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Near surface radial anisotropy in the Rigan area/SE Iran

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ABSTRACT

By analyzing Rayleigh and Love wave empirical Green's functions extracted from ambient seismic noise and earthquake data, we obtained near surface radial anisotropy structure beneath the hidden part of the Kahurak fault in the Rigan region, in the southeast of Iran. The deduced seismic radial anisotropy within the hidden part of the Kahurak fault can reveal record of shallow crustal deformation caused by the Rigan earthquake (M_W 6.5) occurred on 20 December 2010. Significant radial anisotropy with positive magnitude ($V_{SH} > V_{SV}$) appears in the shallow subsurface of the upper part of the crust. The magnitude of radial anisotropy varies from predominantly positive ($V_{SH} > V_{SV}$) to mostly negative ($V_{SH} < V_{SV}$) values with increasing depth which is correlated with a known sedimentary layer. The sedimentary layer is observed with prominent positive radial anisotropy ($V_{SH} > V_{SV}$). The thickness of the sedimentary layer varies between 1 and 3 km from the south to the north beneath the study area with an average radial anisotropy of about 5%. However, cross-section profiles indicate that negative anomaly stretches inside a thick sedimentary layer where the aftershocks occurred. Also, the investigation of cross-section profiles reveals that a dipping angle of the hidden part of Kahurak fault is resolved at approximately 85° using the anisotropy pattern. Moreover, the aftershocks generally occurred in the transitional zones where signs of radial anisotropy anomalies change. Our study indicates that the influence of different resolving powers and path coverage density of Rayleigh and Love waves, which can be artificially interpreted as radial anisotropy, have minor effect on calculated radial anisotropy and they are estimated in the range of −2% to +2%.

1. Introduction

We studied shear wave velocity and seismic radial anisotropy in the Rigan region/SE Iran using ambient noise method developed by Shapiro and Campillo (2004) with the additional of data from 41 recorded aftershocks. The central Iranian plateau is located between the Arabian and Eurasian plates with a convergent regime (23 to 25 mm/yr; Berberian et al., 1984; Walker and Jackson, 2004). The southern part of the Lut block and the northern edge of the Jaz-Murian depression, in the central Iran, surround the Rigan region, in the south-eastern part of the central Iran plateau as shown in Fig. 1. The north part (Saif Al-Dini plain) of the study area (central box in the Fig. 1) is in the low-lying Narmashir desert region, in south of Lut block, and also south of the studied area is bordered by the Shahsavaran mountain chain (Berberian, 1990). The Shahsavaran Mountains are predominately composed of Tertiary and Quaternary volcanic rocks. The northward of central box is bounded by Pliocene Andesites which is overlaid on a small alluvial plain; the Saif Al-Dini plain (Aghanabati, 1992) as depicted in Fig. 1.

The major characteristics of seismicity in the central Iran include the followings: (1) scattered seismic activity with large-magnitude earthquakes, (2) long recurrence periods and (3) seismic gaps along several Quaternary faults (Berberian, 1976). According to the seismicity of the region, a moderate earthquake with $M_W = 6.5$ occurred in the thinly populated part of the Rigan region on 20 Dec 2010. Neither historic seismicity nor significant instrumental seismicity has been reported for such a causative fault. However, variety of major active strike-slip faults, including the Bam fault (from the west-northwest), the Kahurak fault (from the northeast) and Nosrat-Abad fault zone (from the east) surround the Rigan region as shown in Fig. 1. Additionally, the causative fault of the earthquake occurred on 20 Dec 2010 triggered another moderate earthquake (M_W 6.2) less than a month later, on 27 January 2011 with an almost similar focal mechanism as the first earthquake (Fig. 1). The epicenter of the two mainshocks and the two largest aftershocks reported by Global Centroid Moment Tensor (Global CMT) are also depicted in Fig. 1. In addition, >300 aftershocks were reported by the Iranian Seismological Center (IRSC) network with Nuttli magnitude (M_N; Nuttli, 1973) as shown in Fig. 1 which were re-located by Rezapour and Mohsenpur (2013). Note that the study area experienced

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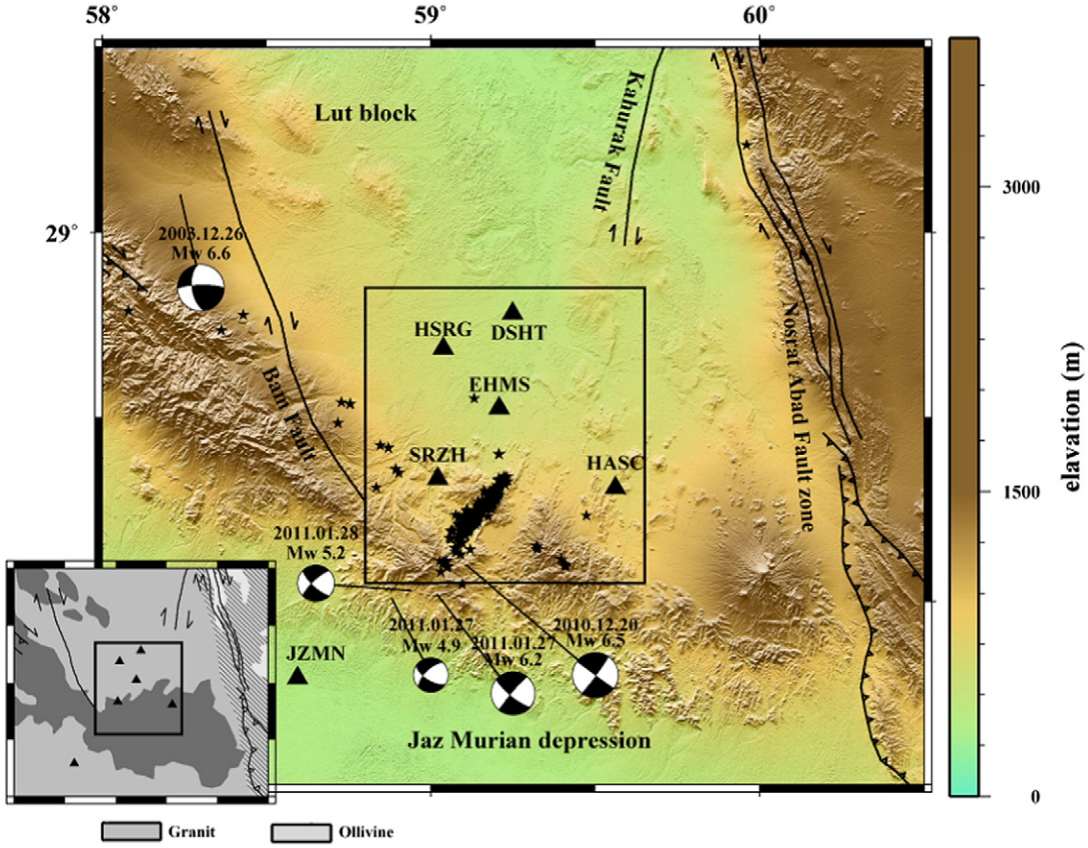

Fig. 1. Maps of the Rigan area showing the locations of IRSC seismic temporary stations used in this study, which are marked with black triangles. In addition, the central black box (or the bottom left map) indicates the study area. The focal mechanisms of the first ($\mathbf{M}_W$ 6.5) and second ($\mathbf{M}_W$ 6.2) mainshocks and their corresponding largest aftershocks were obtained by Global Centroid Moment Tensor (Global CMT) catalog (available at http://www.globalcmt.org/CMTsearch.html, last accessed May 2016). Aftershocks, relocated by Rezapour and Mohsenpur (2013), are plotted by black stars, and known active faults are shown by black solid lines.

a catastrophic and massively destructive earthquake in Bam occurred on 26 December 2003 (M_W 6.6; see Fig. 1).

In the past few years, extensive research has been performed on retrieving inter-station EGF using ambient seismic noise, and calculating corresponding dispersion measurements. Moreover, vertical and transverse components of shear wave velocities can be actually obtained from these calculated dispersion curves. The reliable discrepancy of vertical and transverse components of shear wave velocities, which is defined as anisotropy, provides valuable information about the nature and distribution of the solid earth deformation. This approach has been widely used to map the radial anisotropy on local (Shirzad and Shomali, 2014), regional (Moschetti et al., 2010; Guo et al., 2012; Xie et al., 2013; Jaxybulatov et al., 2014) and global (Becker et al., 2008) scales. Studies were conducted to investigate the hidden part of the Kahurak fault, from the re-location of aftershocks (Rezapour and Mohsenpur, 2013) to earthquake clustering (Walker et al., 2013). Shirzad et al. (2013) also obtained 2-D group velocity maps using ambient seismic noise and aftershocks recorded at period band of 1–7 s for the Rigan region.

The main goal of this study is to continue Shirzad et al. (2013) work to study near surface seismic radial anisotropy beneath the hidden part of the Kahurak fault utilizing separate inversions of the Rayleigh and Love wave group velocity dispersion curves calculated from ambient seismic noise method and aftershock signals record from temporary stations. For the purpose, we should firstly address three problems in our analysis including: (1) producing suitable path coverage database, (2) extracting optimum Rayleigh and Love empirical Green's functions (EGFs), and (3) obtaining group velocity dispersion curves for each geographic grid knot-point. Some of these problems were not completely addressed in the previous study by Shirzad et al. (2013).

2. Dataset

Ambient seismic noise data used in this study are from temporary seismic stations in the Rigan region installed by Iranian Seismological Center (IRSC) denoted by black triangles in Fig. 1. The temporary stations are equipped with the Trillium-40 seismometer sensor. The data were recorded with sampling rate of 100 sps on three components from 23 December 2010 to 6 January 2011. Total number of inter-station ray paths are computed using the formula $n \times (n\text{-}1)/2$, where n is the number of stations which is six for the current database. Therefore, to obtain suitable path coverage, we used records of >40 aftershocks of the first event, $M_N > 2.0$ with average horizontal uncertainty <1.0 km located in upper 4.0 km of the crust. More quantitative discussion of influence of path density on radial anisotropy are given in Sections 4.1 and 4.2. The aftershocks were re-located by Rezapour and Mohsenpur (2013) using the location software HYPOINVERSE (Klein, 1985). The depth uncertainties of the selected events used in this study are <2.0 km (Rezapour and Mohsenpur, 2013).

2.1. Processing steps

To prepare single-station raw data, we divided continuous data to 10-minute time window following Shirzad et al. (2013). To make the computation more efficient, three components of the 10-minute windowed raw data were rotated to obtain vertical (Z), transverse (T) and radial (R) components outlined in Lin et al. (2008). The mean and trend of the rotated 10-minute time window components (R, T, Z) were removed and then decimated to 10 sps. Afterwards, a band-pass filter within the period range of 1 to 7 s was applied following Pedersen et al. (2007). Instrumental irregularities, earthquakes and