Estimating of dynamic modulus of elasticity for top soil layers by borehole seismic survey in industrial area of Sulaimani city, NE-Iraq

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Abstract

A near-surface geophysical study was conducted at Sulaimani city, NE-Iraq, using up-hole seismic technique in order to image shallow subsurface in terms of main dynamic elastic properties of soil and rock layers covering the study area. The arrival times of the propagated body (P-and S-) waves are measured within (1–2 m) interval in four boreholes in successive positions and the time-depth curves were plotted. The boreholes No.1 and No.2 were at western part and boreholes No.3 and No.4 at eastern part of the studied area. In the boreholes (1,2) the arrival times were measured down to approximately(12 m) but in the boreholes (3,4) the measurements had completed down to (16 m) depth. Then, the primary and shear wave velocities (Vp,Vs) and the dynamic modulus of elasticity including the poisson's ratio (σ) shear modulus (G) and elastic modulus (E) for the subsurface soil in the four boreholes were determined.

The results of the up-hole seismic survey in the boreholes (No.1) and (No.2) at the western part of the studied area showed the presence of two layers. The first layer extended down to the depth range (0–5 m) through this layer the Vp values ranged from (737 m/s – 870 m/s) and Vs from (400 m/s – 480 m/s), with relatively high values of (σ) ranged from (0.28 to 0.29) and relatively low values of both (G) from (3.50×10^8 N/m^2 – 5.01×10^8 N/m^2) and (E) from (8.91×10^8 N/m^2 –12.83×10^8 N/m^2). These values revealed to a non-cohesive soil layer.

while, the first layer in the boreholes (No.3) and (No.4) at the eastern part within the depths (0–10 m) showed the values of Vp, ranged from (1033 m/s–1127 m/s) and Vs from (665 m/s –705 m/s) and relatively lower values for (σ) ranged from (0.15) in borehole (No.3) to (0.17) in borehole (No.4). Also, the values of both (G) from (11.01×10^8 N/m^2) in boreholes (No.4) to (22.46×10^8 N/m^2) boreholes (No.3) and (E) from (10.62×10^8 N/m^2–25.77×10^8 N/m^2) in the boreholes (No.3) and (No.4) respectively referred that first layer in the eastern part more cohesive and consolidated sediments.

Furthermore, based on the derived seismic velocities and relative dynamic elastic values, the first layer in the eastern part of the study area was relatively cohesive and more suitable for engineering project, where as the soil composition of this layer in the western part varied and considered as non-cohesive sediment up to (5 m) depth and considered as non suitable for constructing high buildings. Also, the results revealed that the second layer in both parts of the area was specified as a consolidated and more cohesive soil layer for the borehole penetrated depths.

Keywords: Primary and shear waves, soil layers, dynamic modulus, seismic uphole technique.

حساب المعامل الديناميكي للمرونة لطبقات التربة السطحية بالمسح الزلزالي البئري في المنطقة الصناعية في مدينة السليمانية, شمال شرق -العراق

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الخلاصة

اجريت دراسة جيوفيزيائية في مدينة السليمانية ـ شمال شرق العراق لمعرفة الصفات الديناميكية الاساسية المرنة لطبقات التربة و الصخور بالقرب من السطح لمنطقة البحث باستخدام تقنية المسح الزلزالي البئري الصاعد. وقيس زمن وصول الامواج (P وS) و بعمق (1–2 م) متتالية في اربعة ابار و رسمت منحنيات الزمن ـ العمق.

يقع البئران (1) و (2) في الجهة الغربية و البئران (3) و (4) في الجهة الشرقية لمنطقة البحث. قيس زمن وصول الموجات في البئرين (1) و (2) الى العمق (12 م) و في البئرين (3) و (4) الى العمق (16 م) . حسبت سرع الموجات الانضغاطية (Vp) والقصية (Vs) و المعاملات الديناميكية المرنة في الابار الاربعة لطبقات التربة تحت سطح الارض. واظهرت نتائج المسح الزلزالي البئري الصاعد في البئرين (1) و (2) وجود طبقتين, الاولى تصل الى العمق (0–-5م), وتتراوح قيم (Vp) و (Vs) و نسبة بيوسون (σ) العالية نسبيا, ومعامل القص (G) ومعامل المرونة (E) الواطئتين نسبيا في الجهة الغربية بين (737–870 م/ثا)، (400–480 م/ثا)، (0.29–0.28)،(3.5–5.01 × 10^8 نيوتن/م^2)، (8.91 –12.83×10^8 نيوتن/م^2) على التوالي, و تشير هذه القيم الى طبقة غير متماسكة.

تشير القيم في البئرين (3) و (4) ايضا الى وجود طبقتين. يصل عمق الطبقة الاولى الى (0–10 م), وتتراوح قيم (Vp) و (Vs) بين (1033–1127 م/ثا) ، (665–705 م/ثا) على التوالي, وقيم نسبة بيوسون (σ) الواطئة نسبيا في كل من البئر (3) تساوي (0.15) وفي البئر (4) تساوي (0.17) , والقيم العالية نسبيا لكل من معامل القص (G) حيث تتراوح بين (11.01×10^8 نيوتن/م^2) في البئر (4) الى (22.46×10^8 نيوتن/م^2) في البئر(3) ومعامل المرونة (E) (10.62–25.77×10^8 نيوتن/م^2) في البئرين على التوالي, والتي تدل على انها طبقة من التربة الاكثر تماسكا.

بناء على الصفات الديناميكية وسرع الموجات المستحصلة المرنة وجد ان الطبقة الاولى الواقعة في الجهة الشرقية لمنطقة البحث متماسكة وملائمة اكثر نسبيا لبناء المشاريع الهندسية بينما اعتبرت مكونات التربة لهذه الطبقة في الجهة الغربية من الرواسب الهشة لحد خمسة امتار من السطح غير ملائمة لبناء المنشات الهندسية عليها. وتشير النتائج الى ان الطبقة الثانية في كلا الجزئين من منطقة الدراسة تعد من التربة المتصلبة و الاكثر تماسكا في الاعماق التي اخترقتها الابار.

الكلمات المفتاحية : الموجات الاولية والثانوية, طبقات التربة, المعاملات الديناميكية, تقنية المسح الزلزالي الصاعد

1. Introduction

Among different geophysical methods, the use of borehole seismic technique has distinct advantages. It can give in-situ measurements for dynamic elastic properties of soil and rock layers for shallow investigations encountered by foundation engineering projects (Hamdi et. al., 1996). Uphole seismic refraction can be conducted to determine the thickness of the strata and velocities of the waves with a view of ascertaining the suitability of these layers for data acquisition and engineering structures (Adeoti et al., 2013).

Accordingly, the velocities of the primary wave (Vp) and shear wave (Vs) were used in determining the dynamic-elastic modulus (Al–Khafaji, 2004). The first type of body wave is a compression wave through which its particles propagation with higher velocity; here the stresses in the wave are due to constrained uniaxial compression. While the second type of body wave is shear wave in which particle motion is perpendicular to the direction of propagation, during the passage of the shear wave through the medium is subjected to a shearing stress (Khan, 2013). Moreover, the generated body waves by the source (Hammer pivoted to a piece of wood) can be used to determine the elasticity of the successive layers after propagating through these layers. Seismic wave propagation in soils and rocks can be interpreted in different constitutive schemes leading to different degrees of approximation of the actual soil behavior (Taylor and Francis group, 2013)

The studied area covers ($50km^2$) with (10x5) km length and width. It is located at southwestern part of Sulaimaniya city, NE-Iraq between Latitude (35^o 27^-–35^o 35^- N) and Longitude (45^o 19^--45^o 30^- E) (fig.1). In this investigation the P- and S-wave velocities and the depths of shallow subsurface soil layers were determined with addition to the estimation of the principal dynamic modulus of elasticity of the soil.

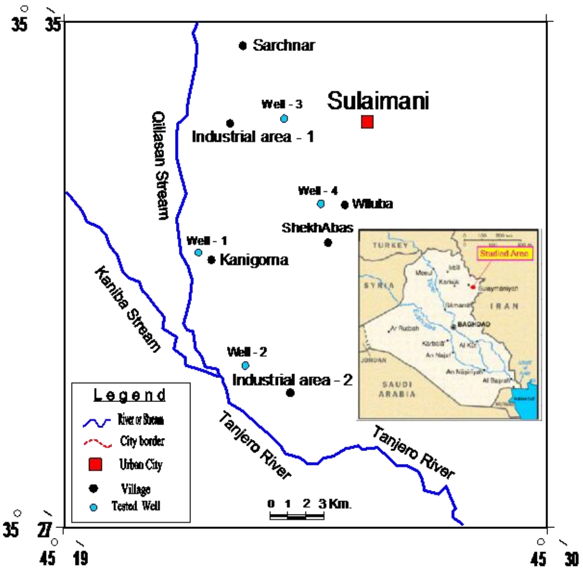
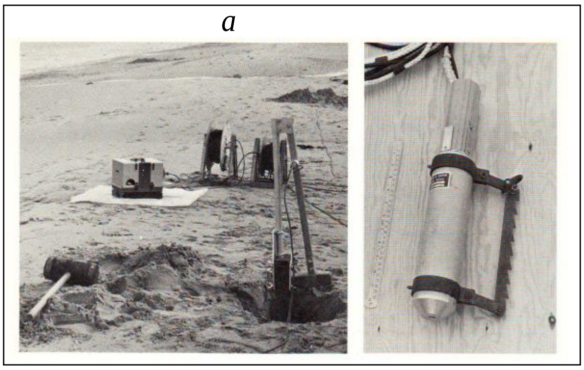


Fig.(1) Showing the study area with the four boreholes locations

2. Borehole instrumentation

In this study, ABEM multi-pulse energy source had been used, which consists of ground pole, an impact hammer and a hammer support. The energy source is driven (50cm) vertically into the surface material and the hammer pivoted above it. ABEM Teralloc Seismic device is connected to three component geophone arranged in an X-Y-Z pattern, two orthogonal horizontal geophones are used to detect shear-wave (S-wave) arrivals and a vertical geophone is used to detect compression-wave (P-wave) arrivals, through cable. The geophone in borehole is fixed and fitted against the wall of the tested borehole with a clamping devices, so that a good attaching can be made between the geophone and the medium as shown fig.(2a).

When the hammer is made to strike the side of the ground pole mainly shear waves are generated. By the impact direction through (180^o) the horizontally polarized shear wave will be at (180^o) phase reversal in polarity on Seismograph as shown in fig.(2b).



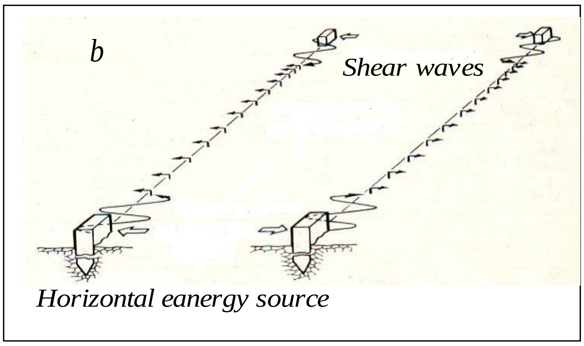


Fig.2 Shows (a) borehole survey instruments (b) the phase reversal in polarity on the Seismograph

Borehole survey procedure consists of measuring the time for seismic waves generated by an impulsive source at the surface to travel for a geophone moved uphole at successive positions, and detecting by Seismograph, fig.(3).

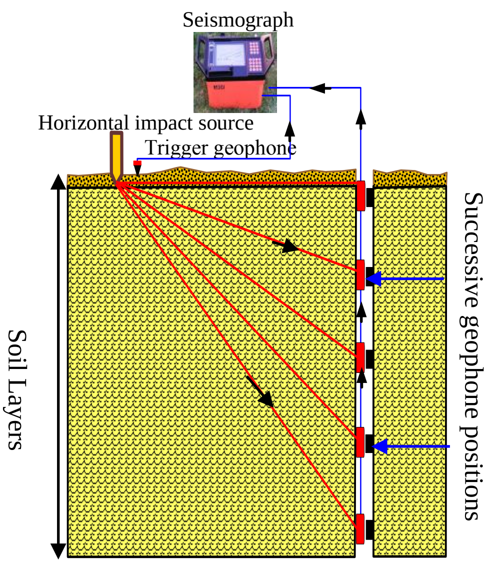


Fig.(3). Generating waves from horizontal energy source to the successive geophone depths

The survey was carried out in four distributed boreholes throughout the area of study and in each borehole the arrival times of shear and compressional waves were measured within (1–2 m) interval at successive positions up to maximum depth (16 m**).**

3. Data analysis

By a known horizontal distance (X) for the surface source up to the top of the receiver hole with a known depth (Z) of detector in the hole, the slant time (Ts) can be converted into a vertical time (Tz) by the following relation (Telfod et al, 1990).

$$\mathbf{Tz = T_S\, Z / \sqrt{Z^2+X^2}}$$

The vertical velocity therefore is given by:

$$\mathbf{V_Z = Z / Tz}$$

and the slant range $=\sqrt{\mathbf{Z^2+X^2}}$

The interval velocity was derived from the time-depth (T–Z) curves for the compression and shear waves by getting the inverse slope (T-Z) curves. These computations had been done because the critical velocity requires an isotropic condition and an absence of boundaries between source and detector particularly when the depth (Z) is comparable to or less than horizontal distance (X), and these conditions could not be obtained.

The measured slant times were picked in the field on the seismic records and converted to vertical times, as shown in the tables (1,2,3 and 4). The vertical times were used in determining the compression and shear wave velocities by taking the inverse slopes using the least square curve fitting technique, as shown in fig.(4,5,6 and 7).

According to the elastic wave propagation theory, if the longitudinal, transverse wave velocities and rock density are known, the dynamic elastic modulus Poisson's ratio can be calculated (Meng et al, 2006). Subsequently, elastic modulus and shear modulus of elasticity have been computed through the following equations (Chien, 2000); (Osman, 2010)**:**

$$\boldsymbol{\sigma = \frac{\frac{1}{2}(Vp / Vs)^2 - 1}{(Vp / Vs)^2 - 1}}$$

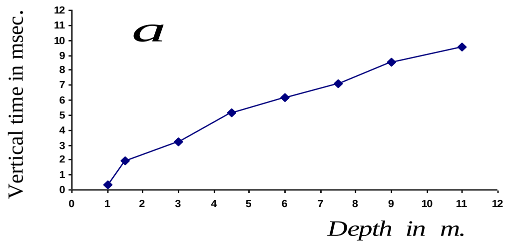
$$\mathbf{E = 2V_s^2\, \rho\, (1+ \sigma)}$$

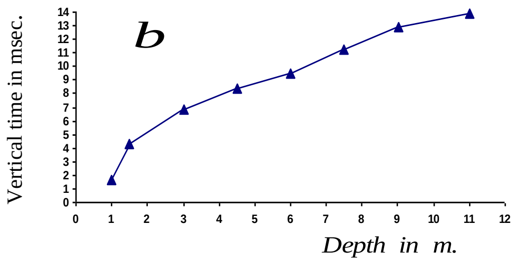
$$G = \rho V_s^2$$

Where σ is poisson's ratio, ρ is the density, E is the elastic modulus and G is the shear modulus. The values of ρ were measured in the lab. after taking the samples for the successive depths in each borehole. From the above equations the shear wave velocity (Vs) is independent on porosity and pore fluid, where as the compression wave velocity (Vp) is a good detector of pore fluid and gas (Telfod et. al, 1990). The internal software of the computerized instrument had been used in recording the time interval values.

4. Results

Fig.4 and table-1 show the result of seismic measurements from borehole No.1



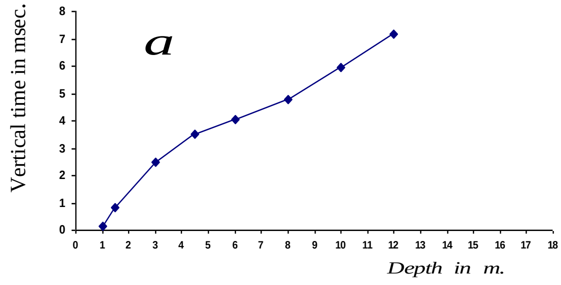


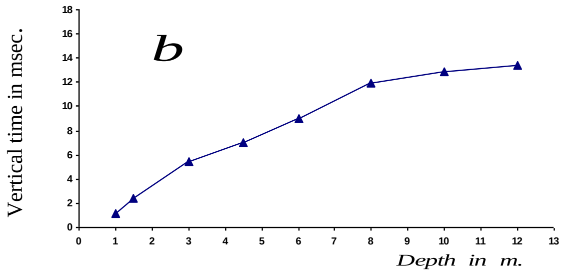
Fig,(4) Time - Depth curve for (a) primary wave (b) shear wave in borehole No.1

Table-1 The results of seismic measurements

B.H-1		P-wave		S-wave	
Depth	Slant range	Slant time	Vertical time	Slant time	Vertical time
m.	m.	msec.	msec.	msec.	msec.
1	1.41	0.48	0.34	2.4	1.7
1.5	2.23	2.16	1.93	4.8	4.3
3	3.16	3.36	3.19	7.2	6.83
4.5	4.61	5.38	5.15	8.64	8.43
6	6.08	6.24	6.16	9.6	9.47
7.5	7.56	7.2	7.14	11.28	11.19
9	9.05	8.6	8.55	13	12.92
11	10.21	9.6	9.55	14	13.93

Fig.5 and table-2 show the result of seismic measurements from borehole No.2



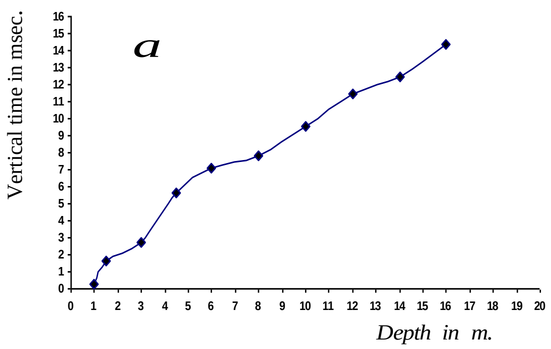


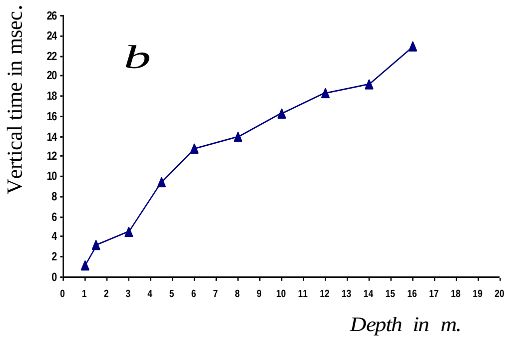
Fig,(5) Time - Depth curve for (a) primary wave (b) shear wave in borehole No.2

Table-2 The results of seismic measurements

B.H-2		P-wave		S-wave	
Depth	Slant range	Slant time	Vertical time	Slant time	Vertical time
m.	m.	msec.	msec.	msec.	msec.
1	1.41	0.24	0.17	1.7	1.2
1.5	1.8	1	0.83	2.88	2.4
3	3.16	2,64	2.5	5.7	5.41
4.5	4.6	3.6	3.52	7.2	7.04
6	6.08	4.1	4.04	9.12	9
8	8.06	4.8	4.76	12	11.9
10	10.04	6	5.97	12.96	12.9
12	12.04	7.2	7.18	13.44	13.39

Fig.6 and table-3 show the result of seismic measurements from borehole No.3



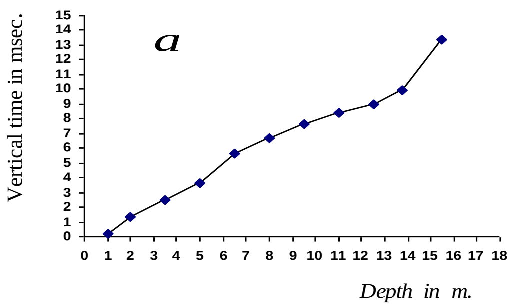


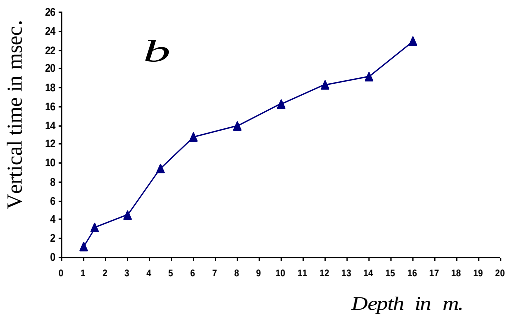
Fig,(6) Time - Depth curve for (a) primary wave (b) shear wave in borehole No.3

Table-3 The results of seismic measurements

B.H-3		P-wave		S-wave	
Depth	Slant range	Slant time	Vertical time	Slant time	Vertical time
m.	m.	msec.	msec.	msec.	msec.
1	1.41	0.16	0.25	1.68	1.19
1.5	1.8	1.92	1.6	3.84	3.2
3	3.16	2.88	2.73	4.8	4.55
4.5	4.6	5.76	5.63	9.6	9.39
6	6.08	7.2	7.1	13	12.82
8	8.06	7.9	7.84	14	13.89
10	10.04	9.6	9.56	16.3	16.23
12	12.04	11.5	11.46	18.3	18.24
14	14.03	12.5	12.47	19.2	19.16
16	16.03	14.4	14.37	23	22.96

Fig.7 and table-4 show the result of seismic measurements from borehole No.4





Fig,(7) Time - Depth curve for (a) primary wave (b) shear wave in Borehole No.4

Table-4 The results of seismic measurements

B.H4		P-wave		S-wave	
Depth	Slant range	Slant time	Vertical time	Slant time	Vertical time
m.	m.	msec.	msec.	msec.	msec.
1	1.41	0.24	0.17	1.8	1.28
2	2.23	1.5	1.34	3.36	3
3.5	3.64	2,6	2.5	3.8	3.65
5	5.09	3.66	3.59	6.4	6.29
6.5	6.58	5,7	5.63	9.6	9.48
8	8.06	6.7	6.65	10.5	10.42
9.5	9.55	7.7	7.66	13.9	13.82
11	11.04	8.5	8.45	15	14.94
12	12.53	9	8.98	16.8	16.76
14	13.78	10	9.98	17.6	17.46
16	15.43	13.44	13.41	19.2	19.16

The results of the measured (Vp) and (Vs) as well as the dynamic modulus of elasticity Poission ratio (σ), Shear modulus (G) and Young modulus (E) for ranges up to (16 m) depth in four Boreholes, as well as the values of (ρ) were measured in the laboratory, after taking the samples for the successive depths in each borehole, then taking the average values for a rang of depths as shown in Table (5).

Table (5). The calculated values of Dynamic Modulus of Elasticity in surveyed Boreholes

Boreholes	Depth h	Vp	Vs	ρ	σ	G	E
	m	m/s.	m/s.	Kg / m^3		$N / m^2 \times 10^8$	$N / m^2 \times 10^8$
B.H. 1	0 – 5	737	400	2176	0.28	3.50	8.91
	6 – 11	1290	851	2176	0.10	15.75	34.60
B.H. 2	0 – 5	870	480	2176	0.29	5.01	12.83
	6 – 12	2000	990	2226	0.33	21.81	58.03
B.H. 3	0 – 10	1033	665	2216	0.15	22.46	9.80
	11 –16	1579	790	2440	0.33	15.18	40.40
B.H. 4	0 – 10	1127	705	2216	0.17	11.01	25.77
	11– 16	1750	970	2440	0.27	22.95	58.31

5. Conclusions

The primary and shear wave velocities are powerful soil parameters representing a family of geotechnical soil parameters. Extensive borehole and laboratory testing of soil samples would no longer be needed if the shear and primary velocities are measured as accurately as possible right under the foundation level. Then the allowable bearing pressure, various other elasticity modulus as well as the approximate value of the unit weight can be determined, for the designing of any construction project.

The results of uphole survey will refer to the presence of two soil layers, the first in boreholes (No.1) and (No.2) located in the western part of study area and extended nearly down to the depth (0–5 m). Through this layer the Vp values from (737 m/s to 870 m/s) and Vs from (400 m/s to 480 m/s), with relatively high values of (σ) ranged from (0.28 to 0.29) and relatively low values of both (G) from (3.50×10^8 N/m^2 – 5.01×10^8 N/m^2) and (E) from (8.91×10^8 N/m^2 – 12.83×10^8 N/m^2). These values are reveal for a non-cohesive soil layer. While the second layer extended to the depths range (6–12 m) with the values of Vp ranged from (1290 m/s – 2000 m/s) and Vs from (851 m/s – 990 m/s) with relatively lower values of (σ) from (0.10 – 0.33) and higher values of both (G) from (15.75×10^8 N/m^2 – 21.81×10^8 N/m^2) and (E) from (34.60×10^8 N/m^2 – 58.03×10^8 N/m^2) respectively, which is refer to the presence of a cohesive soil layer.

Accordingly, the first layer in the boreholes (No.3) and (No.4) at the eastern part within the depths nearly (0–10 m) showed the values of Vp, ranged from (1033 m/s –1127 m/s), Vs from (665 m/s – 705 m/s) and relatively lower values for (σ) ranged from (0.15) in borehole (No.3) to (0.17) in borehole (No.4). Also, the values of both (G) from (11.01×10^8 N/m^2) in boreholes (No.4) to (22.46×10^8 N/m^2) boreholes (No.3) and (E) from (10.62×10^8 N/m^2 –25.77×10^8 N/m^2) in the boreholes (No.3) and (No.4) respectively is indicate the first layer in the eastern part was cohesive and compact. In general, the results revealed that the second layer in both parts were specified as a cohesive soil and were suitable for designing construction projects even at the depth lower than (10 m). Moreover, from the penetration data of the boreholes, the second layer had reached to nearly (16 m) depth.

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