Comparing the geotechnical tests and the well seismic survey to determine the dynamic modulus of elasticity for the surface soil profile in Al-Sayidah Ruqayya Hospital (Hilla city)

A Thesis
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In partial fulfillment of the requirements
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science in Geology (Engineering Geology)

By

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CERTIFICATION OF THE EXAMINATION COMMITTEE

We certify that we have read this thesis entitled " **Comparing the geotechnical tests and the well seismic survey to determine the dynamic modulus of elasticity for the surface soil profile in Al-Sayidah Ruqayya Hospital (Hilla city)** " as Examining Committee examined the student (**Zahraa Naseer Kadhim Jaber**) on its content and that in our opinion it is adequate the award for the Degree of Master of Science in applied Geology.

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بِسْمِ اللهِ الرَّحْمَنِ الرَّحِيمِ

{ شَهِدَ اللهُ أَنَّهُ لاَ إِلَهَ إِلاَّ هُوَ وَالْمَلاَئِكَةُ وَأُوْلُواْ الْعِلْمِ قَآئِمَاً بِالْقِسْطِ لاَ إِلَهَ إِلاَّ هُوَ الْعَزِيزُ الْحَكِيمُ }

صدق الله العلي العظيم

آل عمران{١٨}

Dedication

I dedicate this thesis to:

-To my parents, especially to my father and my lovely mother who have spent nights awake to subvention me.

-To my husband who is proud of me and for his endless support, to my beautiful daughter.

- My supervisor for his great kindness and guidance,

- To my brothers, sister, relatives, friends, colleagues, and professors.

-To all who helped me with warm regards.

Zahraa Jedi

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Abstract

This study aims to determine the modulus of elasticity for surface soil in Al-Hilla city in two modes (dynamic and static) using two methods, namely the engineering method and the geophysical method. The engineering method included conducting well survey in two ways that are cross-hole and down hole, while the geophysical method included conducting some geotechnical tests in the studied area to calculate the velocity of seismic waves and some geotechnical properties.

Six wells have used in the study area; four of them were used for engineering purposes at a depth of more than 10 meters. While, the remaining two wells utilized for well seismic survey, where longitudinal and transverse wave velocities calculated between these two wells, one of them considered a source and the other is at a distance 6.7 m away for receiving at the same depth, an ABEM Terralloc Mark6 recorder was used to record data in the field.

The first time down captured to interpret all the recorded information of the two methods and for all depths. In addition, the speeds of the longitudinal and transverse waves calculated up to a depth of 10 meters. Based on these waves, a number of geotechnical characteristics were calculated, which were Busan ratio (v), material coefficient (I_m), Concentration coefficient (Ic), lateral pressure coefficient (K_o), internal friction angle ($\emptyset$) and maximum bearing capacity (qu). Furthermore, elasticity coefficients including (Young's modulus E, shear modulus μ, volume modulus K, and Lami's constant λ) were calculated depending on the measured seismic velocity values and measured density values at the same depth.

The determined physical and mechanical properties of the studied soil was used to evaluated some geotechnical properties which included

granule size analysis, moisture content, dry density, strength limits L.L, P.L, P.I, L.I, C.I. Additionally, the standard penetration test (SPT) was conducted to calculate the penetration value (N-Value).

From the results of the geotechnical examinations of the site, the dynamic modulus of elasticity was calculated for the same depth based on the penetration values (N-Value) measured by using mathematical equations.

The soil layer extended down to the depth range (0-10) m, through this depth the Vp values ranged from (482.01 m/sec) to (1116.66 m/sec) and Vs from (180.11 m/sec) to (609.1 m/sec). The bulk density range of the studied soil was 16 - 18 Kn/m^3, and it increased with depth increment. Internal friction angles ranged from 33 to 37 for the depth range (1 – 10) m and the internal friction angle ratio was 37.4. P and S wave velocities increased with increasing depth because of increasing density with depth (the section compaction or soil load). Based on the ratio of compressional and shear velocities to density, elastic and geotechnical parameters were determined. Additionally, poisson's ratio v of the studied soil layers ranged between 0.42 and 0.29, so soil type of these layers could be classified as sandy saturated clay.

The results of the comparison confirmed the existence of a relationship between the dynamic modulus of elasticity calculated from the engineering tests and the seismic well survey. Through the application of the Pearson relationship, the results of the correlation showed a reasonable convergence, as the value of the correlation coefficient for this relationship is R = 0.64, which is a correlation with a moderate positive value for the data set.

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Abbreviations

Abbreviations	Meaning
P-wave	Primary wave velocity
S-wave	Shear wave velocity
B.H	Borehole
S	Stress
ε	Strain
ϕ	Shear strain
E	Young's modulus
μ	Shear- Rigidity modulus
K	The bulk modulus
υ	Poisson's ratio
ρ	Density
λ	The Lame's constant
SR	Slant distance
Tcorr	Time travel correction
USGS	Unified Soil Classification System
Im	Material index
Ic	Concentration index
K_o	Coefficient of lateral earth pressure at rest
ϕ	Effective angle of internal friction
qu	Ultimate bearing capacity
q_a	Allowable bearing pressure
SPT	Standard Penetration Test
GPS	Global Position System
ASTM	American Society for Testing and Materials

Chapter One
Introduction

Chapter one
Introduction

1.1. Preface

The estimation of static elastic moduli of the subsoil through its seismic velocities is very important for the design of foundations and structures in civil engineering projects. It gives an indication to the deformability and mechanical resistance of the subsoil. The shear modulus is fundamental to determine response of the soil to seismic or vibrations (Miller, 2001).

The shear modulus indicates the structure of the soil, so this allows well understanding of its behavior. In engineering geology, geophysics is used to determine boundary conditions, the engineering properties of materials and mass or to locate bodies of unusual properties (voids, buried pipes etc.).

It becomes necessary to increase dialogue between engineering geologist and geophysicist to determine the best techniques of the geophysical survey.

Codes of modern building include provisions for designing structure against seismic. They mainly depend on the dynamic properties of subsurface soils.

Geophysics is becoming a most important science in engineering geology and has the potential to become the most important method investigation in the future. The reason for this is that one of the main aims of engineering geologists is to determine (De Freitas, 2009).

The mass geotechnical properties and geophysical methods offer the only opportunity to examine ground conditions on the scale of the ground mass underlying or surrounding a proposed construction.

There are many types of tests designed to determine geotechnical properties of the soil, which lead in determining the profiles of soil and engineering characteristics of the subsurface conditions at the site. In addition, they help in measuring structure foundation depth and geotechnical design parameters that will be required for a safe and economic design as well as engineering excavation works. For example, the soil bearing capacity assists in finding the settlement side slope stability, the seismic refraction method is considered the best for layered soil profile where wave velocities increase with each successive lower layer (De Freitas, 2009).

The test measures the arrival-times of the seismic body waves generated by a seismic source, to a linear array of detectors placed at the ground surface. The Seismic Refraction method is used to map geologic stratigraphy, including depth to bedrock/water table, and lithology. Since the predicted seismic wave velocity is related to the mechanical properties of materials, this means that the characterization of material, such as type of rock, degree of weathering, and rip-ability is decided based on seismic velocity and other complementary geologic information (Davis and Selvadurai, 1996).

1.2. Location of the study area

The study area is located in Al-Eskan at Al-Hilla city, which is the center of Babylon governorate, and it is around 100 Km from the capital. The location is plain and it is specified for constructing "Site Mrs. Ruqayya Hospital Building Project", which occupies around 4500 m^2. Geographically, it lies some between N 32˚27' 44.85" north latitude and E 44˚25' 06.85" east latitude as shown in Fig. (1-1)

Fig 1-1: location of the study area

1.3. Topography and geomorphology of the study area

The proposed study area is located in the Mesopotamia Plain in the Babylon governorate, this governorate is characterized by its flat surface, and its slope generally gentle.

The Quaternary sediments exhibit an exceptional development in the Mesopotamia Plain. They consist of gravels, sands, silts, and clays that are mainly related to the cyclic fluvial sediments of the Tigris and Euphrates Rivers, with their tributaries and distributaries. These sediments form extensive, flood plains with a complex network of natural levees and channels, and terraces. The Quaternary sediments of the Mesopotamia Plain exhibit progressive thickening from northwest to southeast. They reach their maximum thickness near Babylon city, about 180m (Fouad, 2010b).

1.4. Hydrology of study area

The Quaternary sediments exhibit an exceptional development in the Mesopotamia Plain. They consist of gravels, sands, silts, and clays that are mainly related to the cyclic fluvial sediments of the Tigris and Euphrates Rivers, with their tributaries and distributaries. These sediments form extensive, flood plains with a complex network of natural levees and channels, and terraces (Al Jiburi and Al-Basrawi, 2008).

Babylon Governorate depends mainly on surface water through the Hilla River, which is one of the two branches of the Euphrates River and connected to it at Hindiya Barrage, which controlled the discharge of water from the Euphrates River to Hilla River, it was rebuilt again because it was subject to collapse.

Hilla River is the main channel that branches from the left and right sides of the Euphrates river figure (1-3), and the total length of Hilla river is about 104 km, from Al-Hindiya dam along the Babylon Governorate to the borders of Al-Diwaniyah Governorate; It is considered an important source of water in the governorate, as it passes through large areas, is divided into several branches and nourishes and irrigates large agricultural lands (Al-Saadoun,1988).

The activities of the Al-Hillah River have played a major role in creating a range of geomorphological phenomena such as meandering rivers, river islands, terraces, flood plains, and natural dams (Al-Zamili and Hussain, 2015).

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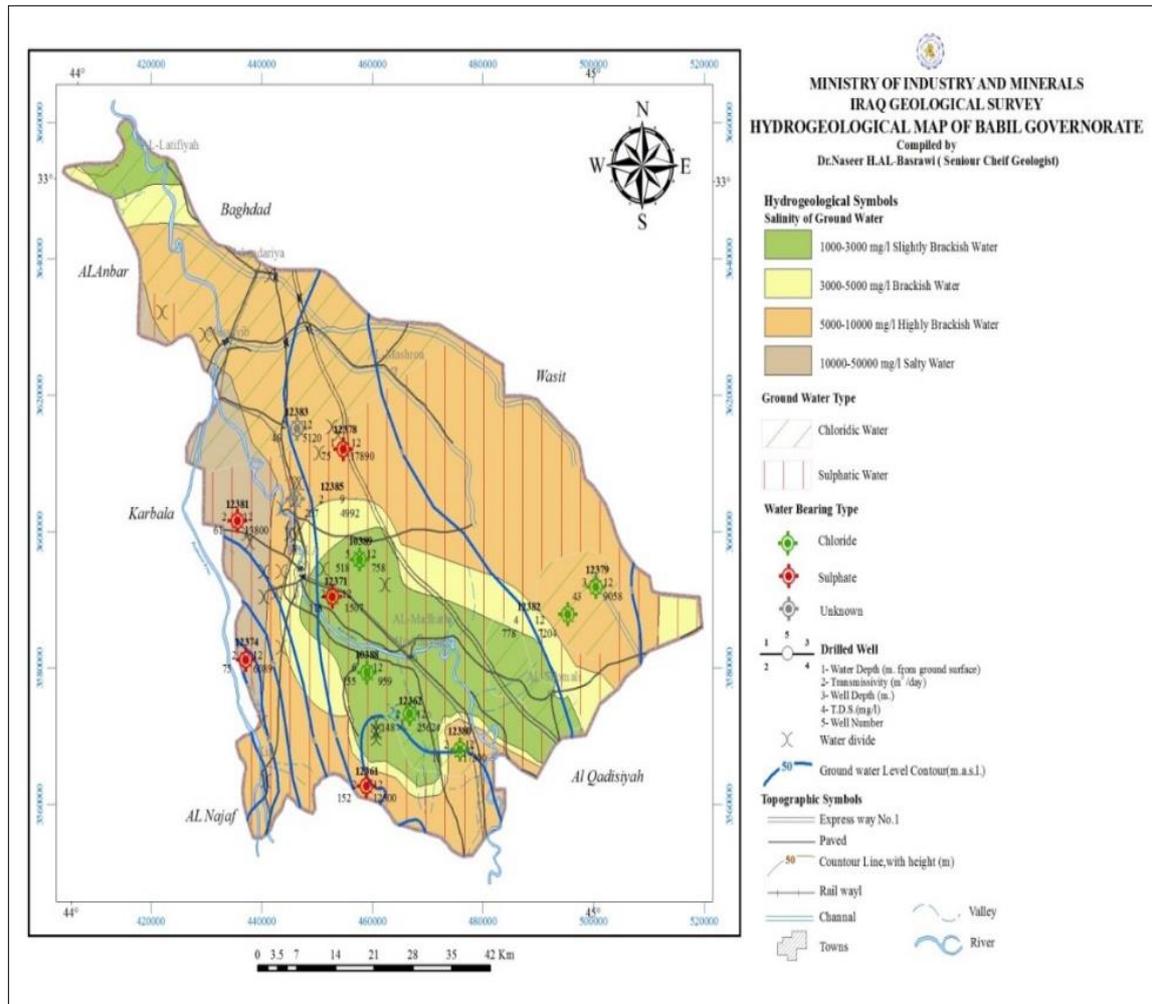
Figure (1-2): Hydrological map of Babylon

1.5. Previous studies

1.5.1 World studies

- Durgunoglu, *et al*., (1989) used cross-hole survey at a nuclear power plant site where large range of values for both shear and compressional wave velocities are measured. The results obtained were especially useful in determining the weak zones in the form of the low velocities.

- Sayed, *et al.,* (2007) used seismic refraction method in south of Marsa Matrouh and Sedi Abd El-Rahman cities for near surface in order to describe the subsurface structure of the overburden and bedrock surface and to obtain estimates of elastic parameters of these sediments.

The results showed one major acoustic impedance boundary at the overburden-bedrock contact. Then, from obtained velocities, geotechnical conditions can be used to evaluate the dynamic properties of the subsurface materials. Also, they provided the basic information needed to evaluate the site response effects.

- Redpath, (2007) described the procedures and the results of a series of down hole measurements of P and S wave velocities performed as part of the seismic boreholes project at the Waste Treatment Plant (WTP) DOE Hanford site.

- Al-Hassan, *et al.,* (2010) used the seismic refraction for subsurface structure investigation at the southern part of Niger state college of education, Minna, Nigeria from the data collected and interpreted. The basement surface varied in depth, from 2.05m to 10.13 m. The geologic materials identified in the surveyed area are chiefly sand, saturated clay, gravel and granite.

- Shirgiri, (2012) made a correlation between geotechnical and geophysical (seismic refraction) properties of soil in the UK road network depended on shear wave velocity and shear modulus in his study. The results showed the shear wave velocity and hence the shear modulus, decreased with increasing moisture content and it had an inverse relation with density before it reached the optimum water content (or maximum dry density), the shear wave velocity decreased when the density decreased.

- Atat, *et al.,* (2013) used seismic refraction method for calculating allowable bearing capacity for shallow foundation in Eket local government area, Akwa Ibom state, southern Nigeria. They based on the Tezcan relations.They showed that the allowable bearing capacity increases with the increasing of the shear modulus and shear wave velocity.

- Al-Hussein, *et al*., (2014) used seismic refraction and electrical resistivity techniques at New Borg El-Arab industrial city, Egypt to determine the dynamic

characteristics and geotechnical parameters at the proposed site. The obtained results reveal that the subsurface consists of three layers with a gentle general slope toward the Mediterranean Sea.

- Taipodia, *et al., (*2014) used geophysical methods such as multichannel analysis of surface waves (MASW) and cross hole at IIT Guwahati India for identification of subsurface. From the results, the conducted tests showed an agreeable match, thus hinting about the efficiency of the both methods.

1.5.2. Locality studies

- AL- Juraisy,(1992) , conducted seismic refraction survey along downstream side of Mosul dam area to investigate the possibility of existence the subsurface channels and to establish its source and also to delineate the shallow subsurface faults in the study area.

- AL-Fahdawi,(2000), used seismic refraction and cross-hole methods to evaluate an engineering site in AL-Madain archeological area, and to determine the depth of layers and to measure some of geotechnical properties and dynamic elastic module , the geotechnical values measured across the foundation of the building concluded that the abundance of weak zones in them leads to differential settlement which be responsible for appearance of cracks and fractures in the walls of the building.

- Al-Kafaji, (2004) investigated soil geotechnical properties of a study area located at southwest of Baghdad. The well seismic method adopted in this investigation. The seismic wave's velocities calculated in order to determine depths of the roads and then geotechnical properties of the studied site were calculated; including (Poission ratio (v), material

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modulus (I_m), concentration factor (I_c), ground pressure factor (K_o), internal friction angle ($\emptyset$) and maximum load capacity (qu). In addition, some of the elastic properties calculated; such as: Younk's modulus (E), shear modulus (μ), Lamy's constant (λ), and volumetric modulus (K) using the values of Measured seismic velocities and measured intensity values at the same depths.

- AL-Awsi (2005) used Seismic refraction and electrical resistivity methods to conduct geotechnical engineering study at proposed site to construct a new building for housing the professors of Tikrit University. This study includes measuring of seismic velocities, electrical resistivity, determination of depths, horizontal and vertical distribution of layers and calculating some geotechnical and physical properties for site geotechnical evaluation. The results of the current study indicated that the layers sequence, weak zones and depth to the ground water are determined. Depending on the values of the geotechnical properties the strength of different layers are determined, where it conclude that the first and third layers have good geotechnical properties by comparing with the second and fourth layers, therefore the first layer may be more suitable for construction of the project of housing the professors of Tikrit university.

- Al-Banna, *et al.*, (2006) used geophysical methods such as seismic refraction, cross-hole survey in Al-Hussian water project of Kerbala, Iraq to detect the possible causes of cracks in the walls of buildings and storage tanks. The results showed that water seepage from broken pipes and their infiltration through the soil play the great role in washing the soil and changing the water table level from one point to others. The differential washing of soil causes differential settlement beneath the buildings which appears as cracks at the walls.

- AL- Shujairy , (2008) , carried out geophysical and geotechnical study for soils of Baghdad at two different sites . Physical, chemical and engineering properties for some samples are tested in laboratory, Ultrasonic method is used to calculate the longitudinal wave (Vp) and shear wave(Vs) velocities and these velocities are used to calculate the elastic module and some of geotechnical parameters. The seismic refraction survey is used also and the values of (Vp) and (Vs) are compared with these obtained by ultrasonic method. An empirical relationship between shear velocity (Vs) and number of blows (N) is derived.

- AL- Khafaji , (2010), used seismic cross hole technique, GPR survey, drilling and sampling to get a geotechnical evaluation for soil underneath the foundation of AL-Abbas Holy Shrine site in Karbala governorate. The obtained information from these methods put together to define buried objects at shallow depths such as cavity weak zones, water table and graves. The results of this study are conformable with previous studies at the study area.

- Khorshid, *et al.*, (2014) used seismic refraction survey in Tikrit university, Iraq for geotechnical evaluation to the soil based on P and S waves velocity calculated Poisson's ratio(σ), Material index (Im) and Plasticity index (PI), then plotted contour maps for different layers. These maps are divided into two zones, Zone A represents the area which has good geotechnical properties, and Zone B represents the area which has weak geotechnical properties such as loose unconsolidated sediments or weak zones. The first and third layers are fairly competent to intermediate competent layers because they have good geotechnical properties by comparing with second and fourth layers which have poor geotechnical properties which represent incompetent layers.

- Al-Khersan. ,et al(2014) each technique was carried out as a means of determine the overburden thickness at the pre-determined studied locations, delineate the subsurface layers and their geophysical(geoelectric) characteristics, to detect lateral changes and the anomalous geologic conditions, boot to the existence of water table. Moreover, longitudinal and shear waves velocities of the underlying strata were also aimed in order to derive the dynamic elastic properties of the rocks.

- Al-Jabban (2014) used the geotechnical evaluation and made a general description to determine types of the subsoil of the study area, Five boreholes were drilled to a depth of (15m) from existing ground surface at several sites and laboratory tests were carried out in each area of Hilla city, in addition to large existing data as a results of in-site and laboratory tests from previous geotechnical studies taken from 110 boreholes distributed over different area in Hilla city.

- Ali (2006) carried out an investigation in Shewasoor small dam site in northwest of Kirkuk city/ northern Iraq; using shallow geoelectire sounding with seismic refraction and deep gravity explorations as well as to geotechnical study. Seismic refraction and vertical electrical sounding emphasis that the subsurface of the dam site is generally suffering from heterogeneity. Gravity exploration indicates the subsurface in moderate depth is characterized by antieline and syncline with two anticipated faults presense in depth between (2.2 – 2.8) km. geotechnical study proved the site rocks are generally moderate to good quality and strength. Finally dynamic response procedure categorized the dam site subsurface rocks as (Rock) Class, which is, used for dynamic response and site classification for seismic design in future seismicity studies.

1.5.3. Previous studies near the study area

There are many geophysical studies for engineering purposes conducted at Babylon governorate some of these studies are:

- Al-Khersan, et al., (2012) used geophysical methods such as seismic refraction, electrical survey with the assistance of the engineering information at both gas power Hilla-2 and Karbala-2 plants which located within Babylon and Karbala Governorates/Central Iraq. They were able to obtain on elastic modulus such as Poisson ratio, Young modulus, Shear modulus and Bulk modulus. As well as, they obtained on standard penetration test and bearing capacity values which performed and calculated for the studied soils. They gave five subsurface layers in these two plants, depths, thicknesses and resistivities of these layers were identified. They indicated that the subsurface layers which belonging to Karbala-2 has resistivity values higher than Hilla-2. This is due to the dry soil and high gypsum content.

-Three seismic refraction profiles for both compressional (P) and shear (S) waves have been surveyed within a proposed building designed as use for future landfill purposes at AlKifil District/Babylon Governorate, Middle of Iraq, by the use of three impacts; normal, center and reverse shootings. In addition, cross-hole, down-hole and up-hole seismic refraction using couple boreholes were also conducted in the investigated site. Results demonstrate that there are two shallow subsurface layers. The first layer consists of gray silty sandy clay soil. The second layer consists of brown and green silty clay soil with sand. The water table level is 1.20 meter during Sep. 2015. (Fakher, 2013)

- Fakeher,(2016) a geophysical engineering study of landfill site at Al-Kifil District-Babylon governorate ,site engineering information including geotechnical properties were also measured and analyzed to enhance the main goals of this study. Standard penetration test and

bearing capacity values were performed and calculated for the studied soils. The obtained results the soil is harder and contains high percentage of sand and low clays.

1.6. Aims of the study

The main objectives of this study are:

1- To determine the modulus of elasticity for surface soil in "Site Mrs. Ruqayya Hospital Building Project", this is located in Al-Hilla city at Babylon Governorate in two modes (dynamic and static) using two methods, namely the engineering method and the geophysical method.

2- To calculate a number of geotechnical characteristics of the study soil based on the measured seismic velocity values.

3- To compare the dynamic modulus of elasticity derived from results of geotechnical tests and the well seismic survey method for the surface soil layer.

Chapter Two

Theoretical Background

Chapter Two
Theoretical Background

2.1. preface

Seismic methods are applied in the study of the earth's subsurface physical characteristics. Seismic methods involve measurement of impulses generated on or below the earth surface and recorded by a receiver on the surface. The impulses which are the seismic wave are generated either artificially by an energy source such as an explosive or naturally through geological processes (Telford et al., 1990). Of all the geophysical exploration methods, seismicsurveying is unequivocally the most important, primar-ily because it is capable of detecting large-scale tosmall-scale subsurface features. Simply stated, seismicmethods involve estimation of the shapes and phys-ical properties of Earth's subsurface layers from thereturns of sound waves that are propagated through theEarth.There is an increasing requirement for geo-physical surveys carried out during geotechnical investigations to provide direct information about rock quality or other geotechnical para-meter (Kimata, 2018). This chapter reviews the fundamental conceptsemployed in seismic exploratio and The close relationship between the properties of seismic waves in a medium and the elastic properties of that medium.

2.2. Elasticity theory

Seismic waves progress through solid layers of the earth. Subsequently, seismic wave's progress depends on the elastic properties of the medium (Telford, et al, 1990). When a power is applied to a material, it disfigures. This implies that the material particles are displaced from their original positions. Progress of the power does not

exceed a critical value, the displacements are reversible, as well as no permanent deformation results (McDowell,et al., 2002). So, there are forces within the layer resist this force and the layer tries to come back to the original position after the external power is removed. This called elastic behavior (Al-Sinawi, 1981).

The seismic refraction is a fast, efficient and non-invasive method. This method is based on the generation of seismic P waves that propagates on the subsoil and refract in the interfaces with increasing propagation velocities in depth, and with sufficiently different elastic characteristics, which means that the velocity of propagation of P-waves has always to increase in depth (Redpath, 1973).

Elastic deformation can be described by the following example: Suppose a right cylindrical body has height (h) and it's cross-section area is A.When a power affects the cross-section area of the cylindrical body, deformation or extension in the size and shape of the cylinder body by Δh amount will be observed Fig 2-1. The experience shows that the deformation happened directly proportional to the amount of applied force on the cylinder to the dimension of body, and inversely with the cross-sectional area.

That is:

$$\frac{F}{A} \propto \frac{\Delta h}{h} \dots \dots \dots ..2-1$$

Where:

F: Force acting on a cylindrical body.

A: Cross-section area of cylinder.

h: Original length of cylinder.

Δh: Amount change of cylindrical length.

a

$$\text{a) Poisson's ratio:} \quad \sigma = -\frac{\Delta d / d}{\Delta l / l}$$

b) bulk modulus: $\quad k = pV / \Delta V \quad$ (p hydrostatic pressure; V volume)

$$\text{c) Young's modulus:} \quad E = \frac{s}{\Delta l / l} \quad \text{(s axial stress)}$$

d) shear modulus: $\quad \mu = \tau / \alpha \quad$ (τ shear stress)
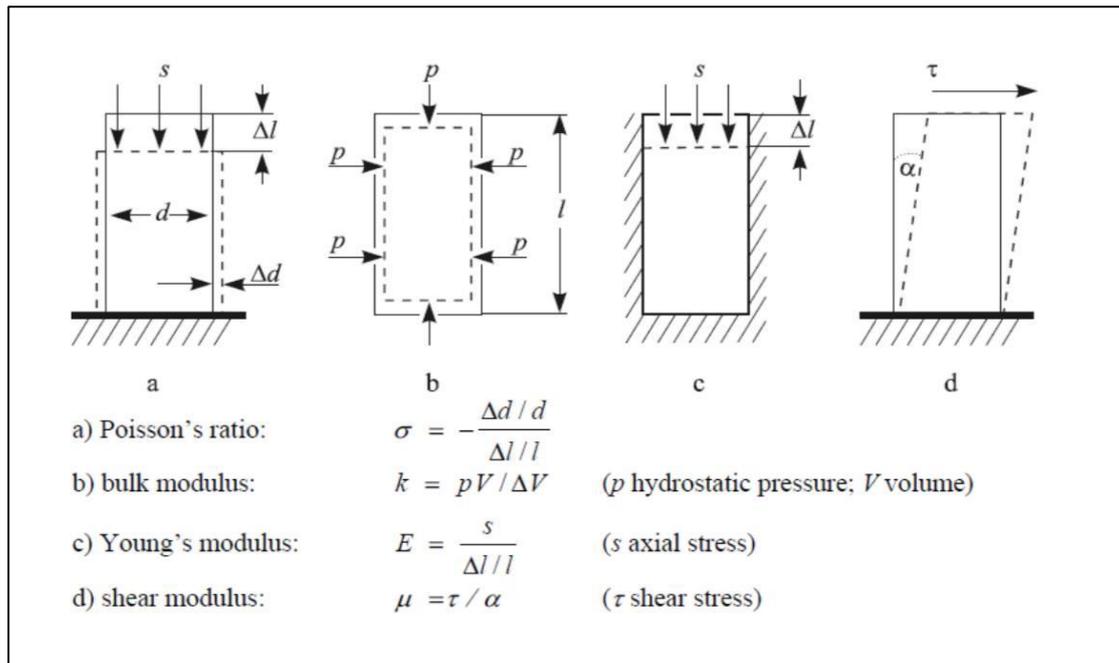
Figure 2-1: Elastic deformation in cylinder (*Knödel et. al.,2007*)

2.2.1. Elasticity stages

According to Robert Hooke's law of elasticity, the amount by which a material body is disfigured (the strain) is linearly related to the force causing the deformation (the stress) Fig (2-2). This linear relationship is called Hooke's law.It forms the basis of elasticity theory (Sheriff and Geldart, 1995).There are three stages that can deform a body during strain and time,Fig 2-2 (Lourie, 2007).

a. The elastic limit: If the solid material is deformed beyond a certain point (the material will not return to its original shape when the applied stress is removed), in this range a little increase in applied stress causes a disproportionately large increase in strain. Before that there is proportionality limit, the material still elastic (it comes back to its original shape when stress is removed), the stress-strain relationship is non-linear.

b. Plastic range: If the applied stress is removed in the plastic range, the strain does not come back to zero; a permanent strain has been produced.

c. Brittle behavior: Eventually the applied stress exceeds the strength of the material and failure occurs. In some rocks, failure happens suddenly inside the elastic range.
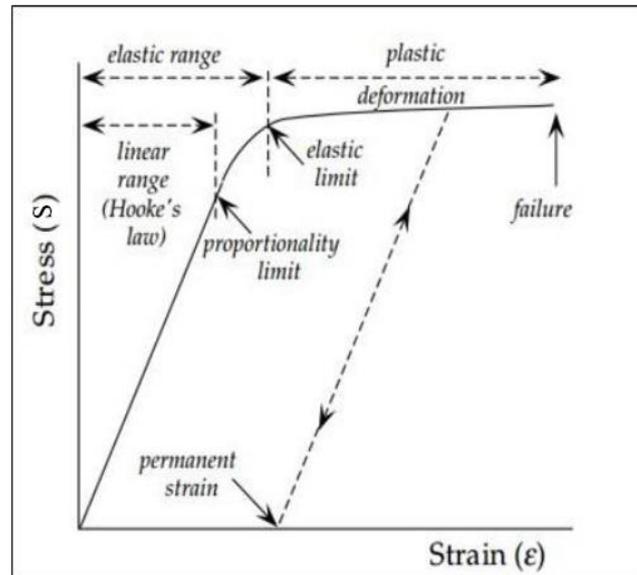
Figure 2-2: Boundary conditions of stress and strain, (after Lourie,2007).

2.3. Stress (S)

When the seismic waves propagate in solids, deformations will occur. These descriptions can be observed in terms of the forces, two useful concepts, stress and strain (Dobrin and Savit, 1988).

The ratio of the force to area (F/A) is known as stress (Parasnis, 1972) ;(Telford, *et al*, 1981);(Sharma, 1986).

$$S = \frac{F}{A} \dots \dots 2 - 2$$

Where:

S: Stress measured by Pascal or $\frac{Newton}{Meter^2}$.

F: Force measured by Newton or dyne.

A: Area measured by m^2 or cm^2.

There are two types of stress as follow: (Dobrin, 1976);(Sharma, 1986)

a. Normal stress (Vertical): Force acting perpendicular to planar element, can either be compressive stress when the trend towards the body. Which leads to the mansion in the body, or tensile stress when the direction of the body inside toward outside, thus it causes elongation of the body.

b. Shear stress (Transverse): Force acting on tangent or parallel to planar element, hence confining stresses result a change in the size without changing the body shape while shear stresses change the body shape without its size.

2.4. Strain (ε)

The change that occurs in an elastic body (deformation in size and shape of a body) is a result of the force (stress) affecting it (Sjogren, 1984).There are three types of strain Fig. (2-3): (Sharma, 1997)

a. Longitudinal strain (ε_i): It is the ratio between the change of length (ΔL) to the original length (L), that is a result of vertical stress.

$$\varepsilon_i = \frac{\Delta L}{L} \dots \dots \dots \dots 2\text{-}3$$

b. Transversal strain (εw): It is the ratio between the change of width (Δw) to the original width (w), that is a result of vertical stress.

$$\varepsilon_w = \frac{\Delta w}{w} \ldots\ldots\ldots\ldots\ldots \quad 2\text{-}4$$

c. Shear strain (Δ*sh*): This is measured by tangent of deformation angle (tan Ø) that is a result of shear stress.

$$\varepsilon_{sh} = \phi \ldots\ldots\ldots\ldots\ldots\ldots \quad 2\text{-}5$$

Where:

Φ: angle of the deformation.
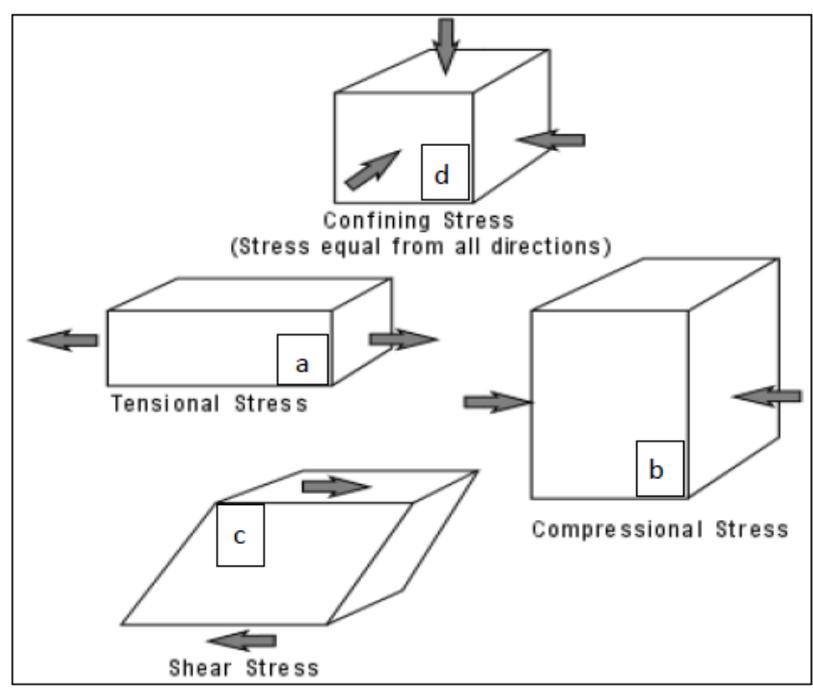
Figure (2-3): Strain elements, (a) Transversal Strain, (b) Longitudinal strain,(c) Shear strain, (d) Confining strain (after Sharma, 1997).

2.5. Elastic constants

Hooke's law states that within the elastic limit, the ratio of the stress to the strain is constant. This constant is called the modulus of elasticity of the material (Tippens,2007).

There are many modulus of elasticity:

a. Young's modulus (E):

It is characterized by the extensional distortions Fig (2-4). Each stress component is proportional to the corresponding longitudinal strain. Young's modulus is also called modulus of elasticity (Billings, 1972), and also can be defined as the relationship between the length stress divided by length strain.

$$E = \frac{S}{\varepsilon} = \frac{F/A}{\Delta L/L} = \frac{F*L}{A*\Delta L} \ldots\ldots\ldots\ldots \quad 2\text{-}6$$

The unit of Young's modulus (E) is force unit by area unit, Young's modulus value of solids material is high, but when material hardness is low Young's modulus value is less (Dobrin, 1976).
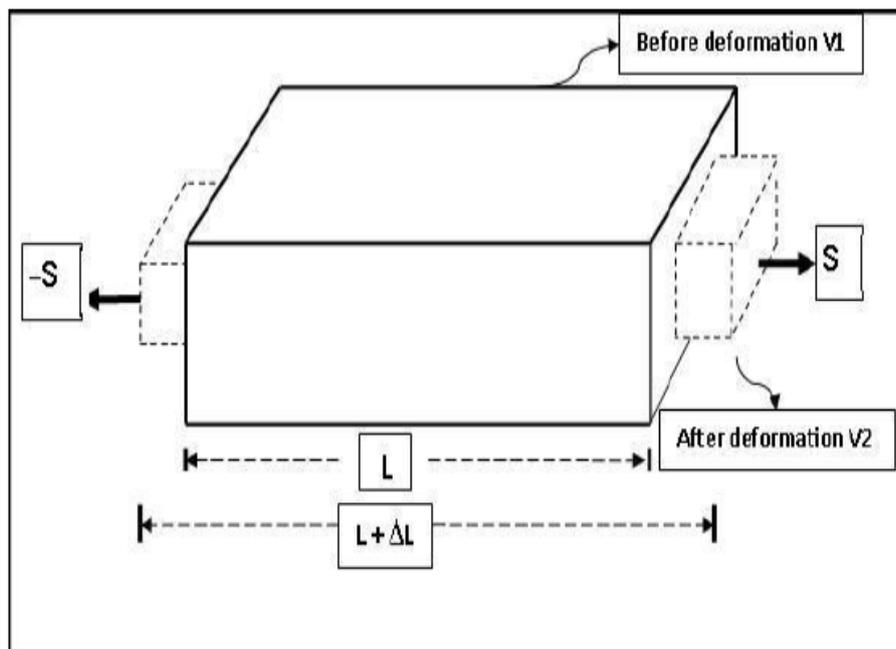
Figure 2-4: Young's modulus (after Dobrin, 1976)

a. Shear-rigidity modulus (μ):

It is a ratio between shear stress on shear strain, where a shear deformation gives proportional value to stress value affecting the body (Telford, et al, 1990), fig(2-5). The value of this parameter varies because it depends on changes in shear velocities that are very sensitive to changes in porosity of soil and rock, especially in shallow depths , and increasing in the value of this modulus indicates to the rock hardness,   also it is very important from an engineering standpoint, where its value is zero in fluids ,Table(2-1) represents the values of shear modulus regarding different materials as mentioned below, (Domenico,1984).

$$\mu = \frac{F/A}{\varnothing} \dots\dots\dots\dots\dots\dots \quad 2\text{-}7$$
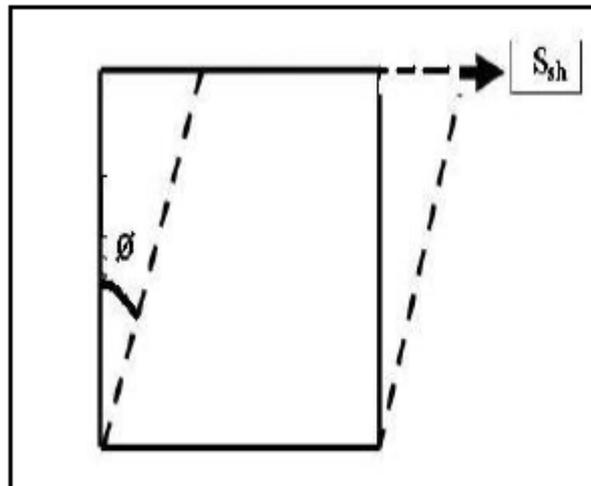
Figure (2-5): Shear modulus (after Dobrin, 1976).

Table 2-1: Shear modulus (μ) to different types of materials. (after Bowels, 1988)

Material	Shear modulus (MN/m^2) or (MPa)
Clean dense quartz sand	$12 - 20$
Micaceous fine sand	16
Loamy sand	10
Wet soft silty clay	$9 - 15$
Dry soft silty clay	$17 - 21$
Dry silty clay	$25 - 35$
Medium clay	$12 - 30$
Sandy clay	$12 - 30$

b. **The bulk modulus (K):** is known as the change of body volume which is strongly affected by confining stress from all directions (Sjogren,1984), fig(2-6).when the value of (K) increases in some areas that means low porosity of that area increases and vice versa ,(Abdel-Rahman,1989)

$$K = \frac{S}{\Delta V/V} = \frac{F/A}{\Delta V/V} \dotfill 2\text{-}8$$

Where:

ΔV/V = Volumetric strain.

The inverse of K is called the compressibility modulus (β) (Billings,1972).

$$\beta = \frac{1}{K} \dotfill 2\text{-}9$$
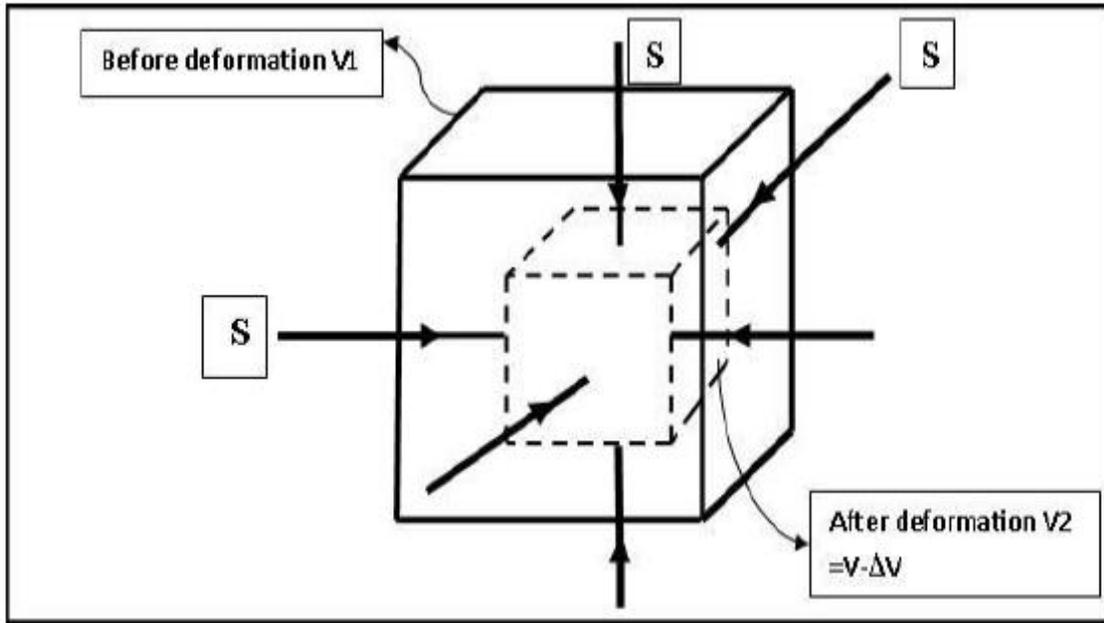
Figure (2-6): Bulk modulus (after Dobrin, 1976).

c. **Poisson's ratio (v):** The geometrical change ratio in elastic body, which is defined as the relation between width strain and axial strain that caused by compressional and tensile stresses, respectively (Sjogren, 1984).

$$v = \frac{\Delta W / W}{\Delta L / L} \quad \text{.................... 2-10}$$

v is unit less, it lies between zero (no parallel compression) and a maximum value of 0.5 (no volume change) for an incompressible liquid. A body rocks have v equals to 0.25 (Sjogren,1984), while v is ranged between (0.4-0.5) for saturated clay (Bowels, 1984). Table (2-2) shows the real values of v according to different types of materials (Hunt, 1986),(Subramanian,2008) and (Bowels,1996). Table (2-3) shows classification of the soil according to the poisson's ratio (Gercek, 2006).

Table (2-4) shows classification of the soil according to the poission's ratio (Birch, 1966), (Gassman 1973), (Tatham, 1982), (Sheriff and Geldart, 1986).

Table (2-2): Typical values of Poisson's ratio for soils *[Bowels, 1996]*

Description	Poisson's ratio (ν)
Clay(saturated)	0.4 – 0.5
Clay(unsaturated)	0.1 – 0.3
Sandy clay	0.2 – 0.3
Silt	0.3 - 0.35
Sand, gravelly sand	0.3 - 0.4
Dense sand	0.2 - 0.4
Rock	0.1 - 0.4

Table (2-3): Classification of the soil according to the Poisson's ratio (Gercek, 2006)

Soil type	Poisson's ratio
Loose sand	0.20-0.40
Medium dense sand	0.25-0.40
Dense sand	0.30-0.45
Silty sand	0.20-0.40
Sand and gravel	0.15-0.35

Table (2-4): Classification of the soil according to the Poisson's ratio (Birch, 1966), (Gassman 1973), (Tatham, 1982), (Sheriff and Geldart, 1986)

Soil description parameter	Incompetent to slightly incompetent	Fairly to moderate competent	Competent materials	Very high competent materials
Poisson's ratio	0.41-0.49	0.35-0.27	0.25-0.16	0.12-0.03

d. **The Lame's constant (λ):** Lame's constant and shear modulus (μ) are used largely for homogeneous substance where elastic modulus is not dependent on a specific direction, and can express a function of these two modulus, Young's constant and Poisson's ratio (Sjogren, 1984).

$$\mu = \frac{E}{2(1+v)} \dots\dots\dots\dots\dots \ 2\text{-}11$$

$$\lambda = \frac{v*E}{(1+v)(1+2v)} \dots\dots\dots\dots \ 2\text{-}12$$

Also, bulk modulus is associated with Lame's constant by the equation as show below:

$$K = \lambda + \frac{2}{3}\mu \dots\dots\dots\dots\dots \ 2\text{-}13$$

2.6. The dynamic modulus of elasticity

In addition to the static modulus of elasticity, which is determined from the real stress and deformation of the sample subjected to stresses, there is another type of The modulus of elasticity, which is called the dynamic modulus of elasticity. Dynamic elastic modulus can be determined by several methods, there are indirect relationships between physical properties measured by geophysical method and geotechnical properties required for civil engineering purposes , therefore in this study the seismic velocity is using to calculate the following geotechnical and physical properties**:-**

1- Poisson's ratio is related with the seismic velocities by many equations used to determine its values .

$$v = \frac{Vp^2 - 2Vs^2}{2(Vp^2 - Vs^2)} \dots\dots 2 - 14, (Swain, 1962)$$

According to the velocity of P- wave and S -wave, Poisson's ratio can be calculated from the following equations :-

$$v = \frac{0.5\left(\frac{Vp}{Vs}\right)^2 - 1}{\left(\frac{Vp}{Vs}\right)^2 - 1} \dots\dots 2 - 15, (Dominco, 1984)$$

$$v = \frac{0.5 - \left(\frac{Vs}{Vp}\right)^2}{1 - \left(\frac{Vs}{Vp}\right)^2} \dots\dots 2 - 16, (Griffith \ and \ King, 1981)$$

The above mentioned equations show that the Poisson's ratio independent of density, therefore it is widely used in seismic studies as diagnostic lithological indicator (Kearey ,et al. 2002).

2- Young's soil modulus, Es, may be estimated from empirical correlations, laboratory test results on undisturbed specimens and results of field tests. Laboratory tests that may be used to estimate the soil modulus are the triaxial unconsolidated undrained compression or the triaxial consolidated undrained compression tests. Field many tests include the plate load test, cone penetration test, standard penetration test (SPT) and the pressuremeter test, table (2-5, Gopal Ranjan et. Rao, 2000).

Table (2-5): The typical range of values for the static stress-strain (secant) modulus E_s for selected soils - field values depend on stress history, water content, density (Gopal Ranjan et. Rao, 2000):

Type of soil	Consistency or Density of soil	Modulus E_s [MPa] N/mm²
Silt	Very soft	0.2 – 2
Clay	Very soft	2 – 15
	Soft	5 – 25
	Firm, medium	15 – 50
	Hard	50 – 100
	Sandy	25 – 250
Loess sand	Silty	7 – 21
	Loose	10 – 24
	Dense	48 – 80
Sand and gravel	Loose	50 - 145
	Dense	100 – 190

3- Dynamic Shear Modulus :

It is essential to determine low strain shear modulus (G) to model dynamic soil response and estimate the site effects due to earthquakes. Several correlations have been developed between dynamic soil properties and soil penetration resistance values such as N-values from Standard Penetration Test (SPT),(P.Anbazhagan,2021). Oshaki and Iwasaki, (1973) determined G for different soil type:

$$G.(MPa) = 12.2 \ (N^{0.8}) \ \ldots\ldots 2 \text{ --} 17$$

4- In addition, dynamic elastic modulus is associated with seismic wave's velocities by these relations. So, the researcher will use these equations for the research (Davis and Schultheiss, 1980 in Khorshid, *et al.* 2006)

$$dynamic\ bulk\ modulus\ k = \rho\ Vp^2 - \frac{4}{3}\mu \ldots\ldots 2-18$$

$$dynamic\ lame\ constant\ \lambda = \rho\ Vp^2 - 2\ Vs^2 \ldots\ldots 2-19$$

Where:

ρ: Density and it is measured by gm/cm3

2.7. Seismic waves

There are two types of seismic waves when they are generated at a point source (P) as follows:

2.7.1 Body waves

The body waves propagate through subsurface layers and they are divided into:

a. **Compressional waves (P-waves):**

We can calculate the P-wave velocity (Vp) by using the equations below: (Matib, and Atya,2015).

$$Vp = \sqrt{\frac{M}{\rho}} = \sqrt{\frac{\lambda + 2\mu}{\rho}} = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}} = \sqrt{\frac{E(1-v)}{\rho(1+v)(1-2v)}} \ldots\ldots 2-20$$

Where:

VP : Velocity of primary wave (m/sec).

M : Effective elastic modulus.

ρ : The density (gm/cm3).

b. Shear waves (S-waves):

We can calculate the S-wave velocity (Vs) by using the equations below:

$$Vs = \sqrt{\frac{\mu}{\rho}} = \sqrt{\frac{E}{2\rho(1-v)}} \quad \ldots\ldots 2-21$$

Table 2-6 and 2-7 illustrates the range of P and S-waves velocities in some rocks and soils.

Table 2-6: P-waves velocities in some rocks and soils (Kohnen, 1974)

Material	Vp (m/s)
Air	330
Water	1450-1400
Petroleum	1300-1400
Loess	300-600
Soil	100-500
Snow	350-3000
Solid glacier ice	3000-4000
Sand (loose)	200-2000
Sand (dry, loose)	200-1000
Sand (water saturated, loose)	1500-2000
Glacial moraine	1500-2700
Sand and gravel (near surface)	400-2300
Sand and gravel (at 2 km depth)	3000-3500
Clay	1000-2500
Estuarine muds / clay	300-1800
Floodplain alluvium	1800-2200
Permafrost (Quaternary sediments)	1500-4900

Sandstone	1400-4500
Limestone (soft)	1700-4200
Limestone (hard)	2800-7000
Dolomites	2500-6500
Anhydrite	3500-5500
Rock salt	4000-5500
Gypsum	2000-3500
Shales	2000-4100
Concrete	3000-3500
Disturbed soil	180-335
Clay landfill cap (compacted)	355-380

Table 2-7: Classification of subsoil based on shear wave velocity as per NEHRP or IBC (Eker et al.,2012; ICC, 2006)

Depth (m)	Vs (m/sec)	Type of soil
0-7	180>Vs>360	Stiff soil
7-8.9	360>Vs>760	Very dense soil, Soft rock
8.9-26.8	760>Vs>1500	Rock
26.8-30	Vs>1500	Hard rock

2.7.2 Surface waves

Wave's energy that do not penetrate deep into sub-surface media are known as surface waves.

2.8 Density value calculation

There is a direct correlation between seismic velocity and the density and ripability of subsurface materials. The bulk density ρ can be given as (Uyanik, 2010)

$$\rho = 16 + 0.002\,vp1 = 16.45\ kN/m^3 \ \ldots\ldots\ 2\text{-}22$$

2.9. Seismic survey methods

Seismic wave velocity is one of the important parameters for geotechnical and geophysical site characterization, (Imai and Tonouchi, 1982 in Lau, 1998) The critical refraction case depends on the propagation of the elastic waves to shallower subsurface layers with different velocities and densities (different elastic modulus) (Reynolds, 1997). The applied energy of source generates elastic waves on the ground surface using Normal, Center or Reverse shooting, (ASTM: D 5777 – 00). After that the critically refracted energy travelsalong the boundary between the layers or on high-speed layer continually will totally reflect the energy and return to the upper medium, (Redpath, 1973).According to Snell's law, the angle of incidence equals the angle of reflection, and the angle of transmission is related to the angle of incidence through the velocity ratio. The energy arrived from the seismic source is recorded by the seismograph at each geophone, Fig 2-7 ;(Dasgupta and Gupta, 2009).
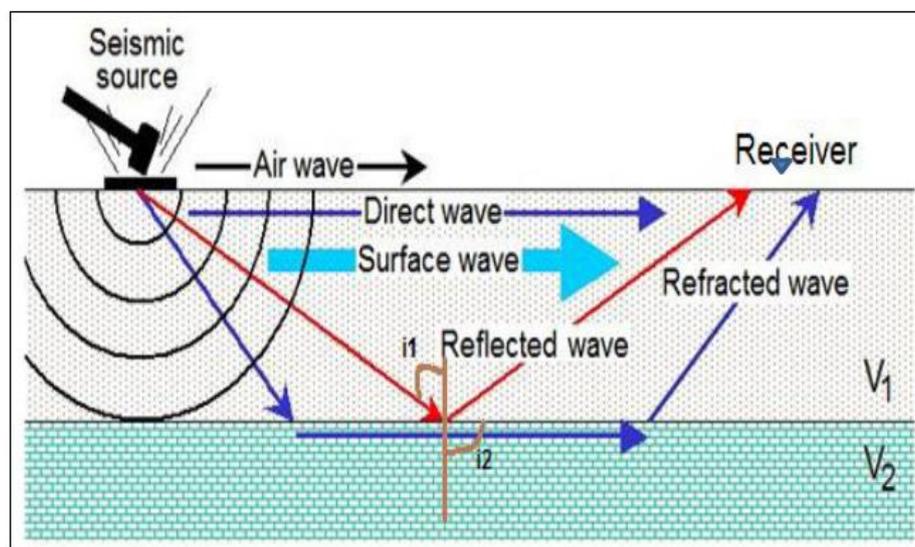
Fig 2-7: Seismic raypaths and critical refraction seismic waves.

(Reynolds,2011)

$$\frac{\sin i^1}{V^1} = \frac{\sin i^2}{V^2} \dots \dots 2-23$$

When $i_2 = 90^\circ$ (Critical angle) $\therefore \sin i_2 = \sin 90^\circ = 1$

$$\sin ic = \frac{V^1}{V^2} \dots \dots 2-23$$

There are mainly principles governed the seismic waves propagation such as Huygens' principle which can be stated on all points. A wave front can be regarded as point sources for the production of new spherical waves; the newwave front is the tangential surface (or envelope) of the secondary wavelets (Lourie, 2007).

2.10. Seismic refraction ambiguities

Sometimes, seismic refraction method that gives set of information cannot be associated with a unique set of subsurface conditions. Moreover, ambiguities in subsurface cannot be resolved by surface geophysical measurements alone. There are many causes of this problem including cavities, un-homogeneity of earth material and undiscovered near surface structures.

2.11. Seismic survey in boreholes

Here two types of body waves can be utilized for seismic surveys, P and S-waves. P-wave passes faster and thus arrives first at the observation point geophones. There is an important advantage to S-wave which is influenced by ground water when it passes through ground water; as a result, S-wave is slower than P-wave. Additionally, because the lower propagation velocity, the S-wave velocity can be calculated with more accuracy, as the arrival time interval is longer than in P-waves case, (Massarsch, 2007). Construction of foundation systems for civil structures often requires detailed information of the site soil properties (Gupta, 2013). So, because subsurface wave velocities cannot be reliably measured on the surface, we can use seismic surveys in boreholes as high frequency sources for problems solution such as thin layer and velocity inversion. There are three principal methods: Cross-hole, Down-hole and

Up-hole survey, (Whiteley and Greenhalgh, 1979) ;(Crice, 2002).The boreholes may be uncased in rock site survey, while with the soil site survey, the boreholes must be cased, (Gupta, 2013).

2.11.1 Seismic cross-hole survey

The basic testing setup of cross-hole technique was described earlier by(Stokoe and Woods, 1972); (Durgunoglu and Tezcan, 1989), that has been used in geotechnical engineering for the past 40 years (Mok and Park, 2007). The cross-hole survey depends on two or three boreholes drilled side-by-side with known distance (Bormann, 2002). A source capable to creating compressional and shear waves is lowered in one of the boreholes, impulsive sources like explosives, hammers, air guns, and standard penetration test (SPT) may be used. Thus, a pair of matching three component (Tri-axial) geophone receivers (one vertical and two horizontal transducers mounted at right angles, only the vertical component will be acceptable for S-wave arrival determinations, (ASTM:D4428/D 4428M – 00));(Park, *et al.* 2008). The geophones and source are lowered to the same depth in two additional boreholes set at evenly spaced increments (typically10 and 20 feet from the source borehole) in a line, Fig (2-8). Three geophone receivers are positioned on the side of the two or several borehole casing to give detection of the passage of compressional and shear waves (www.solgeo.it); (Crice, 2002). Cross-hole seismic trace showed a low amplitude, high frequency for P-wave and high amplitude, a low frequency for S-wave (Stokoe and Woods, 1972 in Al-Khafaji, 2004 a). The cross survey is constant for all test depths as regards resolution and accuracy, whereas in the surface surveys, the accuracy and resolution decreases with depth (Gupta, 2013). However, this test required two or more boreholes,cased and inclinated for their verticality therefore it is expensive (Mok, and Park, 2007).
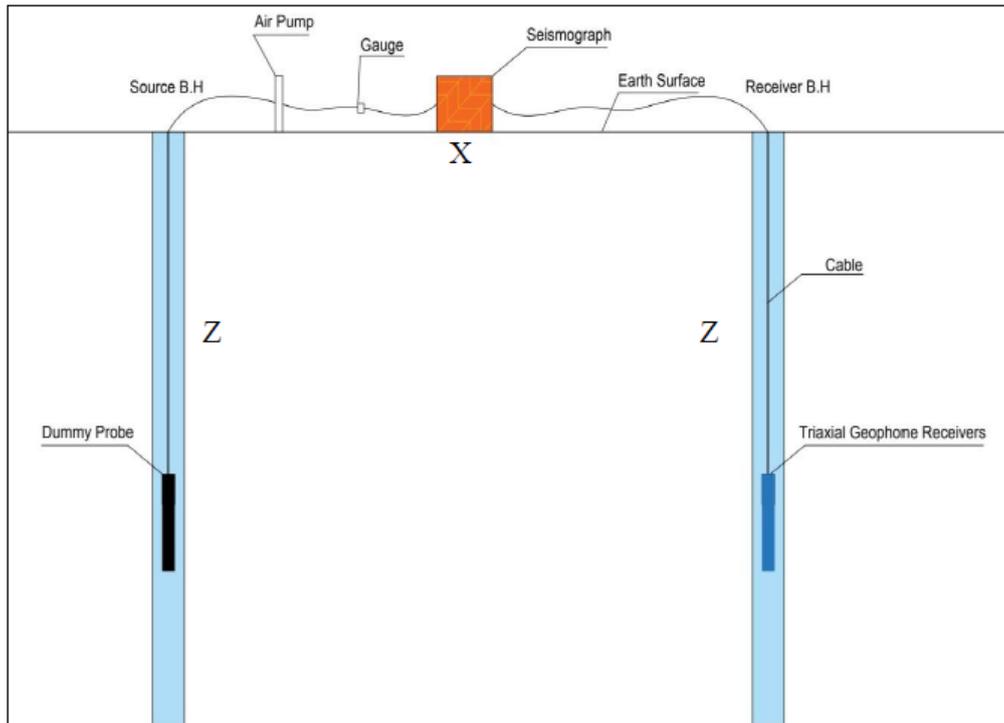
Fig 2-8: Cross-hole survey configuration (after Gupta, 2013)

In this technique, seismic velocity can already be calculated from the simple formula below.

$$V = \frac{X}{T} \ldots .2 - 24$$

Where:

X: The distance between source and receiver.

T: Travel time of either compressional and shear wave.

Seismic survey by borehole such as cross hole, down hole and up hole are usually used for civil engineering investigations and petroleum exploration, which can prove its accuracy and possibilities. It is a successful alternative to a lot of soil testing operations especially in confined areas containing cavities or find out the extended cables position or wires and other. Seismic survey by borehole is used in civil engineering problems that fall within the following projects are foundation pads,

embankments, dikes, dams and road construction. Seismic method applications by boreholes are very few in Iraq.

a. Seismic cross-hole data

The cross-hole (Tomographic) survey is one of the best methods utilized for determining the variation with depth of low strain shear wave velocity (Luna, and Jadi, 2000). The cross-hole method compared to the surface methods can be used in relatively deep holes and can provide much finer resolution, (Boore, 2006).

b. Seismic cross-hole data profile

The main target of cross hole method is to obtain a detailed in situ seismic wave velocity profile (P and S-wave) for depths sequentially from ground surface to bottom (the desired depth). Through seismic wave velocity we get lateral change to layers in situ (may be the presence of cavities or foreign body can be determined). And thus give very accurate information to the layers of elastic properties and geotechnical characteristics of the soil.

2.11.2. Seismic down-hole survey

The down-hole survey is called (Vertical Seismic Profiling, VSP),(Reynolds, 1997).The seismic source is typically a hammer hitting a plate of iron on the ground surface near the borehole and requires only one borehole. Additionally, there are three component geophones, and lowered downhole of borehole, and a single triggering receiver is located close to the energy source, (Gupta, 2013). The hammer source produces both P and S-wave energy and it is recorded by the receivers. P-waves are the vertically propagating waves which are captured by the vertical component of the receiver and shear wave (Sh) is the horizontally polarized which senses the radial transverse component, (Crice,2002). The goals of the down-hole survey are to measure the travel times of P and S-waves from travel waves during subsurface layers between the energy source to the three component geophone. It can determine the location of the positions of a receiver, a plot of travel time versus depth can be created,

Fig (2-9). The slope of the travel time curve at any depth represents the wave propagation velocity at that layer.
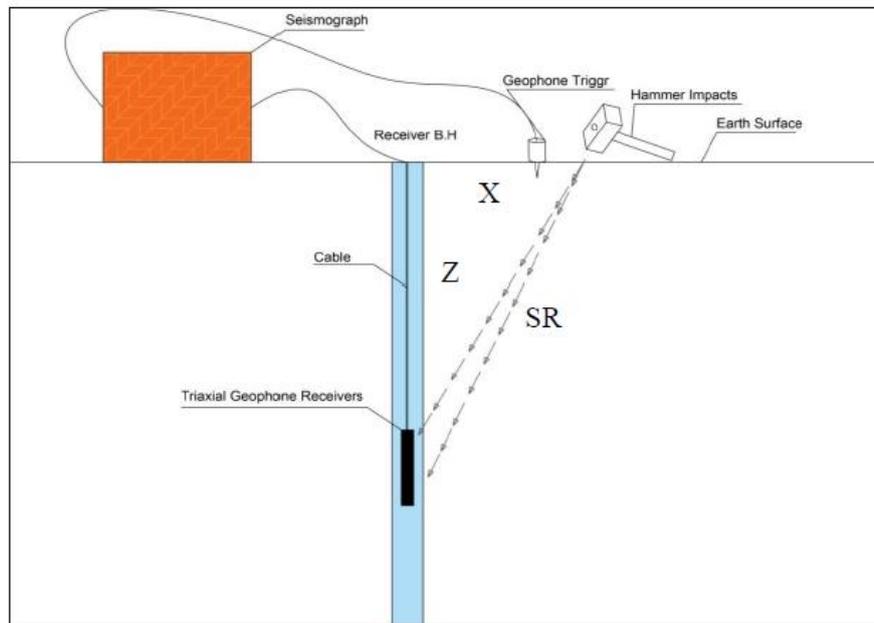
Fig 2-9: Down-hole survey configuration (after Gupta, 2013).

In the down-hole survey, S-waves can be created much more easily than the up-hole survey. According to that, using of the down-hole survey is more common. With Sh-waves source, the down-hole survey measures the velocity of waves similar to those that carry most seismic energy to the ground surface, because the waves should pass through all materials between the seismic source and the geophones. The downhole seismic survey compared to the cross-hole survey is simpler to perform in the field and less expensive. Furthermore, it is simpler to analyze the field data than the others. Also, the depth measurements increase while resolution and quality of data decrease with depth because the ray paths are becoming longer and longer, (Mok and Park, 2007). Just one borehole need to down-hole method in comparison with cross-hole method and the cost is less. However, the disadvantage is that wave energy has to pass increasingly larger distances as the depth of testing increases, (Stokoe and

Santamarina,2000). The depths of investigation for engineering studies have generally been in the 30- to 150-m range, (Stokoe, *et al.,* 2008).

In addition, unlike seismic refraction, this method measures the travel time of the direct wave, and as a result it does not have difficulty in resolving hidden layers. In fact, the downhole test can easily detect thin layers and velocity inversions in the subsurface, (Aqaba report, 2015).

The calculations:

First, slant distance (SR) is calculated based on Phithagors theory as in the equation. (ASTM: D 7400 – 08).

$$SR = \sqrt{Z^2 + X^2} \dots\dots 2 - 25$$

Where:

SR = Straight ray (Slant distance). Z = Depth measured in meter unit.

X = Offset between source and borehole measured in meter unit.

Then, travel time correction (Tcorr) is calculated based on the depth, time of field and slant distance. The transform is from field times to the vertical time. As shown in equation below (Hamdi, *et al.* 1996 in Al-Khafaji, 2004 b).

$$Tcorr = \frac{Z * T}{SR} \dots\dots 2 - 26$$

Where:

Tcorr = Time travel correction in sec.

T = Time travel in field in sec.

The velocity (V) is the difference between the two depths as distance (ΔZ) to the difference between two times for the same depth (ΔT).

$$V = \frac{\Delta Z}{\Delta Tcorr} \dots\dots 2 - 27$$

a. Seismic down-hole data profile

The goal of the down-hole survey is to determine the travel times of P and S-wave from propagation wave during layers of soil between source and receiver boreholes.

2.12. Geotechnical properties of soil

It is geologic properties affect the engineering behavior of soil and rocks when the building establishment, (https: // en.wikipedia.org / wiki / Geotechnical _ engineering)

1. **Classification properties**

Soil classification gives generalized information about the behavior and nature of soil belonging to a particular region or location. It also gives scientists and engineers information about the kind of soil they are going to be dealing with.Soil properties can broadly be divided into many major categories depending upon their properties achieved during soil formation process:

-The physical properties of soil

-Mechanical properties of soil

-The chemical properties of soil

This series cover the basic of soil mechanics and should be of interest to those in geotechnical and civil engineering fields. Shrinkage characteristics, liquid limit, plastic limit, and different densities of soil are called the index properties of soil mass. These properties are determined using different laboratory index test methods (Poulos,1989).

2. **Engineering properties**

Mechanical properties of material help us to measure how materials behave under load. In order to achieve optimal system performance, mechanical properties include density, hardness and elasticity. Mechanical properties of material reflect relationship between its response to and deformation from an applied load or force. Properties of

materials that find out its behavior under applied forces are called mechanical properties, (Robertson,1989).

a. Material index (Im)

It describes the material quality from the foundation point of view. It addresses the degree of material competence on the basis of their elastic moduli. This index must have relations to the factors which affect the elastic moduli such as the degree of consolidation, mineral composition, fracturing and fluid saturation. It depends upon numbers of elastic moduli ratio such as (μ / K) and (λ / K) (Abdel Rahman, 1989 in Al- Kafaji, 2004 a). So, Im can be calculated by basis on Vp and Vs waves velocities as follows:

$$Im = \frac{3 - \left(\frac{Vp}{Vs}\right)^2}{\left(\frac{Vp}{Vs}\right)^2 - 1} \dots \dots 2 - 28$$

$$Im = \frac{3\left(\frac{Vp}{Vs}\right)^2 - 1}{1 - \left(\frac{Vp}{Vs}\right)^2} \dots \dots 2 - 29$$

Table 2-8 shows classification of soil competence depending on Im.

Table 2-8: Classification of soil competence depending on Im (Abdel Rahman, 1994).

Im	Degree of Competent
(-1)-(-0.5)	Non- less competent
(-0.5)-0	Intermediately competent
0-0.5	Competent
0.5-1	Highly competent

b. Concentration index(Ic)

Bowles in 1984 defined the degree of material compaction or concentration by this index. Soil or rock compaction status is considered as a measure of the competence degree for foundation and other civil engineering purposes. It is specially using to measure the qualification of foundation and other engineering objects. It can be calculating through relation with (v) as the equation below.

$$Ic = \frac{1 + \upsilon}{\upsilon} \ldots \ldots 2 - 30$$

When $v = 0.5$ to a weak or saturated material with ground water Ic will be equal to 3, either in shallow depth, it will be limited between (3-6), (Bowles,1984). So, Ic = 6 for solid or dense rocks, that mean Ic is proportional with solid material (Al-Khafaji, 2004 b). From the relationship between compressional and shear velocities we can get on Ic, (Abdel Rahman, 1991 in Al-Khafaji, 2004 a).

$$Ic = \frac{3 - 4\left(\frac{Vp}{Vs}\right)^2}{1 - 2\left(\frac{Vp}{Vs}\right)^2} \ldots \ldots 2 - 31$$

And Ic relates to other elastic moduli (Al-Khafaji, 2004 a)

$$Ic = (K + \lambda) + 2 \ldots \ldots 2 - 32$$

$$Ic + \frac{1}{1 - 2\frac{\mu}{E}} \ldots \ldots 2 - 33$$

c. Coefficient of lateral earth pressure at rest (Ko)

It is one of the important geotechnical properties of the soil. The ratio between the horizontal principal effective stress to the vertical principal effective stress is called coefficient of lateral earth pressure at rest (K0), Fig 2-10. So, at-rest condition implies that no deformation occurs (Budhu, 2000).

$$K_\circ = \frac{\sigma_\circ}{\sigma h} \ldots \ldots 2 - 34$$

Where:

σo = The vertical principal effective stress.

σh = The horizontal principal effective stress.
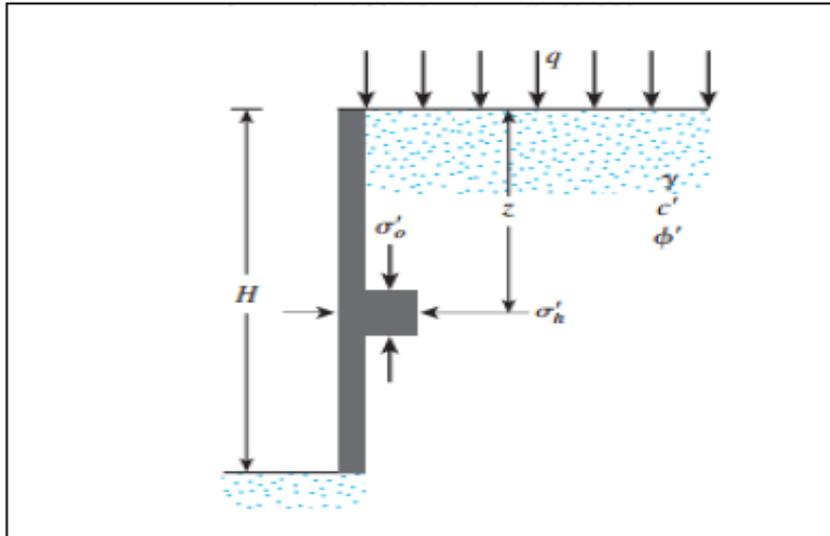
Figure (2-10): Coefficient of lateral earth pressure method at rest (K0),
(after Das,2011).

Hooke's law can be used to obtain a relationship between (Ko) and (v) for soil with no water (Hunt,1986):

$$K_\circ = \frac{v}{1 - v} \dots \dots 2 - 35$$

Where:

Ko = Coefficient of lateral earth pressure at rest.

There is a theoretical relation between Ko and the angle of internal friction Ø equation 2-46. It is for normally consolidated soil, the relation for (Jaky,1944) is an empirical approximation. For loose sand**:**

$$K \approx 1 - \sin\emptyset \dots \dots 2 - 36$$

Table 2-9: The range of coefficient of lateral earth pressure at rest, (after Craig,2004).

| Soil description parameter | Weak | | Fair | | Good |
| | Incompetent | | Fairly competent | | Competent |
	Very soft	Soft	Fairly competent	Moderate competent	Compacted
Concentration Index (Ic)	3.5-4.0	4.0-4.5	4.5-5.0	5.0-5.5	5.5-6.0
Lateral earth pressure (Ko)	0.7-0.61	0.61-0.52	0.52-0.43	0.43-0.34	0.34-0.25

Also, Ko can be calculated depending on the ratio between P-wave and S wave velocity.

$$K_\circ = 1 - 2\left(\frac{Vp}{Vs}\right)^2 \ldots\ldots 2-37$$

Ko may be used to: (Hunt, 1986)

1- Calculate the value of lateral creep for structures.

2- Calculate the value of collapse for various projects.

3- Analysis failure in mud slops.

4- Calculate the lateral earth pressure for soil that importable creep.

d. Effective angle of internal friction ($\emptyset$)

It is one of the important geotechnical characteristics that are measured in the laboratory by using Mohr's circles in triaxial test, Fig (2-11). The friction angle ($\emptyset$) can be calculated by using P-wave and S-wave velocity through putting them instead of Ko in equation (2-45), as in equation below.

$$\sin\emptyset = 2\left(\frac{Vp}{Vs}\right)^2 \ldots\ldots 2-38$$

The friction angle is affecting by density, water content, and shape of grain and mineral composition. The friction angle increases where the density increases and water content decreases. Also, the friction angle decreases with the increase in plasticity index. Table 2-10 shows typical range of values of true angle of internal frictions (Ø) for several soil types (after Bowles, 1988).
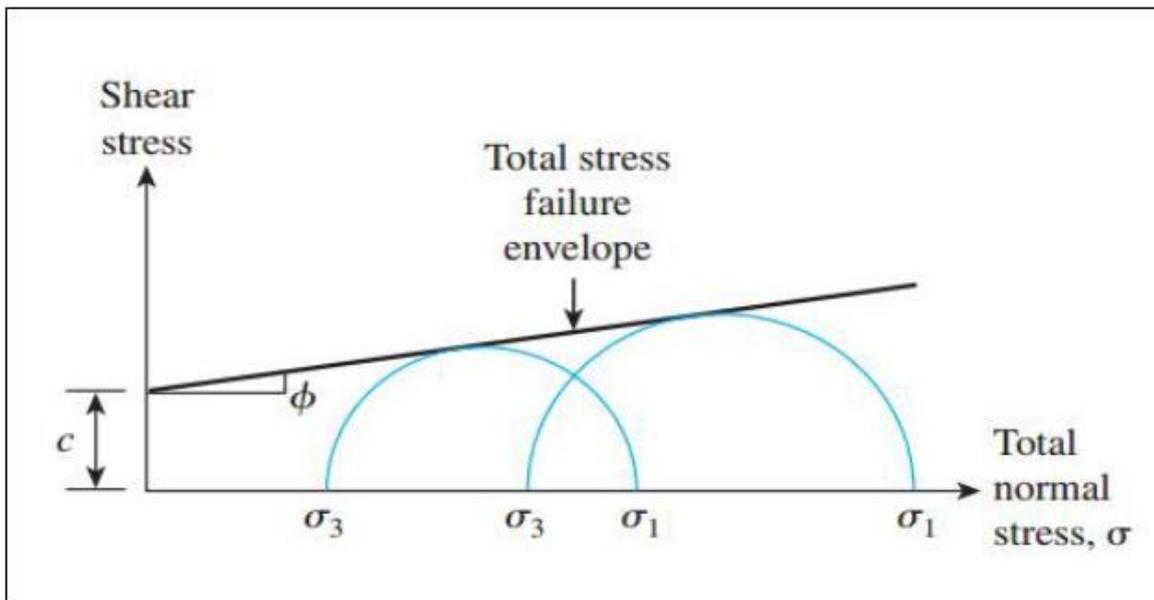
Fig 2-11: Effective angle of internal friction (after Das, 2011).

Table 2-10: Typical range of true angle of internal frictions Ø values for several soil types. (after Bowles, 1988).

| Soil type | Ø | | Soil type | Ø | |
	Loose	Dense		Loose	Dense
Gravel	32 – 36	35 – 50	Fine sand	27 – 33	33 – 39
Coarse sand	32 – 38	35 – 48	Sandy gravel	30 – 38	36 – 45
Clayey sand	28 – 32	35 - 40	Gravely sand	30 – 38	36 – 50
Silty sand	28 – 32	32 - 38	Silt	20 – 30	25 – 32

e. Ultimate bearing capacity (qu)

Bearing capacity is one of the most important geotechnical parameters in engineering projects. The importance appears in sites that are exposed to a static load resulting from construction or a dynamic load resulting from seismic activities or industrial vibrations (Bowels, 1984). The maximum bearing capacity is measured locally by conducting a standard penetration test (SPT) and calculating the value of N, which represents the number of penetration The standard is calculated from the Meyerhof equation, as well as the endurance value is calculated from the velocity of the compression waves.

The average contact pressure value between the soil and the foundation which leads to produce shear failure in the soil, so allowable bearing capacity is the maximum allowable net loading intensity on the soil allowing for both shear settlement effects, (Smith and Smith, 1988).The allowable bearing capacity depends primarily on the position of the water table relative to foundation level, the stress history, the density index and the foundation size, (Craig, 1997). The secondary importance are particle shape and grading for sand soil. Additionally, the ultimate bearing capacity of soil beneath a foundation load relies primarily on the shear strength, (Bowles, 1984). There are many methods to calculate bearing capacity by using P-wave and S-wave velocity and SPT. It can be calculated according to Meyerhof's equation.

The allowable bearing capacity is calculated from SPT results using the following equation :

qall = qall = N/0.08 {(B+0.3)/B}2(1+0.33Df/B) (Meyerhof 1965) ….. 2-39

 (Meyerhof's equations:)

Df= Depth of foundation or footing(m)

B =Width of foundation(m)

N = No. of blows for SPT (average)

An equation showing the relationship of compressive velocity and ultimate bearing capacity (NCCL,1997b).

$$Qu = \frac{1}{3}\left(\frac{VP}{240}\right)^{2.38} \ldots\ldots 2\text{ - }40$$

It can be evaluating according to Parry's formula (1977) by using standard penetration test or N-value as:

$$qu = 30N(Kpa)or\ (KN)/m^2 \ldots\ldots 2-41$$

N is the average SPT value (Imai 1979 in Al-Khafaji, 2010) was able to find the empirical relationship between the N-value and shear velocity for wet materials as:

$$Vs = 89.8\ N^{0\ .341} \ldots\ldots 2-42$$

And qu can be calculated directly from Vs; hence qu unit is (Kg/cm2)(Abdel Rahman, 1994 in Al-Salihi, 1999).

$$\log qu = 2.348\ (\log Vs - 1.45) \ldots\ldots 2-43$$

or calculated from Vp (NCCL, 1999)

$$qu = \frac{1}{3}\left[\frac{Vp}{240}\right]^{2.38} \ldots\ldots 2-44$$

The last equation is for unconsolidated soil. (Table 2-11) shows approximate correlation between standard penetration test (SPT), consistency and bearing capacity of clay and silt (Das, 2002).

Table 2-11: Approximate correlation between standard penetration test (SPT), consistency and bearing capacity of clay and silt (after Das, 2002). Also, Tezcan, *et al.* (2009) assumed other method for getting ultimate bearing

Consistency	Standard Penetration Test N-value	Unconfined compression Strength kN/m^2	q_u	
			Ton/m^2	kN/m^2
Very Soft	<2	<25	<2.5	<25
Soft	2 – 4	25 – 50	2.5 – 5	25 – 50
Medium stiff	4 – 8	50 – 100	5 – 10	50 – 100
Stiff	8 – 15	100 – 200	10 – 20	100 – 200
Very Stiff	16 – 30	200 – 400	20 – 40	200 – 400
Hard	>30	>400	>40	>400

capacity through matching between shear wave velocity and thickness of foundation H and unit weight density for layer, Fig 2-12.
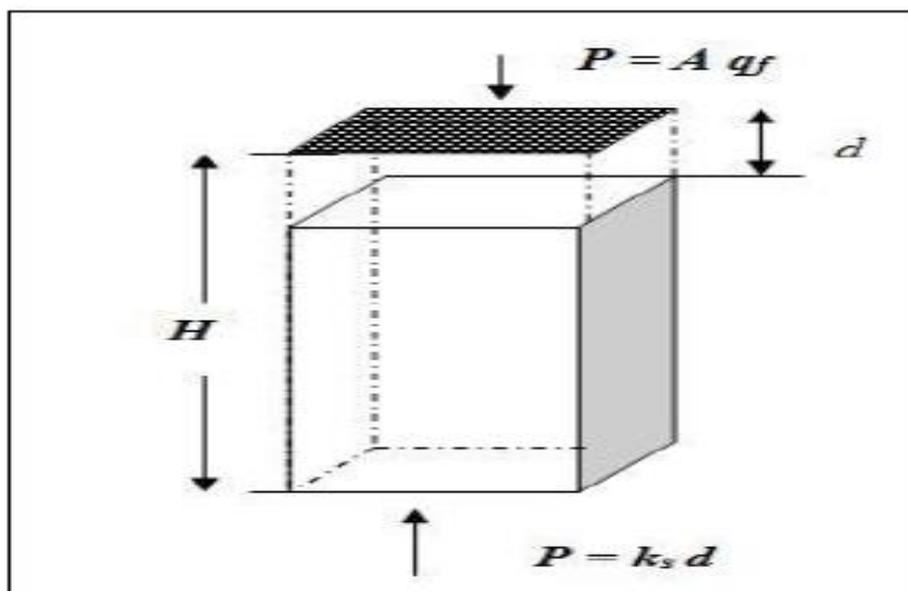
Fig 2-12: Soil column and related parameters.

$$qf = \frac{P}{A} = \frac{AH\gamma}{A} = \gamma H \ldots \ldots 2-45$$

Where:

qf = ultimate bearing capacity at failure, P = stress on a unit of area.

A = area, γ = unit weight of soil.

So, we can get allowable bearing pressure by.

$$qa = \frac{qf}{n} = \frac{\gamma H}{n} \ldots \ldots 2-46$$

$$H = Vs\, t \ldots \ldots 2-47$$

$$qa = \gamma Vs\, t/n \ldots \ldots 2-48$$

Where:

qa = allowable bearing pressure, n = factor of safety.

Vs = S-wave velocity measured under the foundation within a depth H

t = is an unknown time that will be determined and replaced by an"arbitrary"

value on the basis of a calibration process.

Increasing in the shear wave velocity and shear modulus leads to increase the allowable bearing pressure. Additionally, there were increases in the allowable bearing capacity with depth shown through the empirical relation between shear modulus and allowable bearing capacity, (Atat, 2013) found allowable bearing pressure by using shear modulus.

$$qa = 0.0146\sqrt{\mu} \ldots \ldots 2-49$$

$$qa \approx 4*10^{-6}\mu \ldots \ldots 2-50$$

f. Standard penetration test (SPT)

The Standard Penetration Test, as defined by the American Society for Testing and Materials (ASTM D 1586). The borehole is advanced to the desired testing depth, the drilling tools are removed, the sampler is attached to a series of drill rods, and the entire assembly is lowered to the bottom of the borehole.

It is most commonly used in-situ test in geotechnical engineering and it is indicate to soil consistency, soil conditions. The test uses a thick-walled sample tube, with an outside diameter of 50.8 mm and an inside diameter of 35 mm, and a length of around 650 mm. In the SPT, a standard split-barrel sampler is driven into the soil at the bottom of a borehole by repeated blows (30 to 40 blows per minute) of a 63.3 kg hammer released from a height of 76 cm. The sampler is usually driven 45 cm; the number of blows required to achieve the last 30 cm of penetration is taken as the standard penetration resistance, N.Upon completion of driving, the sampler is withdrawn from the borehole. The split-spoon sampler is opened and the soil sample is removed and logged. The SPT drilling and sampling configuration is shown in Figure (2-13), and the dimensions of then standard split-spoon sampler are shown in Figure (2-14). (McGregor and Duncan,1998). The N value is a function of the soil type, confining pressure, and soil density, but is also influenced by the test equipment and procedures.
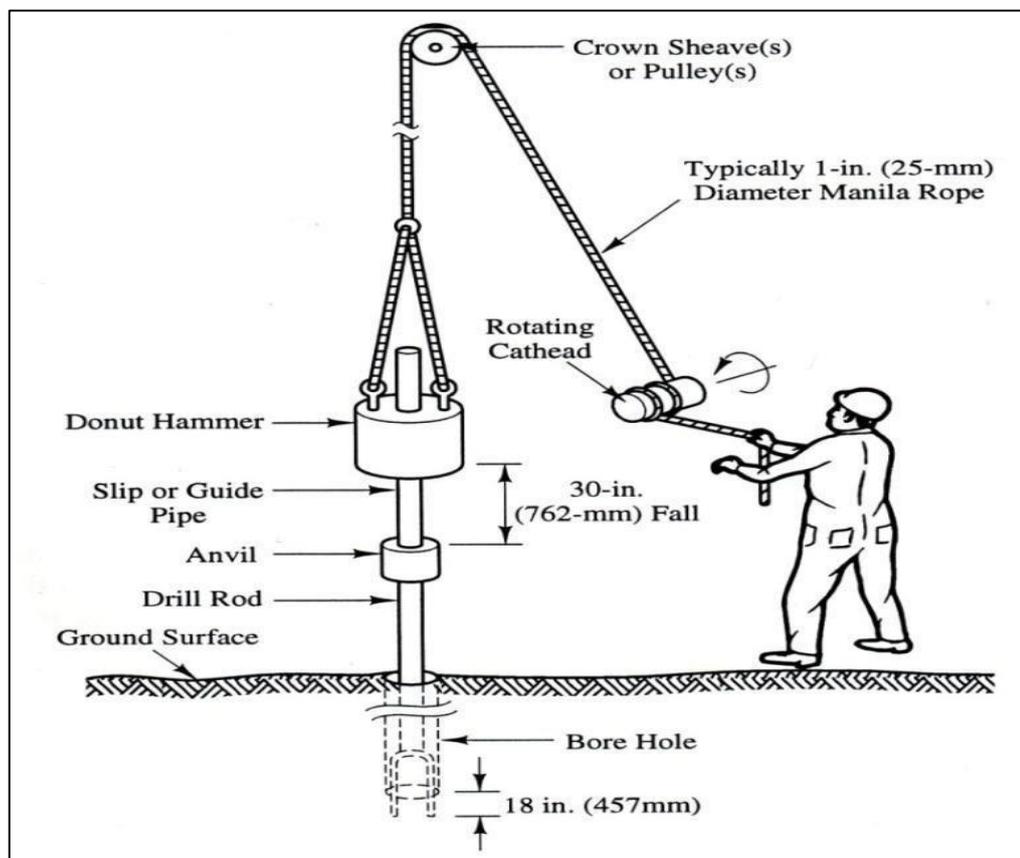
Figure (2-13):SPT drilling and sampling configuration (McGregor and Duncan,1998).

The SPT sampler (Adapted from ASTM D1586; Copyright ASTM, used with permission)
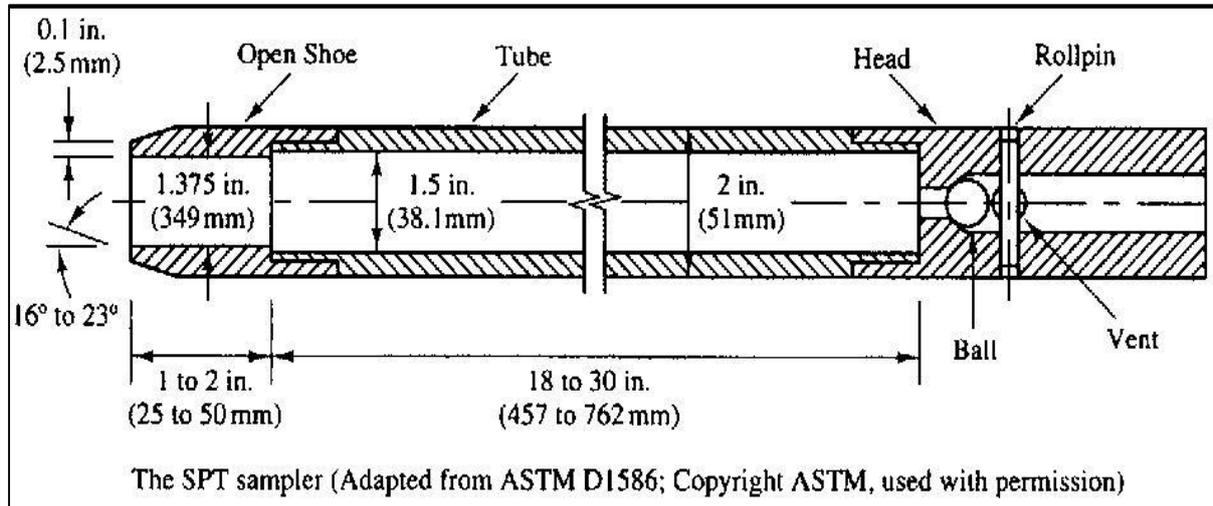
Figure (2-14): split –barrel sampler for use the SPT (McGregor and Duncan,1998).

g. Plasticity Index (P.I)

This index is defined as the soil moisture content in percent at which the soil remains at plastic state (P.I) or it is defined as the difference between the liquid limit and the plastic limit of the soil.

Equations (2-49) and (2-50) were used for determination of this index. These equations show that there is a relationship between the coefficient of lateral earth pressure at rest (Ko) and (P.I) for soil and as follows, (Hunt,1989):

$$K_{\text{o}} = 0.4 + 0.007(P.I)\quad 0 < P.I < 40 \dots \dots 2 - 51$$
$$K_{\text{o}} = 0.64 + 0.001(P.I)\quad 40 < P.I < 80 \dots \dots 2 - 52$$

Chapter Three

Data Acquisition and Equipment

Chapter Three
Data Acquisition and Equipment

3.1. Preface

This chapter dealt with the methods used in this study, taking models, and conducting the necessary geotechnical tests for all samples (plate 1-3) includes the following:

Collecting information about the nature and terrain of the location, geologic features, and the negative conditions that may be found and affect or obstruct the work besides other features relating to the location. In addition, the boreholes' number and locations are determined, from which samples will be taken from the soil and the turbulent-non turbulent water to conduct all the necessary field and laboratory investigations, including the chemical tests, to get the physical, chemical, and mechanical features under the soil. This leads to geologic description for the obtained materials and applying the geometrical analysis and assessing the field and laboratory results which is a very important and valuable way for the geo-technic engineering and its utilisation to understand the nature of soil in the field with the seismic survey via some boreholes, like (down-hole, cross- hole)(Danson,2005).

Stages of completion of the study

Data collection

field work

Laboratory work

Office work

Well drilling

Engineering investigation

software use (reflex2DQuick)

Sample collection

Sieve analysis

Interpretation of geotechnical tests to find the dynamic modulus of elasticity

Interpretation of seismic data

Conducting seismic surveys

bulk density

Make a comparison between laboratory tests and seismic survey

Direct shear test

Plate (3-1): Flowchart for structuring the study

3.2. Field survey:

3.2.1. Borehole drilling and sampling

In the determined area for investigation, four boreholes are drilled in each location; as shown in plate (3-2) and table (3-1). Additionally, two boreholes are drilled (BH1, BH2) at depth of 10m by using the Flight Auger machine on November 21, 2021 via laboratories of Faculty of Science, University of Babylon.

The standards of American testing and materials association are approved for drilling the field (ASTM D-1452-D5783). Using boreholes for the seismic survey.

The boreholes depth is measured from the current natural surface of the earth (NGS). However, a cover for the boreholes are made by using plastic tubes (PVC) to prevent borehole collapse and to gain a high seismic energy as well as supporting these boreholes for the seismic survey in future. After that, the samples will be transferred to the lab to make geometric tests.

Plate (3-2): Map of the drilled boreholes

Table (3-1): coordination of the drilled wells

Designation	East (E)	North (N)
BH1	44 25 8.36	32 27 47.17
BH1	44 25 6.68	32 27 47.24
BH1	44 25 6.74	32 27 45.96
BH1	44 25 6.80	32 27 45.12
BH1	44 25 6.22	32 27 46.22
BH1	44 25 6.29	32 27 45.60

3.2.2. Seismic refraction by boreholes

The seismic refraction has been done to each of the P and S waves for the field by using the following methods, on 28/11/2021:

3.2.2.1. Cross-hole method

It contains making one seismic test between BH1 and BH2 boreholes, in which only one borehole is the source and the other is the receiver (geophone). The displacement between boreholes is 6.7 m (plate 3-3). The survey starts from depth of 1m from the earth's surface to 10m and the interval between trace and another is 1m.

Plate (3-3): pictures showing seismic refraction surveys (cross-hole).

3.2.2.2. Down-hole method

It contains the one seismic test in BH1, which has been regarded as a receiver, transmitted power source put on the earth's surface and the displacement between the borehole and the source has 2 m (plate 3-4). The survey began from depth of 1m from the surface to 10m, and the interval between traces was 0.5m.

Plate (3-4): pictures showing seismic refraction surveys by borehole.

3.3. Equipment

Some equipment has used to reach the required aims for the study:

3.3.1. Drilling machine vehicle

The location of the boreholes is determined in the field via GSP by hand, in which the location exists in Babylon and it is a part of quaternary deposits. In general, it is a flat earth and, to drill the boreholes, an Auger machine is used (plate 3-5), which is installed on a vehicle and the used drilling equipment to execute the field work contains four multi-way drilling machines to accomplish drilling (20, 25, 30m) depth from the current earth's surface as it adopts the standards of American testing and materials association are approved for drilling the field (ASTM D1452-09 & D5783- 12). The standard penetration test (SPT) is done on different depths in all boreholes as turbulent samples, and the tests are done according to(ASTMD1586-99).
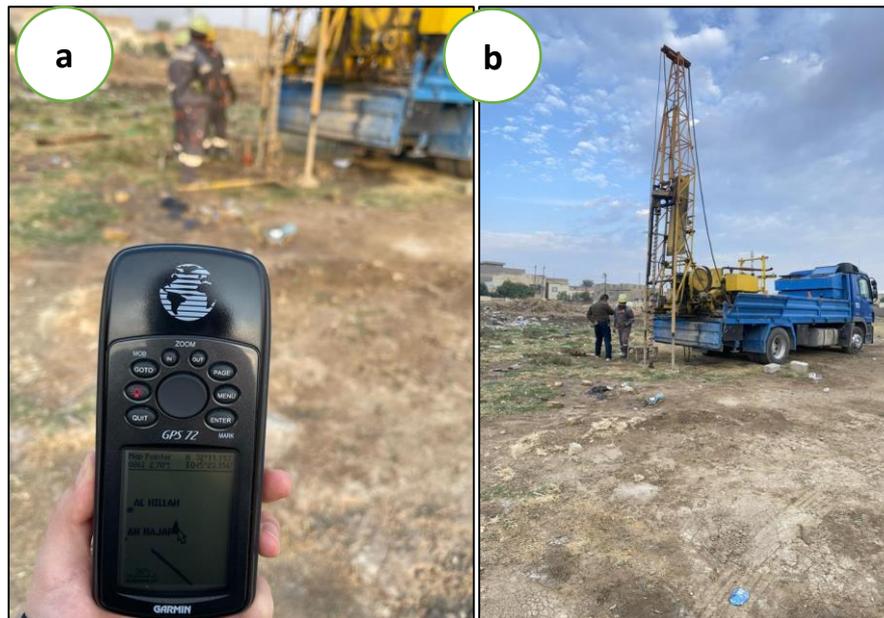
Plate (3-5):a- Mechanical type auger in the study area.
b- Use GPS-handheld based.

3.3.2. ABEM terraloc pro

A modern Sweden (2011) equipment known as (ABEM Terraloc Pro), Plate (3-4) was used for the purpose of this study in seismic refraction survey traces and seismic survey by boreholes (Cross-hole and Down-hole). Is owned department of applied geology, this new version is used in Iraq for the first time and they are utilized anywhere in the world in all weather conditions, (ABEM Instrument AB: instruction manual, 2011). ABEM Terraloc Pro 2 is a versatile seismograph. A user-friendly set-up wizard ensures an efficient fieldwork, with outstanding dynamic range, recording everything from "a whisper to an explosion".   Operating power comes from power source that delivers from 10-30 volts DC or any external battery pack or an internal battery. Typically, this means a re-chargeable battery pack, AC/DC power supply (office power supply unit) or a car (or truck) battery.

ABEM Terraloc seismic system is used to record all of the seismic cross-hole and down-hole waves, it has a high ability of analysis of seismic recording to shallow depth. The ABEM Terraloc consists of two main separate units as shown in plate (3-6). The field information units consist of printer unit, a hard disk with a size of at least 100 GB and internal Compatible computer and the picking form the boreholes

by seismic receivers designed to measure P and S wave velocity in borehole consisting three geophones, two horizontal and one vertical. Vertical shear and compressional waves propagating in a horizontal layer were detected by two receivers placed in adjacent boreholes at the same depth as the energy source.

Seismic methods are commonly used for civil engineering and infrastructure studies, where data can easily be compared with complementary geotechnical methods for determining depth to bedrock, bedrock quality, soil stability, finding fractures and weak zones, as well as more traditional geological mapping. ABEM Terraloc Pro can be configured for all of these applications, and more. The seismograph is triggered by ground vibrations created by an energy source. Time is then recorded accurately until these vibrations have propagated through the ground and can be measured by geophones connected to the seismograph, (Willmore, 1959).

plate (3-6): ABEM terraloc pro equipment.

3.3.3. The geophones used in this study

a. Normal geophones

A cylindrical coil is suspended by a leaf-spring in a magnetic field provided by a small permanent magnet which is fastened to the geophone casing (Reynolds, 1997). Geophone of the frequency response is that of a harmonic oscillator and standard geophones usually resonate at or below than 10 Hz (Milson, 2003). The geophone is implanted into the ground with a spike. Geophone plays on convert ground movement (velocity) into voltage to electrical signal, and the signal may be recorded at seismograph or a recording station. Moreover, the seismic response is the deviation of this measured voltage from the base line and it is analyzed for structure of the earth**.** The basic principle of geophones is utilized in seismic refraction waves to record the energy waves that came back from the subsurface layers. So, a coil/magnet geophone response is proportional to ground velocity (Willmore, 1959).Vertical and horizontal geophones has used in this study for Compression and shear wave's recordings respectively, plate (3-7).
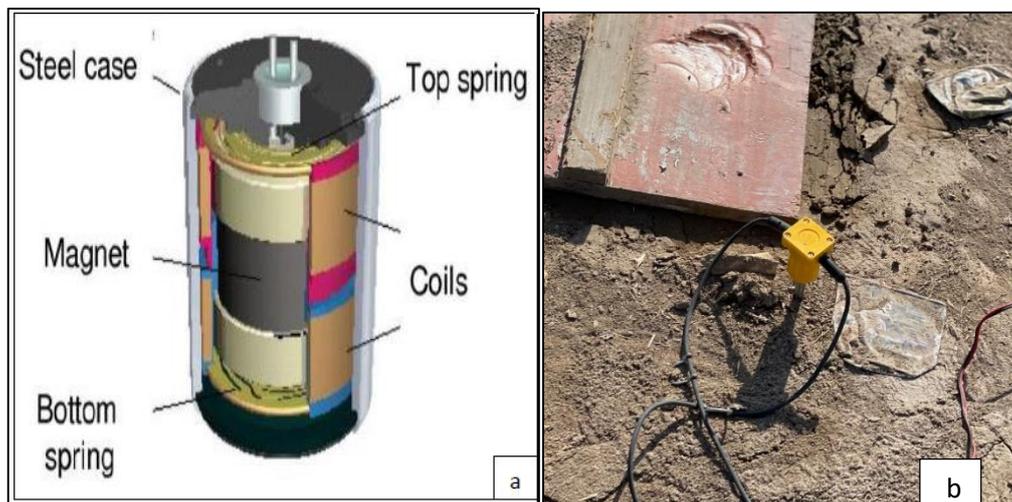
Plate 3-7: geophones of Survey. (a), The inside parts of the geophone (after Gadallah and Fisher, 2009). (b), Vertical and horizontal geophones that are used in the study area.

b. Tri-axial geophone for borehole

It is utilized in cross-hole, down-hole and up-hole surveys, and consists of three (3 components). One of the geophones for P waves and the other two are for (vertical and horizontal S-waves). So, it is put into the borehole and there is an attach wire stay with a person, plate (3-8).

Plate 3-8: Tri-axial geophone for borehole (after ABEM France *Ballard borehole manual).*

3.3.4. The seismic source that were using in study area

1. A Sledgehammer

Seismic waves (compressional and shear) can be created using a sledge hammer with a weight of 25 kg by rising it up and then downfall it on iron or wood plate (3-9). This process is repeated more than once to get bestead seismic records. It is worth mentioning; the power is not enough to get distinctive wave record. Therefore, and in order to receive good signals, must use 25 Kg a weight with keeping one hit steady without recoil.

Plate (3-9): sledge hammer that is used in this study, (25 Kg hammer with wood plate).

The advantage of this source is that it is cheap, causes minimal environmental damage and is extremely easy to use. For shallower seismic work, the hammer source may provide sufficient energy for spreading up to refraction line lengths of over 200 m, and interface depths of 30 m of more, depending on the local geological conditions (Reynolds, 1997).

3.3.5. Ballard borehole seismic source

The ballard source is manufactured by the R.T. Clark Companies, INC in the USA, and distributed in France by ABEM FRANCE. To conduct high quality P and S-wave cross-hole, down-hole and up-hole surveys this tool was designed to enable geotechnical engineers and engineering geophysicists with ASTM standards (ABEM France: Ballard borehole, 2011). In site, ballard borehole seismic source was used to make seismic survey boreholes. (V_P and V_s) seismic waves generated by air pressure and Ballard borehole seismic source put into borehole with stack on sidewall (in the selected depth) than it lifted up by wire to arrive to the end to fall down plate (3-10). So, there are three generated waves: direct, refracted and reflected waves.

Water is always removes from the seismic source borehole. This leads to give better results. It is designed to offer S wave enhancement, S wave phase reversal,

suppressed P wave energy (but adequate), maximum reliability, light weight, high frequency (fast rise time), low cost, and signal repeatability, (ABEM France: Ballard borehole, 2011).

Plate (3-10): Ballad borehole seismic source.

The borehole-clamping tool is an inflatable sidewall anchor system. It is positive designed as a single three in-one, 0.5-inch diameter cable houses the controls for zero-time geophone, reversible spring loaded hammer activation and air for the clamping mechanism, (ABEM France: Ballard borehole, 2011).

3.4. Geotechnical laboratory testing

The laboratory tests of the samples started on 30/11/2021 and continued for a period of (1.5) months. For the types of samples collected from the studied wells, for more information Examination and testing as described below, table(3-2):

•   Disturbed samples (DS) were obtained according to (ASTM D-1586) at intervals of (0.5-1.5) meters, and are required to determine the classification of the soil layers. All disturbed samples were sent to the laboratory for further examination and testing.

- Split Spoon Samples (S.S) were taken from the Standard Penetration Test (S.P.T) carried out on site. These were also used as disturbed samples**.** Split spoon sampling is generally used to collect undisturbed soil cores of 18 or 24 inches in length. A series of consecutive cores may be extracted with a split spoon sampler to give a complete soil column profile, or an auger may be used to drill down to the desired depth for sampling. The split spoon is then driven to its sampling depth through the bottom of the augured hole and the core extracted. When split spoon sampling is performed to gain geologic information, all work according performed in accordance with ASTM D1586-98, "Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils". (McGregor and Duncan,1998)

- Undisturbed Samples (US) were obtained according to (ASTM D-1587) at intervals of (1-2m) or any change of strata to cover all layers. After extraction, the undisturbed sample was trimmed off, capped with polyethylene sacks or paraffin wax from top and bottom, and sealed properly at both ends, transported to the laboratory for further examination and testing as shown in table (3). (ASTMD-4220), Practice for description and identification of soils. ASTMD-2488). plate (3-11). Sampling Water table measured after 24 hours of boring according to (ASTM D-4750).

Plate (3-11): Showing sampling in site

Table (3-2): Summary of Laboratory Testing

Type	Test	Testing Standard
Type of samples	Disturbed samples (DS)	ASTM D -1586
	Undisturbed Samples (US)	ASTM D-1587
	Split Spoon Samples (S.S)	ASTM D 1586-99
Physical Properties	Specific Gravity	ASTM D 854
	Natural Water Content	ASTM D 2216
	Unit Weight	BS1377:1990
SPT	Standard penetration test	ASTM D 1586-99

3.4.1. Soi l classification tests :

The purpose of geotechnical investigation for the site is to determine the existing soil profiles and engineering characteristics of the subsurface conditions at the site and to provide the information on the geotechnical design parameters that will be required for a safe and economic design and excavation of the engineering works, such as the soil bearing capacity and other special recommendation which depends on the site nature. Included that the experiments following are performed:

- Specific Gravity, Water Content (to determine the natural water content of the soil), Atterberg Limits (LL, PL, and PI values), Sieve Analysis test (to determine grain size analysis) were made to SPT and UD samples.

-The Standard Penetration Test (SPT), an in situ or field technique can provide much of the information required during a site investigation as compared to other field techniques. This is because the method is simple, relatively inexpensive and rugged. The method has the advantage of providing a representative disturbed soil sample in addition to the undisturbed samples obtained during the test. The object of the SPT is to determine the resistance of soil to the penetration of the standard-size sampler, in order to obtain a estimate of the properties of soil in situ. The test can give valuable information regarding the uniformity and compactness of sand layers. This information together with other information from situ test enables the investigator to conclusion comparative the correlation between the results in different ways (Parihar and Rashmi, 2012).

Chapter Four

Results and Interpretation

Chapter Four

Result and Interpretation

4.1. Subsurface Seismic survey

4.1.1. preface

This survey was conducted in two ways that are cross-hole and down hole. Wells have been utilized to achieve this investigation.

The processing method consist of several stages: -

4.1.1.1. The travel times for seismic sections

By using program reflex2DQuick, the first arrival times for all (seismic sections) is between BH1and BH2 (plate 3.1, chapter three). Sometime the first arrival (first pick) may be noise or refracts wave specially when there is a high contrast across the interface such as soil and hard rock.

Three types of times (Tp, Tsv and Tsh) were recorded due to the horizontal waves travelling between borehole source and receiver indeed, (Fig4-.1) However, the time will change owing to the horizontal variations in types and densities of layers between boreholes.
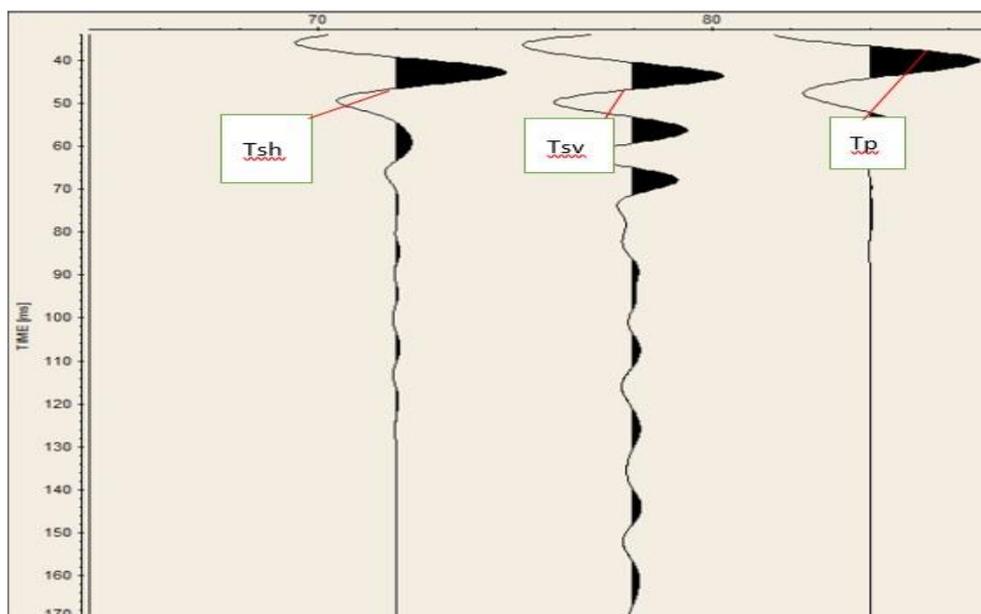
Figure (4-1): reflex2DQuick between BH1 and BH2 showing (Tp, Tsv and Tsh).

4.1.1.2. Calculation of wave velocities for cross-hole profiles

Primary and shear wave velocities can be calculated from the travel time between source and one or more receivers for each depth interval sequentially (Stokoe, and Santamarina, 2000). The velocities were calculated from ground surface until the tasked depth of each 1 m interval becomes 10 m total depth using the equation below:, Tables 4-1.

Information thus obtained will enable the investigator to compute true vertical depth and horizontal position at any point within the borehole so that actual distance between the holes can be computed to within ±2 % to a depth of about 10.0 m.

$$V = \frac{x}{T} \ldots\ldots\ldots\ 4\text{-}1$$

$$Vp = \frac{x}{Tp} \ldots\ldots\ldots\ 4\text{-}2$$

$$Vs = \frac{x}{Ts} \ldots\ldots\ldots\ 4\text{-}3$$

Where:

Vp = Compressional wave velocity.

X = The distance between source and receiver two boreholes.

Tp = Travel time of compressional wave.

Vs = Shear wave velocity.

Ts = Travel time of shear wave.

Table (4-1): The travel times (Tp and Ts) and velocities of seismic wave (cross-hole profile) in the study area.

Depth(m)	Distant(m)	T(msec)	Vp (m/sec)	T(msec)	Vs (m/sec)
1		13.9	482.01	37.2	180.11
2		13.4	500.00	33.6	199.40
3		12.6	531.74	30.8	217.53
4		10.6	632.07	26.4	253.80
5	6.7	8.8	761.36	22.5	297.80
6		7.5	893.33	18	372.22
7		7.1	943.66	15.7	426.75
8		6.8	985.29	13.8	485.51
9		6.3	1063.49	12.9	519.40
10		6	1116.66	11	609.10

Seismic velocity measurements are available for local datasets. The testing methods that generated vp and VS data in this study are: downhole and cross hole. Table 4-1 above indicate the results of times and velocities of P and S wave for cross-hole survey, P-wave velocity ranged from482.01m/sec to 1116.66 m/sec to 1-10 m depths, and S-wave velocity ranged from 180.11m/sec to 609.1 m/sec to 1-10 m with seen P and S-wave velocity increases in depth 5-10 m where P-wave is between 761.36-1116.66 m/sec and S-wave is between 297.8-609.1 m/sec that reflected the variations in lithology of soil and its components.

In general, P and S-wave velocity have low velocity of soil in the study area because the soils do not have a sufficient hardness where the velocity affected by the density of soils (Mavko,2005).

Soil densities and seismic wave velocities (Vp and Vs) are used to determine the suitability of subsurface construction materials for geotechnical engineering purposes (Berwari and etal,1995).

Shear velocity data indicates that a component layers of stiff soil at depth 1 to 5 m and very dense soil at depth 6 to 10m. (typical values for these sediment types in

Table 2-7). In addition, depending on results of compression velocity and table (2-6), soil could be classified as clay and lose sand and clay landfill cap compacted.

4.1.1.3. Relationship between wave velocities with depths

It is well known that near surface P and S-wave seismic velocities provide valuable information for studies of ground motion behavior, geotechnical properties, natural frequencies and the liquefaction potential under the effects of an earthquake in (Carvalho, et al., 2009). After computing the seismic velocities for (P) and (S) waves for all profiles, Velocity-depth curves can be drawn to shows variations of seismic velocities with depth and determining the weak zones. Important relationships between velocities, travel time (X-axis) versus depths (Y-axis), for both P and S-waves were constructed for this type of survey Fig (4-2).
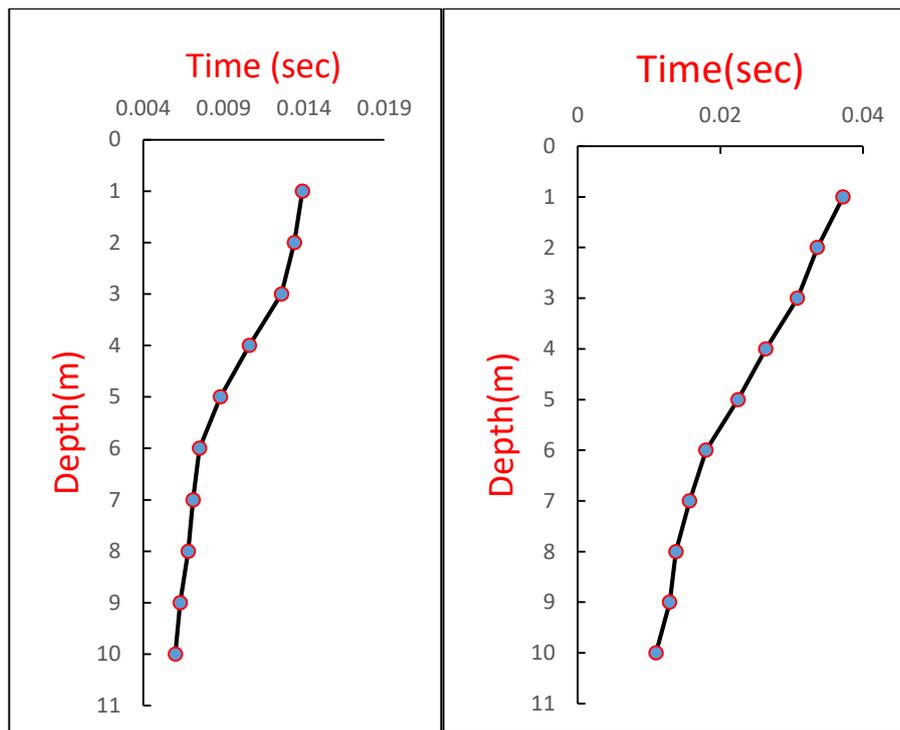
Figure (4-2-a): for cross-hole profile between BH1 and BH2, show the relation between depth and travel time
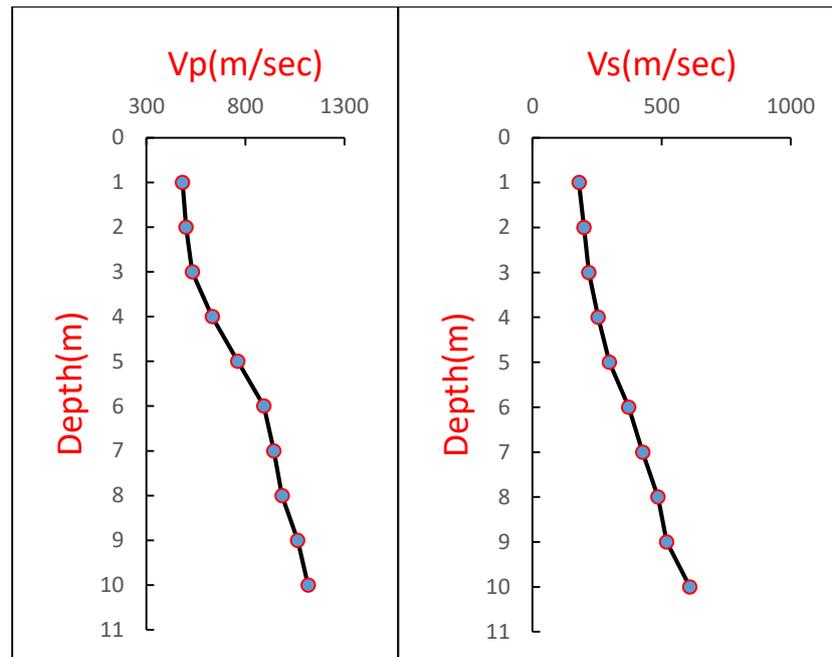
Figure (4-2-b):for cross-hole profile between BH1 and BH2, show the relation between depth and velocity.

Knowing the time of arrival of the wave as well as the velocity in the rock layers, it becomes possible to calculate the depth and thickness of the various rock layers and underground formations.

From above curves, it can be seen that the soil has low Vp and Vs at depth interval between the ground surface until 4m, either in depths 5 to 10 m there are change in a curve of Vp and Vs, as well as, due to density of rock formations and layers. the values of P and S-wave velocities give a gradual increase with depth from the surface to the depth 10 m.

4.1.1.4. Elastic and geotechnical properties from cross-hole results

Seismic wave responses are affected by the soil texture and structure, and they are sensitive to the variations in soil properties. Propagation of seismic waves through soils is a small-strain phenomenon that introduces a small perturbation without altering the fabric of the soil. As a result, can be used to estimate and observe on-going internal changes of soil properties.

Elastic and geotechnical properties were calculated based on compressional and shear velocities and the ratio between them with density. It is very important to know the amount of change in elastic modulus and geotechnical properties for each 1 m subsurface soil interval at the location between BH1 and BH2 which were calculated using the equations mentioned in chapter two (2-11, 2-12, 2-13, 2-14, 2-20,2-21,2-28,2-31,2-37 and 2-38).

Table 4-2: The calculated elastic modulus for cross-hole results between The BH1and BH2.

Depth (m)	ʋ	E N/mm²	ʎ N/mm²	μ N/mm²	k N/mm²	ρ(gm/ cm³)
1	0.42	159.34	337.30	56.15	402.10	1.73
2	0.41	193.88	354.14	68.97	433.58	1.73
3	0.41	230.61	397.68	82.39	492.21	1.74
4	0.4	318.58	574.99	113.46	703.66	1.76
5	0.41	447.01	859.13	158.54	1036.26	1.78
6	0.4	701.55	1171.32	251.46	1448.08	1.81
7	0.34	911.76	1261.13	332.40	1624.92	1.82
8	0.34	1158.12	1308.76	432.24	1779.62	1.83
9	0.34	1340.61	1552.52	498.96	2091.36	1.84
10	0.29	1778.40	1578.01	690.24	2319.07	1.86

The variation in velocity even in the same layer was attributed to variations in lithology, grain size, porosity and saturation (Salem ,2000). The low velocities in layer are presumably due to the presence of fine deposits such as clays and silts. In general, the velocity fact that velocity increases with depth as porosity decreases (Salem 1993). VS increases with increasing grain size of predominant sediment type: clays have lower VS than sands, which have lower VS than gravels (Barbara, etal.,2015).

The Lame and bulk modulus proportional with P-wave, while Young and Shear modulus proportional with S-wave that indicates the water content or saturation of the soil led to decrease Young and shear modulus. The values of Poisson's ratio v ranged from 0.42 to 0.29 to 1-10 m depths that indicate the soil in the study area is clay and sandy clay that depending on Table 2-3 in chapter two. Fig (4-3).
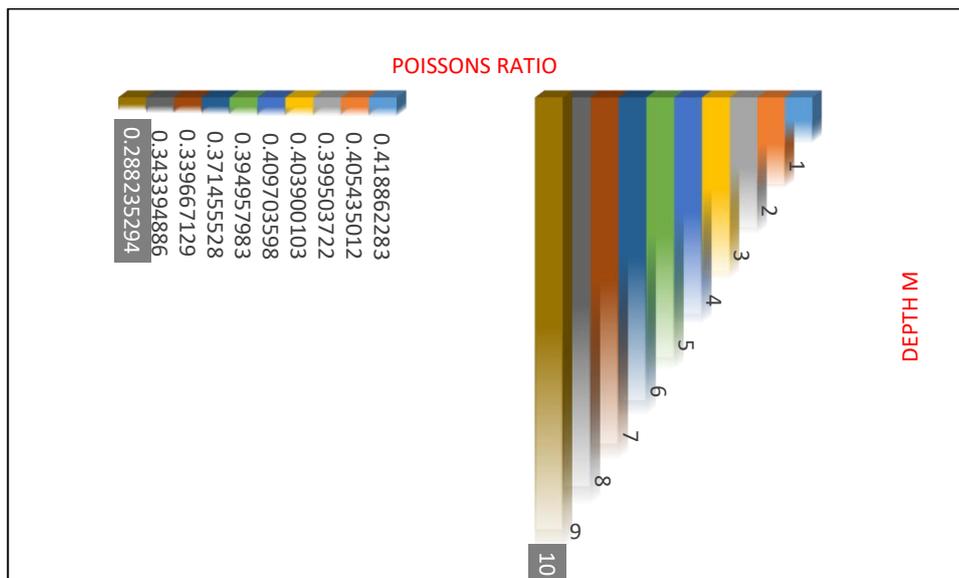
Figure (4-3): Relation between Poisson ratio with depth

The relationship between bulk modulus (K) and Shear modulus (μ) is linear, where with increase Bulk modulus (K), the Shear modulus (μ) will increase, depending on the ratio between velocities of (P) wave to velocity of (S) wave (Barbara, etal.,2015).

There are many relationships among seismic velocities and elastic modules most of them are linear, but some of them are directly proportional, other are inversely.

(Khorshid,2016). The results indicate that a correlation between velocity values and Elastic modulus. These values refer to the behavior of a material when it is subjected to a certain stress, as a finaly,in the study area, we noticed that the value of (K) increases with depth that means low porosity of that area increases and the Poisson's ratio is reflects the ratio of voids in the area, pointed as inverse relationships, this means that reduce of Poisson's ratios increases the ratios of (Vs / Vp) with depth and this will increases the brittleness and rigidity of materials and which described as saturated with water. (μ) increasing in the value of this modulus indicates to increasing the quality factor of the soil with depth. We therefore use seismic waves to describe the speed, direction and location of elastic deformations as they propagate through materials.

4.1.1.5 geotechnical properties

depending on the seismic wave velocity (P and S-wave), geotechnical properties were calculated for cross-hole profile, Table 4-3.

Table 4-3: The calculated geotechnical properties for cross-hole results between BH1 and BH2.

Depth(m)	Vp (m/sec)	Vs (m/sec)	$\mathring{k}$	Im	Ic	Φ	qu kg/cm²
1	482.01	180.11	0.72	0.67-	3.38	15	0.17
2	500.0	199.40	0.68	0.62-	3.46	17.4	0.19
3	531.74	217.53	0.66	0.59-	3.50	17.4	0.22
4	632.07	253.8	0.67	-0.61	3.47	18	0.33
5	761.36	297.8	0.69	0.63-	3.44	17.7	0.52
6	893.33	372.22	0.65	0.57-	3.53	19.8	0.76
7	943.66	426.75	0.59	0.48-	3.69	23	0.86
8	985.29	485.51	0.51	0.35-	3.94	28.6	0.96
9	1063.49	519.4	0.52	0.37-	3.91	28	1.15
10	1116.66	609.1	0.40	0.15-	4.46	30	1.29

The values of Ko near from 0.5, depending on Table 2-9 in chapter two, and concentration index Ic is more than 4 that refer the soil is saturated. Therefore, Pwave

is increased while S-wave is highly absorbed with the depth. The values of ultimate bearing capacity qu increases with depth and ranged between 0.17-1.29 kg/cm².Also, it can be seen the values of the coefficient of lateral earth pressure at rest equal the material index Im but in inverse sign ranged between -0.67 to -0.15 and classification for soil is intermediately competent to competent. The engineering laboratory tests and down-hole survey give the exact results with cross-hole seismic survey. It tells that soil between 0-10 m consists of clayly sand and silty sand depending on the Φ. In this study, it has been relied mainly on shear wave velocity as it passes through the layers in a low velocity. Therefore, shear wave has low in frequency and high in amplitude. Therefore, and according to these results, the underneath soil in this site of study it can be said that there are two layer, first layer extends from the natural ground surface to end 6m and the second layer started from 7m. as shown in Fig 4-4.
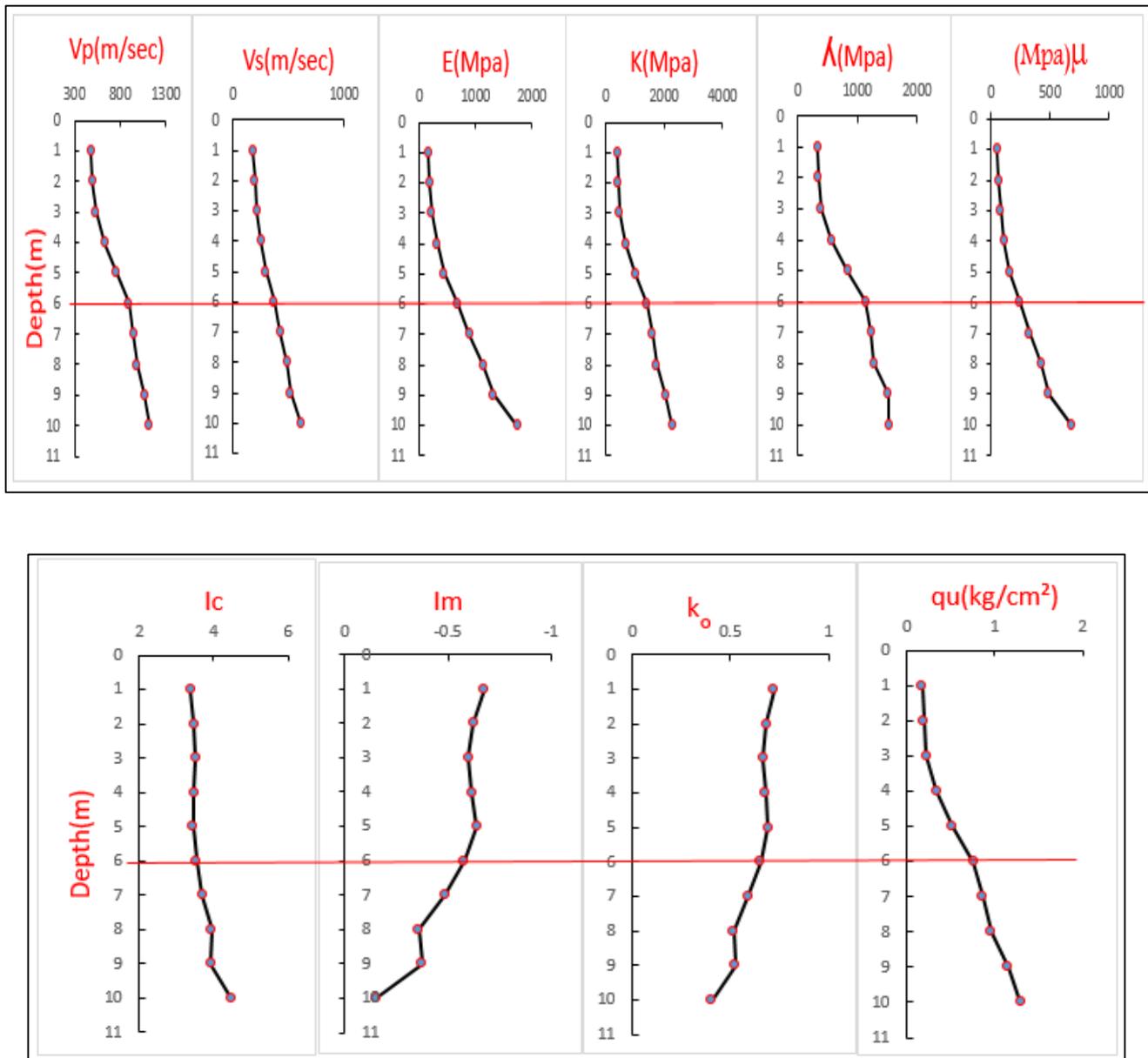
Fig 4-4: The relationship between elastic moduli, geotechnical properties and velocity with depth for cross-hole survey.

The seismic velocity values, elastic modules and engineering parameters indicate that the layer from surface to depth 5m of the study area have low or non-competent material quality, while the rest of the area have intermediately competent material quality. So, the suggested area for construction activities at a depth of beyond 6m.

4.1.2. Seismic down-hole survey

An improved downhole test has been developed for use in geotechnical earthquake engineering studies.

4.1.2.1. The horizontal distance between the source and the receiver

In this study, the distance was determined between both source and receiver borehole that depends on the study target and area conditions.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 (Abdulla and Omar ,2015).in this profile the distance was 2 m only.

4.1.2.2 Picking of first arrival times

The survey was carried out in Bh_1 Located within the area of study and calculated the first travel time was of compressional and shear waves in the borehole were measured within (1–1.5 m) interval at successive positions up to maximum depth (10 m).

4.1.2.3. Calculation of slant distance (SR)and travel time correction (Tcorr)

When analyzing downhole seismic testing data in soil profiles with minimal variance in impedance between the various soil layers, the Straight Ray Assumption (SRA) methodology can be utilized to calculate interval velocities (Baziw, and Verbeek, 2012). It was determined from the source to receivers in the boreholes, (ASTM:D 7400–08). It can be a triangle shape therefore can be using Pythagoras theory. The values of slant distance shown in Table 4-4, (ASTM: D 7400–08).

$SR = \sqrt{Z2 + X2}$ …………….. 4-4

Where:

SR = Straight ray (Slant distance).

Z = Depth measured in meter unit.

X = offset between source and borehole measured in meter unit.

After calculating the slant distance, a standard straight ray geometry assumes that the down going rays have spent an equal amount of time or have the same travel path within each interval layer. The slant ray and refraction calculation take into account the time spent and corresponding travel path within each layer (Baziw, and Verbeek, 2012) and calculate travel time correction as shown in Table 4-4. Tcorr was calculated according to (Hamdi, et al, 1996).

$$Tcorr = \frac{Z*T}{SR} \ldots\ldots\ldots\ldots\ldots 4\text{-}5$$

Where:

Tcorr = Travel time correction.

T = Travel time in field.

4.1.2.4. Calculation of velocity (V)

The wave velocity of soils plays an important role in the calculated of elastic and geotechnical properties. Measurements of P and S-wave velocity (V) to down hole in this study. The velocities are calculated as direct velocities by using travel time correction (Tcorr) and depth (Z) as distance. Table 4-4 shows the values of primary and shear wave velocities of down-hole profile in BH1.

$$V = \frac{Z}{Tcorr} \ldots\ldots\ldots\ldots\ldots 4\text{-}6$$

Table 4-4: The values of the travel time, the slant distance, the time correction and the velocity of P and S-wave from down-hole method profile in BH1.

Depth (m)	SR (m)	Tp (msec)	Tp(corr) sec	Vp (m/sec)	Ts (msec)	Ts(corr) sec	Vs (m/sec)	ρ gm/cm³
1	2.23	4.5	0.002	496.90	13.479	0.006	165.89	1.734062
1.5	2.5	4.7	0.002	531.92	14.476	0.008	172.69	1.706383
2	2.82	5.6	0.003	505.11	16.474	0.011	171.69	1.701015
2.5	3.20	6	0.004	533.60	16.74	0.013	191.25	1.706719
3	3.60	6.7	0.005	538.14	17.388	0.014	207.35	1.707628
3.5	4.03	7.3	0.006	552.21	18.004	0.015	223.90	1.710442
4	4.47	7.5	0.006	596.30	19.129	0.017	233.78	1.719257
4.5	4.92	8.1	0.007	607.95	19.803	0.018	248.67	1.721591
5	5.38	8.6	0.007	626.18	20.967	0.019	256.84	1.725236

5.5	5.85	9.2	0.008	636.12	22.505	0.021	260.04	1.727225
6	6.32	9.5	0.009	665.74	23.526	0.022	268.83	1.733149
6.5	6.80	10.2	0.009	666.7388	26.957	0.025	252.28	1.733348
7	7.28	10.6	0.0101	686.8028	28.455	0.027	255.84	1.737361
7.5	7.76	11	0.0106	705.6443	29.952	0.028	259.15	1.741129
8	8.24	11.1	0.0107	742.9019	31.45	0.030	262.20	1.74858
8.5	8.73	11.9	0.011	733.792	35.943	0.034	242.94	1.746758
9	9.21	12.5	0.012	737.5636	46	0.044	200.42	1.747513
9.5	9.70	12.6	0.012	770.4955	37.441	0.036	259.29	1.754099
10	10.19	13.7	0.013	744.3824	38.938	0.038	261.90	1.748876

To measure VP and VS using accurate methods whether in the laboratory or in the field. The waves velocity are typically measured using the seismic field tests (cross hole and down hole and other methods) .Table(4-4) above indicates the results of times and velocities of P and S wave for down-hole survey, P-wave velocity ranged from 496.8 m/sec to 744.3 m/sec to (1-10) m depths where interval time 0.5 m, and S-wave velocity ranged from 165.89 m/sec to 261.9 m/sec to (1-10)m with seen P and S-wave velocity increases in depth7 m where P-wave is 686.8m/sec and S-wave is 255.84 m/sec that reflected the variations in lithology of soil and its components. In general, P and S-wave velocity have low velocity of soil in the study area because the soils do not have a sufficient hardness where the velocity affected by the density of soils.

4.1.2.5. Relationship between wave velocities and depths.

As in cross hole method, when using seismic survey, the wave propagation speed within the soil is measured, curves between depth (Y-axis) with velocity and time (X-axis) were very important for both P and S-wave velocity which can be known by the nature soil layers, Fig 4-5. Any change in velocity with depth means there is a change in the elastic parameters evaluation or the type of the layer. (Tavakoli & Rasmussen, 2016).
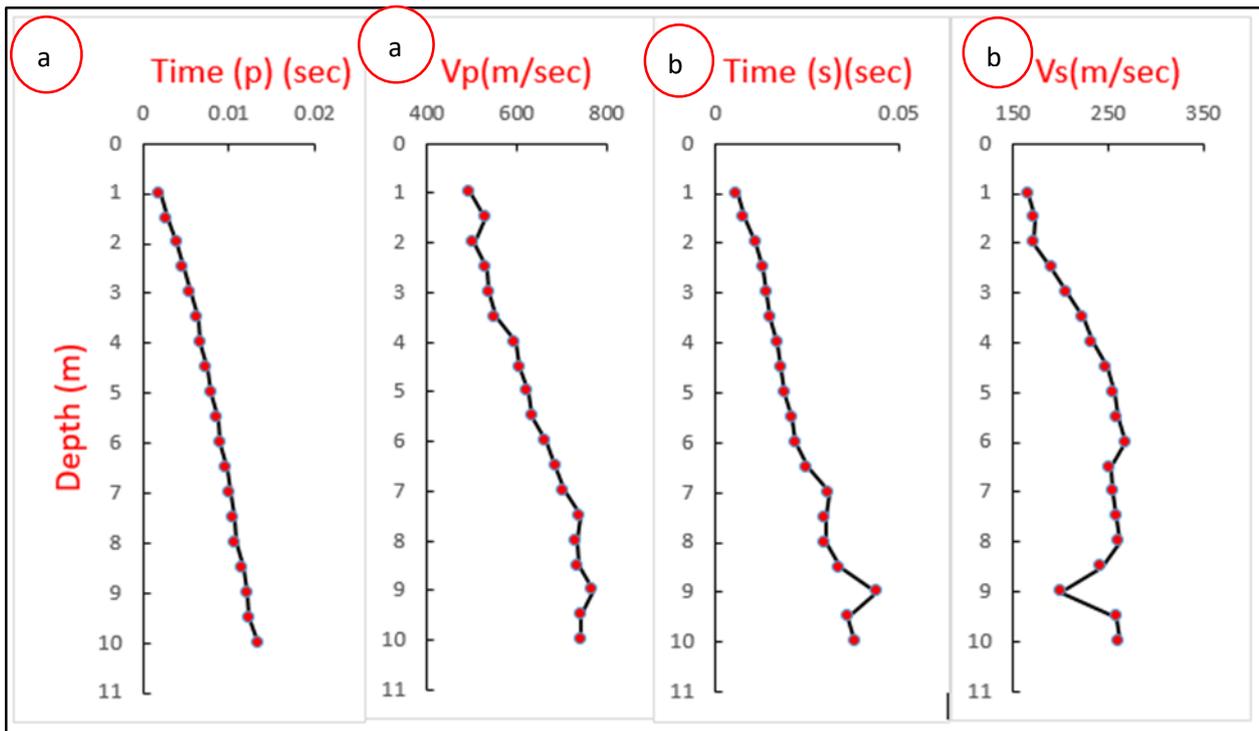
Figure 4-5: The relation between depth and velocity (a), depth and travel time (b) of down-hole method profile in BH1.

From these curves, it can be seen that the soil in depth 6 m changes in a curve of Vp and Vs, as well as, the values of P and S-wave velocities give a gradual increase with depth from the surface to the depth 10m depending of the density increase with depth (compaction in layer or soil load). Density in turn depends on a variety of different aspects such as degree of the compaction, porosity, water content and of course the composition of the material. In general, both the density and velocity of the seismic waves will increase with increasing depth. (Tavakoli & Rasmussen, 2016)

4.1.2.6. Elastic and geotechnical properties from down-hole

Elastic and geotechnical properties of each interval 0.5 m subsurface soil at the site location in BH1at depth 10m were calculated based on primary and shear waves velocities and the ratio between them with density and using the equations mentioned in chapter two (2-11, 2- 12, 2-13, 2-14, 2-20,2-21,2-28,2-31,2-37 and 2-38) as illustrated in Tables (4-5) and (4-8) below. Elastic modulus variations were calculated to know the change in layers with depths by elastic modulus.

Table 4-5: The calculated elastic modulus values from down-hole method results in BH_1

Depth (m)	ʊ	E N/mm²	μ N/mm²	K N/mm²	ʎ N/mm²
1.0	0.43	137.18	47.72207	428.0998	373.1227
1.5	0.44	146.6824	50.89316	482.725	423.1425
2.0	0.43	143.8745	50.14182	433.8656	374.9773
2.5	0.42	178.08	62.42735	485.8575	412.7859
3.0	0.41	207.4694	73.4239	494.4258	408.5285
3.5	0.40	240.373	85.7479	521.4597	421.31
4.0	0.40	264.839	93.96937	611.1661	501.9774
4.5	0.39	297.9856	106.4584	636.1723	512.6398
5.0	0.39	318.4052	113.8083	676.3201	544.5382
5.5	0.39	326.971	116.8024	698.7745	563.6817
6.0	0.40	351.3652	125.2563	767.9875	623.6125
6.5	0.41	312.5262	110.32	770.3963	643.2521
7.0	0.41	322.8451	113.7231	819.3581	688.5949
7.5	0.42	332.5682	116.9328	866.8111	732.6487
8.0	0.42	343.5351	120.2135	964.8869	827.5488
8.5	0.43	296.5976	103.0965	940.4058	822.5
9.0	0.46	204.9967	70.19783	950.5533	870.3066
9.5	0.43	338.7412	117.9345	1041.187	906.8772
10.0	0.42	342.9386	119.9624	968.9016	831.8736

The bulk and Lame modulus are proportional with P-wave, while Young and Shear modulus are proportional with S-wave that indicates the water content or the saturation of soil led to decrease Young and shear modulus.

The values of Poisson's ratio were ranged between (0.43-0.42) from 0.5 to10 m for the borehole. After calculation of this ratio, some areas show high values, and that reflects the ratio of the voids in that area saturated with water, that indicates the soil in study area is clay and saturation depending on Table 2-3 in chapter two.

Based on the seismic wave velocity (P and S-wave), geotechnical properties were calculated for down-hole profile in BH1 Table (4-6). They are very important to the engineering purposes. We can know material index, concentration index, etc.

Table 4-6: The calculated geotechnical properties values from down-hole method results in BH1.

Depth (m)	Vp (m/sec)	Vs (m/sec)	K̥	Im	Ic	Φ	qu kg/cm²
1	496.90	165.89	0.77	0.74	2.33	12	0.18
1.5	531.92	172.69	0.78	-0.76	2.36	12	0.22
2	505.16	171.69	0.76	-0.73	2.30	13	0.19
2.5	533.59	191.25	0.74	0.70-	2.22	14	0.22
3	538.14	207.35	0.70	-0.65	2.11	16	0.22
3.5	552.21	223.90	0.67	-0.60	2.01	18	0.24
4	596.28	233.78	0.69	-0.63	2.07	17	0.29
4.5	607.95	248.67	0.66	0.59-	1.99	19	0.30
5	626.18	256.84	0.66	0.59-	1.99	19	0.32
5.5	636.13	260.04	0.66	-0.59	2.01	19.2	0.33
6	665.74	268.83	0.67	-0.61	2.02	18	0.37
6.5	666.74	252.28	0.71	0.66-	2.14	16	0.37
7	686.80	255.84	0.72	0.67-	2.16	15	0.40
7.5	705.64	259.15	0.73	0.68-	2.19	15	0.43
8	742.90	262.20	0.75	0.71-	2.25	13.8	0.49
8.5	733.79	242.94	0.78	0.75-	2.34	12.6	0.47
9	737.56	200.42	0.85	0.84-	3.10	8	0.48
9.5	770.49	259.29	0.77	0.74-	2.32	12.7	0.53
10	744.38	261.90	0.75	0.71-	2.25	13.8	0.49

The above parameters are calculated by indirect relationship to calculate them from seismic velocities by geophysical method, they are useful for engineering purposes. The values of Ko near from 1, Ko refer to the material strength at depth, which is subjected to the constant geostatic pressure resulted from the weight of sediments (Hunt, R.E. 1986), depending on (Table 2-8 in chapter two) classified soil material which is loose sand and normally consolidated clays, and

concentration index Ic is equal (3) for soil loose or saturated materials. Therefore, P wave is increased while S-wave is highly absorbed with the depth. The values of ultimate bearing capacity qu ranged between (0.18-0.49 kg/cm2).

Also, it can be seen that the values of the coefficient of lateral earth pressure at rest equal the material index (Im) but in inverse sign. (Im) can be Classified as, non-less competent.

Elastic and geotechnical observations indicate that the occurrence of soil homogeneity between natural ground surfaces to end of investigation. Therefore, a gradual change in elastic behavior was noticed. The engineering laboratory tests and cross-hole method survey give the exact results with down-hole method seismic survey. In this study, it has been relied mainly on shear wave velocity as it passes through the layers in a low velocity. Therefore, shear wave has low in frequency and high in amplitude. According to these results, the underneath soil in this site of study it can be said there are two layer, the one layer extends from the natural ground surface to 6m and the second layer which extends from the 6m to end boring. as shown in Fig 4-6. Also, results showed that the Vp and Vs decreased at depth (9 – 10)m because the soil type at that depth is soft clay that led to a change in density.
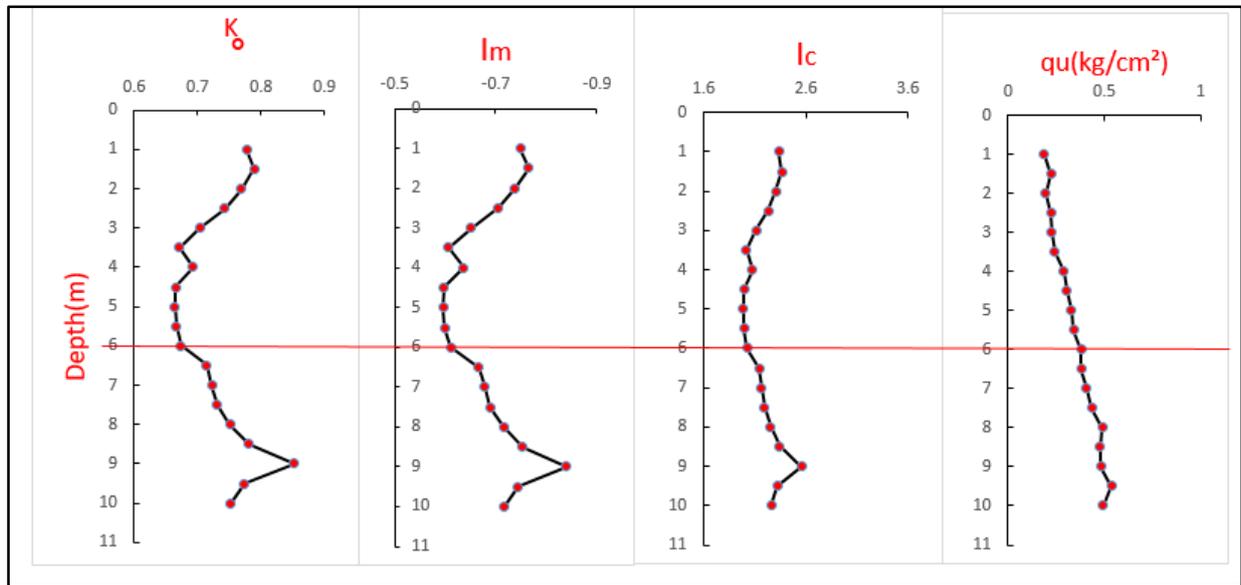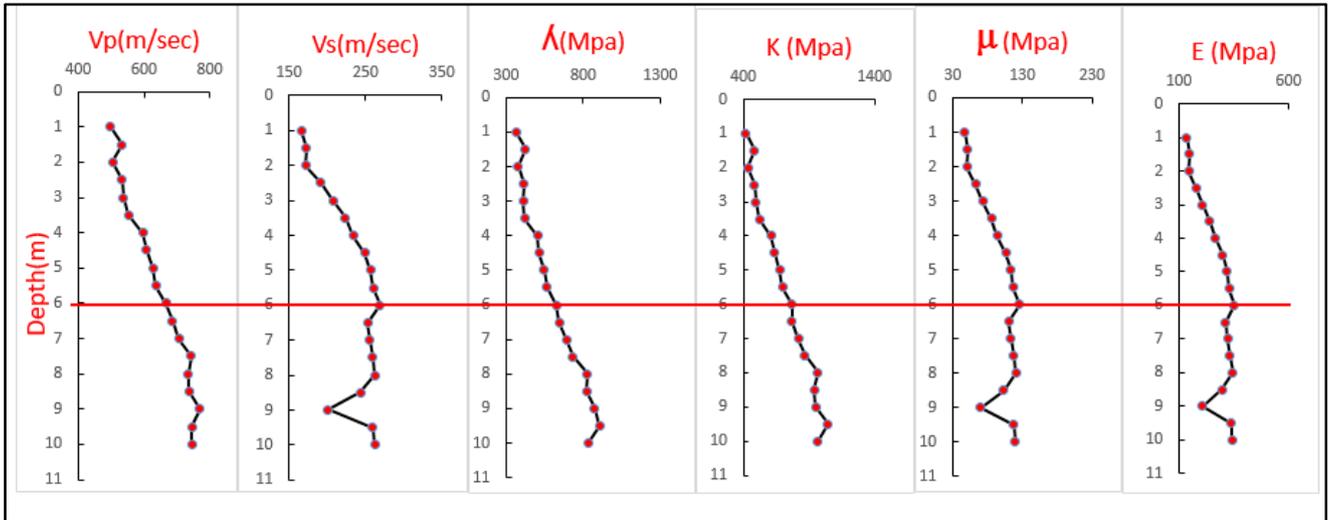
Figure 4-6: The relationship between elastic moduli, geotechnical properties and velocity with depth for down-hole.

4.3. Standard Penetration Test Data Interpretation

The SPT is widely used for estimating in situ properties of soils. In order to interpret the results of the Standard Penetration Test, a correlation chart is used to determine the mechanical properties of soils and to design foundations. The soil in the split-spoon sampler can be inspected in order to describe the soil profile (Budhu, 2004), Appendix (1). From the correlation table, the allowable bearing capacity of the soil can be estimated. The number of blows can also be related to the allowable bearing pressure - the coarser or harder the material, the higher the number of blows

needed to be able to penetrate the soil in question. Typical correlation among SPT (N blows), relative density (Dr), and angle of internal friction (φ′) are given in Table(4-7, A and B).Tables below:

Table (4-7-A): Relative density and consistency of soil (after Terzaghi & Peck, 1968 and Sanglerat, 1972).

SPT-N	Relative Density (Dr)	Description of Compactioness	Compactioness Static cone Resistance (qc)	Angle of internal Friction φ′degrees
4	0.2	Very loose	Under 2.0	Under 30
4-10	0.2 to 0.4	Loose	0.2 to 0.4	30-35
10-30	0.4 to 0.6	Medium dense	0.4 to 12	35-40
30-50	0.6 to 0.8	dense	12 to 20	40-45
>50	0.8 to 1	Very dense	Over 20	Over 45

Table (4-7-B): N–values, consistency and unconfined compressive strength of cohesive soils.

N	Consistency	Unconfined compressive Strength KN/m2
Under 2	Very soft	Under 20
2 to 4	Soft	20 to 40
5 to 8	Firm	40 to 75
9 to 15	Stiff	75 to 150
16 to 30	Very stiff	150 to 300
Over 30	Hard	0ver 300

The results in Table (4-8) shows N values, the dominant adjective to N values is the gradually increase with depth because it increases the bulk density with depth as a result to compaction or load of the layers. Therefore, the value N is a function of confining pressure, soil density and soil type. The equation to N values correction are below, depending on the formula (Terzaghi & Peck,1967 and Terzaghi (1969))

$Nc = 15+ 0.5 (N-15)$ ……. 4-7

From the results of in-suite of the soil from N-SPT method for depth from (1.5 m to 10.0m) for all boreholes average SPT-N by AL- Mawal For soil investigation. Table (4-8)

Table (4-8): corrected N for all BH1-4

Depth m	Nav.
1-1.5	10
1.5-2	10
2.5-3	10
3.5-4	12
4.5-5	12
5.5-6	16
6.5-7	9
7.5-8	29
8.5-9	18

4.4 Calculation of geotechnical properties of soil

These tests show that the engineering behavior for soil whence density, grain size analysis and the soil moisture content. Thus, geophysical study is mainly affected by soil quality. Also, they play a role in giving a clear picture to soil layers of site which as in geophysical methods.

4.4.1. Direct Shear Test

The direct shear test was carried out according to the American standard, Table (4-9).

Table (4.9): The results of the direct shear test

BH. No	Depth m	Direct shear test	
		C T/m^2	Ø
BH1	2.5-5	0.23	14
BH2	4.5-5	0.19	15
BH3	7.5-8	1.15	22

The results of the direct shear test were Table (4-9), where the values of the angle of friction of the soil at the study site ranged between 14 to 22, while the values of

cohesion ranged from 0.23 to 1.15 because the soil contains clays, which reflect the sedimentation environment in the region.

4.4.2. Grain size distribution

The results of grain size distribution and bulk density (wet and dry density in gm/cm3) is measured by (ASTM D4318).

Table (4-10): Physical properties and field-test of soil layers for all borehole.

Depth m	Type of Sample	Soil classification				Soil Description of **BH1**	Unit weight gm/cm³		G. S	SPT(N)
		Cla y %	Sil t %	San d %	Gra ve. %		Dry	wet		
0.5-1	DS	58	18	24	0	Grayish silty sandy clay soil , medium consistency , CH	-	-	-	
1-1.5	SS	53	20	27	0		-	-	-	10
2-2.5	US	23	46	31	0	Grayish clayey sandy silt soil , medium consistency, ML	1.2 1	1.5 4	2.6 9	
2.5-3	SS	4	32	64	0	Greenish , medium dense , fine to medium , silty sand soil, (river sand) SP-SM	-	-	2.6 5	11
3.5-4	DS	50	29	21	0	Brownish sandy silty clay soil, medium consistency , CH	-	-	2.7 5	
4.5-5	SS	54	27	19	0		-	-	-	16
5.5-6	US	56	26	18	0		1.3 4	1.6 7	2.7 6	
6.5-7	DS	52	28	20	0		-	-	-	
7.5-8	SS	49	23	28	0	Greenish silty sandy clay soil , medium	-	-	-	21
8.5-9	US	48	21	31	0		1.3 8	1.7 1	2.7 2	

Depth m	Type of Sample	Soil classification				Soil Description of	Unit weight gm/cm³		G.S	SPT(N)
		Clay %	Silt %	Sand %	Grav e. %		Dry	Wet		
						consistency , CL				
9.5-10	DS	5	29	66	0	Greenish , medium dense , fine to medium , silty sand soil, SP	-	-	2.6 5	

Depth m	Type of Sample	Soil classification				Soil Description of BH2	Unit weight gm/cm³		G.S	SPT(N)
		Clay %	Silt %	Sand %	Grav e. %		Dry	Wet		
0-0.5	DS	49	30	21	0	Brownish sandy silty clay soil , medium consistency , CL	-	-	-	
0.5-1	DS	44	33	23	0		-	-	2.71	
1.5-2	SS	3	32	65	0	Greenish , medium dense , fine to medium , silty sand soil, (river sand) SP-SM	1.18	1.63	2.65	14
2.5-3	DS	42	27	31	0	Greenish silty sandy clay soil , medium consistency ,CL	-	-	-	
3.5-4	US	41	25	34	0		1.33	1.67	072.	
4.5-5	SS	5	28	67	0	Greenish , medium dense , fine to medium , silty sand soil, (river sand) SP	-	-	-	17
5.5-6	DS	4	30	66	0		-	-	2.75	
6.5-7	DS	47	29	24	0	Reddish sandy silty clay soil , stiff consistency ,CL	-	-	2.72	
7.5-8	SS	51	27	22	0		-	-	-	39
8.5-9	US	48	24	28	0	Greenish silty sandy clay soil , stiff consistency ,CL	1.45	1.79	2.72	
9.5-10	DS	43	26	31	0		-	-	-	

Depth m	Type of Sample	Soil classification				Soil Description of BH3	Unit weight gm/cm³		G.S	SPT(N)
		Clay %	Silt %	Sand %	Grav e. %		Dry	Wet		
0-0.5	DS	49	23	28	0	Grayish silty sandy clay soil , medium consistency , CL	-	-	-	
0.5-1	DS	46	25	29	0		-	-	2.72	
1.5-2	SS	41	27	32	0		-	-	-	11

Depth m	Type of Sample	Clay %	Silt %	Sand %	Grav e. %	Soil Description	Dry	wet	G.S	SPT(N)
2-2.5	US	28	21	51	0	Greenish , medium dense , fine to medium , silty clayey sand soil, SC	1.22	1.61	2.67	
2.5-3	DS	47	24	29	0	Greenish silty sandy clay soil , medium consistency , CL	-	-	2.72	
3.5-4	SS	52	27	21	0	Reddish sandy silty clay soil , medium consistency ,CH	-	-	-	12
4.5-5	US	55	25	20	0		1.32	1.63	2.76	
5.5-6	SS	54	24	22	0		-	-	-	16
6.5-7	DS	50	26	24	0		-	-	-	
7.5-8	SS	29	18	53	0	Greenish , medium dense , fine to medium, silty clayey sand soil, SC	1.33	1.72	2.67	27
8.5-9	US	52	21	27	0	Greenish silty sandy clay soil , medium consistency , CL	1.41	1.74	-	
9.5-10	DS	48	23	28	0		-	-	2.72	

Depth m	Type of Sample	Soil classification				Soil Description of BH4	Unit weight gm/cm³		G.S	SPT(N)
		Clay %	Silt %	Sand %	Grav e. %		Dry	wet		
0-0.5	DS	49	24	27	0	Greenish silty sandy clay soil , medium consistency , CL	-	-	-	
0.5-1	DS	47	23	30	0		-	-	2.72	
1.5-2	SS	46	21	34	0		-	-	-	5
2-2.5	US	28	17	55	0	Greenish , medium dense , fine, silty clayey sand soil ,SC	1.18	1.47	2.67	
2.5-3	SS	24	22	54	0		-	-	-	9
3.5-4	US	20	48	32	0	Grayish clayey sandy silt soil , medium consistency , ML	1.20	1.51	2.69	
4.5-5	SS	23	47	30	0		-	-	-	7
5.5-6	US	27	21	52	0		1.21	1.54	2.67	

6.5-7	SS	30	19	51	0	Greenish, medium dense, fine, silty clayey sand soil ,SC	-	-	-	9
7.5-8	DS	54	25	21	0	Reddish sandy silty clay soil , medium consistency ,CH	-	-	2.76	
8.5-9	SS	51	29	20	0		-	-	-	18
9.5-10	US	49	28	23	0		1.35	1.68	2.73	

From Tables 4-10 containing BH1,BH2,BH3 and BH4 can be observed the following:

a-The subsoil strata starting from a natural ground surface consisting of a layer consists of grayish ,brownish silty clay (CL, ML). This layer extends from the depth of (0.0-2.5)m.

b-a layer consists of greenish silty sand (SP- SM,SC), with clay, with medium dense. This layer extends from the depth of (1.5-3.5) m.

c-a layer consists of brownish ,greenish silty clay (CL, CH,ML) with sand, medium strengthens with depth to medium consistency. This layer extends from the depth of (3.5-9.5)m.

d-a layer consists of greenish silty sand (SP,SC), with clay, medium dense. This layer extends from the depth of (4.5-10.5) m.

e-The values of bulk density in BH1 ranged between 1.21-1.31 gm/cm3 to dry density and wet density values ranged between 1.54-1.71gm/cm3 while in BH2 ranged between 1.18-1.45 gm/cm3 to dry density and wet density values ranged between 1.63-1.79 gm/cm3.

f-The values of bulk density in BH3 ranged between 1.22-1.41 gm/cm3 to dry density and wet density values ranged between 1.61-1.74gm/cm3 while in BH4 ranged between 1.18-1.45 gm/cm3 to dry density and wet density values ranged between 1.35-1.68 gm/cm3.

4.4.3. Atterberg (Consistency) limits

It is one of the important tests, through which it is possible to know the case of soil relative to moisture content. In this test accrediting is used (ASTM D-4318) to get liquid limit (LL) and plastic limit (PL).

From Table 4-11 can be observed the following:

a. Liquid limit (LL) value in BH1 49 % and its value in BH3 45 %. boreholes soil is plastic state-intermediate strength.

b. Plastic limit (PL) value in BH1 18 % and plastic limit values BH3 19%.

c. Water content values in BH1 25.3% while its values in BH3 24 %.

d. Plastic index (PI) value in BH1 31 % and its value in BH2 26 %. Additionally, in the study area the soil with PI > 15 that refer to medium plastic.

e-The ratio of Plasticity Index to clay content, is a measure of the degree to which soil will exhibit colloidal behavior. Values of Activity (A) in Table (4-11) less than 0.75 are termed inactive clays. Normally active clays have activities between 0.75-1.25. The samples with activity more than 1.25 are active clays. The test results indicate that most of the soil samples have an activity of less than 0.75. This means that the samples are of inactive clay.

Table (4-11): Index properties and water content in BH1,BH3.

Type of sample	B.H. No	Depth (m)	System of classification Sieve &Hydrometer				Properties index			Mc	LI	A
			Clay %	Silt %	Sand %	Grave. %	PL %	LL %	PI %			
DS	1	3.5-4	50	29	21	0	18.0	49.0	31.0	25.3	0.235	0.620
DS	3	9.5-10	48	23	28	0	19.0	45.0	26.0	24.5	0.212	0.542

Through drawing plasticity index and liquid limit (Casagrande plasticity chart), The results show the soil of the study area is low to medium plasticity inorganic clays and silty clays (CL). fig (4-7)
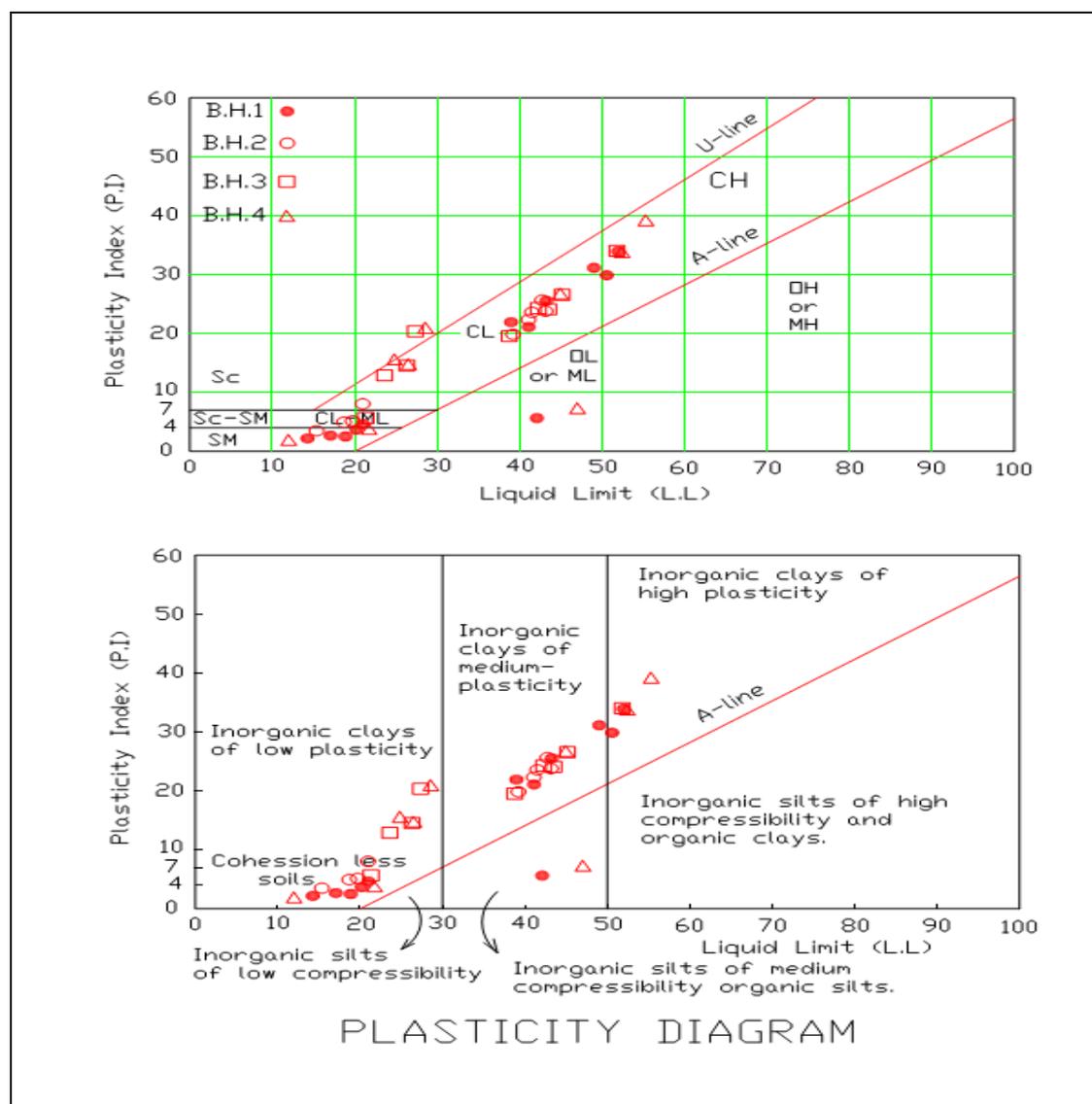
Figure (4-7): Plasticity diagram.

4.4.4. Typical values of Young's modulus from SPT-N

Equations (4-7)-(4-9) as presented by Webb (1969) can be used to determine the Young's modulus of the soil from the uncorrected SPT blow counts, N for saturated silty sands, clayey sands, and sands with intermediate fine contents, respectively. Equation 4-7 of the following equations were used to calculate the young modulus from uncorrected value of N table 4-9:

$$E = 5(N + 15) \ldots \ldots 4\text{-}7$$
$$E = 3.33\,(N + 5) \ldots \ldots 4\text{-}8 \quad \text{(Mitchell et al, 1978)}$$
$$E = 4(N + 12) \ldots \ldots 4\text{-}9$$

Table 4-12: Results of Young's modulus from N value and elastic modulus.

N	E (SPT) modulus (N/mm2)	E Modulus (N/mm2)
10	125	134
10	125	143
10	125	207
12	135	264
12	135	318
16	155	351
9	120	322
29	220	343
18	165	204
38	265	342

The calculated range values of Young's modulus (E) which is equivalently to the range of N value for soil mechanics works lies between (125-265 Mpa), refers to sediment types that found its clay sandy (that depending on the table 2-5 in chapter two).

When Comparisons has been achieved between the results of Young's modulus (E) from elastic modulus and those estimated from S.P.T. correlations were reasonable convergence.

4.4.5. Calculation of Bearing Capacity

In most instances of construction, the subsoil is not homogeneous and the load carried by various shallow foundations of a given structure can vary widely. As a result, it is reasonable to expect varying degrees of settlement in different parts of a given building, so the estimated allowable bearing capacity is made for the sake of probable needing during construction. Results of the equation (Meyerhof) for determining bearing capacity the various method are shown in table (4-13) below.

Table 4-13: Results of bearing capacity .

Depth (m)	Meyerhof's allowable bearing capacity T/m²
1	4.46
2	5.27
3	5.96
4	6.57
5	7.12
6	7.70
7	8.31
8	9.00

4.5. Comparison between standard penetration test (SPT) and young's modulus

In this study gives an experience and interpretation on correlation between results. Geotechnical with seismic survey, show that the results obtained from seismic refraction and SPT are shown in (Figure 4-8) soil description (or profile) is for all boreholes. Referring to the results of the SPT results, the sand, and silty sand can be

described as medium dense to very dense since SPT values are in general lower than 50.

A summary of information obtained from these results is presenting where two layers were observed with different velocities increase with depth and according to the time-distance curves generated from the picking of the first arrival.

One of geotechnical features Coefficient of lateral earth pressure at rest is calculated depend on the ratio between P-wave and S wave and refers to the material strength with depth which is subjected to the constant geostatic pressure resulted from the weight of sediments Hunt, R.E. 1986), which increases with depth.

where compared with SPT appear when the SPT blow count is higher than 50, the material is considered impenetrable. Meaning that, from this depth on, the soil provides good ground stability for engineering purposes (Alves, 2009). when the compared the elastic properties with SPT, we note one of the factors of the elastic properties, which is the young modulus shear wave velocity used for correlations is obtained from well borehole seismic tests.

The recent and very popular method for computation of shear wave velocity is cross hole and downhole of subsurface Waves. This method is widely used for subsurface characterization and is increasingly being applied for seismic and site response studies (Matsushima,2006).

In the final the paper, the SPT and Young moduli estimates present a reasonable convergence from 1 to 10m depth. (figure 4-8).

The present paper deals with the comparison between dynamic modulus obtained from Seismic cross hole test, down hole test and Standard Penetration Test (N). when attempted to calculate link exactitude correlate between them by Pearson correlation, such that the result always has a value between -1 and 1. Based on the information calculated in this paper, it is noted that there is coefficient correlation R2= 0.645 which is reasonably a good value. Figure (4-9)
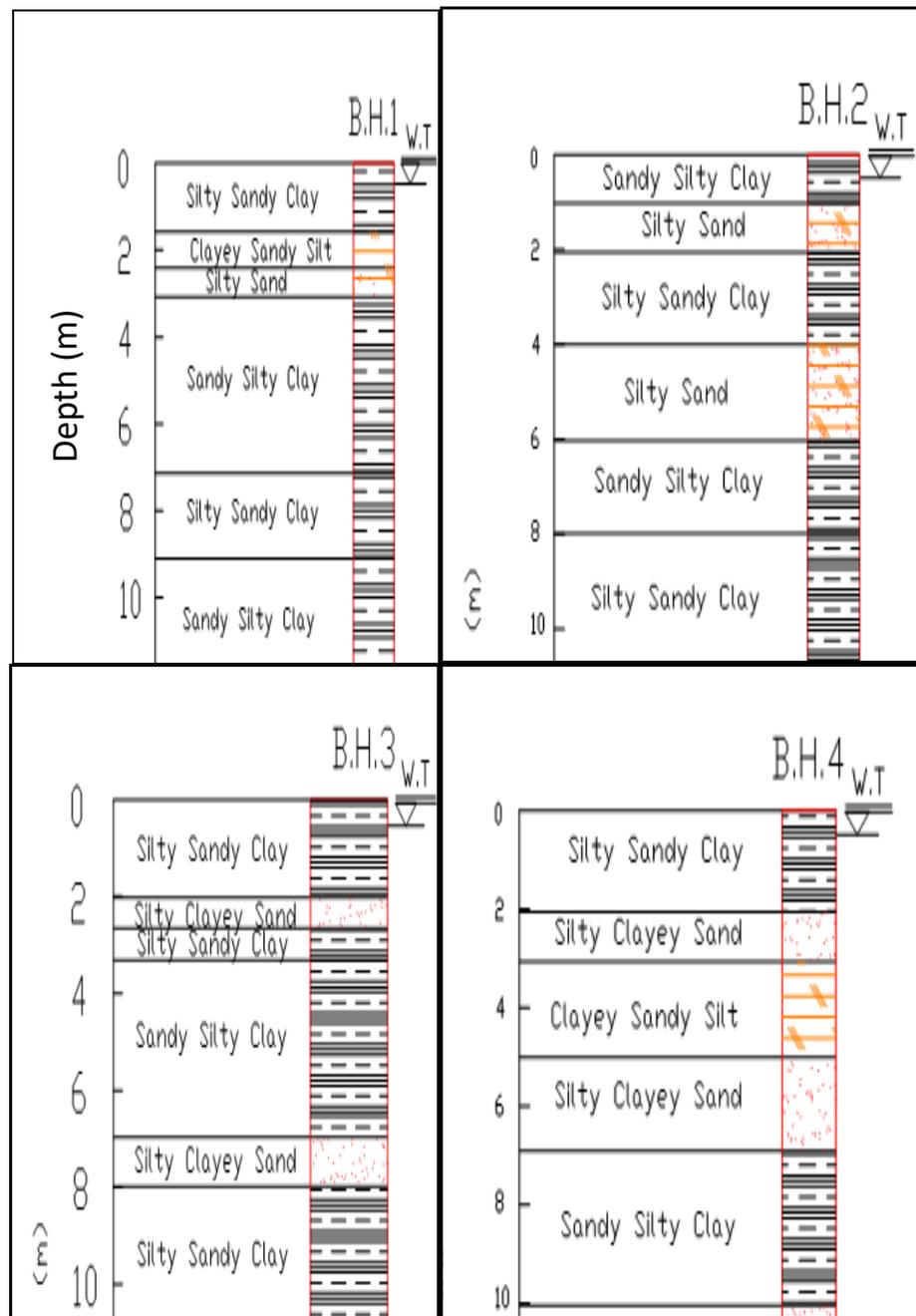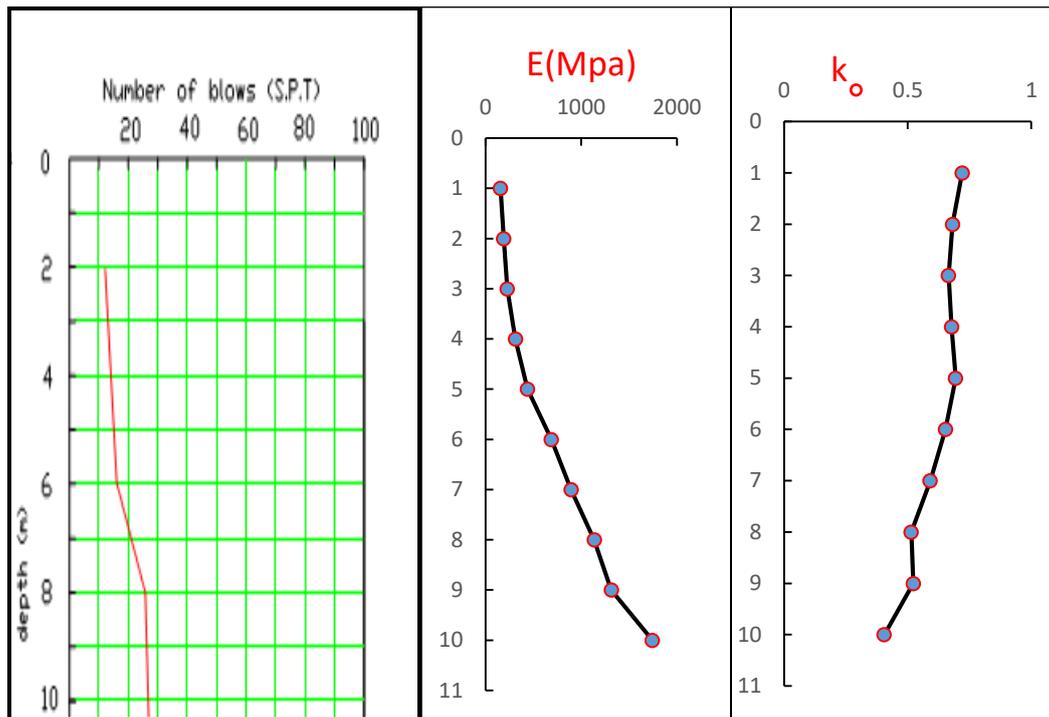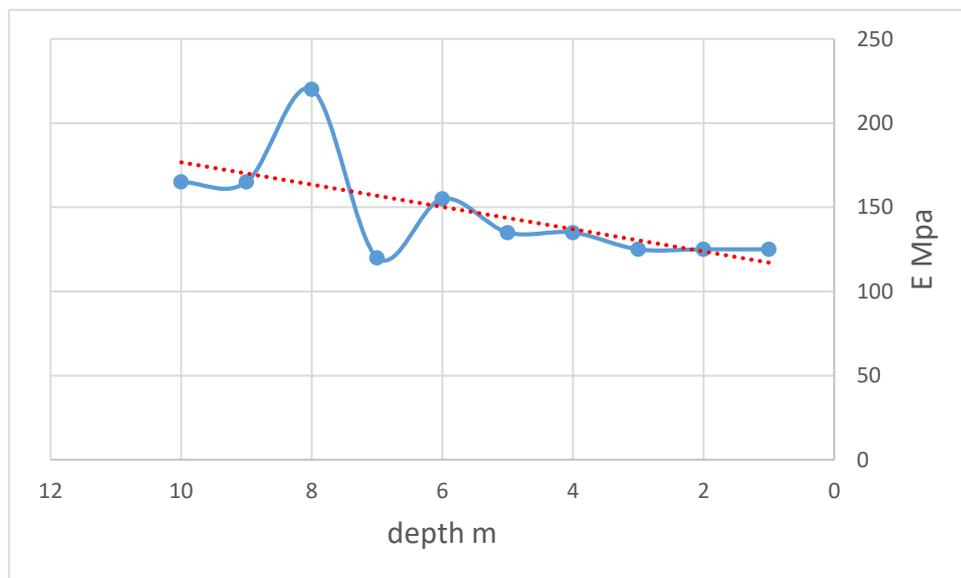
Figure (4-8): soil profile through all boreholes (1-4)

(a)

(b)

Figure (4-9): (a) correlation between SPT, Young module, coefficient of lateral earth pressure at rest (b) correlation coefficient of the comparison of dynamic modulus.

Chapter Five
Conclusions
and
Recommendations

Chapter Five
Conclusions and Recommendations

5.1. Conclusions

Depending on the results of interpretation of seismic survey and geotechnical properties and according to the available information at the study area the following conclusions are acquired: -

1- In general, it has been found that the results of the seismic survey methods agree approximately with the results of geotechnical one. These results indicated the main layers' properties of the studied soil. It has concluded that layers extended from the depth of (0.0-2.5) m are silty clay, while layers extended from the depth of (2-3.5) m classified as silty clay with clay and silty clay with sand. Also, classification of soil layer extends from the depth of (4.5-10.5) m was silty sand (SP, SC), with clay, medium dense.

2- One or in some cases two layers were recognized when cross hole and down hole method applied. The range of compressional and shear wave velocities for the first layer was between (482.01-893.33 m/sec) and (199.40-372.22m/sec) respectively, while for the second layer was between (943.66 -116.60 m/sec) and (426.75-609.10m/sec) respectively.

3- The variations in values of seismic velocity reflected the lithological change and/or variation in degree of consolidation and water content.

4- Depending on the ratio (Vs/Vp) and (Vs) values, many geotechnical properties were calculated .

5- Based on the values of geotechnical properties, the ratio of Plasticity Index to clay content and the test results indicated that most of the soil samples had an activity of less than 0.75.This means that the soil samples were inactive clay.

6- According to the material classification that mainly depends on material index values (Abdel Rahman, 1989), layers of the study area classified within the first and second categories.

7- The ultimate bearing capacity for the sediments of the study area increased with depth, where the minimum value was at the depth of 1m and the maximum value was at the depth of 10 m, which indicated compaction increment with depth.

8- Results of cross-hole survey, down-hole survey and laboratory demonstrated that there was a gradual change in the elastic and engineering behavior of the studied soil with depth.

5.2 Recommendations

1- Conduct geotechnical study by engineering and geophysical methods to the different regions of Hilla city to obtain more details about the behavior of the soil and compare result with each other.

2- Emphasize the use of cross-hole method due to their ability to give valuable results and asymptotic to geotechnical properties.

References

1- A.Mcgregor and J.hael Duncan; Department of civilians Environmental Engineering; by Virginia Tech. October 1998.

2- Abdel Rahman, M., 1989. Evaluation of the Kinetic moduli of the surface materials and application to engineering geologic maps at Ma′Barr Sabah area (Dhamar province): Northern Yemen, Egypt. J. Geol., 33, 1-2, 229- 250P.

3- Abdel Rahman, M., 1991. Rock material competence assessed by seismic measurement with emphasis on competence scale and application in some urban areas in Yemen: E.G.S. proc. Of 9th the Ann. meet. 206-228.

4- Abdel Rahman, M., Helal, A. N. M. A., Mohamed, H. C. and Al-Malqi, I., 1994. Exploration seismic for site evaluation of the new city of El- Minya: Egypt- E.G.S. proc. of the 12th Ann. Meet. 59-74P.

5- Abdulla K. A., Omar Q. A.,(2015): Estimating of dynamic modulus of elasticity for top soil layers by borehole seismic survey in industrial area of Sulaimani city, NE-Iraq, JOURNAL OF KUFA – PHYSICS Vol.7/ No.2.P.28-33.

6- AL-Awsi, M 2005, 'Geotechnical evaluation to the soil by using seismic refraction and electrical resistivity methods at Tikrit University site', M.Sc. thesis, Baghdad University, Baghdad.

7- Al-Banna, A. S., Al-Khfaji, A. J. and Banno, Esam., 2006. Seismic refraction and cross-hole techniques for investigating the topsoil and water table beneath the high pumping station hall of Al-Hussian water supply station, Karbala, Iraq: Journal of Karbala University, vol. 4 no4 scientific.

8- AL-GAZZAR Consultant Engineers, Soil investigation for Lamar towers, Geotechnical Report, Project # J-07-33, Jeddah, Kingdom of Saudi Arabia, 2007

9- Al-Hassan, D. U., Dangana, L. M. and Salaka, K. A., 2010. Seismic refraction investigation of the subsurface structure at the southern part of Niger state college of education: Minna, Nigeria, Bayero journal of pure and applied science, Vol 3 No2.

10- Al-Hussein, A. B., Abdelnasser, M. A., Hany, S. M. and Khamis, K.M.,2014. Application of geophysical methods for geotechnical parameters determination at new borg El-Arab industrial city: Egypt, Geomagnetic and geoelectric department, the national research institute of astronomy and geophysics, Helwan, Cairo, Egypt.

11- Ali, D 2006, 'Geophysical and geotechnical study in Shewasoor dam site northeastern Kirkuk/northern Iraq', PhD thesis, Baghdad university, Baghdad.

12- Al-Jiburi, H. K and Al-Basrawi, N. H., 2008. Hydrogeology-geology of Iraqi southern desert: Iraqi bull. Geol. min. special issue, 2009. 77-91P.

13- Al-Khafaji A. T., 2004 (a). Using Seismic cross-hole Technique in geotechnical Evaluation of engineering construction: M.Sc thesis, college of science, university of Baghdad. (Unpublished) .

14- Al-Khafaji, A. J. M., 2010. Geophysical and geotechnical investigations of the soil underneath the foundation of Al-Abbas holy shrine site in Kerbala Governorate: College of science, university of Baghdad. (Unpublished) .

15- Al-Khafaji, A. J. M., 2015. The seismic cross-hole and geotechnical surveys for Al Khiam hotel in the sacred city of Karbala: University of Babylon journal, pure and applied sciences, Issue 1, Vol. 23. (In Arabic) .

16- Al-Salihi, M. A. R., 1999. Measurement of some geotechnical properties by using refracted (P and S waves) for selected sites between Baji and Samarra: M.Sc thesis, university of Baghdad, College of Science. (unpublished)

17- Al-Shimaree, A. A., 2012. Geophysical study for both Hilla-2 and Karbala-2 gas power plants/central Iraq with the assistance of the engineering information: college of science, university of Basra. (unpublished thesis). (In Arabic).

18- Al-Sinawi. Introduction to Applied Geophysics, first ed., Printed at Mosul University .142 p,1981

19- Aqaba report, 2015. Downhole and MASW measurements of shear and compression waves velocities at Al-Maabar-Aqaba region-south Jordan:

20- ASTM (1999) Standard Test Method for Penetration Test and Split barrel Sampling of Soils (D1586). ASTM International, West Conshohocken

21- ASTM Standard D4428/D4428M-07, 2007, "Standard Test Methods for Crosshole Seismic Testing," ASTM International, West Conshohocken, PA, 2007, DOI: 10.1520/D4428_D4428M-07, www.astm.org.

22- ASTM Standard D5777-00, 2011, "Standard Guide for Using the Seismic Refraction Method for Subsurface Investigation," ASTM International, West Conshohocken, PA, 2011, DOI: 10.1520/D5777-00R11E01, www.astm.org.

23- ASTM. Standard test method for performing the flat plate dilatometer. ASTM D6635-01, West Conshohocken, PA, 2007.

24- Atat, J., Akpabio, I. and George, N., 2013. Allowable bearing capacity for a shallow foundation in Eket local government area: Akwa Ibom state, southern Nigeria. International journal of geosciences, 1491-1500.

25- Baziw, E. and Verbeek, G. (2012), "Passive (Micro-) Seismic Event Detection by Identifying Embedded "event" Anomalies within Statistically Describable Background Noise", Pure appl. geophys., vol. 169, Issue 12, pp 2107-2126.

26- Berwari, Anwar Mustafa, Saliwa, Nasira Aziz. Report on the Geology of the Karbala Plate, General Company for Geological Survey and Mining, Baghdad, Iraq. 1995.

27- Billings, M.P., 1972. Structural geology: Third edition, U.S.A., 606P.

28- Boore, D. M., 2006. Determining subsurface shear-wave velocity, A review: U.S. Geological Survey, Menlo Park, California, USA. 5-6P.

29- Bormann, P., 2002. New manual of seismological observatory practice: Volume 1&2, Geo forschungs zentrum potsdam. 418P.

30- Bowles, J. E. (1996). Foundation analysis and design. New York: McGraw-Hill.

31- Bowles, J. E., 1984. Physical and geotechnical properties of soil: 2nd ed, Intonation student edition, McGraw Hill Japan Ltd, Tokyo, Japan, 578P.

32- Bowles, J. E., 1988. Foundation analysis and design: 4th edition.

33- Brahma, P. Mukherjee, S.P.,2015: A Realistic Way to Obtain Equivalent Young's Modulus of Layered Soil. Indian Geotechnical Conference – 2010, GEOtrendz December 16–18, 2010 IGS Mumbai Chapter & IIT Bombay.p.306-308.

34- Briaud, J.-L.: Introduction to Soil Moduli. Geotechnical News, June 2001, BiTech Publishers Ltd, Richmond, B.C., Canada.

35- British standards, (1377:1990) "Method of testing soils for civil engineering purposes.

36- BSSC 2009. NEHRP recommended provisions for seismic regulations for new buildings and other structures. Part 1 : (provisions FEMA 368). Federal emergency management agency, Washingtons, DC.

37- Budhu, M., 2000. Soil mechanics and foundations: department of engineering and engineering mechanics, university of Arizona, wily, Library of congress cataloging in publication data. 30-109-188P.

38- Carvalho, J, Torres, L, Castro, R, Dias, R, and Mendes-Victor, L.,2009, Seismic velocities and geotechnical data applied to the soil micro zoning of western Algarve, Portugal: Applied Geophysics., Vol.68No.2, P.249-258.

39- Cox, M., 1999. Static corrections for seismic reflection surveys: Society of exploration geophysics, Tulsa, Oklahoma. 530P.

40- Craig, R. F., 1997. Soil mechanics: Sixth edition London and NewYork,485P.

41- Craig, R. F., 2004. Craig's soil mechanics: Seventh edition, Department of civil engineering, university of Dundee UK. 176P.

42- Crice, D., 2002. Borehole shear-wave surveys for engineering site investigations: Geo stuff, Olson engineering, INC., 12401 W. 49th Ave., Wheat Ridge, CO 80033-1936 USA. 303,423,1212P.

43- Danson E., 2005. Geotechnical and geophysical investigations for the offshore and nearshore developments, Technical Committee 1, International Society for Soil Mechanics and Geotechnical Engineering, September 2005.

44- Das, B. M., 2002. Principles of geotechnical engineering: Fifth edition, published in U.S.A, 589P.

45- Das, B. M., 2011. Principles of foundation engineering: SI, Seventh edition. Library of Congress. 2,15-16,50,58,325-326P.

46- Dasgupta, S. and Gupta, A., 2009. Physics and chemistry of the Earth's interior– Seismic refraction: Indian national science academy a platinum jubilee special issue: 337-338P.

47- Davis, A.M. and Schultheiss, P.J., 1980. Seismic signal processing in engineering site investigation-a case history: Ground engineering, 5P.

48- Davis, R.O. and Selvadurai, A.P.S. (1996) "Elasticity and Geomechanics," Cambridge University Press. The United States of America, 216 pages.

49- Dobrin, M. B. and Savit, C. H., 1988. Introduction to geophysical prospecting: 4ed, McGraw – Hill publ. Co, New York, 25-49P.

50- Dobrin, M. B. and Savit, C. H., 1988. Introduction to geophysical prospecting: 4ed, McGraw – Hill publ. Co, New York, 25-49P.

51- Dobrin, M. B., 1976. Introduction to geophysical prospecting: 3rded, McGraw–Hill publ. Co, New York. 630P.

52- Domenico, S. N. 1984. Rock Lithology and Porosity Determination from Shear and Compressional Wave Velocity. Geophysics, 49(8) pp: 1188-1195.

53- Durgunoglu, H.T., Tezcan, S. S., Acar, S. E., 1989. Cross-hole survey at a nuclear power plant site, Bogazici University, Istanbul.

54- Durgunoglu, H.T., Tezcan, S. S., Acar, S. E., 1989. Cross-hole survey at a nuclear power plant site, Bogazici University, Istanbul.

55- Dwain K. Butler and Joseph R.Curro, Jr., Crosshole seismic testing – procedures and pitfalls, Geophysics, Vol.46 . No. (January 1981) ; p, 23 29 . 15 figs.

56- Eker, A.M., 2009. Determination of the dynamic characteristics and local site conditionsof the Plio-Quaternary sediments situated towards the north of Ankara throughsurface wave testing methods. M.Sc. Thesis, METU, 145 pp (unpublished).

57- NEHRP and International building Code(IBC2000).

58- Fakher, A 2013, 'A geophysical engineering study of landfill site at Al-Kifil district-Babylon governorate middle of Iraq', B.Sc. thesis, Basra University, Basra.

59- G.G. Meyerhof, Shallow foundations. Journal of the Soil Mechanics and Foundations Division, ASCE, 91(2), 1965, 21-31.

60- G.Sanglerat, The penetrometer and soil exploration. (Elsevier, Amsterdam.1972)-

61- Gadallah, M. and Fisher, R., 2009. Exploration geophysics: Springer-Verlag Berlin Heidelberg 2009, 34-42P.

62- Gopal Ranjan and A.S.R. Rao (2000). Basic and Applied Soil Mechanics .Indea.8122412238.New Age international (p) limited,Publishers.

63- Gopal Ranjan et. A. S. R. Rao: Basic and Applied Soil Mechanics. New Age International, 2000, chapter 10.11, pp. 328-330. ISBN: 8122412238, 9788122412239.

64- Griffiths, D. H., and King, R. F., 1981. Applied geophysics for geologists and engineers: Pergamon press. 64-68P.

65- Gupta, S., 2013. Crosshole and downhole seismic test: Workshop cum demo session.

66- Hamdi, F. A. I. Said, I. and Qasim, I. S., 1996. Application of geophysical methods in geotechnical engineering: National center for construction labs, soil investigation Report. (unpublished) .

67- Hamdi, F.A.,Said, I.A.,Qasim,I. S.,(1996): Application of geophysical method in geotechnical problem, Juor. Geol. Soc., Iraq, Vol. 9, No. 3, pp. 261 – 273.

68- Hunt, R. E., 1986. Geotechnical engineering analysis and evaluation: McGraw- Hill Book Co. 730P.

69- Hussein, H. Mahmoud R.Wisam R, 2014.Studying Soil Undrained Shear strength Due to Driving piles Using Seismic Cross-Hole Technique.

70- Illustration of the direct method for interpreting downhole velocities (after Kim et al., 2004).

71- Imai, J., 1979. An introduction to geophysical prospecting for civil engineering purposes:

72- Imai, T. and Tonouchi, K., 1982. Correlation of N-value with S-wave velocity and shear modulus: In proceedings of the 2nd European symposium on penetration testing, Amsterdam. 67-72P.

73- Jaky J. 1944. The coefficient of earth pressure at rest. Journal of the Society of Hungarian Architects and Engineers, Budapest, Hungary, 355-358 (in Hungarian).

74- Joyce, M., 1982. Site investigation practice, E & F.N. Spoon, London, 369P.

75- K. Terzaghi, and R. K. Peck, Soil mechanics in engineering practice (John Wiley, New York, 1986).

76- Kearey, P., Brooks. M. and Hill. I., (2002): An introduction to geophysical exploration, 3 ed. Blackwell Publ. Co., 262p.

77- Kezdi, A. (1974). Handbook of Soil Mechanics. Elsevier, Amsterdam.

78- Khorshid, S. Z., Al-Khersan, E. H. and Al-Kashan., 2006. P and S-waves evaluation for engineering site investigation at a hostel complex inside Basrah University: southern Iraq, Basrah Journal of Science (A), Vol. 24 (2), 27-37P.

79- Khorshid, S.Z., Al-Awsi, M. D., Al-Banna, A. S., 2014. Geotechnical evaluation of the soil of Tikrit University using seismic refraction method: Diyala journal for pure sciences.

80- Kim, D. S., Bang, E. S., & Kim, W. C. (2004). Evaluation of various downhole data reduction methods for obtaining reliable Vs profiles. Geotechnical Testing Journal, 27, 6, 585

81- Kimata, J, 2018, 'Seismic methods: refraction and seismic monitoring', paper presented at the SDG Short Course III on Exploration and Development of Geothermal Resources, Kenya, 7 – 27 November 2018.

82- Knödel K. ; Lang G . ; Voigt H.J. (2007), "Environmental Geology" Handbook of field methods and case studies, Hannover Federal Institute for Geosciences and Natural Resources, Springer Books, 1357p.

83- Koçkar, M.K., Akgün, H., 2008. Development of a geotechnical and geophysical database for seismic zonation of the Ankara Basin, Turkey. Environ. Geol. 55, 165–176

84- Kohnen, H , 1972: Seismic and ultrasonic measurements on the sea ice of Eclipse Sound near Pond Inlet, N.W.T. on northern Baffin Island. Polarforschung, Jg. 42, No. 2, pp. 66-74.

85- Lambe, T. W. et. Whitman, V. R.: Soil Mechanics. New York: John Wiley and Sons, 1969, 576 p. ISBN: 978-0-471- 51192-2.

86- Lau, K. C. 1998. A review of downhole geophysical methods for ground investigation: Geo Report No. 99, 1998. 21P.

87- Lourie, W., 2007. Fundamentals of geophysics: 2nd ed, Cambridge, new work university press.122-133P.

88- Luna, R. and Jadi, H., 2000. Determination of dynamic soil properties using geophysical methods: Proceedings of the first international conference on the application of geophysical and NDT methodologies to transportation facilities and infrastructure, St. Louis, MO.

89- M. Budhu, Foundations and earth structures (draft), http://www.ic.arizona_edu/ic/ce440/site%20characterization.pdf. (2004)

90- Massarsch, K. R., 2007. The practical application of seismic testing in geotechnical engineering: Geoengineering AB, Stockholm, Sweden.

91- Matsushima J (2006) Seismic wave attenuation in methane hydrate-bearing sediments: vertical seismic profiling data from the Nankai Trough exploratory well, offshore Tokai, central Japan. Geophys Res Lett 32:L03306. doi:10.1029/2005GL024466.

92- Mavko, G. (2005). A conceptual overview of rock and fluid factors that impact seismic velocity and impedance. Stanford Rock Physics Laboratory. Retrieved from https://pangea.stanford.edu/courses/gp262/Notes/8.SeismicVelocity.pdf

93- Milson, J., 2003. Field geophysics: Third edition, university college London, John Wiley. 189P.

94- Mitchell, J.K. Guzikowski, Frank Villet, Willem C.B. 1978, The Measurement of Soil Properties in-situ -- Present Methods -- Their Applicability and Potential, university of California, California

95- Mok, Y. J. and Park, C. S., 2007. In-hole seismic method for dynamic stiffness measurements of geomaterials: 4th international conference on Earthquake geotechnical engineering. Paper No 1299.

96- Mooney, H. M., 1973. Handbook of engineering geophysics: Bison instruments, Minneapolis.

97- Mutib, M., 2000. New contribution to the geology of Mosul Area from geoelectric investigations, Mosul University, Iraq, PhD. thesis, (unpublished).

98- Obrzud R. & Truty, A.THE HARDENING SOIL MODEL-PRACTICAL GUIDEBOOKS Soil.PC 100701 report, revised 31.01.2012

99- Ohsaki, Y. and Iwasaki, R. 1973. On dynamic shear moduli and Poisson's ratios of deposits. Soils and Foundations, Vol. 13, No. 4, Dec. 1973, pp. 61-73.

100- P. Anbazhagan,Aditya parihar and H Rashmi;2011; Review of correlations between SPT N and shear modulus: A new correlation applicable to any region: ELSEVIER; Soil Dynamics and Earthquake Engineering, volume 150 2021.

101- Park, C. S., Lim. J. Y., Choi. C. L., Kong. B. C., and Mok. Y.J., 2008. development of borehole seismic tests: the 14th world conference on earthquake engineering, Beijing, China.

102- Poulos, H. G. et. Davis, E. H.: Pile Foundations Analysis and Design. New York: John Wiley and Sons, 1980, chapter 5.5, pp. 101-104.

103- Poulos, H.G. The pile-enhanced raft – An economical foundation system. Proceedings of XI Brazilian Congress of Soil Mechanics and Geotechnical Engineering, Brasília, Brazil, 5, pp. 527-43, 1998.

104- Prat, M., Bisch, E., Millard, A., Mestat, R, and Cabot, G. (1995). La modelisation des ouvrages. Hermes, Paris.

105- R.B. Peck, W.E. Hanson, W.E. and T.H. Thornburn, Foundation engineering. (John Wiley & Sons, New York, 1974)

106- Rebert, H. and Sheehan, A., 2006. Introduction to applied geophysics: the university of colorado at boulder. 67-70P.

107- Redpath, B. B. 1973. Seismic refraction exploration for engineering site investigation, Technical Report E-73-4, U.S. Army Engineer Waterways Experiment Station, Explosive Excavation Research Laboratory, Livermore, California, May, pp. 4 –13.

108- Reynolds, J. M., 1997. An introduction to applied and environmental geophysics: John Wiley and Sons. 215-343P.

109- Rinu And Samuel, Geotechnical Surrogates For Sediment Shear Behavior in Southern Nevada, University of Nevada, Las Vegas,(2015).

110- Robertson, P.K., Davies, M.P. & Campanella, R.G. Design of Laterally Loaded Driven Piles Using the Flat Dilatometer. Geotechnical Testing Journal. 12(1), pp. 30- 38, 1989.

111- Rollins, K.M., Diehl, N.B.,Weaver, T.J., 1998. Implications of Vs-BPT (N1)60 correlations for liquefaction assessment in gravels; GSP 75. J. Geotech. Geoenviron. Eng. ASCE 124, 506–517.

112- S.Zainal and A.Khorshid 2016, Determination of Elastic Moduli and Geotechnical parameters of the Upper Soil layer Using Ultrasonic Waves in Al-Jadiriyah Area university of Baghdad-Iraq; Iraqi Journal of Science,2016, Vol.57.

113- Salem H. 1993. A preliminary study of the physical properties of the Terra Nova and Hibernia oil fields in the Jenne D' Arc Basin, Offshore Newfoundland, Canada. Open file Dossier Public, Geological survey Commission, Ottawa (Canada).

114- Salem, H.S. 2000. Poisson's ratio and the porosity of surface soils and shallow sediments, determined from seismic compressional and shear wave velocities. Géotechnique 50(4): 461 – 463.

115- Sayed, S. R., Adel, M. E and Abd El-Aal, A. K., 2007. Applicability of near-surface seismic refraction technique to site characterization: National research institute of astronomy and geophysics, Helwan, Cairo, Egypt.

116- Schmeller, R., 1982. Some aspects of velocity inversion and hidden layer problems in seismic refraction work: Geoph. Pres. 30,735-751P.

117- Sefindia. (2017). Retrieved September 07, 2017, from Structural engineering forum of India:
https://www.sefindia.org/forum/files/appc_soil_properties_718.pdf.

118- Sharma, P. V., 1986. Geophysical methods in geology: 2nded, Elsevler NewYork. 422P.

119- Sharma, P. V., 1997. Environmental and engineering geophysics: Cambridge university press. 113-119,174-175P.

120- Sheriff. R. E. and Geldart. L. P., 1995. Exploration seismology: 2nd ed, Cambridge, New work university press. 25P.

121- Shirgiri, N., 2012. Correlation between geotechnical and geophysical properties of soil: the University of Birmingham, (master thesis).

122- Sjogren, B. 1984. Shallow refraction seismic: Champman and Hall London. 9-12P.

123- Skempton, A.W., 1953. The colloidal activity of clays. 3rd international conference soil Mech found Eng. Switzerland, vol. 1.

124- Smith, G. N., Smith, I. G., 1988. Elements of soil mechanics: seventh edition. Formerly of Heriot-Watt and Napier University, Edinburgh. 6- 12,269P.

125- Stokoe, K. and Santamarina, J., 2000. Seismic wave-based testing in geotechnical engineering: the University of Texas, Austin, Texas, USA Georgia Institute of Technology, Atlanta, Georgia, USA.

126- Stokoe, K. and Woods, R., 1972. In situ shear wave velocity by cross-hole methods: J. Soil mech, and found, Div., ASCE, 5,443- 459.

127- Subramanian, N. (2008). Design of steel structures. New Delhi: Oxford University Press.

128- Swain, R.J.(1962).Recent techniques for determination of in- situ elastic properties and measurement of motion amplification in layered media. Geophysics , Vol.27, p.237-241.

129- Tavakoli, S., & Rasmussen, T. M. (2016). Tillämpad Geofysik. Luleå: Course material, Applied Geophysics o0001k

130- Telford, W. Geldard, L. Sheriff, R. and Keys, D., 1981. Applied geophysics: Cambridge university press, 6th ed. New York. 860P.

131- Telford, W. Geldard, L. Sheriff, R., 1990. Applied geophysics: Cambridge university press, 2nd ed. New York. 140-147,171P.

132- Terzaghi, K. & Peck, R. B. (1967), "Soil Mechanics in Engineering Practice", 2nd Edition, John Wiley &Sons, Inc., New York.

133- Tezcani, S., Ozdemiri, Z and Keceli, A., 2009. Seismic technique to determine the allowable bearing pressure for shallow foundations in soils and rocks: Acta geophysical, Volume 57, Number 2.

134- Uyanik, O. (2010): Compressional and shear-wave velocity measurements in unconsolidated top-soil and comparison of the results, Physical Sciences Vol. 5, No. 7, p. 1034-1039

135- Webb, D.L. (1969) "Settlement of Structures on Deep Alluvial Sandy Sediments in Durban, South Africa," Conference on In-Situ Behavior of Soil and Rock, Inst. of civil Engineers, London, pp. 181-188.

136- Whiteley, R. J & Greenhalgh, S.A, (1979): velocity inversion and shallow seismic refraction method. Geoexploration, 17:p 125-141.

137- WILLMORE, T. J., An Introduction to Differential Geometry (Clarendon Press: Oxford University Press, 1959), 326 pp., 35s.

الخلاصة

تتضمن الدراسة مقارنة نتائج الفحوصات الجيوتكنيكية لمقطع تربة في موقع محدد ضمن محافظة بابل مع المسح الزلزالي البئري .

استخدمت 6 ابار في موقع الدراسة موزعة داخل منطقة الدراسة, 4 من هذه الابار للأغراض الهندسية وكانت على عمق يزيد على 10 متر، اما البئران المتبقيان فقد استخدما للمسح الزلزالي البئري حيث يتم حساب سرعات الموجات الطولية والمستعرضة بين هذين البئرين، أحدهما يعتبر مصدر والأخر على مسافة تبعد 6.7 متر للاستلام على نفس العمق، وقد استخدم جهاز التسجيل ABEM Terralloc Mark6 لتسجيل المعطيات في الحقل.

فسرت جميع المعلومات المسجلة بهذه الطريقتين ولجميع الأعماق من خلال التقاط أولى الازمان وصولا، يليها حساب سرعة الموجات الطولية والمستعرضة ولغاية عمق 10 متر. وبالاعتماد على قيم السرع الزلزالية تم حساب عدد من الخصائص الجيوتكنيكية منها (نسبة بوسان ν, ومعامل المادة I_m, ومعامل التركيIc ومعامل الضغط الجانبي $K_\circ$ وزاوية الاحتكاك الداخلي($\emptyset$) وسعة التحمل القصوى qu) وذلك باستخدام العلاقات الرياضية التي تربط بين هذه الخصائص وسرع الموجات الزلزالية بالإضافة الى حساب معاملات المرونة ومنها (معامل يونك E ومعامل القص μ ومعامل الحجم K وثابت لامي λ) بالاعتماد على قيم السرع الزلزالية المقاسة وقيم الكثافة المقاسة عند نفس العمق.

تم الاستفادة من نتائج الفحوصات المختبرية لبعض الخواص الفيزيائية لتربة الموقع والمنفذة من قبل شركة المعول للفحوصات الهندسية والمختبرية وذلك لأغراض التقييم الجيوتكنيكي ومن هذه الخواص: (التحليل الحجمي الحبيبي، محتوى الرطوبة، الكثافة الجافة، حدود القوام (حد الانكماش, حد اللدونة, حد السيولة), إضافة الى اجراء فحص الاختراق القياسي SPT وحساب قيمة الاختراق (N-Value)).

من خلال نتائج الفحوصات الجيوتكنيكية للموقع، تم حساب معامل المرونة الديناميكي لنفس العمق بالاعتماد على قيم الاختراق (N-Value) المقاسة باستخدام المعادلات الرياضية.

اكدت نتائج المقارنة الى وجود علاقة بين معامل المرونة الديناميكي المحسوب من الفحوصات الهندسية والمسح الزلزالي البئري. ومن خلال تطبيق علاقة بيرسون أظهرت نتائج الارتباط تقاربا معقولا حيث ان قيمة معامل الارتباط لهذه العلاقة R=0.64 وهو ارتباط ذات قيمة موجبة معتدلة لمجموعة البيانات.

مقارنة الفحوصات الجيوتكنيكية والمسح الزلزالي البئري لتحديد معامل المرونة الديناميكي لمقطع سطح التربة في مستشفى السيدة رقية (مدينة الحلة)

رسالة مقدمة الى كلية العلوم – جامعة بابل
وهي جزء من متطلبات نيل درجة الماجستير في العلوم
اختصاص علم الأرض (الجيولوجيا الهندسية)

من قبل
زهراء نصير كاظم جابر
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