

SURFACE WAVES DISPERSION OF NORTH AND ORTHWESTERN IRAQ

Nawal A. Alridha¹, Ghassan I. Al-Eqabi², Talal K. Abdul-Baqi³

¹ Geology Dept., College of Science, University of Baghdad, Baghdad, Iraq

² Saint Louis, Washington University

^{3v} Geology Dept., College of Science, University of Tikrit, Tikrit, Iraq

Abstract

Surface waves have been used to estimate velocity variations within the earth at different scales, from small scale site characterization for engineering purposes to global tomography of surface waves dispersion data. Generally group velocities of surface waves along the bath from epicenter to recording give the average structure along the bath. In this study, dispersion parameter extracted from surface wave waveforms where inverted for crustal structure with great success, using least square inversion technique. Group velocity at 10, 15, 20, and 30s periods were obtained and mapped. Group velocities of Rayleigh waves vary between 2. 229-2.768 km/s in 10s period, 2.461-2.857 km/s in 15 s period, 2.581-2.944 km/s in 20s period and 2.789-3.656 km/s in 30s period accordingly. The group velocities agree well with expected low group velocity values of the Mesopotamia, they seem to reflect clearly the effect of thick sediment of the study area. Results are shown in 2D and 3D representation and generally agree with known or expected results from available models derived from global or regional geophysical studies.

1. Introduction

Surface wave signals are generally the strongest arrivals recorded at teleseismic distances. They provide some of the best constraints on the earth's crust and upper mantle structure. Their waveforms are more complicated than body waves. They travel more slowly and decay less with distance than body waves and they are dispersed. Interpreting surface-wave dispersion measurements provides an important method for determining the shear-wave velocity variation in the earth. Modern studies of surface waves and their application in structure interpretation were propelled by (1) matrix formulation of the multi-layered system period equation, which made possible rapid, accurate computation of dispersion curves for complex earth models, (2, and 3).

The modern use of seismic surface waves for studying crustal and upper mantle structure started in the 1950s. Several studies on observations of surface waves are available for both global and regional models. Regional

surface wave studies of the crust and upper mantle were reviewed by (4) presented surface wave dispersion for different tectonic provinces. (5) Provided an overview of how surface-wave data from earthquakes are analyzed to infer details of the earth structure over particular propagation paths.

Experimental methods for measuring surface wave dispersion, including the Fourier phase methods, the time correlation method, the band-pass filtering method, the group delay time method, and various digital moving window techniques, were described by (5). Dispersion data derived for paths that traversed the study area (Latitude: 33 -38°N, Longitude 40 -45°E) were obtained from the recent deployment of 10 seismic stations in central and northern Iraq, North of Iraq Seismological Network (NISN), (6), and 2 seismic stations from International Research Institute of Seismology (IRIS) Figure (1).

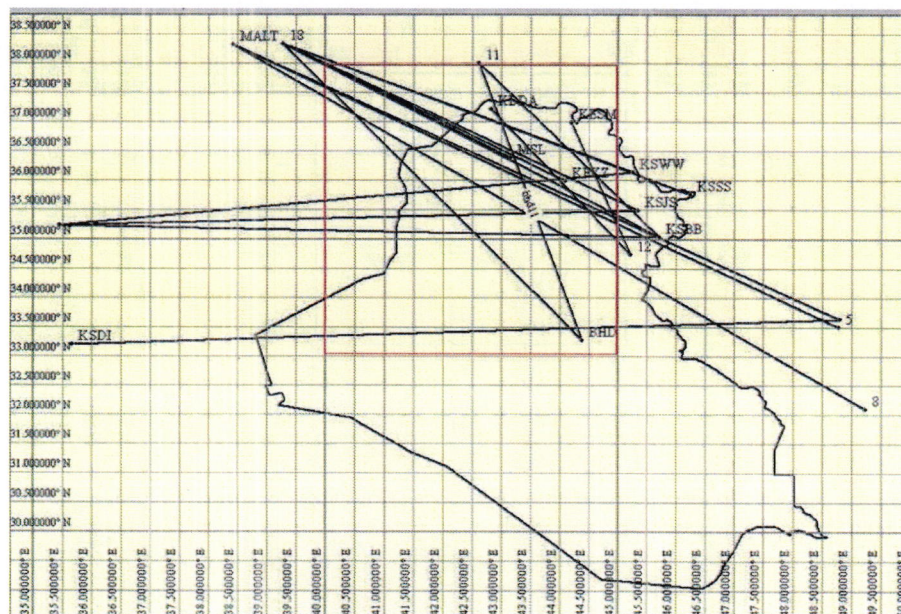


Figure (1) showing the stations of (NISN) and IRIS and the event paths which cover the area of the present study.

Eighteen seismic paths from seven seismic events recorded by the NISN (4 events) and IRIS (3 events)

provided coverage to the study area, in North and North-Western part of Iraq (Latitude: 33-38°N, Longitude 40-

45□E); multiple filter technique (7, 8) was used to extract Rayleigh wave group velocities from dispersed wave field along the traversed paths.

2. Dispersion in surface Waves

Dispersion is observed in the frequency dependent travel times of surface waves, resulting from the increase of velocity with depth. In general, short period surface waves travels slower than long period waves. Long periods are more sensitive to the faster velocities found deeper in the earth. Both Love waves and Rayleigh wave's exhibit dispersion and are used to estimate shear velocity variations in the crust and upper mantle. In a homogeneous elastic half-space with no damping, Rayleigh waves propagate along the surface of the body at a constant, frequency independent, phase velocity. In a layered or vertically heterogeneous half-space different frequency surface waves propagate with different phase velocities and different wavelengths. Each harmonic component of an observed signal has a velocity called phase velocity, $C(\omega)$, defined by (9) as the instantaneous velocity of the plane waves at a given frequency:

$$C(\omega) = \frac{\omega}{k(\omega)}$$

Where;

ω (The angular frequency) = $2\pi f$

f = frequency

k = wave number

For a given angular frequency (ω), $C(\omega)$ depends on the medium parameters such as layer thickness (h), (ρ) density, shear and compress ional velocity wave disturbances with wide spectrum of period interfere with each other, producing constructive or destructive patterns that influence the total ground motion.

3 Multiple Filter Analysis and Phase Match Filter

The Multiple Filter Analysis performs extraction of surface-wave group velocities and spectral amplitudes. This process is done by filtering the input signal by Gaussian filter, if we assume the dispersed single mode surface-wave signal as:

$$s(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} A(\omega) e^{i(\omega t - kx + \phi)} d\omega$$

A filtered signal resulting from action of filter $H(\omega)$ of a form like

$$H(\omega) = e^{-\alpha(\omega - \omega_0)^2 / \omega_0^2}$$

Is

$$g(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} A(\omega) H(\omega) e^{i(\omega t - kx + \phi)} d\omega$$

Whose envelopes reaches maximum at the group velocity arrival time. Searching for the peaks of the envelopes at each period will map the dispersion curves.

We generate phase-match-filtered (PMF) seismograms from the original vertical components waveforms using the `do_mft` program (10). This program uses the multiple filter technique (MFT) (7) to plot the group velocity curve for an event at single station. We pick the fundamental mode dispersion curve from these plots (Figure 2) and then use phase-match-filter (PMF) analysis (11) to generate the corresponding PMF waveform. Phase match filter is linear filter in which Fourier phase of the filter is made equal to that of the given signal. The PMF waveforms are preferable to the original waveforms because they contain less noise and allow for examination of only fundamental mode. The PMF waveforms are then MFT to obtain the final dispersion curve, (12).

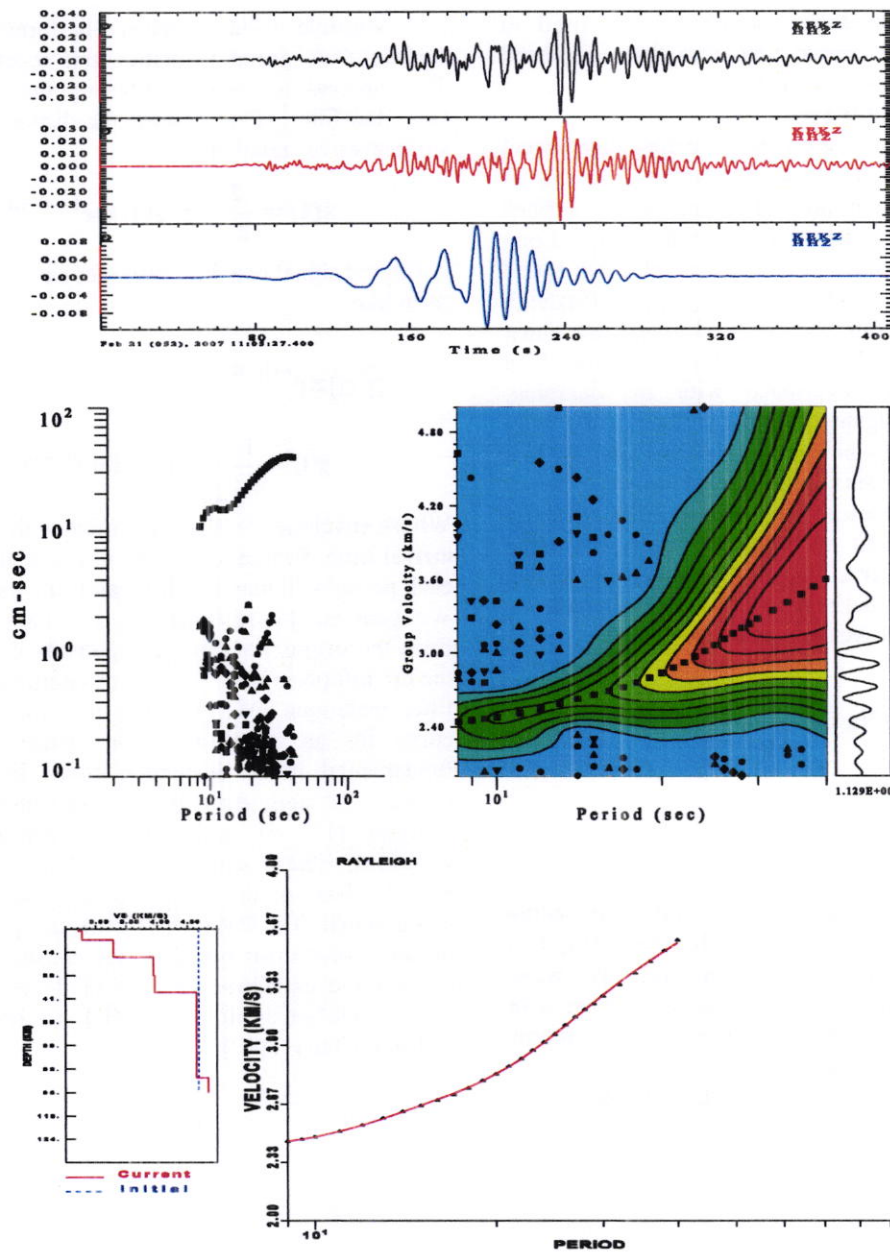


Figure (2) Result of path from event 18 to Station KEKZ. Surface wave inversion technique.

4.Presentation of Surface Wave Group Velocity

Generally, surface waves dispersion provides good indication of the shear wave structure of the crust.

In the ensuing sections we present group velocities for Rayleigh wave paths across the study region, Table 1, that are obtained from the Multiple filter analysis in a three dimensional maps. Maps of Rayleigh waves are created in period ranges between 10s to 30s.

Table (1) Sample group velocity values observed in the study area at different periods.

Name	Long	Lat	10s	15s	20s	25s	30s
BHD11	43.4961	35.637	2.22931	2.46099	2.58094	2.76745	2.96984
BHD18	41.8283	35.802	2.235	2.468333	2.691	2.971	3.239
KDDA12	44.01875	35.97295	2.37925	2.5449	2.79987	3.30367	3.6
KEKZ18	41.6839	37.15945	2.47838	2.6589	2.83788	3.064	3.27992
KESM12	44.70745	35.859	2.76825	2.85751	2.9444	3.14022	3.65618
KSBB11	44.1578	36.52055	2.69258	2.71556	2.65691	2.67258	2.85126
KSBB13	40.57455	35.1414	2.45225	2.54962	2.68439	2.97387	3.24101
KSBB18	42.49	36.68555	2.41291	2.55398	2.72821	2.9803	3.19753
KSDI7	42.22965	33.4093	2.31316	2.53005	2.6367	2.79521	3.01313
KSJS13	40.39255	35.3689	2.44597	2.6019	2.75022	2.99616	3.27014
KSJS18	42.308	36.91305	2.46568	2.5782	2.74258	2.99532	3.22439
KSSS18	42.7535	37.0496	2.61683	2.68111	2.75909	2.94171	3.16673
KSWW13	40.35115	35.6953	2.52684	2.62932	2.79219	3.06308	3.24143
KSWW18	42.2666	37.23945	2.54207	2.64466	2.74843	2.96551	3.19356
MALT07	43.6138	35.97	2.71364	2.76232	2.71372	2.78552	2.87734
MALT08	43.83085	35.2003	2.56577	2.61953	2.63444	2.59885	2.78861
MSL18	41.20955	37.35565	2.53132	2.68813	2.85909	3.10346	3.41336
max	44.70745	37.35565	2.76825	2.85751	2.9444	3.30367	3.65618
min	40.35115	33.4093	2.22931	2.46099	2.58094	2.59885	2.78861

4.1 Group Velocity at 10 Seconds

Group velocity at a period of 10 seconds is affected by the upper 10 km of shallow sediments and the shallow upper crust. Figures (3) and (4) represent regionalization of group velocity at 10 sec across the study region in two

and three dimensional displays. We notice lateral as well as vertical variations in the group velocities. From Figure (3) and (4), the group velocity of Rayleigh at 10 sec ranges between 2.229 and 2.7683 km/sec.

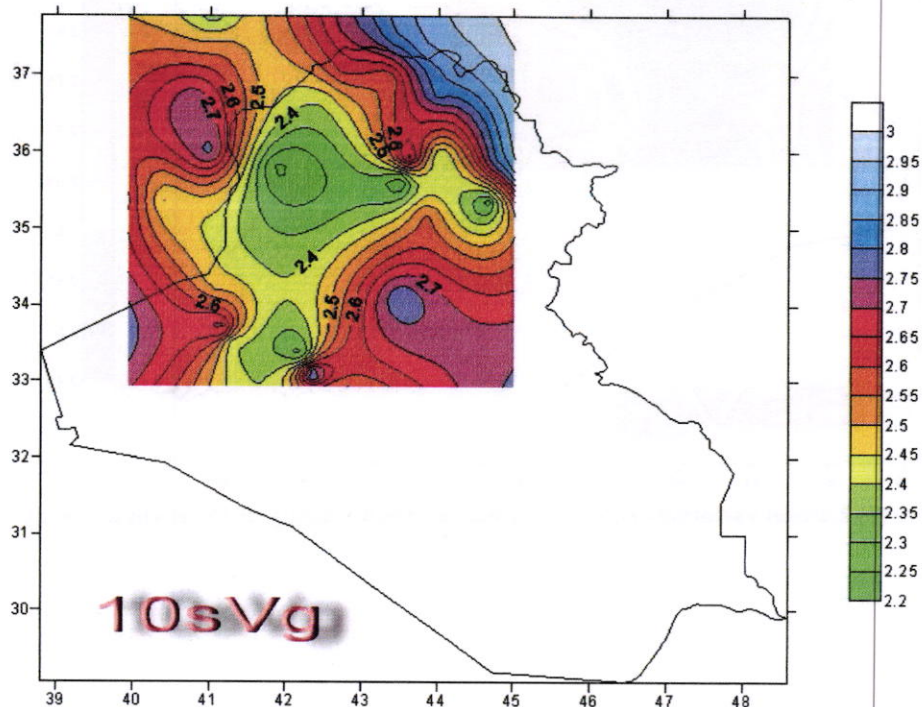


Figure (3) Lateral variations of Rayleigh waves group velocity at 10 sec (in km /sec).

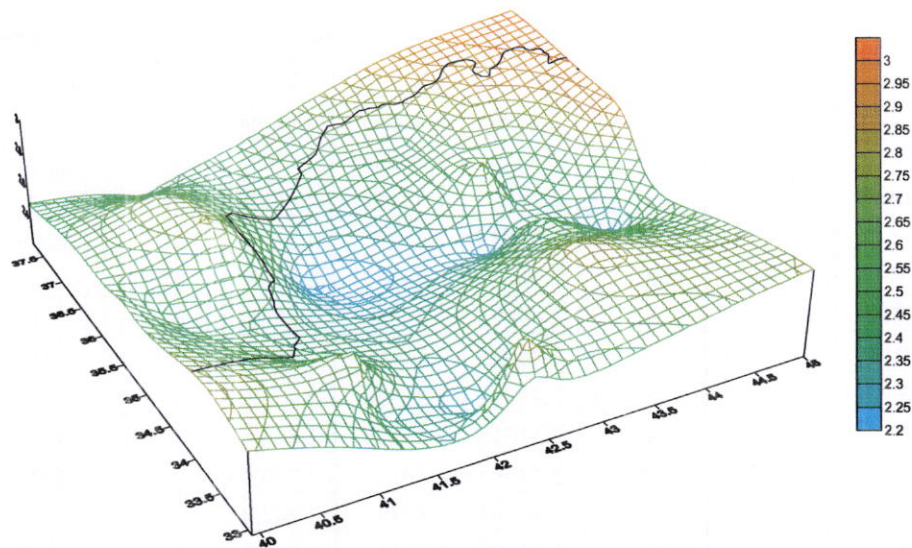


Figure (4) Three dimensional representation of Rayleigh wave group velocity at 10 sec in N-NW of Iraq (in km/sec).

4.2 Group Velocity at 15 Seconds

At 15 sec, surface wave would have sampled the crust at places deeper than the 10 seconds. At nearly 15 km where the upper crust is sampled. Rayleigh wave dispersion measurements at 15 sec are sensitive to velocities in the upper 15 km or so and affected by crustal velocity, and crustal thickness. Figure (5) and

Figure (6) represent regionalization of group velocity at 15 sec across the study region in two and three dimensional displays. We notice lateral as well as vertical variations in the group velocities. Generally, we notice slow group velocities which probably reflect the thick sedimentary section of Mesopotamia Valley.

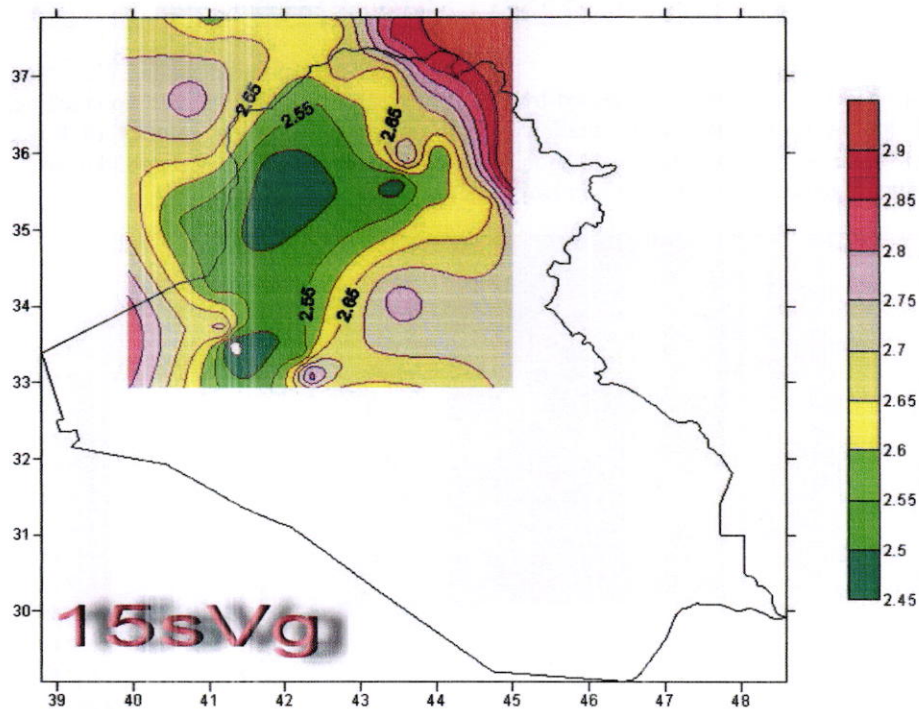


Figure (5) Lateral variations in Rayleigh waves group velocity at 15 sec (in km /sec).

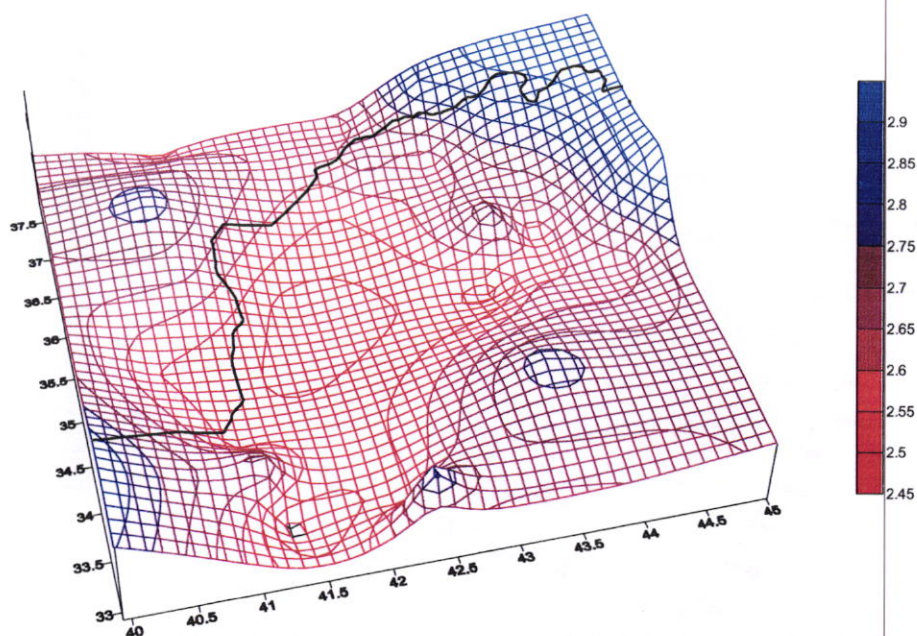


Figure (6) Three dimensional representation of Rayleigh wave group velocity at 15 sec in N-NW of Iraq (in km/sec).

4.3 Group velocity at 20 seconds

Figures (7) and (8) show group velocity variations in two and three dimensional regionalization of Rayleigh waves at 20 sec. Rayleigh wave at this period would be

sensitive to upper and middle crust. We found a group velocity values in the range between 2.581 and 2.944 km/sec at 20 sec period

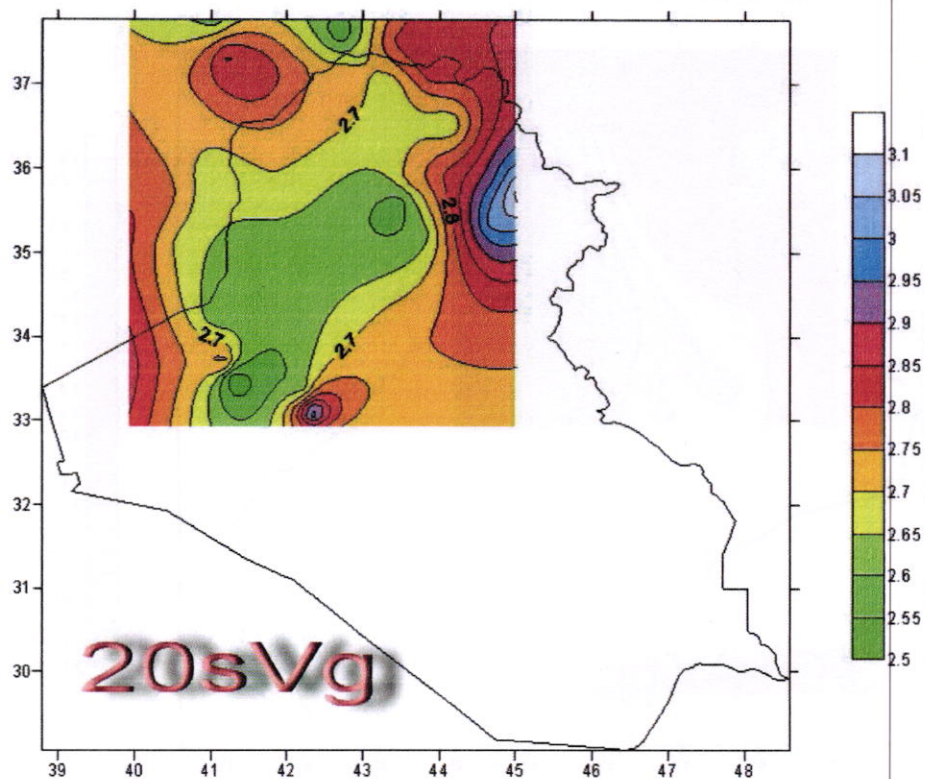


Figure (7) Lateral variations in Rayleigh wave group velocity at 20 sec (in km/sec).

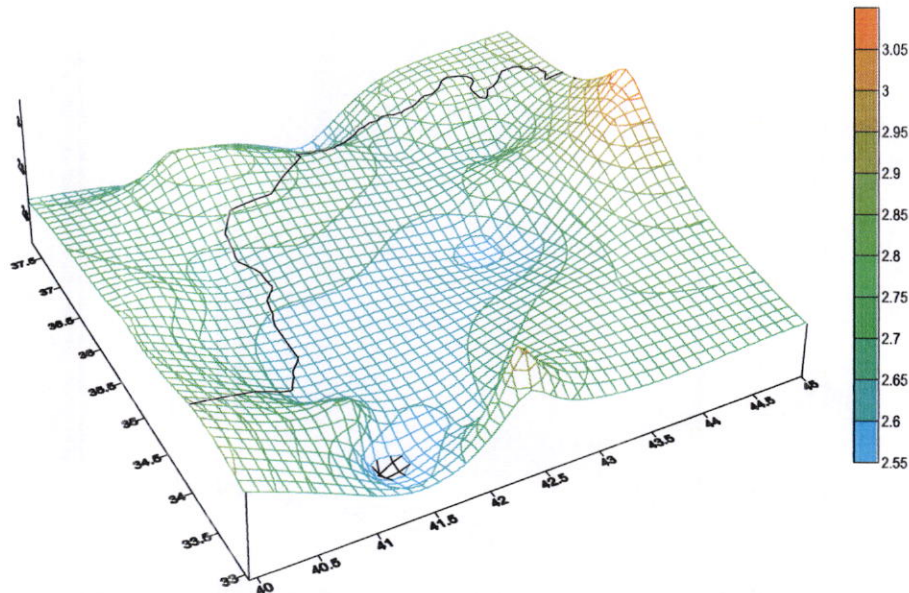


Figure (8) Three dimensional representation of Rayleigh waves group velocity at 20 sec group velocity in N-NW of Iraq (in km/sec).

4.4 Group velocity at 30 seconds

At 30 sec, Rayleigh waves are sensitive to the whole crust with noticeable sensitivity to the deeper parts of the crust including upper mantle. Figures (9) and (10) display the group velocity values in both two and three

dimensional distribution. The group velocities observed at 30 sec period ranges between 2.789 and 3.656 km/sec and correspond with typical continental crust. The effect of lower crust is clearly shown.

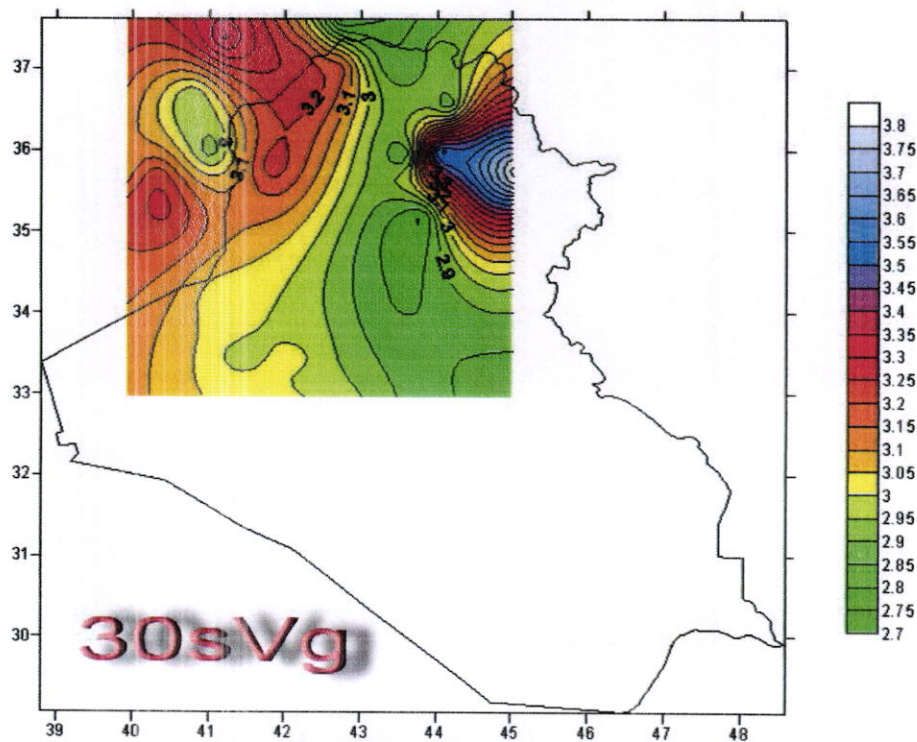


Figure (9) Map of lateral variations of Rayleigh waves group velocity values at 30 sec period (in km /sec).

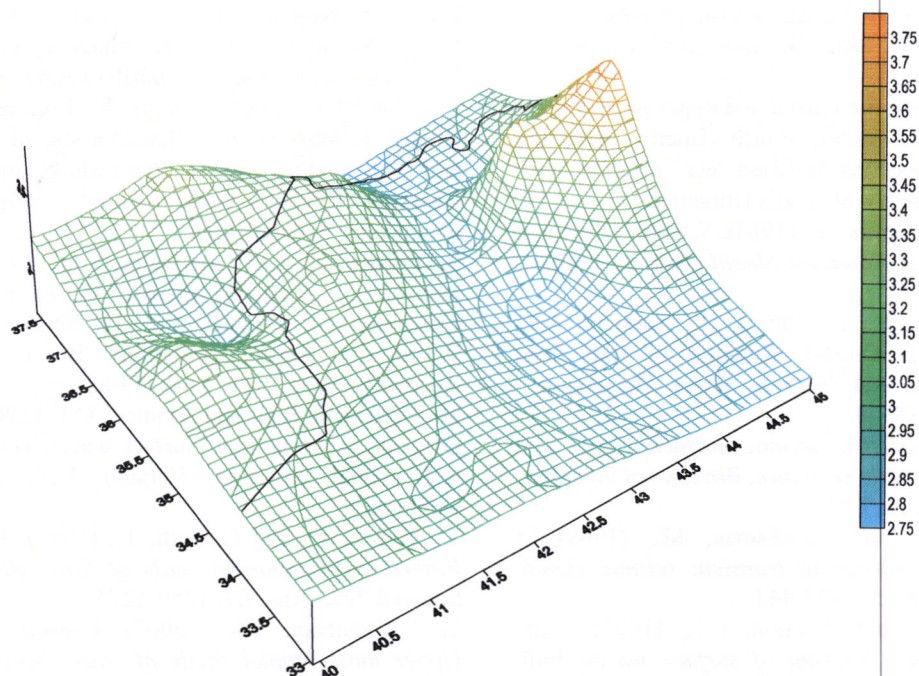


Figure (10) three dimensional representation of Rayleigh wave group velocity at 30 sec in N-NW of Iraq (in km/sec).

Conclusions

A recent deployment of ten, three components broadband seismometers throughout central, northern and northeastern Iraq has provided an unprecedented set of seismic data. Observed seismograms from regional events are phase match filtered to isolate fundamental mode of Rayleigh wave surface. Eighteen paths that traversed the study area were chosen from seven earthquakes that occurred within the region were analyzed.

At a period of 10 seconds Rayleigh wave to be most sensitive to depth of approximately 10 Km. Variations of Rayleigh wave group velocity at 10 seconds period (2.229-2.768)Km/sec compare well to the variation in the sediments thickness in the region.

The group velocity variations at 15 sec period Rayleigh wave dispersion (corresponding to approximately 15 km.

thickness) compares well with the variations in the combined sediments thickness and upper crust in the region and vary between 2.461 and 2.857 Km/sec

The group velocity variations at 20 second period Rayleigh wave dispersion (corresponding approximately to 20 km. thickness) compares well with the variations in the combined sediments thickness, upper crust and part of the middle crust in the region and vary between 2.581 and 2.944 Km/sec.

The 30 second Rayleigh wave is most sensitive to depth around 30 km. At these depths we expect to encounter lower crust and upper mantle material beneath continental crust. Our values compares well with the variation in the combined the lower crust and upper mantle in the region and has range between 2.789 and 3.656 Km/sec.

Reference

1. Haskell, N.A., (1953), *The dispersion of surface waves in multilayered media*, Bull. Seismol. Soc. Am. 43, 17-34.
2. Fnais, M.S., (2004), the crustal and upper mantle shear velocity structure of Eastern North America from the joint inversion of receiver function and Surface wave dispersion. Ph.D. Thesis, St. Louis University.
3. Brune, J.N. and Dorman, J., (1963), *Seismic waves and Earth structure in the Canadian Shield*, Bull. Seism. Soc. Am., 53, 287-303
4. Gok, R., Mahdi, H., Al-Shukri, H., Rodgers, A.J., August 31, (2006), Crustal Structure of Iraq from Receiver Functions and Surface Wave Dispersion, LLNL, UCRL-Tr-224124.
5. Kovach, R.L., (1978), *Seismic surface waves and crustal and upper mantle structure*, Reviews of Geophys. And Space Physics, 16, 1-13.
6. Dziewonski, A. and Landisman, M., (1969), *A technique for the analysis of transient seismic signal*, Bull. Seism. Soc. Am. 59, 427-444
7. Herrmann, R.B. and Ammon, C.J., (1973), *some aspects of band pass filtering of surface waves*, bull. Seismol. Soc. Am., 63, 663 - 671
8. Ghalib, H.A.A., Ghassan, I. Al-Eqabi, Bakir S. Ali , Borhan I. Saleh , Dawood S. Mahmood, Indra N. Gupta,
- Robert A. Wagner , Patrick J. Shore , Aras Mahmood, Shaho Abdullah , Omar K. Shaswar, Fadhil Ibrahim, Basoz Ali , Layla Omar, Nokhsha I.Aziz, Nian H.Ahmed , Ali A. Ali , Abdul-Karem A. Taqi and Samira R. Khalaf, (2006), Seismic characteristic of Northern Iraq and Surrounding region, Proceedings of 28th seismic Research Review: Ground-Based Nuclear Explosion Monitoring Technologies.
9. Dziewonski, A.M., and Hales, A.L., (1972), *Numerical analysis of dispersed seismic Waves in Methods in Computational Physics Vol 11 Seismology: Surface Waves and Earth Oscillations*, B. A. Bolt (Editor) Academic Press, New York, 39-85
10. Herrmann, R.B. and Ammon, C.J., (2002), *Computer program in seismology*; surface waves receiver functions and crustal structure, Version 3.15, Saint Louis University.
11. Herrin, E., and Goforth, T., (1977), *Phase-matched Filters: Application to study of Rayleigh Waves*, Bull. Seismol. Soc. Am., 67, 1259-1275
12. Abdulbaqi, T.K., (2007), *Crustal Structure and Upper most Mantel Study of North-Northwest of Iraq Using Rayleigh waves Analyses*. PhD Thesis, University Of Baghdad, Unpublished.

انتشار الموجات الزلزالية السطحية لشمال شمال غرب العراق

نوال عبد الرضا¹ ، غسان إبراهيم العقابي² ، طلال كامل عبد الباقي³

¹قسم علوم الارض ، كلية العلوم ، جامعة بغداد ، بغداد ، العراق

²سنت لويس ، جامعة واشنطن

³قسم علوم الارض ، كلية العلوم ، جامعة تكريت ، تكريت ، العراق

المخلص

استخدمت السرعة الزلزالية السطحية لتحديد التغيرات في السرعة في طبقات الارض السطحية للاغراض الهندسية وإلى انتشارها خلال باطن الارض . ان تغيير قيم سرعة مجموعة رايلي تعطي فكرة عن التركيب التحت السطحي لذلك المسار . لقد تم حساب ورسم سرعة مجموعة رايلي ولفترات (10 15 20 30) ثانية وكانت القيم تتغير بين (2,229 2,768) كم/ثا في 10 ثانية (2,461 2,857) كم/ثا في 15 ثانية (2,581 2,944) كم/ثا في 20 ثانية و (2,789 3,656) كم/ثا في 30 ثانية ووجد توافقا جيدا بمجموع السرعة مع قيم سرعة حوض بلاد ما بين النهرين المنخفضة المتوقعة وهي تعكس بشكل واضح تأثير الرواسب السميكة لمنطقة الدراسة . عرضت النتائج ببعدين ومثلت بثلاثة ابعاد وهي عموما متوافقة مع قيم النتائج المعروفة والمتوقعة من النماذج المتوفرة من الدراسات الجيوفيزيائية العالمية والاقليمية والمحلية.