Strong Motion Records in Sarpol-e-Zahab Earthquake

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ABSTRACT

In this study, seismological aspects of the 2017 Sarpol-e Zahab earthquake has been investigated. The Sarpol-e Zahab earthquake, of magnitude 7.3 (Mw), occurred in southwestern Iran on November 12, 2017. Here, we investigated the properties of the strong ground motions of the earthquake using the records provided by Iranian Strong Motion Network (ISMN). At Sarpol-e Zahab (SPZ) station, about 30 km south of the epicenter, the recorded peak ground acceleration (PGA) and peak ground velocity (PGV) in both horizontal and vertical components were remarkably large, and visual inspection of the velocity time history reveals a pulse-like shape. Besides, the response spectra of the recordings were determined and were compared to the 2800 seismic code spectrum. Furthermore, the earthquake engineering parameters for this earthquake were estimated and were compared with the values of other large destructive earthquakes in Iran. Finally, based on the recorded strong motion data and observed information such as the macroseismic intensity, ShakeMaps of this earthquake have been generated, which clearly shows the most affected areas that needed the immediate assistance and aid after the earthquake. These maps are fundamental for earthquake rapid response procedures and the earthquake crisis management.

Keywords:
Sarpol-e Zahab; Strong motion; Response spectra; Shakemap

1. Introduction

On Sunday November 12, 2017, at 18:18:16 UTC, (21:48:16 local time), a strong earthquake with Mw 7.3 occurred in the border region between Iran and Iraq in vicinity of the Sarpol-e Zahab town. This earthquake is the largest seismic event after the M 7.4, 1909 AD Silakhor earthquake near the Borujerd city in the Zagros region. The historical earthquake of 958 AD, with a magnitude of 6.8, caused the destruction of Sarpol-e Zahab town and many deaths. The main earthquake of November 12, 2017 was preceded by a number of foreshocks, where the largest one was a magnitude 4.5 event 43 minutes before the mainshock that warned the local residence to leave their home and possibly reduced the number of human casualties. Iranian Seismological Center (IRSC) reported the epicenter coordinates of the earthquake at 34.77 N and 45.76 E with a focal depth of 18.1 km. This earthquake has been recorded by 113 strong motion stations of Iran Strong Motion Network (ISMN) of Road, Housing and Urban Development Research Center (BHRC) in the western and central provinces. The maximum recorded acceleration of this event was recorded at Sarpol-e Zahab (SPZ) station with acceleration of about 681 cm/s2. Unfortunately, this catastrophic event caused 620 causalities, thousands of injured

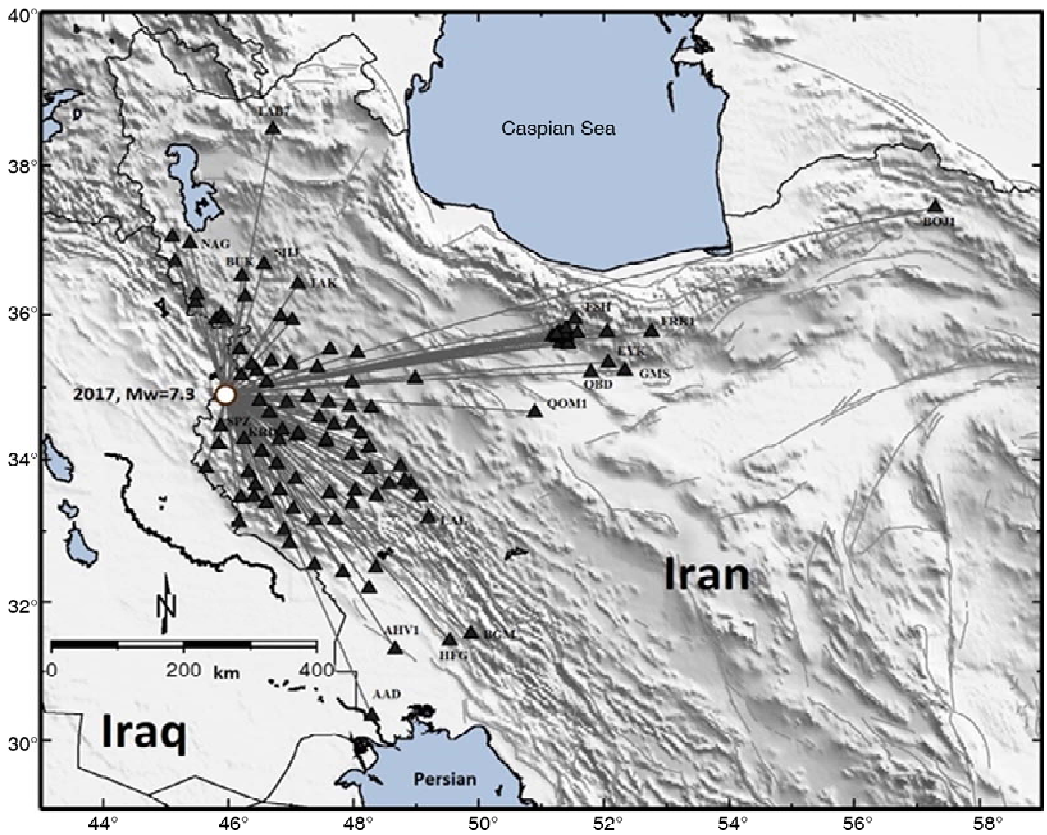

Figure 1. Map of the recording stations of the Sarpol-e Zahab earthquake. The Iran strong motion stations of BHRC are shown by the triangle and the epicenter is shown by circle.

and vast amounts of damage to the buildings, houses and infrastructures in the epicentral area. It destroyed two cities and more than 70 villages. The focus of the earthquake was located about 15 km south of Ezgeleh and about 10 km north of Sarpol-e Zahab in the Zagros seismotectonic zone. The area is surrounded by branches of the active faults. The mainshock of the event was so strong that it was felt in the entire western and central provinces of the country and in some areas such as the cities in the Lorestan, Ilam, Kurdistan and East Azarbaijan provinces, people were terrified and leaved their homes.

1. The Recorded Strong Motion Data of the Sarpol-e Zahab Earthquake

This earthquake has been recorded by 113 strong motion stations (by SSA-2 and Guralp CMG5TD instruments) across the country. Figure (1) shows the location of the strong motion stations that recorded the mainshock. Figure (2) shows the instruments at the Sarpol-e Zahab station (SPZ and SPZ1). Figure (3) provides the detail of the recorded accelerograms acquired from these stations. The CMG-5TD accelerometers recorded this event with sampling frequency of 200 samples per second continuously. One of the most interesting points in this event is the fact that the earthquake was felt in very large distances; therefore, the majority of stations that were equipped with CMG-5TD accelerometers were triggered by this event and recorded the earthquake acceleration. Among them,

Figure 2. Sarpol-e Zahab station (SSA-2 permanent instrument along with the temporary CMG-5TD instrument).

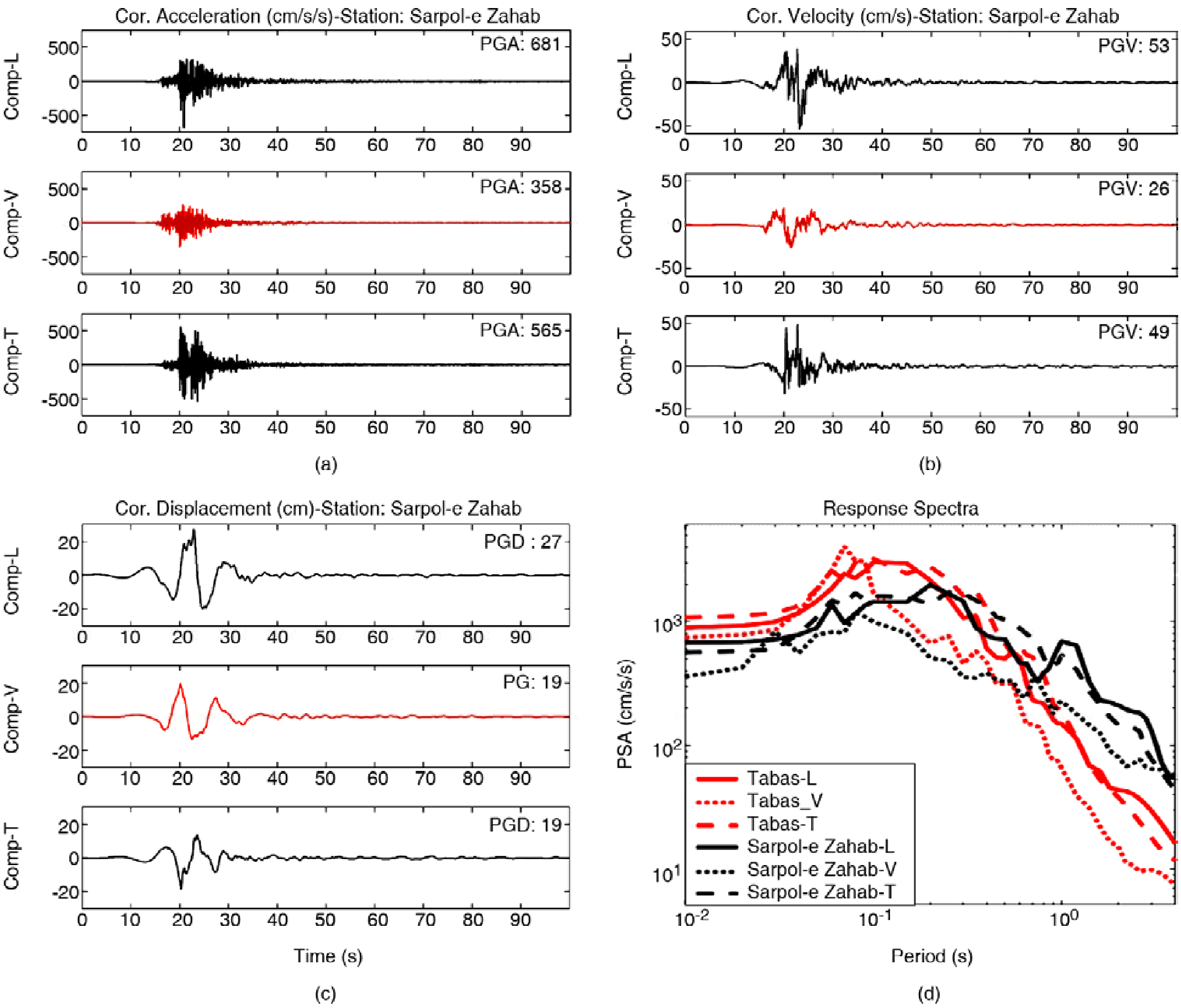

Figure 3. (a) Recorded acceleration time history, (b) Recorded velocity time history, (c) Recorded displacement time history, and (d) Acceleration response spectra at Sarpol-e Zahab station at about 40 km epicentral distance.

we can refer to the recordings at Bojnord station in North Khorasan (Bojnord University station, at distance of about 1063 km) and recordings registered at Damavand, Fasham, Mosha, Qom and most stations in Tehran with a distance of more than 500 km.

SPZ station was the nearest station to the epicenter of the earthquake at a distance of about 39 km (epicentral distance). This station has been installed as a free field station at the site of the Sarpol-e Zahab Governor's building (Figure 2). The peak ground acceleration (PGA) on horizontal and vertical components are about 684, 553 and 385 cm/s^2 respectively (uncorrected data). The recorded acceleration time series at SPZ station were processed with a band-pass filter. The results of the filtering process indicates the corrected PGA of 681 cm/s^2 on the longitudinal component, 385 cm/s^2 on the vertical component and 565 cm/s^2 on the transverse component. The dominant period on the longitudinal, vertical and transverse components are 0.22, 0.08, and 0.3 s respectively. The significant duration of this record is about 11 second. This means that the maximum energy of the earthquake has been released in 11-second in the epicentral area.

Figure (3a) shows the recorded acceleration time histories of the SPZ station. The time difference between the first P- and S-wave arrivals recorded at this station is about 5.13 s, which indicates that the distance between the hypocenter and this station is about 35 to 41 km. Figures (3b) and (3c) show the recorded velocity and displacement time histories of the SPZ station. The velocity components clearly show the existence of the long period signal, especially on the transverse component of the velocity time histories (see Figure 3b). It is noteworthy that, there are two clear pack of energy in the recorded time histories of the Sarpol-e Zahab, Kerend and some other stations (such as Noosud, Palangan, Marivan and ...) that possibly indicates two sequential failures or two simultaneous seismic events, which requires further investigations. Note that, all recordings were filtered using a band-pass filter and their acceleration, velocity and displacement time histories along with their response spectra were extracted.

3. Epicenter Location and Moment Magnitude Based on Strong Motion Data

As the number of recorded accelerograms has well registered the first P- and S-wave arrival, we were able to determine the epicenter location and the moment magnitude of this event (Figure 4). Based on the 10 recorded accelerograms, the epicenter of this earthquake is determined at 34.81 N and 45.91 E.

Moreover, the moment magnitude (Mw) is determined from the seismic moment (M0), which is calculated through spectral method that is based on the Brune source model [1-2] in the frequency domain. In this method, M0 is calculated based on the value of the low frequency plateau and then Mw is calculated using the following equation [3]: $Mw = 2/3 \log 10 (M0) - 6.03$ where the scalar moment, M0, is the seismic moment in N.m. Those strong motion data recorded by ISMN stations that are located in epicentral distance of less than 100 km were selected. The earthquake ground motion that has been recorded by these 10 closest strong motion stations provided the good quality of the recordings and all 10 three-component recordings were used in the calculation of the Mw. The calculated Mw values for each station, along with other relevant records information are available in Table (1). The final estimated Mw is determined based on the average of the Mw values at 10 closest stations (R < 100 km), which is Mw = 7.3.

4. Aftershocks

After the main earthquake, five stations were installed in the macro-seismic area for more precise seismic monitoring. Three 24-bit instruments were installed in Sarpol-e Zahab, Ghasr-e Shirin, and Gilan-e Gharb city, and two SSA-2 instruments were installed in Ezgeleh and Sarable. These stations

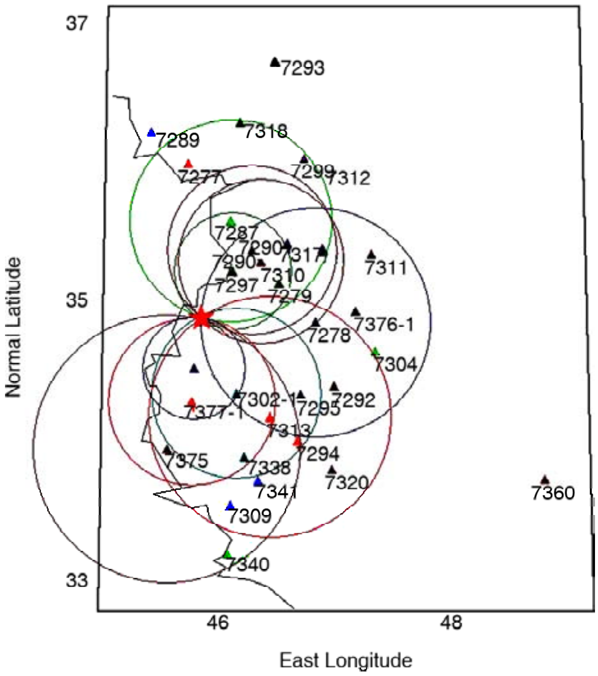

Figure 4. Epicenter location determination using the recorded accelerograms.

Table 1. The calculated Mw for each station along with other relevant record information.

	Record Number	Station	Station Latitude	Station Longitude	Epicentral Distance (km)	Mw	M0
1	7278	Kamyaran	34.791	46.928	94.09	7.11	6.60E+19
2	7290	Sarv Abad	35.311	46.369	67.70	7.07	4.44E+19
3	7310	Degaga	35.226	46.447	65.89	7.25	8.33E+19
4	7297	Nosood	35.161	46.203	45.26	7.03	3.94E+19
5	7279	Palangan	35.067	46.605	69.16	7.25	8.35E+19
6	7384-1	Sarpolezahab	34.459	45.868	42.35	7.47	1.77E+20
7	7377-1	Goorsefid	34.218	45.845	69.23	7.56	2.47E+20
8	7302-1	Kerend	34.279	46.24	69.66	7.52	2.12E+20
9	7313	Eslamabadqarb	34.11	46.529	99.53	7.67	4.56E+20
10	7317	Shoeisheh	35.358	46.677	91.32	7.29	9.57E+19
			Average			**7.33**	**1.12E+20**

were added for more accurate recording of the future seismic activities and aftershocks in the following years.

After the mainshock until 17/11/2018, 652 three-component waveforms from 401 event (aftershocks) have been recorded by the ISMN, BHRC, as shown in Figure (5). The most important aftershock happened on 2018/08/25 close to the Salas-e Babajani (SLS2) area with Mw 6, which has been recorded by 27 ISMN stations (https://smd.bhrc.ac.ir/Portal/en/BigQuakes/Details/151). Although the observed PGA was 781 cm/s^2 and was larger than the PGA of the mainshock (681 cm/s^2), its observed PGV is 34 cm/s and lower than the mainshock. Accordingly, it shows that the energy of the aftershock is smaller than the mainshock which is expected.

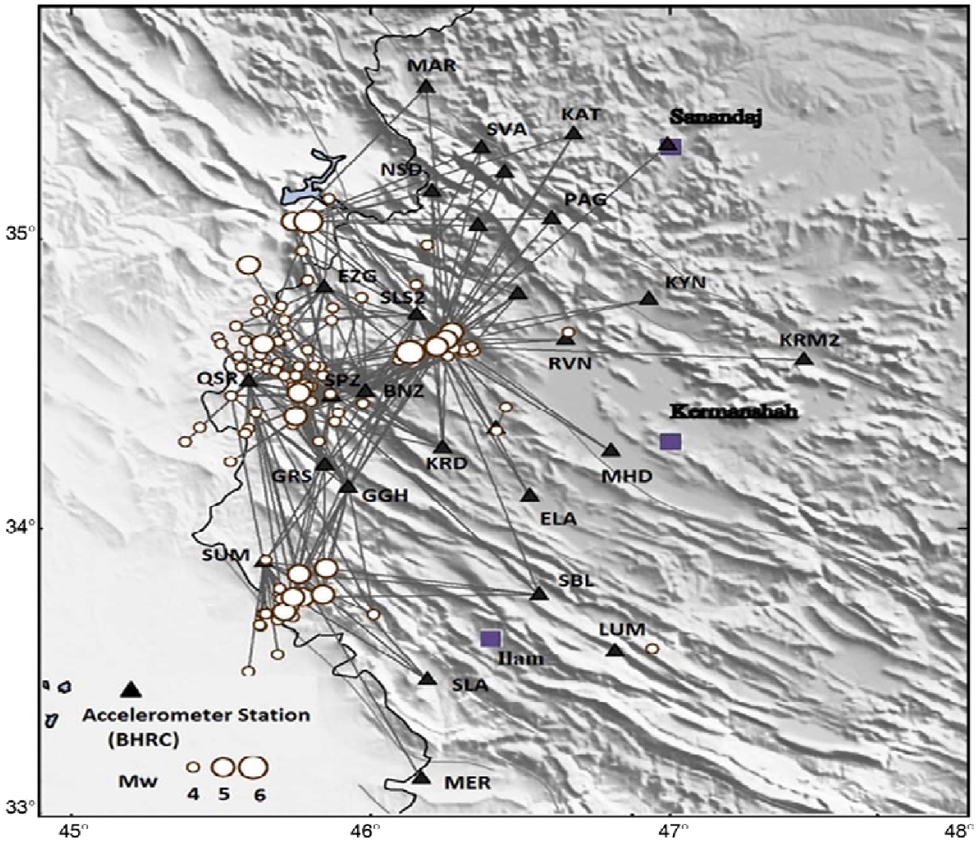

Figure 5. The map of aftershock event that have been recorded by the strong motion network, BHRC. Events with magnitude larger than 4 are shown by the circle and the strong motion station of BHRC are shown by triangle.

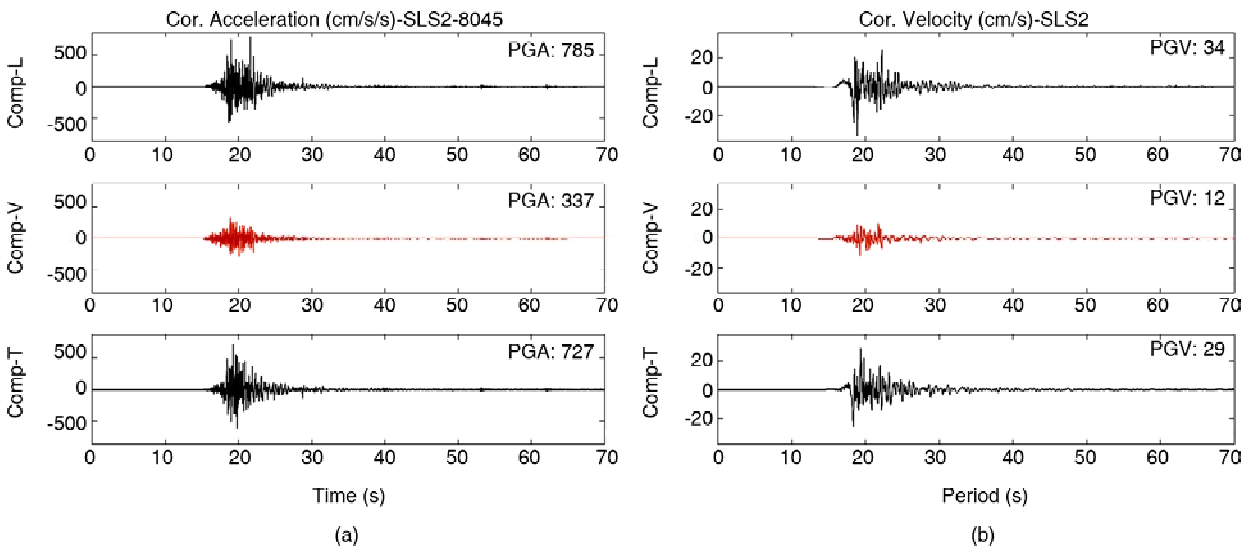

Figure 6. (a) Recorded acceleration time history of the 2018/08/25 aftershock event with Mw 6 at SLS2 station at about 14 km epicentral distance, and (b) Recorded velocity time history at SLS2 station.

5. Earthquake Engineering Parameters

In Figure (7), the comparisons of the observed PGA and PGV recorded in this earthquake with the ground motion prediction equations (GMPEs) presented by Boore et al. [4] (BSSA2014) are shown. As it can be seen, SPZ station recorded a close acceleration value relative to the predicted mean value. The distance mentioned in these figures is a minimum distance of station to the surface projection of the fault plan (Rjb). It is noteworthy that both observed acceleration and velocity parameters are close to the predicted mean values by the GMPEs at the nearest station (SPZ) and the farthest station (Bojnord), which shows that these relations provide acceptable solutions for estimation of the PGA and PGV values in the region. These values are very important for use in seismic hazard procedure and ultimately play a vital role in reducing the earthquake risk.

In Figure (8), the spectral responses of the SPZ and Kerned (KRN) records are shown in comparison to the 2800 code spectrum. In Figure (8), the response spectral acceleration is clearly above the 2800-code range in short period. Besides, in the range of about 1 second, along period pulse is observed that is due to the effect of the earthquake directivity from the hypocenter to the city of Sarpol-e Zahab.

The significant difference between the spectra of the SPZ and the 2800 seismic code can be explained

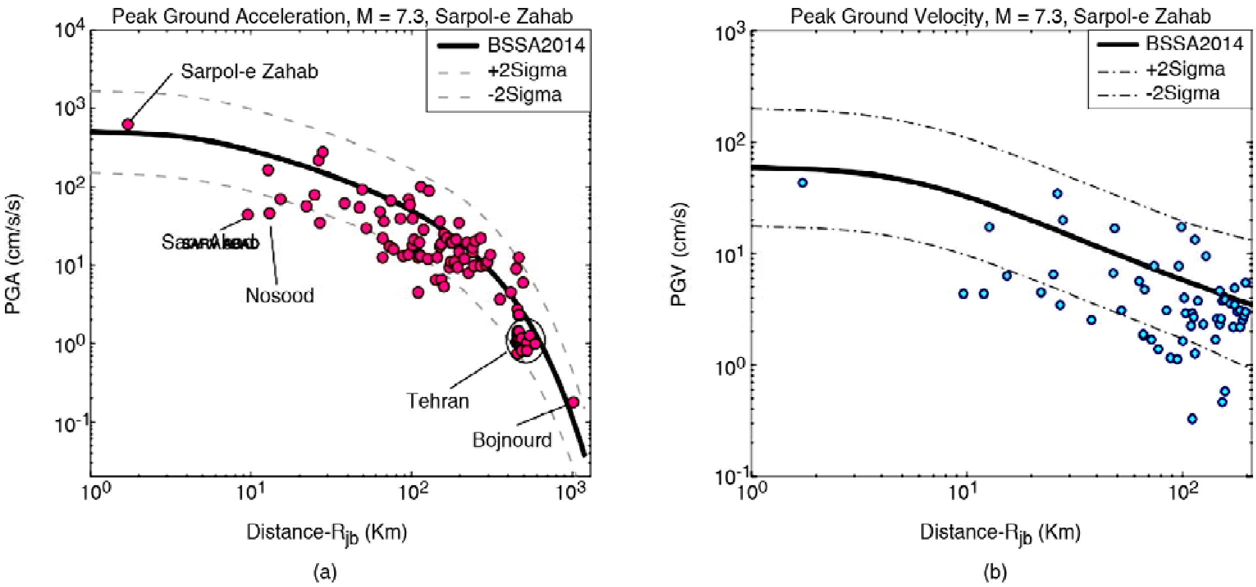

Figure 7. Comparison of observed PGA (a) and PGV (b) with the BSSA2014 GMPE.

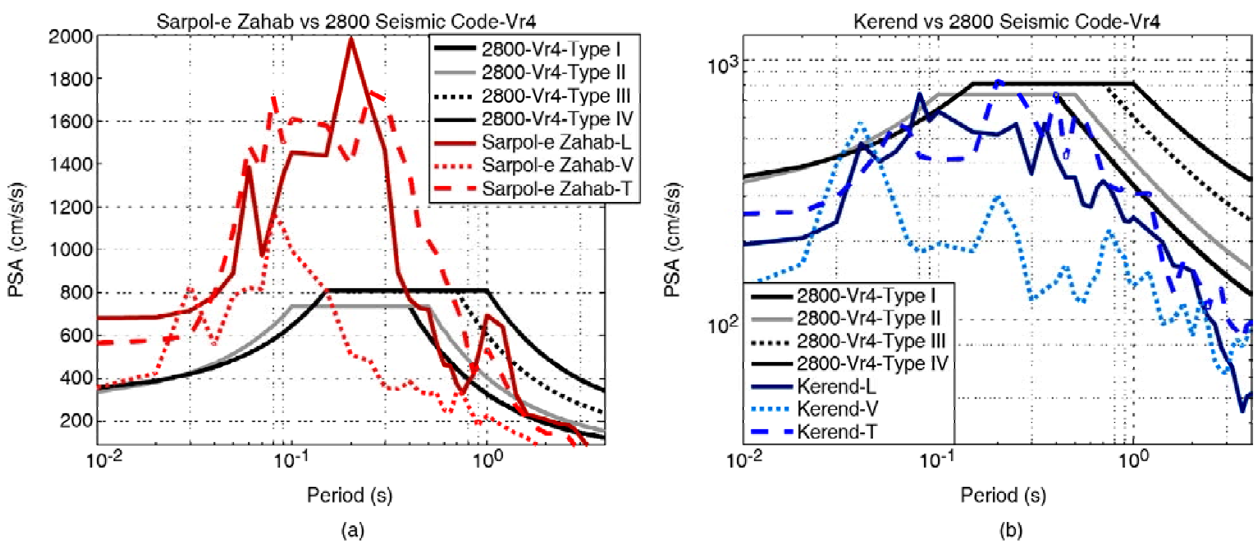

Figure 8. Comparison of response spectra of SPZ (a) and KRN (b) records with 2800 seismic code.

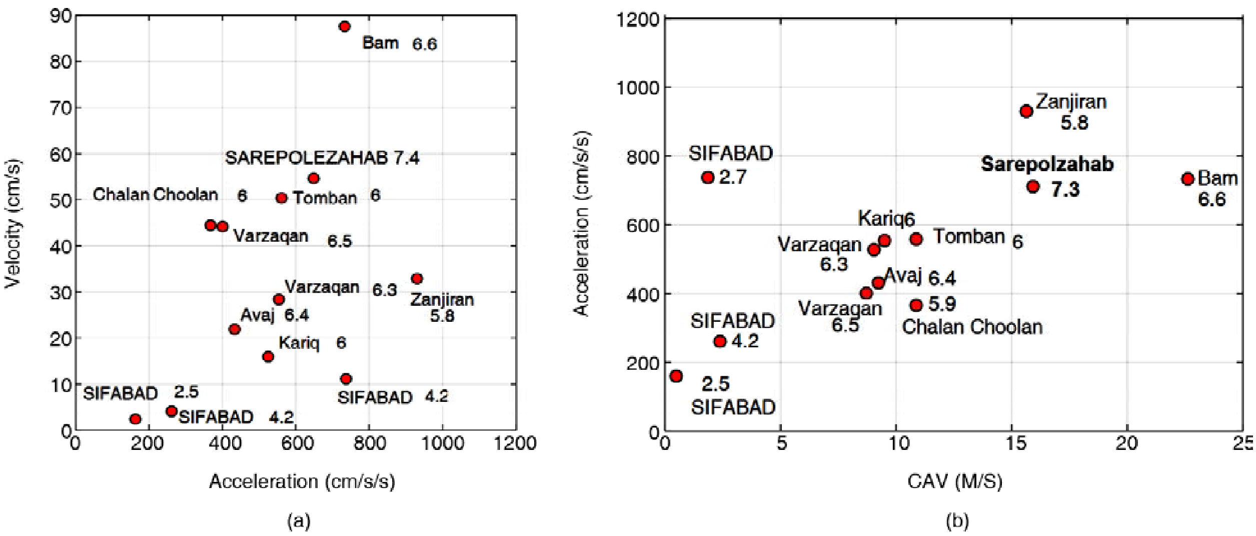

Figure 9. Comparison of engineering parameters of Sarpol-e Zahab earthquake with other major events in Iran.

by the difference in the return period of these two spectra. The response spectrum in 2800 seismic code regulations is suggested for the return period of 475 years (10% in 50 years), while the return period of Sarpol-e Zahab earthquake is about 1000 years, according to the historical events [5]. This fact to some extent explains the observed damage of the buildings and the infrastructures.

Regarding the extent of the damage and fatalities of the Sarpol-e Zahab earthquake, a comparison was made between the engineering parameters of this event and other large destructive events in Iran such as the Mw 6.6 2003 Bam earthquake, Mw 6 2007 Chalan-Choolan event, Mw 6.5 2012 Ahar-Varzaghan event, and some other major earthquakes, as shown in Figure (9). For example, although the magnitude of the earthquake is larger than the Bam earthquake, it had fewer casualties and financial losses. In Figure (9), it is clear that the engineering parameters of this earthquake were less than the Bam earthquake according to the greater depth of the earthquake, as well as the station's distance to the hypocenter.

As mentioned before, a 24-bit CMG-5TD instrument was installed in the city of Sarpol-e Zahab just two days after the mainshock, which is collocated with a SSA-2 instrument, and they both recorded the small and large aftershocks following the mainshock. In Figure (10), the comparison of the waveforms recorded by these collocated instruments has been shown for one of the large aftershocks at SPZ station, on 2018/04/01 08:35:25

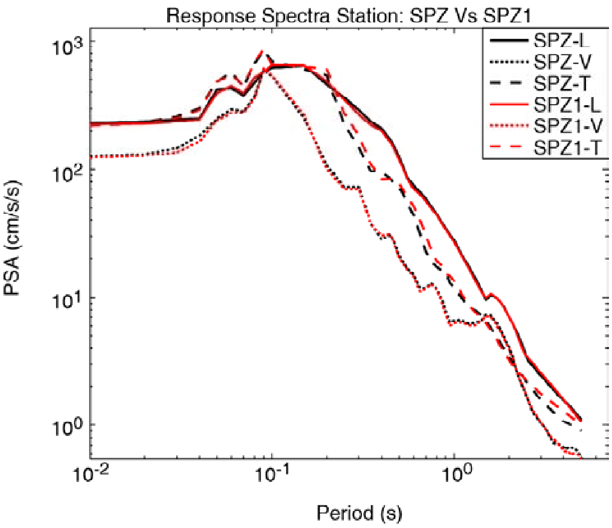

Figure 10. Comparison of response spectra of SPZ (SSA-2) and SPZ1 (CMG-5TD) records during the Mw 5.2 aftershock on 2018/04/01.

with Mw 5.2. Figure (10) shows that the difference between the recordings of the same event is less than 3%, due to the fact that the 24-bit device and the 11-bit device have been operating properly during this aftershock.

6. ShakeMaps

According to the strong motion records at ISMN stations and the macroseismic intensity, ShakeMaps of the Sarpol-e Zahab earthquake have been generated and are shown in Figure (11a). The data used to produce the ShakeMap are collected by 113 strong-motion records around the epicenter and are improved with macroseismic intensity data of 45 places based on the observed

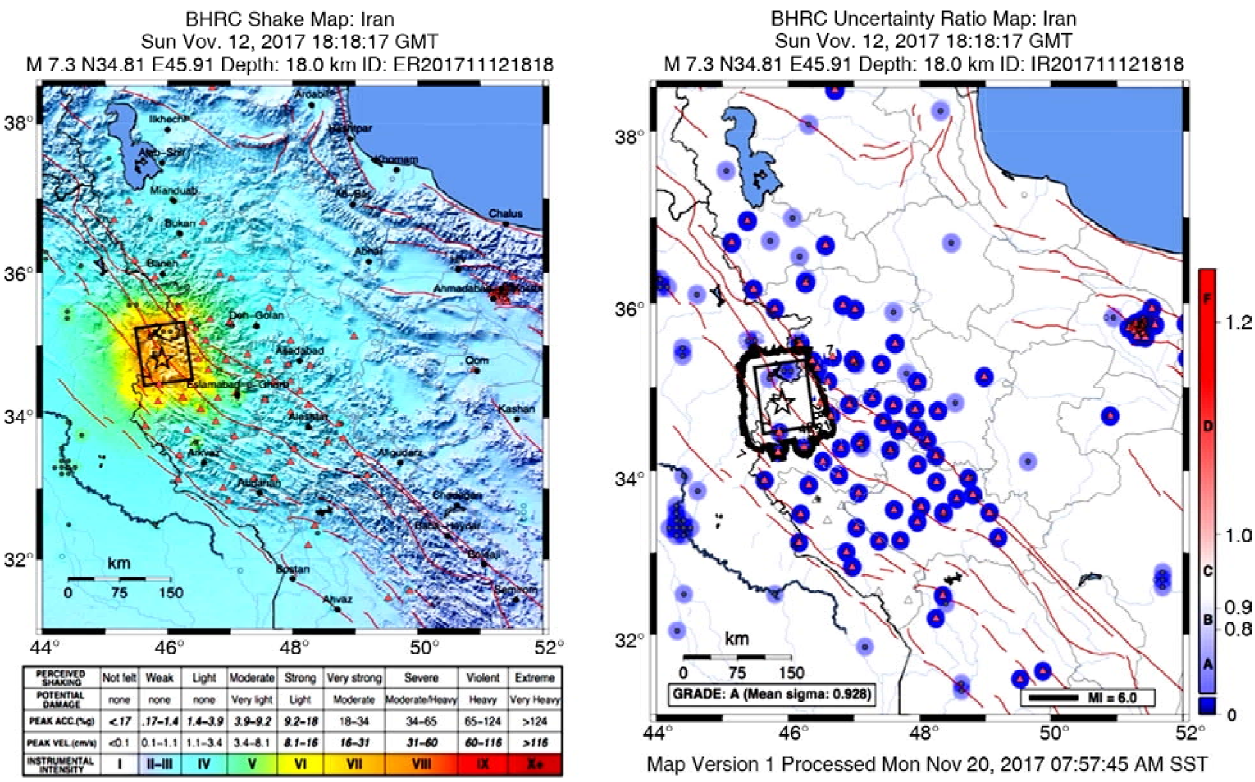

Figure 11. ShakeMap of Sarpol-e Zahab earthquake (a) and the uncertainty of the ShakeMap (b).

effects of ground shaking on people and buildings. The area of variant intensities is divided using the collection of each contour. The annotation number of contour levels corresponds to a modified Mercalli scale.

For easy evaluation of the uncertainty of a ShakeMap, a color-coding map was introduced by Wald et al. [6-7] and Worden et al. [8]. The average value and the corresponding letter grade on the scale on the right side is displayed on the bottom left of the uncertainty map (Figure 11b). Besides, the area of intensity of VI or higher, over which the average uncertainty is computed, is shown with a bold black line. The derived ShakeMaps indicate that the instrumental intensity is in strict conformity with macrosesismic intensity.

7. Conclusions

This study has investigated the 2017 Sarpol-e Zahab earthquake using seismological aspects, and the study and process of the strong-motion data recorded by ISMN stations. A regional strong-motion network consisting of 113 strong-motion stations (SSA-2 and CMG5TD Accelerographs) located within 39-1026 km from the epicenter, recorded the earthquake.

Although the earthquake magnitude is rather large, the damage level was not high in comparison to the Bam or Manjil earthquakes. This level of damage can be associated with the mid-depth of the earthquake, and the poor engineered construction specifically at the Sarpol-e Zahab city. The highest intensity of shaking VIII (MMI) was observed in the Dasht-e Zahab village. The earthquake was not associated with any significant surface faulting, but with coseismic folding and huge landslide. The source of this shock was reported to have a reverse mechanism initiated in a fault with the northwestern-southeastern direction. The pulse-shaped arrivals of strong signals recorded at the SPZ station suggest that velocity pulses can be identified in fault-normal components by the considerably larger amplitude.

One of the significant points about this event is that the mainshock has been recorded at different stations in vast area, which indicates the uniqueness of this event and for sure requires further specialized studies. Therefore, ISMN has installed a temporary network within the macro-seismic area.

This earthquake had a PGA of about 681 cm/s^2, duration of about 11 seconds near the focus and very wide range of frequency content. The recorded waveforms of the event in some stations (such as

Nosood, Palangan and Marivan stations) shows that at least two fractures have occurred in a very short-time interval in this earthquake. In other words, this event can be interpreted as a multiple event; however, further investigations are suggested. Study of the response spectra at SPZ and Islamabad stations indicates the domination of the long period components, which can amplify the damage to the multi-stories structures (from two to six floors buildings). The effect of the directivity in this earthquake is obvious. The fracture began at a region on the border between Iran and Iraq and moved along the southeast towards the cities of Sarpol-e Zahab and Islamabad. The existence of long period pulses in the record of Sarpol-e Zahab station completely confirms the directivity effect. The record of stations like Bagh-Malek, 400 km away along this path, is an indication of the directivity of the fault fracture. Unfortunately, no other recording stations were located close enough to the fault to capture the directivity pulse

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Most of the Figures were produced using the GMT software of Wessel and Smith [9].

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