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Estimation of Elastic Modulus for Basalt Rock using Laboratory and In-situ Tests

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ملخص البحث:

يعتبر معامل المرونة أحد الخصائص المهمة للتربة في الهندسة الجيوتقنية ، حيث يستخدم هذا المعامل في تقدير الهبوط أسفل الأساسات تحت تأثيرالأحمال المختلفة ، ويترتب على تقدير الهبوط تحديد إجهاد التأسيس المناسب .وفي هذا البحث تم تقدير قيم معامل المرونة لتشكيلات الصخور البازلتية باستخدام بعض الاختبارات المعملية والموقعية لبعض مشروعات المباني الشاهقة في العاصمة الإدارية الجديدة في مصر ، حيث تم استخدام اختبار التحميل باللوح واختبار مقياس الضغط كاختبارات في الموقع ، بينما تم استخدام اختبار مقاومة الانضغاط غير المحصور للصخور الأساسية السليمة في المختبر. وقد تم التنبؤ بقيم الارتباطات لمعامل المرونة للبازلت باستخدام الاختبارات المختلفة التي أجريت في الموقع أو الاختبارات المعملية للتنبؤ بالقيمة المناسبة التي يستخدمها مهندسو الجيوتقنية فى تصميم الأساسات وحسابات الهبوط.

Abstract:

The elastic modulus is an important parameter in geotechnical engineering.

Elastic modulus is calculated for both types of soil and rock formations as an elastic parameter most commonly used in the estimation of settlements predictions under foundations due to the expected different loads. Consequently, the appropriate values for the bearing capacity used for foundation design can be defined according to that. In this research, the estimation of the elastic modulus values for basalt rock formation was predicted using different laboratory and in-situ tests for one high rise building projects of New Administration Capital in Egypt. Many different tests were performed in the field or/and the laboratory for elastic modulus prediction and only some of them were used in this research. Plate load and pressure meter tests were used as an in-situ tests while, the unconfined compressive strength test of the intact core rock (UCST) was represented the laboratory one. Plate load tests on rock and pressure meter tests are most commonly used in field, especially for design of shallow foundations. Both tests are the most accepted and frequently used recently in geotechnical studies. Correlations values of the elastic modulus of basalt was predicted using the different tests performed in field or

laboratory tests to predict the suitable value used by geotechnical engineers to predict the foundation design and the calculations of its settlements.

Introduction

Modulus of elastic deformation is important parameter in geotechnical engineering. The elastic modulus is characterized by describing the relationship between the applied load on soil or rock formations and the resulting strain in them. Elastic modulus is often estimated for soil or rock formations by indirectly from classification methods (Hoek, 2015; Plamstroum, 2001). In other cases the modulus of elasticity is assumed based on the experience of the geotechnical engineer or the literature data. In this paper the modulus of elasticity for rock formation using in situ and laboratory tests have been analyzed. Farmer and Kemeny, 1992 found that the deformation modulus on intact rock samples is in the order of 5-20 times higher than in situ tests. Many investigations showed that the in situ deformation modulus is not constant value but varies and depend on the different stress conditions. It will be higher in rock subjected to high stresses and lower under low stresses. Different in situ tests on rock formations are characterized using : shear tests, compression tests, plate load tests, pressure meter tests, borehole expansion tests (dilatometer), and seismic geophysical tests. Bieniaswki, 1989; Pells, 1983; and E. Unal, 1997, investigated different in situ tests to allow a meaningful comparison elastic modulus values. In situ testing remains the most reliable methods for establishing the rock elastic modulus parameter. The plate load tess (PLT), pressure meter tests (PMT), dilatometer tests are common tests (Bieniawski, 1978; Palmstroum, 2001; Boyle, 1992; Alireza et al, 2012). The authors in this paper predicted the modulus of elasticity for Basalt rock formation encountered in the eastern part of Cairo in Egypt. The chosen site of investigation is located at the New Administration Capital which high rise building project is to be established. Laboratory tests were performed on intact core samples for different laboratory tests. In situ tests of the study was concentrated on the plate load tests and the pressure meter tests. Comparisons between the different in situ and laboratory tests are predicted to fulfill the modulus of elasticity of basalt rock which can be used in the design and prediction of foundation settlement.

Location and Geology of the Study Area

The study area is located at the New Administration Capital city which located in the eastern part of Cairo which is the capital of Egypt. The Site of the New Administrative Capital located about fifty kilometers east of Cairo and just outside the second greater Cairo ring road in a currently largely undeveloped area halfway from Cairo to the seaport city of

Suez. The new capital could be a part of a national project to distribute Egypt’s population across its desert lands. In this new city, the government started to build a new huge capital city for moving all the administration and commercial buildings to relief the capacity and the crowded traffic jam on the old capital. Figure 1 shows the map represents the location of the study area with respect to the ordinary capital city of Cairo. The geology study of the area has been subject to many investigations and researchers such as: (Issawi, 1961; Said et al., 1961; and Ghobrial, 1967). The stratigraphic succession in the study area ranges in age from the late Early Eocene to the Oligocene. and the Oligocene succession is called Gabal Al-Ahmer formation is of a fluviatile origin deposited from westerly and northerly flowing meandering fluvial system filling local topographic depressions in the stretch between Gebel Ataqa in the east and Gebel Mokattam in the west. The Oligocene sediments were highly controlled by the structural and topographic lows, where a substantial thickness of these sediments was deposited occupying several grabens and gently sloping areas between many synthetic faults.

A subsequent phase of basalt eruptions took place after the deposition of the Early Oligocene sands and gravels, due to the rejuvenation of the E–W and NW–SE faults during the late Oligocene. This has resulted into basalt sheets covering the early Oligocene sediments. Stratigraphically, the Gebel Al-Ahmer Formation unconformably overlies the Upper Eocene Maadi Formation and unconformably underlies the Miocene sediments. Soil investigation performed at the study area shows that, the site consists of a surface soil layers consists of cemented sand or gravelly sand down to a depth ranged between 11.0 and

12.0 meter below the natural ground surface followed by a basalt rock layers of different weathered conditions which appeared below the surface soil layer and extended down to the end of boring depth. Twenty two boreholes are executed at the site and executed up to a depth ranged between 35.0 and 100.0 meter below the natural ground surface. Figure 2 shows sketches for the site formation where it is obvious that, at the surface of the site consists of weathered soil layers followed by a rock Basalt layer of thickness ranged between forty and fifty meters.

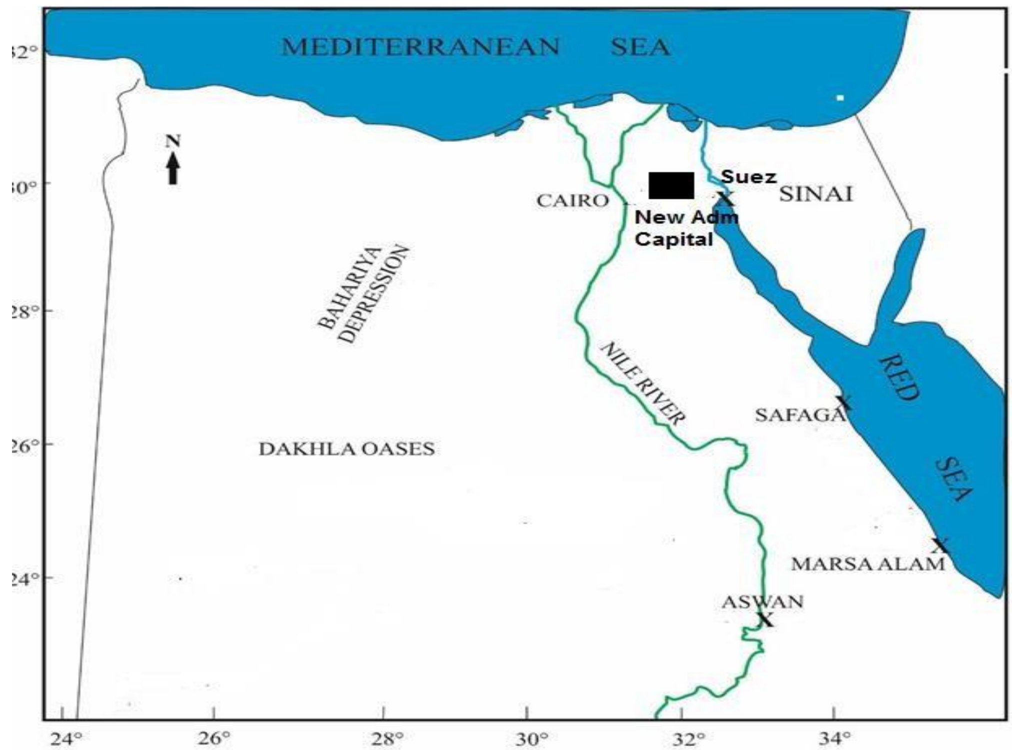

FIG. 1. Location of the New Administration Capital on Egypt map

The high rise building was designed to be rested on the basalt formation layer at a depth of 12.0 meter below natural ground surface as shown in figure 2.

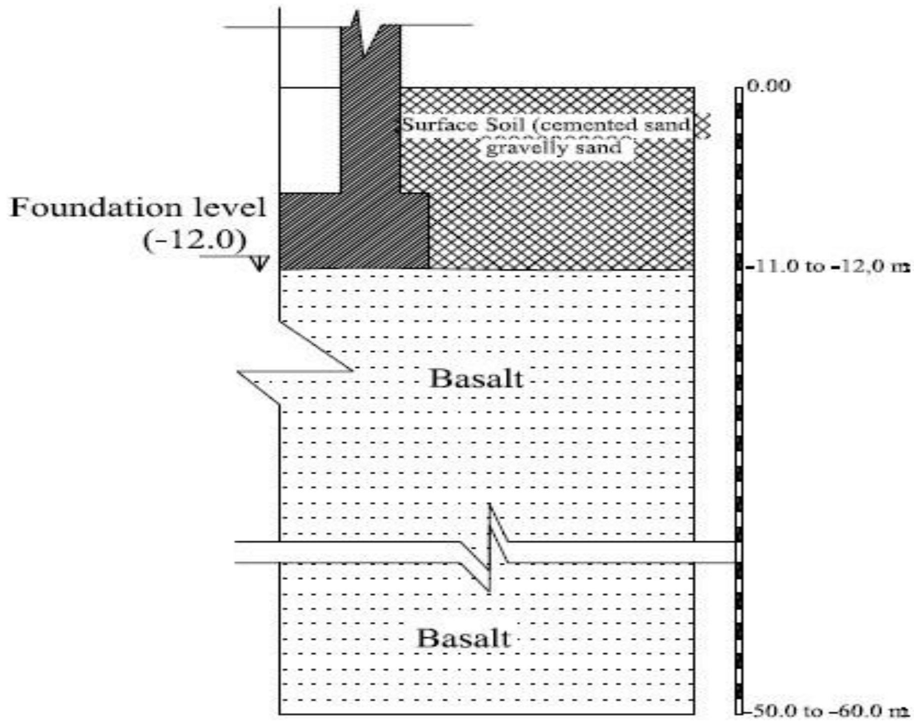

FIG. 2. Soil and rock formation of the study area of New Administration Capital region

Test Program

The study test program in the study area mentioned above consists of in situ and laboratory tests. The in situ tests used in this study consists of plate load tests (PLTs) and pressure meter tests (PMTs) which performed on the basalt rock formation located beneath the foundation level. Figure (3) shows the locations of the in situ tests performed at the site, where five locations for plate load tests and two locations for pressure meter tests as mentioned. The geological longitudinal cross section in figure (2) shows that, the bedrock layer of basalt started from 11.0 to 12.0 meter below the ground surface. All in situ tests performed below that level. Different laboratory tests were performed on the samples collected from the site. The unconfined compressive strength test of the intact core rock (UCST) was the test used in the present study.

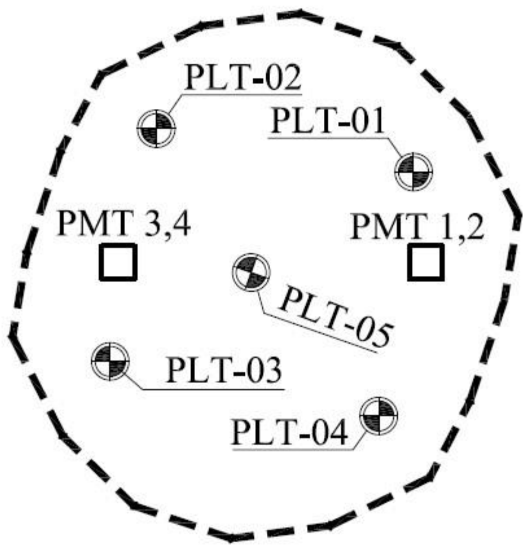

FIG. 3. Layout of the In situ tests of Plate load tests (PLTs) and Pressure meter tests (PMTs)

Results of Insitu Tests Plate Load Tests

Plate load tests are performed as shown in figure (3) in five locations as mentioned. Photo (1) shows the shape of the test during site work. The diameter of the plate was 900 mm and the tests performed on the basalt formation at level 12.0m below the ground surface. Figures (4-a to 4-c) show the test results relationship between the stress and settlement for three different stresses and the each stress of loading continued by an unloading to start the next loading stage of the next one. The loading test at each location continued up to three different stresses of 2000, 4000, and 6000 kPa respectively. Table (1) shows the value of the elastic modules of rock formation as calculated from equations (1-a, or 1-b) mentioned below (ASTM D4394).

$E = (1-\mu 2)\ P/(2\ \delta a\ R\ )$ ………(1-a) where

μ = poisson's ratio of the rock, P = total
load on the rigid plate, (kN),
δa = average deflection or settlement of the rigid plate, (mm)

R = radius of the rigid plate, (mm)

Photo 1. Plate load tests

Assuming that poisson's ratio of the basalt rock of average value equal to 0.22, equation (1) can be rewritten in the terms of the applied stress (σ) in kPa, as follows:

$$E = 1.5\ R\ \sigma / \delta a \quad \ldots\ldots\ldots \quad (1\text{-b})$$

The elastic modulus for basalt formation was calculate from the curves shown in figures 4-a to 4-c and its value was tabulated in table (1) which shows the value of deformation modulus at three different stresses 2000, 4000, and 6000 kPa for the three different loading tests at the five locations of tests.

Results showed that the value of basalt deformation modulus was increased at the same stress level with the increase of the loading test by percentage ranged between 38% and 175% as shown in Fig. 5-a, while it was decreased with the increase of cyclic of loading at each site by percentages ranged between 20% and 45% as shown in Fig.5-b, and table (1) illustrated the comparison of all results achieved from the different tests with the cyclic ones

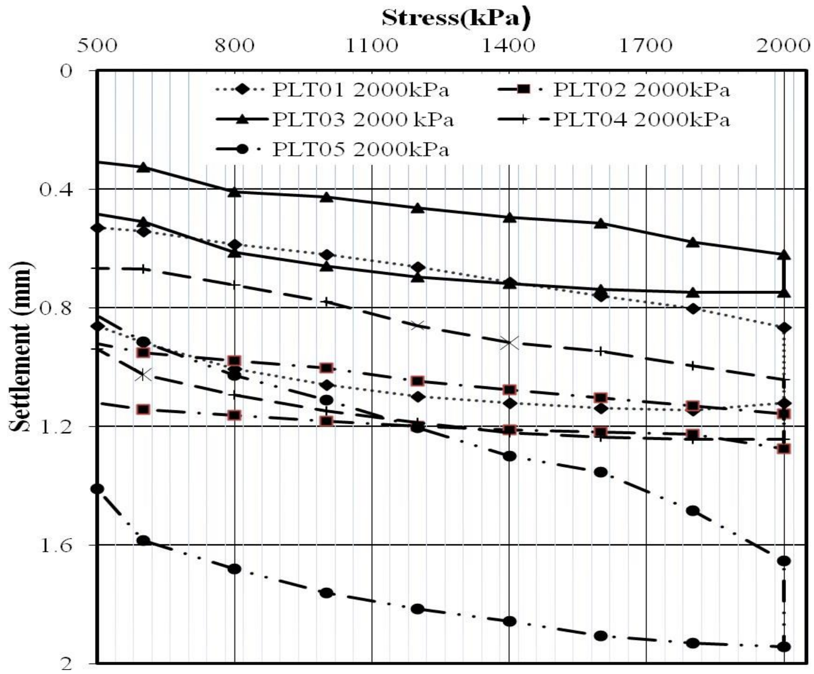

FIG. 4-a. Plate load tests (PLTs) up to 2000kPa

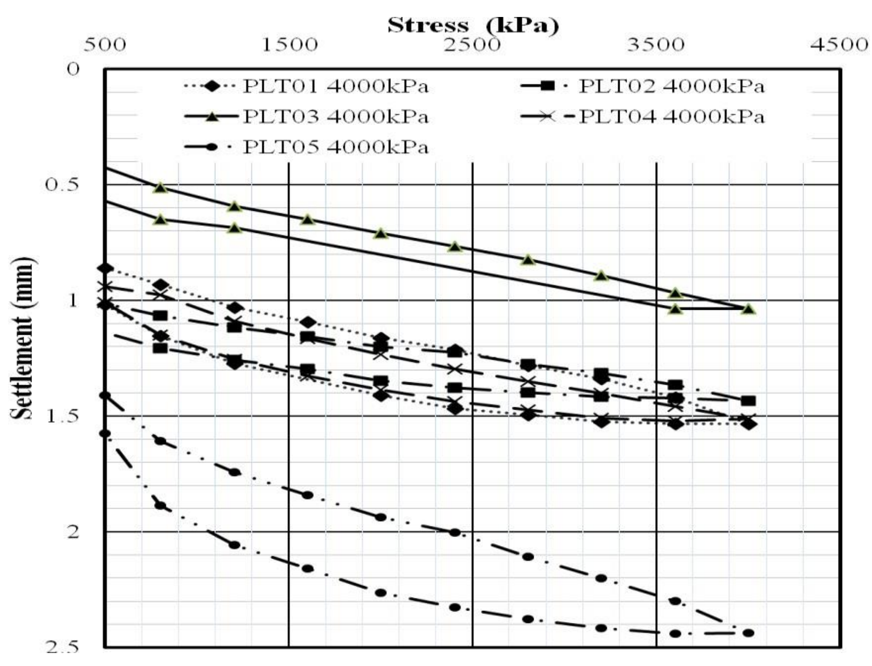

FIG. 4-b. Plate load tests (PLTs) up to 4000kPa

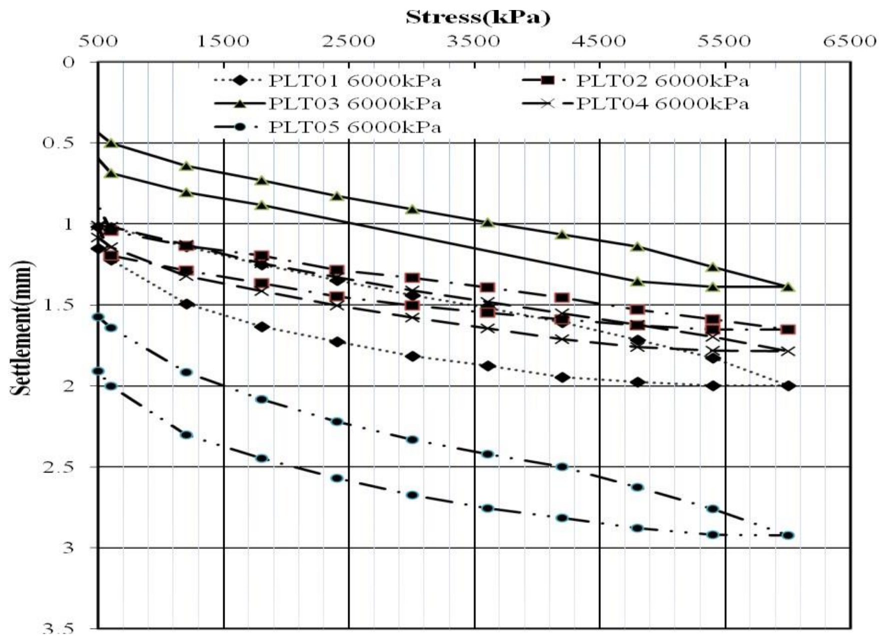

FIG. 4-c. Plate load tests (PLTs) up to 6000kPa

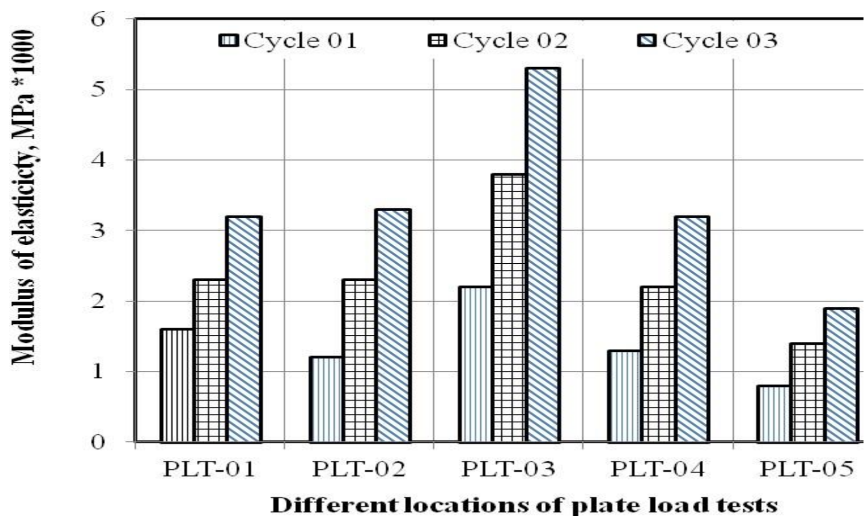

FIG. 5-a. Modulus of elasticity from PLTs at different locations

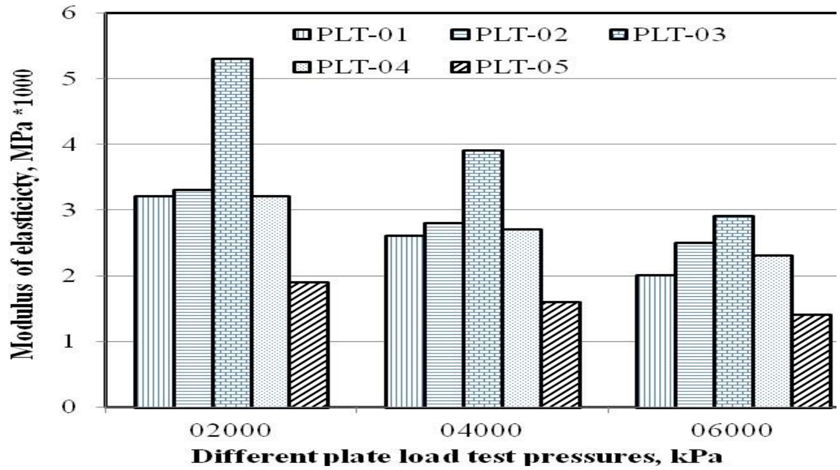

FIG. 5-b. Modulus of elasticity from PLTs at different pressures

Table 1. Modulus of elasticity of basalt at different cycle of loading

Test No.	E (MPa)					
	Max. stress 2000kPa	Max. stress 4000kPa		Max. stress 6000kPa		
	2000kPa	2000kPa	4000kPa	2000kPa	4000kPa	6000kPa
PLT-01	1.6	2.3	1.8	3.2	2.6	2.0
PLT-02	1.2	2.3	1.9	3.3	2.8	2.5
PLT-03	2.2	3.8	2.6	5.3	3.9	2.9
PLT-04	1.3	2.2	1.8	3.2	2.7	2.3
PLT-05	0.8	1.4	1.1	1.9	1.6	1.4

Pressure Meter Test

The Pressure meter Testing was carried out using an OYO Elastlogger-2 model 4022

Pressure meter and operated under the manufacturer's guidelines which are in general accordance with the ASTM D-4719. All tests were performed using 70mm NX size membrane. The Elastmeter-2 is new version of lateral load tester capable of testing wide range ground from soft rock to hard rock. Highly accurate transducers and related electrical circuitry are built into the probe to improve the measurement accuracy, reliability and operability. With the two arms stretched inside the rubber packer, the system converts the displacement with the inner radius of rubber packer into that representing the deformation with the borehole diameter. The Elastlogger-2 consists of a probe, a pump with pressure gauge and an electronic logger unit together with the umbilical hoses and electrical cables. A flexible, cylindrical bladder is lowered into the borehole and then inflated with water pressure provided by the pump at the surface. This bladder applies stress to the borehole walls and two calipers monitor the change in radius of the stressed part of the borehole. The water pressure is read directly from the pressure gauge on the pump. The readings of applied pressure and borehole radius are recorded by the digital logger at an interval of 60 seconds.

Figure (6-a) shows the ideal pressure-volume relationship achieved from field pressure meter tests (PMT) where, the value of the modulus of deformation can be deducted using (ASTM D4394) of equation (2) mentioned below.

$$Ep = 2(1-\gamma)\ (V_o + V_m)(\Delta P/\Delta V) \quad \ldots\ldots\ldots(2)$$

Where,

Ep =pressuremeter modulus,kPa, an arbitrary modulus of deformation as related to the pressure meter based on data reduction.

γ = poisson ratio, equal to 0.33

V_o = volume of the measured portion of the un-inflated probe at zero volume reading at ground surface

V_m = corrected volume reading at the center portion of the ΔV volume increase

V = corrected volume reading of the measuring portion of the probe

ΔP = corrected pressure increase in the center of the part of the straight line portion of the pressure-volume curve,

ΔV = corrected volume increase in the center of the part of the straight line portion of the pressure-volume curve, corresponding to ΔP pressure increased,

$V_o + V$ = current volume of inflated probe,

The pressure meter tests was carried out in two boreholes at depths of 33.0m and 39.0m for

PMT-1and PMT-2, respectively as shown in Fig. 7-a, and at depths of 45.0m and 51.0m for PMT-3 and PMT-4, respectively as shown in Fig. 7-b. The modulus of deformation predicted from the Pressure meter tests (PMT’s) showed that the modulus of deformation was ranged between 250kPa and 500kPa.

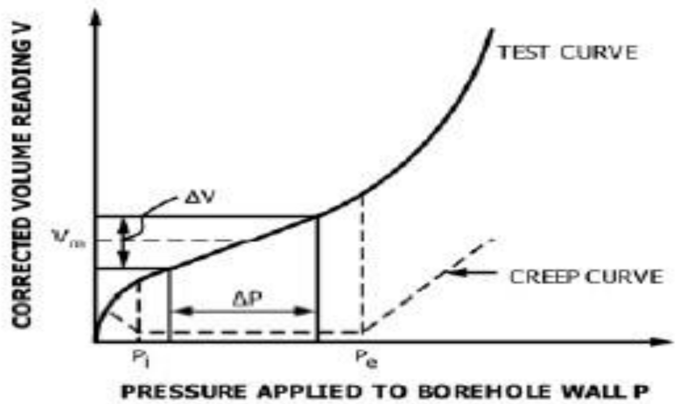

FIG. 6. Pressure-volume relationship representing PMT

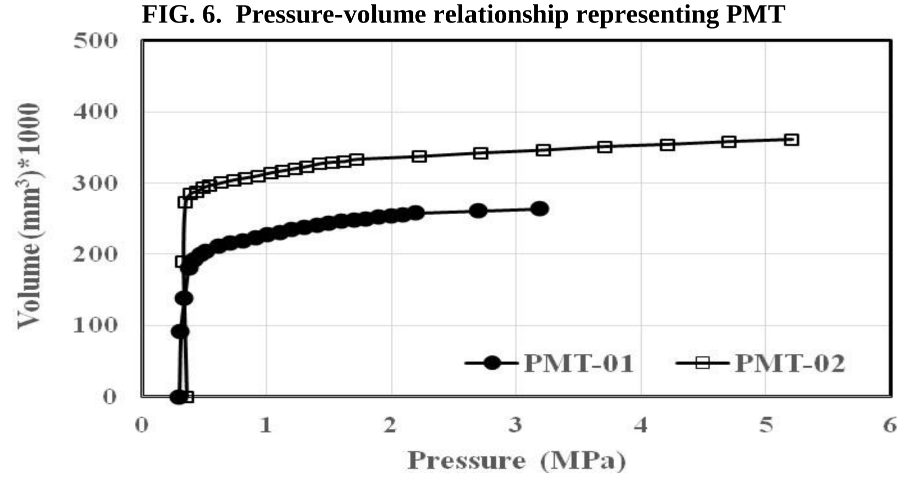

FIG. 7-a. Pressure meter tests at PTM-01 and PMT-02 locations

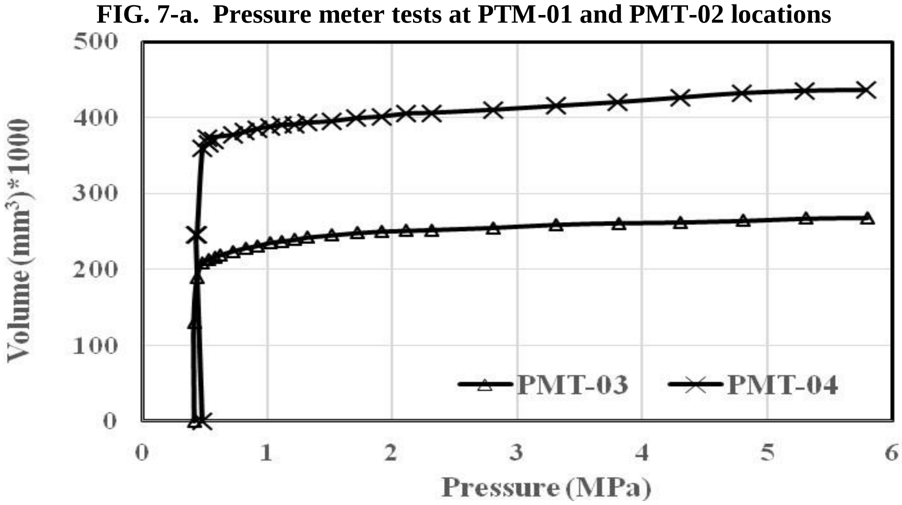

FIG. 7-b. Pressure meter tests at PTM-03 and PMT-04 locations

Unconfined Compressive Strength Tests (UCS)

The modulus of deformation was calculated in the laboratory using the unconfined compressive strength tests on most of the basalt samples collected from the different boreholes at site. The test was performed according to the ASTM, D7012 method. The trend line for the modulus of deformation of basalt rock predicted from laboratory USC tests was increased with depth as shown in figure 8.

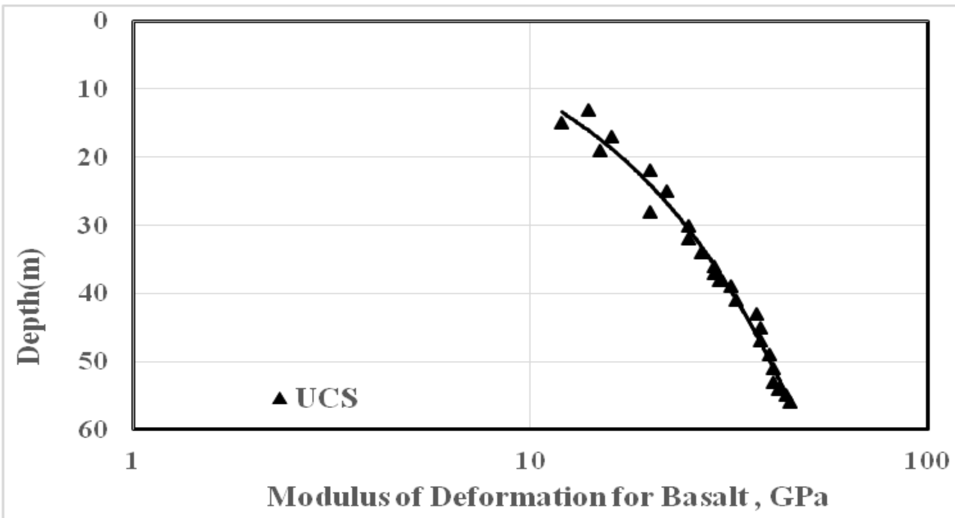

FIG. 8. Modulus of deformation from laboratory USC tests

Comparison between the Field and Laboratory Tests

The modulus of deformation was represented from the in-situ and laboratory as shown in Fig.9. From this figure it was illustrated that the laboratory tests using the UCS tests gives higher values of the modulus of deformation for basalt rock compared to the in-situ tests. The values of the modulus of deformation predicted from field plat load test (PLT) was located between the values of modulus of deformations predicted from the pressure meter tests (PMT) and the unconfined compressive strength tests (UCS). It was obvious that the laboratory tests give higher value of modulus of deformation more than the field laboratory tests. The modulus of deformation predicted from laboratory using UCS tests was 5 to 10 times and 50 to 100 times that predicted using PLT, and PMT, respectively. Thus, the pressure meter test was the lowest value of the modulus of deformation for the basalt rock which can be used for the design value for this rock formation. In spite that, the plate load test (PLT) is an easy and low cost test compared to the pressure meter test (PMT) but in the same time gives only modulus of deformation at the level of test layer. According to the different tests mentioned, the geotechnical engineer could choose the available tests in the project which could be used and can deduced the suitable value of the modulus of deformation used in the design according to the relation between the field and laboratory tests.

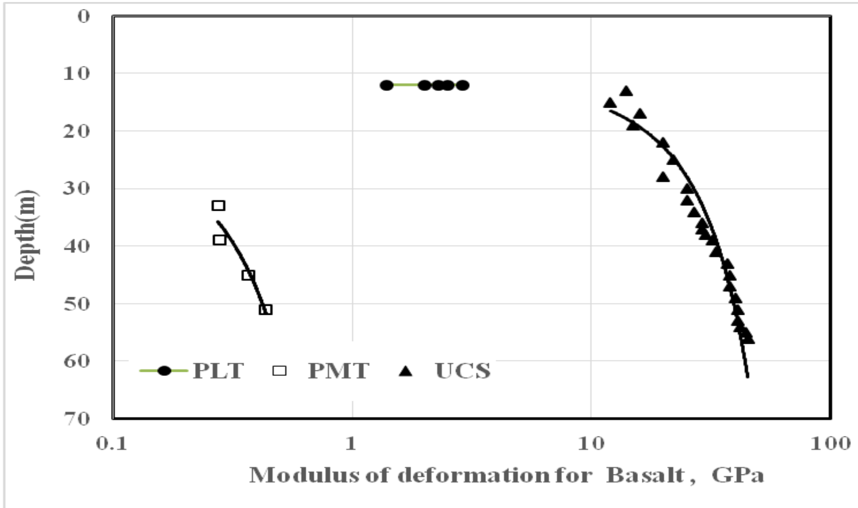

FIG. 9. Modulus of deformation from the in-situ and laboratory tests

Conclusions

In our study for the modulus of deformation for basalt rock formation of the study region at the eastern part of Cairo in Egypt, the following conclusions are summarized:

1- Plate load tests shows that, the deformation modulus was increased at the same stress level with the increase of the loading test by percentage ranged between 38% and 175%, while it was decreased with the increase of cyclic of loading at each site by percentages ranged between 20% and 45%

2- The modulus of deformation predicted from the Pressure meter tests showed that the modulus of deformation was ranged between 250kPa and 500kPa.

3- It was obvious that the laboratory tests give higher value of modulus of deformation more than the field laboratory tests.

4- The modulus of deformation predicted from laboratory using UCS tests was 5 to 10 times and 50 to 100 times that predicted using PLT, and PMT, respectively.

5- The pressure meter test was the lowest value of the modulus of deformation for the basalt rock which can be used for the design value for this rock formation.

6- The plate load test (PLT) is an easy and low cost test compared to the pressure meter test (PMT) but in the same time gives only modulus of deformation at the level of test layer.

7- The modulus of deformation used in the design for foundations established on the basalt formation should be well defined according to the results and the relation between the field and laboratory tests.

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