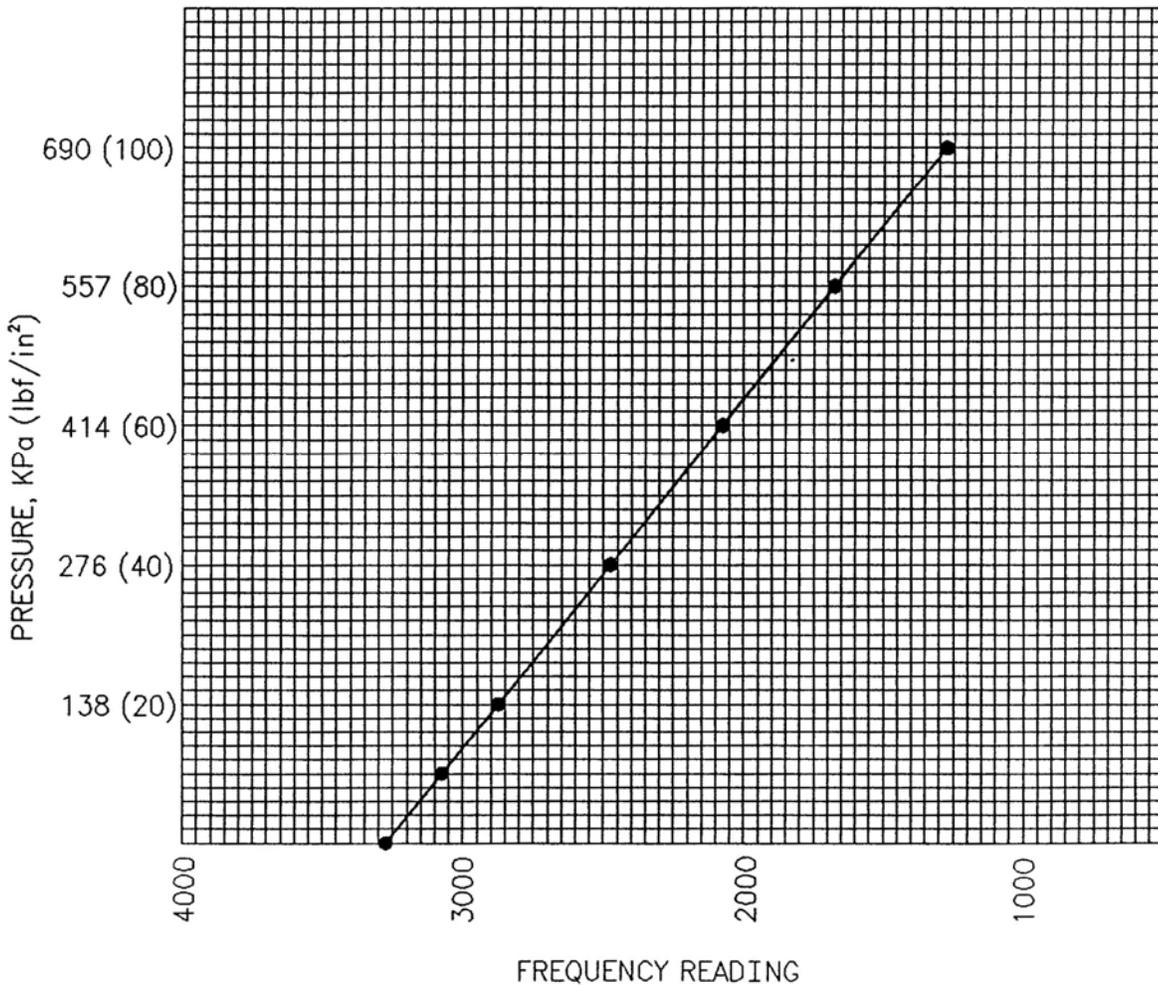


Figure 3.- Calibration graph for a vibrating wire piezometer

13.3.2 The barometric pressure changes at a rate of about 0.0034 MPa (0.5 lbf/in²) per 305 meters (1000 ft) of elevation difference.

13.3.3 The corrected pore pressure, allowing for the barometric pressure change, is obtained by adding (for higher elevations than the factory) or subtracting (for lower elevations than the factory) the change in barometric pressure (MPa [lbf/in²]) with respect to the factory conditions, to the calculated pore pressure $P_{(T)}$.

Note 4.-Vented piezometers designed to eliminate barometric effects are available but not used by Reclamation. For vented piezometers, barometric pressure corrections (section 13.3) are not required because the space inside the piezometer is no longer isolated and evacuated but is connected via a tube to the atmosphere. But with time, water may enter the tube and destroy the connection to the atmosphere, making the piezometer readings erroneous.

s14. Report

14.1 The report shall include:

14.2 *Background*.-Project name, project location, scope and purpose of the piezometer program.

14.3 *Installation*.-The piezometer installation report shall include the following:

14.3.1 Types and details of drilling equipment used.

14.3.2 Log of drilling, including description of important geological features and difficulties in drilling, if encountered.

14.3.3 Borehole coordination and collar elevation.

14.3.4 Elevations of installed piezometers.

14.4 *Monitoring*.-The monitoring report shall include the following:

14.4.1 A set of tabulated field data (see table 1).

14.4.2 A plot of variations of pore water pressure (uplift pressure) with time (figure 4).

14.4.3 An interpretation of the piezometric data.

14.5 *Results*. The laboratory test results shall be reported in accordance with Reclamation designations [USBR 3000](#) and [USBR 9300](#).

15. Precision and Bias

The precision and bias for this designation have not been determined. Any variation observed in the data is just as likely to be caused by specimen variation as by operator or laboratory testing variations. Because of the variability of rock, this test procedure has no reference value.

Table 1. - Tabulated field data.

VIBRATING-WIRE PIEZOMETERS										
Dam _____			Observer(s) _____							
Reservoir Elevation _____			Date _____							
Tailwater Elevation _____			Sheet _____ of _____							
Borehole number _____										
Piez. No.	Serial No.	Gage Factor	Initial Reading (Hz)	Current Reading (Hz)	Piez. Head m (ft)	Piez. Tip EL m (ft)	Piez. EL m (ft)	<u>Temperature Correction</u> Resistance Temperature ($\Omega \times 10^3$) °C (°F)		Piez. EL After Correction (ft)
		<i>G</i>	<i>R₀</i>	<i>R₁</i>	<i>H*</i>	<i>A</i>	<i>H+A</i>			

$$H^* = 2.308 G(R_0 - R_1)$$

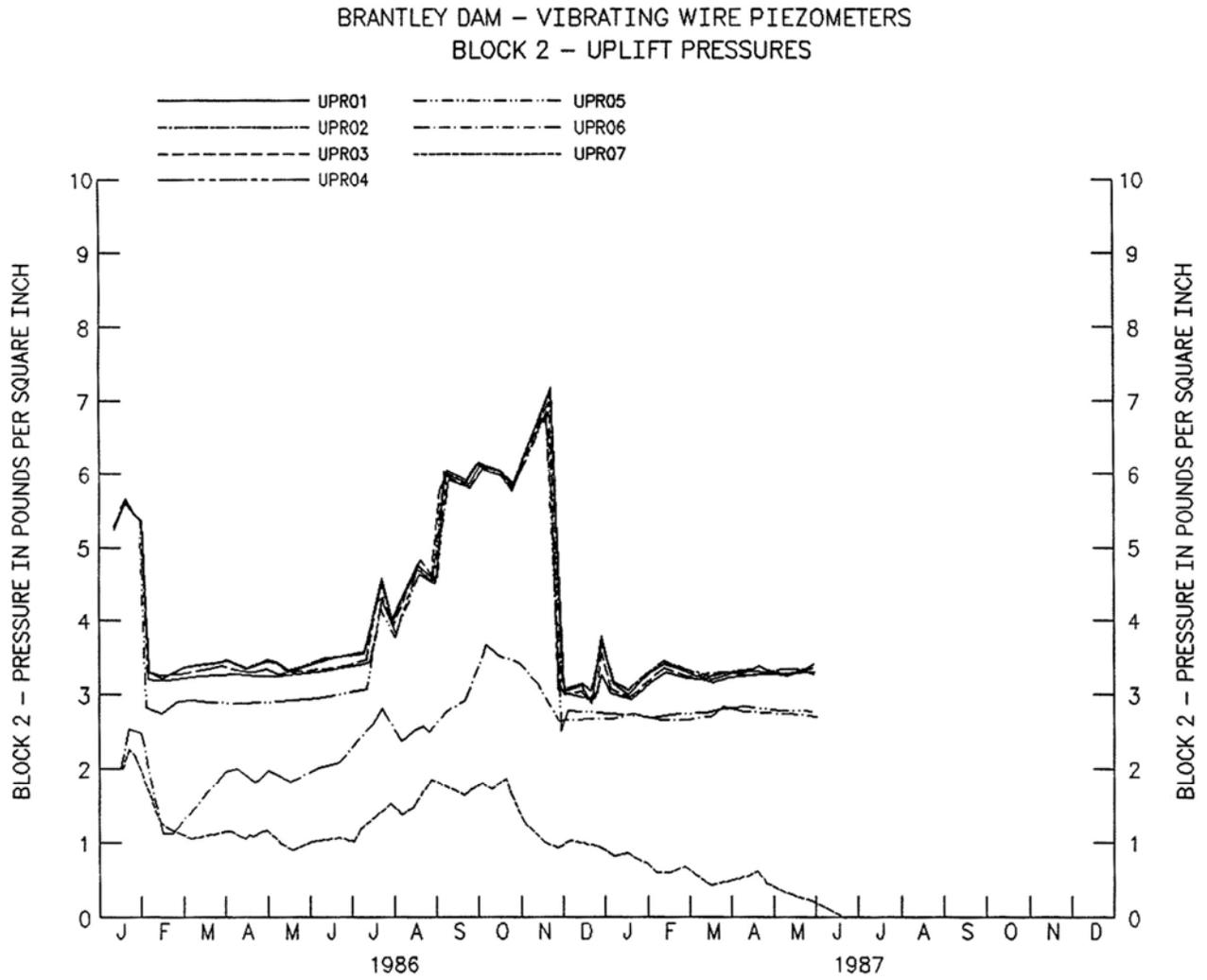


Figure 4. - Data plots on vibrating wire piezometers.