Preliminary Seismic Site Classification Map of Sarpol-e Zahab

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ABSTRACT

The destructive earthquake of Sarpol-e Zahab (Mw=7.3, Depth=18 Km) lead to sever damages to many of structures of the affected region. The first reconnaissance of the area showed that the structures damage distribution could be interpreted by the effect of local site conditions. Therefore, some microtremor measurements and geophysical surveys were performed to investigate this concern. The survey included totally 41 locations of microtremor measurements and 40 locations of geophysical refraction profiles, the distribution of which covered all over the city. The recorded motions were analyzed using horizontal to vertical spectral ratio (HVSR) method to determine the natural frequencies of the alluvium; primary and secondary waves velocity were also measured as a complementary data. The survey results concluded to the preliminary seismic site classification map for the city, which would be useful for future safe design of structures.

Keywords:
Seismic site classification; Geophysical surveys; Microtremor measurements

1. Introduction

A destructive earthquake (Mw = 7.3, Depth = 18 Km) struck the city of Sarpol-e Zahab and a vast region in west of Iran on 12th of November 2017 at 21:48 local time. The epicenter was reported near the Iran-Iraq border at a distance of 10 km from Ezgeleh and 37 km North West of Sarpol-e Zahab. Due to the concentration of damages in the city of Sarpol-e Zahab and its surrounding area, the earthquake was so called Sarpol-e Zahab earthquake. The city has been explored by many research groups of different disciplines, including the authors who carried out geotechnical surveys to explore local site effects in the city of Sarpol-e Zahab. The first reconnaissance of earthquake affected region showed that the damage distribution can be interpreted by the effect of local site conditions. Therefore, some microtremor measurements were conducted by the International Institute of Earthquake Engineering and Seismology (IIEES) and Razi University. Seismic refraction surveys were also conducted by the IIEES. The main aim of this investigation is to prepare preliminary seismic site classification map of Sarpol-e Zahab. Such a map is required in conjunction with the necessity of considering the revised bedrock acceleration (0.34 g, [1]) and the proper design spectrum preference form the latest version of the Iranian Code of Practice for Seismic Resistant Design of Buildings (Standard No. 2800) [2].

It is well known that the capability of local geologic deposits to amplify strong ground shaking depends on the physical properties of the materials as well as their geometrical distribution. Due to the lack of such data on geotechnical properties and three-dimensional distribution of underlying soil at the region, the seismic site classification map was developed relying on the distribution of geologic materials on the ground surface, geophysical surveying and microtremor measurements. The adopted methodology of the seismic site classification map assessment throughout the study area consisted of the following steps:

1. Field observations and the existent geological map map were compared to the earthquake damage maps developed from satellite imagery;
2. The natural frequencies throughout the study area were estimated based on the microtremor measurements;
3. The primary and secondary waves velocities were also measured by seismic refraction surveys;
4. The seismic site classification map is suggested based on the above-mentioned results and the Standard No. 2800 provisions [2].

2. Field Observations

Effect of local geological conditions on the intensity of ground shaking and the damages by earthquakes has enough precedents to be known as a necessary measure for earthquake resistance design [3-5]. In this study, field observations gave rise to the hypothesis that the distribution of building damages could be interpreted by local site effects on the earthquake intensity, especially in the western area of Sarpol-e Zahab city (Figure 1). The thickness of the alluvium varies considerably from zero in the northeast up to tens of meters in the southwest of the city. As depicted in Figures (1) and (2), the most sever damages were observed in the structures located in the south of the main boulevard.

Interestingly, Figure (2) demonstrates the differences in the damage intensity in the structures with similar design and construction, but different underlying soil conditions. Figure (2-a) is captured from the mountains neighboring the Mehr buildings, which are least affected by the local site effects; in this figure, another Mehr building complex may be observed far from the mountain, neighboring the river in Shiroodi area. Different damage intensity of the mountain-side Mehr structures (Figure 2-a, 2-d and 2-e) and the river-side Mehr buildings (Figures 2-b and 2-c) could be a clear evidence of local site effects.

The earthquake induced damage maps developed from satellite imagery captured by UNITAR (Figure 3), which are in agreement with field observations, show that the earthquake damages are most sever in the structures located in the south of the main boulevard (Shiroodi area) [6].

Figure 1. Aerial photo of Sarpol-e Zahab city (from ISNA news agency).

Figure 2. West of Sarpol-e Zahab city, (a) structural damages most likely to be affected by the local site effects, (b, c) buildings near to the river, (d, e) buildings near to the mountain.

3. Microtremor Measurements

Ambient vibration recordings are one of the most applicable surveys in earthquake-related geotechnical investigations. The survey is rather simple as well as time and cost effective in both application and analysis. The simplest ambient vibration or noise measurement method is simultaneously recording of three components of noise by a single seismometer. The analyses of the single station records were firstly introduced by Kanai and Tanaka [7] and Nogoshi and Igarashi [8] and then developed by Nakamura [9]. The analysis method is generally known as Nakamura technique and formally is called Horizontal to Vertical Spectral Ratio (HVSR) or simply H/V method. The method considers the peak frequency of the Fourier spectrum ratio of the average horizontal components to the vertical component as the natural frequency of the site. Although the analytical bases of the HVSR method has been criticized (the review chapter by Lunedei and Malischewsky in Ansal [10]), it is widely accepted and applied in determination of the site natural frequency [11].

The ambient vibration recordings of the current study were started on the 16th of November 2017 and spanned to the 30th of November, by the aid of 41 stations across Sarpol-e Zahab city. Two seismometers were used for these measurements; a three-component broadband (30 s to 50 Hz) seismometer of CME-4111 [12] and a three-component seismometer (5 s) of Lennartz [13]. Recordings of CME-4111 were sampled by frequency of 200 Hz and the Lennartz's ones were sampled by frequency of 100 Hz. Figure (4) demonstrates the positions of the 41 stations of the recordings. The stations were located densely at severely damaged places. The duration of the recorded signals were at least 30 minutes. However, the recordings of CME-4111 were longer as it took

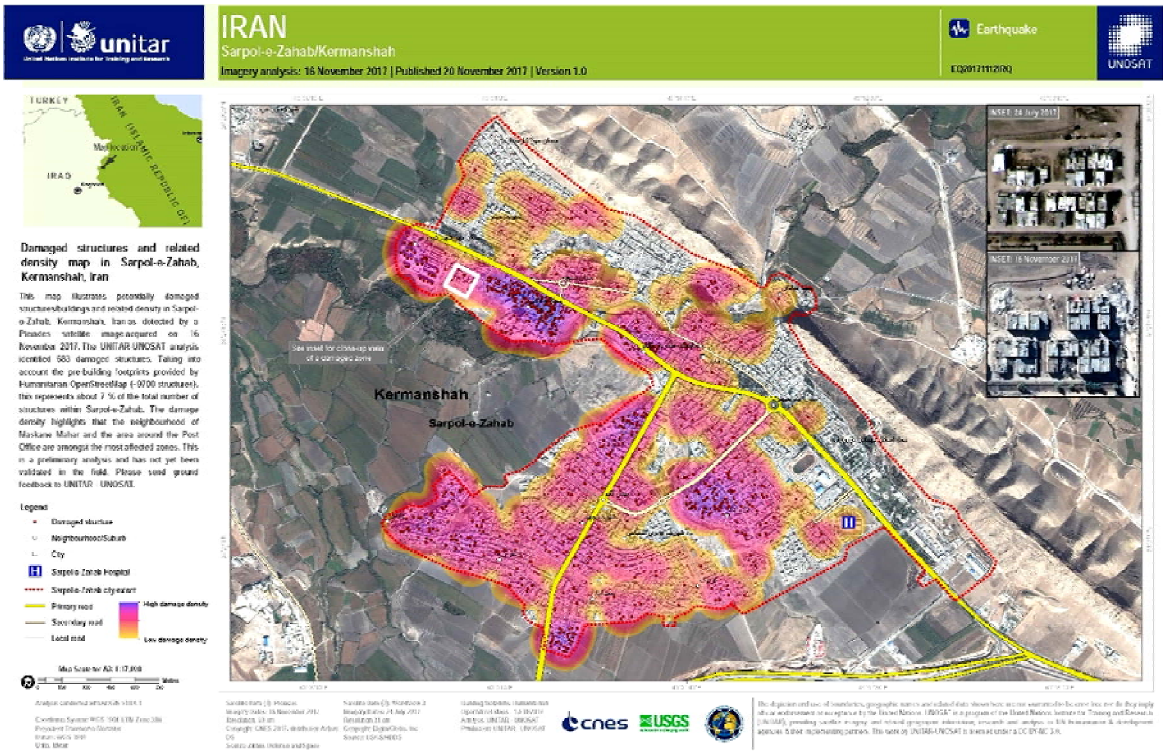

Figure 3. Earthquake damage map of Sarpol-e Zahab city developed from satellite imagery captured by UNITAR [4].

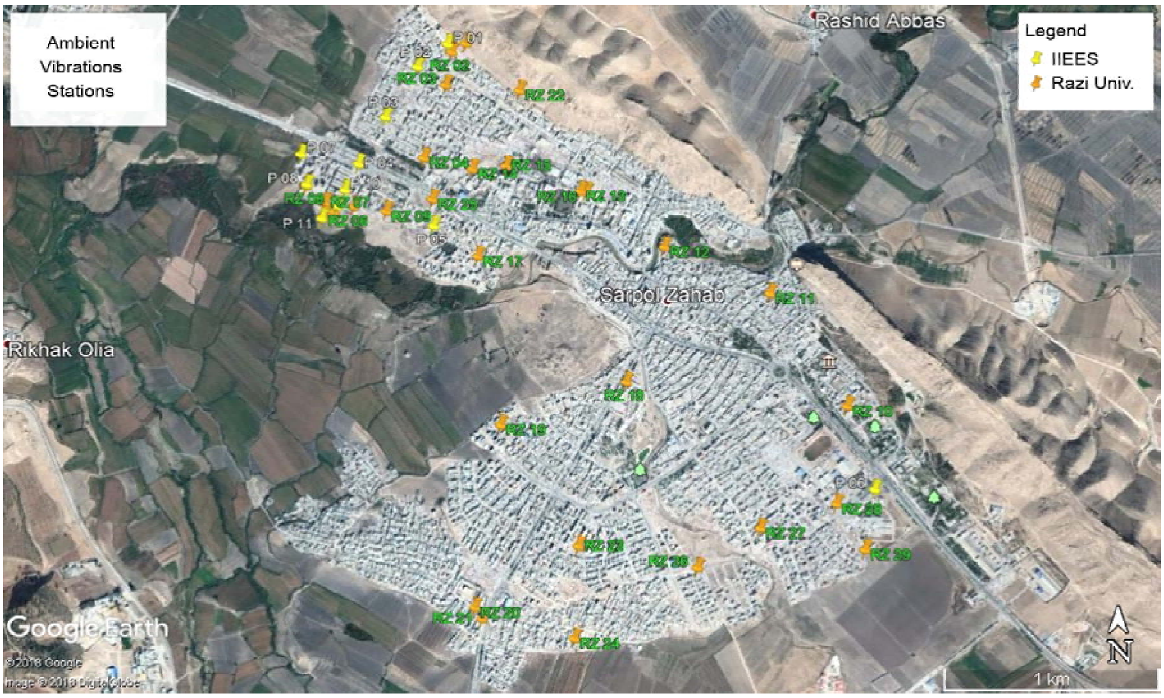

Figure 4. Location of 41 stations of ambient vibration recordings in Sarpol-e Zahab city.

longer to stabilize.

The ambient vibrations were analyzed using the specialized software of Geopsy [14]. The final results of the analyses were used to produce the map for natural frequency of the ground, as shown in Figure (5).

4. Geophysical investigation

Locations of the seismic refraction surveys conducted by the IIEES are indicated in Figure (6).

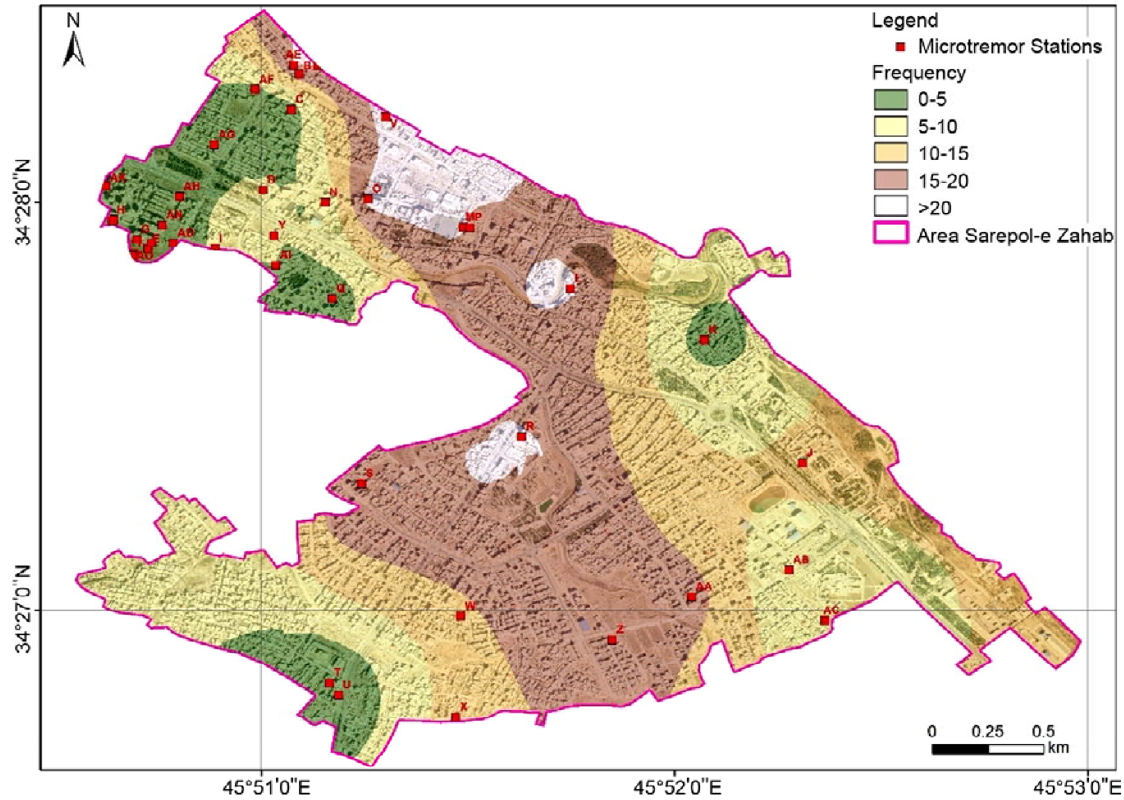

Figure 5. Map of the ground natural frequency (F0) distribution.

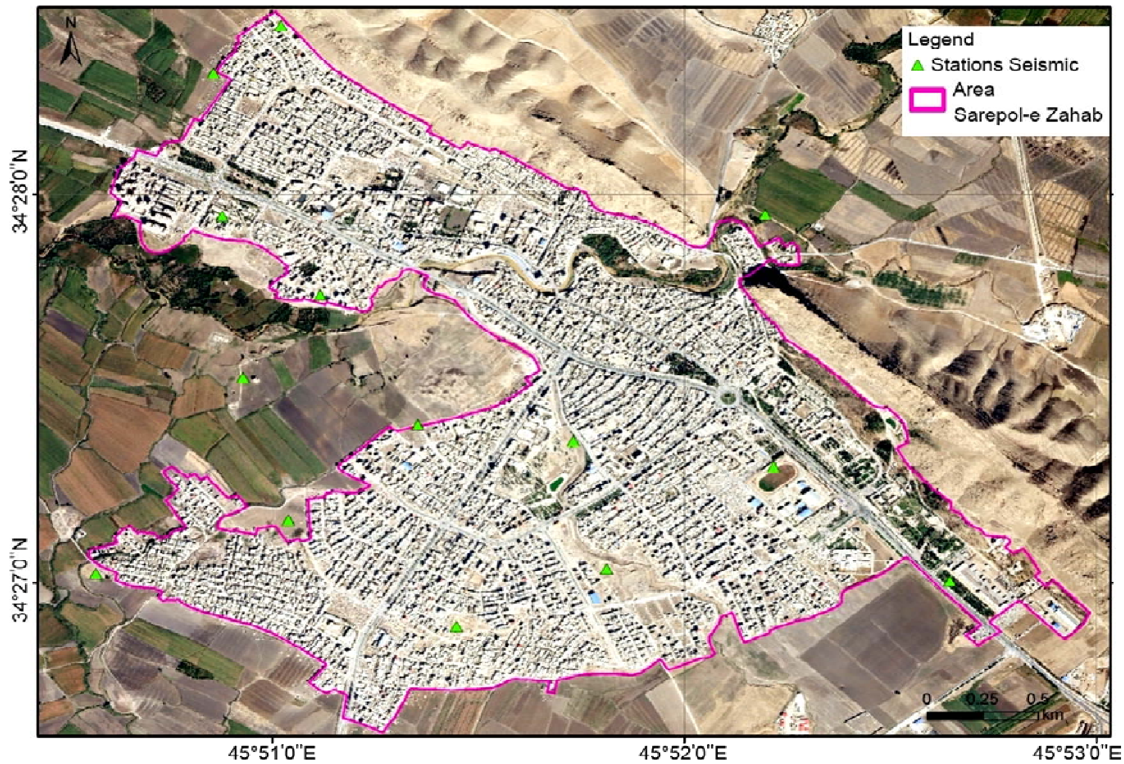

Figure 6. Locations of the seismic refraction profiles conducted by the IIEES.

Based on the seismic refraction profiles, the thickness of deposits increases from the north to the south. Although some irregularities at bedrock formation may exist at some parts of the Sarpol-e Zahab city, the obtained shear wave velocity of bedrock is mostly higher than 1200 m/s. Based on geophysical studies, the maximum depth of Quaternary alluvial in the study area is estimated to be less than 30 m generally, except some parts near the river and agriculture farms. Figure (7) shows the shear wave velocity of surface layer measured in the study area.

5. Site Classification Based on Standard Provisions

Taking into account the existent geological map, the damage distribution map based on satellite imagery, natural frequency distribution map based on the microtremor measurements, and shear wave velocity map based on geophysical surveys, the seismic site classification map of the Sarpol-e Zahab city was preferred according to the Standard 2800 [2] provisions, and also the reliable literature in this regard [15]. Relying on extensive field observations, the city could be categorized into the following four distinct site classes as shown in Figure (8):

- Class 1 represents rock formation that underlies few meters of stiff soils;
- Class 2 represents stiff soil formation in shallow layers of 8 to 15 meters thickness and low shear wave velocity contrast of surface layers with the seismic bedrock.
- Class 3 represents medium stiff soil formation with a higher soil thickness of 14 to 25 meters and more shear wave velocity contrast of surface layers with the seismic bedrock, compared to class 2.
- Class 4 represents soft soil formation with considerable shear wave velocity contrast with the underlying seismic bedrock

The seismic bedrock is the same as the geological bedrock in geophysical classes 1 and 2 and lies in a deeper level in geophysical classes 3 and 4.

6. Conclusion

This study was a preliminary exploration of the local site effects on strong ground motion during the destructive Sarpol-e Zahab earthquake. Initial field observations and existing geologic data inspired the compatibility of the expected alluvium properties and its consequents on the incident waves, with the damage intensity throughout the area.

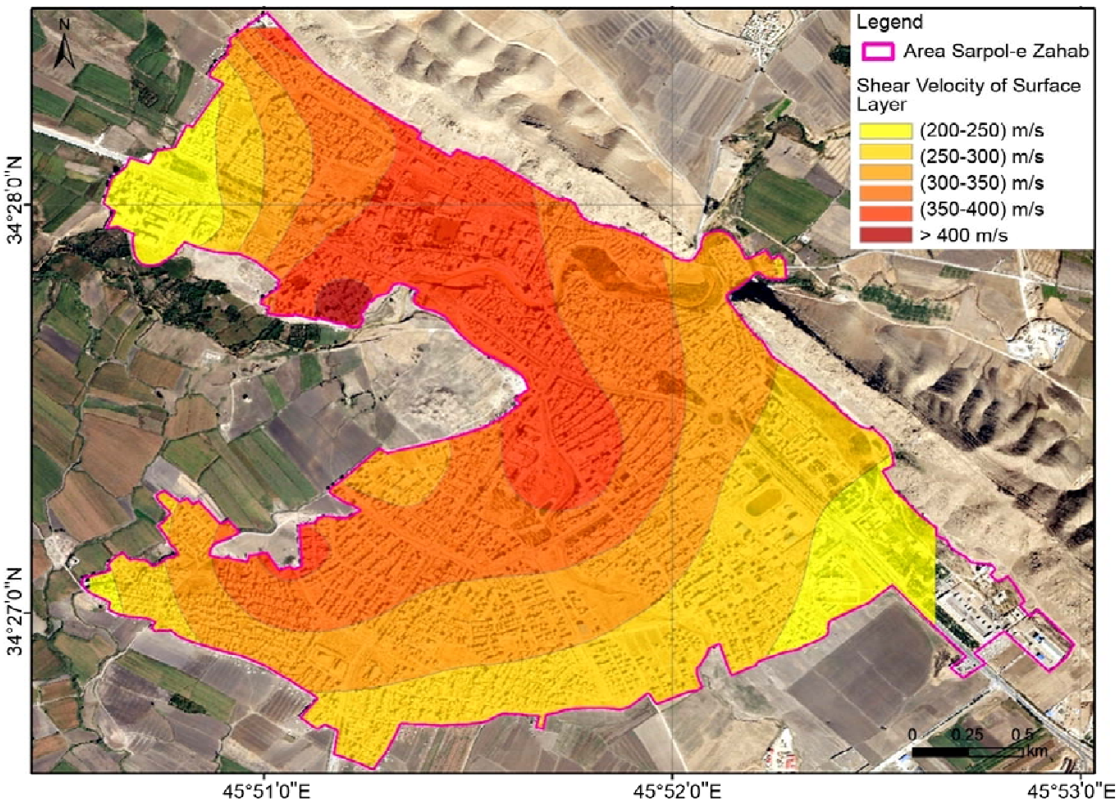

Figure 7. Shear wave velocity of surface layer measured in the study area.

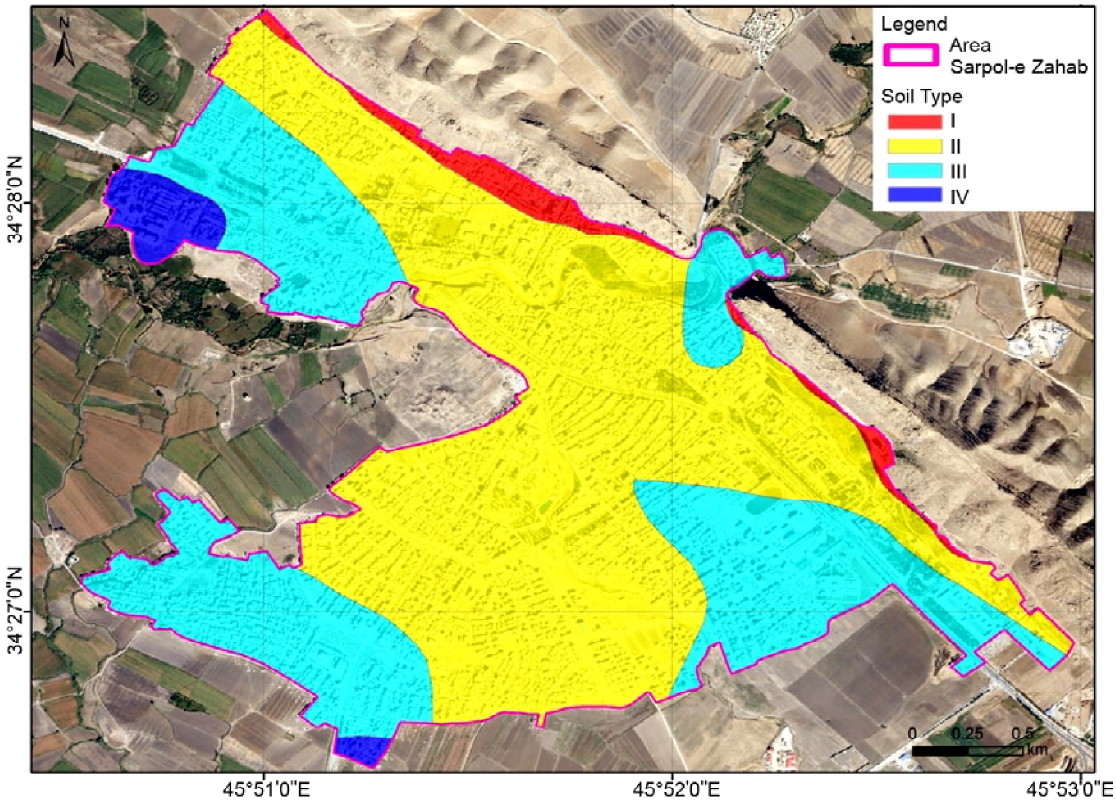

Figure 8. Preliminary Seismic Site Classification Map of Sarpol-e Zahab.

Extensive microtremor and geoseismic surveys in addition to the satellite imagery data concluded to the site classification based on Iranian Standard No. 2800 provisions. The classification would be very useful in future retrofit or re-construction design of structures in the area and is necessary to prefer proper design spectrum from Standard No. 2800 in this regard. Care must be taken that such data is not enough for tall buildings, which require site specific design spectrum calculation regarding near fault effects [1].

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