Model 800P Portable Tiltmeter

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1 Introduction

The Model 800P Portable Tiltmeter is a hand-held instrument designed for surveying the angular position of any surface. It allows a large number of points to be surveyed with a single instrument in projects where continuous monitoring is not required. Among the many uses of the Model 800P are:

- Tracking the progressive movement of natural and manmade structures, e.g., slopes, walls and foundations. The *Tilt Plate Option* is normally used in these applications.
- Precisely measuring surface flatness and contouring the relief and curvature of surface plates, table tops, floors, beams and columns. The *Metrology Option* is used in these applications.
- Measuring structural rotation (tilt) in response to applied loads. This technique is used in evaluating the mechanical performance of bridges, buildings, and other structures. The *Tilt Plate* and *Metrology Options* may both be used in these applications.

Your Portable Tiltmeter operates with the Model 870 Readout Module, which powers the tiltmeter, and a hand-held multimeter that displays the output. The Model 800P System comes with an RMS-225 4-digit multimeter, the Model 870 Readout Module, and a rugged carrying case.

With the *Tilt Plate Option* (Figure 1) measurements are taken from ceramic, brass or stainless steel tilt plates (Figure 2) that are cemented, screwed or bolted to any horizontal or vertical surface. With the *Metrology Option* (Figure 3) the tiltmeter base and sides each have three steel balls in a triangular pattern. The steel balls are placed directly on surface being measured.

The Model 800P Portable Tiltmeter is constructed of stainless and nickel-plated steel parts for corrosion resistance and dimensional stability. The tooling balls used in the *Metrology Option* are hardened tool steel and should always be kept clean and lightly oiled to prevent the formation of rust.

Your Portable Tiltmeter incorporates a high-precision electrolytic tilt transducer as the internal sensing element, offering resolution and stability previously unavailable in a practical engineering instrument. Measured angular movement is referenced to the unchanging vertical gravity vector, eliminating the time and expense of locating an external survey datum.

The Model 800P Portable Tiltmeter is rugged and field-proven – intended for use outdoors, in the laboratory and on the factory floor. High-reliability components and surge protection enhance performance under electrically noisy or transient-prone conditions. A low-pass filter removes vibration effects for static measurements, and a built-in temperature sensor provides data for analysis of thermoelasticity and other temperature-dependent effects.

2 Specifications

General specifications for the Model 800P Portable Tiltmeter are listed below. Appendix B presents the custom specifications for your instrument.

MODEL 800P PORTABLE TILTMETER	
OUTPUT CHANNELS	Inclination (tilt), temperature
ANGULAR RANGE	±5 degrees from null position
RESOLUTION	0.0001 degree (0.36 arc second)
REPEATABILITY	±0.004 typical
LINEARITY	1% of full scale typical
SCALE FACTOR	Approx. 1.000 degree/volt
FILTERING	2-pole Butterworth low-pass filter to remove vibration and jitter. See Appendix B for filter time constant
TEMPERATURE OUTPUT	100°C/volt, 0°C = 0 volts, ±0.75°C accuracy, −40°C to +100°C output range
OUTPUT IMPEDANCE	270 ohms on both channels, short circuit and surge protected
POWER REQUIREMENTS	+7.5 to +17.5 VDC @ 10 mA typical, 250 mV peak-to-peak ripple max. Power is supplied by Model 870 Readout Module
CONNECTOR	6-pin quarter-turn male connector on tiltmeter, sealed with O-ring (see Appendix B)
ENVIRONMENTAL	−25°C to +70°C operational, −30°C to +100°C storage. 0 to 90% humidity, noncondensing. Tiltmeter is splashproof but *not* submersible. Protect from rainfall. Do not allow water to pond on tiltmeter surfaces or inside connector. Keep tooling balls (*Metrology Option* only) lightly oiled to prevent rust.
DIMENSIONS & WEIGHT	143 x 102 x 127 mm (5.6 x 4 x 5 inches), 2.7 kg (6 lb)
MATERIALS	Base and side plates: nickel-plated steel. Locator bars, handle, fasteners: 303/304 stainless steel. Tooling balls: hardened tool steel. Cover: painted PVC or ABS plastic. Seals: rubber, silicone rubber

MODEL 870 READOUT MODULE	
FUNCTION	Powers tiltmeter, switches tiltmeter outputs to multimeter for display
POWER	One 9-volt alkaline battery provides up to 24 hours of continuous tiltmeter operation
OUTPUTS	3 switchable outputs: tilt, temperature & voltage of positive battery, all single-ended
RESOLUTION	Depends on multimeter/voltmeter used for display. With RMS225 multimeter resolution is 0.001 degree (3.6 arc seconds) at tilts greater than 1 degree, and 0.0001 degree (0.36 arc second) at tilts less than 1 degree
CONNECTIONS	6-pin quarter-turn female connector on cable to tiltmeter (see Appendix B). Two banana plug jacks on case for multimeter/voltmeter interface
ENVIRONMENTAL	0 to 90% humidity, noncondensing. Nonsubmersible. Operating and storage temperature ranges same as for Model 800P Portable Tiltmeter
DIMENSIONS & WEIGHT	111 x 62 x 32 mm (4.4 x 2.4 x 1.3 inches) with 1.2 m (4 ft) cable, 285 g (0.62 lb) including batteries
MATERIALS	Case: ABS plastic

3 Taking Readings With the Model 870 Readout Module and Multimeter

3.1 Making Connections, Checking Batteries

The Model 870 Readout Module (Figure 4) is designed for use with a hand-held multimeter or voltmeter containing banana plug sockets with standard 0.75 inch center-to-center spacing, such as the multimeter provided with your 800P system. The multimeter/voltmeter serves as the display for your readings.

The Model 870 powers the tiltmeter from one internal 9-volt battery. The Model 870 cable has a quarter-turn connector on the end, which mates with the connector on the tiltmeter. There are two switches on the Model 870 panel: a three-position toggle switch and a push-button switch. Their functions are described below.

To operate the tiltmeter, turn the toggle switch to the **OFF** position and attach the quarter-turn connecter on the end of the cable to the tiltmeter. Then plug the Model 870 into the multimeter so that the red (+) banana jack connects into the socket labeled "V" and the other banana jack plugs into the socket labeled "COMMON". Next set the multimeter to its "DC Volts" setting. Now, depress the **BATTERY CHECK** button and observe the battery voltage on the display. If the voltage level is below 8.0 volts, the internal battery must be replaced with a fresh new battery. To replace the battery, refer to Section 11, "Model 870 Battery Replacement."

> **Note:** When the **Battery Check** button is depressed, the tiltmeter is *not* powered up – it is not drawing current from, or *loading*, the battery. A battery with 8.0 volts of charge can be drawn down to 7.5 volts under load, the minimum voltage for stable tiltmeter operation.

When the battery in the RMS225 multimeter needs to be replaced, a battery symbol will appear in the display. Replace the battery at this time.

3.2 Reading the Tiltmeter

After completing the above checks, you are ready to read the output of your tiltmeter. The multimeter/voltmeter must be in the "DC Volts" setting. If you are using an RMS225 multimeter for display, push the **MENU** button once, then push the **SELECT** button once. There should now be three digits to the right of the decimal point, so that the last digit is 1/1000th of a volt (1 millivolt). Now turn the toggle switch of the Model 870 to **TILT** and read the tiltmeter angle on the multimeter display. The displayed number is in volts. But because the tiltmeter scale factor is very nearly 1.000 degree/volt, the output can be read as degrees tilt. Use the scale factor in Appendix B to more precisely convert volts to tilt angle.

To read the tiltmeter temperature, turn the toggle switch to **TEMPERATURE**. The displayed number is in volts. This can be converted to temperature using the scale factor 100°C/volt.

4 Tilt Directions and Sign Convention

The Model 800P Portable Tiltmeter measures tilt angle in a vertical plane that parallels the tiltmeter handle. When the tiltmeter is viewed from above, labels indicating the (+) and (–) directions of tilt are visible (Figures 1 and 3). The sign of the tilt angle is displayed whenever you take a reading using the Model 870 and multimeter/voltmeter. The sign of the angle is an important part of your measurement and should *always* be recorded. Take a little time after performing the check-out procedures in the next section to thoroughly familiarize yourself with your equipment and the (+) and (–) tilt sign convention.

5 Initial Check-Out Procedures

Before using your tiltmeter, verify that it is functioning properly by following the steps below:

1. Connect the tiltmeter to your Model 870 Readout Module and the Readout Module to a multimeter/voltmeter as described above.
2. Turn the 870 switch to **TILT**.
3. Rotate the tiltmeter in the (+) and (–) directions and verify that the sign of the displayed output conforms to this convention.
4. Check that the tiltmeter output moves through its full range of approximately +5 to –5 degrees (+5 volts to –5 volts).
5. Turn the 870 switch to **TEMPERATURE**. Verify that the displayed temperature approximates your estimate or independent measurement of the temperature in your location. (Remember to convert the displayed voltage to temperature in °C by multiplying by 100.)

6 Converting Readings to Tilt Angles and Temperatures

The voltage displayed on your multimeter/voltmeter is a close approximation of the tilt angle in degrees. Use this number directly or, for an even closer approximation, multiply the voltage reading by the scale factor supplied in Appendix B. For example, if the scale factor is 1.005 degree per volt, and the voltage output reading is +1.352 volt, then the indicated tilt angle is +1.356 degree from sensor null.

Similarly, multiply the voltage reading from the tiltmeter temperature sensor by 100°C/volt to obtain temperature in °C. For example, if the displayed voltage is +0.184 volt, then the temperature is +18.4°C.

7 Obtaining Absolute Angles, Determining Instrument Bias

7.1 Horizontal Surfaces

Because of built-in instrument offset, or *bias*[1], your tiltmeter will not read exactly 0.000 degrees when the base is exactly horizontal. To obtain the true, or *absolute*, angle θ_{abs} of a surface, this bias must be subtracted from your measurement. The basic procedure for doing this is the same whether you are using a *Tilt Plate Option* or a *Metrology Option* tiltmeter. The subscripts below refer to the coordinate directions in Figure 2.

[1] In geotechnical engineering bias is sometimes called the *check sum*.

1. Place the tiltmeter on a previously installed tilt plate (*Tilt Plate Option*) or a flat, uniform surface (*Metrology Option*).

2. Allow the display to stabilize and record the angle, θ_1.

3. Rotate the tiltmeter 180 degrees so that it is facing in the opposite direction. Place it on the tilt plate or surface.

4. Allow the display to stabilize and record the angle, θ_3.

5. Each reading is the sum of the true angle from horizontal and the tiltmeter bias. The bias component B is the same in both readings. The angle component has opposite sign in the two readings because the tiltmeter direction has been reversed. In other words, $\theta_1 = \theta_{abs} + B$ and $\theta_3 = -\theta_{abs} + B$.

6. Compute tiltmeter bias as $B = \frac{\theta_1+\theta_3}{2}$. Compute true surface angle as $\theta_{abs} = \frac{\theta_1-\theta_3}{2}$.

In projects where you need to know absolute angles, the above procedure must be followed. When using tilt plates, which provide highly repeatable contact points, this method should be used at each measurement location. With the Metrology Option, surface irregularities may contribute to differences in the readings when the tiltmeter direction is reversed. In this case, bias should first be measured on a rigidly mounted reference plate and then subtracted from all subsequent survey readings. The reference plate should be as flat as possible, and its flatness should be known in advance. When this technique is used, only one reading is required per survey point. However, the bias should be measured before and after the survey, and at hourly intervals during it, to verify that the bias has not changed.

Many projects require only relative angle measurement. The change in the angle of a surface over time, or the angular differences among survey points may be the only variable of interest. In these cases instrument bias theoretically can be ignored. Even in these cases, however, there are good reasons for measuring and recording the bias. Firstly, a tiltmeter may be dropped or otherwise altered between measurements, thereby changing the built-in offset. Accuracy requires that the offset be removed before comparing measurements. Secondly, when writing down a reading, digits can be transposed or otherwise misrecorded. This sort of error is quickly apparent when biases are calculated and compared for each measurement location. Bias values for the good data points are all about the same. The bad data points are notably different.

7.2 Vertical Surfaces

The Model 800P is typically used for measuring differences in vertical angle from point to point and vertical angle changes over time. These are relative measurements, meaning that all readings are referenced to one another rather than to the absolute vertical.

It is not possible to obtain the absolute angle of a vertical surface using the reversal procedure described in the previous section. In vertical measurements the side of the tiltmeter is held against the measured surface. As before, the reading is a combination of the true angle and a bias component. However, the two side plates of the tiltmeter are not perfectly parallel, so there is a different bias for each side. Subtracting the two opposing readings does not fully remove the bias. Machined tolerances can result in a residual bias up to 0.3 degrees.

To obtain absolute angle measurements on vertical surfaces, the bias of one or both sides of the tiltmeter must be measured independently and then subtracted from your readings. To measure the bias, record the indicated angle when the tiltmeter is held against a vertical surface of known absolute angle. Subtract the known angle from the indicated angle to obtain the bias.

If you are using tilt plates, taking two readings with opposite sides of the tiltmeter held against the vertical surface is still a good idea because the readings can be summed to compute a *total bias*. This total bias is the sum of the individual biases of the two sides of the tiltmeter. It should not change from location to location or over time. Readings at different times and locations can therefore be compared to check for instrument drift and data recording errors.

8 Using the Tilt Plate Option

8.1 Installing and Orienting Tilt Plates

The Model 800P precisely measures the angular position of tilt plates which have been bonded or fastened to any natural or manmade surface. Applied Geomechanics ceramic tilt plates (part no. 1263) or stainless steel tilt plates (part no. 1273) are recommended. However, your tiltmeter also will work with tilt plates sold by other suppliers (call us if you have questions about compatibility).

Ceramic tilt plates are bonded to their mounting surfaces using epoxy or a ceramic cement. Devcon no. 11800 epoxy (AGI part no. 11800) or Sauereisen no. 30 ceramic cement (AGI part no. SAU30) are recommended. The Devcon product can be used on both horizontal and vertical surfaces. The Sauereisen cement is practical for horizontal surfaces only because it is thinner ("runnier") when first mixed. Applied Geomechanics stainless steel tilt plates contain four countersunk holes sized for 1/4–20 screws or bolts. They may be screwed or bolted down, or they may be bonded in place with the products listed above. Epoxy or cement always should be allowed to cure fully according to the manufacturer's specifications before you begin your tilt measurements.

Each tilt plate has four raised mounting pads that are numbered 1, 2, 3, and 4 (Figures 2 and 5). The pads are polished to provide a uniform mounting surface. When the tiltmeter is properly positioned on a plate, the locator bars touch the sides of three pads and the tiltmeter base or side contacts the tops of the pads at three discrete points.

Tilt plates must be installed within ±5 degrees of vertical or horizontal so that the tiltmeter is on scale when it is set on the plate. You can use the tiltmeter to measure the angle of the plate during installation to keep it within this range. For best results, the tops of the pads of horizontally mounted tilt plates should define a plane that is as close as possible to true horizontal. For tilt plates on vertical surfaces opposing pads 1 & 3 and 2 & 4 should define vertical and horizontal lines respectively (Figures 2 and 5).

Always record the azimuth (heading or bearing) of the vertical surface or the tilt plate pads when you install a tilt plate. We suggest that you orient one pair of pads (e.g., 1 & 3) parallel to the direction of greatest expected movement.

8.2 Taking Measurements from Horizontal Tilt Plates

The tilt plate log sheet in Appendix C is designed to assist you in recording your readings and applying the check-sum method. Copy the log sheet and prepare a log book of blank copies. Take this log book to the field with you to record your data. Fill in the information at the top of each sheet before you begin your measurements. Use one sheet for each tilt plate. Use the same log book each time you go to the field.

Tracking the deformation of any structure begins with a set of initial readings of all of your tilt plates. These readings are subtracted from each of your subsequent sets of readings to determine progressive deformation over time. Remember that results are best when the tiltmeter is placed in exactly the same location on the tilt plate every time. Clean the pads and the tiltmeter surfaces before every measurement. Try to be consistent. Technique is important!

8.2.1 Readings in 1–3 Direction

Begin all readings by recording the date, time and instrument temperature. To take a reading, position the tiltmeter on the tilt plate so that the long locator bar rests against the sides of pads 1 and 3 (Figure 5a). The short locator bar must rest against the side of pad 4. In this position downward movement of pad 1 (relative to pad 3) will give positive X tilt.

Release your grasp on the tiltmeter and wait until the reading on the display stabilizes. Record this reading (volts) in the X_1 column of the log sheet. Lift the tiltmeter off the plate and set it down again in the same position. Record the X_1 reading on the next row of the log sheet in the same column. Do this at least four or five times.

Now rotate the tiltmeter 180 degrees and position it as shown in Figure 5b. Release your grasp. After the display stabilizes, record the reading (volts) in the same row as your first X_1 reading, but in the X_3 column. Lift the tiltmeter off the plate, reposition it, and record the X_3 reading on the next row of the log sheet in the same column. Do this as many times as you have X_1 readings.

Add each X_3 reading to its companion X_1 value and divide by 2. Record this value (volts) in the bias ($\frac{X_1+X_3}{2}$) column of the log sheet. Compare bias values for each row. Discard the data from any row that has a bias anomalously different from the others.

Now subtract each X_3 value from its companion X_1 value and divide by 2. Enter the result in the $\frac{X_1-X_3}{2}$ column. Multiply this value by the scale factor written at the top of the sheet to obtain the tilt angle of the plate in the 1–3 direction. Enter this value in the $Tilt_1$ column of the log sheet. If the value is positive (+), pad 1 is lower than pad 3. If the value is negative (–), pad 1 is higher than pad 3. For example, a tilt angle of +1.06 degrees would indicate that the tilt plate is tilted downward 1.06 degrees from horizontal in the direction of pad 1.

If the $Tilt_1$ values are not the same in all rows, compute and record the average. Use the average in your study of deformation.

8.2.2 Readings in 2–4 Direction

Now rotate the instrument 90 degrees anticlockwise and repeat the process described above. The long locator bar should rest against pads 2 and 4 and the short bar against pad 1 (Figure 5c). Release your grasp on the tiltmeter and wait until the reading on the display stabilizes. Record this reading (volts) in the X_2 column of the log sheet. Lift the tiltmeter off the plate and set it down again in the same position. Record the X_2 reading on the next row of the log sheet in the same column. Do this at least four or five times.

Now rotate the tiltmeter 180 degrees and position it as shown in Figure 5d. Release your grasp. After the display stabilizes, record the reading (volts) in the same row as your first X_2 reading, but in the X_4 column. Lift the tiltmeter off the plate, reposition it, and record the X_4 reading on the next row of the log sheet in the same column. Do this as many times as you have X_2 readings.

Add each X_4 reading to its companion X_2 value and divide by 2. Record this value (volts) in the bias ($\frac{X_2+X_4}{2}$) column of the log sheet. Compare bias values for each row. Discard the data from any row that has a bias anomalously different from the others.

Now subtract each X_4 reading from it companion X_2 reading and divide by 2. Enter this value in the $\frac{X_2-X_4}{2}$ column. Multiply this value by the tiltmeter scale factor to obtain the tilt angle of the plate in the 2–4 direction. Enter this value in the Tilt_2 column of the log sheet. If the value is positive (+), pad 2 is lower than pad 4. If the value is negative (–), pad 2 is higher than pad 4.

If the $Tilt_2$ values are not the same in all rows, compute and record the average. Use the average in your study of deformation. The two vector components $Tilt_1$ and $Tilt_2$ may be summed to obtain the total tilt vector of the tilt plate (Figure 8).

8.3 Taking Measurements from Vertical Tilt Plates

A tilt plate mounted on a vertical surface is able to measure rotation in one direction only: in a vertical plane perpendicular to the surface. This uniaxial capability is sufficient for many projects, such as monitoring the progressive toppling rotation of a retaining wall. If you need to measure the movement of a vertical structure in more than one direction, look for vertical surfaces with different orientations on which to affix your tilt plates, e.g., adjacent sides of a vertical column. Alternatively, you may use an Applied Geomechanics Model 719 Universal Mounting Bracket. This bracket attaches to a vertical surface and has a horizontal shelf. A tilt plate mounted on the shelf enables you to make biaxial measurements.

To begin your measurement, place the tiltmeter against the vertical tilt plate with the (+) tilt arrow pointing toward the plate. The locator bars should be positioned as shown in Figure 5a. Wait until the reading on the display stabilizes, or note the average if the displayed reading fluctuates.[2] Record this value (volts) in the X_1 column of the log sheet. Lift the tiltmeter off the plate and then replace it in the same position. Record the new X_1 reading on the next row of the log sheet in the same column. Do this at least four or five times.

Now rotate the tiltmeter 180 degrees so that the (–) tilt arrow points toward the plate. The position of the locator bars will again be as shown in Figure 5a. Wait until the displayed reading stabilizes, or note the average if the reading fluctuates. Record this value (volts) in the X_3 column of the log sheet. Lift the tiltmeter off the plate and then replace it in the same position. Record the X_3 reading on the next row of the log sheet

[2]Unsteady pressure on the tiltmeter can cause the readings to fluctuate a few millidegrees.

in the same column. Do this as many times as you have X_1 readings.

Add each X_3 reading to its companion X_1 value and divide by 2. Record this value in the "bias" ($\frac{X_1+X_3}{2}$) column of the log sheet. Compare bias values for each row. Discard the data from any row that is anomalously different than the others.

Now multiply each X_1 reading by the tiltmeter scale factor to obtain the indicated tilt angle of the plate. Enter this value in the $Tilt_1$ column of the log sheet. If the values are not all the same, compute and record the average $Tilt_1$. Use the average in your study of deformation.

$Tilt_1$ is the relative tilt angle of the vertical tilt plate. It differs from the absolute angle by a bias component that can be up to ± 0.15 degrees based on machined tolerances. The reason for computing bias in the previous paragraph is to verify that the difference remains constant from point to point and survey to survey.

If you have a second vertical tilt plate in this location, repeat the above procedure using the $Tilt_2$ side of the log sheet.

9 Using the Metrology Option

9.1 Measuring Horizontal Surfaces

9.1.1 Bias Determination

Most surfaces contain small irregularities that may cause your *Metrology Option* tiltmeter to read a slightly different angle each time the surface is measured. This variation, or *false bias*, will be a component of the bias measured with the procedure outlined in Section 7.1.

The maximum false bias B_f^{max} caused by surface relief is simply the amplitude y of the relief (the flatness tolerance) divided by the tooling ball separation r of the tiltmeter (11.0 cm = 4.331 inches).[3] If the flatness tolerance is 0.001 inch, the maximum error will be $B_f^{max} = (y/r) = (0.001/4.331) = 0.000231$ radian $= 0.0132$ degree. B_f^{max} may have positive or negative sign.

To minimize this error, we recommend that you measure the instrument bias on a rigid surface of known flatness. A granite surface plate is excellent, as is a ground steel plate. One of these can be carried with you to the survey site and used on location to periodically check instrument bias. At a minimum, you should check the bias at the beginning and end of a set of measurements, or at least once an hour, using the same

[3] For small angles measured in radians $y/r = sin\theta = \theta$.

surface plate. Follow the procedure in Section 7.1 and record the readings in the "Bias Measurement" area of the metrology option log sheet (Appendix C). Measure the bias several times during every check and compute the average, B_{avg}, and standard deviation, sd. The standard deviation should be less than the maximum false bias as derived above: $sd < B_f^{max}$. Subtract B_{avg} from your surveyed angles to obtain an estimate of the absolute angle.

9.1.2 Taking Readings

The metrology option log sheet in Appendix C is a master. Make copies for recording data during your survey. To survey the angle of a surface, place the tiltmeter in the desired location and read the output (volts). Write this number in the X_1 column of the log sheet. Multiply the number by the scale factor to obtain the relative angle of the surface. Enter the relative angle in the θ_1 column. To obtain the absolute angle, subtract B_{avg} from θ_1 and enter the result in the $Tilt_1$ column.

The log sheet contains a second set of columns for recording angles in a second (X_2) direction at the same measurement point. This direction is normally orthogonal to the X_1 direction. Tilt components (vectors) in the two directions can be summed to obtain the total magnitude and direction of slope at a point (total tilt vector).

To obtain surface profiles, traverses may be made with the tiltmeter placed end to end (Figure 6) or with greater separation between measurement points (Figure 7). Six tiltmeter positions (black circles in triangular pattern) are shown in Figure 6, five in Figure 7. The figures illustrate how to compute surface elevation differences from your tilt measurements. In Figure 7 we assume that the surface profile is divided into straight-line segments and that the connection between segments is half way between adjacent measurement points.

9.2 Measuring Vertical Surfaces

The procedure below yields relative angles for comparison from point to point or over time. Before beginning your survey, make several copies of the log sheet in Appendix C and use them to record the survey data.

To verify that there has been no instrument drift or damage, we recommend that you periodically check the total bias of the tiltmeter using a granite or steel surface plate of known flatness, mounted vertically and rigidly. First, place the tiltmeter against the plate with the (+) tilt arrow pointing toward it. Record the displayed output (volts) in the X_1 column of the bias section of the log sheet. Reverse the direction of the tiltmeter so that the (–) arrow points toward the plate. Write the output in the X_3 column. Add the two readings and divide by 2, then record this number in the $\frac{X_1+X_3}{2}$ column. Multiplying by the scale factor gives the total bias in degrees, B_{degree}. Do this several times, then compute the average B_{avg} and standard deviation sd of B_{degree}. Verify that $sd < B_f^{max}$ (Section 9.1.1). Perform this check at the beginning and end of a survey, and at least once an hour during it. B_{avg} should remain constant within the specified instrument repeatability.

To begin your survey, place the tiltmeter in the desired location with the (+) arrow pointing toward the wall. Read the output in volts. Write this number in the X_1 column of the log sheet. Convert the result to a relative angle by multiplying by the tiltmeter scale factor SF. Enter the angle in the θ_1 column. If you independently know the bias of the (+) side of the tiltmeter, subtract it from the relative angle to obtain the absolute angle. Enter the result in the $Tilt_1$ column.

The log sheet contains a second set of columns for recording readings taken in a different (X_2) direction at the same elevation. This direction is normally orthogonal to the first. Tilt vectors in the two directions can be summed to obtain the total tilt vector.

Vertical traverses may be made with the tiltmeter placed end to end (Figure 6, or with greater separation between measurement points (Figure 7).

10 Making Contour Maps

You may use your Model 800P Portable Tiltmeter to contour the relief of a predominantly horizontal surface or to contour surface elevation changes since your last survey. There are two methods for making contour maps. Both assume that the wavelength of surface relief is much greater than the distance between tilt measurements, and that your measurements approximate the average slope of the surrounding area.

1. **Parallel traverses.** After your initial traverse, perform a series of parallel traverses orthogonal to the first (Figure 9). Calculate elevations along each traverse as shown in Figures 6 and 7. The datum for each parallel traverse is the elevation at the connecting point along the initial traverse. After elevations (or elevation changes) have been determined, they may be contoured by hand or with a surface contouring software package (e.g. SURFER by Golden Software).

2. **Array of tilt vectors.** Sometimes it is not possible to obtain a series of straight-line traverses with your tiltmeter. In this case, surface elevations can be derived from tilt vectors at random measurement points on a surface using Applied Geomechanics' SURFCALC software. For angles under 5 degrees the tilt vector is closely approximated by the vector sum of tilts measured in the X_1 and X_2 directions[4]

[4]For a detailed discussion of the tilt vector, ask for a copy of Applied Geomechanics report no. A-93-1005, "Understanding Tilt Vectors and Processing Tiltmeter Data."

(Figure 8). Elevations derived by SURFCALC can be plotted using a surface contouring package, as has been done in Figure 10. This figure shows the tilt vectors from which the surface elevations were derived. Vector mapping software is also part of the SURFCALC package. Although the tilt measurement points in Figure 10 are evenly spaced, irregular spacing also produces good results. Contact Applied Geomechanics for more information.

11 Model 870 Battery Replacement

To replace the battery in the Model 870 Readout Module, follow the steps below:

1. Remove the four metal screws from the back panel.
2. Carefully separate the back panel from the front portion of the Readout Module. Do not twist or pull any of the internal wiring.
3. Replace the old battery with a fresh new one. Use a 9-volt alkaline battery, the type widely available in supermarkets and hardware stores.
4. Replace the back panel, taking care not to pinch or pull any of the internal wires.
5. Replace the four metal screws that attach the back panel to the front portion of the Readout Module. Do not overtighten.

After you have replaced the battery, connect the Readout Module to a multimeter/voltmeter and to your tiltmeter to verify that is it working properly. Using procedures outlined in Sections 3.1 and 5, verify that the Readout Module reads tilt, temperature and battery voltage. Depressing the BATTERY CHECK switch should display a value above 9 volts when a new battery has been installed.

12 Maintenance and Troubleshooting

12.1 Routine Maintenance

The routine maintenance procedures given here will help ensure that your Portable Tiltmeter system provides many years of trouble-free service.

Keep your equipment clean and away from extremes of heat and cold. Dirt and extreme temperatures shorten the life of the seals and unnecessarily stress the electronic components. Keep the tiltmeter out of direct sun because solar radiation can create internal temperatures considerably greater than the ambient temperature. Always store your equipment in its protective case when it is not in use.

Keep the hardened steel tooling balls (*Metrology Option* only) lightly oiled to prevent rust.

Your tiltmeter has been sealed in the factory with silicone rubber cement. This is intended to protect the tiltmeter against splashes or occasional light rainfall. However, your tiltmeter, readout module and multimeter are not fully waterproof and should NEVER BE SUBMERGED in water or any other liquid. Avoid ponding of water in the connectors or on instrument surfaces during rainfall. Leakage can occur through the interior of the tiltmeter connector. WATER DAMAGE TO INTERNAL COMPONENTS VOIDS THE WARRANTY!

The cement that holds the cover onto the tiltmeter (Figures 1 and 3) provides a firm mechanical bond. To maximize the bond life, always lift the tiltmeter holding the knurled handle. *Do not twist or pull on the cover when handling the tiltmeter.*

12.2 Determining Cause of Malfunctions

Apart from the procedures described in this manual, your tiltmeter and readout module are not field-serviceable. If you encounter problems not described here, please contact Applied Geomechanics Inc. at telephone (831) 462-2801 or fax (831) 462-4418. A service engineer will assist you in determining the cause of any problem.

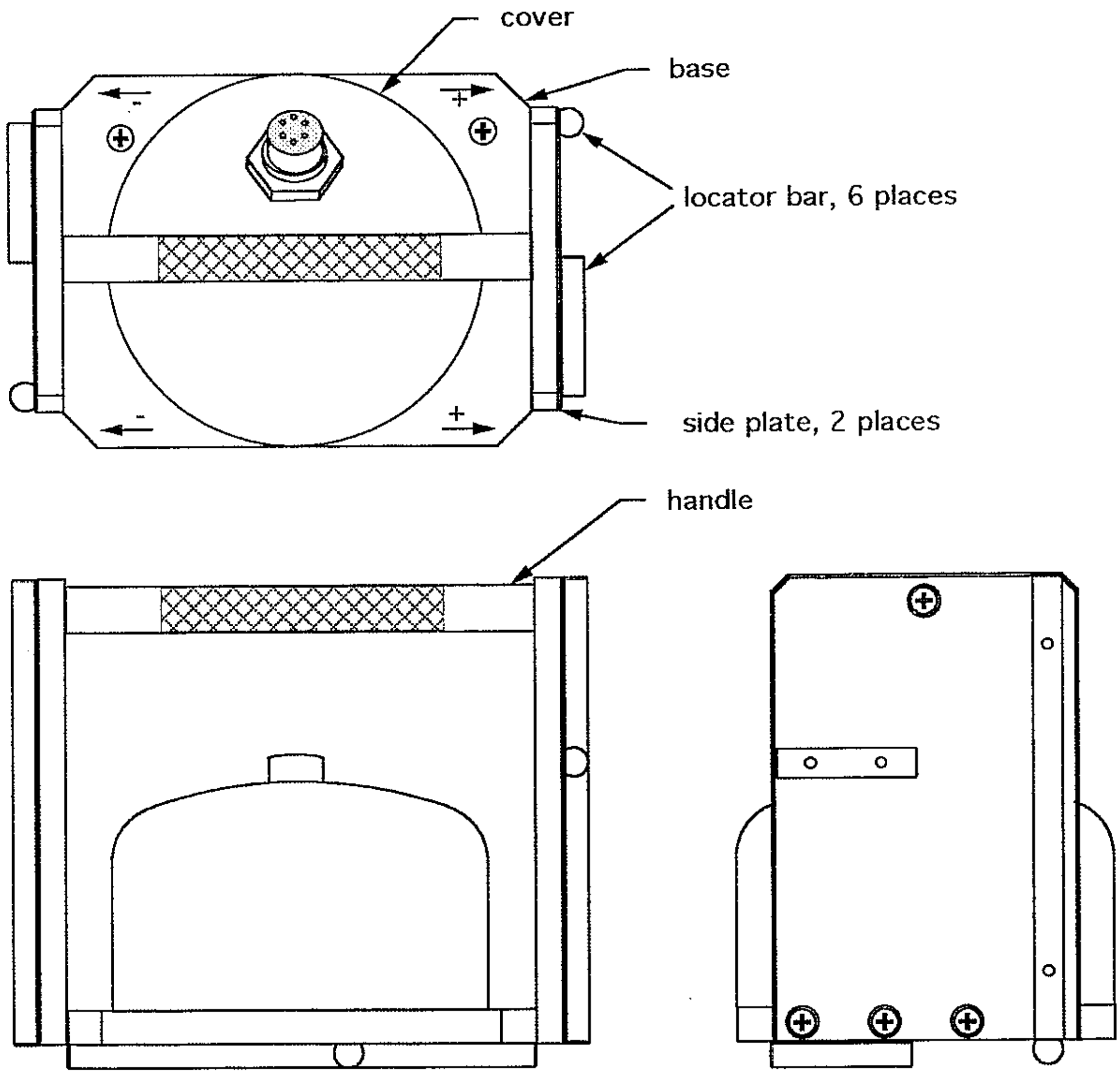
The following simple checks should be performed if you encounter problems:

If there is no output when you have connected the tiltmeter to the Model 870 Readout Module and multimeter/voltmeter, first check that they contain batteries and that the multimeter/voltmeter is functioning properly. Then be sure that all connectors are securely attached. Failure to obtain an output signal from the tiltmeter normally is the result of lack of power or a broken wire or connection.

If the tiltmeter output is firmly "pegged" at either end of its output range (approx. ±5 degrees = ±5 volts), the tiltmeter is probably tilted off scale. Tilt it in the opposite direction to check this possibility. The tiltmeter output should pass through 0 as you move it through its null (level) position. If the tiltmeter output remains "pegged" at its positive or negative limit no matter how much you move it, the cause may be a broken power connection in the Model 870 or in the cable that connects it to the tiltmeter. To check this possibility, remove the back of the Model 870 and inspect the internal wiring. If no breaks are found, test for continuity between the wires inside the Model 870 and the connector at the opposite end of the cable (you must disconnect the cable from the tiltmeter first). Use the ohmmeter setting of your multimeter and the probes in the system carrying case to perform this check.

If the continuity check reveals no broken connections, the problem may be internal to the tiltmeter. Contact the factory to arrange for a repair. Model 800P tiltmeters cannot be opened without special tools. OPENING THE TILTMETER VOIDS THE WARRANTY!

MODEL 800P PORTABLE TILTMETER, TILT PLATE OPTION

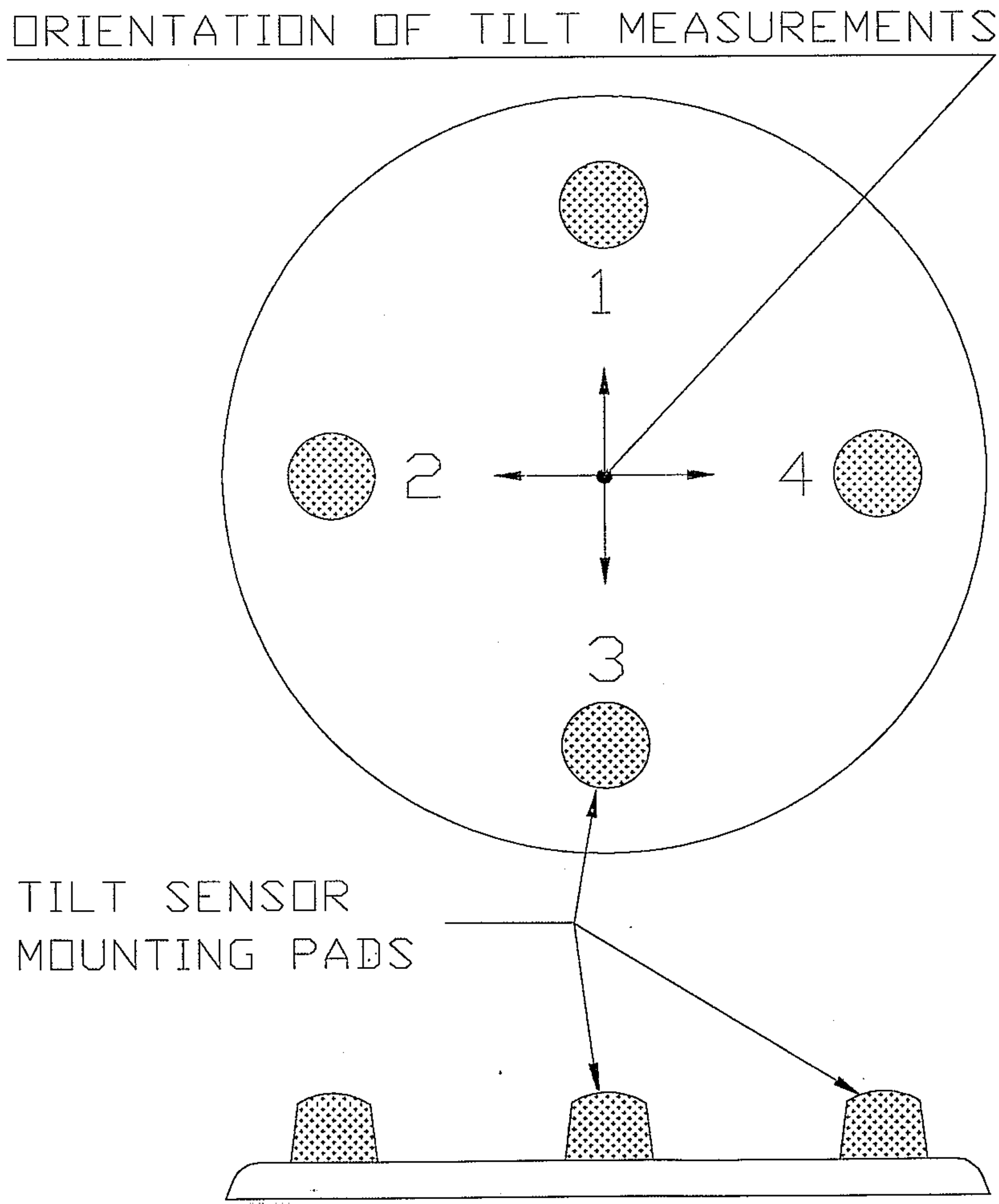


D-94-1032

APPLIED GEOMECHANICS INCORPORATED

MODEL 800P PORTABLE TILTMETER, TILT PLATE OPTION			DRAWN	CHECKED
			BSC	GRH
DWG. NO.	DATE	REV	SCALE	
D-94-1032	12/9/94		1/2	©1994

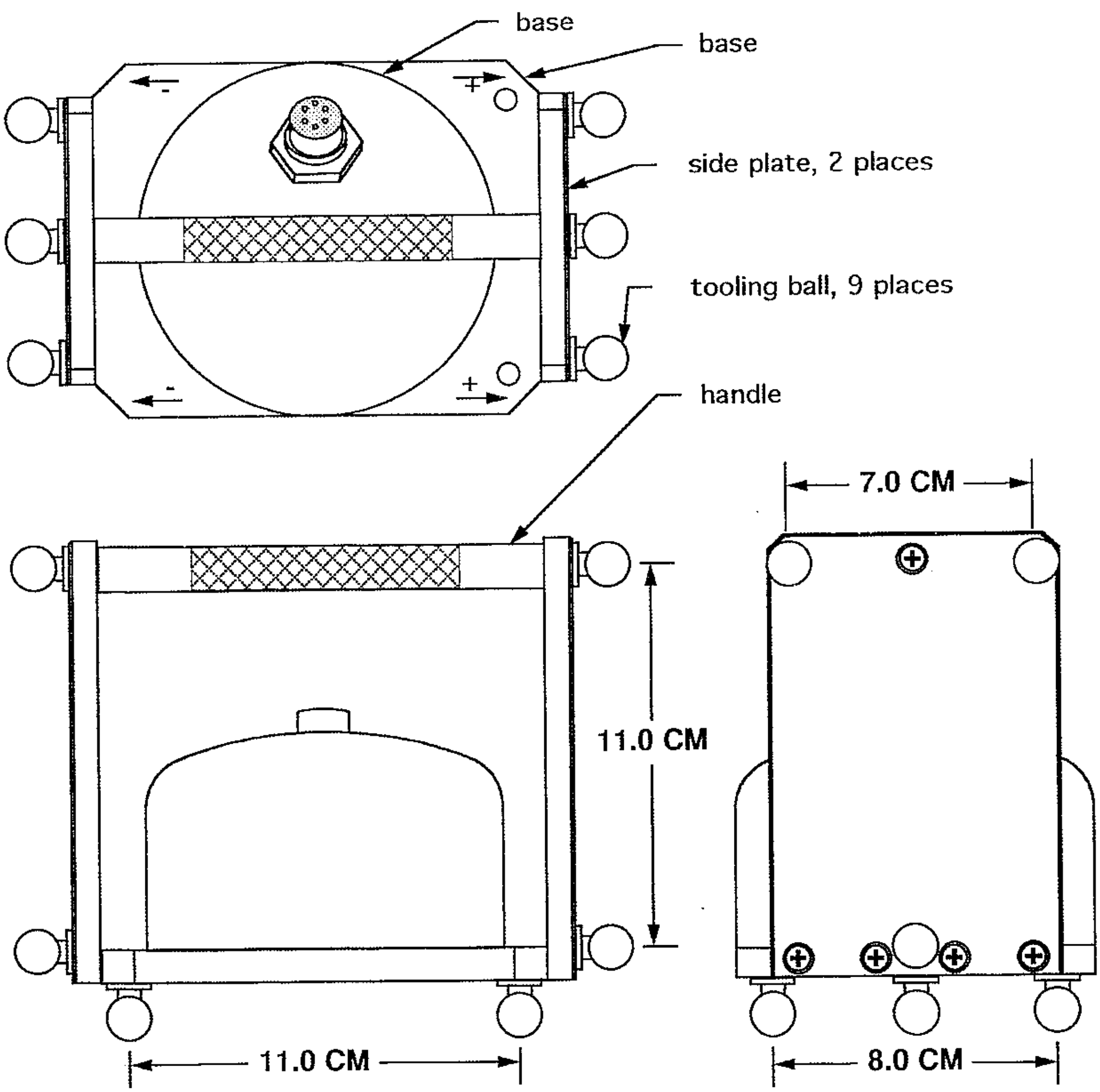
Figure 1: Model 800P Portable Tiltmeter, Tilt Plate Option



APPLIED GEOMECHANICS INCORPORATED	TILT PLATE - MODEL 750 -323			DRAWN DEH	CHECKED BRH
	DWG. No. D-90-1024	DATE 6/19/90	REV	SCALE	©1990

Figure 2: Tilt Plate

MODEL 800P PORTABLE TILTMETER, METROLOGY OPTION



D-94-1033

APPLIED GEOMECHANICS INCORPORATED	MODEL 800P PORTABLE TILTMETER, METROLOGY OPTION			DRAWN BSC	CHECKED GRH
	DWG. NO. D-94-1033	DATE 12/9/94	REV	SCALE 1/2	©1994

Figure 3: Model 800P Portable Tiltmeter, Metrology Option

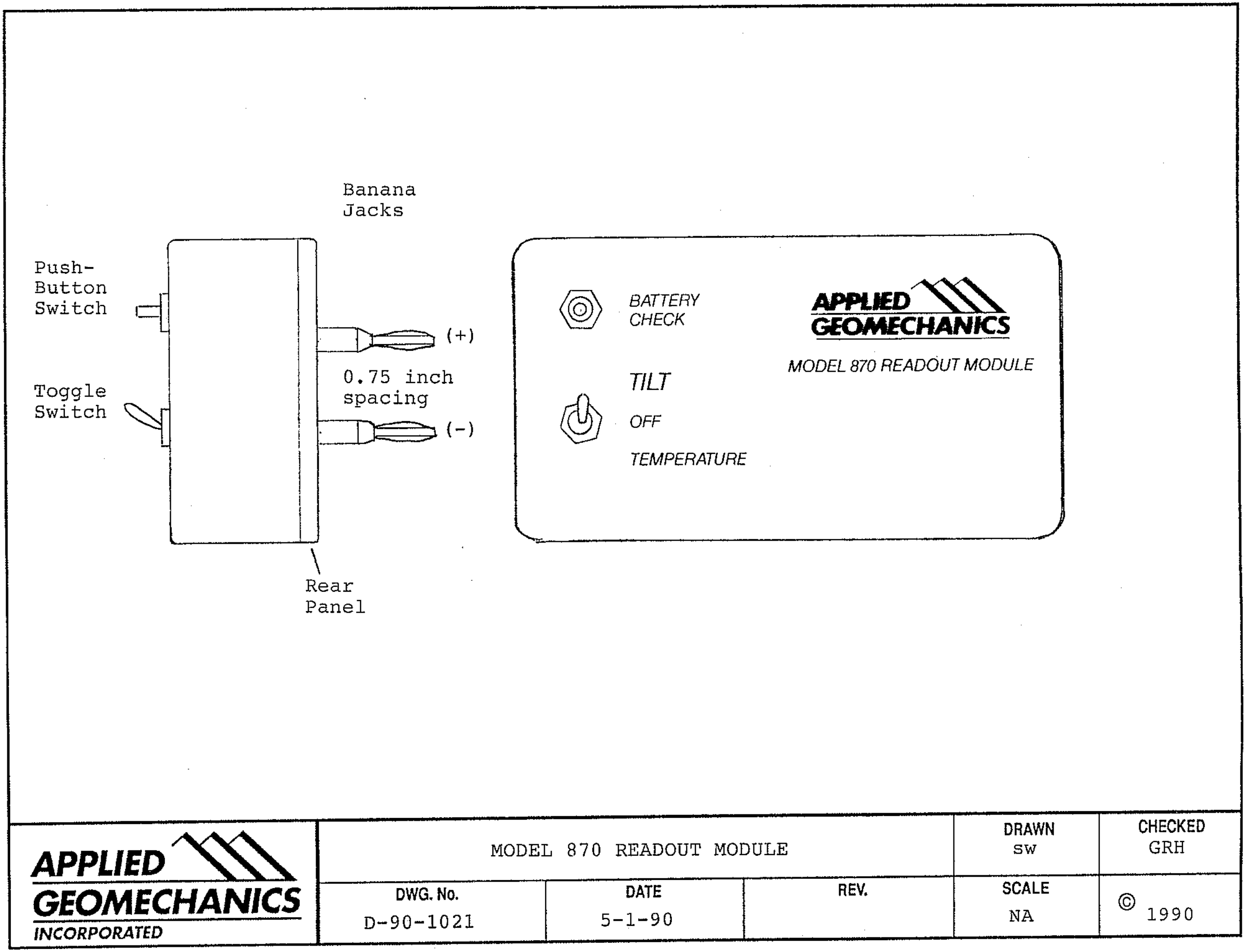


Figure 4: Model 870 Readout Module

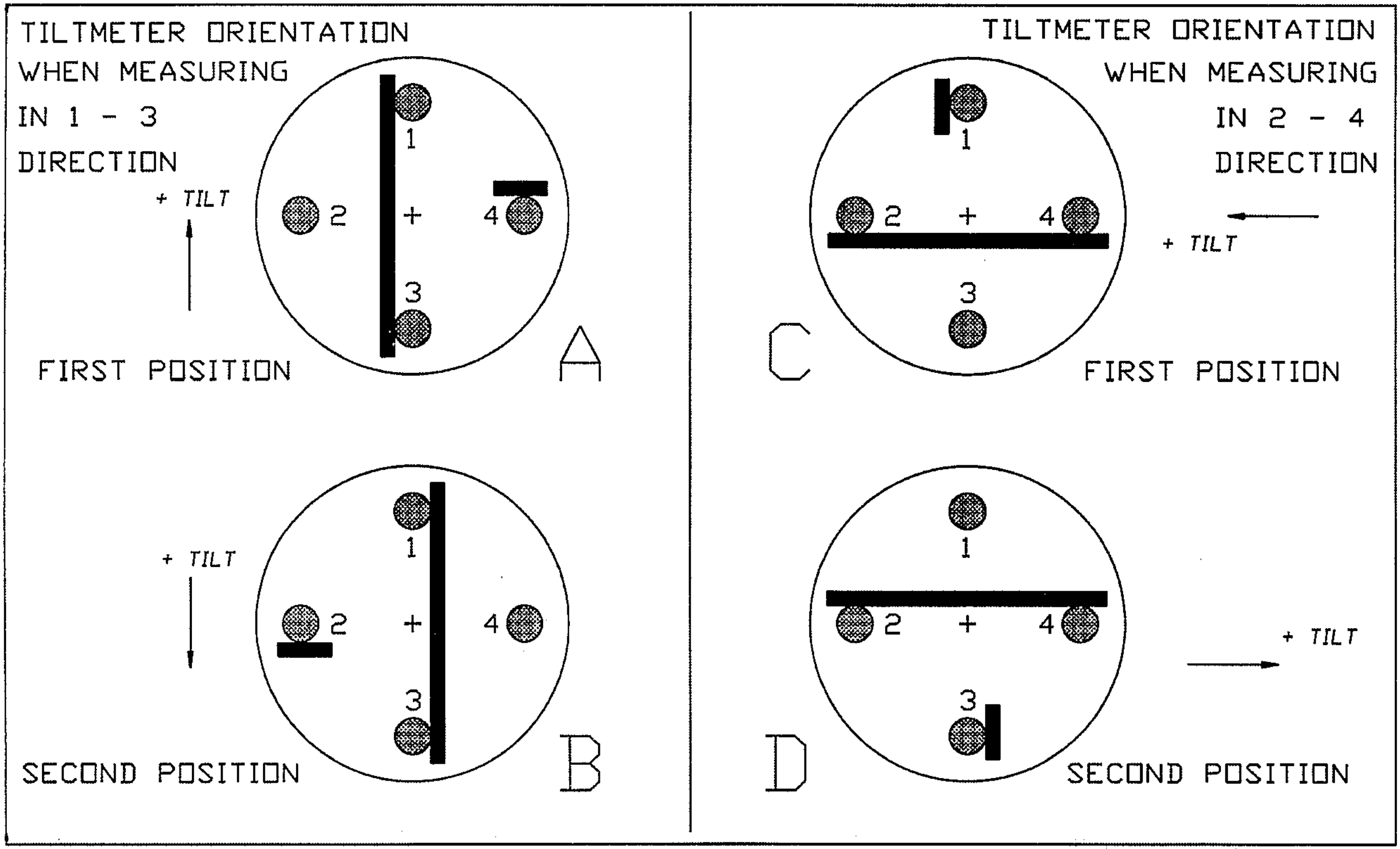


Figure 5: Tiltmeter Positions on Horizontal Tilt Plate

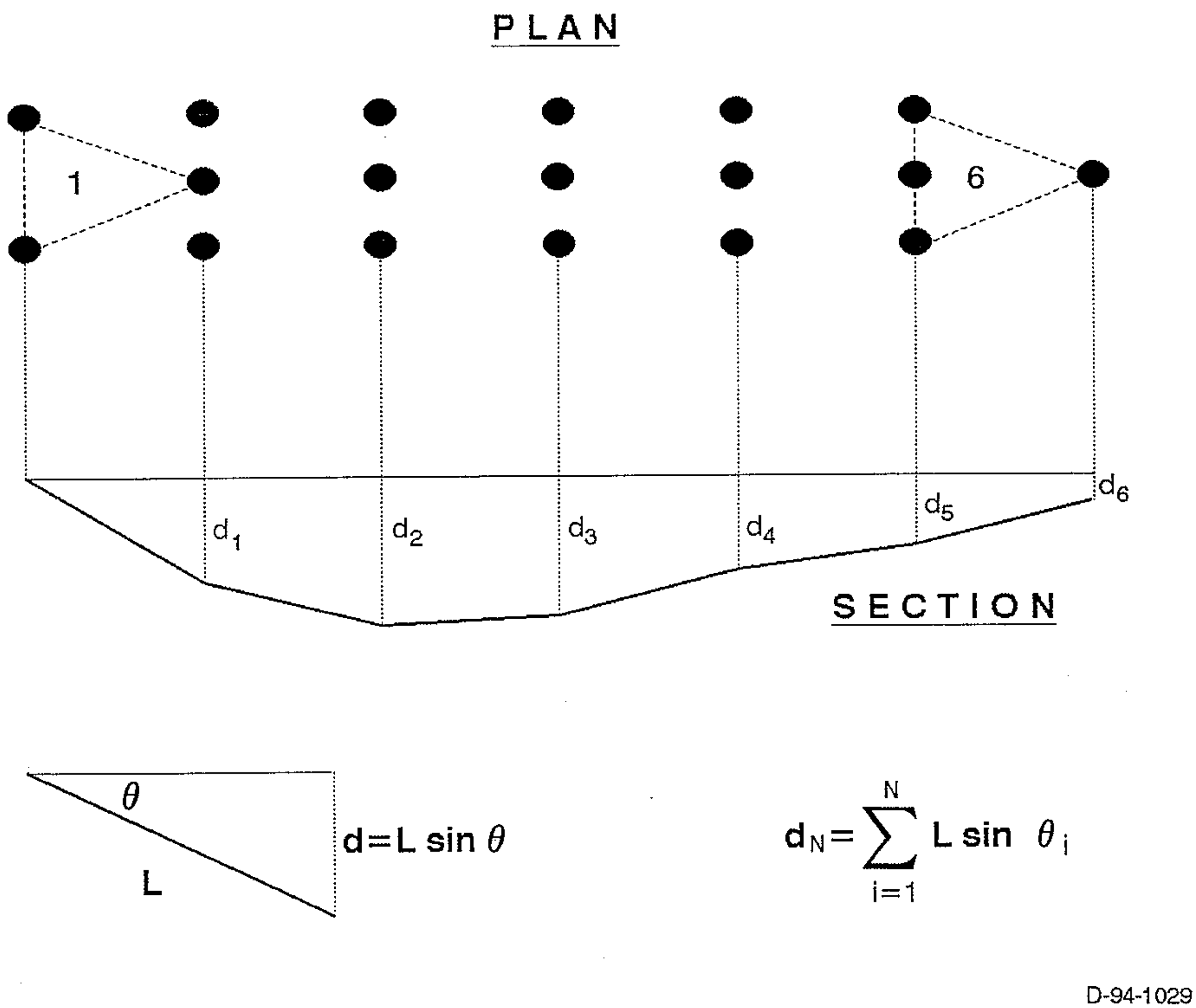


Figure 6: Metrology Option Traverse Method, Tiltmeter Placement End to End

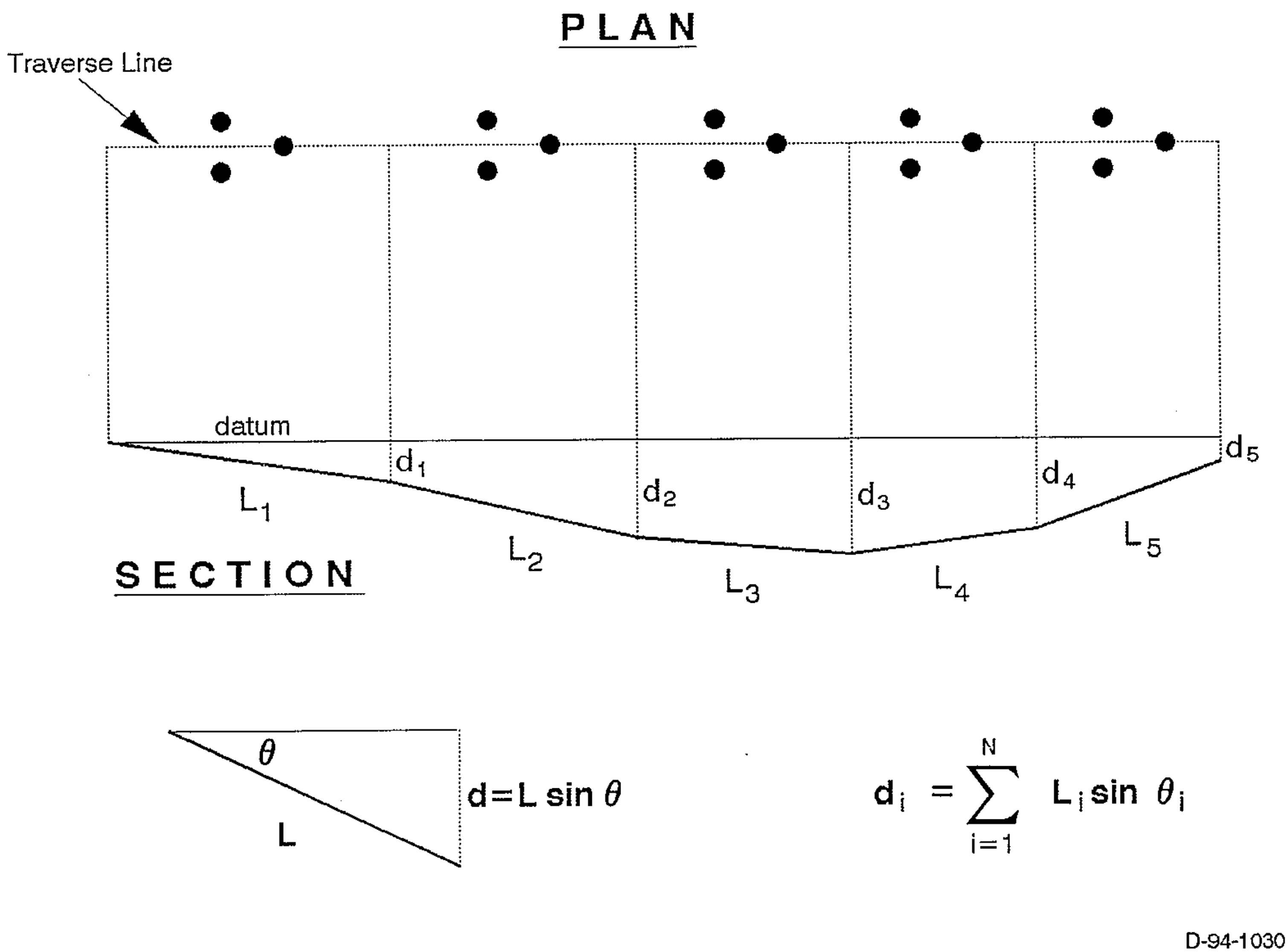


Figure 7: Metrology Option Traverse Method, Uneven Tiltmeter Spacing

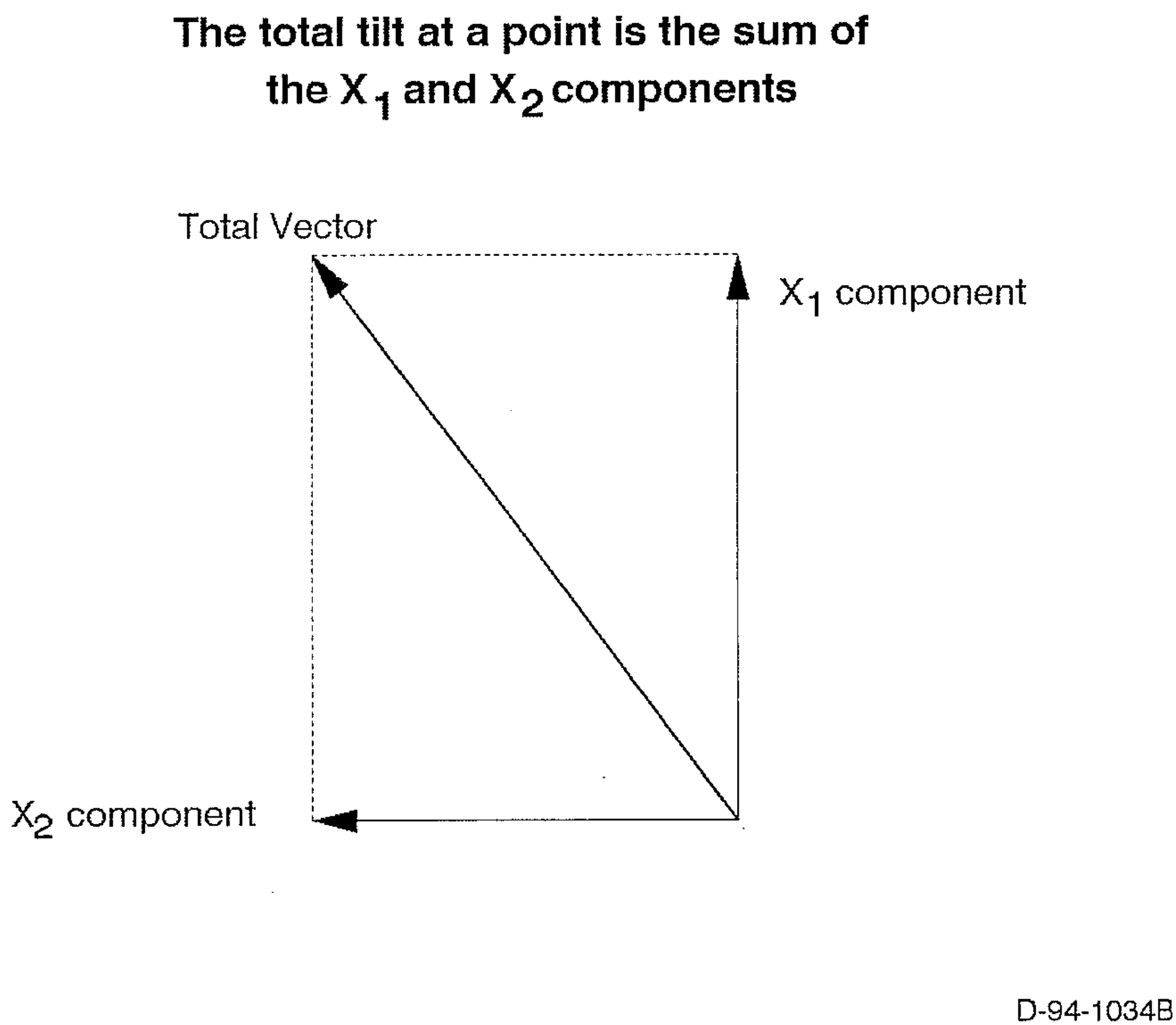


Figure 8: The Tilt Vector

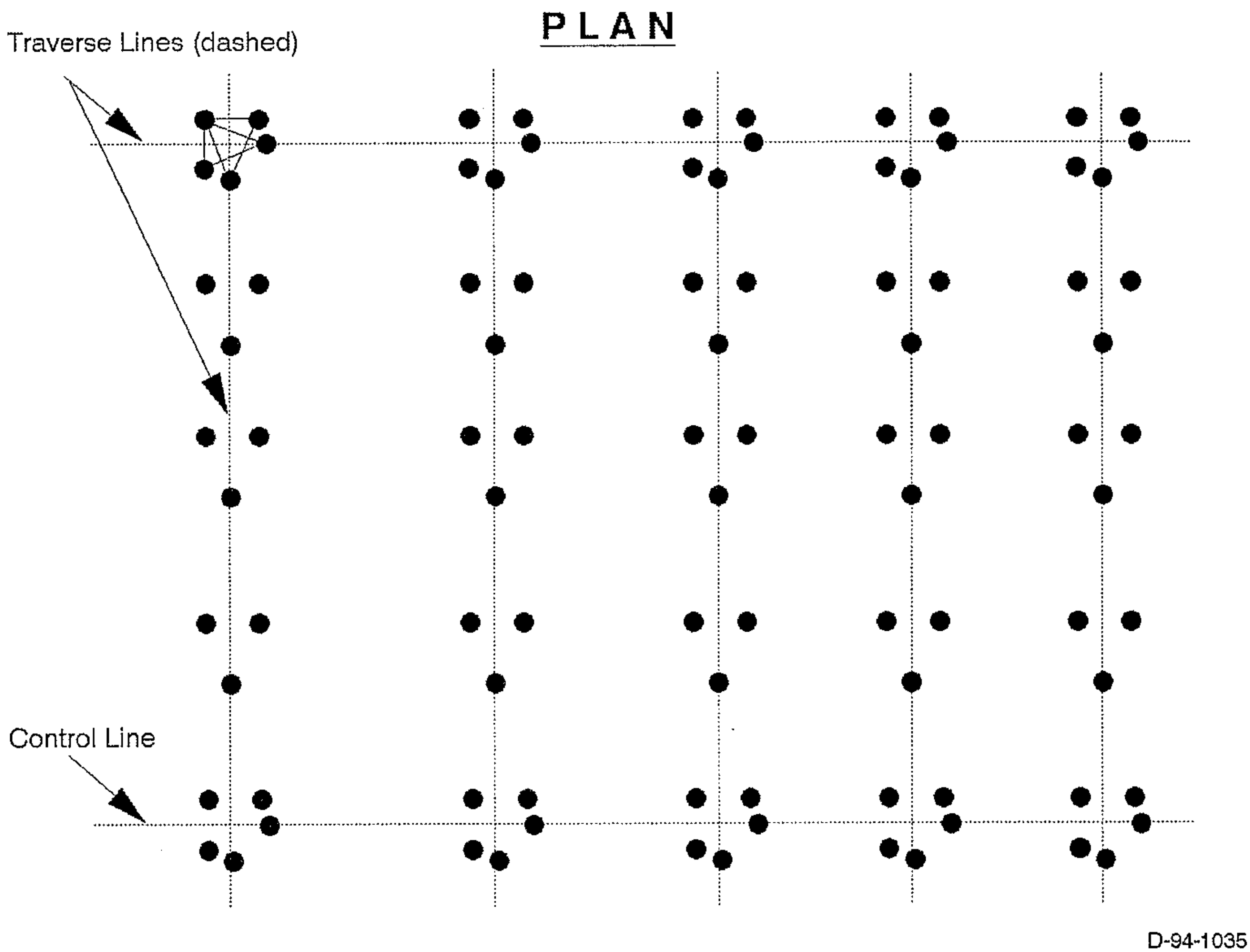


Figure 9: Traverse Pattern for Measuring Surface Relief

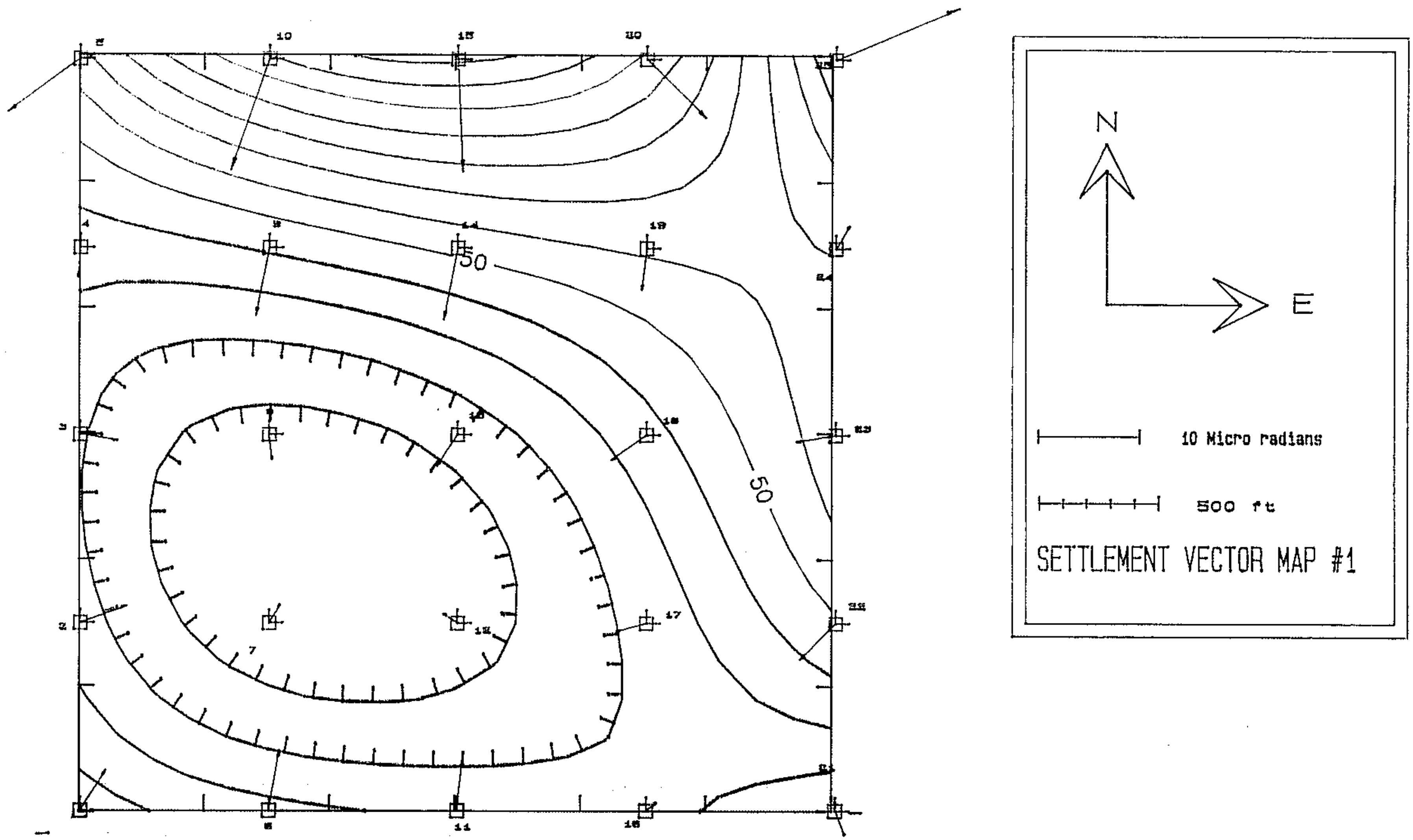


Figure 10: Surface Contour Map Derived From Tilt Vectors

D-94-1036

A Warranty and Assistance

The components of your portable tiltmeter system (Model 800P Portable Tiltmeter, Model 870 Readout Module, RMS225 Multimeter and carrying case) are warranted against defects in materials and workmanship for one year from the date of delivery. We will repair or replace (at our option) products that prove to be defective during the warranty period provided they are returned prepaid to Applied Geomechanics Inc. No other warranty is express or implied. Water damage voids the warranty. After expiration of the warranty, AGI will repair the equipment at its factory for parts and labor charges. Products returned after warranty expiration should be accompanied by a purchase order to cover repair costs. Applied Geomechanics Inc. is not liable for consequential damages.

THE REMEDIES PROVIDED HEREIN ARE THE BUYER'S SOLE AND EXCLUSIVE REMEDIES. AGI SHALL NOT BE LIABLE FOR ANY DIRECT, INDIRECT, SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES, WHETHER BASED ON CONTRACT, TORT OR ANY OTHER LEGAL THEORY.

B Custom Specifications for Your Model 800P Tiltmeter

Serial number: ____________ ☐ Tilt Plate Option ☐ Metrology Option

B.1 Scale Factors

The scale factor of your tiltmeter is listed below. Calibration units are circled. Scale factors are determined by linear regression with a minimum of 10 steps over the calibration range. Maximum nonlinearity is the greatest deviation of any calibration point from the regression line divided by the full calibration span (±5 degrees range = 10 degrees span), expressed as a percentage.

Calibration temperature:	°Celsius			
Scale factor units:	μradian/mV	arc second/mV	arc minute/mV	degrees/volt
Angular range units:	μradians	arc seconds	arc minutes	degrees
The scale factors below are for	single-ended	differential	output.	

SCALE FACTOR	
Max. nonlinearity	
Calibrated over angular range of	±

The temperature sensor output is single-ended only. Scale factor is 100°C/V.

Outputs displayed using the Model 870 Readout Module and a multimeter/voltmeter are single-ended. Single-ended tilt output is measured between pins D and B in the tiltmeter connector. Differential output is measured between pins D and E. The scale factor for differential output is one-half the scale factor for single-ended output.

B.2 Filter

Your tiltmeter has a two-pole Butterworth low-pass filter to remove vibration and jitter. The time constant (τ) for the filter is listed below. After an instantaneous rotation the output of your tiltmeter settles to 98% of its final value within 4 time constants. Filter corner (cutoff) frequency (f_c) can be calculated as: $f_c = 1/(2\pi\tau)$.

$\tau =$ ____________ seconds

B.3 Connectors

Bendix PT07A-10-6P (male) on tiltmeter

Bendix PT06A-10-6S(SR) (female) on Model 870 cable

Connector Pin Assignments and Cable Color Coding

Bendix Pin #	Model 870 Wire Color	Signal/Function
A	red	+12 VDC in
B	white	Signal Ground†
C	black	Power Ground†
D	green	+Tilt out
F	yellow	Temperature out

†Signal and Power grounds are common on the circuit board inside the tiltmeter.

ANGLE CONVERSION CHART						
	degrees	arc minutes	arc seconds	μradians	mm/meter	inches/ft
degrees	1	60	3600	17453	17.5	0.209
arc minutes	0.0167	1	60	291	0.291	$3.49E^{-3}$
arc seconds	$2.78E^{-4}$	0.017	1	4.85	$4.85E^{-3}$	$5.82E^{-5}$
μradians	$5.73E^{-5}$	$3.44E^{-3}$	0.206	1	0.001	$1.20E^{-5}$
mm/meter	0.057	3.436	206.2	1000	1	0.012
inches/ft	4.785	286.5	17182	83333	83.33	1

C Field Data Log Sheets

Use these sheets as masters. Make copies for use during your surveys.

APPLIED GEOMECHANICS

TILT PLATE LOG SHEET: MODEL 800P PORTABLE TILTMETER

Job Name: Job No.:

Tilt Plate No.: ☐ Vertical ☐ Horizontal

Tilt Plate Location:

Azimuth of Tilt Plate:

Scale Factor (SF) of Tiltmeter (*degrees/volt*):

Remarks:

All variables X below are measured in volts. $Tilt_1$ and $Tilt_2$ are in degrees. For horizontal tilt plates $Tilt = SFx\Delta$. For vertical tilt plates $Tilt = SFxX$.

Date & Time	$Temp$ ($^\circ C$)	X_1	X_3	$\frac{X_1+X_3}{2}$ (bias)	$\frac{X_1-X_3}{2}$ (Δ)	$Tilt_1$	X_2	X_4	$\frac{X_2+X_4}{2}$ (bias)	$\frac{X_2-X_4}{2}$ (Δ)	$Tilt_2$	Meas-ured by

APPLIED GEOMECHANICS

METROLOGY OPTION LOG SHEET: MODEL 800P PORTABLE TILTMETER

Job Name: Job No.:

Surface Orientation: ☐ Vertical ☐ Horizontal

Scale Factor (SF) of Tiltmeter (*degrees/volt*):

Remarks, Map of Traverses, Direction of Readings, Etc.:

Bias Determination (Use Plate with Known Flatness):

Date & Time	$Temp$ ($°C$)	X_1	X_3	$\frac{X_1+X_3}{2}$ (B_{volt})	$SFxB_{volt}$ (B_{degree})
					B_{avg}
					sd

All variables X below are measured in volts. θ_1, θ_2, $Tilt_1$ and $Tilt_2$ are in degrees.

Loc.	Date & Time	$Temp$ ($°C$)	X_1	θ_1 (X_1xSF)	$Tilt_1$ ($\theta_1 - B_{avg}$)	X_2	θ_2 (X_2xSF)	$Tilt_2$ ($\theta_2 - B_{avg}$)	Meas-ured by