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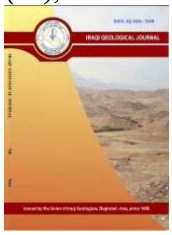

Engineering, Geophysical Investigation of a Multistory Building, at Hilla, Iraq, Utilizing the MASW Method

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Abstract

The Multi-Channel Method for Surface Waves (MASW) was used to estimate the average velocity of shear waves in order to construct an engineering structure and its relationship to bearing capacity, foundation depth and soil thickness in this construct in the center of Hilla city. Active MASW was used in this study which allows us to measure the apparent dispersion curve or the phase velocity within the frequency range from 5 to 70 Hz, which gives information about the shallow layers (25-50 m) and depending on the ground hardness and spreading length. Where it was found that this area consists of two layers and each layer has a shear velocity, as the first layer has shear velocity (171.891) m/sec and the depth (8.244) m and the second layer has shear velocity (274.788) m/sec and the maximum bearing capacity value relative to the depth of the foundation is 1, 2 and 3 is 4.46, 5.27 and 5.96 T/m^2 respectively. According to this study, this area is suitable for constructing an engineering structure on it.

Keywords: Multi-channel Analysis of Surface Wave; Active MASW; Al-Sayidah Ruqayya Hospital building; Terraloc Mk 6; SeisImager/SW

1. Introduction

Multi-channel Analysis of Surface Wave (MASW) method extracts the shear wave velocity. (MASW) the method is a seismic method characterized by ease of use and application in urban areas, shortening the time, money, and effort and reducing the number of test pits. The most important engineering factors that we will rely on are the quality of the soil and the ability of the soil to bear the various stresses and loads on it due to the facilities that will be built on it. Multi-channel Assessment of Surface Waves Test (MASW) is a non-destructive surface wave method for obtaining essential geotechnical parameters such as shear and bulk moduli from the Vs and Vp of materials at the surface. (Park et al., 2001).

Multi-channel Assessment of Surface Waves (MASW) allows us to compute the velocity of shear seismic waves (VS), which aids in the engineering assessment for various sites (Socco et al., 2010). When a source produces seismic waves, both body and surface waves are produced. The surface waves are made up of the fundamental and higher modes of Rayleigh waves, whereas the body waves are made up of direct, reflected, refracted, and air waves. Pattern recognition algorithms are used to record each type of seismic wave on a multichannel record. This recognition results in the creation of an optimal field design that produces the best signal-to-noise ratio feasible. By incorporating several different sorts of waves.

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A hammer's impact is commonly utilized as a seismic source. Each receiver is linked to a separate recording channel. A measurement is composed of several recording of seismic wave fields, known as traces, at various offsets from the source (Park et al., 2001).

The MASW method's key advantages are pattern matching capabilities and measurement redundancy. Pattern recognition enables quality control throughout both data collecting and processing. It distinguishes between body and surface waves due to their distinct amplitude and arrival time patterns. Measuring redundancy enables noise suppressing techniques to be used to optimize the signal-to-noise ratio (Park et al., 2001). The MASW approach allows for the simultaneous use of 12 to 60 geophones, resulting in very effective data gathering (Long et al., 2008). From previous studies are Al-Heety (2014) studied seismic refraction survey for Teaching Hospital Project site of Mosul University and he concluded that the study area has three layers by using MASW method that appears good results from shear velocity and thickness. Also, Shakir (2012) conducted investigations for the proposed location for the metro in Najaf using geophysical methods and Multi-channels Analysis of Surface Waves (MASW) determine the quality of the subsurface layers and their geotechnical properties.

The aim of this study is studying the relationship between the values of the shear waves velocity with the bearing capacity of the soil and the depth of the foundation. Drawing contour maps showing the distribution of the velocity of shear waves, bearing capacity, foundation depth and layer thickness, and observing the extent of compatibility between each of them in the study area.

2. Materials and Methods

2.1. Location of the Study Area

The study area is located between latitudes 32º 27′ 44.85″ N and longitudes 44º 25´ 06.85″ E. The Al-Sayidah Ruqayya Hospital Building project located within Babylon Governorate in central Iraq around the city of Hilla (Fig. 1). This location is selected to Al-Sayidah Ruqayya Hospital Building Project.

2.2. Stratigraphy and Tectonic Setting

The study area is located within the range of the sedimentary plain in the stable pavement area relative to the division of Iraq (Budy, 1980) This range also called the Mesopotamian tectonic zone of Iraq (Mesopotamian Zone), is located within the geosyncline basin between the Zagros Mountains in the northeast and the stable Arab Plateau in the southwest and this plot extends west of the folds sector in central and southern Iraq and is characterized by the fact that the area is flat and covered with river and wind sediments. This basin receives the products of erosion and weathering of the mountainous area as the downward movement continues (Abdullah, 1982). That the clear evidence of the tectonics of the sedimentary plain is the survival of the marshes and swamp areas for a long time without being destroyed. It is worth noting that, based on geological and geomorphological evidence, it appears that the sedimentary plain is a broad concave fold (Synclinorium) active tectonically. The study area generally covers modern sediments from the Quaternary in the Pleistocene and Holocene, and these deposits are derived from the sediments of the Tigris and Euphrates rivers and their tributaries. It consists of a succession of well-permeable silty sand and clay layers of varying thickness, and the vertical and lateral directions change abruptly and within very short ranges, which is a distinctive feature of these sediments.

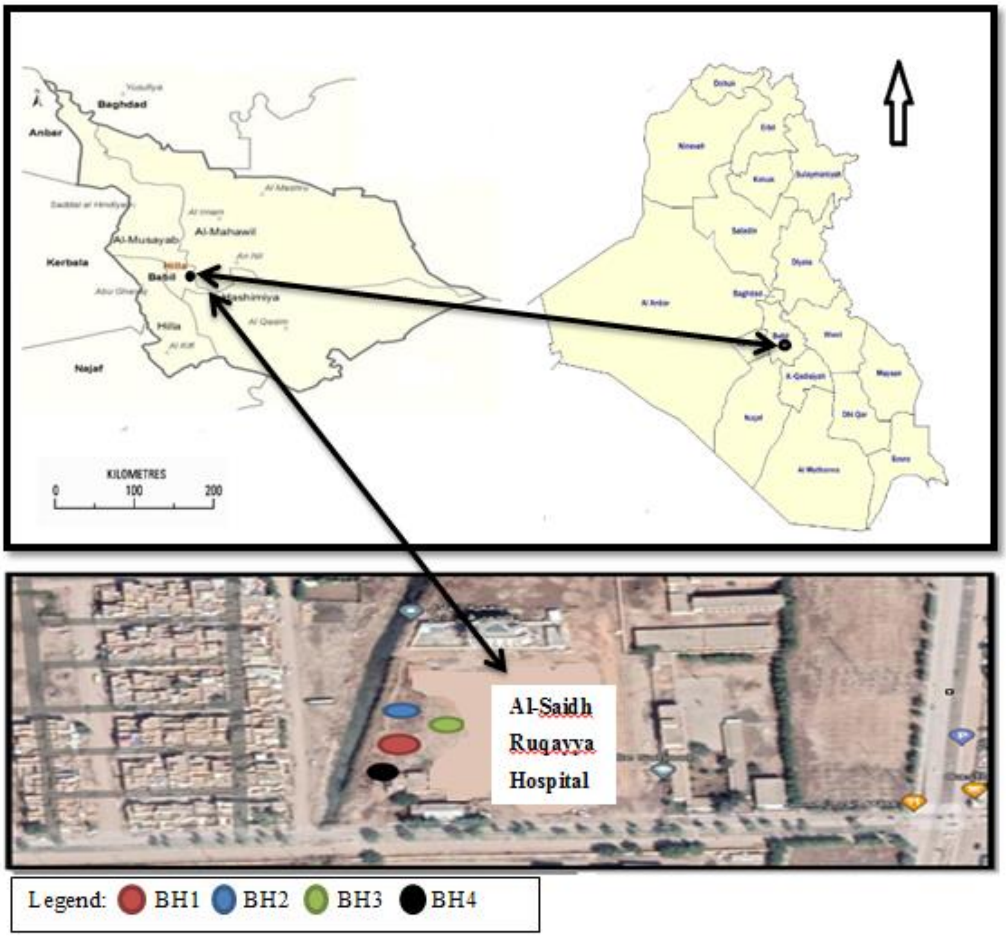


Fig. 1. Location map of the study area and satellite image of the study site

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 (Jassim, and Goff, 2006). The Quaternary sediments are uplifted along with the structure with about 10 - 15 m relief in comparison with the surrounding. Consequently, local drainage divide lines are developed along the crests of these structures (Fouad, 2010).

The ancient alluvial deposits were formed during the Pleistocene, which was characterized by a rainy and semi-rainy climate in the Middle East, more humid than the climate of the present time. Therefore, the sediments and the stratigraphic sequence depended on climate changes that led to a re-cycle of erosion and sedimentation in high areas and then sedimentation in the wide plains, and then the sediments of this period include gravel, sand, silt and clay, which are Flood deposits (Budy, 1980). The most important of these deposits are flood plain deposits and shallow depression deposits. The governorate of Babylon is located within the sedimentary plain area, which is characterized by its flat surface, flatness, and lack of general slope, where the degree of slope is about 22 cm per kilometer (Al-Jubouri, 2002), where the land descends from the northern and western sides towards the eastern, southeastern and southwestern parts. Some sand dunes have been found in some areas, such as southern Hilla. These dunes have fixed bases, but their tops move, with shapes forming winds according to their direction (Al-Saadoun, 1988).

2.3. Data Collection

The data was obtained from a report prepared by the Hussainiya holy shrine. In this report, there were four test pits. The borehole drilling is implemented by the drilling machine mounted on the truck and the twisted auger drilling method is used in combination. The boring equipment used in carrying out the fieldwork was four multi drilling method rig using continuous flight auger and rotary drilling method using wash boring process.The wash boring method uses the rotation of the drilling bit, with appreciation of pressure simultaneous to advance the hole. The water is then forced under pressure through the hollow of the drill rod and it emerges at high velocity through openings in the drilling bit, to carrying out the eroded soil, and then rises through the annular space between the borehole sides and the drill rod. The depth of boring of 20, 25 and 30 m was decided by the contractors consultant to extend beyond the zone of influence of significant foundation pressure to relatively incompressible materials. As the type of foundation might be a raft, from a geotechnical point of view the depth of the borehole extended to the point where the net increase in stress due to the load action of the structure is: either: less than 10% of the total surface load, or less than 5% of the overburden stress in the soil.

The location of the boreholes was set-up by the client. The boreholes coordinates are as shown in Table 1.

Table 1. The number,depth and coordination of boreholes

BH No.	Depth (m)	Coordination	
		E	N
1	30	44°25'06.20″	32º27'45.98″
2	25	44º25'07.06"	32º27'44.96"
3	20	44º25'07.92″	32º27'46.15"
4	25	44º25'06.85"	32º27'44.85"
Total boreholes No.= 4	Total depths = 100 m		

2.4. Seismic Survey By MASW

The field seismic survey was carried out using the Multi-channel Analysis of Surface Wave (MASW) (Active MASW). The value of the Vs was extracted from the seismic data obtained from the device Terraloc Mark 6 (ABEM Instruction).

The necessary equipment was provided to carry out the survey process, including the hammer with a weight of 10 kg, as well as the stone plate, the measuring tape, the seismograph and its battery, and the geophones S which are represented by the destructive Rayleigh waves. These geophones were connected with a cable in order to transfer mechanical energy and convert it into an electrical signal, this signal is transmitted to the seismograph and recorded, where this happens after the process of hammering by the hammer with a weight of 10 kg on the stone slab. The Active MASW type was used in this study and at a frequency of 50 Hz. Then the fieldwork began by installing the seismograph, fixing the location of the geophones, and taking a distance of 72 m, which represents the length of the track (MASW Track) where the number of geophones are 24 geophones. The distance between geophone and another geophone was 3 m represented by dx, while the distance between the geophone and the 10 kg hammer is 4 m represented by X (Fig .2).

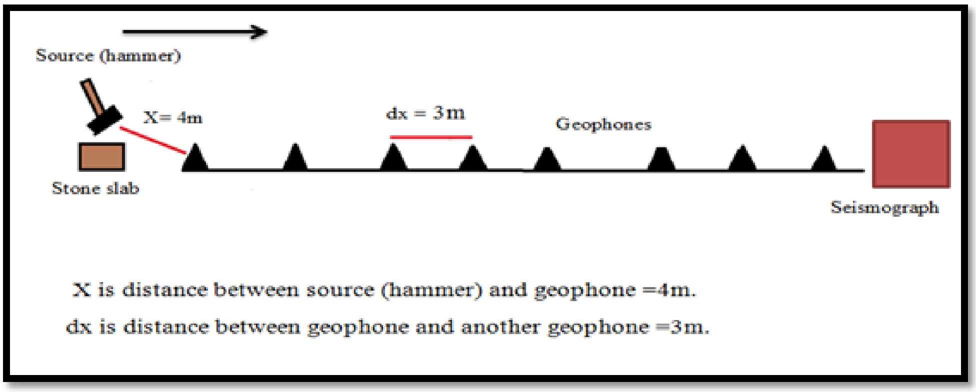


Fig. 2. The diffusion geometry for recording MASW method (Researcher)

The stone slab was placed next to the geophone, which was attached to a cable. This slab was hammered three ways by means of a hammer, in order to record the readings after the transmission of mechanical energy and convert it into an electrical signal, where this signal is transmitted to the seismograph in the form of a wave (Fig. 3).

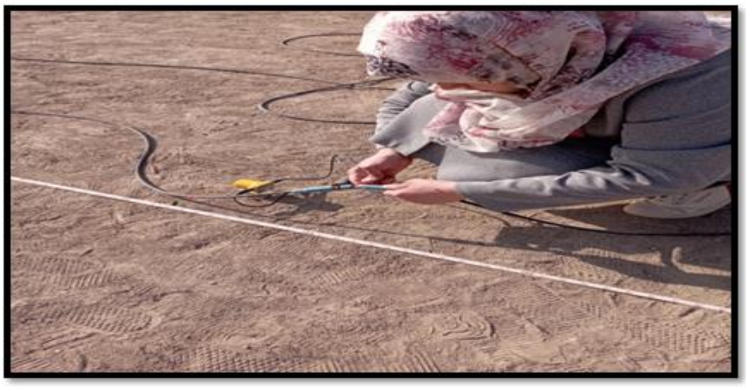


Fig. 3. The process of connecting the geophone (S) to the cable to convert the signal into a seismograph

3. Results and Discussion

3.1. Processing and Interpretation of MASW

Data of MASW has been analyzed by inversion process using SeisImager/SW program to calculate the one-dimensional model (1D) for shear wave velocities operations are damaged the processing is derived from extracting the dispersion properties (the velocity phase of the dominant Rayleigh waves as a function of frequency) and this is done by analyzing the primary data of the survey that are affected by other seismic events and using Fourier transforms then plot the dispersion curves using f-k transform allows plot the dominant data (Dal Maoro et al., 2003). That transforms f-k give an image of the shape of the surface wave propagation and the dispersion curves are always displayed as phase velocity with frequency (Fig. 4).

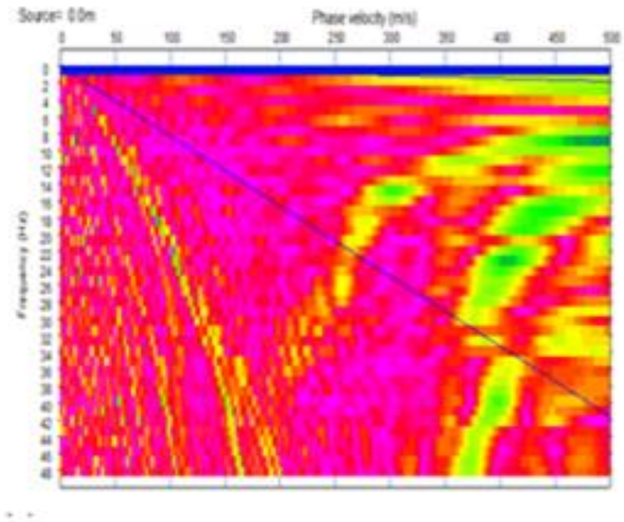
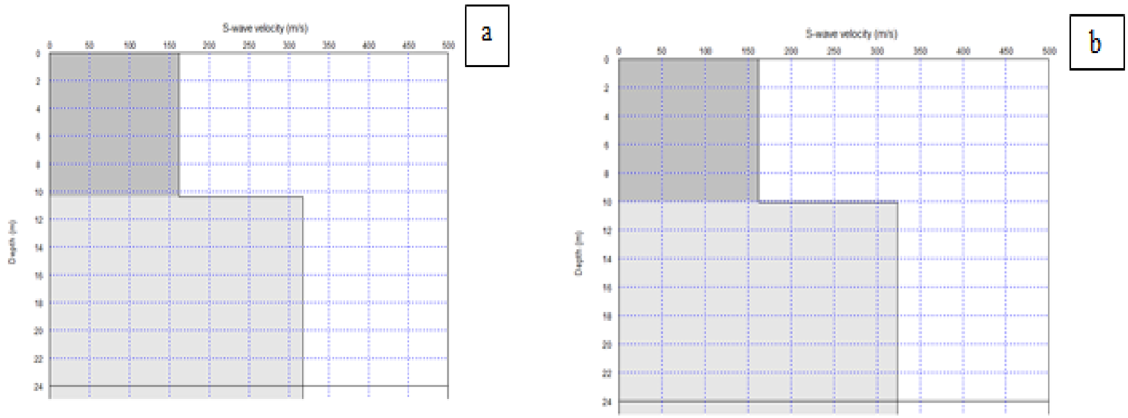


Fig. 4. Dispersion curve between frequency and phase velocities for MASW track

Fig. 4 shows a stage of data processing for MASW method, which is the spectral analysis and capturing of dispersion curves for the phase velocities of Rayleigh waves, where the change in the phase velocity of surface waves is calculated, where the change in the velocity of waves at each wavelength is called the phase velocity, then the dispersion curve is plotted and represents the relationship between phase velocity and frequency. Rayleigh waves are characterized by the phenomenon of dispersion (spreading) that occurs as a result of the change in the phase velocity and frequency of surface waves during their transmission between the surface layers. The dispersion curves show a good curve for the normal modes in the low velocity surface layers, which descend from the high phase velocities of low frequencies to the phase velocities of high frequencies. This stage is done automatically using the SeisImager/SW program.

The processing consists of extracting the dispersion characteristics (phase velocity of dominant rayleigh waves as a function of frequency) and this is done by analyzing the primary data of the survey that are affected by the seismic events Fourier transforms and then drawing the dispersion curves using f-k transformations. The f-k transformations always give a picture of the surface wave spreading shape and the dispersion curves are presented as a phase velocity with frequency.

Also, the program SeisImager/SW is used to calculate the one-dimensional model (1D) for shear wave velocities (Fig. 5).



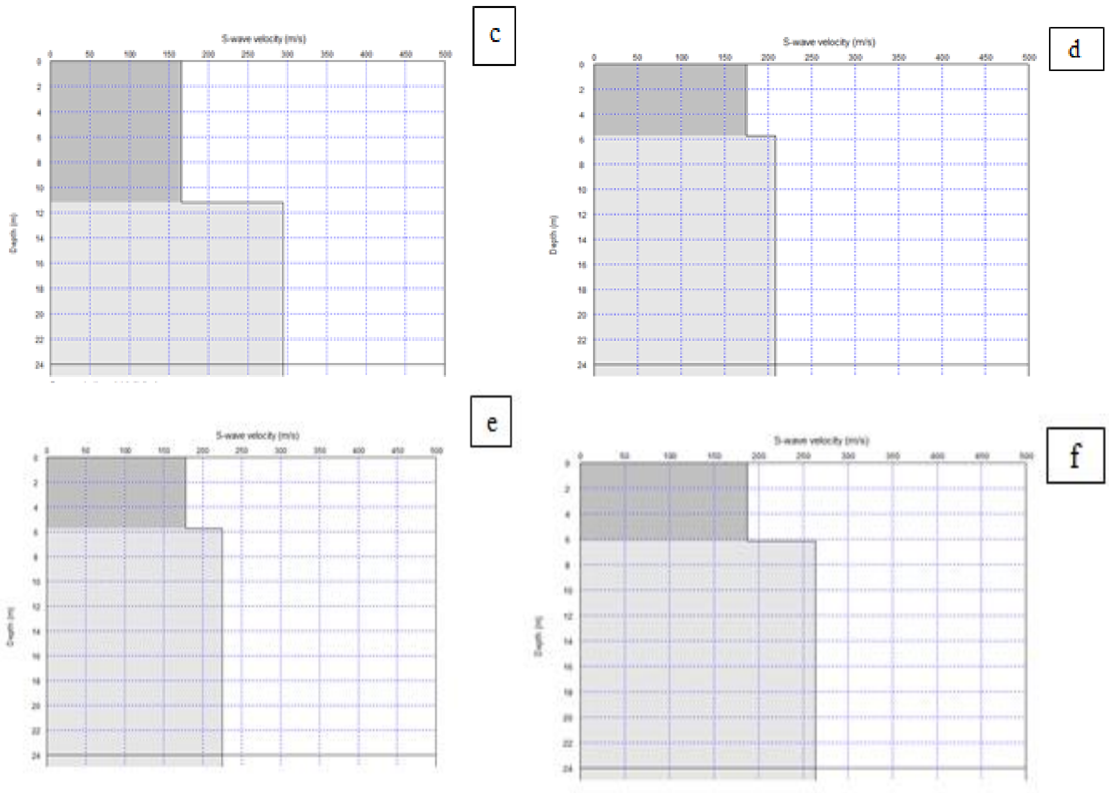


Fig. 5. One-dimensional section of the shear velocity of the MASW track: (**a**) One-dimensional section of the shear velocity for first reading; (**b**) One-dimensional section of the shear velocity for second reading; (**c**) One-dimensional section of the shear velocity for third reading; (**d**) One-dimensional section of the shear velocity for fourth reading; (**e**) One-dimensional section of the shear velocity for fifth reading; (**f**) One-dimensional section of the shear velocity for sixth reading.

As interpretation for Fig. 5 is:Fig. 5.a illustrates the relationship between depth and shear velocity, as the greater the velocity the greater the depth. We notice that the depth through this figure is 10.39 m and the value of the shear velocity is 161.96 m/sec. The soil is stiff.

From Fig. 5.b, we notice that the depth through this figure is 10.061 m and the value of the shear velocity is 162.05 m/sec. The soil is stiffness and compacted. From Fig. 5.c we notice that the depth through this figure is 11.231 m and the value of the first shear velocity is 166.05 m/sec, while the value for the second shear velocity is 295.24 m/sec. The soil is stiffness and more compacted.

One-dimensional section illustrates the relationship between depth and shear velocity, the value of the shear velocity is 174.76 m/sec and value of the depth is 5.729 m, so the soil is loose soil and that showen in Fig. 5.d. Also, Fig. 5.e show the relationship between shear velocity and depth. The value of the depth is 5.749 m and the value of the shear velocity is 177.38 m/sec. The soil is loose and compacted.

In the Fig. 5.f the value of the shear velocity is change and became 187.40 m/sec. Therefore, the value of the depth has changed for this reading (sixth reading) and became 6.181 m, so the soil is stiffness. These interpretations according to classify soil type according to estimated Vs, this classifation called NEHRP and IBC (Eker et al., 2012; ICC, 2006) (Table 2).

In this case, the second layer is the bed layer, which starts from a depth of 8.211 and above. As a result of these results, in order to establish the engineering structure, we need to do several engineering treatments for the foundation. The Surfer program was also used in this method to draw contour maps that show the distribution of shear wave velocity and variance, as well as the bearing capacity, the depth of the foundation and the thickness of the layer, and observ the extent of compatibility between each of them in the study area.

Table 2. Classification of subsoil based on shear wave velocity as per NEHRP or IBC

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

The Fig. 6 represents a contour map obtained from the MASW track in the study area, as it shows that the greatest thickness and bearing capacity is in the center of the study area, as it appears in the shape of lenses or layers separated by a horizontal distance in the contour map.

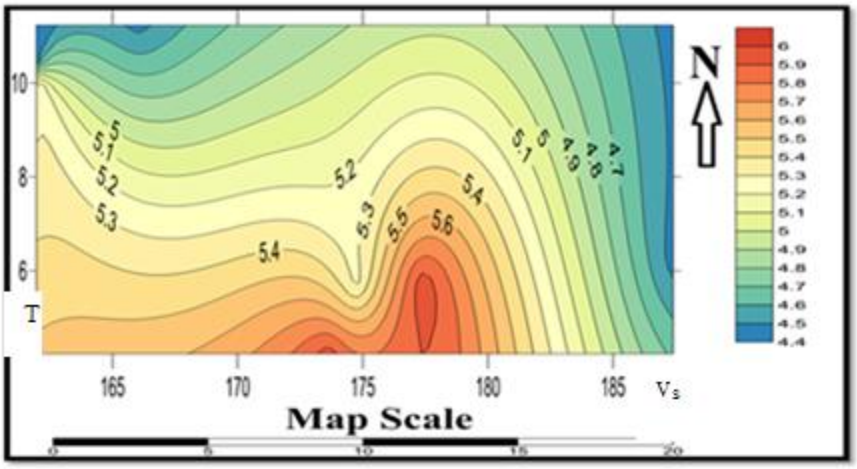


Fig. 6. Contour map for distribution of shear waves velocity and variance, thickness (T) of layers, depth of foundation and bearing capacity for MASW track

After entering the data into the program Reflex 2D Quick. The shear velocity of each layer was measured as it consisted of two layers each layer has a Vs1, Vs2 respectively. Through this program (Reflex 2D Quick), the thickness of the first layer was also obtained. Through special tables from a report prepared at the Husseiniya holy shrine, the amount of bearing capacity was determined according to the depth of the foundation, which was 1, 2 and 3 m as shown in Table 3.

Table 3. The depth of Foundation, Bearing Capacity, Thickness and Shear velocity (MASW)

VS_2 MASW m/sec	Depth of Foundation m	Bearing Capacity T/m2	Thickness m (First layer)	Vs_1 MASW m/sec
317.50	1	4.46	10.398	161.96
	2	5.27		
	3	5.96		
323.66	1	4.46	10.061	162.05
	2	5.27		
	3	5.96		
295.24	1	4.46	11.231	166.05
	2	5.27		
	3	5.96		
288.37	1	4.46	5.729	174.76
	2	5.27		
	3	5.96		

VS_2 MASW m/sec	Depth of Foundation m	Bearing Capacity T/m2	Thickness m (First layer)	Vs_1 MASW m/sec
292.98	1	4.46	5.749	177.38
	2	5.27		
	3	5.96		
293.57	1	4.46	6.101	187.40
	2	5.27		
	3	5.96		
Avarage 301.88			8.211	171.6

By using Excel software, the relationship between distance (m) and time (sec.) was plotted (graph) Fig. 7. a, b, c, d, e, and f. Through the graph, the number of layers, which were two layers, was clarified, and then the value of the velocity (m/sec) was calculated, which represents the distance over time (the law of slope according to the drawing), and then the value of the critical distance (X_c) was extracted from the end of the refraction of the first layer and the beginning of the second layer. By using the critical distance, the depth of the first layer was calculated using the equation (3) .

$V_1 = Y_2\text{-}Y_1/X_2\text{-}X_1$, From drawing (1)

$V_2 = Y_2\text{-}Y_1/X_2\text{-}X_1$, From drawing (2)

Where: V_1 is the velocity of the first layer, V_2 is the velocity of the second layer, Y_2 and Y_1 are the Y axis from the drawing and representing the time (T_2, and T_1, alternately), X_2, and X_1 are the X axis from the drawing and representing the distance.

$$Z_1 = \frac{XC}{2}\sqrt{\frac{V2-V1}{V2+V1}} \quad (3)$$

Where Z_1 is the depth of the first layer, X_C is cross-over distance.

4. Conclusions

The track taken for the MASW in the study area consists of two layers. Each layer has a shear velocity, where the velocity of the first layer vs_1 is 171.6 m/sec with a depth of 8.211 m, while the velocity of the second layer vs_2 is 301.88 m/sec. The bearing capacity was 4.46, 5.27 and 5.96 T/m^2 according to the depth of the foundation 1, 2 and 3 m, respectively.

The second layer is the best layer to establish the engineering structure on it (Al-Sayidah Ruqayya Hospital building) because all engineering and geophysical results support the use of this layer as the bed layer.

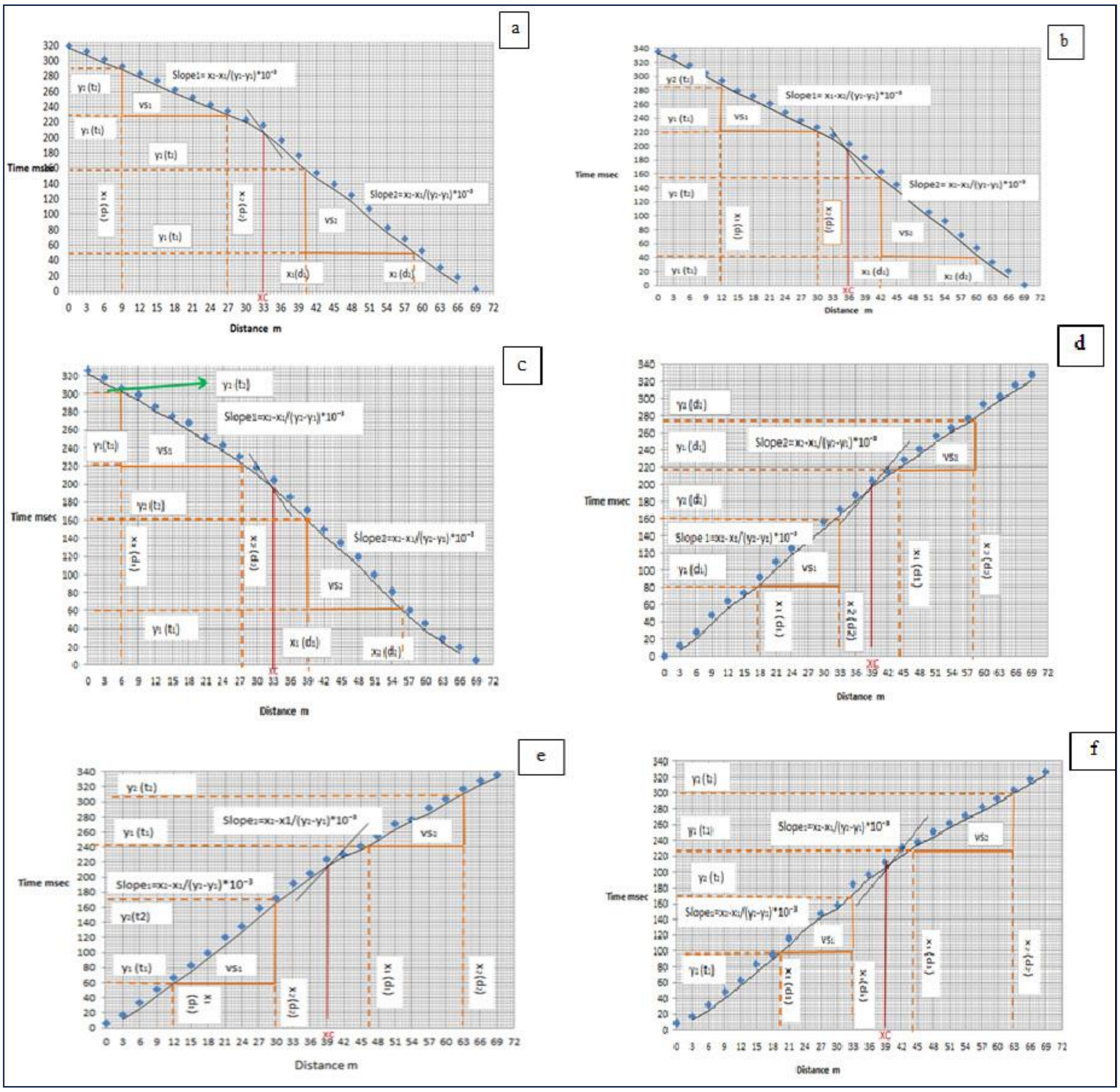


Fig. 7. The relationship between distance and time for MASW readings (MASW track)

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