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Correlation between Coulomb stress change and Aftershocks Distribution in Sarpol-e-Zahab Earthquake

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ABSTRACT
West of Iran experienced a large earthquake in the 2017 November 12 with moment magnitude of 7.3. This event killed about 500 people and caused vast damages in the region. We calculated the static Coulomb stress changes due to this earthquake on the optimally oriented faults to investigate correlation of transferred stress and spatial distribution of aftershocks.
By using slip model from USGS and catalog of the aftershocks from Iranian Seismological Center (ISC) for Sarpol-e-Zahab earthquake we investigated the correlation between Coulomb stress changes and aftershocks distribution. In this study we selected about 300 aftershocks that had magnitude larger than 2.5 and their azimuthal gap were less than 180 degree. Calculated Coulomb stress changes on the optimally oriented faults showed that most of the seismicity occurred in regions of stress increase and majority of them concentrated on the ruptured plane, especially in west and south parts. So there is a good correlation between Coulomb stress changes and aftershocks distribution of Sarpol-e-Zahab events.

Keywords: Earthquake; Coulomb stress changes, Aftershocks, West of Iran.

INTRODUCTION
The active tectonic of Iran is dominated by the convergence of Arabian and Eurasian plates. Approximately 22 mm/year of this convergence, is accommodated through crustal shortening and thickening by the Zagros Thrust Zone and a part of that is transferred to the Alborz and Kopet Dagh Thrust Zones in the Northern Iran (Vernant et al., 2004). The November 12, 2017 Sarpol-e-Zahab earthquake occurred along the northwestern part of the Zagros Thrust Zone near the political boundary between Iraq and Iran and caused hundreds of deaths and thousands of injuries and building damages and collapses, especially in Kermanshah province of Iran.
In recent years, many seismology scientists worldwide have focused on coulomb stress triggering and the correlation between the mainshock and subsequent aftershocks in an earthquake sequence. Much research on large earthquake sequences has concluded that stress changes from the mainshock affect the locations of subsequent aftershocks (Sumy et al., 2011). The coulomb stress triggering theory has been proposed for evaluating aftershock hazards after great earthquakes. This theory implies that Coulomb stress changes due to a mainshock can promote nearby faults closer to failure stress and trigger the occurrence of some aftershocks. It was thought that small Coulomb stress changes can alter the likelihood of earthquakes on nearby faults (Reasenberg and Simpson., 1992).
The objective of this study is to calculate the Coulomb stress changes due to Sarpol-e-Zahab earthquake on the optimally oriented thrust faults for investigating correlation between Coulomb stress changes and aftershocks distribution.

SEISMOTECTONIC SETTING AND STUDIED EARTHQUAKE
Continental collision along the Zagros suture resulted from the longlasting convergence of the Arabian plate toward Eurasia and has provided the essential force raising the Zagros Mountains and uplifting the Iranian plateau. The collision was initiated at ∼35Ma and continued to the final stage at∼12Ma (Madanipour et al. 2013). The main Zagros reverse fault (MZRF) and the main recent fault (MRF) in south and north Zagros, respectively are the major faults that take up ∼10 mm yr−1 of oblique convergence in Zagros (Vernant et al. 2004).
At 21:48' (local time), on November 12, 2017, a strong quake of magnitude 7.3 struck the region west of Kermanshah city (within Zagros structural domain), in western Iran. The parameters of this event based on different references are summarized in Table 1. Solaymani Azad et al. (2017) undertook InSar imagery and interferometry analysis and active tectonic field studies to assess the causative fault and the probable co-seismic surface faulting. Their preliminary assessment highlighted the concentration of the secondary order co-seismic geological features on the hanging wall of the mountain front fault (MFF), close to the high Zagros fault (HZF) zone.

Table 1. Parameters of the Sarpol-e-Zahab earthquake. Location are from ISC and fault parameters are from USGS.

Lat. (°)	Lon. (°)	Depth (km)	Length (km)	Width (km)	Moment ($*10^{27}$) dyne.cm	Strike (°)	Dip (°)	Rake (°)
34.77	45.76	18	85	72	1.2	352	16	138

After the Sarpol-e-Zahab event (Mw 7.3) more than 300 aftershocks (Mn ≥2.5 and azimuthal gap less than 180 degree) had been recorded by permanent networks of the Iranian Seismological Center (IRSC) at the Institute of Geophysics of Tehran University during 80 days (Figure 1). These aftershocks are reliable in latitude and longitude (epicenter) but error of their depth are high.

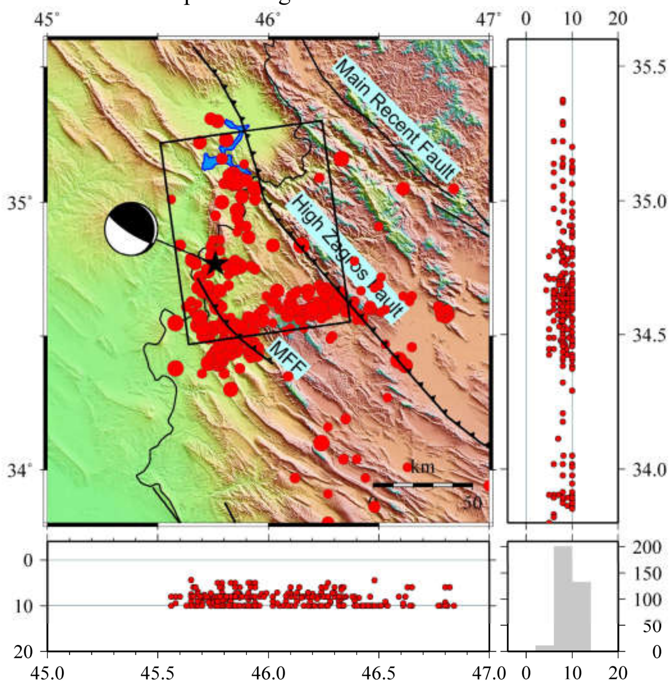

Figure 1. Main tectonic features of study area. Location (black star from ISC) and focal mechanism of the Sarpol-e-Zahab earthquake (from USGS) with epicenter of about 300 aftershocks (red circles) from ISC are shown. Faults are from Hesami et al. (2003). The solid black regtangle shows the surface projection of slipped plane.

THE COULOMB STRESS TRIGGERING HYPOTHESIS

The permanent deformation of the surrounding crust is the consequence of an earthquake fault rupture. Such an earthquake changes the stress on nearby faults as a function of their locations; geometry and sense of slip (Toda et al., 2011). The Coulomb Failure Function ΔCFF, which is the Coulomb stress changes, depend on both changes in shear (Δτ) and normal stress (Δσ), and calculated as follow.

$$\Delta CFF = \Delta\tau + \mu'\Delta\sigma \quad (1)$$

Where μ´ is the apparent coefficient of friction which includes the unknown effect of pore pressure change as well (King et al., 1994). Positive ΔCFF promotes failure, and negative inhibits it (Toda et al., 2011).

COULOMB STRESS CHANGES ON THE OPTIMALLY ORIENTED FAULTS

We used Coulomb 3.4 software to calculate the coseismic static stress changes due to Sarpol-e-Zahab earthquake on the optimally oriented faults. Moreover, the Earth was assumed as a homogeneous elastic half-space and fault were considered as rectangular dislocations embedded within it. In order to consider these assumptions in our calculation, Young modulus, shear modulus, Poisson ratio, and coefficient friction were considered equal to 8×10^5 bar, 3.2×10^5 bar, 0.25, and 0.4, respectively.

For this purpose in addition to parameters describing fault geometry (e.g., location and dip angle) and elastic properties of the material, an estimate of the amount of slip on the fault and regional stress field is necessary to model the Coulomb stress changes on optimally orientations. So we need the slip model of the earthquake and regional (tectonic) stress. Here, we choose a variable finite fault model that was inverted from Global Seismic

Network (GSN) broadband waveforms by USGS (Figure 2). In this model distribution of the amplitude and slip direction for subfault elements of the fault rupture model are determined by the inversion of teleseismic body waveforms and long period surface waves. Based on Zarifi et al. (2013) weighted average azimuth of compression axis based on focal mechanisms stress inversion, seismic strain rate and geodetic strain rate for this region is about 45.92 degree.

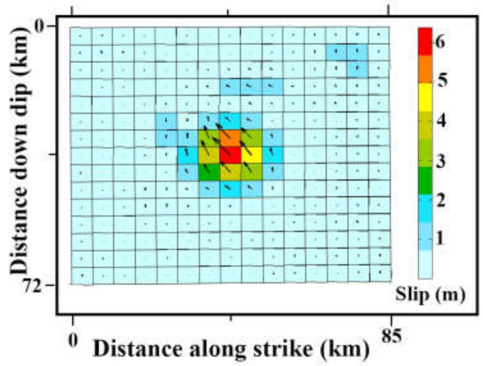

Figure 2. The finite fault model of the M 7.3 Sarpol-e-Zahab earthquake. It is subdivided in 15 patches along the strike and 15 patches along the dip. The black arrows within each patch represents the slip direction. The bar on the right indicates the slip amount of each patch.

We calculated Coulomb stress changes due to this event on the optimally oriented thrust faults (Figure 3) and observed that most of the seismicity occurred in the ruptured plane especially its west and south edge where the stress changes are positive and imparted stress on the optimally oriented faults had been increased. So there is a good correlation between Coulomb stress changes due to 12th November 2017 and location of its aftershocks until 31th January 2018 during 80 days.

CONCLUSION

To investigate a probable correlation between sarpol-e-Zahab earthquake and seismicity we used more than 300 aftershocks (Mn ≥2.5 and azimuthal gap less than 180 degree) during 80 days. For this purpose we used variable-slip model (Figure 2) for this earthquake. Our computation showed that most of the seismicity occurred in the ruptured plane especially its south edge where the stress changes are positive and imparted stress on the optimally oriented faults had been increased and few of them located in the places that Coulomb stress changes are negative (Figure 3).

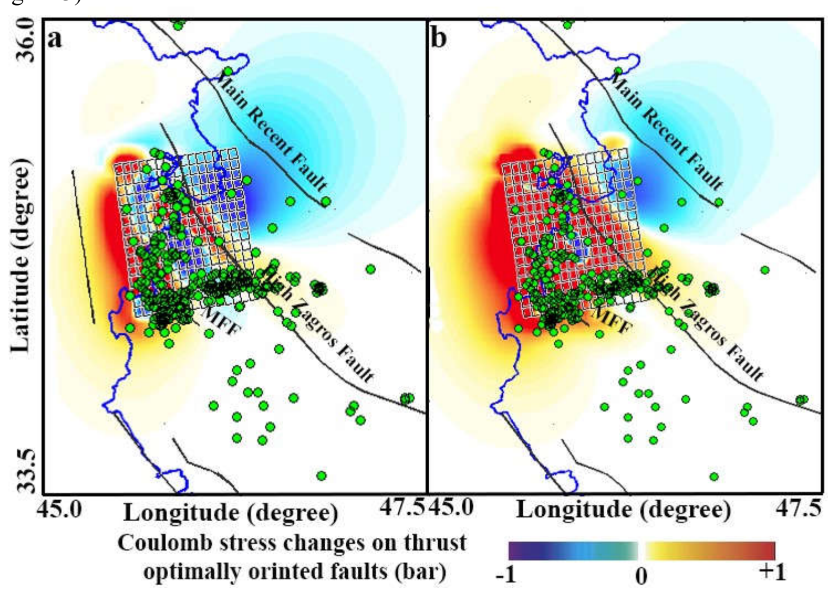

Figure 3. Coulomb stress changes and seismicity. a) Coulomb stress changes due to Sarpol-e- Zahab earthquake on the optimally oriented thrust faults. The calculation had been computed in 7.5 km depth and aftershocks are shown with green circles. b) Maximum resolved stress changes on optimally oriented thrust faults due to Sarpol-e-Zahab earthquake for depth range of 0.0-20.0 km and distribution of aftershocks (green circles) that occurred until 31th January 2018 during 80 days.

As a result, aftershock location of the Sarpol-e-Zahab earthquake, correlate well with areas of increased Coulomb stress changes following the mainshock. Majority of seismicity concentrated near the ruptured plane where the stress changes are in the positive values.

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