PMT some insights

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ABSTRACT: The Pressuremeter Test (PMT) is a method widely used all over the world, for in-situ testing of soils. In its performance related to saturated soils presents some discussion. From experience, there are cases of matching in soil properties as compared to other methods, these based in undisturbed soil sampling. But, also, in some instances there is no accordance in its results as compared to measurements with alternative methods, such as those that include undisturbed soil sampling. For that cases to the PMT based soil properties, it must apply a adequation factor. This author has linked sound properties of soils with the Darcy equation, that governs 3D laminar flow in this case. When the measuring cell of the PMT is dilated in the drilled hole, at any depth, a certain amount of saturated soil, is compelled to move out of its original position, and compress the surrounding medium, thus inducing high pore pressures and important hydraulic gradients in the water that fills the voids. Obviously, the aforementioned, implies an intend of percolation through the soil. If the soil medium is of high permeability, as for clean saturated sands, then the percolation could be established; but if not, the hydraulic gradients would be greater than the critical ones, as Darcy equation shows indirectly. Such a situation involves fabric destruction of the adjacent soil, making impossible to measure sound soil characteristics. This is demonstrated in the present article. Thus, the PMT must be used with caution perhaps for saturated soils different from clean saturated sands. It is the first time that the above is mentioned.

Keywords : PMT; pore pressures; hydraulic gradient; clean sands.

1.Introduction

About the PRESSUREMETER test PMT, [1], it is well known how the test is performed: in the measurement cell localized at some depth in a boring it is injected pressurized water, increasing this central cell volume. Pressure is incremented in steps of 60 seconds each one. The steps (about 10) are repeated up to the failure of the soil. Nevertheless the method is under discussion, since practically in no way a saturated soil (except perhaps clean sands, not including clean fine sands) dissipate the pore pressure induced by the step in 60 seconds; because following the Terzaghi Theory of Consolidation the pore pressure dissipation requires a long time. This pressure steps rising decreases the hydraulic gradient that acts intending to produce a water flow. There exists the doubt that finally the soil fails by hydraulic fracturing and not by plastic failure as it is believed. It is probably that a high hydraulic gradient, greater than a critical one, be the cause of the soil rupture. As a consequence it cannot be deduced any soil mechanics parameter based in this test, at least in saturated soils with coefficients of permeability relatively low. Perhaps in clean saturated sands or clean saturated sand with gravel, this test could be performed with sound results.

2. Theoretical Fundaments

There exist some aspects under discussion in the PMT operation. We must consider an important arching effect function of the quotient of the diameter and the depth of the boring. As a consequence when the membrane of the central cell makes contact with the wall of the boring, the horizontal geostatic stress at rest would not be present; instead a lower horizontal stress would be acting governed by the arching effect. In any case this must be discussed. The soil fails in hydraulic fracturing in some cases as it is demonstrated afterwards; the pressure p of the central cell of the PMT will induce a pore pressure Δu in the saturated soil with i as a consequence,

$$i > ic \tag{1}$$

where i is the hydraulic gradient induced by p, and ic the critical hydraulic gradient that is in the threshold of a laminar flow (i < ic) and a non-laminar flow. The definition of ic is,

$$ic = \Upsilon' \frac{1}{\Upsilon w} \tag{2}$$

where Υ' is the buoyant unit weight of the soil and Υw the water unit weight. The range for ic is 0.8 – 1.2 approximately. Respect to soils of low permeability ($k \leq 10^{-3}$ cm/sec) the injected water in the central cell induces an increment of volume of the cell, with the effect that the water volume in the saturated soil for that increment is ejected out of the soil. This is a logical fact since a volume of saturated soil particles plus water is no more occupying the volume corresponding to the increment of volume of the central cell. Again there is also an increment of the pore water pressure equivalent initially to the pressure applied by the PMT test, in the zone of soil in contact with the membrane of the central cell. Previous to consider the real case quoted earlier we continue with a description of the effects on the soil due to the PMT test(type G probe). The sequence is as following:

1. The measurement cavity (the central measuring cell) in the PMT boring expands owing to water injection.
2. From the above it means that it is produced an increase of volume V.
3. Obviously that V is not related to a compression of the soil particles instead corresponds to the volume of water of the soil pores in the soil volume that is displaced by the expansion, and the volume of the displaced soil particles in that soil volume.
4. Then there exist a water movement coming out the pores.
5. This movement intends to be a flow of water.
6. Every flow has a cause: an hydraulic head (pressure head plus elevation head); this hydraulic head induce an hydraulic gradient.
7. That hydraulic head has its origin in the pressure applied by the PMT to the inside of its measuring cell.
8. Due to the short time the test last and because of the low permeability of some soils, the soil around the PMT cavity cannot consolidate and due to the high hydraulic gradients, greater than critical in some cases it would generate hydraulic fracture.

Thus it can be mentioned that there are two fundaments for the criticism to the PMT in saturated soils. First the high hydraulic gradient as a consequence of central cell expansion in some saturated soils; and the criteria of tension quotient both of which refers to:

$$\frac{\Delta V}{\Delta t} = k \times i \times A \qquad (3)$$

$$\frac{\Delta u}{\sigma vo'} = 1.0 \qquad (4)$$

Regarding Eq. (3) Darcy equation for flow:

ΔV = water volume that fills the voids of the soil displaced by the central cell expansion

Δt = time elapse for any step of the PMT test

k = soil permeability of the contour of the expanded cell

i = hydraulic gradient

A = surface area of the expanded cell (corresponds to surface area of the soil)

Regarding Eq. (4):

Δu = pore pressure increment

$\sigma vo'$ = initial virgin vertical effective pressure of the soil in-situ

$\sigma v'$ = is the current vertical effective pressure in the test = $\sigma vo' - \Delta u$

Quoting Eq. (3) it is clearly observed during the test , an obvious tendency to percolation of the water that fills the voids of the volume displaced by the cell expansion, whose cause is the pore water pressure increment of that volume who intends to establish a 3D water flow around a volume in the form of a hollow cylinder. This phenomenon analysis require the Darcy Eq. (3). Nevertheless the use of Eq. (3) is restricted to soils of high permeability since it was deduced for flow in soils with hydraulic gradients less than critical, that is for laminar flow. If it is required to determine the range of soils for which this criteria is applicable the Darcy equation could be used , with the permeability as unknown and setting i in such a way that doesn´t surpass ic (critical hydraulic gradient), i < ic . Regarding Eq. (4) the criteria of tension quotient needs for good performance that its value must be 0.0 ; any value greater than 0.0 means that the current σv´ in the test is less than σvo´ , 0.0 < σv´ < σvo´ its initial and virgin value, related to good quality (sound)soil characteristics like modulus of deformation and soil resistance. If this criteria achieves a value of 1.0 during the test, it means we face static liquefaction and the soil is transformed in a mixture of soil particles and water. This condition is different from soil failure when the shear resistance is reached. However for high values of permeability deducted from Darcy equation, the criteria of high i and tension quotient are not satisfied giving out permeability´s related to soils that could be actually characterized with the PMT.

3. Case histories

From in-situ measurements with the PMT(G type), [2] and with Eq. (3) the following values of i (hydraulic gradient) are obtained. The soil is sandy silt. Then we suppose two values of k: 10^{-5} and 10^{-4} cm / sec. The sandy silt is overconsolidated. Then we assume a low e (void ratio) ; e = 0.55 . This means that : ΔV (water) = (TOTAL VOLUME INCREASE) x 0.354

The assumed value of e is almost a low bound for this kind of soils; if e is higher than this value then ΔV (water) increases and A increases. Also e could be estimated from a Shelby tube in fine soils, and with adequate methods for other soils.

A: is calculated according to the “lateral area of the expanded cylinder” (the central cell). See Fig 1. ,[3].

For other steps in the PMT test quoted above it is easy to show that i > ic . It is observed in Table 1. later, when k increases 10 times i diminishes 10 times. It is clear the tendency that if k increases then i decrease. It could be argued that Eq. (3) cannot be applied to i > ic , but at least this equation alert when i is too large that is greater than ic . For k = 10^{-4} cm/sec the first steps of pressure implies i ≈ ic, after the contact of the membrane with the soil. Within this level of i any soil characteristic measurement is misleading. For other

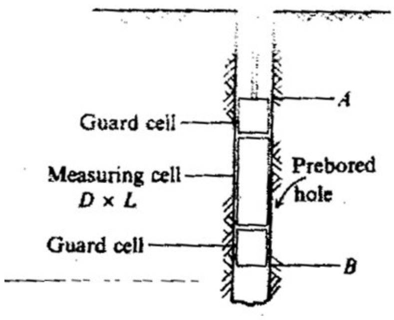

Figure 1. PMT device

steps, i > ic for example step 6. This case history includes 10 steps with p the central cell pressure, up to 13.6 bars. All of these steps except the before mentioned involves i > ic. In the case, k = 10^{-5} cm/sec from step 3 i > ic. As it could be appreciated k = 10^{-4} cm/sec is too low for the PMT been applicable. With higher k that means a soil with better drainage the hydraulic gradients are acceptable, and there is no possibility of hydraulic fracture. Then the PMT when applied to saturated soils they must be with high k for the results being acceptable. It is easy to show when the PMT test is acceptable. With the data of the test it must be calculated the hydraulic gradient for each step and then compared with the critical hydraulic gradient. But first the k (coefficient of permeability) must be estimated, by a permeability test in-situ. Or by inspection of the gradation curve (the amount of fines content FC %) if FC% < 5 % this implies a clean sand (clean fine sand is excluded), then k >

10^{-3} cm/sec. The permeability test must be performed in another boring near the boring for the PMT. Now we consider from another point of view that the PMT is erroneous in soils with low k that is, in soils where the pressure imposed by the central cell is not dissipated immediately. We demonstrate it with the same example used for the calculus of i.

Test depth = 5.75 meters

Water level depth = 0.0 meters

Saturated unit weight of soil = 2 tons / m^3

σvo´ = vertical effective initial virgin pressure

σvo´ = 2 x 5.75 - 1x 5.75 = 5.75 tons/m^2, previous to the PMT.

An increase of total pressure against a saturated soil increases the water pressure in the same amount of total pressure, in the zone of soil immediately in contact with the central cell initially. The data from this real case express that in step 4 of the PMT the pressure inside the central cell is 3.65 bars. This is the same to affirm that the water pressure in the surrounding soil increments in 36.5 tons/m^2. Quoting the **Principle of Pascal** the increment in pore pressure Δu is the same in any direction. Then,

$$\sigma v' \ (during\ PMT) = \ \sigma vo' - \Delta u \qquad (5)$$

Thus,

σv´ (during PMT) = 5.75 tons/m^2 - 36.5 tons/ m^2

σv´ (during PMT) = - 30.75 tons / m^2 < 0.0

This result shows that the particles of soil are not in contact. Then it is not possible to deduct conclusions related to geotechnical parameters. Also in step 3, p = 2.5 bars which implies that σv´ < 0.0 .

Thus probably the range of application of the PMT in saturated soils is for those with $k > 10^{-3}$ cm/sec, which corresponds to " good drainage soils" [4]. It is reiterate that k must be measured for applying Eq. (3) Darcy equation; the calculated i will discriminate between a useful or not useful PMT test. A useful PMT test is one that i < ic . We demonstrate now that the PMT could be make in more permeable soils like clean saturated sands, saturated gravelly sands, or saturated sandy gravels. We consider values of k [5] and deducted water volumes filling the voids, with its corresponding flow times (the time of the step in the test) for this demonstration. From Darcy equation we can derive the following equation for i:

$$i = \left(\frac{\Delta V}{\Delta t}\right) \times \frac{1}{k \times A} = hydraulic\ gradient \qquad (6)$$

This i will be calculated for the first injection step and for the last one (supposed), 10º .

About ΔV water volume filling the voids in the displaced saturated soil for the same pressure increment, being the soils considered in this case of higher stiffness than the sandy silt, for which there exists data this ΔV will be lower ; nevertheless for not favoring what we raised we consider equivalent to the sandy silt. Thus i does not decrease.

ΔV = (TOTAL VOLUME INCREMENT = INJECTED) x 0.354 => e = void index = 0.55 (dense) .

Respect A the external surface area of the hollow cylinder origin of the 3D flow net, remains the same as the case mentioned in the previous paragraph. In the next Table 1. we deploy the solution.

Table 1. Hydraulic Gradients

K (cm/sec)	A (cm^2)	Step	ΔV (cm^3)	Δt (seconds)	Soil	i
10^{-3}	500.6	1º	56.6	60	Sand	1.88
,,	630.7	10º	63.72	60	,,	1.68
10^{-2}	500.6	1º	56.6	60	Clean sand	0.188
,,	630.7	10º	63.7	60	,,	0.168
10^{-1}	500	1º	56	60	Gravel or sand	0.018
,,	630	10º	63	60	,,	0.016

For sands with gravel when $k > 10^{-1}$ cm / sec , i becomes lower than this Table shows. Thus, for $k \geq 10^{-2}$ cm/sec is feasible to make reliably PMT tests. By the other side, the FS (factor of safety : ic/i = FS) implicit in this calculus is: 1 / 0.188 = 5.3; 1/ 0.016 = 62.5 ; which is acceptable. The above assumes conservatively a unit weight of gravel with sand or sand, of 2 tons/m^3 saturated.

Other case histories from reference [2], Table 2.

Table 2. Case Histories

Data	Test	Undrained shear strength (k/cm^2) (Su)
For a fine soil (Chile)	PMT Triaxial CIU Unconfined Compression	3.4 1.4 - 1.55 0.36
Data from France	For some soils Su (PMT) / Su (Vane)	0.75 – 1.8

4. Discussion

It is appreciated that sometimes the PMT tests ends in hydraulic fracture. Now it is not possible to measure geotechnical parameters with this test in some type of soils. The range of application of the PMT technology is then restricted for saturated soils, perhaps basically for sands with high k on the order of $\geq 10^{-2}$ cm/sec, and sandy gravels or gravelly sands with the same characteristic. The steps for this application is first to obtain information about the soils strata and then to perform this test in some of those soils. Those soils that do not satisfy the above criteria could be characterized with undisturbed sampling among other methods. We quote that the coefficient of subgrade reaction, in clay, for piles, has differences up to 100% comparing PMT values and Triaxial values , [6].

5. Conclusion

The PMT is sometimes a very reliably in-situ testing method for some type of saturated soils. Maybe its range of application is restricted. The fundamental discriminant for its application is the value of the soil permeability. This soil characteristic must be at least greater than 10^{-2} cm/sec for sound soil parameters characterization. Probably in soils not saturated the above is not a concern. Perhaps also this method could be applied to saturated gravels with clean sand, in which the gravel has rounded or sub-rounded particles. This is the first time that this article idea is mentioned. And probably perhaps states the cause of its restricted use in saturated soils.

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