2D Local Earthquake Tomography of Rayleigh Waves in Northwest of Iran

Somayeh Shakiba*, Rouhollah Amiri Fard**, Habib Rahimi***

*Graduate student, Institute of Geophysics, University of Tehran, s.shakiba@ut.ac.ir
**Graduate student, Institute for Advanced Studies in Basic Science, r.amirifard@iasbs.ac.ir
***Associated Professor, Institute of Geophysics, University of Tehran, rahimih@ut.ac.ir

ABSTRACT

The tomography method of local earthquakes is of great use for studying the structure of the crust and upper mantle. In this research, two-dimensional surface wave tomography has been used to create tomographic maps for the Northwest of Iran plateau. For this sake, using 1961 local events recorded at 27 seismic stations of Iranian Seismological Center (IRSC) and International Institute of Earthquake Engineering and Seismology (IIEES) have been analyzed. In the first step, the fundamental mode of Rayleigh's waves dispersion curves is obtained. Second, by using a 2D-linear inversion procedure, the group velocity tomography maps are achieved. In this study, the northwest of Iran, the region is divided into 0.50 ×0.50 cells. Low-velocity anomalies beneath Sahand and Sabalan ash cones, in other words long periods, is indicated from the results of surface wave tomography which is correlated with geological setting. The reason of that is the region, the northwest of Iran, is enclosed with low shear wave velocity such as quaternary deposits. In addition, other parameters are of paramount importance in terms of North Tabriz Fault existing, partial melting, and high temperature anomalies are beneath Sahand and Sabalan.

Keywords: Local Earthquake Tomography (LET), dispersion curves, Rayleigh wave.

INTRODUCTION

The studied area is located in northwestern Iran between 44° and 50° eastern longitudes and 34° and 40° northern latitudes. Geographically, this region is located in Alborz, and Zagros Mountains ranges intersect, comprising a part of the collisional zone between the Arabian and Eurasian plates. (Berberian, M. and Yeats, R.S, 1999). In this region, the presence of shear movements has led to the strike-slip faults, such as Urmia Lake Fault, Main Reverse Fault (MRF), Masuleh Fault, and the most crucial fault with drastic historical records (Berberian, M., 1976) which is developed in the region is the North Tabriz fault. Besides, the presence of Sahand and Sablan volcanos further proves the crustal vibrations in the study area. The knowledge of geological structure and characteristics of active faults are significant to evaluate seismic hazard, and more appropriately simulate the seismic ground motion. This study's purpose is to determine 2D local earthquake tomography of Rayleigh waves in the Northwest of Iran using dispersion curves of the group velocity. We calculated the dispersion curves of the Rayleigh wave by using Hermann and Ammon (2002) package. Moreover, the estimation of tomographic maps for the Rayleigh wave is done by a 2D surface wave tomography code, which is developed by Ditmar and Yanovskaya (1987) and Yanovskaya and Ditmar (1990).

BODY OF THE DOCUMENT (Methodology & Data)

In this research, for data processing, a single-station method has been used to calculate Rayleigh wave velocity dispersion along the epicenter-station path., those were subjected to inversion to determine 2-dimensional surface wave tomography of Northwest Iran.

The first step includes identifying and extracting the part of the seismogram, which is related to the fundamental mode of the Rayleigh wave. For this purpose, multiple filtering techniques are applied using a phase-matched filter to extract the Rayleigh wave's fundamental mode from the seismogram. Following the first step, the velocity group of Rayleigh wave dispersion curves from the isolated seismogram are obtained, as a final stage, based on Yanovskaya and Ditmar (1990). The tomographic maps for the Rayleigh wave velocity are obtained by inversion the Rayleigh wave velocity dispersion curves.

Using single- station method, the group velocity of the Rayleigh wave has been obtained using multiple filtering techniques (Dziewonski et al., 1969; Herrmann, 1973). To this end, the waveforms were subjected to narrow-band pass filtering using the operator $exp[-\alpha(f-f_c)^2/f_c^2]$ Where f_c is the central frequency, and α is the filter width, which is determined based on the epicentral center (for an earthquake) or the inter-station spacing (for Green's function). The parameter α takes an essential part estimation of the group velocity accurately. Not all of the calculated dispersion curves were of appropriate quality for surface wave tomography. Therefore, several quality control constraints were adopted to remove inappropriate data. The constraint is the signal-to-noise ratio (S/N), which is used only Green's functions with S/N values above 7, left us appropriate dispersion curves. The dispersion curve inversion was performed using a modified 2D linear tomography method proposed by Yanovskaya et al. (1990). Being a 2D generalization of the 1D Backus–Gilbert (1968) method, the travel time velocity is obtained by integration over the ray path combined with residual time concerning the initial approximation, according to the following linear equation:

$$\boldsymbol{\delta t_i = -\int_{L_{0i}} \frac{\delta V(r)}{V_0^2(r)} ds\, t_i = t_i - t_{0i}} \quad (1)$$

Where r = (x, y), V0(r) is the group velocity corresponding to the initial model, δV = V0(r) – V(r), and t0i is the observed travel time as per the initial approximation along the i th ray path. The parameter L0i denotes the corresponding path to the initial approximation. Assuming m (r) = – δV (r) / V0 and expanding Equation (1) to a 2D domain through integration over the study area, we ended up with the following:

$$\boldsymbol{\delta t_i = \iint_\Omega G_i(r) m(r) d(r)} \quad (2)$$

where Gi (r) is a singular function in the direction of the i th ray path and zero elsewhere, satisfying the following constraint:

$$\boldsymbol{\iint_\Omega G_i(r) dr = \int_{L_{0i}} \frac{ds}{V_0(r)} = t_{0i}} \quad (3)$$

In absence of any observation error, the observed model could be related to the unknown model m (r) using an error term εi which can be assumed as being equal to the variance. Therefore, in order to find the unknown model, one should solve the following minimization problem:

$$\boldsymbol{\sum_i \left(\delta t_i - \iint_\Omega G_i(r) m(r) d(r)\right)^2} \quad (4)$$

Expanding the Backus–Gilbert (1968) method to a 2D domain for m (r) (the solution must have a minimized norm), the final result is obtained as follows:

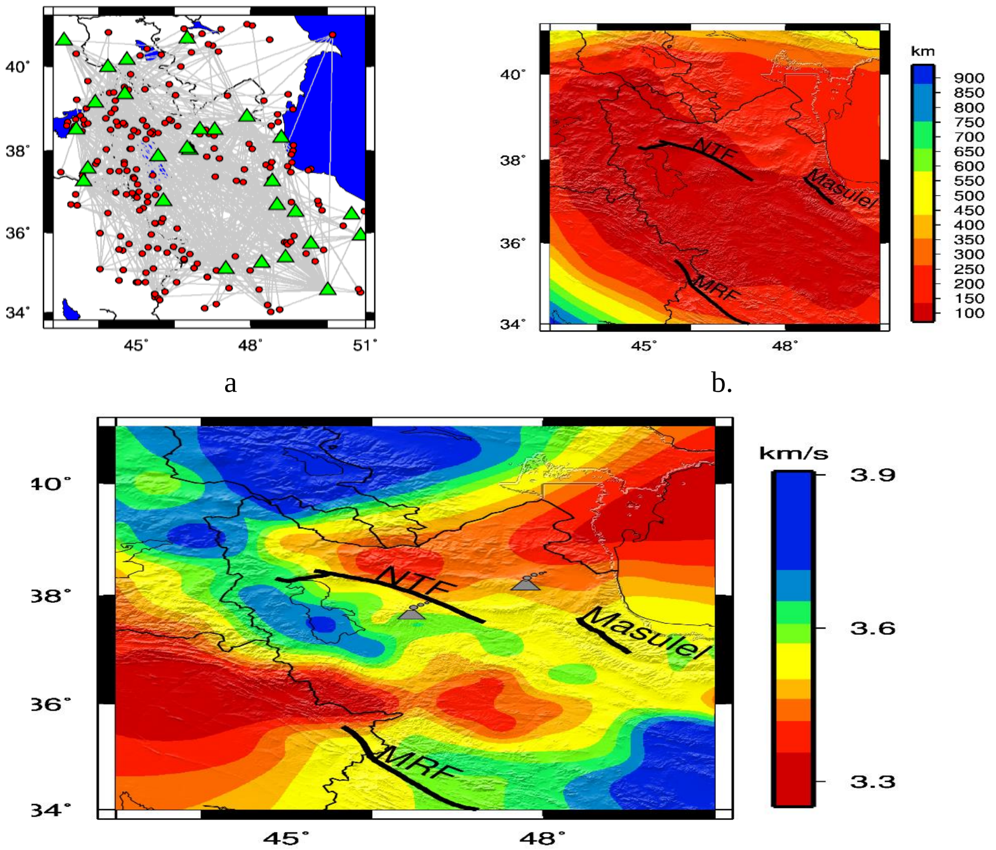
$$\boldsymbol{\sum \left(\delta t_i - \iint_\Omega G_i(r) m(r) d(r)\right)^2 + \beta \iint_\Omega |\nabla m(r)|^2 dr = min} \quad (5)$$

where β is a regulating parameter. According to this tomography method, a group velocity map V(r) is estimated through minimizing Equation (5) for different periods. The smallest resolvable feature was assessed utilizing average area, which is known to be associated with the resolution at each point (Yanovskaya, 1998). The average area is defined by an ellipsoid whose minor and major axes corresponded to the minimum and maximum values of s (x, y), respectively. The resolution at each point is given by a single value called average area and defined as follows:

$$\boldsymbol{L} = \frac{\boldsymbol{G}_i(\boldsymbol{x},\boldsymbol{y}) + \boldsymbol{S}_{max}(\boldsymbol{x},\boldsymbol{y})}{\boldsymbol{2}} \qquad (6)$$

Where Smax and Smin represent the major and minor axes of the ellipsoid, respectively. Resolution of the tomography maps is highly dependent on the density of the ray paths in each cell. Therefore, a small average area indicates high resolution and vice versa. Another important parameter is the elongation, which is defined as follows:

$$\boldsymbol{ex} = \boldsymbol{2}[\boldsymbol{S}_{max}(\boldsymbol{x},\boldsymbol{y}) - \boldsymbol{S}_{min}(\boldsymbol{x},\boldsymbol{y})/\boldsymbol{S}_{max}(\boldsymbol{x},\boldsymbol{y}) + \boldsymbol{S}_{min}(\boldsymbol{x},\boldsymbol{y})] \qquad (7)$$



c.

Figure1, a: In this area ray crossing between stations and earthquakes are well covered, the green triangle are stations and the red circles are earthquakes.

Figure1, b: Averaging area changes for Rayleigh wave for period of 10 seconds. There is not any ray stretching and the smallest anomalies are represented under the 50 km depth.

Figure1, c: Tomography map of Rayleigh wave group velocity for period 10 second.

CONCLUSION(S)

The lateral variation of the group velocity of the Rayleigh wave of 10 seconds, which is extracted from 10 -70 seconds, period that is one of the best tools for detecting both different and fundamental geological features shown in Fig.1.c The studied region in the northwest of Iran is divided into 0.50 ×0.50 cells (~ 50 km × 50 km).

Illustrate low-velocity anomalies under the Sahand and Sablan volcanoes associated with high temperatures. Moreover, the low velocity of North Tabriz Fault, due to fractured and broken areas, is confirmed by results. These parameters have been sampled from mantel's and crust's structures in ever-rising periods in the range of 10 – 70 seconds

The results of surface wave tomography indicate the presence of low-velocity anomalies beneath Sahand and Sablan ash cones, which have been confirmed as a long period. The results illustrate a good correlation with the geological setting of this region. Northwest of Iran is covered by quaternary deposits with a low shear wave velocity. Moreover, the existence of North Tabriz Fault, partial melting, and high-temperature anomalies beneath Sahand and Sablan are the main reasons for these low velocities.

REFERENCES

Berberian, M., 1976, Contribution to the seismotectonics of Iran (partII): p. 518, Geological Survey of Iran, Tehran.

Berberian, M. and Yeats, R. S., 1999, Pattern of historical earthquake rupture in the Iranian Plateau: Bulletin of the Seismological Society of America, 89, 120-13Backus, G.E. & Gilbert, F.,1968, The resolving power of gross earth data, Geophysics. J. 16169-205

Ditmar, P.G. & Yanovskya, T.B., 1987, Generalization of Backus-Gilbert Method for Estimation of Lateral Variations of Surface Wave Velocities, Phys. Solid Earth, Izvestia Acad. Sci. USSR, 23 (6), 470–477.

Herrmann, R.B., and Ammon, C.J., 2002. Computer Programs in Seismology, An Overview of Synthetic Seismogram Computation, Department of Earth and Atmospheric Sciences, Saint Louis University, St Louis.

Yanovskaya, T.B. & Ditmar, P.G., 1990, Smoothness criteria in surface wave tomography. Geophysics. J. Int., 102, 63–72.