APPENDIX A

PRESSUREMETER TEST INTERPRETATION

PRESSUREMETER TEST INTERPRETATION

Description of test

The pressuremeter test, discussed in great detail by Martin (1977), Baguelin et al. (1978), Barksdale et al. (1982), and Gambin and Rousseau (1988), is performed by applying pressure to the sidewalls of a borehole. Figure A-1 shows a schematic of the pressuremeter test setup. The pressuremeter consists of two parts, the read-out unit, which rests on the ground surface, and the probe that is inserted into the borehole. The probe consists of three independent cells, a measuring cell and two guard cells. The probe can be installed by pre-drilling a hole using hollow stem auger or hand auger, or forcing the probe into the ground and displacing the soil by driving, jacking, or vibrating. Self-boring probes have been used for research. Once the probe is at the test depth, the guard cells are inflated to brace the probe in place. Then the measuring cell is pressurized with water, inflating its flexible rubber bladder, which exerts a pressure on the borehole wall. As the pressure in the measuring cell increases, the borehole walls deform. The pressure within the measuring cell is held constant for approximately 60 seconds, and the increase in volume required to maintain the constant pressure is recorded. A load-deformation diagram, as shown in Figure A-2, is recorded for each test run.

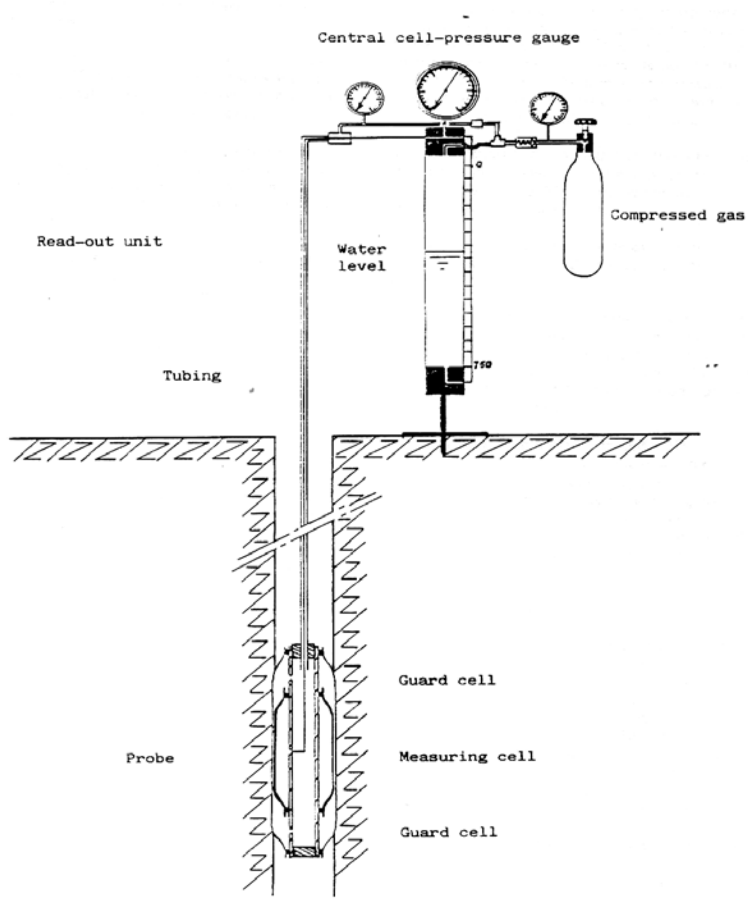

Figure A-1. Schematic of a pressuremeter test in a borehole (from Gambin and Rousseau, 1988).

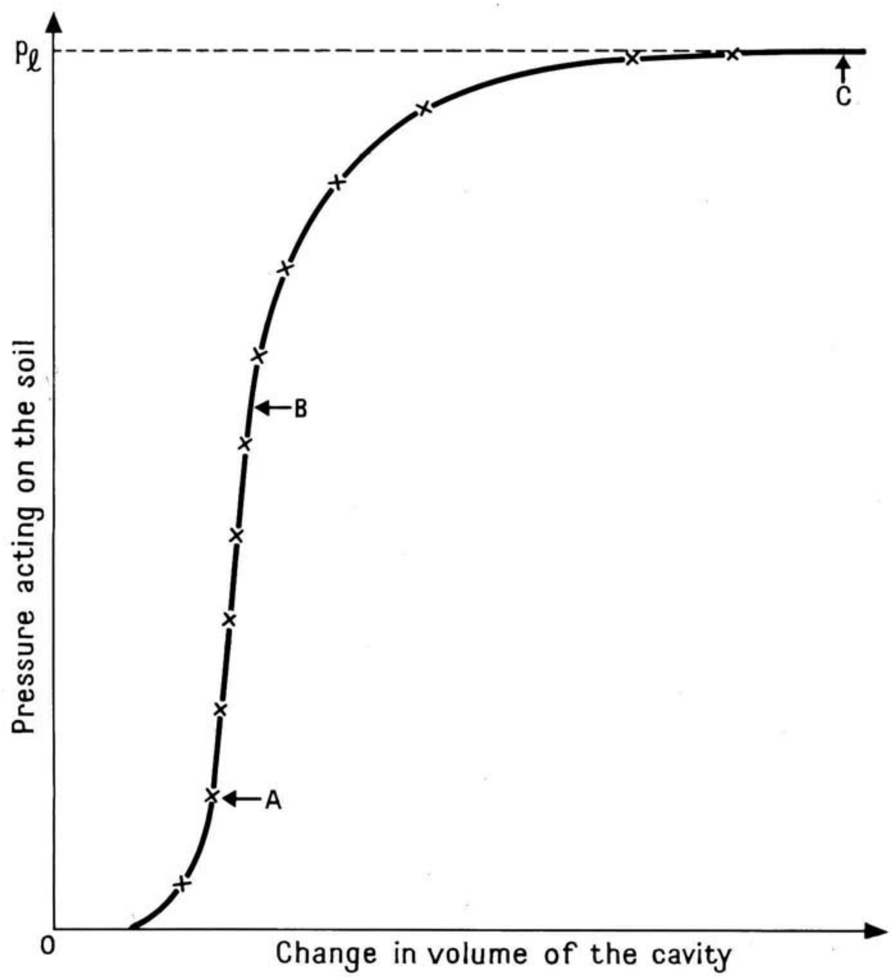

Figure A-2. Example pressuremeter test results (from Baguelin et al., 1978).

Interpretation of test results
There are three phases of the deformation curve: (1) the re-establishing phase, from the origin to point A; (2) the pseudo-elastic phase, from point A to point B; and (3) the plastic phase, from point B to point C.

After the borehole is drilled and the augers are withdrawn, the borehole walls relax, thus reducing the cavity volume. As the pressuremeter probe is initially inflated, the walls of the borehole are pushed back to their original position. Point A marks the point at which the volume of the borehole cavity has fully returned to its initial position, and is given the coordinates, v_0, p_0. The pseudo-elastic phase, the straight-line portion of the curve between points A and B, is dubbed so because of its resemblance to the elastic behavior of steel or concrete. Point B is the point at which creep pressure has been reached, and is given the coordinates, v_f, p_f. The plastic phase begins at point B and extends to point C, which is asymptotic to the limit pressure. Point C, which is given the coordinates v_L, p_L, is defined as the point where the pressure remains constant despite increasing volume.

The limit pressure is defined as the pressure required to expand the measuring cell by an amount v_o beyond the volume required to inflate the pressuremeter (V_C) and to push the borehole wall back to its original position (v_o). This definition of limit pressure is analogous to defining failure in a triaxial test at a given value of axial strain, for example 10% to 15%. The value of V_C depends on the size of the borehole, as shown in Table A-1. The injected volume at the limit pressure (v_L) is thus:

$$v_L = v_0 + V_C + v_0 = 2v_0 + V_C \qquad \textit{(eq. A-1)}$$

where: v_0 = volume required to inflate pressuremeter and push soil to its original position; and
V_C = initial volume of the measuring cell (see Table A-1).

Table A-1. Values of V_C according to pressuremeter probe type (from Gambin and Rousseau, 1988).

Probe	**Diameter of Borehole (mm)**	**V_C (cm^3)**
EX	34	535
AX	44	535
BX	60	535
NX	76	790

If the volumetric increase at the end of the test is less than twice the cavity volume, extrapolation must be used to determine p_L. A plot of pressure versus log-volume for the plastic phase of a test results in an approximate straight line. The straight line can be extended to v_L to determine p_L. Figure A-3 demonstrates this extrapolation procedure.

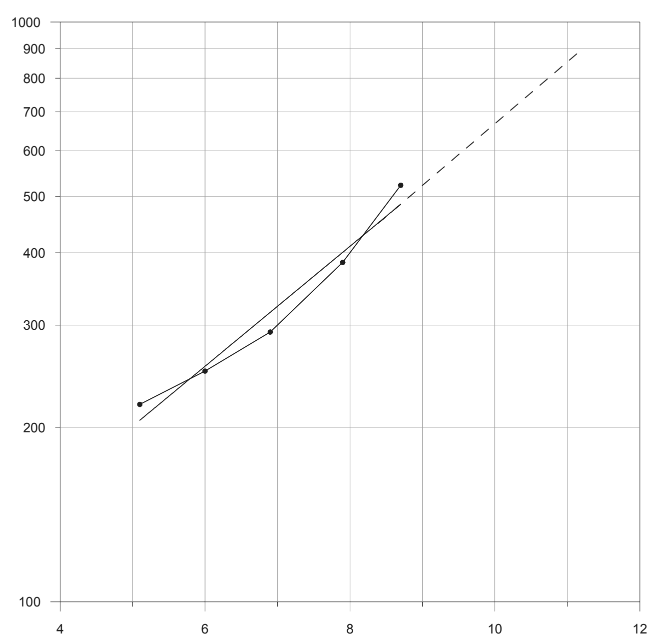

Figure A-3. Pressure vs. log volume plot for extrapolation of limit pressure at NCSU research site (from Wilson, 1988).

The "net limit pressure," p_L^*, is used in foundation design, and is calculated using equation A-2.

$$p_L^* = p_L - p_{ho} \qquad \textit{(eq. A-2)}$$

where: p_L = limit pressure; and
p_{ho} = initial total horizontal pressure in the ground.
$= [(\gamma\text{-u})z\,]\,K_o + u$

Although p_{ho} should equal the pressure corresponding to v_o (i.e. value corresponding to p_o), it is difficult to accurately determine p_o from the test data due to disturbance of the borehole walls and a lack of points at the beginning of the test.

The pressuremeter can be used to aid in the design of foundations for all types of soils, including residual soils. The settlements of foundations can be estimated using a deformation modulus, E_{PMT}, which can be derived from the pseudo-elastic phase (or straight-line portion) of the load deformation diagram. E_{PMT} is a function of Poisson's ratio, the slope of the straight line, and the cavity volume in the pseudo-elastic range. However, the cavity volume increases throughout the pseudo-elastic range, so it is conventional to use the mean volume, v_m, of the cavity during this phase. The deformation modulus, E_{PMT}, can be found using equation A-3, and typical ranges of values for soil types are shown in Table A-2.

$$E_{PMT} = 2\,(1+\nu_s)V\frac{\Delta p}{\Delta v} \qquad \textit{(eq. A-3)}$$

where: ν_s = Poisson's ratio, typically = 0.33;
V = cavity volume during the pseudo-elastic phase = $V_C + v_m$;
V_o = initial or at-rest volume of the measuring cell (see Table A-1 for typical values);
v_m = the mean volume of the pseudo-elastic phase
$= (v_f + v_0)/2$; and
$\Delta p/\Delta v$ = slope of the pseudo-elastic phase.

Example calculation
A pressuremeter test was conducted at the North Carolina State University Research site, in Wake County, North Carolina (Wilson, 1988). Figure A-4 shows the deformation curve from the test conducted in boring BT-2 at a depth of 12-14 feet using a BX probe.

<u>Calculate the limit pressure</u>

Using equation A-1 and Figures A-3 and A-4, p_L can be calculated as follows:

- Determine the value of V_C.
  Using Table A-1 for a BX probe, $V_C = 535\text{cm}^3$.

Table A-2. Range of E_{PMT} and p_L for several soil types (from Gambin and Rousseau, 1988).

Soil Type	**E_{PMT} (bars)**	**p_L (bars)**
Mud, Peat	2 – 15	0.2 – 1.5
Soft clay	5 – 30	0.5 - 3
Medium clay	30 – 80	3 – 8
Stiff clay	80 – 400	6 - 20
Marl	50 – 600	6 - 40
Loose silty sand	5 – 20	1 – 5
Silt	20 – 100	2 - 15
Sand and gravel	80 – 400	12 - 50
Sedimentary sands	75 – 400	10 - 50
Limestone	800 - 200,000	30 – over 100
Recent fill	5 – 50	0.5 – 3
Old fill	40 – 150	4 - 10

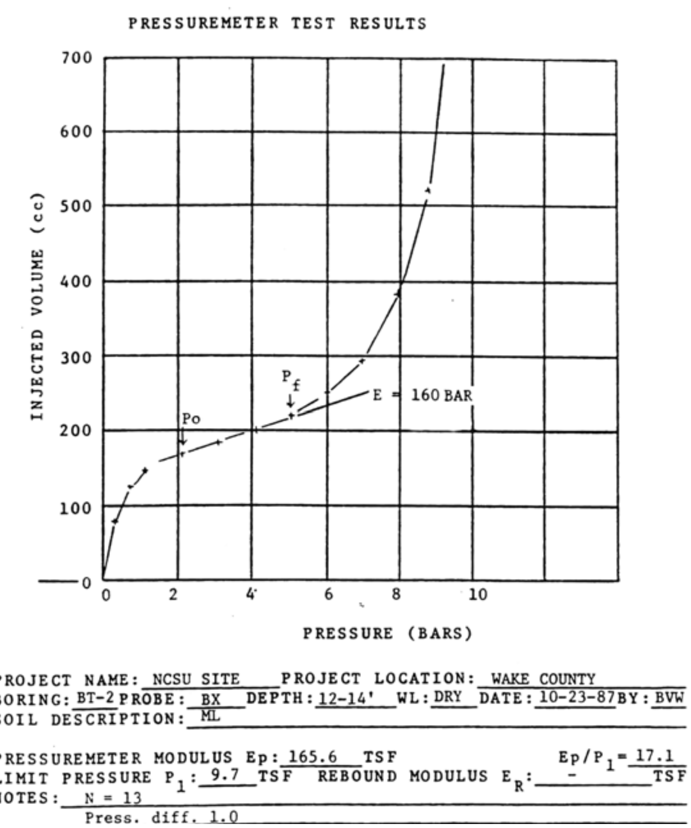

Figure A-4. Pressuremeter test results from NCSU research site (from Wilson, 1988).

- Determine the value of v_o.
  Looking at Figure A-4, the pseudo-elastic phase starts at v_o = 181cm^3.

- Calculate v_l.
  v_l = 535cm^3 + 2(180cm^3) = 895cm^3.

Because the pressuremeter test was not carried out to 895cm^3, p_L cannot be read directly from the Figure A-4. Pressure versus log volume for the plastic phase must be plotted in order to get an extrapolated value for p_L. The following points are within the plastic phase of the load deformation curve, and are plotted in Figure A-3:

Volume (cm^3)	Pressure (bars)
219	5.1
250	6.0
292	6.9
385	7.9
523	8.7

- Determine p_L.
  Using Figure A-3 with v_L = 895cm^3, p_L = **11.3 bars**.

Calculate the pressuremeter modulus:

Using equation A-3, Figure A-4, and V_C = 535cm^3 from the first part of this example, E_{PMT} can be calculated as follows:

- Determine the value of v_m.
  v_o = 180cm^3.
  v_f = 220cm^3.
  v_m = (220cm^3 + 180cm^3)/2 = 200cm^3.

- Calculate the value of V.
  V = 535cm^3 + 200cm^3 = 735cm^3.

- Determine the value of $\Delta p/\Delta v$.
  Using Figure A-4 and the limits of the pseudo-elastic phase:
  Δp = 5.1bars - 2.1bars = 3.0 bars.
  Δv = 220cm^3 - 180cm^3 = 40cm^3.

- Calculate E_{PMT}.
  Using equation A-3:
  E_{PMT} = 2(1+0.33) (735cm^3) (3.0 bars / 40cm^3) = **147 bars**.