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The Pressuremeter Test- an Overview

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ABSTRACT
A Pressuremeter test is an in situ stress-strain test performed on the wall of a borehole using a cylindrical probe that is expanded radially. This test is performed by drilling the borehole or using a self-boring Pressuremeter. The test is conducted by inserting the probe into the bore hole and inflating the test probe in the bore hole so that it apply the pressure on the bore hole walls and deformations take place. The change in volume of cavity/bore hole is measured. The probe is inflated by increasing in the pressure in probe and corresponding change in volume of bore hole measured in both granular and cohesive.
Since the inception of Pressuremeter, the Pressuremeter has consistently been improved in its design, and the latest version of the Pressuremeter, which is called the "auto-controlled Pressuremeter" has been developed to address the issues of repeatability and accumulation of errors in a test. This apparatus is fully automatic and autonomous, and manages all steps of the test as instructed by the operator. The auto-controlled Pressuremeter simplifies the work procedure for the operator, reinforces the reliability of the results, and reduces the time of set up.
The present paper describes the auto-controlled pressure meter, its various parts, methodology, interpretation of the test results and an in-situ test at for a hydroelectric project.

I. INTRODUCTION

Pressuremeter Test (PMT) is one of the geotechnical testing equipment which is used to determine the deformation modulus, limit pressure. According to Gambin (1990), PMT was first discovered by Kogler in 1930 but has not been able to operate properly so that this technology was abandoned. Menard (1954) review the idea of Kloger and improved the working principle so that Pressuremeter became a popular tool in geotechnical investigations. The test is performed either in prebored bore hole or by using the self-boring Pressuremeter. The test is conducted in the borehole by inserting the probe and conducting Pressuremeter tests. This test is applicable for both granular and cohesive soils.

II. PRESSUREMETER TEST

Pressuremeter Test (PMT) is an in situ test to determine soil or rock characteristics. PMT utilizes a probe that is inserted into the borehole upto the test depth of the strata. The probe is a flexible membrane that can be blown and expanded to provide pressure on the borehole wall so the soil or rock will be deformed. The probe is lowered into the borehole to the required test depth and the pressure is applied by equal increments (10 nos.). Pressure and volume is observed from the control unit. The relationship curve of the pressure with lateral deformation of the soil is then used for the analysis of the test results of PMT.

III. THE EQUIPMENT

The apparatus shall consist of a probe that is lowered in the borehole and a measuring/controlling unit that is placed on the ground adjacent to the bore hole. The probe may be either the hydraulic type or the electric type depending upon the equipment used. The hydraulic probe may be of a single cell or triple cell design. In case of electric probe, Pressuremeter permits the transformation of the electrical energy into work pressure applied on the central water cell. The combined height of the measuring and guard cells shall be at least six diameters. The design of the probe shall be such that the drilling liquid may flow

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freely past the probe without disturbing the sides of the borehole during insertion or removal. For both systems, the nominal hole diameter shall not be more than 1.2 times the nominal probe diameter. Typical probe dimensions and corresponding borehole diameters are presented in Table 1.

TABLE 1 - Typical Probe and Borehole Dimensions (ASTM-4719-07)

Probe Designation	Probe Diameter, mm	Bore Diameter	
		Nominal, mm	Max., mm
Ax	44	45	53
Bx	58	60	70
Nx	74	76	89

3.1 THE PROBE

The flexible walls of the probe may consist of a single rubber membrane (single cell design) or of an inner rubber membrane fitted with an outer flexible sheath or cover (triple cell design) which will take up the shape of the borehole as pressure is applied. Figure 1 presents the picture of a typical three cell probe. In case of coarse-grained/weathered rock, a steel sheath made of thin overlapping metal strips is used to protect the rubber membrane.

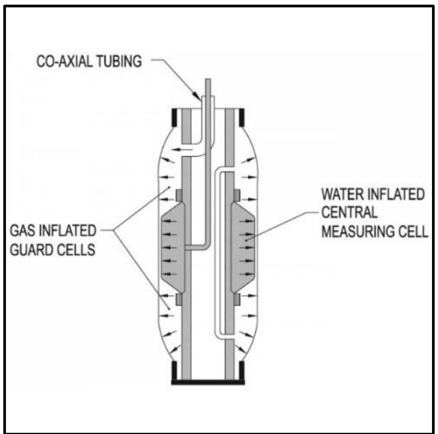

Figure 1: The Pressuremeter Probe

3.2 CONTROL UNIT/MEASURING DEVICES

The control unit is kept on the ground adjacent to the bore hole. The control unit includes a mechanism to apply pressure in equal increments or in equal volume increments to the probe and to measure the volume change or pressure change during the expansion of probe. The equipment which have hydraulic system and measuring cell and guard cells shall also include a regulator by which the pressure in the gas circuit is kept below the fluid pressure in the measuring cell. The magnitude of pressure difference between gas and fluid must be adjustable to compensate for hydrostatic pressures developing in the probe. In the electrical system the volume readings are substituted by an electrical readout on the diameter of the probe. The accuracy of the readout device shall be such that a change of 0.1 % in the probe diameter is measurable. Figure 2 presents the picture of control unit/measuring device.

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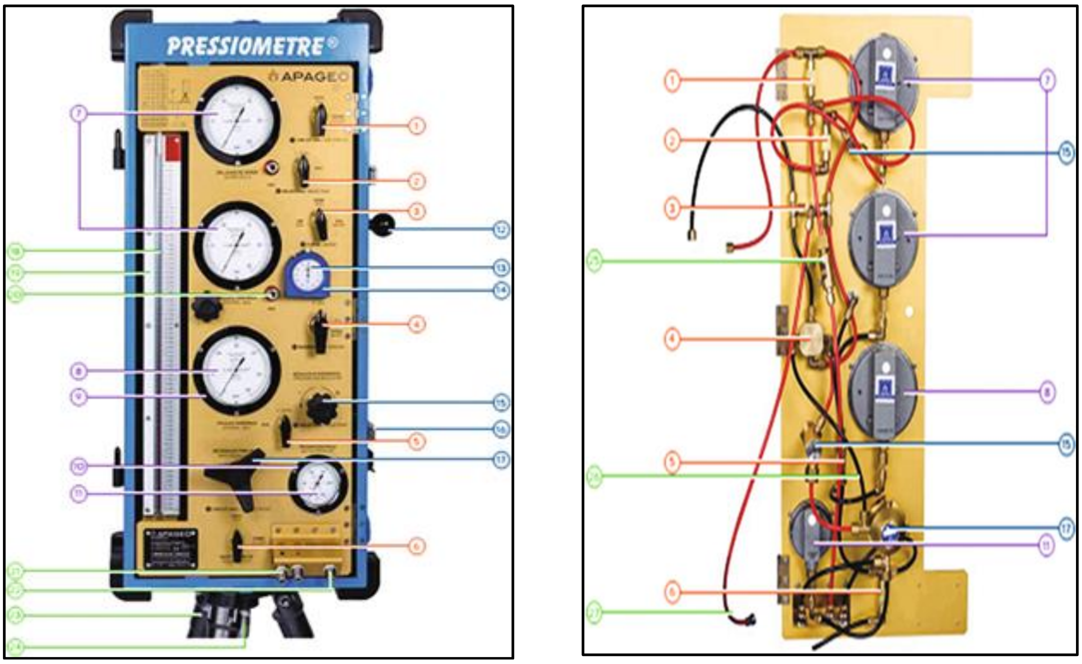

Figure 2: The Control Unit/Measuring Device

No.	Description	No.	Description
1	Gas circuit stop valve	15	Pressure Regulator
2	25/100 bar gas selection valve	16	Fixation of lid type 3
3	Bleed valve for both gas and water	17	Main pressure regulator
4	Inversion valve 0-10 m	18	Sight Tube Complete
5	25/100/60 bar water selection	19	Polycarbonate cover plate for sight tube
6	Water circuit stop valve	20	Quick female socket for extra gauge
7	0-25 bar gauge (vertical outlet)	21	Quick female socket for hose outlet(water & gas)
8	0-60 bar gauge (vertical outlet)	22	Quick female socket for nitrogen bottle inlet
9	Ø 100 gauge ring	23	Tripod
10	Ø 60 gauge ring	24	Stainless steel tripod axis
11	0-250 bar gauge (vertical outlet)	25	Filter housing complete
12	Ball fixation for Geobox[r]	26	Rilason tubing 3x6 pressuremeter inner black lead
13	Stop watch 1 minute	27	Rilason tubing 3x6 pressuremeter inner red lead
14	Protection case for stop watch		

3.3 WATER AND GAS LINES

Water and gas lines connects the probe with the control unit/ readout unit and consist of plastic tubing. In order to minimize the measuring errors, a coaxial tubing is used, whereby the inner tubing is prevented from expanding by a gas pressure at its perimeter. By applying the correct gas pressure, expansion of the inner tubing is reduced to a minimum. Single tubing can also be used. In both cases, volume loss correction is applied. Electric lines need special protection against groundwater.

IV. METHODOLOGY

To conduct the Pressuremeter test, a bore hole is drilled up to the test level or self-boring Pressuremeter is used to reach up to the test level in to the ground. The preparation of a satisfactory borehole is the most important step for a Pressuremeter test. Normally a casing is provide in the bore hole up which extends just above the test length to prevent the collapse of the bore hole (sandy/gravelly soil) or squeezing the bore hole(clayey soil) . The methods used for drilling the bore holes, should have minimum degrees of disturbance to the side of bore holes. The methods to be used for drilling the bore holes depends upon

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the soil at site. When testing in soils, the Pressuremeter tests must be performed immediately after the hole is formed.

The pressuremeter test basically consists of placing an inflatable cylindrical probe in a predrilled hole and expanding this probe in equal pressure increments and measuring the corresponding changes in volume of probe till the limit pressure is reached or the cavity volume has doubled. The volume change is observed after 30 sec and 60 sec. . The probe may inflated under equal pressure increments or under equal volume increments and the test is terminated when yielding in the soil becomes disproportionately large. The pressure-volume increase curve is plotted between the corrected volume and the corrected pressure. To estimate the corrected volume and the corrected pressure, pressure loss and volume loss correction are applied. A limit pressure is estimated from the last few readings of the test and a Pressuremeter modulus is calculated from pressure-volume changes graph during the test. If the diameter of the bore hole is more than the tolerances as specified in Table-1, the test may terminate without reaching sufficient probe expansion in the soil for the evaluation of the limit pressure.

The pressuremeter modulus is determined by using the following formula,

$$E_{pmt} = 2(1+\nu)\,(V_0 + V_m)\,\frac{\Delta P}{\Delta V}$$

Where,

ν = Poisson's ratio

V_0 = Volume of the measuring cell of uninflated probe

V = Corrected volume of the measuring cell of the probe

ΔV = increase in volume of the measuring cell with the increment of pressure, ΔP

ΔP = Increase in the pressure in the measuring cell

V_m = Corrected volume in the measuring cell with the Increase of ΔV

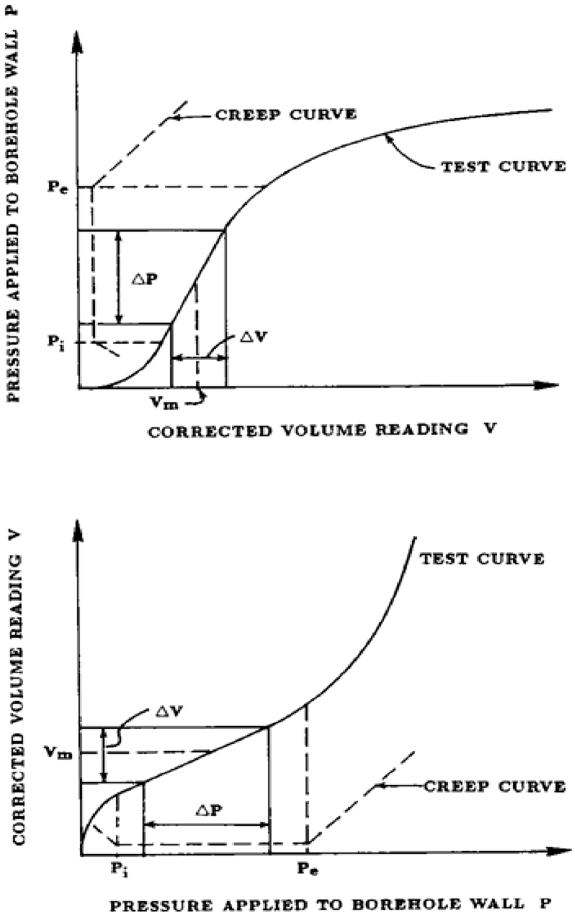

Figure 3: Pressure change - Volume change curve

V. CALIBRATION OF PRESSUREMETER

Before conducting the Pressure meter test in the bore hole, a Pressuremeter equipment is calibrated for the value of the pressure loss and volume loss so that the real stress deformation behavior of the soil can be obtained.

a. PRESSURE LOSSES

Pressure losses (Pc) occur due to the rigidity of the probe walls. The pressure readings obtained during the test on the control unit/readout device include the pressure required to expand the probe walls, this membrane resistance must be deducted to obtain the actual pressure applied to the soil. Calibrations for membrane resistance shall be performed by inflating the probe in air with the probe placed at the level of the pressure gage.

b. VOLUME LOSS

Volume losses (Vc) occur due to expansion of tubing and compressibility of any part of the testing equipment including the probe.

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Calibration is made by pressurizing the equipment with the probe kept inside a heavy duty steel casing or pipe. To calibrate the equipment for volume loss, pressure is increased in steps and corresponding volume change is measured.
Figure 4 presents the picture of pressure losses and volume loss curves.

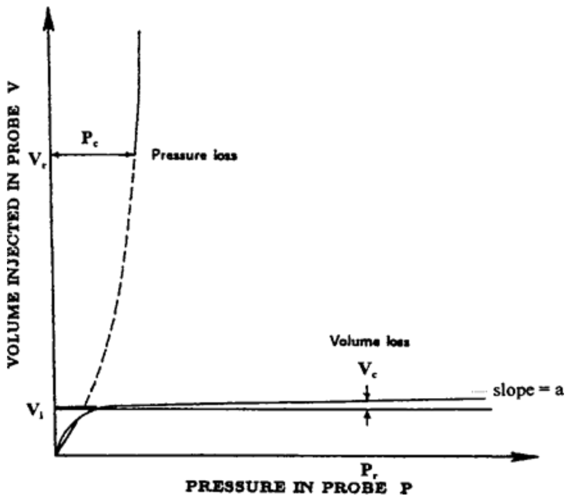

Figure 4: Calibration of Pressuremeter - Pressure loss and Volume loss curves

VI. IN SITU PRESSUREMETER TEST AT OVERBURDEN

The Pressuremeter test was performed for a hydroelectric project in Himalaya region. The geology of the dam area was mainly occupied by a large intrusive body of Jaunsar Traps which is interpreted to be nearly 300 m wide. The country rock is Chandpur Formation comprising of quartzite with slate-phyllite both in the upstream and downstream sides.

The Pressuremeter test was planned at the shear zone encountered at the dam site. The depth of shear zone vary from the 20 m to 150 m. Many investigations were tried to characterise the shear zone and determine the strength and deformation properties of the shear zone. But collection of undisturbed sample or conducting other in-situ tests was practically impossible. Finally, Pressuemeter test was planned at the shear zone to determine the properties of shear zone. The Menard Pressuremeter test equipment was used to conduct Pressuremeter test in the bore holes drilled up in the shear zone. The Pressuremeter test was conducted as per ASTM D 4719. The test was conducted in Nx size bore hole. The test was conducted in the unsupported length (without casing) of the bore hole. The equipment was calibrated (Volume loss and Pressure loss) before the test. Then Pressuremeter test probe was lowered in the bore hole up to the test location and probe was inflated by applying the water pressure through the control unit in equal increments. For each pressure increment, the change in volume of water in central cell is recorded at 15 sec, 30 sec and 60 sec. The pressure was applied normally in 10 increments and for each increment of pressure, the volume of water in the central cell is recorded and a cure is plotted between the increase in pressure and change in volume.

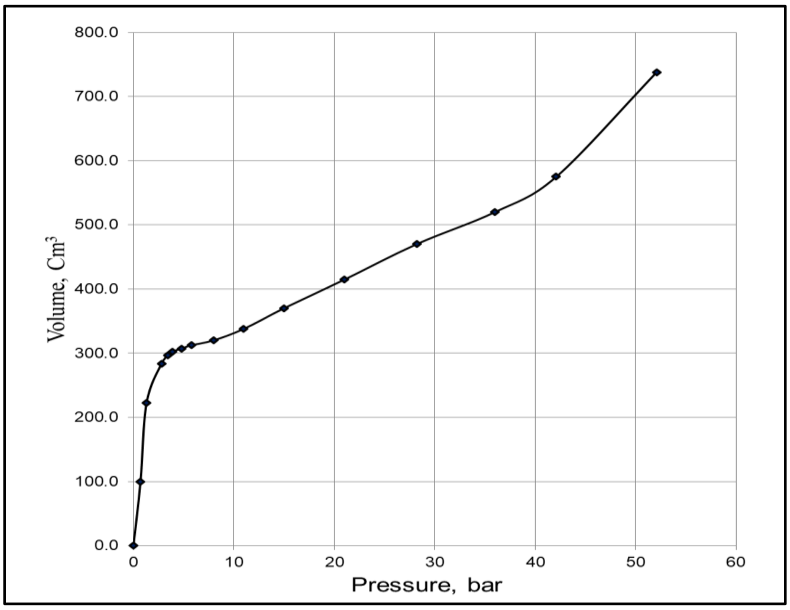

Figure 5: Pressure Vs. Volume change curve

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Based upon the Pressuremeter test concluded in the bore hole, the Menard Pressuremeter Modulus, E_{pmt} and Limit Pressure, P_L is evaluated as 4.721 x 10^4 kPa and 0.665 10^4 kPa (472.1 bar and 66.5 bar) respectively The graphical representation of the Volume V_s. Pressure is presented in Figure 5.

VII. DISCUSSIONS AND CONCLUSIONS

The Pressuremeter is a new apparatus that is able to automatically perform a Pressuremeter test. Such an automatic apparatus enables the geotechnical engineer to obtain repeatable measurements, and reduces inaccuracies that might be induced by the operator, uncertainties, and loss of head. The in- situ test performed demonstrate the feasibility of the auto-controlled test and the possibility to obtain good results.

The provision of self-correction for pressure loss, volume loss in auto-controlled Pressuremeter, has many advantages and is of great interest especially in deep soils when using long tubing. In fact it is integrated into the test and runs at start-up without affecting the test progress. The accuracy of pressures of soil that represent a certain creep is significantly improved. The PMT expansion curve can be used to predict the load settlement behavior of shallow foundations and the load displacement curve of deep foundations under horizontal loading.

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