Site Investigation of the Sarpole-Zahab Earthquake, Mw 7.3 in SW Iran of November 12, 2017

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Key Facts
- Hazard Type: Earthquake
- Date of the disaster: November 12, 2017
- Location of the survey : Kermanshah Province, Iran
- Date of the field survey: December 24th – 28th, 2017
- Key findings:
  1) The heighest recorded PGA was observed at Sarpole-Zahab station with the shortest epicentral distance of 39 km, with 681 cm/s^2, and 562 cm/s^2 and 404 cm/s^2 for longitude, transverse and vertical components, respectively.
  2) The pseudo spectral acceleration at Sarpole-Zahab station indicates that the predominant ground shaking is with a period of 1sec or less, and there are not many long-period components in the near-fault ground motions. This period range usually affects the two to six stories structures in Iran.
  3) This earthquake triggered massive landslides in the mountainous areas close to Mela Kabood and Goorchi Bashi villages, which located to the north of the Sarpole-Zahab City. The largesst landslide reached an area of 4 km long and 1 km wide.
  4) After the earthquake, three cities of Sarpole-Zahab, Qasre Shirin and Tazehabad and the villages in their territory had 100% power outage.
  5) Thirteen cities of Kermanshah Province were damaged to water supply system, and water was cut for two weeks in seven cities because of water contamination.

Key Words : *the Sarpol-Zahab Earthquake, field investigation, damage to houses and buildings, microtremor measurements, damage to lifelines*

1. INTRODUCTION

On November 12, 2017, at 21:48 local time (18:18 GMT) , an earthquake occurred in 5km from Ezgeleh and 43km north of Sapole-Zahab, Kermanshah Province, on Iran and Iraq border. The epicenter of this event was located at 34.88° north latitude and 45.84° east longitude. This event occurred in Zagros seismotectonic zone and shook the western regions on Iran, especially Kermanshah, Kudistan, Ilam and West Azarbaijan Provinces. The deaths were 620 persons, the number of injured persons was about 7,000 and number of houseless persons was about 70,000.

Earthquake Engineering Lab. of Kanazawa University in Japan and Azarbaijan Shahid Madani University in Iran have decided to dispatch a joint

Table 1 Details of moment tensor solution (IRSC).

Centroid; Lat: 34.77° N, Lon: 45.76° E, Depth: 8 km, Time relative to the origin time (Sec): +5.96

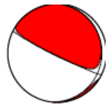
Mw: 7.4, Moment (N.m): 1.366e+20, DC%: 93.4, CLVD%: 6.6, Variance Reduction: 0.51

Nodal Planes; strike: 4°, dip: 10°, rake: 157°

strike: 116°, dip: 86°, rake: 81°

P-axis; azimuth: 215°, plunge: 41° - T-axis; azimuth: 17°, plunge: 48°

Moment Tensor (N.m) ; Mrr: 0.201 , Mtt: 0.035 , Mpp: -0.236 , Mrt: 1.209 , Mrp: -0.572 , Mtp: 0.174 , Exponent :20



reconnaissance team of this earthquake and pointed Prof. Miyajima of Kanazawa University as a team leader. The team has done field investigation between 24th and 28th of December, 2017. This report outlines the findings obtained through the quick survey. Some descriptions in this report are not fully evidenced yet, and therefore, some comments are not yet the conclusions reached after through discussions among the members.

2. SEISMICITY AND EARTHQUAKE

(1) Seismicity

According to the historical earthquake catalogue of Iran gathered by Ambraseys and Melville, the region had been experienced at least two earthquakes in 958 and 1150 AD[1),2)]. In addition, one major event in this region is Farsinaj Earthquake of 13 December 1957, Ms7.1. This earthquake caused heavy damages within an area of 2,800 square kilometers in which 1,119 people were killed and 900 injured and 15,000 left homeless. The Farsinaj Earthquake ruined more than 5000 house units out of 9,000 existed house in the Kermanshah region. Most of the local houses were single-story buildings, and made of mud and adobe materials[3)].

(2) Mainshock and aftershocks

On November 12, 2017, at 21:48 local time (18:18 UTC) a destructive earthquake occurred near the town of Sarpole-Zahab in Kermanshah Province, Western Iran. The earthquake had the moment magnitude of 7.4 as reported by Iranian Seismological Center (IRSC) and Global Centroid Moment Tensor Catalog (GCMT) or 7.3 as reported by United States Geological Survey (USGS). Regarding the event location IRSC seems to have the best estimation since they have used stations near the epicenter. **Table 1** shows the details of moment tensor solution of IRSC[4)]. They report the latitude of 34.77° and longitude of 45.76° and depth of 18 km for the main event. One important foreshock has been reported by IRSC which has occurred at 17:35 UTC (less than an hour before the main shock) with magnitude of 4.4. As of 11 Januaray 2018, there have been 598 aftershocks in magnitude range of 2.5 to 5.4 according to IRSC bulletin[4)].

(3) Seismograpgh

During the Sarpole-Zahab Earthquake, the motion has been recorded on 110 SSA-2 and Gurlap strong ground motion stations of Iran Strong Motion Network (ISMN) which have been installed and maintained by Building and Housing Research Center (BHRC). **Fig. 1a** shows the locations of the stations with epicentral distance shoter than 500 km together with the distribution of the maximum peak ground acceleration (PGA) of two horizontal components. As shown, the highest recorded PGA was observed at Sarpole-Zahab station with the shortest epicentral distance of 39 km, with values 681 cm/s^2, 562 cm/s^2, and 404 cm/s^2 for Longitude (L), traverse (T) and vertical (V) components, respectively. The second highest PGA was recorded at GooeSefid station, which has the epicentral distance of 66 km, and the L, T and V components of the recorded PGA are 309 cm/s^2, 277 cm/s^2, and 233 cm/s^2, respectively. In some acceleration traces (such as Sarpole-Zahab and Nosood in the **Figs. 1b** and **c**), two isolated wave-packets are observed. Although a reliable source model is still not well known, we speculate that these wave-packets can correspond to two strong-motion generation areas (asperities) on the source fault plan. Observations show that the destructions have distributed from earthquake epicenter (red star in **Fig. 1a**) to Sarpole-Zahab, Kerend, and GoorSefid stations in the south, therefore, this is an evidence that the waves were propagated from the north toward the south. To investigate this viewpoint, we have used two acceleration time series recorded in forward and backward directions. In order to decrease the effect of wave attenuation on the results, stations should be considered at roughly the same epicentral distance, hence, Sarpole-Zahab and Nosood (with an epicentral distance of 47 km) where are located in the

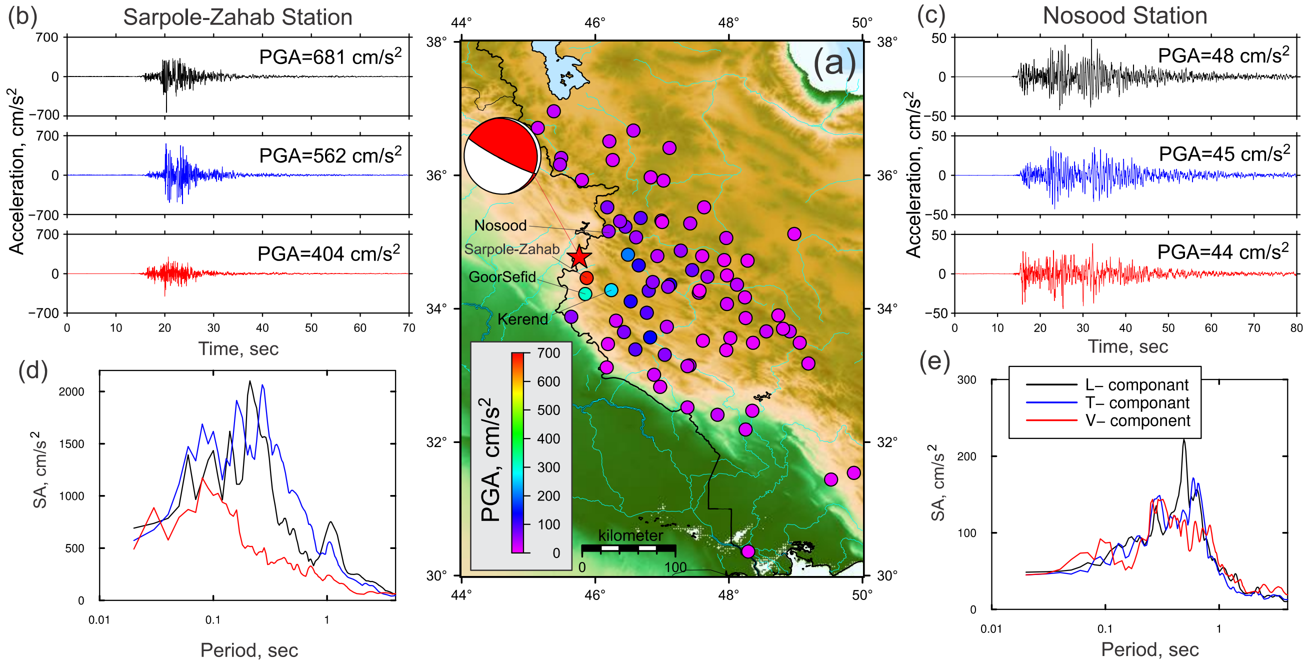


Fig. 1 (a) Locations of the recording stations together with the obtained maximum PGA values of two horizontal components; **(b)** and **(c)** acceleration time series for Sarpole-Zahab and Nosood stations, respectively; **(d)** and **(e)** obtained absolute spectral acceleration for Sarpole-Zahab and Nosood stations, respectively.

south and north of the epicenter, respectively, have been selected. The acceleration traces related to these stations are illustrated in **Figs. 1b** and **c**. It is obvious that Sarpole-Zahab station in forward direction had experienced a much larger PGA than Nosood station in the backward direction. To further examine the fault directivity effect, we compared the significant duration ($D_{5\%-95\%}$)[5] obtained from the acceleration time histories of these stations. As this is expected longer duration (30 sec) was recorded at Nosood station in the backward directivity; in contrast, shorter duration (11 sec) was observed at Sarpole-Zahab station in the forward directivity.

Figs. 1d and **e** show the absolute spectral acceleration (SA) calculated from strong motions recorded at Sarpole-Zahab and Nosood stations, respectively, which were computed at 5% damping. The figures depict that the predominant ground shaking is with a period of 1sec or less, and there are not many long-period components in the near-fault ground motions. This period range usually affects the 2 to 6 stories structures. Also, the peak values of SA at stations in the forward direction are much larger than those in the backward direction, showing a strong rupture directivity effect.

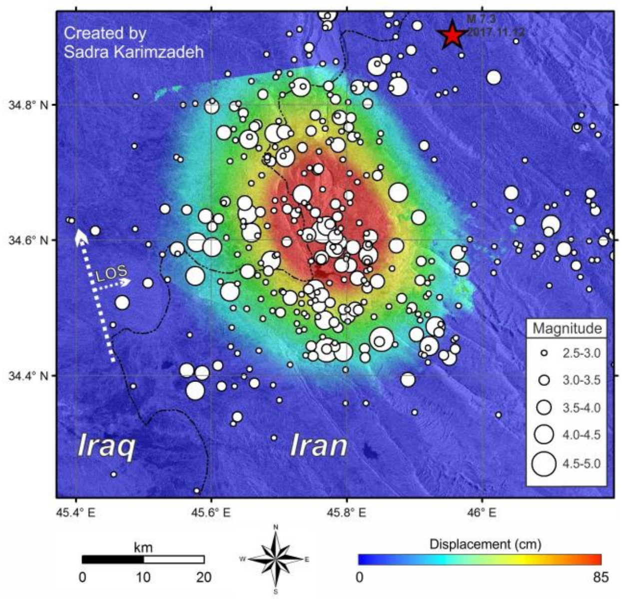


Fig. 2 InSAR unwrapped displacement map of Sarpole-Zahab Earthquake from high-resolution ALOS-2 data indicating maximum 85 cm displacement in the line-of-sight of the satellite. White circles are aftershocks gathered between 2017/11/12 and 2017/12/01 and red star is the main shock in 2017/11/12.

(4) Ground displacement

We calculated ground displacement map of the earthquake using Interferometric Synthetic Aperture Radar (InSAR) method and two ALOS-2 images (2017/10/12 and 2017/11/23) with spatial resolution of 10 m in StripMap mode. The displacement map together with aftershocks (~ 700 recorded aftershocks by Iran seismic network) from 2017/11/12 to 2017/12/1 are shown in **Fig 2**.

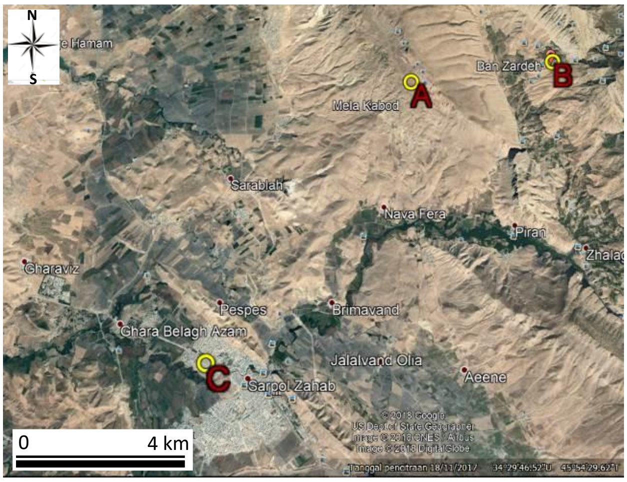


Photo 1 Location of geotechnical damage [6].

3. GEOTECHNICAL DAMAGE

(1) Large scale landslide

During the earthquake, several geotechnical damages occurred in diffeerent locations as can be seen in **Photo 1**. The Sarpole-Zahab Earthquake triggered massive landslides in the mountainous areas close to Mela Kabood and Goorchi Bashi villages, which located to the north of the Sarpole-Zahab City (Point A in **Photo 1**). Landslides that occurred reach an area of 4 km long and 1 km wide. At some points, significant ground subsidence emerged, with a depth varying from 1 m to a maximum depth of 8 m, as can be seen in **Photo 2**. In addition, the gravitational force arising from the sloping soil surface, together with earthquake force, also triggering a lateral ground deformation, where the soil moved downward and creates ruptures on the ground surface with a width up to 1.5 m. According to the information from the residents, the heavy rain that fell two hours after the earthquake deteriorated the situation. Some residential houses were damaged by landslides, as can be seen in **Photo 3**.

(2) Rock fall

Photo 4 shows the rock fall that occurred in Ban Zardeh village, located to the north of the city of Sarpole-Zahab as well (Point B in **Photo 1**). This large rock fall along approximately 1.5 km caused the only road that connecting the Ban Zardeh village with Baba Yadegar tomb which is a famous tourist destination, became inaccessible.

(3) Liquefaction-induced ground deformation

A large ground deformation also found in the

Photo 2 Ground subsidence close to Mela Kabood village

Photo 3 Damaged houses by landslides

Photo 4 Rock fall close to Ban Zardeh Village

Photo 5 Liquefaction-induced ground deformation

Fooladi district-Maskane Mehr, which located within the city of Sarpole-Zahab (Point C in **Photo 1**). This significant ground deformation is most likely induced by liquefaction at the time of the earthquake, which caused the ground surface moved downward. This area is very prone to liquefaction because there is a river that flows in this area. According to the information from the inhabitants, before the earthquake occurred, the government of Sarpole-Zahab City has planned to relocate residents who live in this area due to high groundwater levels here. The ground deformation occurred in the Fooladi district-Maskane Mehr can be seen in **Photo 5**.

4. DAMAGE TO HOUSES AND BUILDINGS

(1) Reinforced concrete buildings

There were a large number of damaged and even collapsed constructions in a few areas of cities such as Sarpole-Zahab. In certain parts of Sarpole-Zahab City, there was considerably severe damage in reinforced concrete (RC) buildings. The observed reasons for the damage to the structural elements of RC buildings were as follows:

(a) Soft story: According to the RC design code of Iran, columns must be at least 20% stronger than beams. However, damaged columns and undamaged beams were observed in numerous damaged buildings. This implies that columns were weaker than beams, and severe damage and collapse occurred as shown in **Photo 6**.

(b) Poor quality concrete material: Multiple cases of damaged RC structures were observed, and this caused concrete damage and failure in these structures (see **Photo 7**).

(c) Improper detailing: 90° hooks instead of 135° hooks of hoop reinforcement of columns was utilized to make confinement in the concrete core (see **Photo 7**). Space interval of hoop reinforcement was not appropriate for confinement at the 1/4 of the upper and lower parts of columns (see **Photo 8**).

Non-structural element damage was observed. The most considerable damage to concrete buildings was the crack and collapse of in-filled walls. The performance of the structures with RC dual systems and frame systems was better compared to that of the structures with only frame systems, as shown in **Photo 9**.

Photo 6 Soft story failure at Sarpole-Zahab city.

Photo 7 Horizontal irregularities due to lack of one of the beams, poor quality of concrete and utilize of 90° hooks instead of 135° hooks in transverse rebar of columns caused the soft story damage in this building at Sarpole-Zahab.

(a) (b)

Photo 8 Improper detailing of rebar at Shohada Hospital of Sarpole-Zahab (a) Big spacing between transverse rebar of columns at special part (b) Short anchorage length at longitudinal rebar of the beams.

Photo 9 Severe non-structural elements damage at Makane-Mehr of Sarpole-Zahab City.

(2) Steel buildings

The steel buildings in Sarpole-Zahab city were severely damaged. Steel buildings should be confined to cities, and they should be constructed under the supervision of engineers. However, this was not the case for most of the steel buildings. A few steel buildings were in good condition. However, most of them were damaged and even collapsed in a few cities of Kermanshah. The causes for the structural element damage to steel buildings were the buckling of braces and insufficient restraining systems against transverse forces. Because that of brick wall does not consist with the dynamic behavior of the braced steel frame, it is thought that different behavior caused damage and collapse.

The steel frame was damaged or buckled during the earthquake in a few braces, and buildings were severely damaged, as shown in **Photo 10**. Non-structural element damage was the same as that in concrete buildings.

(3) Confined masonry buildings

The use of this type of building has increased in villages after promotion by the Housing Foundation of Iran. Severe damage and collapse have been observed in such constructions. The main reason for the damage is the inferior construction of the connection detail of columns and timber being laid horizontally above pillars to support the weight of roofs (see **Photo 11**).

Photo 10 Severe damage to a steel building at Sarpole-Zahab City.

Photo 11 Damage of Esmat Highschool building in Salase Babajani.

(4) Stone and adobe buildings

Most existing buildings in villages at the epicenter of the earthquake are stone and adobe buildings. The characteristic of these buildings is the cover of their roofs. The roofs are fabricated using wooden timber at intervals of 60 to 90 cm on the wall. In addition, the roofs are covered by a thick layer of mud. These types of buildings are extremely weak against earthquakes. A significant amount of death and structural damage have been observed in such buildings.

5. DAMAGE DETECTION BY SAR SATELLITE IMAGERY

SAR data from Sentinel-1 (orbit 72) and ALOS-2 (orbit 179) satellites with spatial resolution of 20 m and 10 m are evaluated to create damage proxy maps (DPMs). However, the temporal baseline of pre- and post-event images in Sentinel-1 (17 days) is smaller than that of ALOS-2 (40 days), indicating that in this case, Sentinel-1 is much suitable to create a DPM since larger temporal baselines and consequently larger post-event human activities deteriorate quality of earthquake-related changes[7)]. Therefore, the Sentinel-1 images with smaller temporal baseline can provide acceptable phase correlation between at least two pre-event and one post-event images with same geometry and imaging characteristics (**Table. 2**). We applied a methodology based on a normalized RGB color composition for the produced InSAR phase correlation maps (coherence), in which subtraction of pre-event and co-seismic coherence represents the red band, subtraction of co-seismic and pre-event coherence represents the green band and mean values of pre-event and post-event images are in blue band. DPMs produced by this method are shown for the affected cities such as Sarpole-Zahab, Qasre-Shirin, Salase-Babajani, and Gilne-Gharb in **Fig. 3**. Due to lack of enough time in mountainous Kermanshah province, we only have visited those suspicious locations (red pixels in **Fig. 3** with numbers) in Sarpole-Zahab and Salase-Babajani cities in 2017/12/25 and 2017/12/26 to confirm the accuracy and reliability of the DPMs. In Sarpole-Zahab with much larger red pixels northwest and southwest edge of the city the major part of the damage was observed correctly, however, in Salase-Babajani most of the red pixels (red-to-pink) were not exclusively collapsed buildings, but also related with immediate establishment of temporary settlements by local people and authorities.

Since the major part of the damage is reported from Sarpole-Zahab, we specifically focused on its DPM and validated with the results of optical im

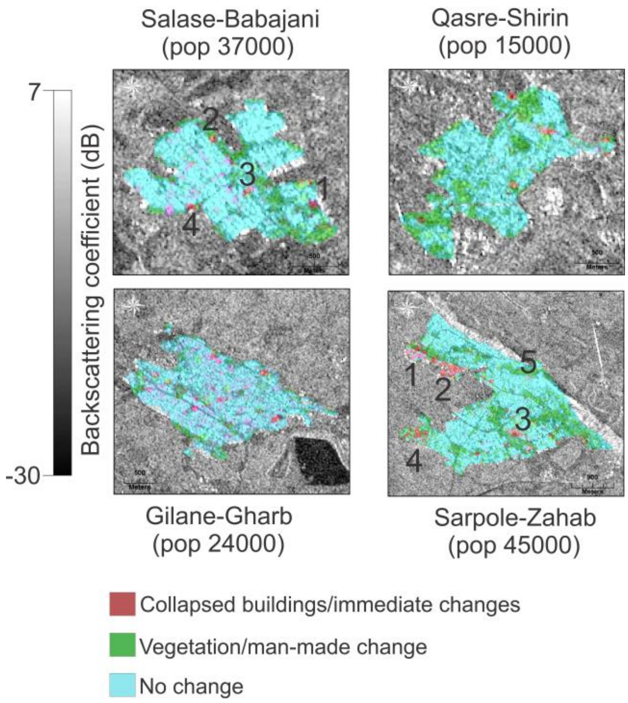


Fig. 3 Damage proxy maps of the affected cities in Kermanshah province of Iran deduced from multitemporal Sentinel-1 dataset. Population of each city is shown on top. Red pixels indicate collapsed buildings, green pixels indicate vegetation and human activities and blue areas are stable areas. Labels (numbers) are the location of the visited areas.

agery[8]. As shown in **Fig. 4**, based on optical images, more than 600 individual buildings (black circles) are damaged in the city. In order to do a fair validation between SAR and optical results, we chose randomly 50 collapsed and intact buildings and calculated their multitemporal differential coherence and relative standard deviations. The results show that differential coherence value from red band is higher among collapsed buildings (**Fig. 4.b**).

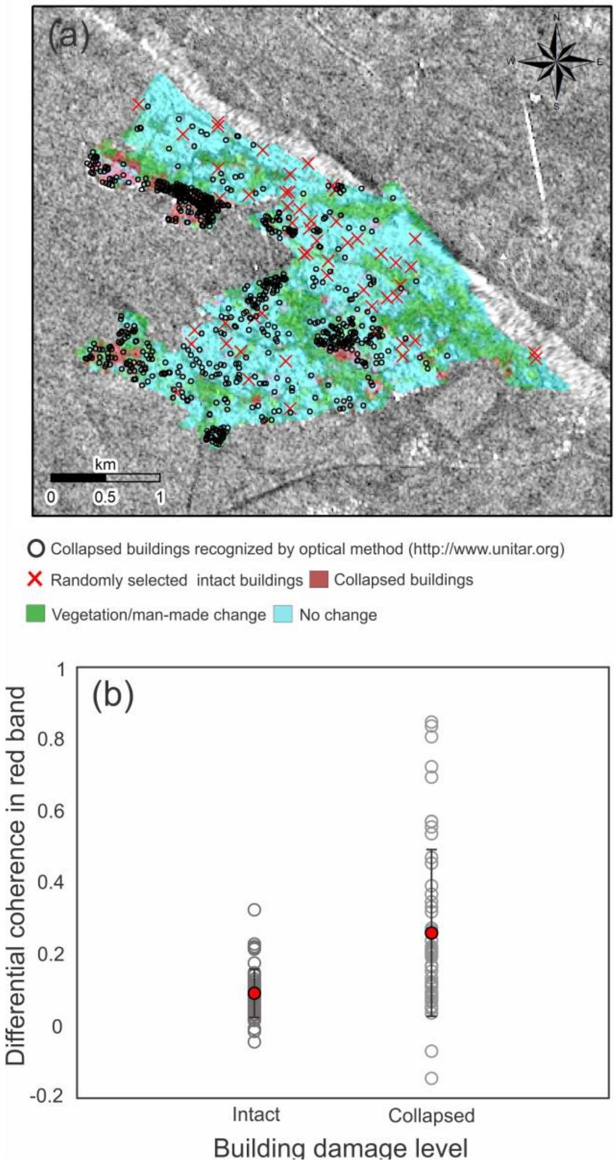


Fig. 4 (a) DPM of Sarpole-Zahab together with collapsed buildings from visual inspections of optical images by UNITAR (black circles). Red cross marks are randomly selected intact buildings in the city. **(b)** Comparison of level of differential coherence value in red band for selected buildings in each category. Gray circles in collapsed category are randomly selected 50 collapsed buildings acquired from http://www.unitar.org. Gray circles in intact category are randomly selected 50 intact buildings in Sarpole-Zahab, Iran. Red circles and black bars are mean pixel values and standard deviations from red band, respectively.

Table 2 Detailed characteristics of SAR images used for damage detection. We analyzed only copolarizations (VV) and cross-polarizations (VH) are ignored. IW: Interferometric Wide Swath; θ: Incidence angle; A: Ascending. * indicates master images in each dataset.

Mode	Date	θ	Polarization	Path (Orbit)
IW	2017/11/17	38.9°	VV	A (72)
IW	2017/10/30*	38.9°	VV	A (72)
IW	2017/10/18	38.9°	VV	A (72)

6. MICROTREMOR MEASUREMENTS

To evaluate site and buildings characteristics and their relations to the extent of damages, we measured microtremors at eight points with duration of 15 minutes at Sarpole-Zahab city and Kooek villages from 2017/12/25 to 2017/12/28. Also, the measurements were performed using seismograph device (GPL-6A3P Akashi Ltd., Japan) with three orthogonal components (two horizontal and one vertical). From the recorded data, three measurements were disregarded due to excessive noise. Locations of measured records which are related to Pawnar, Maskane Mehr_1, Maskane Mehr_2 districts are shown by yellow circles on **Fig. 5a**; also one record was considered at the roof of one of the Maskane Mehr_2 buildings to determine its natural period and compare to the site dominant frequency. The remaining record was measured at Kooek villages where had the highest destruction in the rural areas.

The locations of measurement points were selected based on the number of failures so that in the Pawnar district in the west of Sarpole-Zahab city most of the buildings built by masonry materials had been devastated. 27 seven-story Buildings in the Maskane Mehr_1 district which had been constructed according to engineering guidelines were damaged in non-structural parts, in contrast, there were no structural and non-structural damages in the four-story buildings in the Maskane Mehr_2 district. Kooek villages in the north-east of Sarpole-Zahab city have been completely destroyed, most of the houses were built by heavy and low-quality materials such as stone and mortar.

In this research, the microtremor data were analyzed based on the horizontal to vertical spectral ratio (H/V) method which was employed, for the first time, by Nogoshi and Igarashi[9] and then it was developed to estimate the site effect by Nakamura[10]. This method assumes that the vertical component spectra of microtremors are not affected by geological conditions of soil layers located above the bedrock, i.e. this is the same on bedrock and ground surface. The ratio of H/V was determined using JSESAME software[11]. For each record, several windows were selected with an overlap of 10% and 15 or 20 seconds long (the data were viable in these windows). Also, the Konno and Ohmachi[12] method was applied to smooth the computed spectra for each component.

The result of the spectral ratio (H/V) in the Pawnar district is illustrated in **Fig.5b**. As shown, the domi-

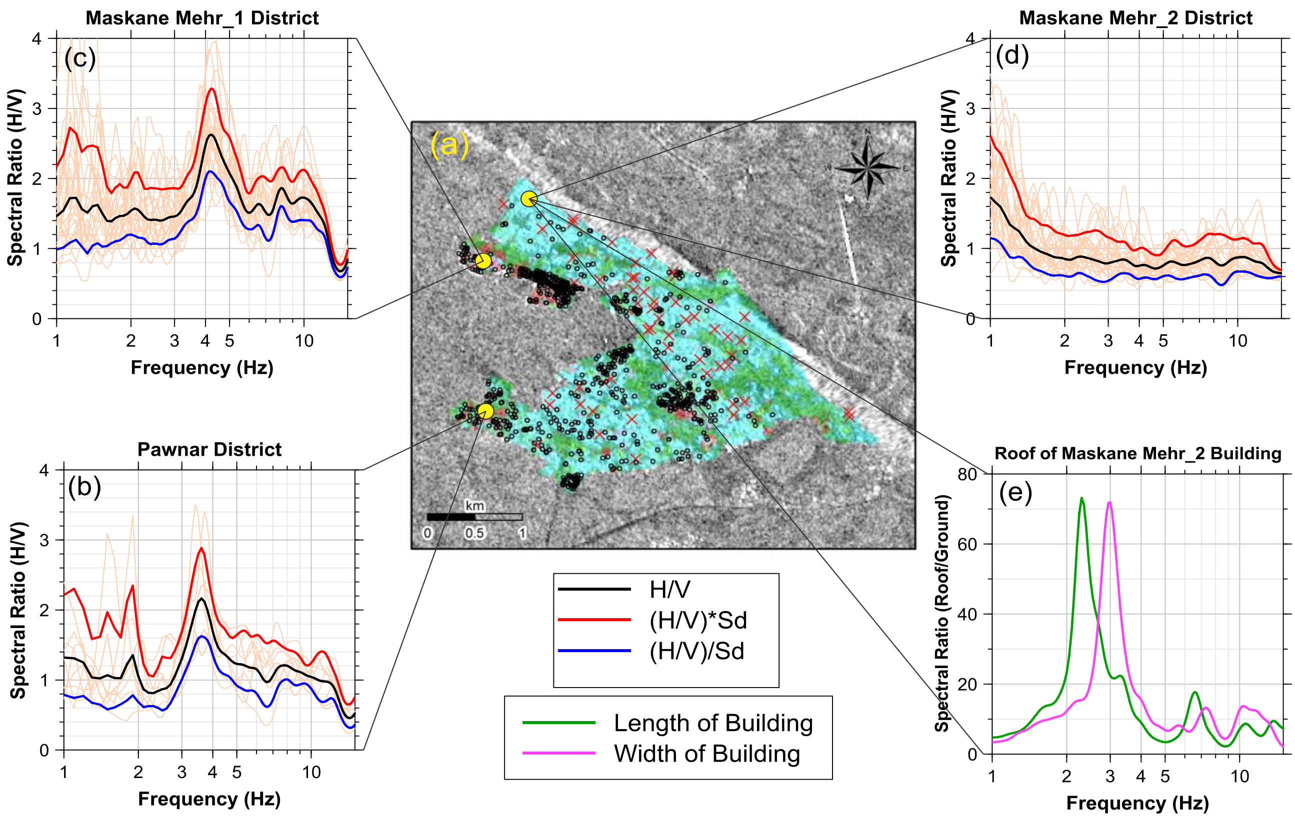


Fig. 5 (a) Location of microtremor measurement points in Sarpole-Zahab city which have been shown by yellow circles; **(b)**, **(c)** and **(d)** Obtained spectral ratio (H/V) (black curve), spectral ratio multiplied by standard deviation (red curve), spectral ratio divided by standard deviation (blue curve) in Pawnar, Maskane Mehr_1 and Maskane Mehr_2 districts, respectively; **(e)** computed spectral ratios along length (green curve) and width (magenta curve) at the roof of a 4-story building in the Maskane Mehr_2 district.

nant frequency and site amplification are 3.60 Hz and 2.16, respectively. Therefore, the soil type can be classified as C and SCII (hard soil) class according to NEHRP1[13)] and Japan Road Association codes[14)]. Obtained spectral ratio (H/V) in the Maskane Mehr_1 site which is depicted in **Fig. 5c** shows dominant frequency of 4.26 Hz with an amplitude of 2.61. This frequency is related to soil class of C and SCII in the mentioned codes. **Fig. 5d** shows computed spectral ratio for the site of Maskane Mehr_2. The H/V spectra do not show a clear peak, which suggests that there is no strong contrast in the velocity structure. Since this district is very close to the outcrop rocks of a mountain (white area in the north of the city in **Fig. 1(a)**, we think the site condition is rather stiff and effect of near-surface amplification is not large[15)]. As aforementioned, no damages were observed in the buildings of Maskane Mehr_2 district, and microtremor result was also presented for this site (**Fig. 5d**). To further examine and estimate the natural period of a 4-story building, microtremors measured at the roof one of these buildings. It is evident that in an asymmetrical structure, stiffness is different for the two directions. Therefore obtained period is not the same. In this study, to determine the natural period of the building, spectral amplitude of record of every direction was divided on those ground surface record[16)]. The results for length and width directions of the building have been drawn by green and magenta curves in **Fig. 5e**. It can be seen from the figure that the length and width directions frequencies were 2.30 Hz and 3.0 Hz, respectively. By comparing the site and building frequencies it was conducted that the rather soft buildings have been constructed on a stiff site which reduces the probability of amplification and resonance occurrence during an earthquake. The outcome of microtremor measurement in the site of Kooek villages has been illustrated in **Fig. 6**. The spectral ratio shows a clear peak at a frequency of 3.20 Hz with an amplitude of 2.07. Also, the site classification is similar to those of Pawnar and Makane Mehr_1 site.

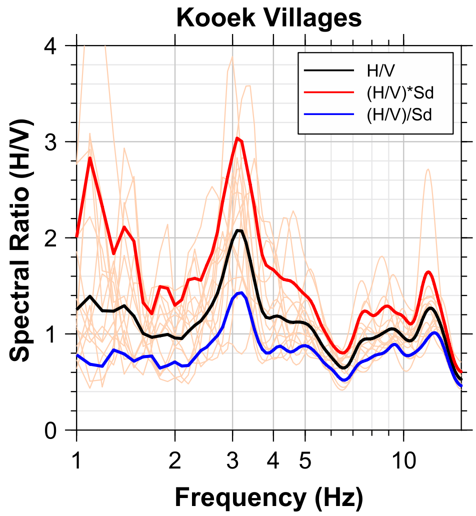


Fig. 6 Obtained spectral ratio (H/V) (black curve), spectral ratio multiplied by standard deviation (red curve), spectral ratio divided by standard deviation (blue curve) in Kooek villages site.

7. DAMAGE TO LIFELINES AND INFRASTRUCTURES

(1) Damage to bridges and roads

In general, the significant structural damage was not observed in main bridges, the deck bridges that are very common for low span bridges were all safe and ready for use. However, in some cases, there were cracks and even collapse in some parts of stone retaining walls beside the structure of the bridge, like the Sarpole-Zahab main road bridge (see **Photo 12**).

On the roads of damage area due to the settlement, landslide and rock fall, some damages were observed on the roads but it was only in some parts only.

(a) (b)

Photo 12 (a) Damage to the retaining walls beside the bridge of Sarpole-Zahab City, (b) Damage to little stone and concrete bridge at a Village road nearby Sarpole-Zahab

(2) Damage to electricity network

After the earthquake, three cities of Sarpole-Zahab, Qasre Shirin and Tazehabad and the villages in their territory had 100% power outage. The cities of Pave, Gilane Gharb and Kermanshah and territory villages had 30-60% power outage, totally around 480 villages had a power outage after the main earthquake. In big cities from some hours to at most 48 hours the power was restored and in villages within less than 4 days power was restored[17)]. In transmission network, different levels of damage have been happened from light to severe. The main observed cases: tilting and collapse of utility poles in cities due to buildings or walls falling on them, falling of 63kV transformer in Sarpole-Zahab city, even one collapse of transmission tower duo to rock fall on the mountains nearby the Sarpole-Zahab city. Damages to the electrical power network were estimated about 36 million dollars by Power Ministry in Iran[18)].

(3) Damage to water supply network

Rural Water and Wastewater Company of Kermanshah Province reported that 13 cities of Kermanshah Province were damaged, and because of contamination in 7 cities mainly Sarpole-Zahab, Qasre Shirin and Gilane Gharb water was cut for 2 weeks. More than 500 cases on the main water pipelines and more than 300 cases on main wastewater pipelines were damaged[19)]. Damages to the water supply network were estimated about 72 million dollars by Power Ministry in Iran[18)].

(4) Damage to the gas network

National Iran Gas Company roported that there was no damage in main gas pipelines. However, there was some damage to joints of the gas pipelines at the entrance to the houses. And because of this, the gas was cut off for one day after the earthquake [20)].

8. CONCLUDING REMARKS

This report outlines the findings obtained thruough the quick survey at the affected sites. Results and findings of the reconnaissance activities on the Sarpole-Zahab Earthquake are as follows:

(1) The heighest recorded PGA was observed at Sarpole-Zahab station with the shortest epicentral distance of 39 km, with 681 cm/s^2, and 562 cm/s^2 and 404 cm/s^2 for longitude, transverse and vertical components, respectively.

(2) The pseudo spectral acceleration at Sarpole-Zahab station indicates that the predominant ground shaking is with a period of 1sec or less, and there are not many long-period components in the near-fault ground motions. This period range usually affects the 2 to 6 stories structures.

(3) This earthquake triggered massive landslides in the mountainous areas close to Mela Kabood and Goorchi Bashi villages, which located to the north of the Sarpole-Zahab City. The largesst landslide reached an area of 4 km long and 1 km wide.

(4) Severe damage areas of damage proxy maps created by using SAR data coincide with the major part of the building damage in Sarpole-Zahab but agrees with the temporary settlement just after the earthquake in Salase-Babajani.

(5) According to the results of microtremor measurements, the soil type can be classified as C and SCII in Pawnar, Makane Mehr_1 and Kooek village where the severe building damage occurred.

(6) After the earthquake, three cities of Sarpole-Zahab, Qasre Shirin and Tazehabad and the villages in their territory had 100% power outage. In big cities from some hours to at most 48 hours the power was restored and in villages within less than 4 days power was restored .

(7) Thirteen cities of Kermanshah Province were damaged to water supply system, and water was cut for 2 weeks in 7 cities because of water contamination. More than 500 cases on the main water pipelines and more than 300 cases on main wastewater pipelines were damaged

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