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Effect of horizontal at rest pressure (P_o) on elastic modulus from pressuremeter testing

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Abstract. Modulus of deformation of soil is an essential parameter used for design analysis of foundations, despite its importance; little attention is paid to developing empirical models for predicting the sensitivity of deformation moduli to other parameters that obtained from the pressuremeter tests. Various methods of analysis used to predict the horizontal at rest pressure from pressuremeter testing (P_o) ,these values showed distinctive variations ,five methods used to evaluate the values of horizontal at rest pressure, these values been used to evaluate the modulus of elasticity using three methods of analysis. The values of modulus showed distinctive increase when the values of horizontal at rest pressure increase for the same pressuremeter test ,these increases may reach to 65%. This sensitivity of the moduli to values of horizontal lead the author to propose some reliable methods of analysis for both the horizontal at rest pressure and the modulus of deformation from pressuremeter testing.

Keywords: pressuremeter; modulus of elasticity; horizontal at rest pressure; sensitivity

1. Introduction

Marcil *et al.* (2015) carried out stress control and strain control pressuremeter tests on clay soils to deduce the values of the Modulus , the results showed that strain controlled tests generally yield slightly higher Modulus than those from stress control pressuremeter testing. Vincent and Maxime (2016) presented the stress path before and during a pressuremeter test using a Modified Cam-Clay model. They concluded that the estimation of saturation and suction variations in unsaturated soil around a pressuremeter cell allows drawing qualitatively the stress path during a pressuremeter test in clayey and collapsible loessic soils. It shows that stresses path are depending on initial saturation degree and suction. This must lead to be very careful when using finite elements calculation with saturated model or pure friction model in order to estimate cam clay soil parameter or modulus. Fawaz *et al.* (2014) conducted Menard pressuremeter tests in many types of soil, at different locations and to several depths. Samples of encountered soil are taken and tested in the laboratory. They used numerical simulations of the pressuremeter tests are performed with Plaxis software. The deduced results of elastic modulus of the soils were compared with pressuremeter modulus measured during the in-situ tests. For every type of soil, the variation of the ratio between both moduli is determined. Miller *et al.* (2012) conducted monocell pressuremeter in pre-bored hole in a calibration chamber containing compacted low plasticity clayey silt.

They concluded that values of the pressuremeter modulus is sensitive to the initial soil state as defined by the net normal stress, matric suction, and void ratio . Kurlenya *et al.* (2015) propose a method to estimate deformation properties of rocks by using the data of pressuremeter testing in hydrofractured interval, allowing in situ values of Young's modulus and Poisson's ratio of rocks. The results showed that combination of pressuremeter tests and hydraulic fracturing expands the scope of. Oztoprak *et al.* (2018) proposed a numerical methodology for analyzing the complete curve of a deformation measurements and improves efficiency of stress assessment in rocks using hydrofracturing method pressuremeter test including initial parts and loops through a stiffness-based approach adopted in three dimensional finite difference code .They used a new hyperbolic model to replace the conventional linear elastic model prior to peak strength of Mohr-Coulomb soil model and update of shear modulus was considered.

Komurlu *et al.* (2015) investigated the effect of horizontal in situ stress on failure mechanism around underground openings excavated in isotropic, elastic rock zones; they suggested modified equations for estimating the plastic zone occurrence and its thickness around the tunnels with circular cross-section. Farid *et al.* (2013) carried out PENCEL Pressuremeter and Cone Penetrometer tests at two sites chosen in Florida, they concluded reliable correlations between the initial elastic modulus and limit pressures that deduced from PENCEL Pressuremeter and Cone Penetrometer tests. Dyka (2012) interpreted the soil modulus which is used in calculation method for pile load-settlement curve. He presented a brief analysis of the results obtained by laboratory tests to assess soil modulus and its nonlinear variability. Likitlersuang *et al.* (2013) carried out pressuremeter tests in Bangkok clay to deduced the strength parameters in order to design four metro stations in Bangkok, the results also compared with Vane shear and triaxial tests, the results showed good correlations.

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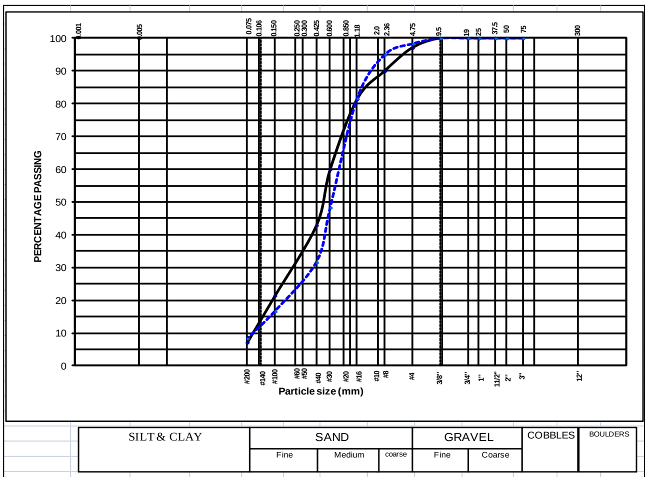

BH No.	Depth	Curve	Description of Soil	GS	Gravel (%)	Sand (%)	Silt/Clay (%)	LL	PL	PI
1	2.0m	———	Poorly graded SAND with silt	(SP - SM)	2.9	90.0	7.1	-	-	N.P
1	6.0m	- - - -	Poorly graded SAND with silt	(SP - SM)	1.7	90.0	8.3	-	-	N.P

Fig. 1 Grain size distribution curve for the tested soil

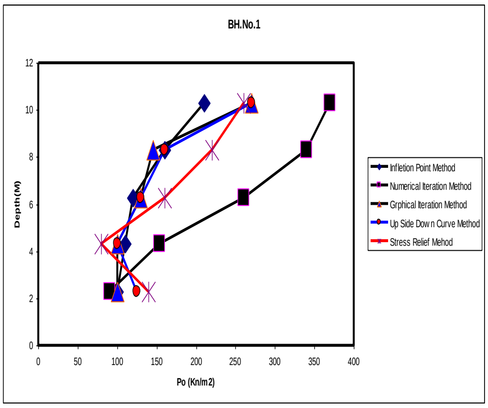

Fig. 2 Values of P_o deduced from different methods for BH.1

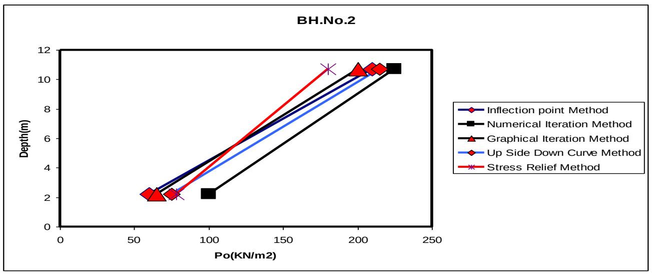

Fig. 3 Values of P_o deduced from different methods for BH.2

The evaluation of pressuremeter modulus extensively examined in present paper using different methods of analysis. The values of horizontal at rest pressure also evaluated using different methods of analysis; the deduced values of modulus seemed to be sensitive to values of horizontal at rest pressure, where great discrepancies in the evaluated values of modulus recorded when using the different values of horizontal of rest pressure deduced from different methods.

2. Evaluation of horizontal at rest pressure, P_o

Alzubaidi (2015) presented five methods for evaluating the horizontal at rest pressure, P_o from the pressuremeter testing of the soil, these are ,

1- Inflection point method
2- Numerical iteration method
3- Graphical iteration method
4- Upside down curve method
5-Stress relief method

Some of the methods listed above have no theoretical background, where the others try to compensate, at least partially for the effects of disturbance that inevitably occur in all predrilled Menard pressuremeter tests. In situ Menard pressuremeter were carried out in a site in Abu Dhabi, the tested soil can be described as poorly graded sand with silt

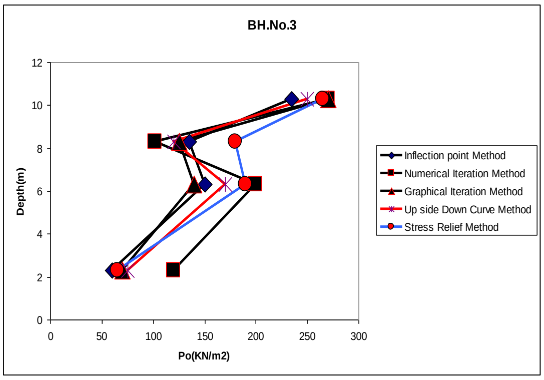

Fig. 4 Values of P_o deduced from different methods for BH.3

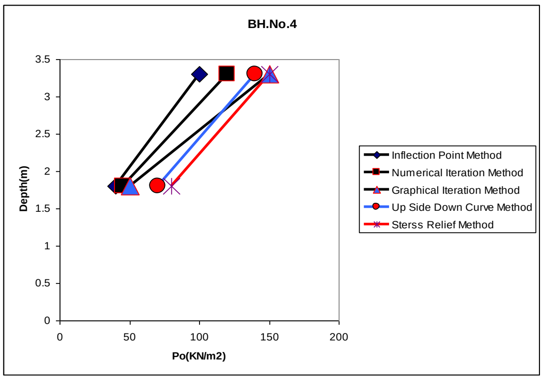

Fig. 5 Values of P_o deduced from different methods for BH.4

as can be seen from sieve analysis test curve in Fig. 1. Menard pressuremeter tests were conducted in four boreholes with different depths, the results were interpreted using five methods of analysis for obtaining P_o values. As can be seen from Fig. 2-Fig. 5 All the methods showed an increase in the values of P_o with depths, but there are some distinctive differences in the results of P_o from different methods for the same test results .The results showed little discrepancies between the values of P_o deduced from inflection point method, graphical iteration method, up side down curve method and the stress relief method where the numerical iteration methods gave higher values for P_o than the other four methods. The methods of interpretation P_o showed variations in the deduced values of P_o ranged from 1% to 57% for the same tests.

3. Modulus of elasticity from pressuremeter testing

The modulus of Elasticity been analyzed using three methods, these methods are as follow:

1- Menard Method
2- Gibson and Anderson Method
3- Palmer Method

Menard (1957) presented the following equation for evaluating the elastic modulus from pressuremeter testing as follows

$$G_M = V_m . (\Delta P/\Delta V) \quad (1)$$

where G_M = shear modulus, V_m = the mean value of the borehole volume in the elastic part, ΔP= difference in applied pressure in the borehole, ΔV =difference in the volume of the borehole.

The elastic modulus can be calculated as

$$G_M = E_P / 2(1+\nu) \quad (2)$$

where E_P = elastic modulus, ν = Poisson's ratio.

Gibson and Anderson (1961) developed another method of interpretation of the elastic modulus; they stated that the values of the elastic modulus can be evaluated from the elastic phase of Menard pressuremeter tests as follows

$$E_P = [\Delta P\,(1+\nu)\,a] / \rho_o \quad (3)$$

where E_P = elastic modulus, ΔP = pressure change in the elastic phase, ν = Poisson's ratio, a= borehole diameter at pressure P, ρ_o = change in radial displacement at borehole wall.

Palmer (1972) presented a solution for the tangent modulus by plotting the applied pressure P versus the radial strain ϵ_o, the shear modulus can be deduced by considering the slope of the elastic portion of the curve where,

$$G = 1/2(dP/d\,\epsilon_o) \text{ at } \epsilon_o=0 \quad (4)$$

The Young's modulus E_P may in turn be derived using

$$E_P = 2(1+\nu)\,G \quad (5)$$

where G= shear modulus, E_P =Young modulus, P= applied pressure, ϵ_o = radial strain.

4. Effect of P_o on the elastic modulus

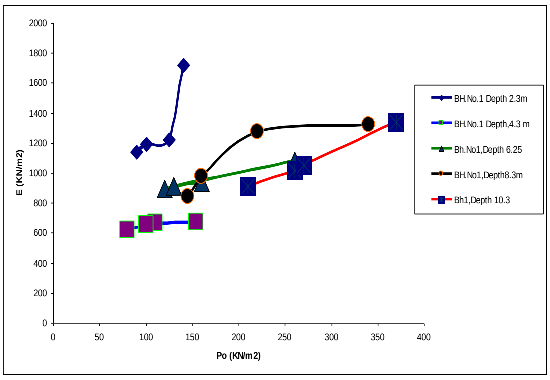

Fig. 6 Values of modulus of elasticity with P_o using Menard Method for BH.1

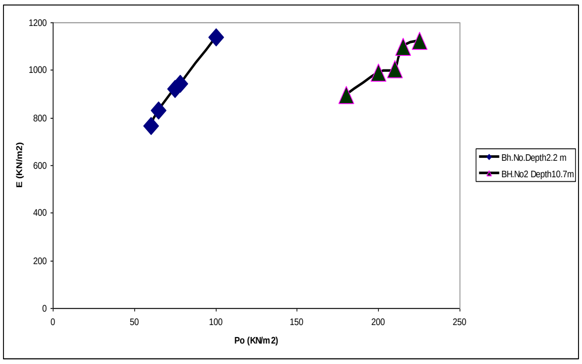

Fig. 7 Values of modulus of elasticity with P_o using Menard Method for BH.2

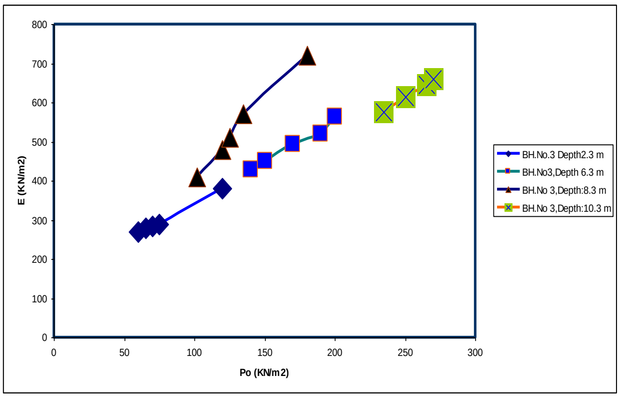

Fig. 8 Values of modulus of elasticity with P_o using Menard Method for BH.3

The different values of P_o that been deduced from different methods been applied in the three methods of evaluation the modulus of elasticity (Menard, Gibson and Anderson and Palmer methods).

4.1 Menard method

Figs. 6-9 showed the values of elastic modulus deduced using Menard method with Po values that evaluated from different methods for the same pressuremeter test, the values of the modulus showed distinctive increase with increasing the values of P_o, as can be seen in Fig. 6 that the values of modulus increased when the values of the

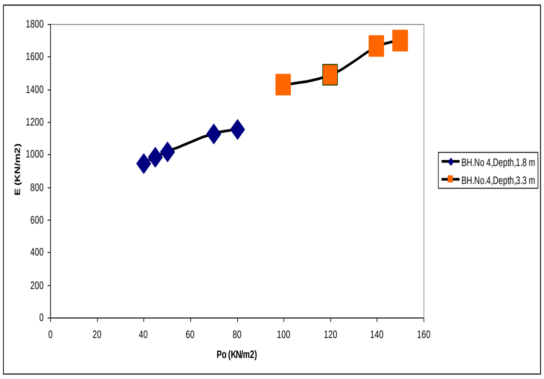

Fig. 9 Values of modulus of elasticity with P_o using Menard Method for BH.4

horizontal at rest pressure (P_o) increased, the values of the elastic modulus increased by 51% when the values of P_o increased by 55% for borehole No. 1.

Fig. 7 showed the values of the modulus increased by 26% when the values of P_o increased by 25% for BH.2. In Fig. 8 the modulus of elasticity increased by 53% when the values of P_o increased by 43% for BH3. The values of the modulus increased by 20% when the values of the P_o increased by 50% for BH.4 as can be seen in Fig. 9.

4.2 Gibson and Anderson method

The modulus of elasticity also evaluated using Gibson and Anderson method using different values of P_o. Figs. 10, 11, 12 and 13 showed the values of modulus of elasticity increased when the values of P_o increased. Some of the results showed that the values of modulus increased by 36% when the values of P_o increased by 47%.

4.3 Palmer method

The values of the modulus of elasticity also showed distinctive increases when the values of P_o increase using Palmer method. Figs. 14-17 stated clearly that even with Palmer method the values of the modulus of elasticity increased when using larger values of P_o,it can be seen that some values of the modulus increase by 83% when the values of P_o increased by 66%.

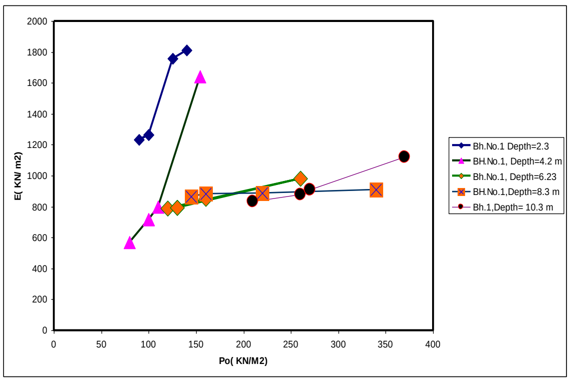

Fig. 10 Values of modulus of elasticity with P_o using Gibson and Anderson Method for BH.1

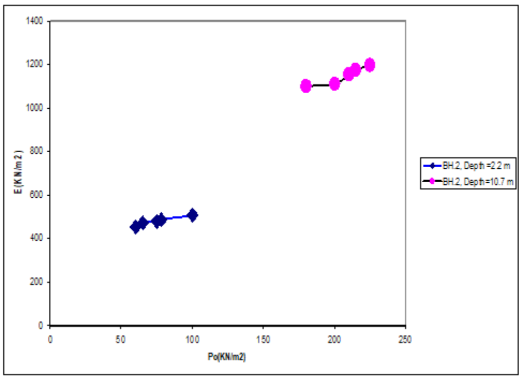

Fig. 11 Values of modulus of elasticity with P_o using Gibson and Anderson Method for BH.2

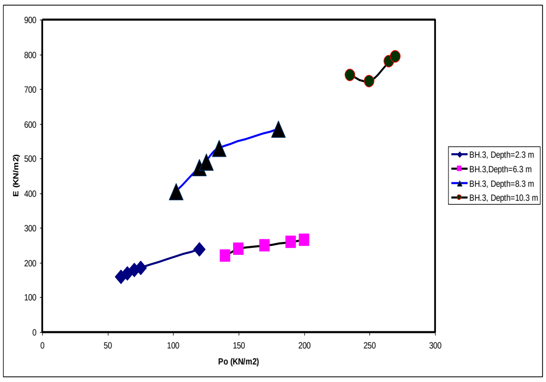

Fig. 12 Values of modulus of elasticity with P_o using Gibson and Anderson Method for BH.3

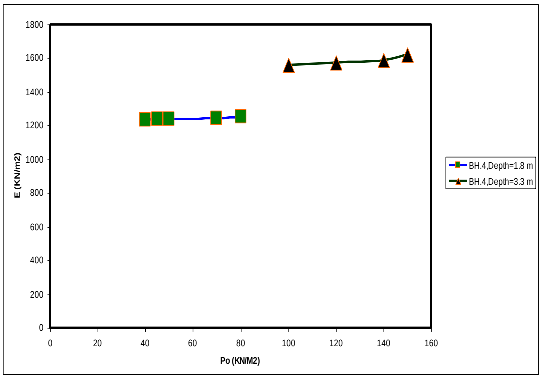

Fig. 13 Values of modulus of elasticity with P_o using Gibson and Anderson Method for BH.4

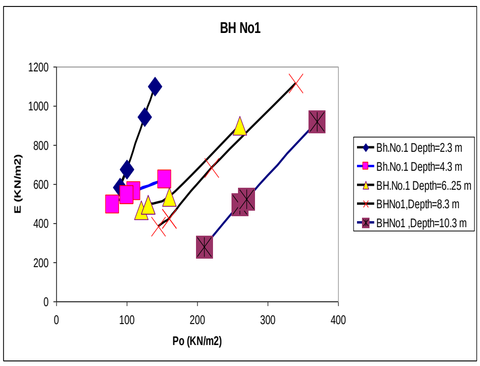

Fig. 14 Values of modulus of elasticity with P_o using Palmer Method for BH.1

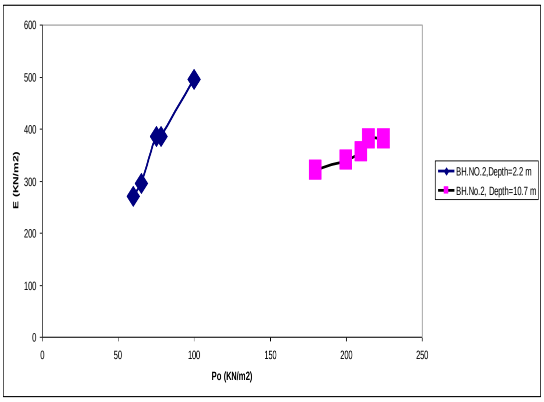

Fig. 15 Values of modulus of elasticity with P_o using Palmer Method for BH.2

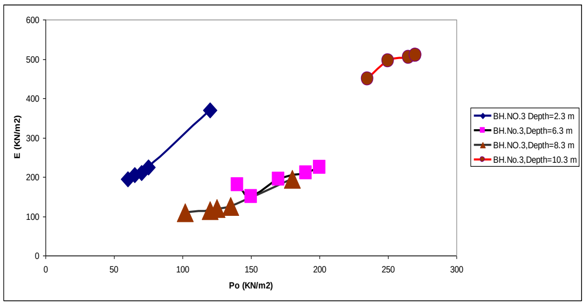

Fig. 16 Values of modulus of elasticity with P_o using Palmer Method for BH.3

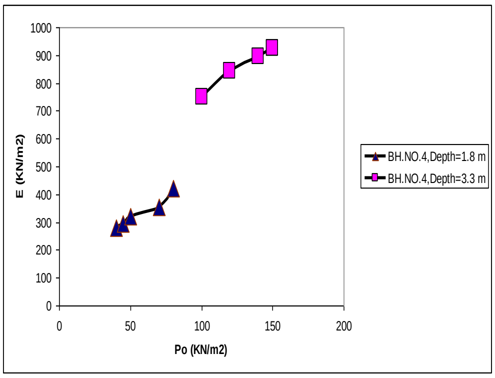

Fig. 17 values of modulus of elasticity with P_o using Palmer Method for BH.4

5. Conclusions

The modulus of elasticity seems to be sensitive to the values of the horizontal at rest pressure (P_o), there are numbers of methods for evaluating the horizontal at rest pressure (P_o) ,the evaluated values of Po from these methods showed distinctive discrepancies , the values of the modulus of elasticity also showed distinctive differences when using different values of P_o , there are number of conclusions can be drawn , these are as follows,

- The horizontal at rest pressure (P_o) evaluated using five methods of interpretation, the differences in the evaluated values of P_o deduced from these methods recorded from 1% to 57% for the same pressuremeter test .

• The modulus of elasticity evaluated using three methods of analysis for pressuremeter tests, these methods showed distinctive sensitivity to evaluated values of P_o.

• Menard method for interpretation the Modulus of elasticity for pressuremeter tests showed a vital increases in the values of the modulus of elasticity when the evaluated values of the P_o are increased. The deduced values of modulus of elasticity showed increases ranged from 20% to 53% when the values of P_o increased from 25% to 55%.

• The method of Gibson and Anderson also produced the same trend of increases in the values of the modulus of elasticity when the values of P_o been increased ,the evaluated values of modulus of elasticity showed increases from 20% to 65% when the values of P_o increases from 15% to 48% .

• Palmer method also reported increases in the values of the modulus of elasticity when the values of Po experienced increases, the values of the modulus of elasticity increased from 2% to 66% when the values of P_o increased from 13% to 57%.

• The three methods of evaluating the modulus of elasticity (Menard, Gibson and Anderson and Palmer) were sensitive to the values of the horizontal at rest pressure (P_o), the values showed distinctive increases when the values of P_o increased.

It is recommended to use the inflection point or graphical iteration method to evaluate the P_o due to consistency deduced values and also recommended to use Palmer method to analyze the modulus of elasticity, as can be considered as a reliable method, where a complete stress-strain curves can be drawn for determining the elastic modulus.

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