REMR TECHNICAL NOTE GT-SE-1.4

OPERATING PIEZOMETERS UNDER FREEZING CONDITIONS

PURPOSE: To describe methods that allow operation of piezometers under freezing conditions.

BACKGROUND: Freeze-up of water within open-standpipe piezometers has been the cause of missing hydrological information at 40 percent of Corps Districts nationwide. Because freeze-up can lead to loss of certain critical information about the stability of a water-retaining structure, numerous methods have been used to prevent its occurrence (Table 1).

ARTESIAN OPEN-STANDPIPE PIEZOMETER OPERATION: Piezometers with continuous artesian flow are normally capped with a pressure gage at or above ground level, creating a static water column vulnerable to freeze-up. However, if the cap is removed in the fall, allowing the water to flow throughout the winter, freeze-up can be prevented if the water has sufficient velocity. Necessary winter readings can then be taken by temporarily reinstalling a gage to obtain a measurement, provided winter conditions do not make the piezometer inaccessible.

STATIC-HEAD OPEN-STANDPIPE PIEZOMETER OPERATION: Several methods of freezing protection have been used for piezometers that have their static head in the riser pipe within the frost zone or above ground level.

a. Low-freezing-point fluid. A common procedure is to add a fluid with a low freezing point to the top of the water column so that the water level is depressed below the depth of frost penetration. The fluid must have a specific gravity less than that of water in order to remain at the top of the column; examples include kerosene, diesel fuel and mineral oil.

   Once the fluid has been added, the hydrostatic pressure shown by the piezometer must be adjusted according to the exact specific gravity and column height of the added liquid. To depress the water level in a standpipe by a certain amount, one must replace that water with an equivalent weight of the added fluid. Since the replacement fluid is less dense than water, a volume greater than that removed will need to be added. The required column height needed for replacement (H_R) can be calculated with the use of the specific gravity of the replacement fluid and the original column height (H_O) as follows:

$$H_R = \frac{G_w}{G_f} (H_O)$$

where G_w = specific gravity of water (1.0)

G_f = specific gravity of replacement fluid.

The upper portion of the water column can also be replaced with an antifreeze-water mixture, provided it is separated from the rest of the water column with a column of mineral oil. Adding water-soluble antifreeze agents to the entire water column should be avoided because this mixture can increase the ionic concentration to the extent that sizable osmotic pressures may develop (Ref a). Cases of flocculation in antifreeze solutions in which flocs eventually clogged the piezometer tips have also been reported (Ref a).

Although the technique of adding a lower density fluid to piezometers during the winter is quite successful in preventing freeze-up, it is labor intensive. Much care must be given to exact recording and to removing the fluid at the end of each freeze season.

b. Physical restriction. Alternate methods of physically restricting the water from rising above the level of frost penetration include: installing a frostproof hydrant, inserting an inflatable packer into the piezometer pipe, or pressurizing the upper air column.

A frostproof hydrant incorporates a foot valve that is installed below the ground surface beyond the anticipated maximum frost depth. When the hydrant is shut off, the water supply is cut off at the foot valve, and any excess water in the pipe above bleeds out through a hole at the foot valve. These hydrants are commonly used in the upper Midwest for outside plumbing applications such as livestock watering or yard taps for summer irrigation and throughout the northern US in fire hydrants. For winter operation, the valve normally remains closed. When manual readings are collected, the valve is opened, allowing water to rise in the standpipe. After the water is stabilized and the height is recorded, the valve is closed, draining the water above. A frostproof hydrant has been used at only one Corps activity. This use was not successful because the static water level was above the frost line. However, frostproof hydrants should prove satisfactory at locations where static water levels are below the depth of frost penetration.

An inflatable packer consists of an expandable, tubular membrane attached to the outside of a cylinder and an associated high-pressure line through which air or water can pass. The cylinder can be equipped with any appropriate end-fitting to suit user needs. A packer equipped with a solid end cap can be inserted into the standpipe below the depth of frost and inflated to a pressure that will resist the expected pore-water pressure. Any excess water above the packer is then evacuated with a suction pump. To obtain a reading during the winter, the pressure within the packer is released, and the packer is withdrawn. Once the measurement has been made, the packer is reinstalled as described above. Commercial sources of packers are listed in Dunnicliff (Ref b). Packers with appropriate end-fittings can also be used more permanently to convert open-standpipe piezometers to closed-system types.

A simple system for restricting the water below the frost zone is to force the water down by capping the top and pressurizing the air column in the upper section of the riser pipe. If a pressure gage is included in this system, fluctuations in the pore-water pressure can continue to be monitored. For this system to operate accurately, the standpipe must be air tight.

c. Insulation. Another freezing prevention technique is to protect the exposed section of the riser pipe from the cold temperatures with some form of insulation. A box filled with foam provides adequate protection in the milder zones of the country (Table 1, Louisville District).

USE OF ALTERNATE PIEZOMETERS: To avoid freezing problems associated with open-standpipe piezometers, alternative piezometer types unaffected by freezing, such as pneumatic, vibrating-wire, or electrical-resistance strain-gage transducers, can be employed. Another advantage of these piezometer types is that they may be integrated into an automatic data acquisition system, either with a datalogger located on site or through communication with a remote computer via telephone line or via telemetry through a satellite. Another piezometer that is less affected by freezing problems in the "heavy liquid" piezometer. Brief descriptions of these piezometers will be given here. More detailed discussions, including source information, can be found in Ref b and c.

a. Pneumatic type. The pneumatic piezometer is operated by pore-water pressure acting on a diaphragm. This pressure is balanced by gas pressure (usually nitrogen) applied externally through tubing from the surface, as shown in Fig. 1. Pore-water pressure is determined by one of two processes that differ as to whether or not gas is flowing during the pressure measurement. In both processes, when the applied gas pressure exceeds the pore-water pressure acting on the reverse side of the diaphragm, the diaphragm moves outward and allows flow along a return line. In the first process, when the return flow is detected, the gas supply is shut off at the inlet valve. Any pressure in the tubes greater than the pore-water pressure bleeds away, and the diaphragm returns to its original position. The incoming pressure then equals the pore-water pressure, which is read from a pressure gage attached to the incoming line. In the second process, the incoming gas pressure is regulated so that it constantly increases by a very small increment. Accordingly, the readout of a pressure gage attached to the incoming line continually rises until the pore-water pressure is barely exceeded and the diaphragm moves outward, allowing return flow. At this point, the pressure gage shows a steady peak value that equals the pore-water pressure. Since interaction between the tip and the surface is by gas flowing through thin tubing, pneumatic piezometers are unaffected by frost penetration at the surface. During installation, however, enough slack should be included in the line to provide for differential movement and seasonal heaving.

b. Electrical-resistance type. This piezometer measures pore-water pressure by means of an electrical-resistance strain gage attached to a diaphragm. The diaphragm, which is exposed to the pore water, expands or contracts as the pressure changes. The attached electrical-resistance strain gage includes a conductor with the basic property that its resistance changes in direct proportion to change in length. Most commercial piezometers incorporate either an unbonded wire or a bonded version of a resistance strain gage within their units.

The unbonded-wire type uses a transducer and contains two similar lengths of highly elastic carbon-steel wire stretched between two posts, one of which is attached to the piezometer diaphragm (Fig. 2). The wires are arranged so that one increases in length and electrical resistance when pressure change occurs, while the other decreases. The ratio of the two resistances is independent of temperature, and therefore the change in resistance ratio is a measure of the pore-water pressure.

The bonded version usually employs a semiconductor crystal as the resistance element, which allows greater sensitivity than conventional conductors (Fig. 3). The crystal changes resistance in direct proportion to the strain applied, so that pore-water pressure can be determined by multiplying the resistance by a conversion factor. These crystals are very expensive but may come down in price as the semiconductor technology expands in the coming years.

Since the signal wire is all that extends to the surface, the electrical-resistance strain-gauge piezometer is unaffected by surface freezing temperatures. However, bonded semiconductor elements are greatly affected by temperature, so care must be taken to acquire a unit calibrated to the in situ temperature range expected. Because electrical-resistance piezometers use voltage as their output signal, they have the disadvantage that the signal may degrade as a result of variations in cable resistance, contact resistance, ground leakage, or transmission over long distances.

c. Vibrating-wire type. The principle of this piezometer is based on converting the pore-water pressure into a frequency output. A vibrating steel wire, which is stretched to oscillate inside a transducer housing, is attached at one end to a flexible metal diaphragm (Fig. 4). The diaphragm is influenced by the pore water, and any pressure change causes it to expand or contract. As a result, the stress level of the connected measuring wire is changed, and consequently its frequency changes. The wire oscillates within a magnetic field, inducing in a coil an electrical oscillation of the same frequency. This oscillation is transmitted via signal cable to a receiver which is positioned at a terminal station. The receiving unit then converts the frequency to a digital output. Using frequency as the output signal eliminates the line loss and transmission difficulties noted with the electrical-resistance piezometer. Temperature fluctuations at the sensor location may influence the vibrating-wire output frequency. A recent development to reduce this effect has been the construction of transducers with housing bodies and wires that have matched thermal expansion coefficients.

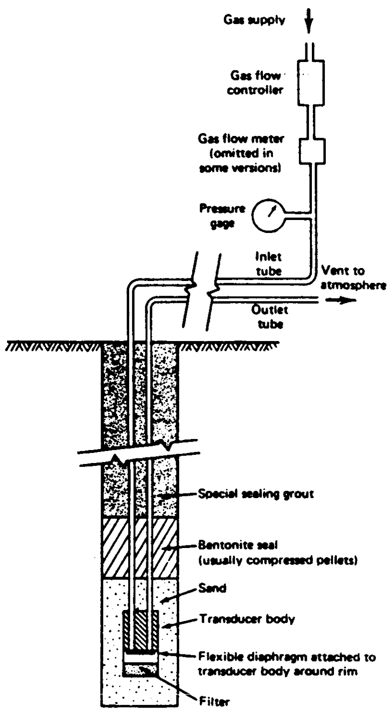

Figure 1. Schematic of Pneumatic Piezometer

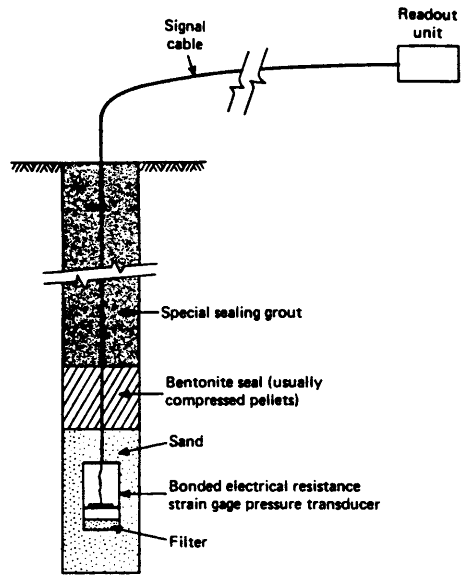

Figure 2. Schematic of unbonded electrical resistance piezometer

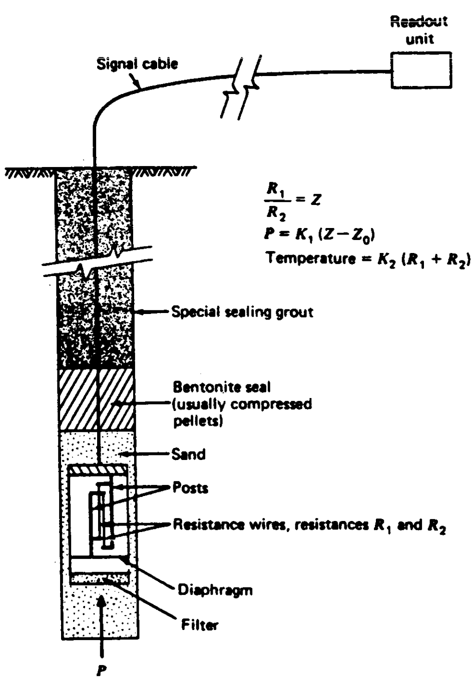

Figure 3. Schematic of bonded electrical resistance piezometer

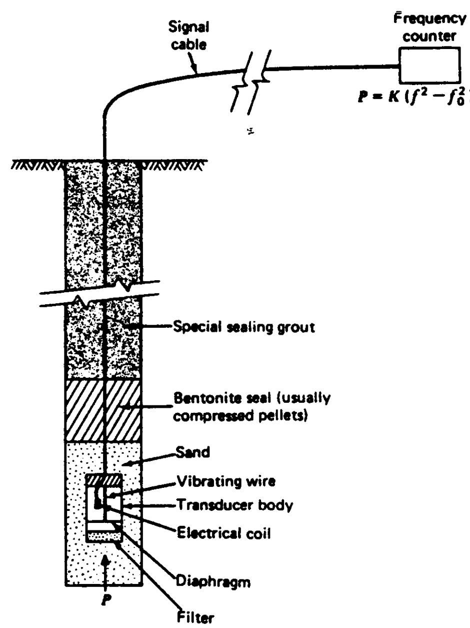

Figure 4. Schematic of vibrating wire piezometer

Again, because a signal cable is all that extends to the surface from the sensor tip, vibrating-wire piezometers are unaffected by surface temperatures, and damage or rupture of the cables should be avoided by making proper allowance for differential movements and seasonal heaving.

Dunnicliff (Ref b) and Sherard (Ref e) address historical experience and current solutions to problems with damage from lightning strikes, corrosion of the vibrating wire, zero drift, etc.

d. "Heavy liquid" type. Another piezometer that has relatively few problems with freeze-up is the "heavy liquid" type (Ref d). It uses acetylene tetrabromide, a liquid with a specific gravity of 2.96, in the standpipe and part of the piezometer tip. As a result, piezometric levels are about three times lower than equivalent water levels and thus are likely to remain at depths below the zone of frost penetration. However, the liquid will freeze if exposed to below-freezing conditions since its freezing point is similar to that for water. For this reason, it should not be used for near-surface applications or for cases with extremely high pore-water pressures.

RECOMMENDATIONS: This technical note has summarized various options for allowing operation of piezometers under freezing conditions, including both low-cost options and those more expensive. The system highly recommended for use in cold regions is a vibrating-wire pressure transducer positioned within a standpipe, either suspended independently (open system) or combined with an inflatable packer (closed system). This unit allows continuous pressure measurements throughout the year, regardless of surface temperatures. When employed within a standpipe, this configuration also has the advantage that the sensors can be removed for periodic recalibration or for moving them to a different location. The output can also be integrated into an automatic data collection system.

The cost of the recommended system (in 1988) is about $300 for the transducer and $0.50/ft for the signal cable. The output can be read manually with a portable readout unit ($1,650) or automatically recorded with a datalogger unit, which varies in price from $4,000 for 12 input channels to $5,000 and up for 32 or more input channels.

REFERENCES:

a. Department of the Army. 1971. "Instrumentation of Earth and Rockfill Dams, Part 1, Groundwater and Pore-Pressure Observations," Engineer Manual 1110-2-1980, Washington, DC.

b. Dunnicliff, C. J. 1988. Geotechnical Instrumentation for Monitoring Field Performance, John Wiley, NY.

c. Hanna, T. H. 1985. Field Instrumentation in Geotechnical Engineering, Trans Tech Publications, Clausthal-Zellerfeld, Federal Republic of Germany; Karl Distributors, Rockport, MA.

d. Piezometer Research and Development. 1972. Procedure for Installing Heavy Liquid Piezometers, Stamford, CT.

e. Sherard, J. L. 1981. "Piezometers in Earth Dam Impervious Sections," Proceedings of the Symposium on Recent Developments in Geotechnical Engineering for Hydro Projects, American Society of Civil Engineers, F. H. Kulhawy, ASCE, New York, pp 125-165.

Table 1

Freeze-up of Piezometers at Corps Districts

Division/District	Example Activities	Action/Remedial Attempts
Lower Mississippi		
St. Louis	(Lock and Dam 24, 25)	Changed to vibrating wire
Memphis	--	
Missouri River		
Kansas City	(occurs - no examples)	Diesel fuel or antifreeze above mineral oil
Omaha	Ft. Peck, Garrison, Oahe	Kerosene (or let freeze)
New England	(not monitored)	
North Atlantic		
New York	Waterbury Dam	(Let Freeze)
Philadelphia	Prompton Dam	Allow continuous flow, install gage just before reading
Baltimore	Tioga/Hammond Dams	(Let Freeze)
Norfolk	--	
North Central		
Buffalo	--	
Chicago	(Coastal well points)	(Let Freeze)
Detroit	--	
Rock Island	--	
St. Paul	Orwell Dam	Replaced PVC with metal pipe; kerosene; frost-proof valves
North Pacific		
Anchorage	Chena River Lakes	Kerosene (or let freeze)
Portland	--	--
Seattle	--	--
Walla Walla	--	--
Ohio River		
Huntington	Dams in N. Central Ohio	Kerosene; foam-filled tile; converted with packers to pneumatic
Louisville	Rough River	Protected riser with foam-filled box
Pittsburg	Kerwin Dam, E. Br. Clarion	Allow continuous flow (or let freeze)
Nashville	--	
South Pacific		
Los Angeles	--	
Sacramento	(occurs - no examples)	(Let freeze)
Southwestern		
Albuquerque	--	--
Little Rock	--	--
Tulsa	(occurs - no examples)	(Let freeze; used to add antifreeze)
Fort Worth	--	