USER'S MANUAL

VIBRATING-WIRE PIEZOMETERS

Big Boy: Model 98050
Slim Jim: Model 98051
Conehead: Model Number 98052

Serial No.______________________________

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1. Introduction and Specifications

The Applied Geomechanics family of vibrating-wire piezometers includes the following models:

- Big Boy Piezometer (Model 98050)
- Slim Jim Piezometer (Model 98051)
- Conehead Push-in Piezometer (Model 98052)

Each of these piezometers is available in a variety of pressure ranges, indicated by the dash number following the model number (Table 1). All are constructed of stainless steel to retard corrosion and enhance long-term performance in field installations. All use an internal magnetic wire, attached at one end to a moveable diaphragm and anchored at the other end, to measure pore water pressure. Pressure changes move the diaphragm, lengthening or shortening the wire and altering its resonant frequency. Factory calibrations of the piezometers are used to convert the measured frequency to pressure. Key features of the three piezometer types are summarized below.

- **Big Boy** – Recommended for general use because of its low cost and robust construction. Diameter is 42mm (Figure 1).
- **Slim Jim** – With a diameter of only 19 mm, the Slim Jim is designed for monitoring water levels and pore water pressure in small-diameter wells and standpipes (Figure 2).
- **Conehead** – The rugged push-in design is useful for measuring water pressure in soft soils or landfills. It has a pointed cone tip at one end and drill rod threads at the other end. May be pushed in hydraulically or by hand (Figure 3).

Each piezometer includes a built-in thermistor for measuring temperature and, if necessary, for correcting the zero reading for effects of temperature change. Each piezometer also contains a surge arrestor that helps protect the vibrating-wire pluck-and-read coils from high-voltage transients. High-voltage transients may be induced by nearby lightning strikes and are one of the common causes of failure of geotechnical field instruments.

Table 1. Piezometer Model Numbers and Pressure Ranges

Big Boy, Model No.	**Pressure Range**
98050-02	0.3 MPa (44 psi)
98050-04	0.7 MPa (100 psi)
98050-05	1.0 MPa (145 psi)
98050-08	3.5 MPa (500 psi)
Slim Jim, Model No.	
98051-01	0.35 MPa (50 psi)
98051-02	0.7 MPa (100 psi)
98051-03	1.0 MPa (145 psi)
98051-04	2.0 MPa (290 psi)
Conehead, Model No.	
98052-01	0.35 MPa (50 psi)
98052-02	0.7 MPa (100 psi)
98052-03	1.0 MPa (145 psi)
98052-04	2.0 MPa (290 psi)

Table 2. Specifications

	Big Boy	**Slim Jim**	**Conehead**
Dimensions	42 mm dia. x 185 mm	19 mm dia. x 100 mm	35 mm dia. x 166 mm
Accuracy	± 0.25% of full span (FS)	± 0.2% of full span	± 0.2% of full span(FS)
Nonlinearity	± 0.5% FS		
Over Range Limit	150% of range		
Temperature Range	-20° to 70°C		
Materials	Stainless steel		

Figure 1. Big Boy piezometer

Figure 2. Slim Jim piezometer

Figure 3. Conehead piezometer

2. Operating Principle

The vibrating-wire piezometer contains a magnetic, high-tensile-strength stretched wire, one end of which is anchored and the other end fixed to a diaphragm. The diaphragm deflects in response to applied pore water pressure, changing the tension in the wire and its resonant frequency. Calibration of the piezometer establishes the relationship between pore water pressure and resonance frequency.
To operate the piezometer, the wire is plucked by sending a broadband signal down the piezometer cable to a coil magnet assembly beside the wire. When the plucking signal is turned off, the wire continues to vibrate at its resonance frequency, which induces an alternating current in the coil magnet. This signal can be read at the other end of the cable and then converted to units of pressure.

The relationship between wire tension and resonant frequency is given by the following equation:

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

where f = resonant frequency
σ = tension of wire in kg/cm^2
g = 980 cm/sec^2
ρ = density of wire in kg/cm^3
L = length of wire in cm

The resonant frequency is directly proportional to the square root of wire tension and inversely proportional to the length of the wire.

3. Taking Readings

The easiest way to take readings from your vibrating-wire piezometer is using the Applied Geomechanics **VW Advisor** portable readout unit. The VW Advisor reads the piezometer, displays the reading, and stores is for subsequent downloading to your computer. Please refer to the VW Advisor user's manual for complete details.

For situations where you need to continuously log piezometer output, Applied Geomechanics offers two solutions: the **Handi-Logger Mini** single-channel logger, and the **Model 798-1000 Handi-Logger**, which can record 128 vibrating-wire sensors using multiplexers. Please refer to the user's manuals of these products for operational details.

Color coding of the wires in your vibrating-wire piezometer cable is as follows:

Table 3. Wire Color Code

Wire Color	Function
Red	Vibrating Wire
Black	Vibrating Wire
White	Thermistor
Green	Thermistor
Bare Wire	Shield

The following sections 4 through 7 describe the conversion of frequency readings to pressure. Many of these functions can be performed automatically by the devices described above.

After installation of the piezometer in the field, allow it to reach thermal equilibrium (typically 20-25 minutes) before taking the first reading. Temperature gradients through the body of a piezometer can cause reading errors.

4. Converting Frequency Readings to Pressure

Calibration values are given in the Calibration Certificate provided with each piezometer. The calibration units (digits) are $frequency^2 \times 10^{-3}$. The Calibration Certificate also gives the coefficients needed to convert field readings into units of pressure using the linear or the polynomial conversion method.
To convert readings to water pressure P using the linear method, apply the following equation:

$$P = (R_0 - R_1) \times G$$

where P = pressure in engineering units
R_0 = initial reading in digits
R_1 = current reading in digits
G = linear gage factor (see calibration certificate)

The initial reading R_0 can be the factory calibration value at zero applied pressure. Or, you may suspect that temperature or barometric pressure conditions are different at the time of installation than they were at the time of calibration. If so, you can take a reading in the field before installing the piezometer and use that as the initial reading.

For polynomial conversion, pressure is calculated by following equation:

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

where R_1 = current reading in digits
A, B, C = polynomial constants (see calibration certificate)

Polynomial constants A, B and C in the calibration certificate are determined at barometric pressure and room temperature at the time of calibration. When the piezometer arrives at your installation site, the value of C can be slightly different as the result of barometric pressure or temperature changes, or rough handling during shipping and transport. To reduce possible error, the value of C should be recomputed to reflect conditions at the time of installation. This is done in the following manner: Take a reading R_1 just before piezometer installation. Substitute that reading into the polynomial equation above. Then set P=0 and substitute the values of coefficients A and B from the calibration certificate into the equation. Compute a new value of C. Use that new value when computing the pore water pressure from future readings.

Table 4

CALIBRATION CERTIFICATE

Instrument	Piezometer	Date	01.06.2006
Serial no.	10211	Temperature	29°C
Capacity	0.3 MPa	Atm. Pressure	0.099 MPa

Input pressure (MPa)	Observed value Up1 (Digit)	Down (Digit)	Up2 (Digit)	Average (Digit)	End point fit (MPa)	Poly fit (MPa)
0.0	6443.0	6441.4	6441.4	6442	0.000	0.000
0.1	6023.9	6023.4	6024.8	6024	0.099	0.100
0.2	5601.6	5601.9	5601.8	5602	0.200	0.200
0.3	5179.2	5179.2	5180.1	5180	0.300	0.300
				Error (%FS)	0.24	0.06

Digit (units)	f^2 X 10E-3	
Linear gage factor (G)	2.376E-04	MPa/digit
Thermal factor (K)	0.000	MPa/°C
Polynomial constants		

A=-1.4257E-09 B=-2.2094E-04 C=1.4826E+00

Pressure "P" is calculated with the following equation:

Linear $P\text{ (MPa)} = G(R_0 - R_1) + K(T_1 - T_0) - (S_1 - S_0)$

Polynomial $P\text{ (MPa)} = A(R_1)^2 + B(R_1) + C + K(T_1 - T_0) - (S_1 - S_0)$

R_1 = current reading & R_0 = initial reading (digits)

S_1 and T_1 = current atmospheric pressure(MPa) and temperature (°C)

Readings at the time of test	Date:	July 10,2006
f	Hz	2540.2
f^2	digits	6452.6
Temperature	°C	19
Thermistor	Ohm	3783
Atm. pressure	MPa	0.099
Coil resistance	Ohm	124

Zero conditions in field must be established by recording digits R_0 (digit), temperature T_0 (°C) and atmospheric pressure S_0 (MPa) at time of installation.

Pin configuration/wiring code:

Red & black: vibrating-wire signal Green & white: thermistor

Checked by Tested by

5. Temperature Measurement

Each piezometer contains a built-in thermistor for temperature measurement. The thermistor is a variable resistor whose resistance decreases nonlinearly with increasing temperature. You can measure this resistance with an Ohmmeter and convert it to temperature using the equation or the lookup table below. (the thermistor is connected between the green and white leads).

Cable resistance may be subtracted from the Ohmmeter reading to get a more accurate thermistor resistance. However the effect is small and is usually ignored. The cable supplied by Applied Geomechanics with our vibrating-wire piezometers has 22 AWG wires, which have a resistance of approximately 50 Ohms per 1000 meters. If you were measuring thermistor resistance at the end of a 1000m cable, the cable would add 100 Ohms to the measurement because there are two wires in the circuit.

Thermistor type Dale 1C3001-B3

Temperature resistance equation

$$T = 1/[A + B(LnR) + C(LnR)^3] - 273.2\ ^oC$$

where T = temperature in ^oC
LnR = Natural log of thermistor resistance
A = 1.4051×10^{-3}
B = 2.369×10^{-4}
C = 1.019×10^{-7}

Table 5. Thermistor Look-up Table

Ohm	Temp. °C	Ohm	Temp. °C	Ohm	Temp. °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

6. Temperature Correction of Pressure Readings

Each vibrating-wire piezometer is individually compensated for temperature-induced zero drift. It is therefore relatively insensitive to temperature changes and the effect of temperature is commonly ignored. However, if temperature compensation is required, it is made by substituting the thermal factor (temperature coefficient) K, provided in the calibration certificate, into the following equation:

$P_{correction} = K \times (T_1 - T_0)$

where T_1 is the current temperature and T_0 is the temperature at the time of calibration. $P_{correction}$ is added to the pressure computed in Section 4 to correct for the effect of temperature change.

The coefficient K is obtained in the factory placing the piezometer in a thermal chamber and then measuring the zero shift that occurs with changing temperature.

7. Barometric Pressure Correction

Your piezometer was sealed in the factory under a vacuum of about 10^{-3} Torr to remove water vapour and other elements present in air that could cause corrosion and affect the readings. For this reason, the piezometer will respond to barometric pressure fluctuations. Since the magnitude of these fluctuations is of the order of +/- 0.0003 MPa, correction is generally not required. If a correction is required, we recommend that you record the barometric pressure each time you take a piezometer reading. This pressure is then referenced to the barometric pressure at the time of piezometer installation, or at the time of factory calibration (see Calibration Certificate), to obtain the pressure correction.

$P_{correction} = (S_1 - S_0)$

This correction is subtracted from the piezometer pressure reading (section 4) to obtain the corrected pore water pressure.

8. Installation

8.1 Saturating Filters

Remove the filter from piezometer and soak or boil it in water for about 15 minutes, or until the filter is saturated with water. In Big Boy the filter can be removed by opening the locking nut with a spanner wrench. In Slim Jim the filter is removed by pulling out the filter holder. In Conehead the filter can be removed by unscrewing the conical tip.

Before replacing the filter, fill the end of the piezometer with water. With the filter end of the piezometer facing up, replace the filter. A small amount of water should squeeze through the filter stone as this is done. Now quickly insert the assembled piezometer into a bottle or bucket off water, keeping it submerged while you transport it to the field. *Make sure that the water enclosed between diaphragm and filter does not leak out before you install the piezometer. A saturated filter with no air gap is necessary for accurate readings!*

8.2 Taking Zero Readings; Acceptance Test

It is important to take zero readings in the field prior to installation of each piezometer. The zero reading provided in the calibration certificate is the output of the piezometer at atmospheric pressure under laboratory conditions. The zero reading that you will take in the field, before the piezometer is installed underground, provides your baseline reference under field conditions. Zero readings are most easily taken with the VW Advisor readout unit. Take a series of readings until repeatable values are attained.

Zero readings should be taken with the piezometer shaded and out of direct sunlight. Temperature extremes and temperature gradients across the body of a piezometer can cause reading errors.

The zero readings that you take before piezometer installation also serve as an acceptance test – a verification that the piezometer is working properly. Small differences between your field readings and the zero readings in the calibration certificate are to be expected. Large differences in these readings may indicate a faulty sensor or damaged cable.

8.3 Borehole Installation Using Sand

A traditional borehole installation requires that the total depth of the hole be drilled to one meter past the planned piezometer installation depth. Installation proceed

1. Flush the borehole with water or biodegradable drilling mud.

2. Create a sand zone using a tremie to drop wet sand to the borehole bottom. Elevate casing to maintain casing above the sand level.

3. Tie piezometer to signal cable in the filter-end-up position.

4. Lower the piezometer into the borehole when the desired sand level is achieved.

5. After piezometer is lowered to the desired depth, add sand with a tremie and continue pulling the casing until it is above piezometer. Continue filling with sand until at least six inches (150 mm) of sand has been layered above the piezometer.

   Alternative to steps 4 and 5: Bag Installation. Placing a piezometer into a canvas bag filled with sand and lowering the bag into the borehole is also an acceptable piezometer placement technique.

6. Isolate the piezometer by creating a bentonite clay seal above the piezometer sand zone created in step 5. Refer to the installation specifications for thickness of seal. Typical seal thickness is a minimum of one foot. Use bentonite chips and create the seal slowly to ensure you do not disturb the piezometer placement. Continue to pull casing up as you complete this step.

   Bentonite Setup Time: Maintain a water-filled borehole while the bentonite sets up. Typical time for the bentonite chips to set up and form a seal is two-to-three hours. Consult bentonite supplier's directions for recommended time intervals.

7. Completely fill remaining borehole with bentonite-cement grout mixture.

8. Mark piezometer cable at surface with stake or flag. Terminate wires and connect to Model 798-1000 Handi-Logger, Handi-Logger Mini or Advisor Vibrating-Wire Readout. The weatherproof field case of the Advisor Vibrating Wire Readout requires no further protection from the elements.

9. Begin to collect periodic readings. Initial pressure readings typically will be high. Continue to evaluate readings as installation stabilizes. Installation stabilization is contingent on local conditions, including soil permeability. Complete datum readings after installation stabilizes; this period can be hours or days depending on local conditions.

8.4 Grouted Borehole Installation

A grouted borehole installation requires that the total depth of the hole be drilled to one meter past the planned piezometer installation depth.

1. Flush the borehole with water or biodegradable drilling mud.

2. Tie piezometer to signal cable in the filter-end-up orientation.

3. Lower piezometer into borehole. Add additional weight (sand bag) if necessary.

4. Completely fill remaining borehole with bentonite-cement grout mixture.

5. Mark piezometer cable at surface with stake or flag. Terminate wires and connect to Model 798-1000 Handi-Logger, Handi-Logger Mini or Advisor Vibrating-Wire Readout. The weatherproof field case of the Advisor Vibrating Wire Readout requires no further protection from the elements.

6. Begin to collect periodic readings. Initial pressure readings typically will be high. Continue to evaluate readings as installation stabilizes. Installation stabilization is contingent on local conditions, including soil permeability. Complete datum readings after installation stabilizes; this period can be hours or days depending on local conditions.

Table 6. Grout Mixes

Grout Mix for Hard and Medium Soils		
Materials	**Weight**	**Ratio by Weight**
Portland Cement	94 lb. (1 bag)	1
Bentonite	25 lb. (as required)	0.3
Water	30 gallons	2.5
Grout Mix for Soft Soils		
Materials	**Weight**	**Ratio by Weight**
Portland Cement	94 lb. (1 bag)	1
Bentonite	39 lb. (as required)	0.4
Water	75 gallons	6.6

8.5 In Situ or Push-In Installation

This installation method requires a Conehead piezometer. It provides the advantage of readings from an instrument placed directly into the native formation. However, it also requires extra precaution to prevent twisting of the signal cable or damaging the piezometer by exerting too much force while driving it into position.

The piezometer has a right-hand thread. You will need a disposable adapter to thread onto to the piezometer to make the drill rod connection.

1. Flush the borehole with water or biodegradable drilling mud.

2. Assemble the adapter to the piezometer.

3. Attach a coupling pin to the bottom of the drill rod and feed signal cable through the drill rod. Continue assembling the drill rod string while threading the cable. Cable length should be adequate for total installation depth plus surface distance requirements. ***Warning:*** *if borehole depth requires drill rod be added as piezometer is lowered, ensure that no twisting of cable occurs!*

4. Connect the Advisor Vibrating-Wire Readout to the cable. Begin taking readings as piezometer is pushed into the borehole bottom. Ensure that pressures do not exceed the maximum range (capacity) of the piezometer shown on the calibration certificate. If pressure exceeds this maximum, slow or halt the piezometer push-in until the excess pressure dissipates.

5. Detach drill rod.

6. Completely fill remaining borehole with bentonite-cement grout mixture.

7. Wait for pressure readings to stabilize. Excessive porewater pressure caused by the push-in is typical immediately after installation. *Exception: Installation of a bentonite cap may cause a reverse pressure effect as the bentonite draws water away from the piezometer.*

8. Mark piezometer cable at surface with stake or flag. Terminate wires and connect to Model 798-1000 Handi-Logger, Handi-Logger Mini or Advisor Vibrating-Wire Readout. The weatherproof field case of the Advisor Vibrating Wire Readout requires no further protection from the elements.

9. Begin to collect periodic readings. Initial pressure readings typically will be high. Continue to evaluate readings as installation stabilizes. Installation stabilization is contingent on local conditions, including soil permeability. Complete datum readings after installation stabilizes; this period can be hours or days depending on local conditions.

8.6 Embankment Installation

This procedure is for piezometers that will be installed in an embankment as it is being constructed.

1. Form a shallow horizontal trench or slot for the piezometer. Carefully place the piezometer into the trench. Avoid kinking the cable during installation.

2. Place a bentonite seal over the installation to isolate the piezometer. Continue to build the embankment over the piezometer.

3. Continue to protect the cable from sharp bends along its path. Avoid crossing cables. If necessary to cross cable paths, isolate cables with fill material between them.

4. Bury cable using fine embankment materials, compacting lightly. Continue process creating layers over the cable until it is covered with at least 18 inches of material. Use only light tamping equipment.

5. Build water stops as specified.

6. Mark piezometer cable at surface with stake or flag. Terminate wires and connect to Model 798-1000 Handi-Logger, Handi-Logger Mini or Advisor Vibrating-Wire Readout. The weatherproof field case of the Advisor Vibrating Wire Readout requires no further protection from the elements.

7. Begin to collect periodic readings. Initial pressure readings typically will be high. Continue to evaluate readings as installation stabilizes. Installation stabilization is contingent on local conditions, including soil permeability. Complete datum readings after installation stabilizes; this period can be hours or days depending on local conditions.

8.7 Installation in Open Standpipes

For monitoring water level in an open standpipe, allow sufficient time for level to stabilize after lowering piezometer assembly into the borehole. This is especially true for small diameter boreholes.

8.8 Cable Care

Cable problems are a common cause of bad data in geotechnical measurement programs. A few simple precautions will help reduce the chances of cable damage in your project:

1. Protect the cable from sharp objects, which can cut through the jacket and into the conductors. If the cable must be buried, use find sand or clay as the burial material, not rocks or sharp stones. If this is not possible, protect the cable by enclosing it in conduit.

2. To prevent tension of buried cable resulting from ground settlement, route the cable with a zig zag pattern. A horizontal zig zag of 0.5m every 15m is normally sufficient.

3. If multiple cables are routed in the same trench, separate them by 25mm or more. Avoid crossing cables.

4. Tag cables at regular intervals to make for easy identification in the field.

5. Keep cables away from chemical solvents, as certain solvents can attack the plastic jacket and insulation.

9. Troubleshooting

After installation a piezometer is typically inaccessible, so that the opportunity for remedial action is limited. Maintenance consists mainly of keeping the cable in good condition and the connections clean and dry. Possible problems that you may encounter, and troubleshooting actions that you can employ, are listed below:

Symptom: piezometer reading unstable

Check the insulation resistance. The resistance between any lead and the cable jacket should be >500 MegaOhm. If not, cut a meter or so from the end of cable and check again.

Check the readout. Does it also give unstable readings with other piezometers? If so, the readout may have a low battery or may be malfunctioning. Consult the manual of the readout unit for charging or troubleshooting instructions.

Is there a source of electrical noise nearby? Common sources of electrical noise are motors, generators, transformers, arc welders and antennas. If so, the problem could be reduced by shielding the electrical noise.

Symptom: piezometer fails to read

Is the cable cut or crushed? Check the nominal resistance between the two VW wires in the cable (red and black) using an Ohmmeter. It should be within 120 - 150 Ohm. The correct value is given in the piezometer test certificate. Remember to add the cable resistance. For our standard 22 AWG vibrating-wire cable, the resistance is 50 Ohm/km. If the resistance reads infinite or a very high value, a cut in the cable is likely. If the resistance reads very low (<100 Ohm), a short in the cable is likely.

Check the readout. Does it also give unstable readings with other piezometers? If so, the readout may have a low battery or may be malfunctioning. Consult the manual of the readout unit for charging or troubleshooting instructions.

Please contact Applied Geomechanics at support@geomechanics.com or telephone 415-364-3200 (USA) for further assistance.

10. Warranty and Limitation of Liability

Standard goods (those listed in Applied Geomechanics' published sales literature, excluding software) manufactured by Applied Geomechanics Inc. (AGI) are warranted against defects in materials and workmanship for twelve (12) months from the date of shipment from AGI's premises with the following exceptions: AGI will repair or replace (at its option) goods that prove to be defective during the warranty period provided that they are returned prepaid to AGI and:

(a) that the goods were used at all times for the purpose for which they were designed and in accordance with any instructions given by AGI in respect of them,

(b) that notice is received by AGI within 30 days of the defects becoming apparent, and

(c) that return authorization is received from AGI prior to the goods being sent back.

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