

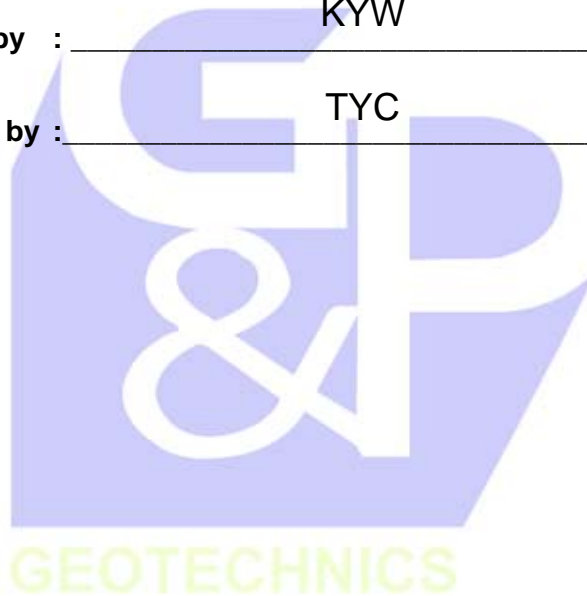


**WORK INSTRUCTIONS FOR ENGINEERS**

Compiled by : \_\_\_\_\_ CCM

Checked by : \_\_\_\_\_ KYW

Approved by : \_\_\_\_\_ TYC



**OP-021. METHODOLOGY FOR EVALUATION  
OF SOIL PARAMETERS FROM  
PRESSUREMETER TEST (CLAYS)**

## 21.0 METHODOLOGY FOR EVALUATION OF SOIL PARAMETERS FROM PRESSUREMETER TEST (CLAYS)

### 21.1. ESTIMATION OF $p_o$

#### 21.1.1. Traditional Method

The traditional method of estimating  $p_o$  is to assume that it corresponds to the start of the linear region of the pressure-volume curve and also to the point on the creep curve where the creep drops to a low, constant value as shown in Figure 1 below.

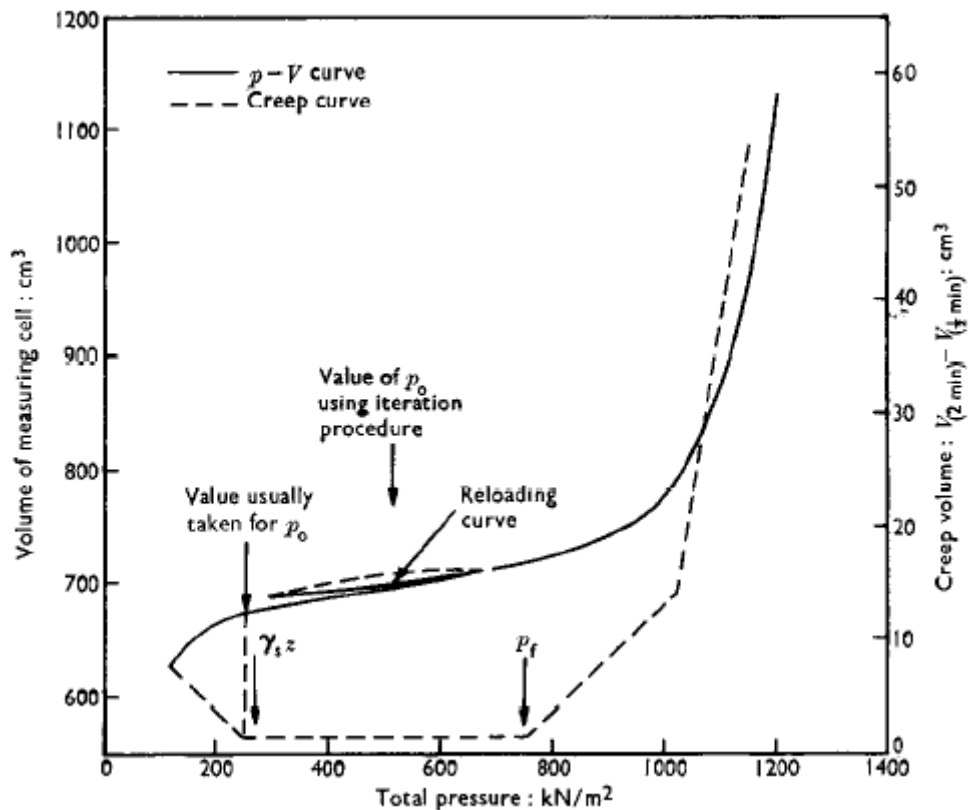


Figure 1: Typical p-V curve from pressuremeter test (after Marsland & Randolph, 1977)

#### 21.1.2. Iterative Method (after Marsland & Randolph, 1977)

According to Marsland & Randolph, 1977, the traditional method tends to underestimate  $p_o$ , in the case of overconsolidated soil, by a considerable amount. The underestimation of  $p_o$  will affect the determination of the value of the undrained shear strength,  $c_u$  with the values of  $c_u$  tends to be higher (unconservative).

The iterative method is outlined as follows:

- 1) An initial estimate of  $p_o$  is made from available information on the consolidation history of the soil. The following formula can be used as an initial estimate of  $p_o$ :

$$K_{onc} = 1 - \sin \phi \quad (\text{for normally consolidated soil})$$

$$K_o = K_{onc} (\text{OCR})^{1/2} \quad (\text{for overconsolidated soil})$$

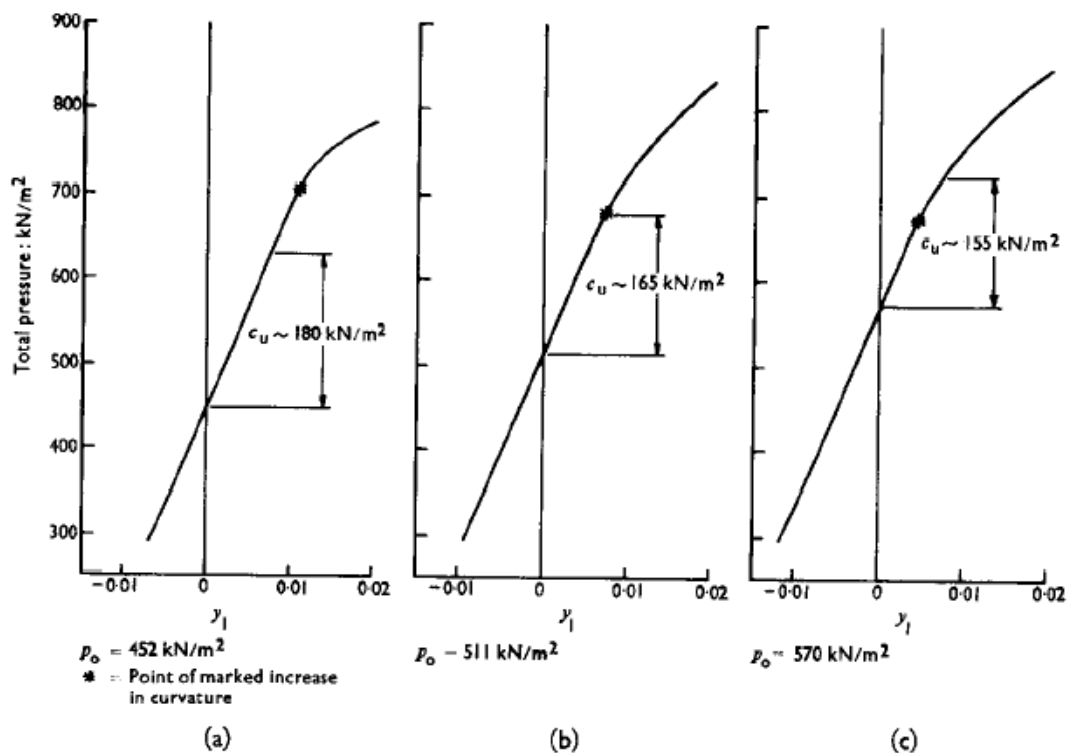
$$p_o = K_o \sigma_v' + u$$

where  $u$  = pore water pressure

$\sigma_v'$  = vertical subsurface stress

- 2) A volume  $V_o$  corresponding to the initial estimate of  $p_o$  was taken from the measured  $p$ - $V$  curve and the corresponding  $p$ - $\log_e(\Delta V/V)$  curve was plotted ( $\Delta V/V = \Delta V/(V_o + \Delta V)$ ). An approximate value of peak shear strength,  $c_u$  is obtained from this curve.
- 3) The value of  $c_u$  obtained from b) above is used to determine whether the value of  $p_o + c_u$  obtained corresponds to the pressure at which the  $p$ - $y_1$  curve becomes significantly non-linear. This process was repeated for other values of  $p_o$ , where the points at which a marked increase in curvature became apparent are marked with an asterisk as shown in Figure 2 below. The value of  $p_o$  for which this point most nearly corresponds to the pressure  $p_o + c_u$  was chosen as the correct  $p_o$ .

For example, Figure 2 below shows that the correct  $p_o$  estimated using this method is approximately equal to  $511 \text{ kN/m}^2$ .



**Figure 2: Procedure for estimating in situ horizontal stress (after Marsland & Randolph, 1977)**

$$y_1 = \frac{\text{increase in radius of borehole due to increase in pressure } (p - p_o)}{\text{radius of borehole at reference state } (p = p_o)}$$

= radial strain

- 4) After the value of  $p_o$  has been obtained, the value of coefficient of earth pressure at rest,  $K_o$  can be calculated from the following equation:

$$K_o = (p_o - u) / \sigma_v'$$

where  $u$  = pore water pressure

$\sigma_v'$  = vertical subsurface stress

## 21.2. ESTIMATION OF $p_L$

The following equation for the later stages of the pressuremeter tests (plastic stage) as derived from Gibson & Anderson (1977) shall form the basis for the determination of  $p_L$  from pressuremeter tests:

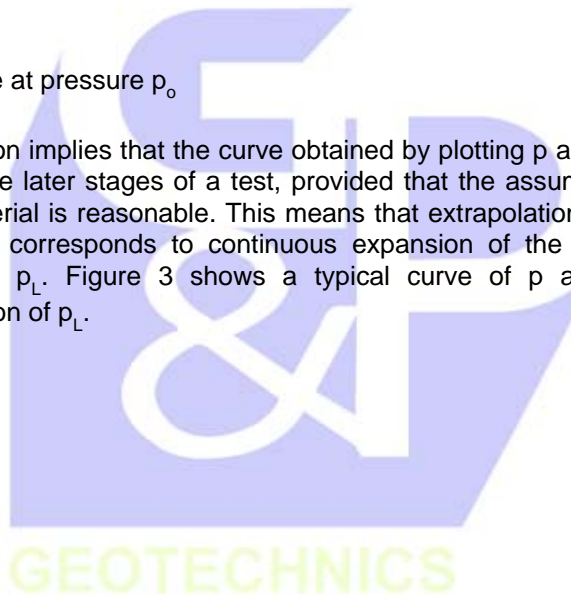
$$p = p_L + c_u \log_e (\Delta V/V)$$

where  $V$  = total volume at pressure  $p$

$$\Delta V = V - V_o$$

$V_o$  = volume at pressure  $p_o$

This equation implies that the curve obtained by plotting  $p$  against  $\log_e (\Delta V/V)$  should be linear for the later stages of a test, provided that the assumption of an elastic perfectly plastic material is reasonable. This means that extrapolation of the curve to  $\log_e (\Delta V/V) = 0$ , which corresponds to continuous expansion of the cavity, will provide a good estimate of  $p_L$ . Figure 3 shows a typical curve of  $p$  against  $\log_e (\Delta V/V)$  for the determination of  $p_L$ .



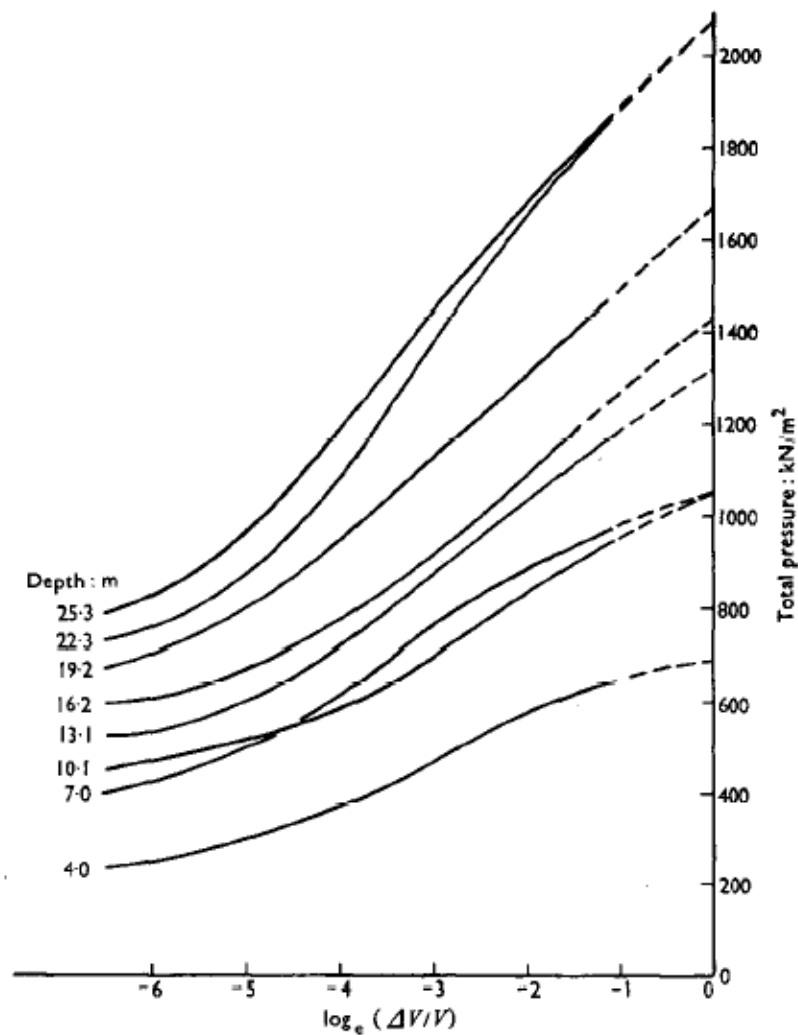


Figure 3: Curves of  $p$  against  $\log_e (\Delta V/V)$  from pressuremeter tests for the determination of  $p_L$  (after Marsland & Randolph, 1977)

### 21.3. ESTIMATION OF SHEAR MODULUS, $G$

For the determination of shear modulus, it is advisable that the reloading cycles of the pressuremeter tests are used.

The expression for the shear modulus is given:

$$G = \frac{1}{2} (\Delta p / \Delta y_1)$$

where  $\Delta p$  and  $\Delta y_1$  are increments of pressure and the corresponding changes in radial strain in the elastic region.

## 21.4. ESTIMATION OF ELASTIC MODULUS, E

### 21.4.1. Estimation from Values of Shear Modulus, G

The relationship between elastic modulus, E and shear modulus, G is given by the following equation:

$$E = 2G (1 + \nu)$$

where  $\nu$  = Poisson's ratio

Therefore, E can be estimated once the value of G is obtained from step 3.0 above.

### 21.4.2. Estimation from Values of Pressuremeter Modulus, $E_{pm}$

If Menard pressuremeter is used, the pressuremeter modulus,  $E_{pm}$  can be obtained from the pressure-volume curve using the following equation:

$$E_{pm} = 2(1 + \nu)(V_i + V_m)(\Delta p / \Delta V)$$

where

$\Delta p / \Delta V$  = the gradient of the pressure-volume curve in the elastic range of the pressure-volume curve

$V_i$  = the volume of the measuring portion of the uninflated probe at 0 volume reading at ground surface

$V_m$  = the corrected volume reading in the centre portion of the  $\Delta V$  volume increase

$\nu$  = Poisson's ratio

The elastic modulus is obtained by applying a correction factor,  $\alpha$  to  $E_{pm}$ :

$$E = E_{pm} / \alpha$$

The correction factor or Menard's factor,  $\alpha$  depends on the soil type, the stress history, etc and is summarised in Table 1 below:

Soil type	Peat		Clay		Silt		Sand		Sand and gravel	
	$E_{pm}/p_L$	$\alpha$	$E_{pm}/p_L$	$\alpha$	$E_{pm}/p_L$	$\alpha$	$E_{pm}/p_L$	$\alpha$	$E_{pm}/p_L$	$\alpha$
Over consolidated		1	>16	1	>14	2/3	>12	1/2	>10	1/3
Normally consolidated	For all values	1	9 - 16	2/3	8 - 14	1/2	7 - 12	1/3	6 - 10	1/4
Weathered and/or remoulded		1	7 - 9	1/2		1/2		1/3		1/4
Rock	Extremely fractured				Other				Slightly fractured or extremely weathered	
	$\alpha = 1/3$				$\alpha = 1/3$				$\alpha = 2/3$	

**Table 1: Menard's a factor (after Briaud, 1992)**

## **21.5. ESTIMATION OF UNDRAINED SHEAR STRENGTH, $c_u$**

Various methods have been published outlining the method for the estimation of undrained shear strength from pressuremeter tests. Among the methods commonly used are methods proposed by the following authors:

- 1) Gibson & Anderson (1961), which assumes an elastic perfectly plastic soil
- 2) Palmer (1972), which assumes a homogenous, incompressible soil

Recent research has shown that undrained shear strength for stiff clays (London Clay) and soft clay (Bangkok Clay) estimated based on the assumption of homogenous, incompressible soil is less reliable (Prust et al., 2001; Marsland & Randolph, 1977). Therefore, shear strengths derived from pressuremeter tests should be determined from the limit pressures using the elastic perfectly plastic theory.

### **21.5.1. Gibson & Anderson Method**

This method can be divided into two approaches for the determination of undrained shear strength:

#### **21.5.1.1. Based on the Measured Shear Modulus**

Gibson & Anderson, 1961 derived the following expression for the net limiting pressure needed to expand an infinitely long cylindrical cavity:

$$p_L - p_0 = [\log_e (G/C_u) + 1]C_u = N_p C_u$$

where  $N_p = \log_e (G/c_u) + 1$

Therefore, the undrained shear strength,  $c_u$  is given by:

$$C_u = \frac{(p_L - p_0)}{[(\log_e (G/C_u) + 1)]}$$

The equation above can be used to calculate  $c_u$  (numerical methods such as iterative method) once the values of the shear modulus are obtained from the reloading cycle.

#### **21.5.1.2. Based on a Constant Value of $N_p$**

The equation expressed in 21.5.1.1 requires numerical methods such as iterative method to calculate the undrained shear strength. In addition, the estimates of the shear modulus from pressuremeter tests may differ considerably from the true undisturbed value. Therefore, an easier and more reliable method (Marsland & Randolph, 1977) using a single value of  $N_p$  can be used to obtain the undrained shear strength. The undrained shear strength,  $c_u$  is given by:

$$C_u = (p_L - p_0)/N_p$$

where  $N_p = \frac{3}{4} (N_c - 1)$

$N_c$  = theoretical bearing capacity factor for a particular type of foundation

## **21.6. REFERENCES**

- 1) Marsland, A. & Randolph, M. F. (1977). Comparisons of the results from pressuremeter tests and large in situ tests in London Clay. *Geotechnique* 7, No.2, 217-243.
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