RTH 362-89

PRESSUREMETER TESTS IN SOFT ROCK

1. Scope

The pressuremeter test consists of lowering an inflatable cylindrical probe into a predrilled borehole, expanding the probe laterally against the borehole wall, and recording the increase in size of the probe and associated pressure within the probe. This method covers the procedure for testing in soft rocks.

2. Principle of the Method

The pressuremeter probe is placed in the ground by lowering it into a predrilled hole. Once the probe is placed at the desired depth, the pressure in the probe is increased in equal increments and the associated increase on probe volume is recorded. The test is terminated if yielding in the rock becomes large. This procedure is repeated at the desired depth intervals but not closer than the length of the probe to the previously tested zone. A pressure-volume curve is plotted and a pressuremeter modulus is calculated.

3. Apparatus

3.1 The pressuremeter consists of two basic components: the probe and the pressure regulator-volumeter. Various sizes of probes are available to accommodate different borehole diameters. The probe consists of a light, flexible inner sheath and heavy, durable outer sheath, as shown schematically in Fig. 1. The inner sheath is pressurized with a liquid (water) through ports in the brass cylinder. The outer sheath is pressurized with a gas (normally dry nitrogen) through ports at each end of the cylinder. During testing, the outer sheath is kept at a pressure slightly less than that within the inner sheath. Normally, a pressure differential of 30 to 45 psi is maintained between sheaths since differences greater than 45 psi could possibly cause a rupture of the inner sheath. The bursting strength of the outer sheath depends on the deformability of the material being tested, but pressures in the range of 1000 to 1500 psi can often be obtained unless the surrounding medium has deformed excessively.

3.2 The purpose of the double-sheath arrangement is to simulate plane strain conditions. All volume change measurements are made within the inner sheath, although pressure is distributed along the entire length of the outer sheath; thus, end effects are greatly reduced.

3.3 The probe pressure is controlled by the pressure regulator-volumeter. The change of volume of the probe caused by the applied probe pressure is also monitored by this device. The probe is connected to the pressure regulator-volumeter by means of a coaxial tube, the inner tube being filled with liquid and the outer tube with gas.

4. Calibration

4.1 The probe must be calibrated to correct for its compressibility and inertia (Fig. 2). The compressibility of the sheaths, the fluid, and the coaxial tubing is determined by placing the probe into a rigid container, such as a pipe, and measuring the pressure-volumeter relationship. During a field test, the volume increase caused by the compressibility (V_p) of the probe system is deducted from that recorded by the volumeter at the corresponding field test pressure.

4.2 The inertia of the system is determined by inflating the instrument with no confining pressure and again determining the pressure-volume relationship. The pressure (P_p) required to inflate the probe to a given volume under no confinement can then be deducted from the (field) recorded pressure (plus pressure due to the head of water), which results in the true pressure exerted on the borehole wall during a field test.

4.3 Corrections for temperature changes and head losses due to circulating fluid are usually small and may be disregarded in routine tests.

4.4 Hydrostatic pressure (P_γ) existing in the probe due to the column of fluid in the testing equipment must be determined before each test. This is accomplished by measuring the test depth (H) and multiplying the unit weight of the test fluid by the distance from the probe to the pressure gauge. This pressure must be added to the pressure readings obtained on the readout device.

5. Procedure

5.1 Drilling of the borehole must be performed in such a manner as to cause the least possible disturbance to the walls of the borehole and produce an adequate hole diameter for testing. The hole is advanced to the test level and cleaned of any debris or cuttings.

5.2 With the probe still at the surface, the fluid circuit valve open, and without applying pressure, an accurate setting of the zero volume reading (V_o) is accomplished by adjusting the water level in the instrument to zero. The volume circuit is then closed to prevent any further change in the volume of the measuring circuit. The probe is lowered to the test depth in this condition. Failure to close the valve will result in probe expansion as it is lowered into the hole. The test depth is determined as the depth to the midpoint of the probe.

5.3 Once the probe is positioned, the volume circuit is opened and the probe allowed to equalize under the hydrostatic head. Since the probe and inner coaxial tube are initially water-filled, a pressure equal to the head of water is exerted on the borehole walls at the beginning of each test. During loading, the pressure is increased in approximately 30-psi increments by controlling the pressure regulator valve. Volume measurements are recorded at lapsed times of 15, 30, and 60 sec after each pressure increase. The 60-sec readings are used for the modulus calculations. Typically, relatively large volume changes occur at low pressures as the probe is seated against the borehole wall; thus, the test usually indicates hardening response until the seating pressure p_o is reached (Fig. 3). This is followed by an essentially linear response range up to some pressure p_e. Above p_e, the curve again becomes nonlinear, but softening, as the material around the borehole begins to fail.

5.4 Once the maximum loading has been reached, or upon reaching the maximum expanded volume of the probe, the test is terminated; the probe is deflated to its original volume and withdrawn or repositioned in the hole at the next test depth. Cyclic testing may be performed when required by alternately inflating and deflating the probe.

6. Calculation

6.1 Calculate the pressure transmitted to the rock by the probe from the pressure readings as follows:

$$P = P_g + P_\gamma - P_p$$

where

P = pressure exerted by the probe on the rock (psi)

P_g = pressure reading on control unit (psi)

P_γ = hydrostatic pressure between control unit and probe (psi)

P_p = pressure correction due to inertia of instrument (psi)

For determination of P_p see paragraph 4.2. The pressure P_γ shall be the hydrostatic pressure as follows:

$$P = H \times \gamma_t$$

where

H = vertical distance from probe to pressure gauge (ft)

γ_t = unit weight of measuring fluid in instrument (lb/ft^3)

6.2 Calculate the increase in volume of the probe from the volume readings. The corrected increase in volume of the probe is calculated as follows:

$$V = V_R - V_P$$

V = Corrected volume increase of probe (cm^3)

V_R = Volume reading on readout device (cm^3)

V_p = Volume correction (cm^3)

The volume correction, V_p, shall be determined as outlined in paragraph 4.1.

6.3 Plot the pressure-volume increase curve by entering the corrected volume of the ordinate and the corrected pressure on the abscissa. Connect the points by a smooth curve. This curve is the corrected pressuremeter test curve and is used in the determination of the test results (Fig. 3).

7. Modulus Interpretations

If it is assumed that the material surrounding the pressuremeter probe behaves in a linear elastic manner and that the theory of thick-walled cylinders is applicable, then the applied internal pressure increment p and tangential and radial stress increments $\Delta\sigma_\theta$ and $\Delta\sigma_r$, respectively, are related by

$$-\Delta\sigma_\theta = \Delta\sigma_r = \Delta p$$

for compression positive. The volumetric strain $\Delta v/v$ of a unit length of the borehole probe may be related to the radial strain ε_r in the material by

$$\frac{\Delta v}{v} = \frac{\pi(r + \Delta r)^2 - \pi r^2}{\pi r^2} \approx \frac{2\Delta r}{r} \approx 2\varepsilon_r$$

where v is the average total volume per unit length of the deformed borehole. From Hooke's law

$$\varepsilon_r = \frac{1}{E}(\sigma_r - \nu\sigma_\theta)$$

where ν is Poisson's ratio and E is Young's modulus. Thus

$$E = \frac{v\Delta p}{\Delta v} 2(1 + \nu)$$

or

$$G = \frac{E}{2(1 + \nu)} = \frac{v\Delta p}{\Delta v}$$

The above equations may be used to interpret the Young's modulus, E, from the pressuremeter tests only if Poisson's ratio is independently determined or assumed. The last equation indicates that the pressuremeter results can be used as a direct measure of shear modulus, G.

8. Limitations

The accuracy of the pressuremeter test is dependent in part upon the stiffness of the material being tested. For stiffer materials, the determination of the instrument compressibility (e.g., apparent change in volume per unit pressure when the probe is completely restrained from external volume change) is important since an increasing proportion of the measured volume response results from the instrument and not the material. The effect of any uncertainties in the instrument stiffness S_I of the pressuremeter (S_I is the reciprocal of the compressibility) on the predicted shear modulus is shown on Fig. 4. As seen in the figure, shear modulus calculations for materials in which the ratio of the instrument stiffness to shear modulus (S_I/G) is small will be less accurate than when the ratio is large, if the instrument compressibility at the time of the test is not accurately known.

9. Report

For each pressuremeter test a data form similar to Fig 5 shall be used.

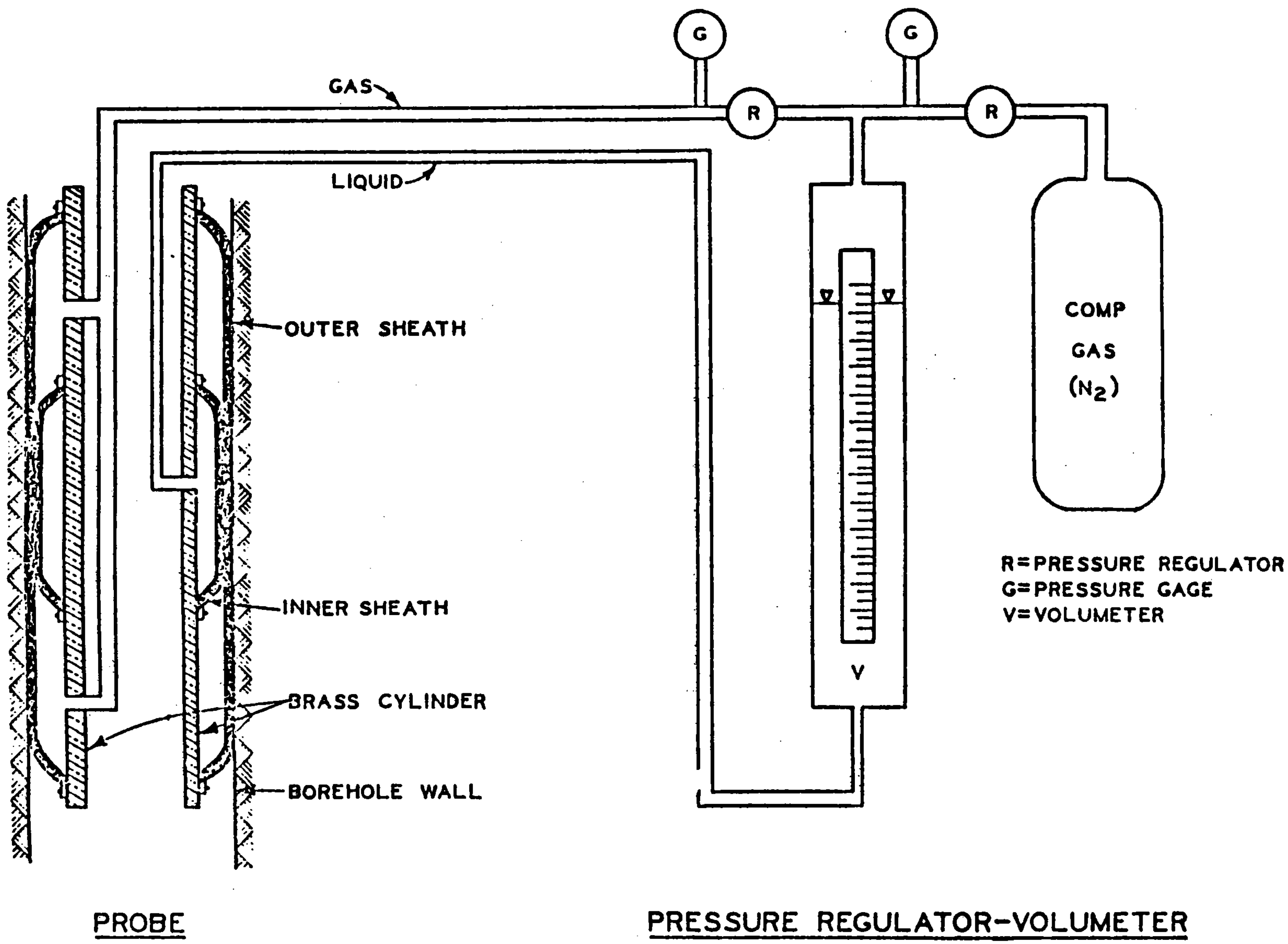

Fig. 1. Pressuremeter Schematic

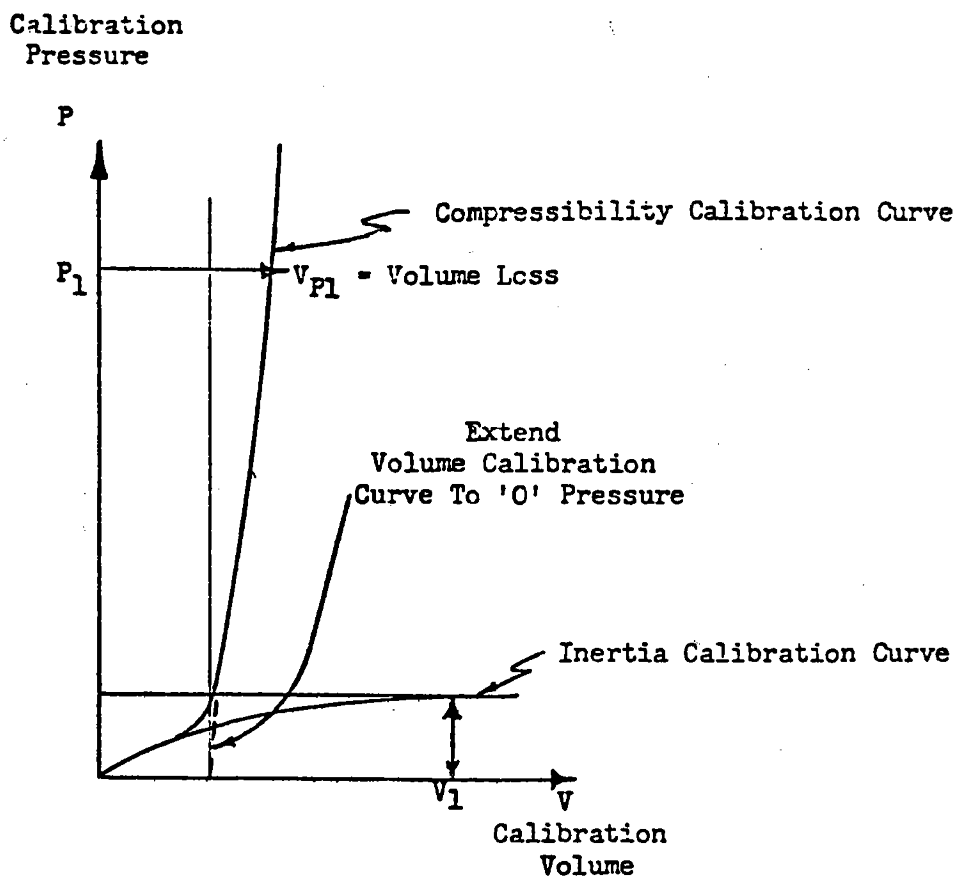

Figure 2. Calibration for Volume & Pressure Corrections.

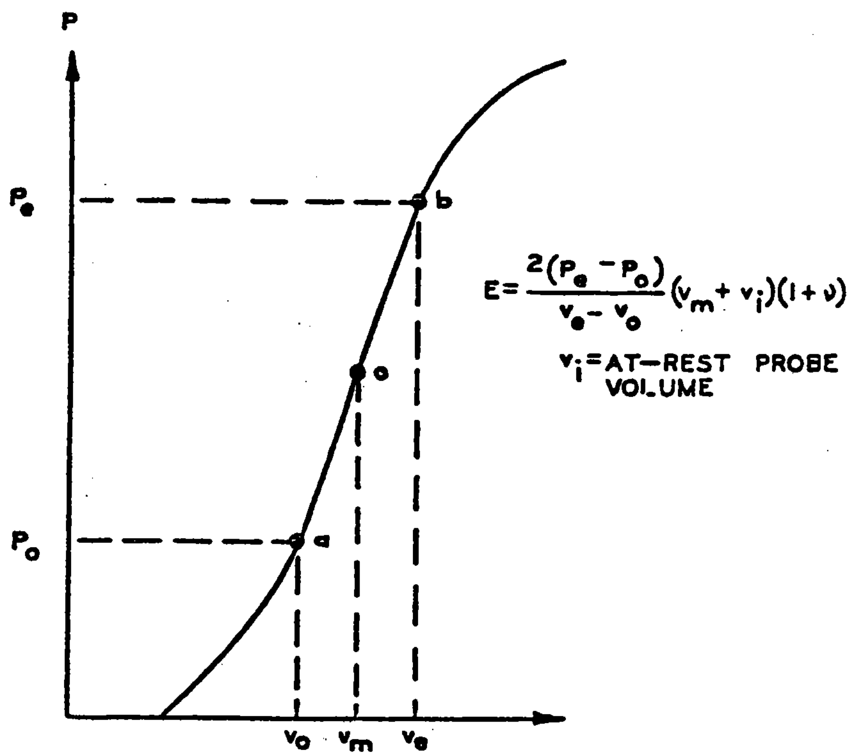

Fig. 3 Idealized pressure-volume relationship

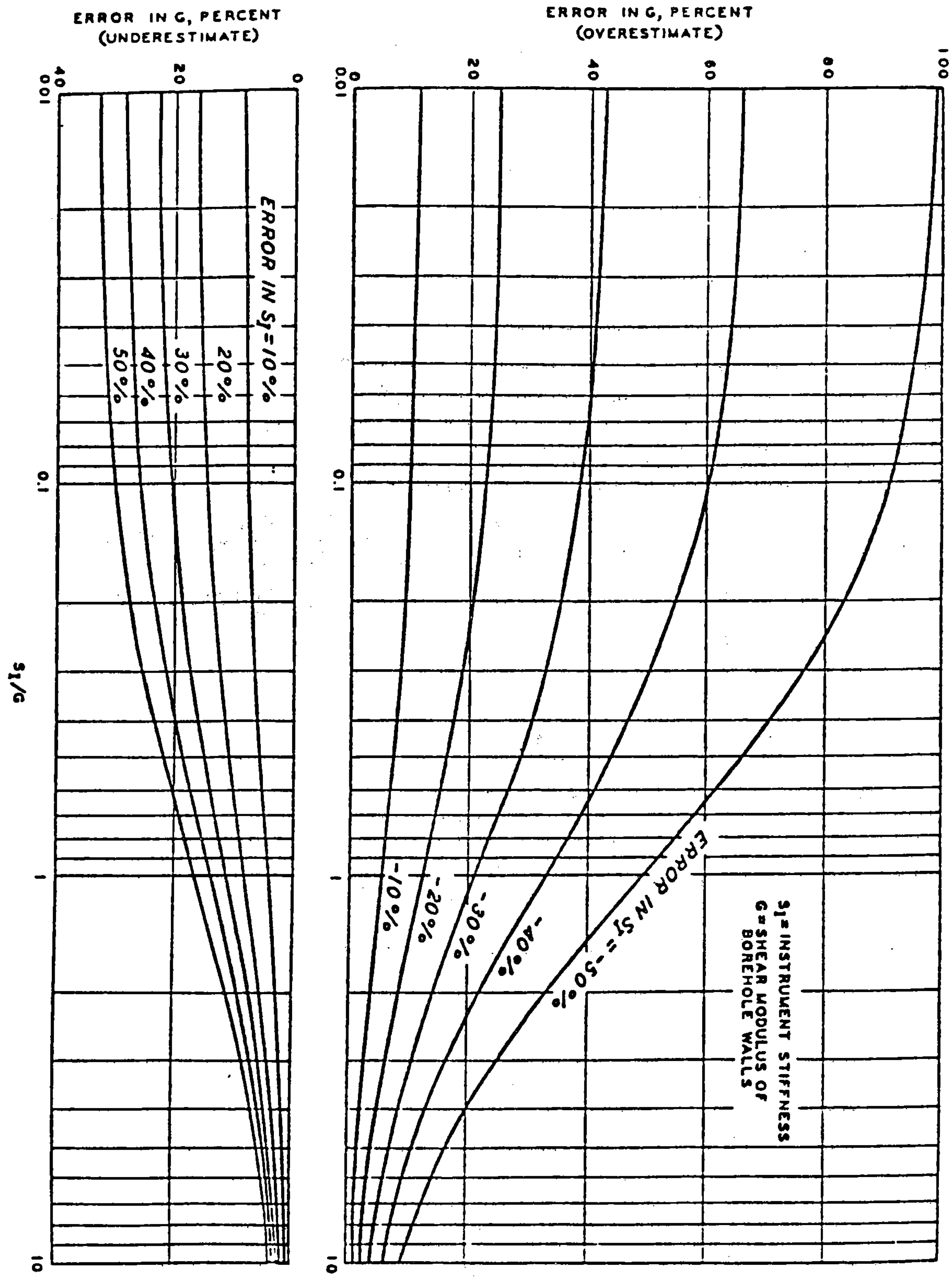

Fig. 4 Uncertainty in predicted shear modulus versus instrument stiffness

RTH 362-89

SITE	DATE	BORING NO.	DEPTH	OPERATOR	PAGE ___ of ___
PROBE SIZE & TYPE	REMARKS				

TIME	LOAD PSI	VOLUME - CM^3			CREEP (30-60) SEC	DIFF (60 SEC)	REMARKS
		15 SEC	30 SEC	60 SEC			

Fig 5: Data Sheet