Journal of Zankoy Sulaimani- Part A (JZS-A), 2014, 16 (1)

گۆڤاری زانكۆی سلێمانی بەشی A

Seismic RefractionTomography and MASW Survey for Geotechnical Evaluation of soil for the Teaching Hospital Project at Mosul University

Nabil H. Al-Saigh [*],Ahmed JaddoaAl-Heety [**]

[*] Dams & Water Resources Research center. Mosul University, e-mail: Nabilalsaigh@yahoo.com

[**] Collage of Science, Dept. Earth Science, Mosul University, e-mail: Ahmedalheety@gmail.com

Received: 16 Sep. 2013, Revised: 13 Nov. 2013, Accepted : 5 Dec. 2013

Published online: 26 Mar. 2014

Abstract:

This study includes Seismic Refraction Tomography (SRT) and Multi-channel Analysis of Surface Waves (MASW) survey. 12 shallow refraction profiles and 2 profiles for MASW were conducted in teaching hospital project site in Mosul University to delineate some of shallow soil engineering characteristics for construction purpose. The linear arrays by using 12 geophones with 10 Hz frequency are used. Both of compressional (P) waves and MASW data were acquired and interpreted using seismic tomography method and MASW methods to create 1-D shear velocity model respectively. A number of engineering parameters such as Concentration Index, Material Index, Density Gradient and Stress Ratio are calculated. The seismic velocity values ,engineering, consolidation ,and strength parameter show that the site have three layers just as follows: the first one is the upper layer which corresponds to recent superficial deposits is characterized by an incompetent rock quality, the second one is the middle one that corresponded mostly to the river deposits composed especially of River terraces and clays is characterized by fairly competent rock quality While the third one is the lower layer is corresponded to the upper part of Fat'ha formation which is mostly composed of marl layers is good competent rock quality .Hence the 3rd layer is suggested for engineering and foundation purpose.

Keywords: Refraction Tomography, MASW, geotechnical investigation, engineering parameter.

1. Introduction:

Seismic Refraction surveying is a geophysical method traditionally used in many types of exploration programs. The initial application of these surveys was mapping of salt domes in the early days of oil exploration. This method is now routinely used in foundation studies, civil engineering projects and siting studies, engineering environmental, geotechnical investigations, groundwater, dam safety analyses, and tunnel alignment studies [1-4]. Also it is popular and extensively used for imaging the subsurface structure. It is appealing because of its cost effectiveness field operation and easy data interpretation [5].

A Seismic refraction Tomography (SRT) is a geophysical method of interpreting seismic refraction data that use inversion technique to determine the velocity of 2-D and 3-D model. The principle of tomography divides the object into cells which are called pixels in 2-D and voxels in 3-D. Tomographic imaging of the velocity distribution in the object can be determined within a profile as opposed to modeling velocities as layers. This inversion method iteratively computes the travel time of the initial model, which has to be created before the inversion starts, and compares it with the actual data. The initial model is then modified to minimize the misfit between the computed travel time and the actual data. The final model is obtained when the misfit or the Root-mean square (RMS) error is at the lowest value. Such as further iterations would not reduce the (RMS) error, which usually occurs after 10 iterations [6]. The relatively recent advent of seismic Refraction Tomography techniques has provided a significant new geophysical tool in several studies that indicate how well the refraction tomography performs, in many situations, where traditional refraction techniques fail, such as velocity structures with both lateral and vertical velocity gradients

The Multichannel Analysis of Surface Waves (MASW) is one of the most important surface wave methods. It is a non-invasive nature method and greater efficiency in data acquisition and processing. Also, it is less time-consuming (no boreholes are needed).The term “MASW” originated from the publication made on Journal of Geophysics by Park, et al (1990). Field procedures and data processing steps are briefly explained in [7-10]. (MASW) method recently has become a popular one and a main tool in estimating the Vs velocities for applications of near-surface geology, environment, and engineering [11].

The aims of this research are as follows:

1. Delineating depths and thicknesses of subsurface Layers.

2. Identifying the stiffness and distribution of subsurface materials and their suitability for the establishment of engineering project through a Geotechnical investigation for these Layers.

3. Using MASW method to derive the S-wave velocity from the phase velocity of Rayleigh surface wave for the evaluation of the engineering characterization that serves construction evaluation for the site.

2. Materials And Methods

The Study covers an area of about (35140) m^2, lying between longitude 43º 8′ 40.39″ and 43º 8′ 28.69″ E and latitude 36º 23′ 23.68″ and 36º 23′ 25.7″ N. that geographically located on the eastern side of the Tigris River of northern Mosul city, more specifically in the Northwest Part of the University of Mosul (previously known as Presidential Palaces compound) .Structurally, the region is located at the Foot-Hill zone. Fig. (1) Show the studied area at the Iraq map.

2.1. Geology

The study area is an open land overall and flat with a few undulations. Mosul City is covered by Quaternary Deposits Represented by River terraces Deposits, and these deposits covered both of Fat’ha formation and Injana formation. The River terraces cover a large part of the study area, and the most thicknesses that had distinguished distribution in the study area are River terraces [12].Which are covered with soil that has a brownish to dark or reddish color that consists of sand and clay or a mixture of sand and clay with gravel.

The Fat’ha Formation (Middle Miocene) is widespread across large areas in northern of Iraq that covers the most Study area .This formation mainly consists of alternation of evaporates (gypsum and anhydrite), marl (calcareous shale) sandstone and red clay stone with possible limestone[13],[14]. Also, Injana Formation (Upper Miocene) that is not exposed except at little places. This formation mainly consists of marl, siltstone and sandstone whose size vary from medium to coarse and clay stone whereas limestone and shale exist in lower part of the formation [15].

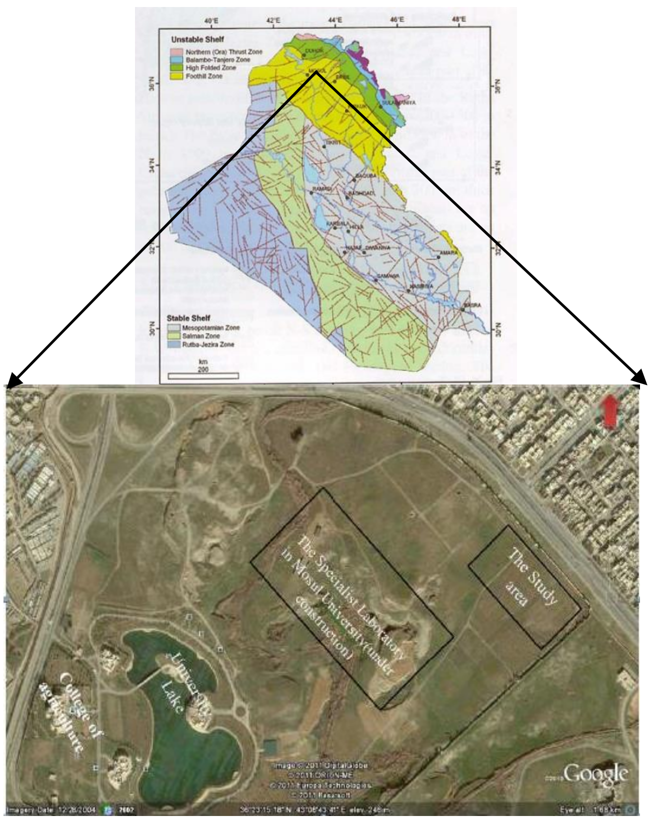


Fig. (1): Iraqi tectonic map and Satellite picture show Study Area [14].

4. Data Acquisition

Seismic Refraction Tomography and MASW profiles were conducted by using the 12-channel Terraloc MK.6 seismograph manufactured by ABEM Corporation. Each Refraction survey conducted at 12 profiles in order to cover the study area and every profile composed of 5 lines with length 80 m overlapping with each other by a distance of 30 m. The total length of each profile is 280 m, while MASW conducted at 2 profiles extends to (55 m) .In the refraction Survey the inter-geophone spacing was unfixed and the shot point was at the 1st geophone Fig. (2). While in the MASW Survey the inter-geophone spacing was (5 m) and the shot-to-1st geophone offset was 6 m Fig. (3).

The total record length of P-waves was 820ms with sample interval of 50µs while for MASW total record length was 8.19 sec with sample interval of 50µs. A total of 10 shots were recorded at each Profile (Forward and Reverse) and total of 4 shots were recorded at each test location for MASW survey. A total of (15 to 20) stacks were made per each P-wave and MASW shot location to enhance the signal to noise ratio because study area is located near from many noise sources such as traffic, daily human activates, machinery, and other factors. Both of (P-waves and MASW) were recorded using 10Hz vertical geophones.

A sledgehammer (10kg) was used to generate the seismic P-waves and MASW. To generate the waves a circular aluminum disc or rubber disc (0.3m in diameter) was used to receive the sledgehammer strikes. The data acquisition Parameters are summarized just as follows:

1. Shot spacing: 6 meters for MASW and 0.0 to 1st geophone for refraction.
2. Geophone interval: 5 meter for MASW, unfixed for Refraction.
3. Profile total length: 280m for refraction, 55m for MASW.
4. Seismograph: Terraloc MK.6 multi-channel.
5. Number of channels: 12.
6. Sampling rate: 0.50µs.
7. Seismic energy source: sledgehammer.
8. Geophones: 10-Hz vertical component

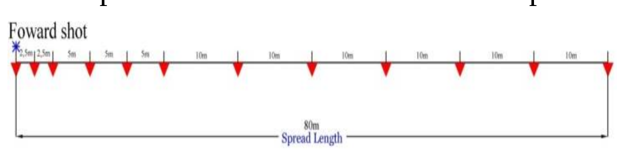


Fig. (2): Layout of the Refraction survey.

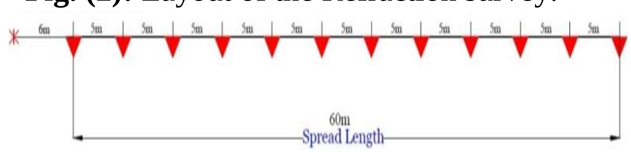


Fig. (3): Layout of the MASW survey.

4. Data processing & Interpretation of (SRT)

The acquired seismic Refraction Tomography data processed and interpreted was carried out by using the software package SeisImager/2D (Pickwin & Plotrefa). The first stage involved accurate picking of the first breaks from the seismic signal Fig. (4) by using Pickwin program for every shot record to obtained time-distance curves. The time-distance curves were constructed based on the distance along the survey line, geophone spacing, source location and the first arrival time. The second stage is analyzed time-distance curves which generated from each seismic line by using Plotrefa program .these curves were corrected and checked for the exact estimation of the P-waves velocity. The third stage is modeling velocity-depth profiles from the observed seismic velocity by a tomographic inversion method which provided by Plotrefa program. This method starts with an initial velocity model and iteratively traces rays through the model with the goal of minimizing the RMS error between the observed and calculated travel times. The observed and calculated data have a difference of RMS error of less than 4% although the low RMS errors value indicated a best fit between the observed and calculated travel-times as shown in Fig.(5) and (7).Then creating final depth-velocity models were represented in 2D forms. This model converted the tomogram to a layered model to better represent the layered nature of the geology. Figs.(6) and (8) shows the final depth-velocity models and layered model for the study area revels three subsurface layers. It did not necessary mean that the resulted velocity- depth model was geologically the correct model. Another verification tool such as outcrops, boreholes or other geophysical tool was always helpful [18]. In this work, we used outcrops information as another source of information that verifies the resulted seismic velocity-depth models.

The result demonstrated that the site has three layers. The upper layer has low seismic velocities (V_P range from 340 to 700m/sec) and a thickness ranges between 0.0 to 4.2m. This layers corresponding to recent superficial deposits. The middle layer had seismic velocity higher than the upper layer (V_P range between 840 to 1,700m/sec, and a thickness range between 4.7m to 18m.This layer corresponded to mostly the river deposits composed specially of river terraces and clays. This showed a good agreement between the seismic refraction results and the information of adjacent outcrops. The lower layer has high seismic velocity (V_P ranges between 1,900 to 2,800 m/sec, and a depth ranges between 5.8m to 20m. This layer corresponded to the upper part of Fat'ha formation which mostly composed of marl layers. Fig. (9) represent counter map showing the thickness of 2nd Layer within study area. The most thickness appeared in the central and southern part where this layer formed lenses or layer spread by horizontal distance approximately 50m extend toward NW-SE agreement with general geological direction for area. Fig.(10) represented counter map showing the depth to 3rd layer within study area.

This interpretation corresponds with [12] [16] .where River terraces keeping original sedimentary structure shaped, these structure take longitudinal structure shapes (Bars) and small Island where these structures extend toward SE-NW and have length ranges between (10-140m), whereas variation in this structure thickness reflects river weathering amount of riverbed.

5. Data processing & Interpretation of MASW

Acquired MASW data were processed and interpreted using SeisImager/SW software to determination of shear-wave velocity (Vs).this software has three more softwares i.e., Pickwin, WaveEq and GeoPlot for the Analysis of Surface Wave Data Using SeisImager/SW. The first step in the analysis is making the file list in which all waveform files and source receiver configuration are mentioned and then cross correlation CMP gather is calculated. Dispersion curves are calculated by converting it into frequency domain through Fourier transformation of the data and then checked. Generation of a dispersion curve is one of the most critical steps for generating an accurate shear wave velocity profile. Dispersion curves are generally displayed as phase velocity versus frequency. This relation can be established by calculating the phase velocity from the linear slope of each component of the swept frequency record. Fig.(11)show the phase velocity curves . The 1D shear wave velocity profiles are calculated using non-linear least square method using the dispersion data. Fig (12) an extended discussion of the MASW method is given by [17].

The results of MASW data indicated that the site has three layers. The upper layer had V_S ranges from 138 m/sec to 275 m/sec. The middle layer V_S ranged between 410 m/sec to 775 m/sec. The lower layer had V_S ranges between 1100 m/sec to 1630 m/sec.

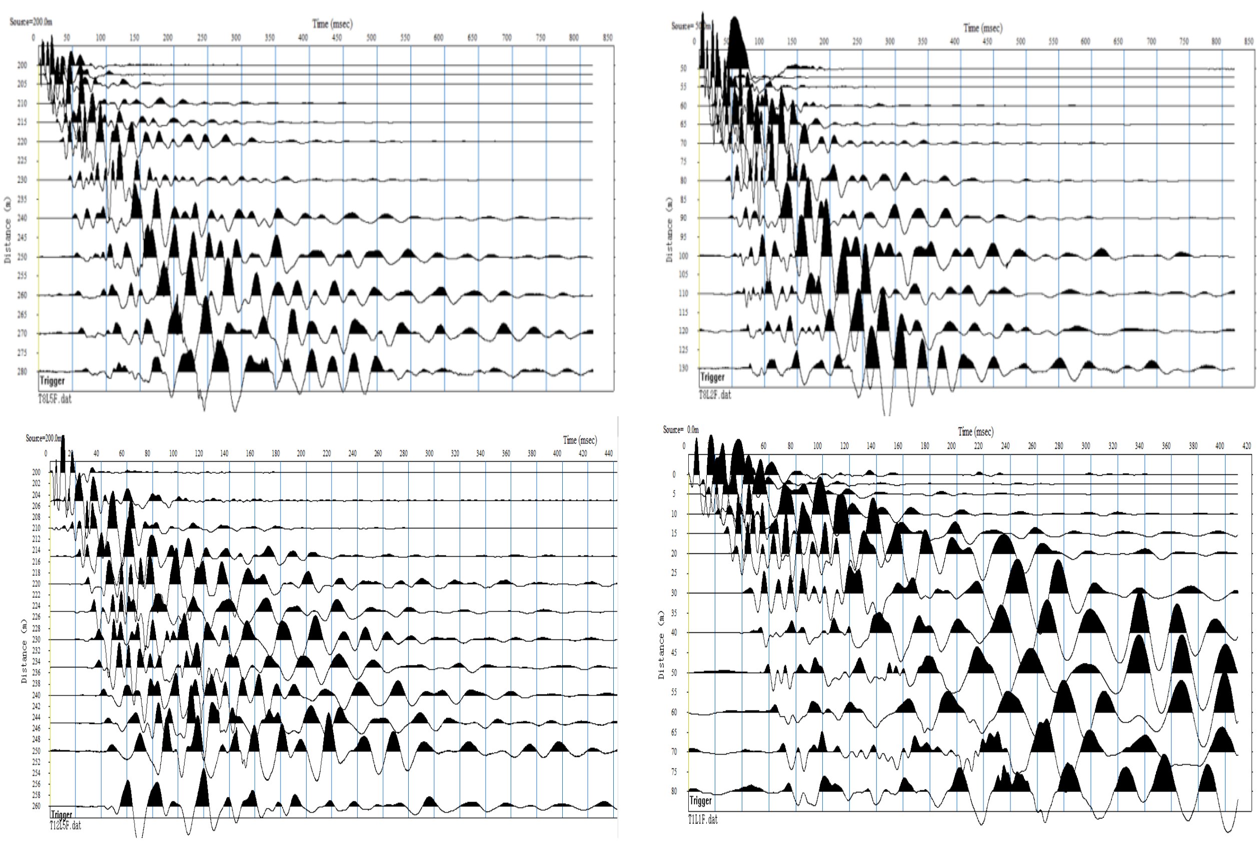


Fig. (4): Samples of the collected raw data at the study area.

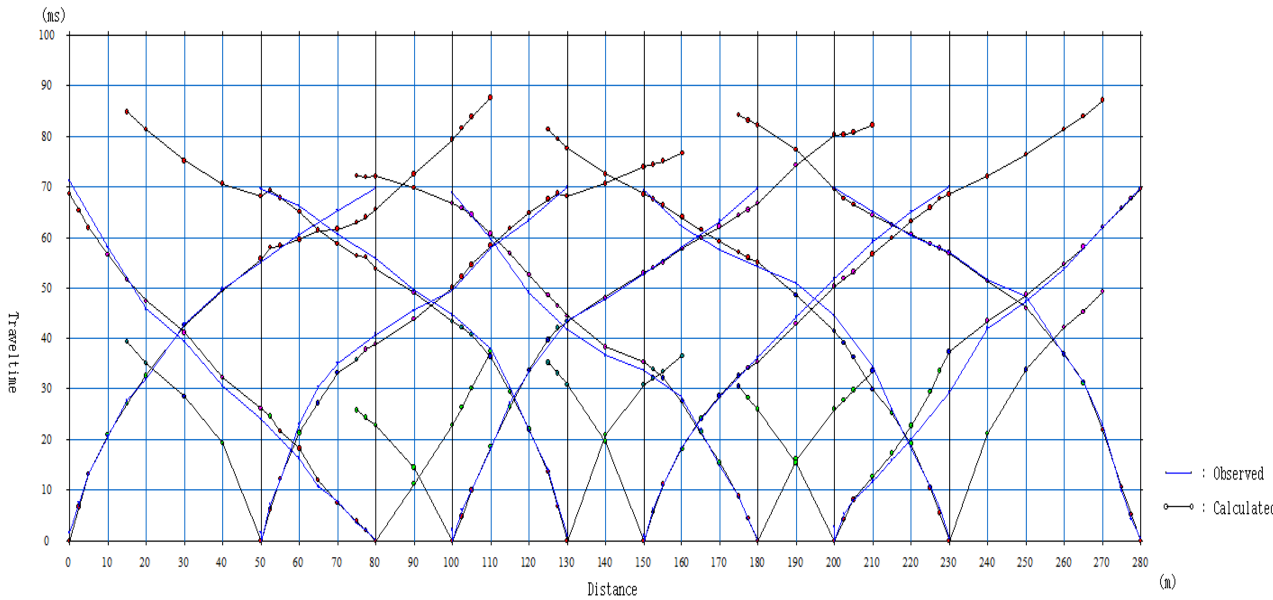


Fig. (5): The P-wave travel Time Curves of profile # 1.

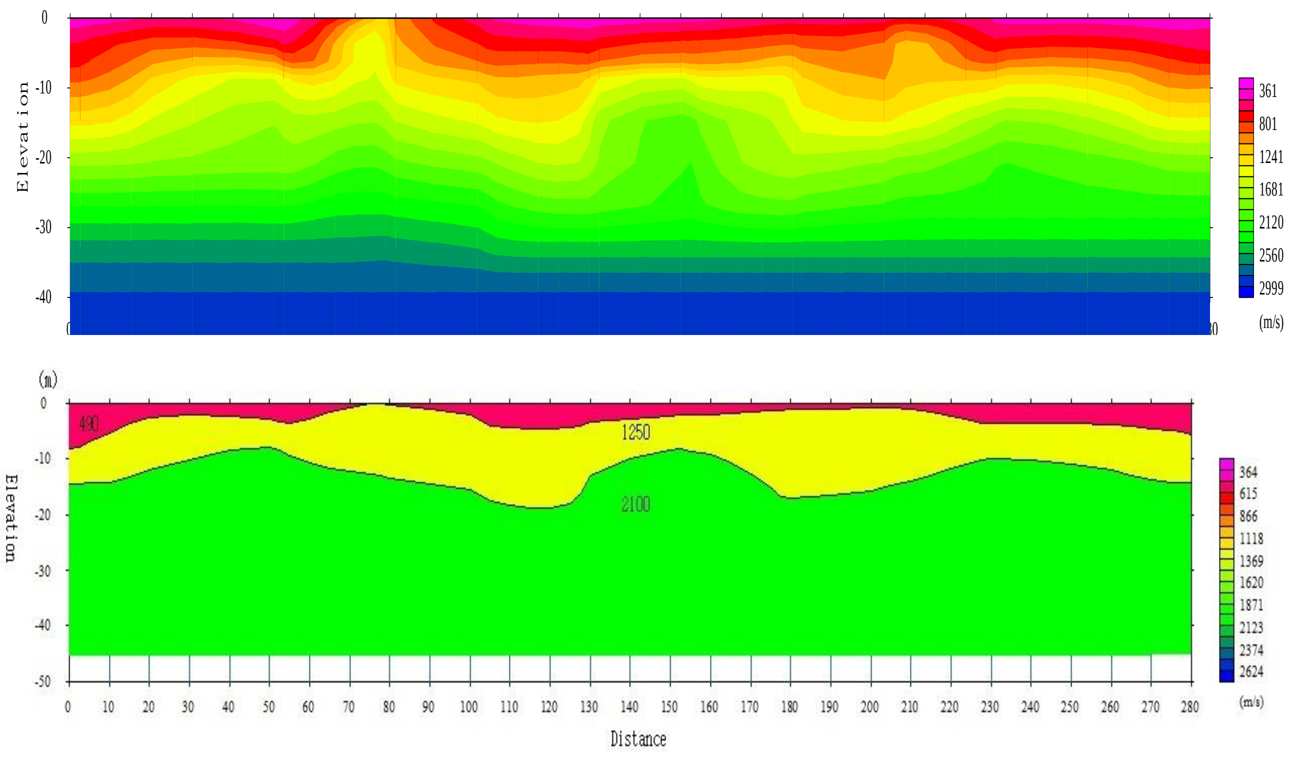


Fig. (6): velocity depth model and Layer model of the subsurface layers result from tomography inversion for profile #1.

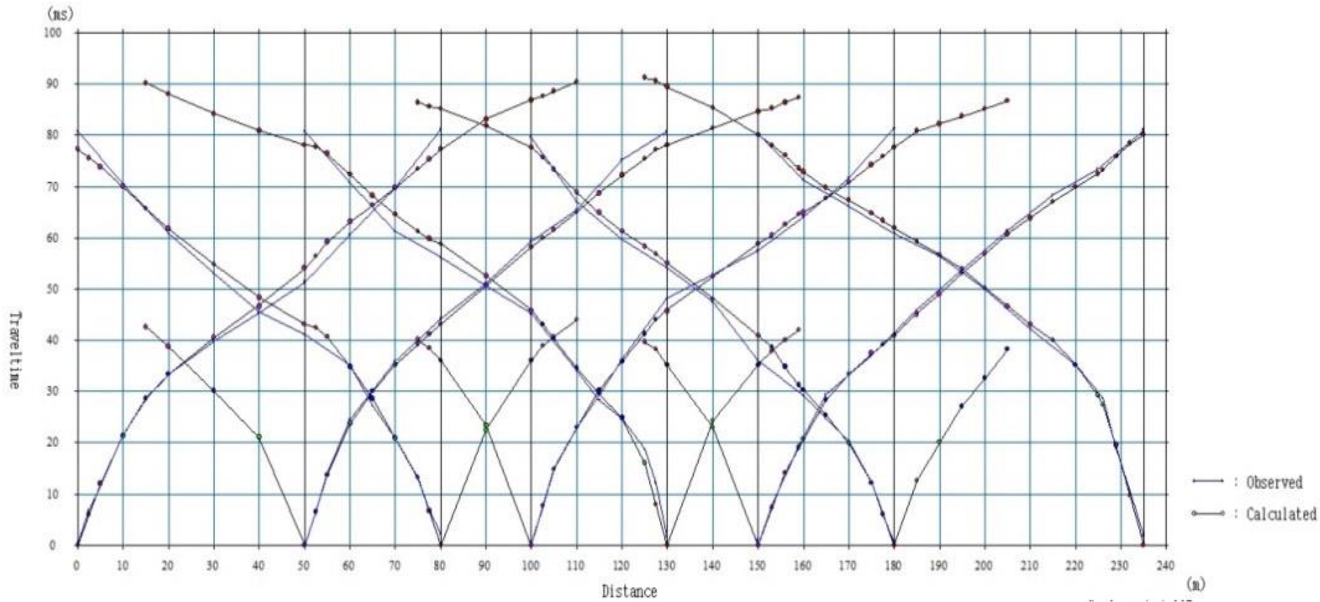


Fig. (7): The P-wave travel Time Curves of profile # 2.

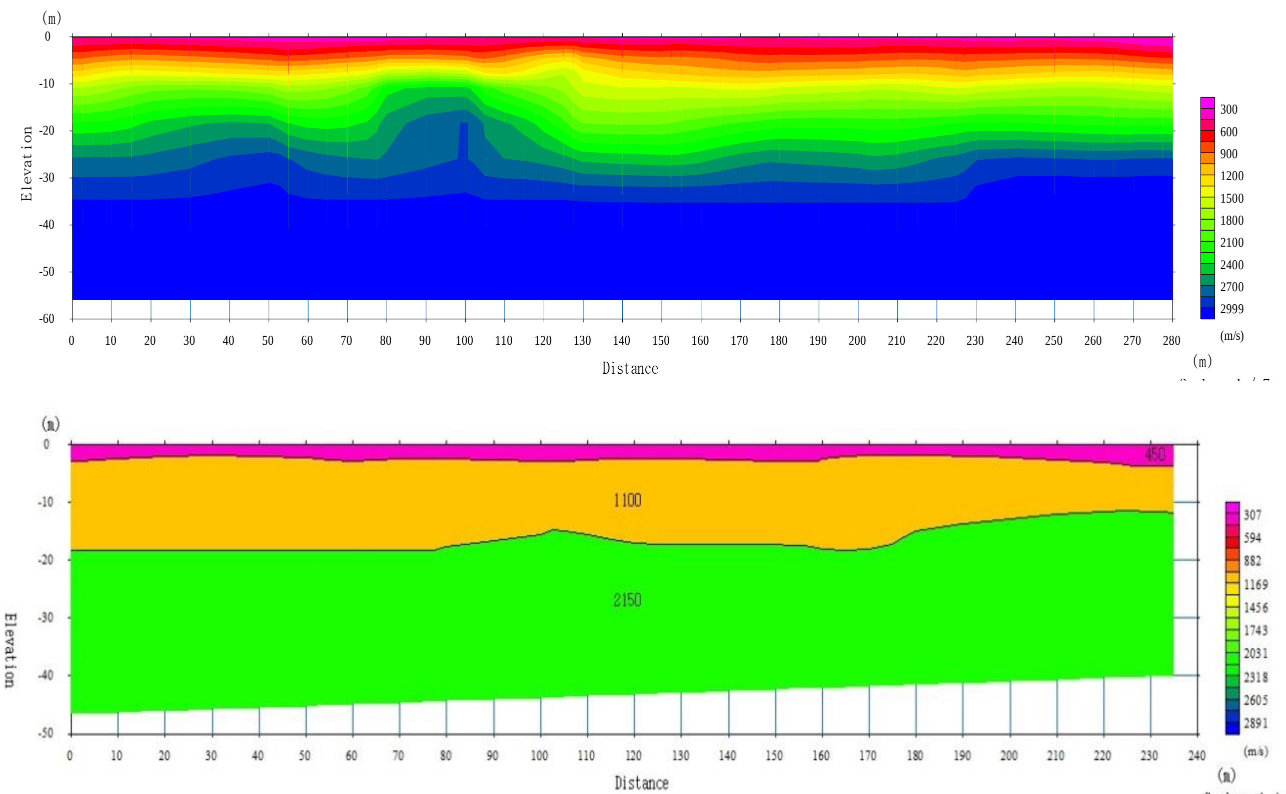


Fig. (8): velocity depth model and Layer model of the subsurface layers result from tomography inversion for profile #2.

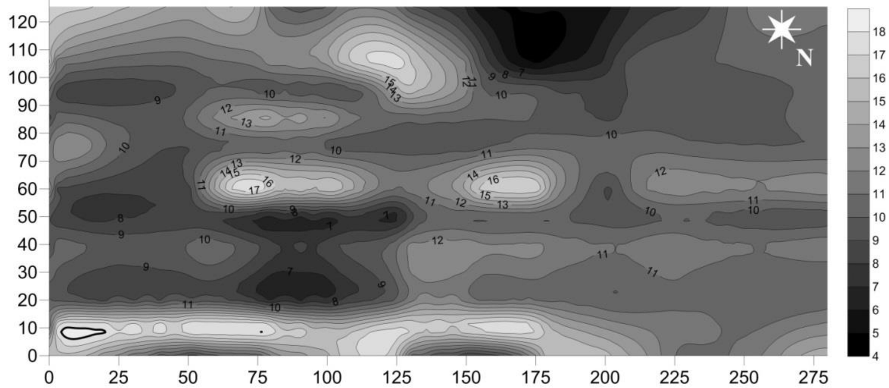


Fig. (9): A counter map showing the thickness of 2nd Layer within study area.

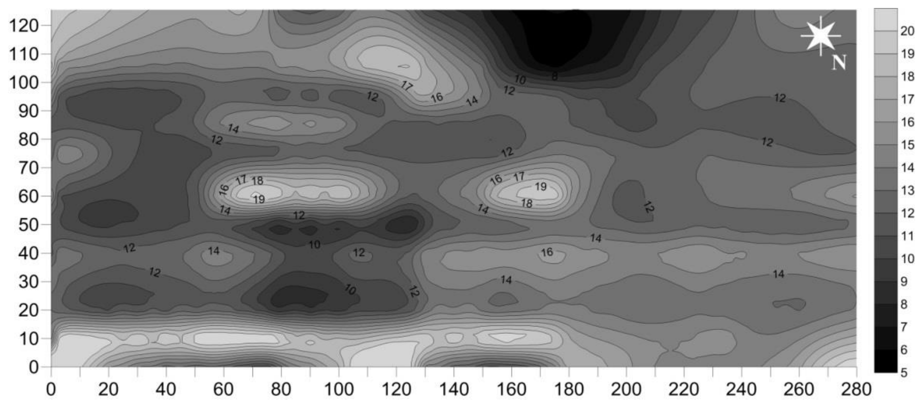
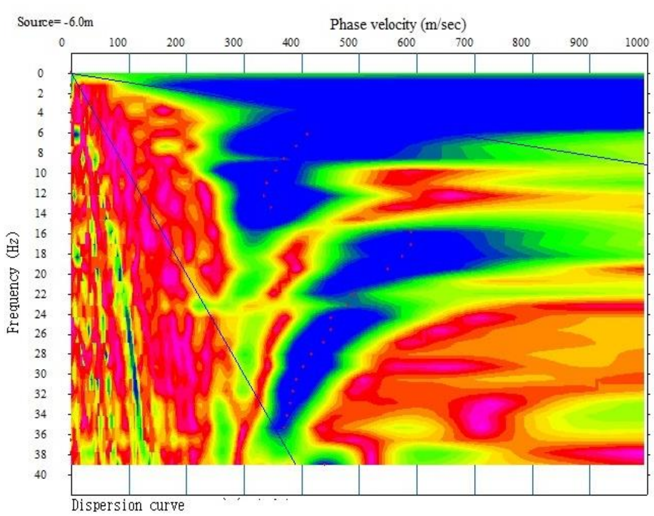


Fig. (10): A counter map showing the Depth to 3rd Layer within study area.



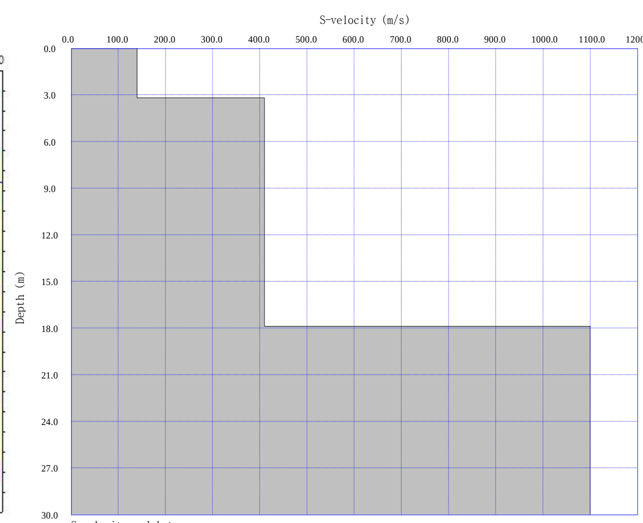


Fig. (11): Dispersion Curves profiles

Fig. (12): The 1D shear wave velocity

6. Engineering Parameter

No construction material has more variable engineering and physical parameters than the ground's soil. These parameters vary both laterally and vertically and often the variations are strong [18]. In order to evaluate the competence of the subsurface for construction, some of the shallow engineering parameters were calculated. Four parameters were calculated; the Concentration Index (Ci), the Material Index (V), the Density Gradient (Di), and the Stress Ratio (Si). Integration of these four parameters was used to select the most appropriate layer for construction.

To calculate engineering parameters which given in Table (2), the values of P-wave velocity and S-wave velocity, Field density (ρ), Poisson's Ratio (σ), Young's Modulus (E), and the Shear Modulus (μ) were required. To calculate elastic modules we are using the equation given in Table (1).

The P-waves were obtained from the acquired seismic refraction while S-waves obtained from MASW. The density values for two upper layers were obtained in the field by using Sand cone experiment while the density for 3rd layer obtained in laboratory of collected samples from available outcrops. The field density of 1st layer ranges from 1.31 to 1.48 gm/cc ,2nd layer ranges between 1.62 to 1.78 gm/cc while ranges from 1.92 to 2.1 gm/cc for 3rd layer which characterized by relative high rock density .

Table (1) : List of Equations used to Calculate Elastic parameter [19].

Elastic parameters	Used equation	Ref.
Poisson's Ratio	$\sigma = \frac{1}{2}\left[1-\frac{1}{\left(\frac{vs}{vp}\right)^2-1}\right]$	[20], [21]
Young's Modulus	$E=\rho\left[\frac{3Vp^2-4Vs^2}{\left(\frac{vs}{vp}\right)^2-1}\right]$	[21]
Shear Modulus	$\mu=\left[\frac{E}{2(1+\sigma)}\right]$	[22], [23]

The elastic moduli results for the subsurface layers can be summarized as follows:

1. Poisson's Ratio (σ): ranged from 0.40 to 0.42 for the 1st layer is characterized by relative high Poisson's Ratio, which indicates incompetent soil/rock and ranged from 0.34 to 0.36 for the 2nd layer, which indicates fairly to moderate competent while ranged from 0.247 to 0.244 for the 3rd layer. The 3rd layer is characterized by relative low Poisson's Ratio, which indicates a relatively competent materials soil according to Table (4).
2. Young's Modulus (E): ranges between 70 to 278 Mpa (Mega Pascal = (Newton/m^2/10^6) for 1st layer and ranges between 722 to 2927Mpa for 2nd layer while ranges between 5798 to 13878Mpa for 3rd layer. The 3rd characterized by relatively high values of Young's modulus.
3. Shear Modulus (μ) or Rigidity: ranges between 24 to 97Mpa for 1st layer and ranges between 269 Mpa to 1069 Mpa for 2nd layer while ranges between 2323 to 5579 Mpa for 3rd layer. The 3rd layer is characterized by relative high rigidity or shear modulus (μ) values.

Table (2): List of Equations used to calculate [19].

Engineering Parameter	Used Formula	Ref.
Stress Ratio	$S_i=1-2\left(V_s/V_p\right)^2$	[23]
Index Material	$V=\frac{3-(V_p/V_s)^2}{(V_p/V_s)^2-1}$	[24]
Concentration Index	$Ci=\left[3-4\left(\frac{V_s^2}{V_p^2}\right)\right]/\left[1-2\left(\frac{V_s^2}{V_p^2}\right)\right]$	[23]
Density Gradient	$D_i=\left[\left(\frac{3}{V_p^2}\right)-\left(\frac{4\mu}{E}-1\right)\right]=\left[\left(\frac{3}{V_p^2}\right)-\left(\frac{1-\delta}{1+\delta}\right)\right]$	[23]

The engineering parameter results for the subsurface layers can be summarized as follows:

1. The first Layer was characterized by low Concentration Index (Ci) and high Stress Ratio (Si) according to Table (3) reflects weak incompetent soil.
2. Second layer was characterized by relative low Concentration Index (Ci) and less Stress Ratio (Si) which reflected fairly competent soil.
3. Third layer was characterized by relative high Concentration Index (Ci) and low Stress Ratio (Si).which reflected Moderate competent soil.
4. Material Index (v) values for 1st layer reflected incompetent to slightly competent soil , 2nd layer reflected fairly to moderate competent soil while for the 3rd layer reflects moderate competent to competent soil according to Table (4).
5. The calculated Density Gradient (Di) for the 1st layer is characterized by relative hight Density Gradient where 3rd layer reveals values characterized by relative low Density Gradient. The calculated engineering parameters for the whole region are given in Table (5).

7. Results

The study area was divided into three layers due to the seismic wave values and the engineering parameter values.

1. The upper layer was characterized by incompetent rock quality. This layer had V_P and V_S ranges between 340 to 700m/sec, 138m/sec to 275m/sec respectively and a thickness of 0.0 to 4.2m, the concentration index, Material index, Density gradient and stress ratio were ranging between (3.3-3.4), (-0.63 to -0.68), (-0.40 to -0.42), (0.69-0.73) respectively .
2. The middle layer was characterized by fairly competent rock quality. This layer had a V_P and VS ranges between 840 to 1,700m/sec, 410m/sec to 775m/sec respectively and a thickness 4.7 to 18m. The concentration index, Material index, Density gradient and stress ratio were ranging between (3.7-3.9), (-0.37 to -0.47), (-0.46 to -0.49), (0.52-0.58) respectively.
3. The lower layer was characterized by good competent rock quality. This layer had V_P and V_S ranges between 1,900 to 2,800m/sec, 1100m/sec to 1630m/sec respectively and a depth of 5.8m to 20m. The concentration index, Material index, Density gradient and stress ratio were ranging between (5.03-5.1), (0.0 to 0.2), (-0.60 to -0.61), (0.33-0.32) respectively.

8. Conclusions

1. Seismic refraction is a useful geophysical tool for sub-surface also non-destructive method for environmental survey and the velocity-depth model can be estimated from the velocity analyses of seismic refraction data.
2. Seismic Refraction tomography is method of interpreting seismic refraction data. It well suits subsurface investigation.
3. The engineering parameter indicates a good competent of 3rd layer of the site, therefore, this layer is recommended as a most eligible layer for engineering and foundation purpose.
4. MASW technique is a quick, cost effective and reliable method alternative to shear refraction and other seismic borehole measurements for derive the S-wave velocity from the phase velocity of Rayleigh surface wave to evaluating the elastic condition (stiffness) of the ground for geotechnical engineering purposes.

Table 3: Ranges of concentration and stress ratio values with soil stiffness in [19] after [27-30].

Soil description parameter	Weak		Fair		Good
	Incompetent		Fairly competent		Competent
	Very soft	Soft	Fairly competent	Moderate competent	Compacted
Concentration Index (C_i)	3.5-4.0	4.0-4.5	4.5-5.0	5.0-5.5	5.5-6.0
Stress Ratio (Si)	0.7-0.61	0.61-0.52	0.52-0.43	0.43-0.34	0.34-0.25

Table 4: Description of Soil Types by using Poisson's ratio and material Index in [19] after [27-30]

Soil description parameter	Incompetent to slightly competent	Fairly to Moderate competent	Competent materials	Very high competent materials
Poisson's Ratio (δ)	0.41-0.49	0.35-0.27	0.25-0.16	0.12-0.03
Material Index (V)	(-0.5)-(-1)	(-0.5)-(0.0)	0.0-0.5	>0.5

Table 5: Ranges of the calculated engineering parameters of the bedrock layer.

V_p m/s	Vs m/s	ρ gm/cc	σ	Ci	Si	V	Di	E (Mpa)	μ (Mpa)
2nd Layer									
350	138	1.31	0.40	3.45	0.69	-0.63	-0.42	70.25	24.95
700	257	1.48	0.422	3.37	0.73	-0.68	-0.40	278	97.75
2nd Layer									
840	410	1.6٢	0.34	3.91	0.52	-0.37	-0.49	722.7	269
1700	775	1.78	0.36	3.71	0.58	-0.47	-0.46	2927	1069
3rd Layer									
1900	1100	1.92	0.247	5.03	0.33	-0.008	-0.60	5798	2323
2800	1630	2.1	0.244	5.10	0.32	0.025	-0.61	13878	5579

References:

[1] Lankston, R.W. (1989). The Seismic Refraction Method: A Viable Tool for Mapping Shallow Targets into the 1990s, Geophysics, vol. 54, pp.1535–1542.

[2] Hodgkinson, J. and Brown, R.J. (2005). Refraction across an Angular Unconformity between Nonparallel TI Media", Geophysics 70, D19.

[3] Bridle, R. (2006). Plus/minus Refraction Method Applied to 3D Block, SEG Expand. Abstr. 25, 1421.

[4] Yilmaz, O., Eser, M. and Berilgen, M. (2006). "Seismic, Geotechnical, and Earthquake Engineering Site Characterization", 76^{th} Annual International Meeting, SEG, Expanded Abstract, Vol.25, pp. 1401-1405.

[5] Zhang, J. and Toksöz, M.N. (1998). Non-linear Refraction Travel time Tomography, Geophysics, Vol.63, No.5, 1726-1737.

[6] Andy A. Bery, (2013). High Resolution in Seismic Refraction Tomography for Environmental Study, International Journal of Geosciences, Vol.4, pp. 792-796

[7] Park, C.B., Miller, R.D., and Xia, J., 1999, Multi-channel analysis of surface waves, Geophysics, Vol.64, No. 3, pp. 800-808.

[8] Park, C.B., Miller, R.D., Xia, J., Hunter, J.A., and Harris, J.B., (1999). Higher mode observation by the MASW method [Exp. Abs.]: Soc. Exploration Geophysics, pp. 524-527.

[9] Miller, R.D., Xia, J., Park, C.B., and Ivanov, J., 1999, Multichannel analysis of surface waves to map bedrock," The Leading Edge, Vol.18, No.12, pp.1392-1396.

[10] Stokoe II, K. H., Wright, S.G., Bay, J.A., and Roesset, J.M., (1994). Characterization of geotechnical sites by SASW method, in Geophysical characterization of sites, International Society of Soil Mechanics and Foundation Engineering Technical Committee #10, edited by R.D. Woods, Oxford Publishers, New Delhi.

[11] Xia, J., Miller, R.D., Xu, Y., Luo, Y., Chen, C., Liu, J., Ivanov, J., and Zeng, C., (2009), High-frequency Rayleigh-wave method: Journal of Earth Science, Vol.20, No.3, pp. 563-579.

[12] Al-Joubory, M.A.(1988),Geology of Mosul area East Tigris River,M.Sc. thesis , science college ,Mosul university, 158 p. (In Arabic).

[13] Bellen,R.C. Van, Dunnington, H. V., Wetzel, R. and Morton, D.(1959), Lexique Stratigraphique International. Asie, Iraq, 3c. 10a, 333 p.

[14] Jassim S. Z. And Goff J.C. (2006). Geology of Iraq. 1st Edition Dolin, Prague and Moravian Museum, Brno, Czech Republic, 408 P.

[15] Buday, T., (1980). The regional geology of Iraq Stratigraphy and Paleogeography, Dar Al-Kutub publication House. Mosul -Iraq. 352 p.

[16] Al-Dabbagh, T. H. and Al-Naqib, S. Q. (1991). Tigris River Terrace Mapping in Northern Iraq and Geotechnical Properties of the Youngest Stage. Quaternary Journal of Engineering Geology. Geological Society. Special Pub., Vol.7, pp. 603-609.

[17] Reynolds, J. M., (2011). An Introduction to Applied and Environmental Geophysics, Wiley; 2nd edition, 712 p.

[18] Bowles, J.E. (1982).Foundation Analysis and Design", 2nd Ed. McGraw-Hill International Book Company, London, 587 p.

[19] Khalil, M. H., Hanafy, S.M., (2008). Engineering application of seismic refraction method: A field example at Wadi Wardan,Northeast Gulf of Suez, Egypt ,Journal of Applied Geophysics ,Vol.65, pp.132-141.

[20] Adams, L. H. (1951). Elastic Properties of Materials of the Earth's Crust. Internal Construction of the Earth (edited by Gutenberg), Dover Publications, Inc., New York.

[21] Salem, H.S., (1990). The Theoretical and Practical Study of Petrophysical, Electric and Elastic Parameters of Sediments, Germany, Kiel Insitut for Geophysik. Ph.D. Thesis.

[22] King, T.V.V., (1966). Mapping Organic Contamination by Detection of Clay-Organic Processes, Proceeding AGWSE/ NWWA/API.

[23] Toksoz, M.N., Cheng, C.H. and Timur, A., (1976). Velocities of Seismic Waves-Porous Rocks, Geophysics, Vol.41, pp. 621–645.

[24] Abd El-Rahman, M. (1991), The Potential of Absorption Coefficient and Seismic Quality Factor in Delineating Less Sound Foundation Materials in Jabal Shib Az Sahara Area, Northwest of Sanaa, Yemen Arab Republic", Egypt, M.E.R.C. Earth Sci., Vol. 5. Ain Shams University, pp. 181–187.

[25] 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.

[26] Abd El-Rahman, M. (1989). Evaluation of the Kinetic Elastic Moduli of the Surface Materials and Application to Engineering Geologic Maps at Maba-Risabah Area (Dhamar Province), Northern Yemen, Egypt. J. Geol. 33(1–2), 229–250.

[27] Birch, F. (1966). Handbook of Physical Constants, Geol. Society of America. Memoir. 97, 613.

[28] Gassman, F. (1973). Seismische Prospektion, Birkhaeuser Verlag, Stuttgart, 417 p.

[29] Tatham, R.H. (1982). Vp/Vs and Lithology, Geophysics 47(3), 336–344.

[30] Sheriff, R.E. and Geldart, L.P. (1986). Exploration Seismology, Cambridge University Press, Cambridge, 316 p.