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Integrating Geophysical and Geotechnical Methods to Optimize Foundation Design of a Power Station Site in Basrah, Iraq

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ABSTRACT

The geotechnical soil investigation in Al-Siba District in southern Iraq for a Gas Power Plant Project reveals soft to very soft silty clay soil with varying elastic moduli values across different depths. The soil is divided into six layers, with modulus values ranging from 342.23 m/sec to 548.02 m/sec and 215.43 m/sec to 307.73 m/sec starting from 1.0 to 24.0 m depths, respectively. The Poisson's ratio and Young's modulus values are found to be between 0.21 and 0.325 in BH.3, with the minimum and maximum values being 74.5 and 171.5 MPa. The study has identified zones of weakness at depths of 5-19 meters based on low N-values (Number of blows). The foundation soil demonstrated the ability to withstand double the design load without settlement. Plate load tests and elasticity theory results aligned closely, indicating allowable bearing capacity values between 13 to 25.5 T/m2. A strong correlation is found between subgrade reaction and permanent deformation moduli. Overall, the site's soil characteristics and gas production potential support the recommendation for implementing the Gas Power Plant in Al-Siba District.

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دمج الطرق الجيوفيزيائية والجيوتكنيكية لتحسين تصميم الأساس لموقع محطة كهرباء في البصرة، العراق

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الملخص

اجري فحص هندسي لتقييم تربة موقع لإنشاء محطة لتوليد الكهرباء في منطقة السيبة جنوب العراق. اشتملت الدراسة على تقنية الانكسار الزلزالي عبر الفتحات واختبارات تحميل الألواح لتقييم معاملات المرونة والخصائص الجيوتقنية للتربة. تم تقسيم التربة إلى ست طبقات تتراوح قيم معاملات المرونة فيها من 342.23 م/ثانية إلى 548.02 م/ثانية و 215.43 م/ثانية إلى 307.73 م/ثانية تبدأ من 1.0 إلى 24.0 م على التوالي. وجد ان تربة الموقع تقع ضمن الطين الغريني الضعيف الى ضعيف جدا . تراوحت نسبة بويزون مابين 0.21 و 0.325 ، وكان الحد الأدنى والحد الأقصى لقيم معامل يونغ 74.5 و 171.5 ميكا باسكال على التوالي في الحفرة رقم3. وان معامل التقلص الحجمي الذي يصف تشوه التربة تحت حمولة معينة 183 في الحفرة رقم.1 و 533.8 في حفرة.3. كانت قيمة معامل يونك للمواد الصلبة عالية، بينما كانت القيم المنخفضة للمواد الاقل صلابة. تم تقسيم التربة تحت السطحية إلى ست طبقات . كانت الطبقات باعماق تتراوح من 5 إلى 19 مترا ذات قيم اختراق قياسي Standard Penetration Test, (SPT) منخفضة (1.5–2) تمثل مناطق ضعف في التربة. كان الحد الأقصى للهبوط – 3.7 ملم عند 61 طن/م 2 ، مما يشير إلى أن تربة الأساس يمكن أن تتحمل ضعف حمل التصميم المتوقع دون هبوط. كانت تجارب اختبار تحميل اللوحة ونتائج نظرية المرونة قريبة من بعضها البعض مع قيم قدرة تحمل مسموح بها تتراوح من 13 إلى 25.5 طن/م2. لوحظت علاقة قوة قوية بين رد الفعل الارضي ومعامل التشوه الدائم ، مع معامل ارتباط R2 يساوي 1. في الختام ، يوصى بتنفيذ محطة توليد الكهرباء بالغاز في منطقة السيبة نظرا لخصائص التربة الملائمة لذلك وإمكانية إنتاج الغاز .

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Introduction

Geophysical methods have been used successfully in recent years for civil engineering purposes related to soil investigation and foundation. The cross-hole seismic refraction method is the most common method of geophysical exploration. It has critical applications in engineering investigations, as it is used in determining the depths and quality of rock layers and detailed investigations of the sites of tunnels, dams, and mega projects because of excellent penetrability and high-accuracy interpretation (Al-Zubaidi et al., 2022). They are non-destructive test methods for locating subsurface weak zones and determining dynamic elastic moduli. (Mohsain and Al-Khalidy, 2022; Saify and Al-Khalidy, 2023). The study area in Basrah Governorate, at Al-Siba District in Basrah Governorate is severely damaged due to many circumstances resulting in subsurface soil settlements. The settlements caused many problems for the subsurface utilities (like pipes, cables, channels, etc.). Cross-hole seismic refraction is one of the methods that can be considered suitable for such a problem. Yet, there are certain restrictions to using this procedure, notably in Basrah's soil conditions. With the reconstruction of Iraq, particularly in the Basrah area, there is an urgent need for cross-hole seismic techniques for identifying and monitoring subsurface utilities in areas where the water table is shallow, and the soil is composed of clay, silt, and sand with high salt content. Zahraa et al. (2023) and Jaafar et al. (2024) outlined superficial subsurface layering. Using seismic refraction tomography and multi-channel evaluations of shear wave techniques, they determined their geotechnical properties in the Al-Bayt University Campus in Mafraq, NE, Jordan. The main objectives of this investigation are to obtain the elastic moduli, the underlying geotechnical engineering foundation (using cross-hole seismic refraction), and the plate load test of the study site located in Basrah Governorate, Siba District, southern Iraq.

Geology and Tectonic Settings

The geology of the studied area is marked by the existence of Quaternary deposits covering the Pleistocene period - Holocene Mesopotamian plain regions in Iraq. (Al-Siyab, et al. 1982; Al-Heety, et al. 2016). The studied area comprises alluvial and floodplain deposits, representing the Dibdibba Formation (Quaternary deposits). The Dibdibba Formation is widely exposed in southern Iraq and is slightly inclined towards the northeast, forming the Dibdibba Plain. This formation belongs to the Upper Miocene-Pliocene Cycle, whose sediments are generally characterized by a gradual change from marine sediments to estuary and river sediments, as their quantities and grain sizes increase from the oldest to the youngest, in addition to being almost devoid of significant fossils (Al-Dabbas et al., 1989; Al-Ameri et al., 2011). The formation is also distinguished by the inclusion of mud lenses, which reflect a quiet sedimentation environment in closed or semi-closed local basins within the deltaic environment, which may have been affected by tides due to its proximity to the sea during the late Miocene (Buday and Jassim, 1987). The relevance of Quaternary deposits is becoming a basis for many engineering and building deep or shallow foundations.

This type of foundation works in Basrah City and is the source of numerous underground water reservoirs (Hatzfeld and Molnar, 2010). Three boreholes (BH.1, BH.2, and BH.3) were drilled in the study site during the year 2021. The typical stratigraphic column for this site mainly consists of sandy, silty clay in shallow depth and silty sand in moderate depth, as shown in Figure 1 below.

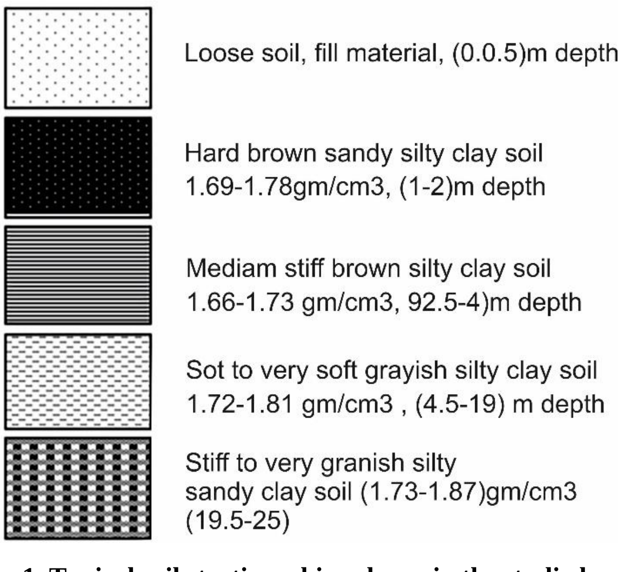

Fig. 1. Typical soil stratigraphic column in the studied area

Depending on the longitudinal and transverse tectonic divisions of Iraq, the location of the research area is in the southeastern part of the unstable shelf belonging to the Basrah block / Zubair sub-zone and forming a part of the Mesopotamian sedimentary plain. The research site is inside the Basrah block, the southern sub-block of the Al-Batin boundary, and the Takhadid-Qurna transverse fault at the north (Fig. 2). The Zagros complex represents a youthful collisional orogeny, where many shallow and deep mechanisms of continental deformation and mountain construction are underway. (Al-Kadhimi et al., 1996). The study area is considered one of the tectonically calm areas. Still, approximately in the last five years, the region was exposed to many earthquakes whose values ranged between 1-4.5 degrees on the Richter scale, which were represented by aftershocks resulting from the collision between the Arabian and the Iranian plate and the formation of the Zagros Mountains since the Miocene.

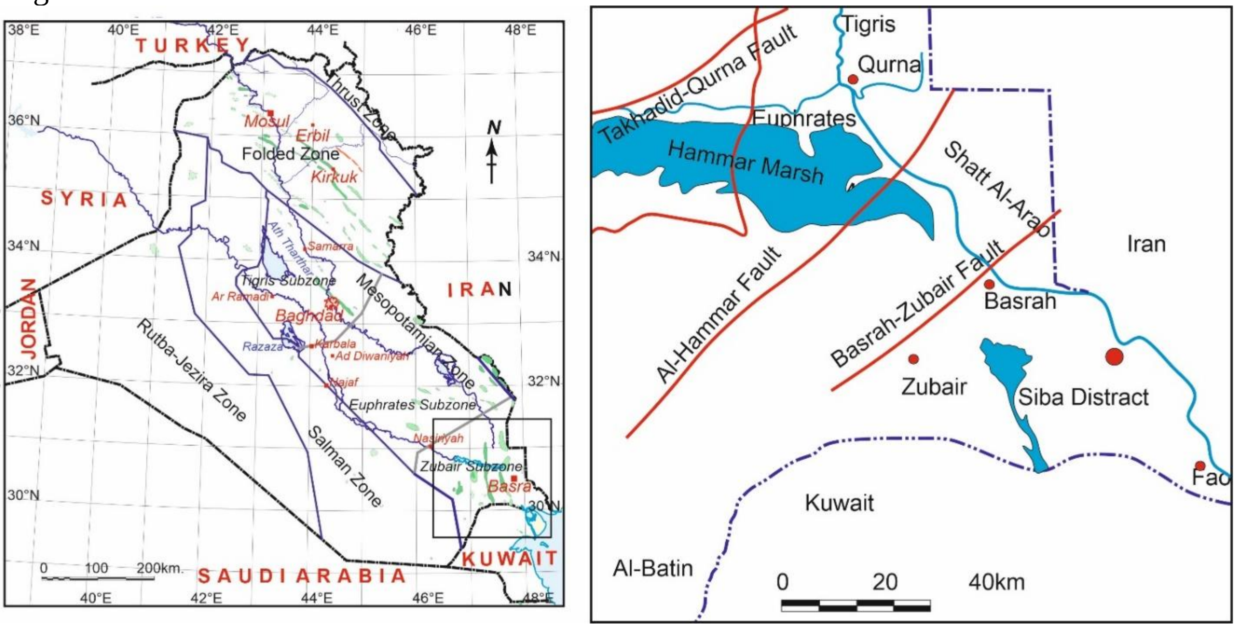

Fig. 2. Tectonic map of Iraq (left), Location of the study area (right) within the Basrah block division, modified from Al-Ameri et al., 2014.

Materials and Methods

The approach used to meet the aims of the current study is outlined in the chart below (Fig. 3). In this study, down cross-hole seismic refraction and plate load engineering tests are done as follows:

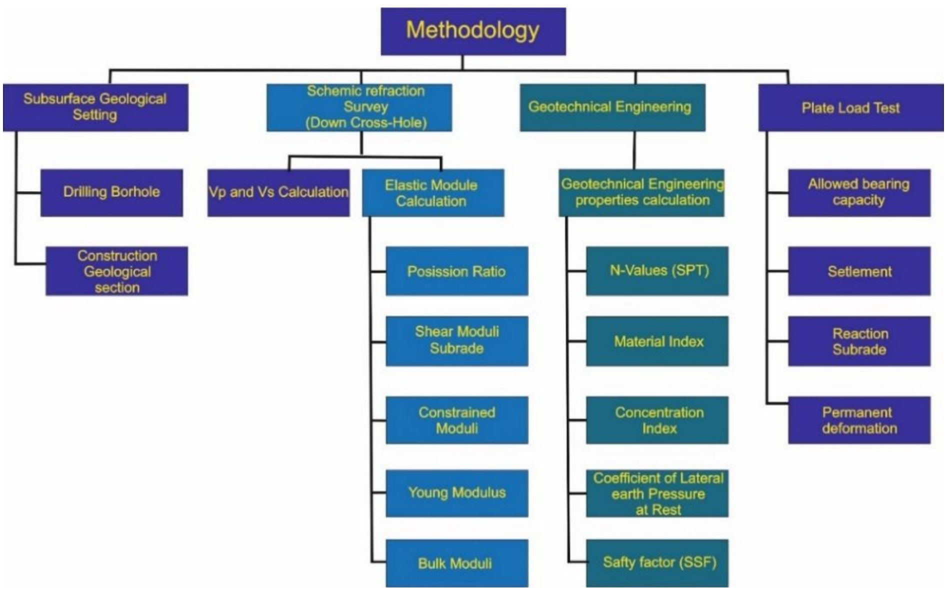

Fig. 3. Flow diagram indicating the adopted approach used in the study site.

Seismic refraction survey in boreholes

Three boreholes were drilled to 24 m depth to allow the performance of this seismic refraction survey (Fig. 4). The coordinates of these boreholes are illustrated in Table 1. Geophone orientation must remain fixed for all depths to ensure the proper wave type, which is recorded and analyzed. One or two tri-axial geophones are used as receivers. The horizontal (tangential) component is used to record horizontally polarized shear (S_h) waves (Uyanik, 2010). The cross-hole seismic refraction survey was designed and carried out to determine the variations of in situ V_p and V_s of soils and rocks with depth at a selected site in Al-Siba Field, Basrah Governorate, southern Iraq, using Olson Instruments WinGeo in addition to their geotechnical properties based on Dobrin and Savit (1988) and Kennedy et al. (2024).

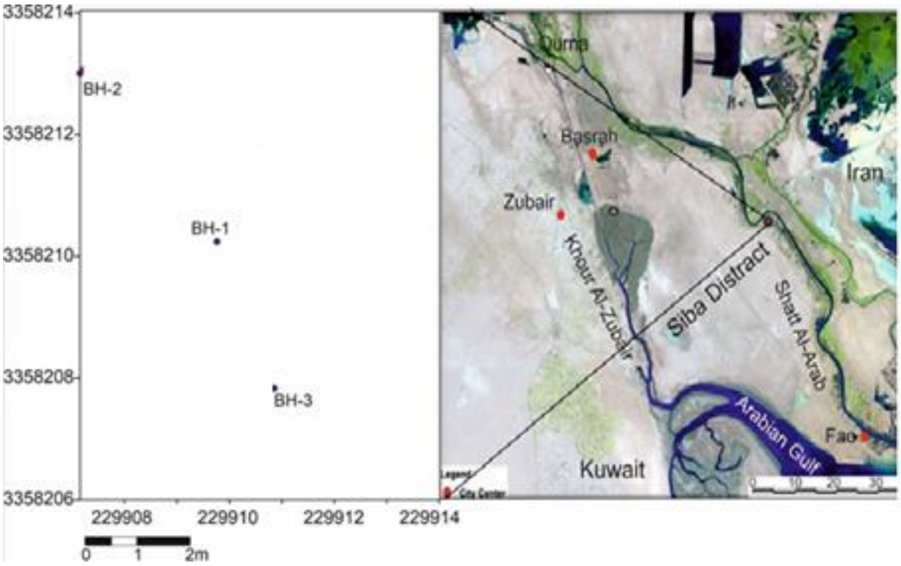

Fig. 4. Landsat satellite image of the study area showing the drilled boreholes BH.1, BH.2 and BH.3.

(a) **(b)**

Fig. 5. Photos of seismic test in the study site.

Table 1: Study site's distances and locations of the drilled boreholes.

BH. No	Coordination using UTM (meter)	
	Easting	Northing
1	229909.7	3358210
2	229907.2	3358213
3	229910.3	3358207

At this study site, the method is used for both P- and S-wave velocities separately. A source capable of producing shear and compressional waves is decreased in BH.1, and a pair of corresponding three-component geophone receivers is brought down to the identical depth in BH.2

and BH.3, which are distributed evenly in a line generally between 10 and 20 feet away from the drill source to conduct a detailed survey of the area. The receivers are set up on the borehole casing's side to detect shear and compressional waves. A three-component geophone is placed at the same elevation in the reception hole to receive the seismic signal as an elastic wave.

Plate Load Test

The plate load test results show that the foundation can be shallow or deep. However, the key criteria that influence these tests include water level, shear strength, permeability, soil density, angle of internal friction, and void ratio. (Ameen, 2006).

A linear equation can be extracted from the plot between subgrade reaction and permanent deformation of moduli or this test. The test was carried out in August 2015 in five locations and conducted at the site under study. It is performed according to the ASTM D-1194- 2003. The hearing test, as shown in Figure 6.

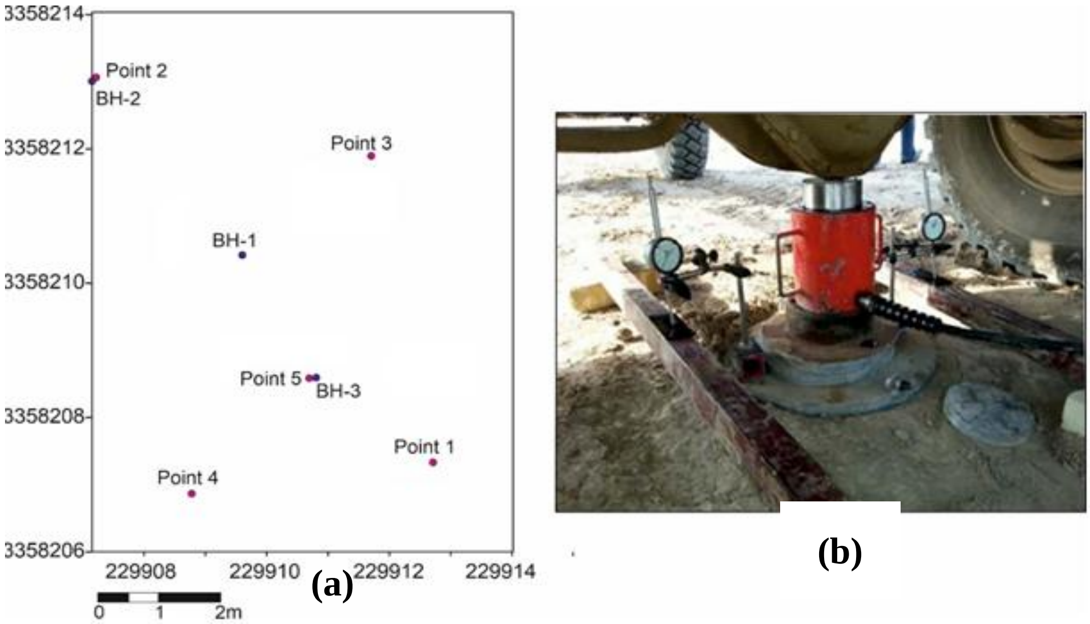

Fig. 6. (a) Base map of the study site showing five plate load test points and boreholes. (b) Photo of field plate load test.

Results and discussion

Vp and Vs outputs

A three-component geophone placed at the same elevation in the reception hole receives the seismic signal as an elastic wave. The WinGeo application selected the initial arrival times (Tp and Ts) for each seismogram (seismic segment) between boreholes. Vp and Vs are calculated using the following equations from the source to receiver boreholes (Dobrin and Savit, 1988).

$$V_p = \frac{X}{T_p} \dots\dots\dots\dots (1)$$

$$V_s = \frac{X}{T_s} \dots\dots . \dots\dots (2)$$

Equations 1 and 2 are used to calculate the Vp and Vs values, as shown in Table 2. The average Vp ranges from 342.23 m/sec to 548.02 m/sec, while the average Vs ranges from 215.43 m/sec to 307.73 m/sec, beginning at 1.0 and 24.0 m depths, respectively, according to this data. Figure 7 shows significant correlations between average velocities (x-axis) and depths (y-axis) for both P and S-waves. It appears that depth causes a partial drop in Vp and Vs. It provides information on the differences in the lithology of soil and its constituent parts. Where the density and water content of the soil influence the velocity, the soil lacks adequate stiffness.

Table 2: Calculated values of Vp, Vs., Vp/Vs., and average velocities in the studied boreholes.

Depth (m)	Borehole No.1			Borehole No.2			Borehole No.3			Average velocities (m/sec)	
	Vp (m/sec)	Vs (m/sec)	VP/Vs	Vp (m/sec)	Vs (m/sec)	VP/Vs	Vp (m/sec)	Vs (m/sec)	VP/Vs	Vp	**Vs**
1	475.0	285.0	1.7	467.2	276.7	1.7	518.2	290.8	1.8	486.8	**284.2**
2	483.1	276.7	1.7	475.0	271.4	1.8	483.1	282.2	1.7	480.4	**276.8**
3	518.2	296.9	1.7	500.0	290.8	1.7	508.9	300.0	1.7	509.0	**295.9**
4	548.1	306.5	1.8	537.7	300.0	1.8	558.8	316.7	1.8	548.0	**307.7**
5	537.7	296.9	1.8	527.8	290.8	1.8	518.2	293.8	1.8	527.9	**293.8**
6	508.9	296.9	1.7	500.0	287.9	1.7	475.0	287.9	1.6	494.6	**290.9**
7	475.0	282.2	1.7	483.1	276.7	1.7	467.2	268.9	1.7	475.1	**275.9**
8	445.3	259.1	1.7	452.4	252.2	1.8	445.3	252.2	1.8	447.7	**254.5**
9	401.4	243.6	1.6	425.4	237.5	1.8	401.4	235.5	1.7	409.4	**238.9**
10	365.4	229.8	1.6	395.8	219.2	1.8	380.0	228.0	1.7	380.4	**225.7**
11	347.6	220.9	1.6	375.0	217.6	1.7	375.0	212.7	1.8	365.9	**217.1**
12	390.4	235.5	1.7	395.8	231.7	1.7	380.0	222.7	1.7	388.7	**230.0**
13	356.3	220.9	1.6	360.8	214.3	1.7	360.8	211.1	1.7	359.3	**215.4**
14	331.4	235.5	1.4	351.9	219.2	1.6	343.4	217.6	1.6	342.2	**224.1**
15	375.0	245.7	1.5	375.0	235.5	1.6	370.1	229.8	1.6	373.4	**237.0**
16	419.1	237.5	1.8	395.8	229.8	1.7	390.4	224.4	1.7	401.8	**230.6**
17	445.3	231.7	1.9	438.5	224.4	2.0	419.1	219.2	1.9	434.3	**225.1**
18	413.0	229.8	1.8	419.1	220.9	1.9	407.1	226.2	1.8	413.1	**225.6**
19	401.4	256.8	1.6	401.4	247.8	1.6	419.1	243.6	1.7	407.3	**249.4**
20	413.0	235.5	1.8	419.1	226.2	1.9	419.1	228.0	1.8	417.1	**229.9**
21	438.5	252.2	1.7	431.8	247.8	1.7	445.3	235.5	1.9	438.5	**245.2**
22	452.4	259.1	1.7	445.3	252.2	1.8	459.7	237.5	1.9	452.5	**249.6**
23	459.7	256.8	1.8	452.4	247.8	1.8	475.0	231.7	2.1	462.4	**245.4**
24	**475.0**	**268.9**	**1.8**	**467.2**	**266.4**	**1.8**	**491.4**	**250.0**	**2.0**	**477.9**	**261.8**

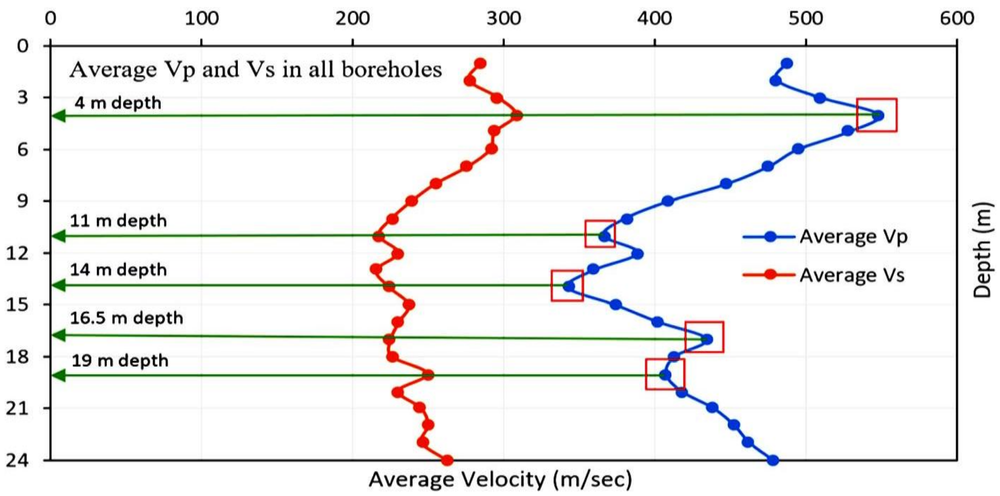

Fig.7. Relationship between depth and average velocities of (Vp, Vs) for each chosen site borehole.

Six layers can be identified within the soil of the research site, as shown in the above figure, and by variations in the values of Vp and Vs with depth. There are 1st layer (2-4) m, 2nd layer (5-11) m, 3rd layer (12-14) m, 4th layer (15-16.5), 5th layer (17-19) m, and 6th layer (20-24). The decrease in Vp and Vs at the top of layers 3 and 4 may indicate the existence of soft, silty clay soil. This fact can be noticed in the elastic modulus versus depth relationships at nearly the same depths, as shown in Figure 8.

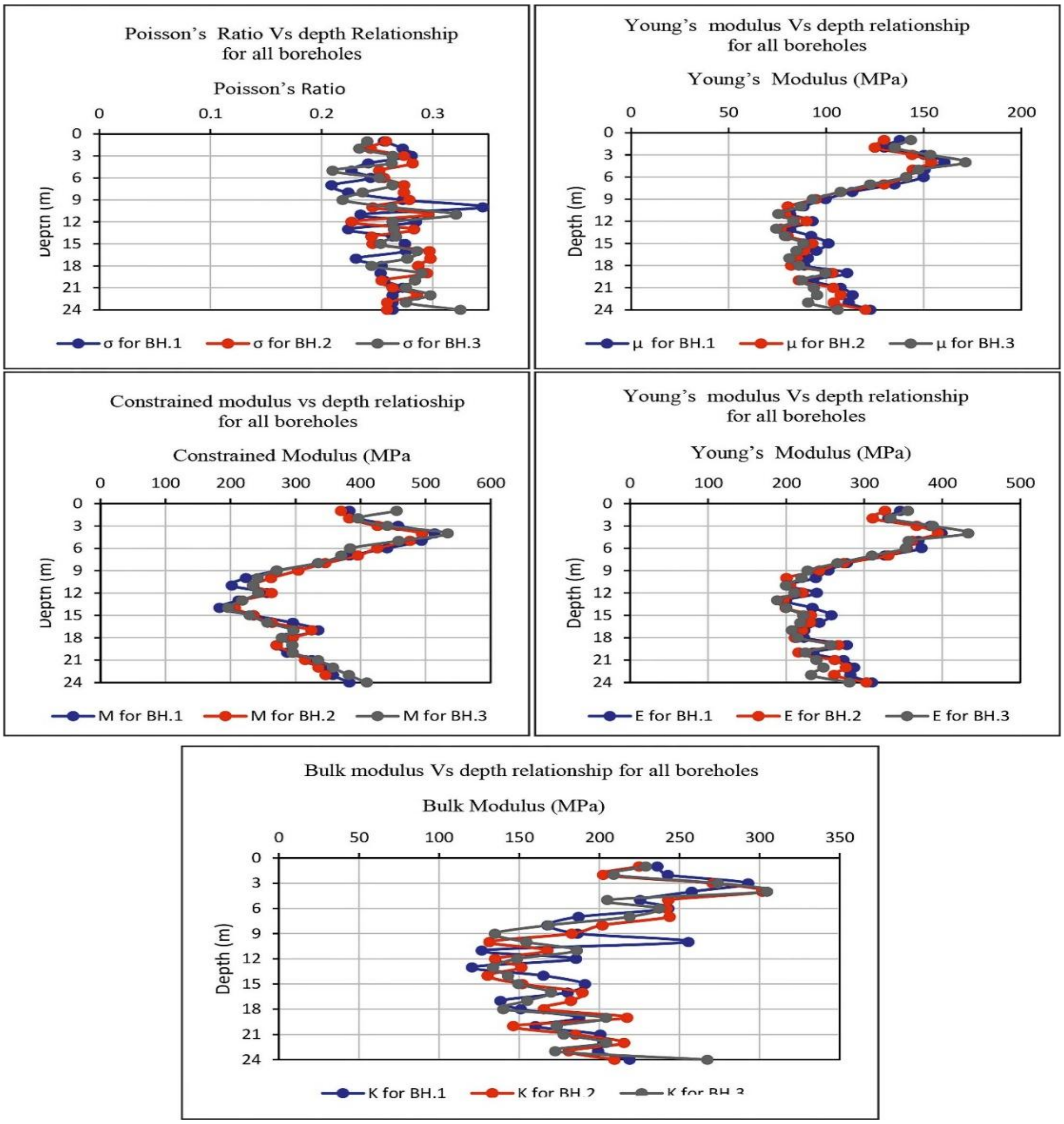

Fig. 8. Relationship between the elastic modulus values and depth for all boreholes in the site, the blue circle tends to decrease these values corresponding to the third layer.

The Poisson's ratio value ranges between 0.21 and 0.325 in BH.3 from depths 1.0 to 24.0 m. This is owed to the lithological changes, the variants in consolidation ratio, moisture content, and the proportion of water saturation in the soil, consistent with engineering parameter results. The variety of (σ) suggests that the soil of these layers is classified from stiff sandy clay soil to silty soil (loose-medium) in the investigated site. Shear modulus reflects the cohesion and stiffness of soil (Hunt, 1986). The moduli's lowest and most excellent values are 74.5 and 171.5 MPa in BH.3. The constrained modulus of elasticity values range between 183 in BH.1 and 533.8 in BH.3. The results range from 196.9 MPa in BH.2 to 433.1 MPa in BH.3. This indicates the presence of soft clay to stiff silty clay. Bulk modulus values range between 120.6 MPa in BH.1 and 304.6 MPa in BH.3, indicating the compacted layers underlying the ground surface.

Geotechnical Properties

Material Index (Im) is a significant geotechnical feature since it shows the degree of material efficiency. However, it affects the joints, degree of consolidation, material composition, fractures, and liquid in pores (water content). Consequently, seismic wave velocities and material elasticity are also affected. This index has limits ranging from -1 (when μ = 0) for liquid materials to 1. It is obtained using the following equation (Craig, R.F., 2004).

$$I_m = \frac{3\left(V_s/V_p\right)^2 - 1}{1 - \left(V_s/V_p\right)^2} \dots\dots\dots\dots (3)$$

Soil suitability as a foundation material can be categorized based on Poisson's ratio and material index values. The average material index values in BH.2 and BH.1 vary from (-0.29) to (1.5), respectively, indicating the presence of somewhat to moderately competent individuals based on their classification.

Concentration Index (Ic)

For rock or soil, the concentration index combines material qualities. The foundation and other civil engineering targets view it as a degree of expertise. It can be computed using the values of the (Vs/Vp) ratio, as described below (equation 4):

$$I_c = \frac{3-4\left(V_s/V_p\right)}{1-2\left(V_s/V_p\right)^2} \dots\dots\dots\dots (4)$$

The average concentration index in BH.1 at the investigated site varies from -15.80 to 2.68. The soil research site's natural values are soil density, stiffness, and natural cohesiveness at shallow and deep depths.

Coefficient of Lateral Earth Pressure at Rest (Ko)

In BH.1 and BH.2, the tabulated values of Ko vary from (-0.01) to 0.48, respectively. Consequently, the site's soil is classified as over-normally consolidated clay. In general, there is a complete correspondence in the behavior of the curves of geometrical properties with depth to those curves of elastic constants, as we notice sudden changes at the beginning of the third layer at a depth of 11 meters, which may indicate the presence of soft to very soft silty clay soil, as shown in Figure 9.

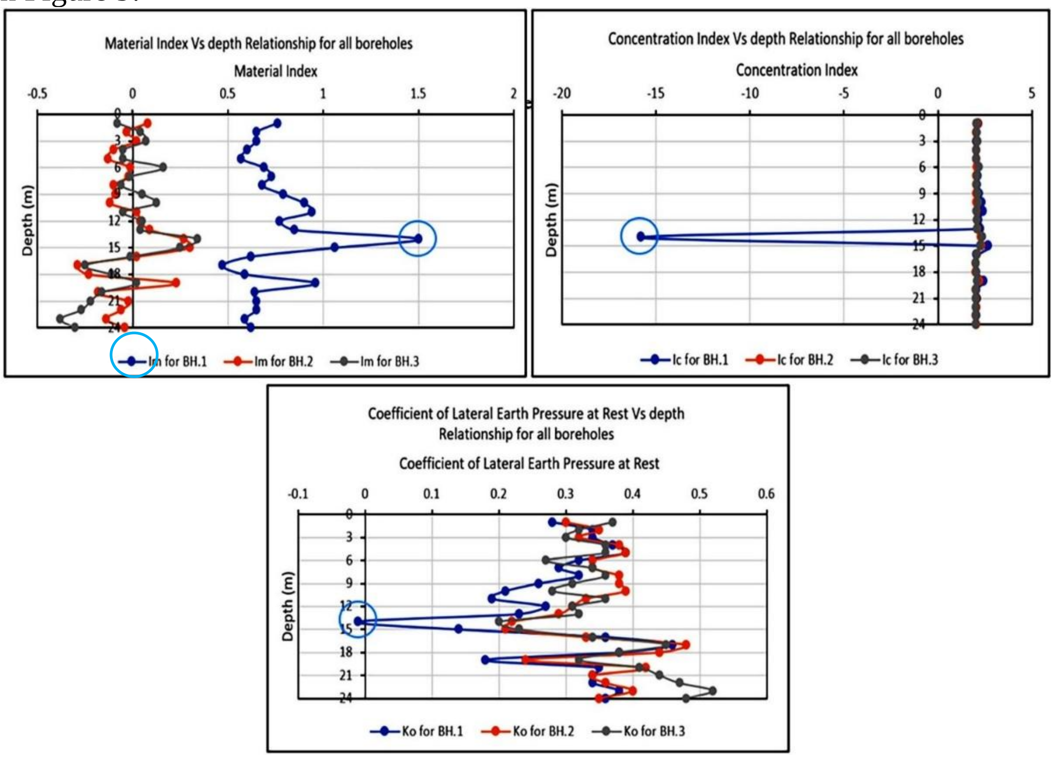

Fig. 9. Relationship between the geotechnical properties' values and depth for all boreholes in the study site, the blue circle tends to decrease these values corresponding to the third layer.

Standard Penetration Test (SPT) and Allowable Bearing Capacity (Q_{all})

The allowable bearing capacity is guessed from SPT data. The behavior of the studied geotechnical properties belonging to the average of BH.1, BH.2, and BH.3 with depth IS built separately, as demonstrated in Figure 10.

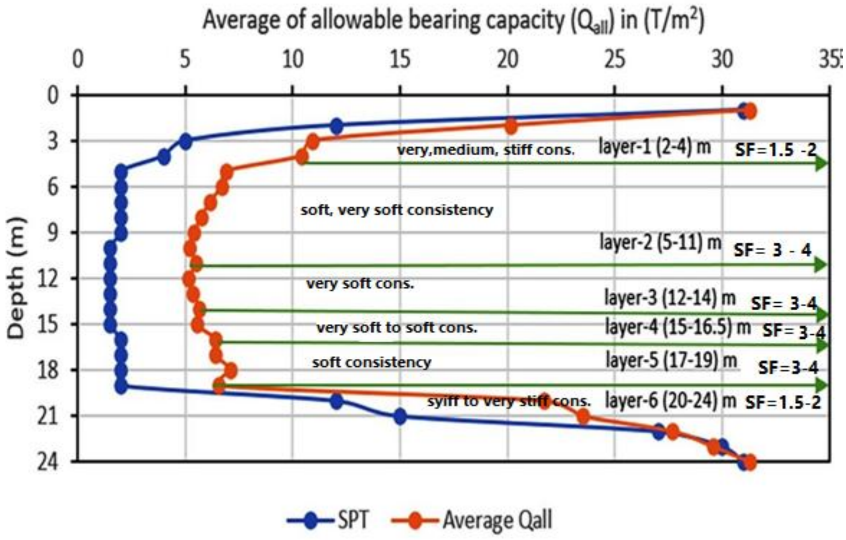

Fig. 10. Relationship between the allowable bearing capacity values and SPT with depth for all boreholes in the study site

This figure shows that six layers underlie the surface ground. Depths are indicated next to each of them. These are different results from the number of SPT and the allowable bearing capacity, which in turn comes from the variations occurring in the lithology of the soil up to a depth of 24 meters. Also, this conclusion is similar to the results we extracted by interpreting the results of seismic velocities, elastic constants, and geometrical properties.

Safety Factor (S_F)

The safety factor denotes the capacity of a design structure that can be applied beyond its projected or actual loads. The S_F of the studied site is about (1.5) and (3-4) based on Table 4. The type of soil found at the place under investigation lies within stiff to very stiff (1.5-2) and loose and soft (3-4) soil. However, the cover layer is considered a soft fill material ranging between 0 and 1 m, which should be eliminated while building. The soil type of the investigated site is lying within stiff to medium stiff (2 to 4) m, soft to very soft (5-11) m, very soft (12-14) m, very soft to soft (15-16.5) m, soft (17-19) m and stiff to very stiff (20-24) m depths described in table (3) below.

Plate Load Test Interpretation

Settlement and Allowable Bearing Capacity

The plate load test was performed at the study site in 2021. It is observed that the average values of settlement ranged between 0.17 mm in point-4 and 3.73 mm in point-2. The relationship between applied pressure and average settlement was plotted for all selected points (Fig. 11). From this figure, the allowable bearing capacity values ranged from 13 to 25.5 T/m^2 in points 3 and 5, respectively. It is also noted that these values are somewhat close to the results of allowable bearing capacity guessed from SPT data.

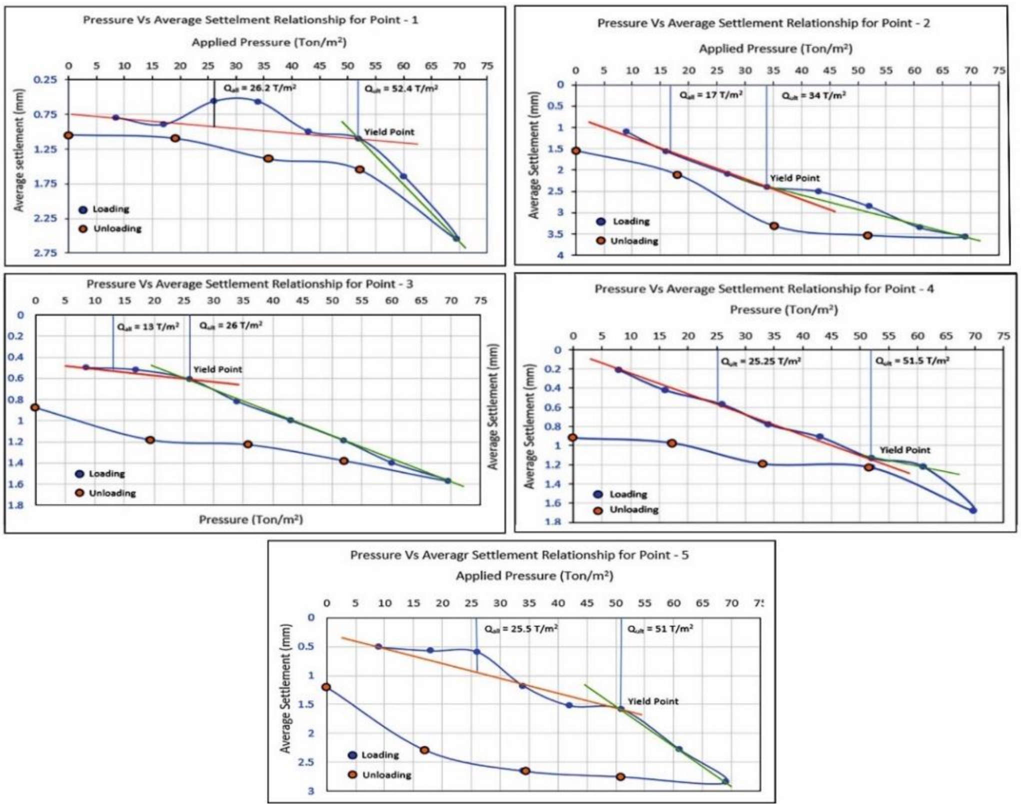

Fig. 11. The relationship between Average settlement values with applied pressure for different points in the study site

Table 3: shows the average values of Vp, Vs, elastic modulus, and geotechnical properties of the studied site

Depth (m)	**Consistency**	**Average Values of**											
		V_p	V_s	σ	μ (Mpa)	M (Mpa)	E (Mpa)	K (Mpa)	I_m	I_c	K_o	Q_{all} (Ton/m^2)	S_F
1	cover												
2	**Very Stiff to medium stiff**	**480.4**	**276.**	**0.25**	**133.3**	**401.5**	**333.6**	**224.0**	**0.22**	**2.07**	**0.34**	**20.1**	**1.5-2**
3		509	296	0.24	152.4	451.0	379.2	247.8	0.25	2.08	0.32	10.9	1.5-2
4		548.0	308	0.27	180.9	574.2	459.5	333.3	0.15	2.04	0.37	10.4	1.5-2
5	Soft to very soft	527.9	294	0.28	164.9	532.4	420.6	312.6	0.13	2.04	0.38	6.9	3--4
6		494.6	291	0.23	161.6	467.7	399.2	252.2	0.28	2.11	0.31	6.7	3--4
7		475.1	276	0.25	139.4	413.1	347.00	227.2	0.23	2.08	0.32	6.1	3--4
8		447.7	255	0.26	118.5	366.8	298.9	208.5	0.17	2.05	0.35	5.7	3--4
9		409.4	239	0.24	104.4	307.0	258.9	167.8	0.25	2.10	0.32	5.4	3--4
10		380.4	226	0.22	93.27	265.1	227.8	140.9	0.30	2.16	0.29	5.2	3--4
11		365.9	217.	0.22	82.93	235.9	202.7	125.2	0.30	2.17	0.29	5.5	3--4
12	Very soft	388.7	230	0.23	93.13	266.1	229.1	141.9	0.29	2.11	0.30	5.1	3--4
13		359.3	215.	0.22	81.70	227.2	199	118.3	0.33	2.15	0.28	5.3	3--4
14		342.2	224.	0.1	88.50	206.2	195.8	89.1	0.70	-3.72	0.14	5.7	3--4
15	Very soft to soft	373.4	237	0.16	102.3	253.7	237.4	117.3	0.54	2.42	0.19	5.5	3--4
16		401.8	231	0.25	96.83	294.1	242.9	1625.	0.21	2.07	0.34	6.4	3--4
16.5 *17*	soft	434.3	225	0.32	92.30	343.5	242.9	220.6	-0.02	2.00	0.46	6.4	3--4
18		413.1	226	0.29	92.67	310.6	238.5	187.3	0.08	2.02	0.40	7.1	3--4
19		407.3	249.	0.2	116.4	310.4	278.2	155.3	0.40	2.25	0.25	6.5	3--4
20	Stiff to very stiff	417.1	230	0.28	98.87	325.3	253.2	193.7	0.10	2.03	0.39	21.7	1.5-2
21		438.5	245.	0.27	112.5	359.7	285.7	209.7	0.14	2.05	0.37	23.5	1.5-2
22		452.5	250	0.28	117.9	387	301.2	229.9	0.11	2.04	0.39	27.7	1.5-2
23		462.4	245.	0.30	114.1	404.2	296.2	252.3	0.02	2.02	0.43	29.6	1.5-2
24		477.9	262	0.28	129.6	431.8	332.1	258.6	0.09	2.04	0.40	31.3	1.5-2

Subgrade Reaction and Permanent Deformation Moduli

Table 5 shows the results tested for the selected points at the study site. Also, a logarithmic graph between the Modulus of Subgrade Reaction and the Modulus of Permanent Deformation at all studied points was constructed, illustrating a strong power relationship between these two moduli (Correlation Coefficient, R^2 = 1), as shown in Figure 12. This means that critical subgrade values must be achieved in the test.

Table 4: The results of Subgrade Reaction and Permanent Deformation tests of the selected points

Point No.	Modulus of subgrade reaction (Ks) (Kg/cm²)	Modulus of permanent deformation (Kg/cm)
1	140	7875
2	142	7987.5
3	185	10406.25
4	270	15187.5
5	20	1125

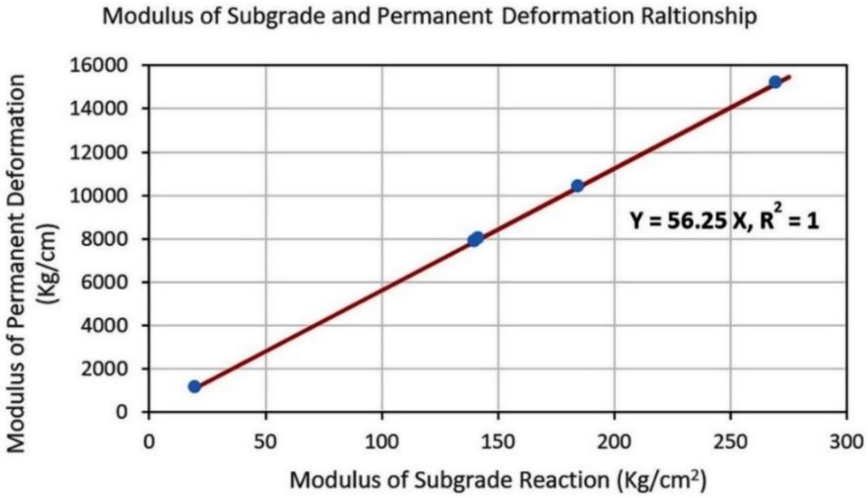

Fig. 12. Relationship between modulus of subgrade reaction and permanent deformation at the studied points of the plate late

Conclusions

1. The results of the engineering properties showed a clear correspondence with the results of Vp and the elastic constants for depths 0-24 meters, indicating the accuracy of the data obtained from fieldwork surveys at the study site.
2. From in-situ information, boring and cross-hole seismic refraction surveys show that the weak zones are subterranean surface phenomena in the research area's soil. The subsurface was divided into six soil layers according to the output results of surveys, there are: stiff to medium stiff (2 to 4) m, soft to very soft (5-11) m, very soft (12-14) m, very soft to soft (15-16.5) m, soft (17-19) m and stiff to very stiff (20-24) m depths.
3. At depths of 5-19 meters are characterized by low N-value (1.5-2), as these depth intervals represent zones of weakness in the soil of the study site, and they can't be used as foundations for building due to their inability to bear the weights coming from the structure.
4. The maximum settlement is 3.7 mm at 61 tons/m2; this indicates that the foundation soil can bear twice the expected design load without subsidence. Plate load test experiments and elasticity theory results are so close.
5. The allowable bearing capacity values ranged from 13 to 25.5 T/m^2 in points 3 and 5, respectively. It is also noted that these values are somewhat close to the results It is also noted that these values are somewhat close to the results of allowable bearing capacity guessed from SPT data.
6. A strong power relationship between Subgrade Reaction and Permanent Deformation moduli was noticed. Correlation Coefficient, R^2, is equal to 1. This means that critical subgrade values must be achieved.

7. The difference in the values of the engineering results was observed despite the small distance between the test wells due to the heterogeneity of the geometric soil properties with depth at the study site.

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