Instructions
K_o STEPPED BLADE

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A. Getting ready to test

1. A drilling machine is required in order to bore a 3-inch or larger hole down to the test depth, and push the Blade. Tests also can be performed through a hollow-stem auger that is a minimum of 3-inches internal diameter. The Blade will be pushed a total of approximately 21 inches (0.53 m) into the bottom of the boring.

2. The Blade has a female AW connector. An AW connector that has been slotted to accommodate the Blade lines is attached to the Blade, and the lines run out through the slot when connection is made to the drill rod.
3.

4. A nitrogen or other inert gas source (not supplied) is required. The source is regulated to 300 psi (2000 kPa) with a supplied regulator. The exact pressure is not critical. 300 psi is used because soils with higher lateral stresses probably cannot be penetrated by the Blade..

5. The 2004 Model Blade steps are 100 mm (3.95 inches) long with the exception of the first step, which is made longer in order to attach the reinforcing rib. Successive test depths therefore will be 50, 150, 250, 350, and 450 mm 17.7 onches) below the bottom of the hole.

6. Level the drilling machine and auger or wash-bore to about 2 to 2½ inches (50 mm) above first desired test depth. Because the first, shallowest depth readings are easily influenced by action of the drill, *as the test depth is approached drilling should ease off with very little down-pressure on the bit.* Wash borings also can be used so long as there is not an over-wash. Any kind of impact boring will almost certainly affect the shallow test data and should not be used.

7. With the drill at the bottom of the boring, make note of the total depth. This is the depth that will be returned to with the tip of the Blade, so allowance must be made for the length of the Blade. After the drill rod is pulled and the Blade attached, the driller should be instructed to insert the Blade so the end is at the bottom of the boring.

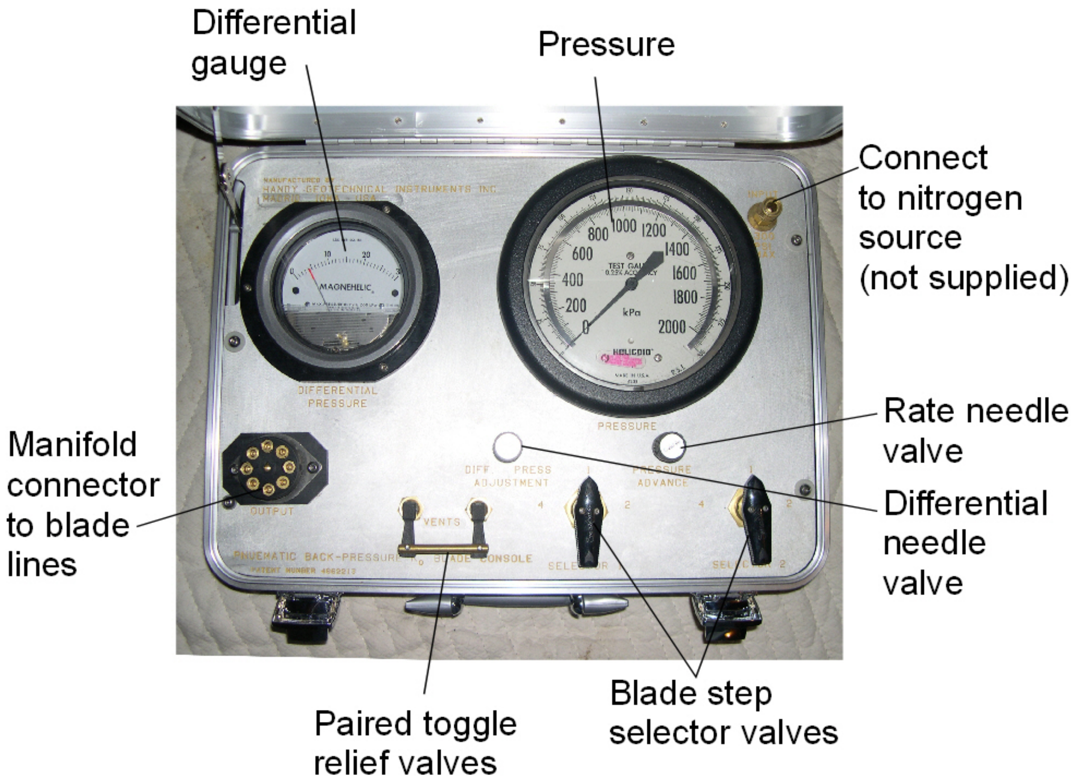
8. As the Blade is lowered, the cased lines should be taped at intervals to the drill rod to prevent looping when the rod is pulled after the test.

9. With the Blade at the bottom of the hole, a chalk mark should be made on the drill rod with reference to a convenient point on the drill rig. Then a series of marks will be made to show how far the rod should be pushed for each test depth increment. The marks are 50, 150, 250, 350, and 450 mm (2.0, 5.9, 9.8, 13.8, 17.7 inches) above the bottom reference point.

B. Attach gas lines.

10. During the drilling operation the Console can be set up at a convenient distance from the boring. The pressure regulator is connected to a nitrogen compressed gas source, and a line is connected from the regulator to the inlet fitting on the Console.

11. Attach the end of the Blades to the manifold on the console. *The connector fits only one way*, according to a keyway at the center of the connector. Rotate the keyway until the connector pushes on. The connector will click, indicating that it is locked in place. (To unlock the connector, pull back on the black ring.)



C. Pushing the Blade.

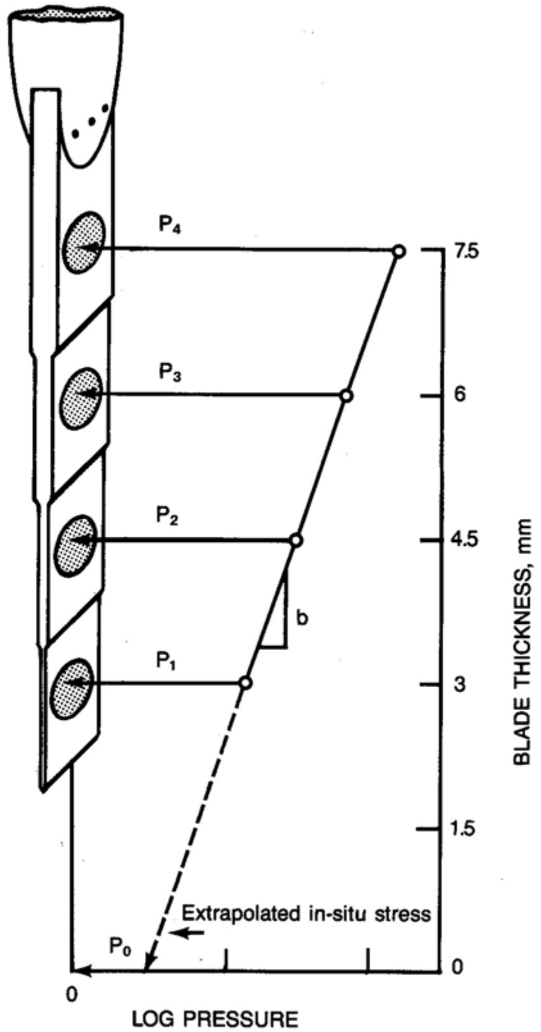
12. Orient the Blade to measure in the desired stress direction, and lower so the end is at the bottom of the boring. Note that tests can be conducted with different orientations to establish directional stresses. Orientation is particularly important to measure lateral pressures on deep foundations such as pile. Orientation also is important for measurements of passive pressures as related to potential slope or bearing capacity failures.

13. Slowly push the Blade into the bottom of the boring to the first mark, which represents a penetration depth of 25 mm (1 inch). Have the driller relieve the down-pressure without lifting the Blade. A slip joint may be incorporated in the drill string to facilitate this action.

D. The first pressure reading.

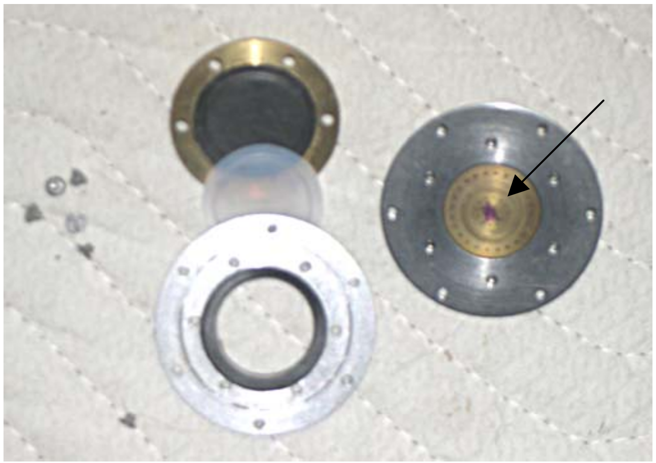
14. The K_o Stepped Blade measures soil pressures on 4 different thickness steps so an extrapolation may be made to obtain a hypothetical soil pressure on a zero thickness step. In preparation fort the first reading, after the Blade has been pushed for the first test increment: (a) Turn both Step Selector valves to 1. (b) Open the toggle valves on the Console and leave open. These will be closed only when making a reading. (c). Attach the nitrogen source and turn the regulator handle out so no pressure will be

applied when the bottle valve is opened. (d). Open the bottle valve and set the regulator to about 300 psi pressure. A small amount of gas now will be flowing through the system and will continue to flow so long as the bottle valve and regulator remain open



15. The pressure cells are pneumatic to avoid electrical problems in a wet, pressured environment below a groundwater table. The patented cells operate as follows:

a. Each cell has two chambers that are isolated from one another by a circular ridge. The cell is covered with a Teflon membrane that contacts the soil and is backed by a rubberized Nylon gasket. Gas pressure is applied to both cell chambers simultaneously, but with a small pressure difference between the chambers.



Inside a pressure cell. Arrow shows the ridge separating two chambers in the cell.

b. The rate of the pressure increase is controlled by the right needle valve on the Console and is adjusted for a rate of approximately 1 psi per second. If the gas source pressure is constant this needle valve will seldom require further adjustment throughout a test or series of tests.

c. When a pressure of about 10 psi is reached, the left needle valve is adjusted so the differential gauge reads about 10-12 psi. Normally this valve will require very little adjustment after being set to the appropriate operational position.

d. When pressure in the cell is equalized, the differential pressure gauge reading starts to decrease and may decrease to zero. Simultaneously as gas bleeds into the low-pressure chamber of the cell, the main pressure gauge holds constant. *The main pressure gauge is read immediately and the twin toggle valves are immediately opened to vent the system and prevent over-pressurizing the cell diaphragm.* <u>The toggle valves are left open until ready for the next reading.</u>

e. This is the procedure to take a single pressure reading. It is rapid, usually requiring less than one minute, as the only valves that normally require manipulation are the twin toggle valves that are closed to start a pressure reading and open upon completion of the reading. After the first reading is determined and recorded, the operator will proceed to the next readings.

E. Test procedure for the second and subsequent readings

16. After the first step pressure has been measured and recorded and the *toggle valves are open,* the Blade is pushed an additional 100 mm to embed Step 2. then,

(1) Both selector valves are turned to position 2.
(2) The toggle valves are closed
(3)..The soil pressure on Cell 2 is read as the differential pressure decreases and the main pressure gauge hold constant.

(4) The toggle valves are immediately opened and left open.
(5) The data are recorded.

17. After Cell 2 has been read, both selector valves are turned back to Position 1 and the pressure read on the first step. Then the toggle valves again are opened and left open while the Blade pushed another 100 mm.

18. At every new position the sequence of reading starts with the highest numbered cell that is embedded and decreases through the cell order:

>First advance (depth 50 mm)	Read Cell 1<
>Second advance (depth 150 mm)	Read Cell 2, then Cell 1<
>Third advance (depth 250 mm)	Read Cell 3, then Cell 2 and 1<
>Fourth advance (depth 350 mm)	Read Cell 4, then Cell 3, 2 and 1<
>Fifth advance (depth 450 mm)	Read Cell 4, then Cell 3, 2, and1<

It will be noted that after the second advance, Cell 2 is where Cell 1 was during the first advance, and so on down each column. In this way several readings are obtained at each subdepth except the lowest, where only one reading is obtained. The data sheet may be set up with sequential readings as shown above, in which case each vertical column represents one subdepth and one data plot (Appendix).

19. Toggle valves open, the Blade is removed, taking care not to allow the pressure lines to tangle or droop. The Blade is removed from the drill stem and cleaned off. Meanwhile the driller will deepen the boring to the next test depth. A minimum advance is 2 ft to prevent overlapping of the data. Larger increments may be used.

F. Interpretation of data

20. Extensive research over the last 25 years has revealed a linear relationship between the logarithm of pressure and Blade step thickness. The analogy to the familiar e-log P relationship obtained during normal consolidation in the consolidation test indicates that the soil is consolidating. .

21. As in the case of the consolidation test, an elastic response can be obtained prior to breakdown of the soil structure. This frequently occurs with the first and thinnest Blade step, and is indicated when the Step 1 pressure is higher than that obtained with Step 2. In that case the Step 1 pressure is ignored in the data interpretation.

22. Another behavioral mechanism that is prevented in the consolidation test by lateral confinement is shearing, referred to as a bearing capacity failure. Evidence for this is when the pressure on a thicker Blade step is lower than on the preceding thinner step, in which case the lower value rejected.

23. Only two data points are required to define a linear relationship, but three is better and four is best. Correlation coefficients obtained from 3 or 4 points should exceed 0.95 and usually will exceed 0.98.

24. Another test of viability of the data is the slope of the t-log P plot. Slopes either should be comparable to that of other tests in the same soil or they may indicate a change to a stiffer or softer soil.

25. Many data points are obtained in a short amount of time, which often allows a statistical evaluation and can give credence to the test results. Generally there will be sufficient time to plot and perform a preliminary analysis of the data while the boring is being advanced.

26. Data the meet the requirements for acceptability still can be erratic because of the high sensitivity of lateral stress to minor changes. For example, abnormally high readings are obtained if the Blade happens to be close to rigid inclusions such as stones or roots. Anomalously low readings are obtained if the Blade is close to a large void such as an open root channel or animal burrow. Such points normally are included on data plots and may be labeled with question marks.

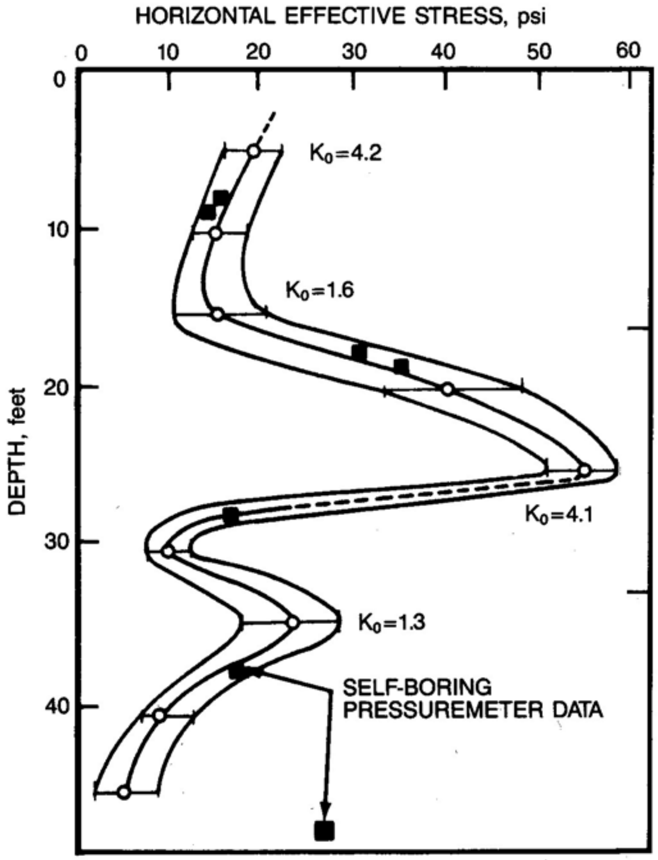
G. A test sequence to reduce influence of pore pressure

27. The sequence of cell readings in Paragraph 18 means that all first readings made after each increment of pushing are at the same depth, as are all second readings and subsequent readings. In this way approximately the same consolidation time is allowed at each position. Horizontal drainage ordinarily is rapid, but if there is remnant pore water pressure it also extrapolates out on the hypothetical zero Blade thickness.

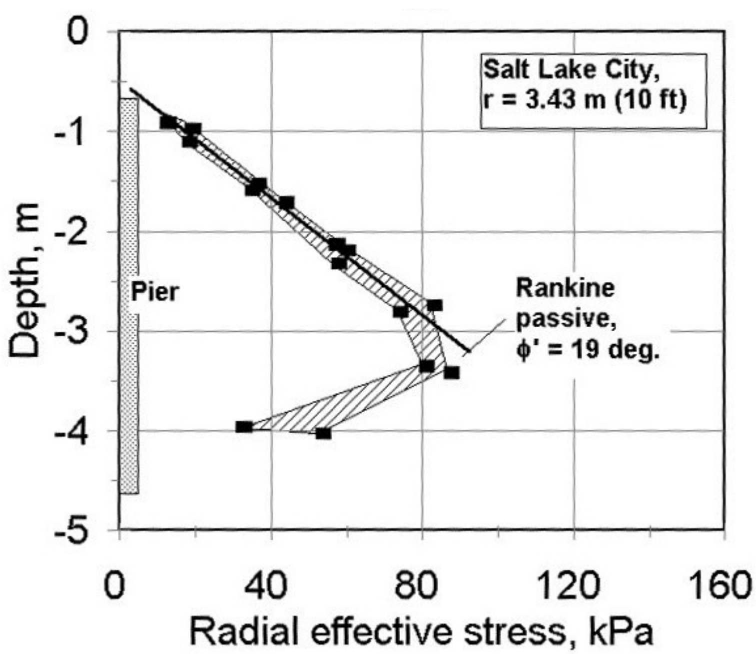
H. Soil characterization.

28. Lateral stress often is highly variable, so data plotted versus depth may appear to be quite scattered. An aid to visualizing the trends is to enclose all data in a shaded area, omitting data points with question marks.

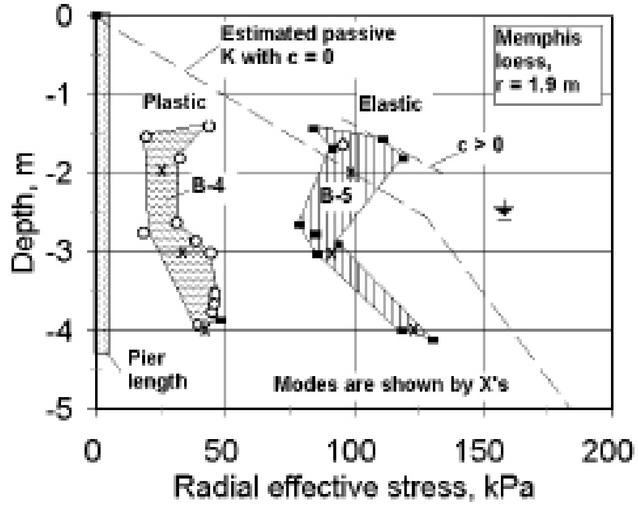
29. A series of tests performed in a saturated silt soil that had been displaced and was in a passive state indicates that data variability is more a function of the soil than of the instrument.



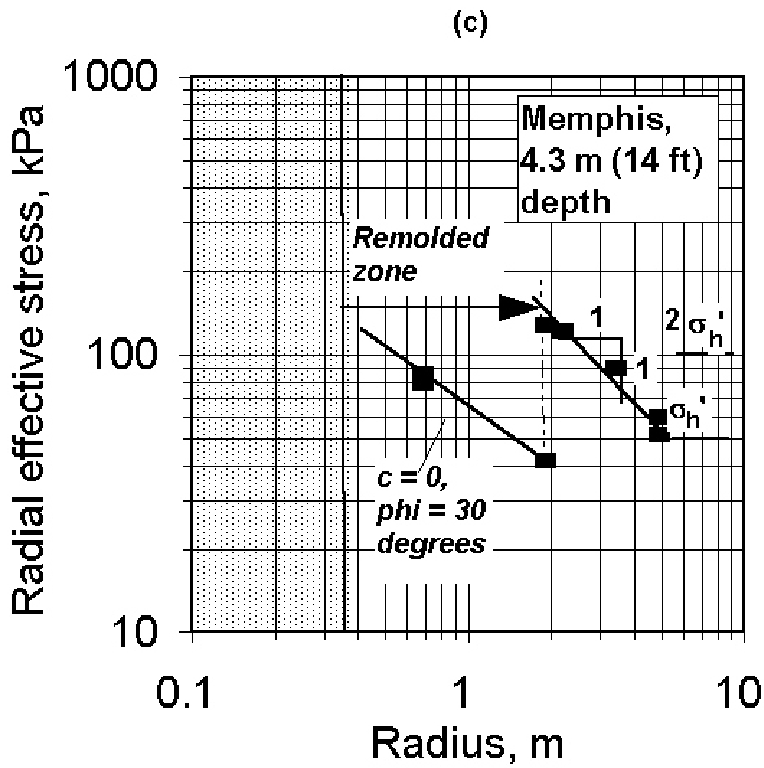
Close agreement with Self-Boring Pressuremeter results, Houston expansive clay. Handy et al., ASCE JGE. Ranges are 95% confidence intervals calculated from the Blade data..



Shaded area encloses all data, which shows a test precision of ± 5%.



Typical data spreads in uniform soil, at a boundary between plastic remolded and elastic stress near a Rammed Aggregate Pier ™.



Stress zones inferred from averaged Stepped Blade data near a Rammed Aggregate Pier. Stress in the elastic zone exceeds two times the pre-existing field stress, indicating radial tension cracking. Unpublished data, Handy and White.

I. Further precautions

30. The Console toggle valves are coupled and release all gas pressure to cells in the Blade. The normal position of the toggle valves is Open, with both valve levers pointing up. Inadvertent closing of the valves can blow an unsupported diaphragm off of the Blade.

31. The two rotating selector valves of the Console both must be turned to the same number that corresponds to the number of the pressure cell being read. A failure to synchronize the two valves will prevent cell operation and will damage the cells.

32. The console needle valves will seldom need resetting. As these are very sensitive microvalves, they must not be overtightened. Neither valve is used as a cutoff, so there no need to fully close either.

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33. Sometimes in soft soils the “break” of differential pressure is less pronounced because of plastic soil behavior. In this case the pressure is read as soon as the differential pressure starts to decrease.

34. **The system will have a continuous slow leak so long as it is pressurized.** The leakage rate is the same regardless of whether a reading is being made or the length of the pressure lines. To shut the system down and save gas, shut off the gas source at the gas bottle.

34. Unlike the Dilatometer or cone, the Blade cannot and must not be pushed continuously. Even with the reinforcing rib the Blade is so long that continuous pushing inevitably will cause it to bend or break. In one case after continuous pushing the Blade was folded into segments like an accordion. The machining required to make a Stepped Blade is precise and considerable, and the instrument should be handled appropriately.

J. Repairs and modifications

35. Replacing pressure cells. A Teflon membrane is much less susceptible to damage than a thin metal covering, which develops pinholes as soil grains rotate and punch into the metal. Nevertheless cell damage can be expected, and extra cells are included to allow rapid replacement in the field. A clean, level workplace is required, and a damaged cell is removed by unscrewing 6 small screws from the back of the Blade. *These are special screws that are specific to the Blade step.* The cell is connected at the back by tiny O-rings, and is lifted out and set aside. The replacement cell then is pushed in, the screws are replaced, and the Blade is ready for further testing.

36. Repairing pressure cells. After a cell is removed from the Blade it is easily repaired by removing 6 screws, lifting off the outer ring, and lifting off and replacing the

Teflon membrane. The rubberized diaphragm under the Teflon also should be replaced if it appears to be damaged. From the outside in the sequence is:

(1) Outer stainless steel ring,
(2) thin rubberized washer,
(3) pre-shaped 0.005-in. Teflon membrane,
(4) rubberized diaphragm,
(5) perforated brass disks,
(6) brass cell back.

37. Checking pressure cells. A plastic block and two clamps are included to enable pressure testing of cells while they are installed on the Blade.   The block is clamped over the cell, a known pressure is applied, and the pressure is read using the Console. Pressures should be within 1 psi. All cells are tested and required to meet this specificatin.

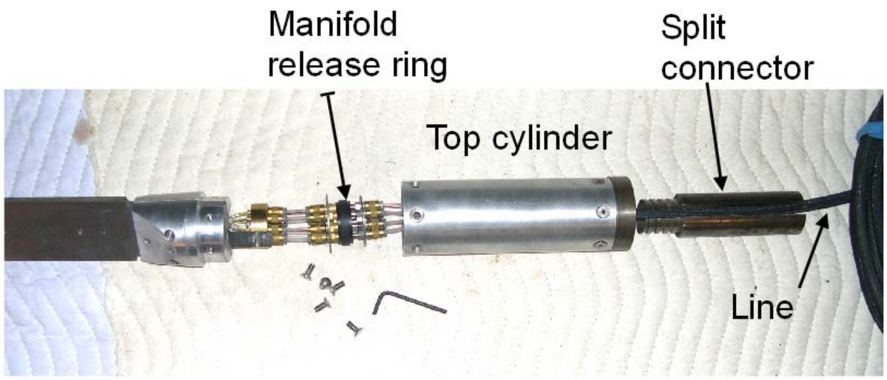
A Borehole Shear Test console may be used to apply a reference pressure. However, as the gauge is calibrated to read soil pressures, the individual calibration sheet included with the BST should be consulted to obtain corresponding gauge pressures is psi. It should not be necessary to recalibrate a cell that is replaced or rebuilt.

38. Removing pressure lines and cleaning the Blade. The standard pressure line length is 75 ft ((22 m). After testing is completed, soil can be flushed from the inner parts of the Blade head by removing the aluminum top cylinder and steel cap as shown in the photo, and sliding them up the line. The connector and lines then may be flushed and cleaned. The hollow U-shaped reinforcing rib optionally may be removed from the back of the Blade for cleaning.

In order to disconnect the lines from the Blade, slide the top cylinder and cap up the lines as discussed above in order to expose the manifold connector. The connector is unlocked by pulling out on the large release ring while pulling on the connector.

If the lines are changed, for example to shorter lines, the connector is unplugges as described above and the aluminum top cap of the Blade is removed. Each line then is removed, individually brought around the top cap, and replaced at the same position in the manifold connector. This procedure is repeated with each line in order to prevent a mixup. *If lines are incorrectly connected, the Blade will be inoperative and cells will be blown open.* If a mixup is suspected, it can be checked by blowing into individual lines at the opposite connector and being certain that they attach to the same positions on the Blade connector.

Plugging the manifold back together will require some jiggling to align the individual fittings.



L. **Uses of the Stepped Blade to solve practical problems.**

38. An important use of Stepped Blade data is to decipher the latest stages in a soil stress history as they leave their record in lateral stress.

For example, Blade data identify expansive clays from high lateral stresses and overconsolidation ratios. Conversely, low stresses and underconsolidation identify collapsible loess soils. In collapsible soil that has been saturated, $K_o = 1$, which also is a further confirmation of accuracy of the test.

A linear plot of lateral stress versus depth can be extrapolated upward to zero stress, which translates into an equivalent thickness overburden or surcharge that has been removed by excavation or erosion.

Because of the sensitivity of lateral stress to compaction, Stepped Blade data indicate uniformity of soil compaction, and can identify localized compaction under wheel tracks.

Lateral stress data are essential to understanding of skin friction on piles and piers. Stepped Blade data and have been used to diagnose a plunging failure, as the major principal stress rotated and increased as the pier was loaded until it exceeded the soil compressive strength, such that yielding suddenly relieved the lateral stress and allowed a plunging failure.

Reprints are available that describe these and other applications.

M. Stepped Blade and research.

39. Historically when a new test is devised that uniquely fits a need, it can open new avenues for research.

For example, recent tests in Memphis indicate a zone of temporary liquefaction in saturated soil close to Rammed Aggregate Piers™. Liquefaction efficiently transfers stress outward until halted by drainage through radial tension cracks in the surrounding elastic zone, indicated by the relationship between radial stress and distance. The stress data also indicate that the cracks are invaded and propped open by liquefied soil. Radial cracking previously has been suggested based on rapid dissipation of pore water pressures close to driven pile, but has not previously been demonstrated with stress measurements. Similarly, liquefaction has been suspected by not previously identified.

Slope stability has been shown to be statically indeterminate, that is there are more variables than measured parameters because lateral stresses are not known and must be guessed at. These stresses now can be measured, and a buildup of passive pressure in the toe area should forecast a landslide. Slope stability analysis usually assumes that an entire slope fails simultaneously, whereas most failures are progressive, starting at the bottom and working headward as passive resistance is decreased by remolding under the sliding soil starting at the toe.

Similarly, the many conflicting bearing capacity theories are based on lateral passive pressures that have not been measured.

The deficiencies of soil mechanics to solve these and other problems has led to the use of finite element modeling, which requires the use of appropriate constitutive equations that can become quite complex if they take into account nonlinear behavior and strain softening. The models provide valuable insight, but the ultimate test is the soil itself.

APPENDIX

SUGGESTED LAYOUT OF DATA SHEET

AND

SAMPLE DATA SHEET

BLADE TEST NO.______DATE__________TESTED BY_____________________

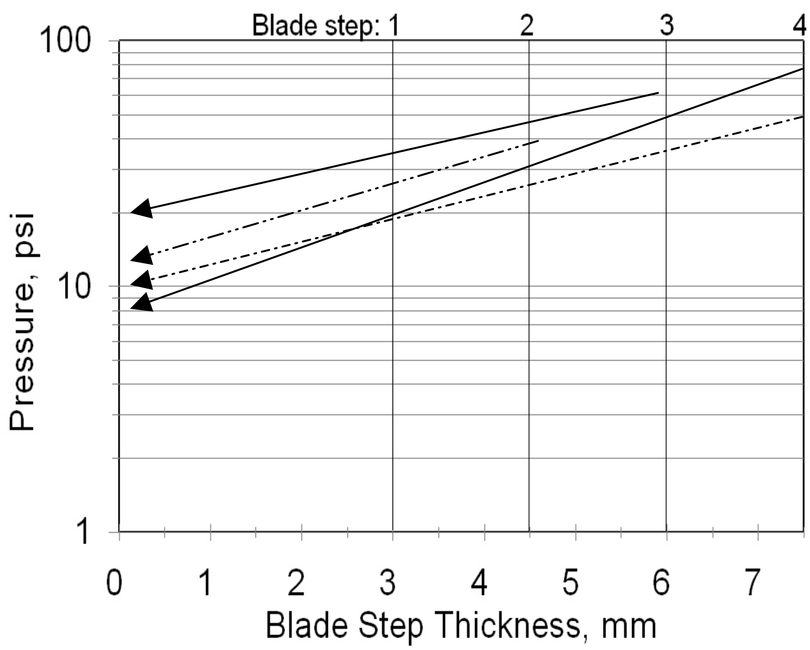
LOCATION_______________________BORING NO._______________________

SOIL TYPE/COMMENTS____

SOIL UNIT WEIGHT_______________DEPTH OF GWT_____________________

DEPTH TO BOTTOM OF BORING________________FT x 0.3048 = _________m,

Depth (Reading):	1	2	3	4	
+0.05m	(cell 1)	…………………………………………………			
+0.15m	(cell 2)	(cell 1)……………………………………			
+0.25m	(cell 3)	(cell 2)	(cell 1)……………………		
+0.35m	(cell 4)	(cell 3)	(cell 2)	(cell 1)	
+0.45m……………………		(cell 4)	(cell 3)	(cell 2)	(cell 1)
Plot symbol	O	⊗	Δ	□	∇
R^2	_______	_______	_______	xxxxx	xxxxx



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Depth (Reading):	1	2	3	4	
+0.05m	______				
+0.15m	______	______			
+0.25m	______	______	______		
+0.35m	______	______	______	______	
+0.45m	xxxxxx	______	______	______	______
Plot symbol	O	⊕	Δ	□	∇
R^2	______	______	______	xxxxx	xxxxx