Geotechnical Mapping of Seismic Risk for Sharjah City, United Arab Emirates

Maher Omar, Abdallah Shanableh, Samar Abduljalil, Khaled Hamad, Mohamed Arab, Moussa Leblouba and Ali Tahmaz

Abstract Seismic hazard and geotechnical microzonation maps of urban communities make it conceivable to describe potential seismic zones that should be considered when planning new structures or retrofitting existing ones. This study looked at a local site-specific ground response analysis, which is an important step in estimating the effects of earthquakes. The soil data from 200 boreholes up to 30 m depth were collected and analyzed using SHAKE2000 and NovoLiq in order to develop local site amplification and liquefaction potential maps for the city of Sharjah. In addition, Geographical Information System (GIS) was utilized to create amplification and liquefaction potentials maps at different areas in Sharjah. These maps show zones of high vulnerability earthquake risk used for earthquake-resistant design of structures. The city of Sharjah was divided into areas, according to the amplification factor, which ranged from 1.44 to 1.83. A high amplification factor was found near the central region of the city, while the rest of the city lies in low amplification potential and relatively low seismic risk. Finally, liquefaction risk of Sharjah estimated and expressed in terms of safety factor. The low values of the

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safety factors against liquefaction were found in the north, northeastern, and southeastern portions of the city. Higher values were found in central and toward south central parts of the studied area. In these parts, the higher safety factor indicates low liquefaction potential of the soil and relatively low seismic risk.

Keywords Seismic · Risk · Microzonation · Amplification · Liquefaction GIS

1 Introduction

Seismic microzonation study is, for the most part, perceived as one of the viable procedures to assess the seismic hazard, evaluate the associated risk, which is defined as the zone with respect to ground motion attributes considering source, and site conditions [1]. Many lessons were learnt from earthquakes that repeatedly happened all over the world that have increased the awareness to public and government regarding the impacts of seismic risk on their structures.

According to [2], a preliminary microzonation study conducted in 2011 for the Abu Dhabi Island based on 245 borings out of approximately 1000 soil borings with average depth of 20 m provided and compiled for the selected area. In order to examine and assess the available geotechnical data, the selected areas within Abu Dhabi, Al Ain, and Western Region Municipalities divided into grids with dimensions of 250 m × 250 m. The locations of selected borings and the grid system are shown in Fig. 1. As it can be seen from Fig. 1, there are limited number of borings in major portion of the area, thus the reliability of microzonation maps for these sections are based on interpolation and extrapolation of the available borings. The reliability of the microzonation maps produced for Abu Dhabi, Al Ain, and Western Region Municipalities will also be dependent on the amount and quality of the available data.

In the review, microzonation concerning ground shaking intensity depended on average spectral accelerations computed between the 0.1 and 1 s, and peak spectral accelerations figured using equivalent shear wave velocities averaged at top 30 m [3]. In Fig. 2, the ground shaking intensity were zoned into three parts, where zone AGS demonstrates the ranges with low ground shaking intensity, zone BGS demonstrates the territories with low to medium ground shaking intensity, and zone CGS demonstrates the zones with high ground shaking intensity.

The susceptibility of liquefaction was calculated for each cell [4, 5]. The factors of safety were determined for each borehole comprising liquefiable sand or silt layers [4]. The liquefaction susceptibility guide map shown in Fig. 3 was created for three districts, where region AL shows very low susceptibility of liquefaction, zone BL shows regions with low to medium liquefaction susceptibility, and zone CL shows the regions with high liquefaction susceptibility. The produced map for the three areas demonstrates that in significant piece of Abu Dhabi Island, liquefaction susceptibly is low and in this manner irrelevant for Abu Dhabi Island.

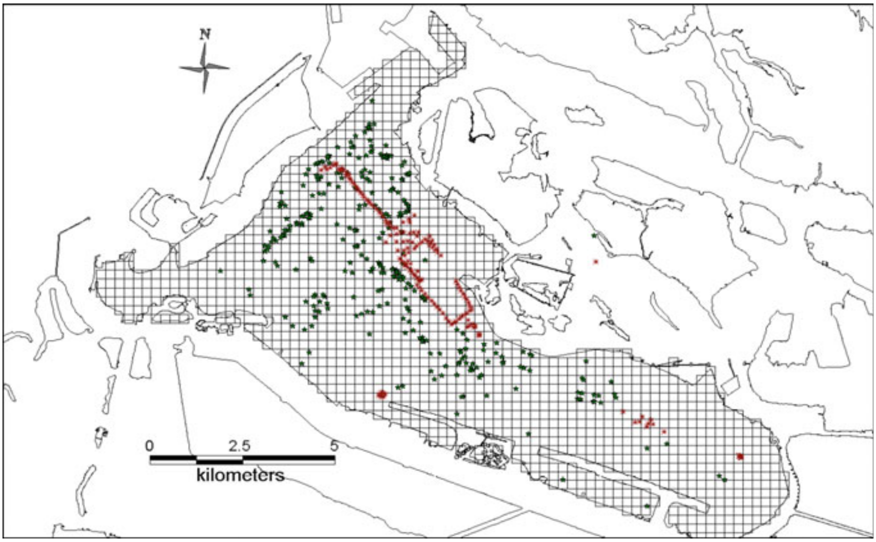

Fig. 1 Location of the borings selected as representative borings [2]

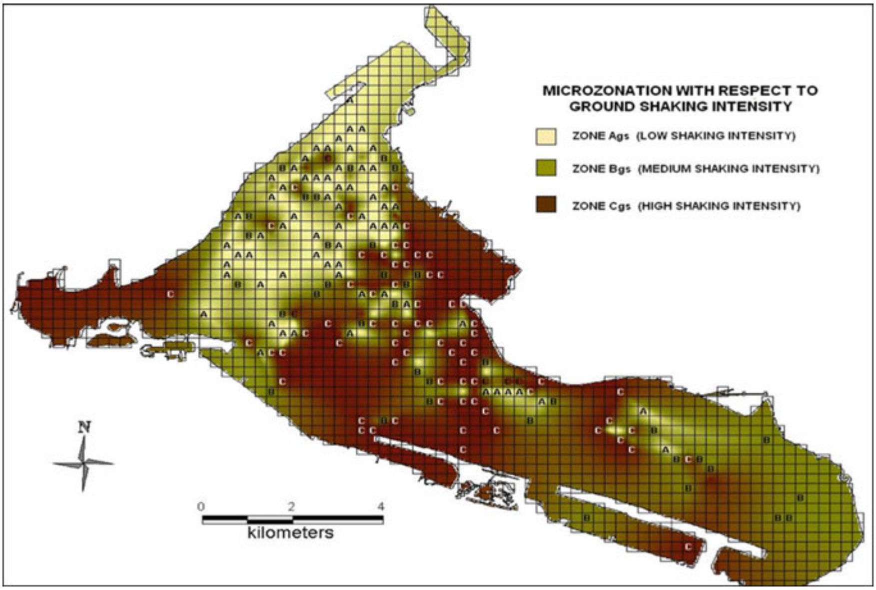

Fig. 2 Zones with respect to ground shaking intensity [2]

Comparative work was done in Dubai in 2008, as revealed by Ansal et al. [6], for which 1094 borehole information were analyzed and profiles for different soil types and shear wave velocity were created. Site response analysis was conducted

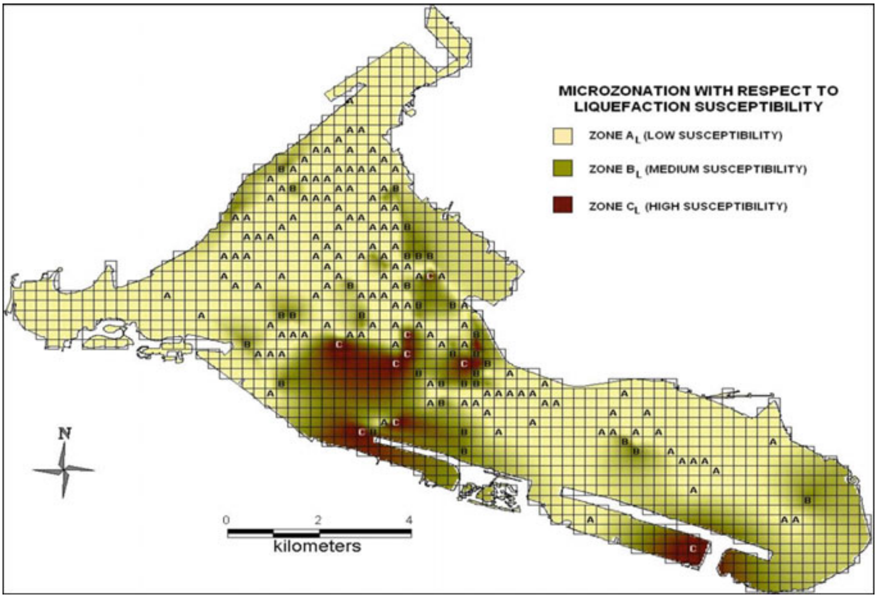

Fig. 3 Zonation with respect to liquefaction susceptibility for RT = 1000 years [2]

using PGA, scaled twelve records for the 1094 soil profiles considering two seismic hazard levels, corresponding to 2475 and 475-year return periods. A total of 25,256 site response analyses were performed and earthquake properties on the ground surface were estimated with respect to peak ground and spectral accelerations, peak ground velocity, and site amplification.

The selected area within the Dubai City was divided into 5110 cells with dimensions of 500 m × 500 m. Since some of the boreholes were shallow, 1094 borings out of 6101 with total depth D $\geq$ 15 m were selected as representative soil profiles. The locations of selected borings and the grid system are shown in Fig. 4. The microzonation area for Dubai City was limited based on the availability of data. There are no borings in major portion of the area, therefore, it would be more suitable to establish the microzonation maps based on 1094 borings for the most part situated in the north of Dubai city using the outer boundary.

The zonation regarding the intensity of ground shaking is produced with respect to three areas, where zone AGS shows the areas with very low intensity, zone BGS shows areas with low to medium intensity, while zone CGS shows the areas with high intensity as can be seen in Fig. 5.

The susceptibility of liquefaction was calculated for each cell [4, 7]. The factors of safety were calculated for each representative borehole containing liquefiable sand or silt layers [5]. The liquefaction susceptibility guide map shown in Fig. 6 was created for three districts, where region AL shows very low susceptibility of liquefaction, zone BL highlights regions with low to medium susceptibility of

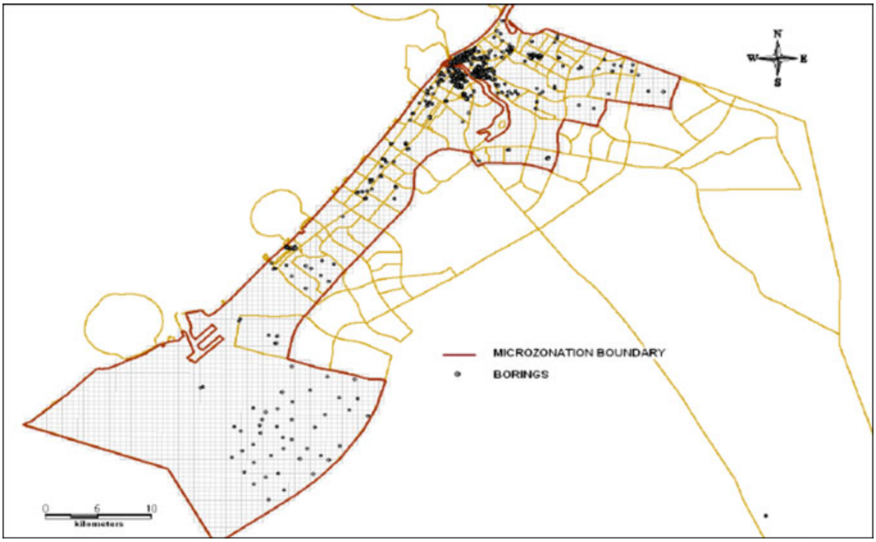

Fig. 4 The location of borings selected as representative borings [6]

Fig. 5 Zonation with respect to ground shaking based on spectral acceleration [6]

liquefaction, and zone CL highlights the areas with high susceptibility of liquefaction. The map produced for three areas demonstrates that in significant piece of Abu Dhabi Island, liquefaction susceptibly is low and in this manner irrelevant for Dubai.

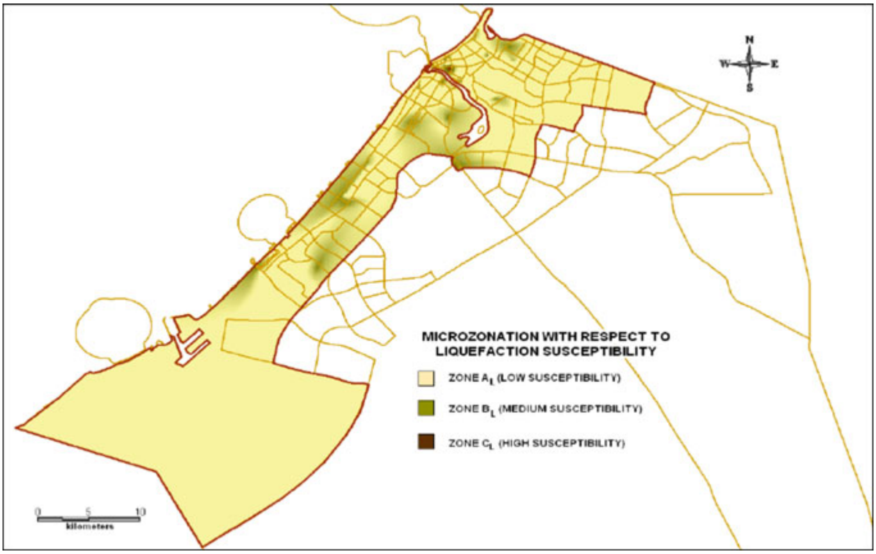

Fig. 6 Zonation with respect to liquefaction susceptibility [6]

In 2011, [8] performed analysis on the influence of local soil conditions on ground response during earthquakes at different areas in the Emirate of Sharjah, UAE estimating amplification potential and prepared a map indicating zones of high vulnerability to seismic hazard as shown in Fig. 7.

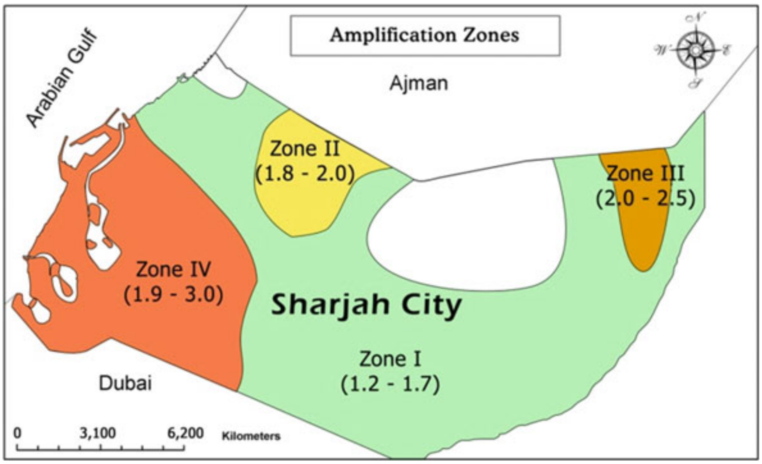

Fig. 7 Site amplification factor zonation map for Sharjah [8]

2 Geology and Seismicity of the Area

UAE has a mountain belt along the eastern coast of the Gulf of Oman; about one fifth of its land is desert. The western part of the UAE is facing the subduction boundary across the Arabian Gulf, opposite the Strait of Hormuz, one of the most seismically active zones in the world. The City of Sharjah faces the Zagros folded belt, one of the most active faults in the world. The main city lies on the Arabian Gulf and other parts of the Emirate lie on the Gulf of Oman. It is located in the geological window between altitudes (25° 25′N and 25° 14′N) and (55° 45′E and 55° 20′E).

It has been generally accepted that the UAE has little or no earthquake activity. However, the country is not as safe from earthquake disasters as often assumed. In March 2002, and according to Jamal and A-Homoud [9], an earthquake magnitude of five shocked al-Masafi area, northeast of UAE with its epicenter at 16 km depth. The strong motions recorded on December 10th, 2002 and April 25th, 2003 represents sufficient evidence of the existence of considerable seismic activity in the UAE.

3 Data Collection

Soil borehole logs from over 200 sites covering most parts of Emirates of Sharjah were utilized in this study. Boreholes selected were those with overburden thickness varying from 1 to 30 m representing typical geological features of Sharjah. The exact GPS locations for all boreholes obtained from Sharjah Directorate of Town Planning and Surveying are as shown in Fig. 8.

3.1 *Shear Wave Velocity*

Due to lack of availability of actually published shear wave velocities for the study area, Lyisan [10] used the following empirical model:

$$V_s = 51.5N^{0.516}, \tag{1}$$

where

N uncorrected SPT
V_s shear wave velocity, m/s

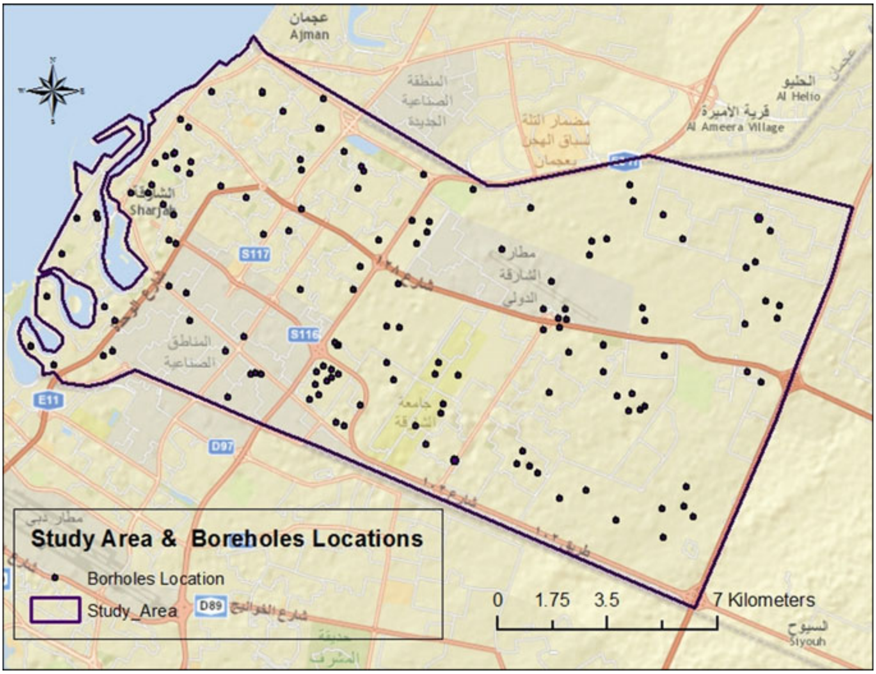

Fig. 8 Boreholes locations in Sharjah City

3.2 Earthquake Selection Procedure at Bedrock Level

Due to the lack of recorded earthquakes in the city, a set of artificial ground motions were generated to match a target response spectrum as shown in Fig. 9, where the minor Masafi earthquake in 2002 with (PGA = 0.03 g) was used as an envelope to the frequency response shown in Fig. 10. Seismosoft, 2016 program was used to perform artificial accelerogram generation following the work of [11].

The proposed analysis and response spectrum construction follows the same technique adopted by Bartlett et al. [12] and are consistent with site-specific ground response analyses and spectra outlined by MCEER/ATC-49 for highway bridge design, but the methods are general enough so that can also be applied to building design [12]. The following steps were followed [13]:

1. Generation of seven earthquakes
2. Performing spectral matching of candidate earthquake records to the target surface level spectrum as shown in Fig. 11
3. Deconvolution of the seven earthquakes using generic boreholes, Figs. 12 and 13, deconvolution of the generated earthquakes through generic boreholes representing different locations of the city to get the bedrock motion

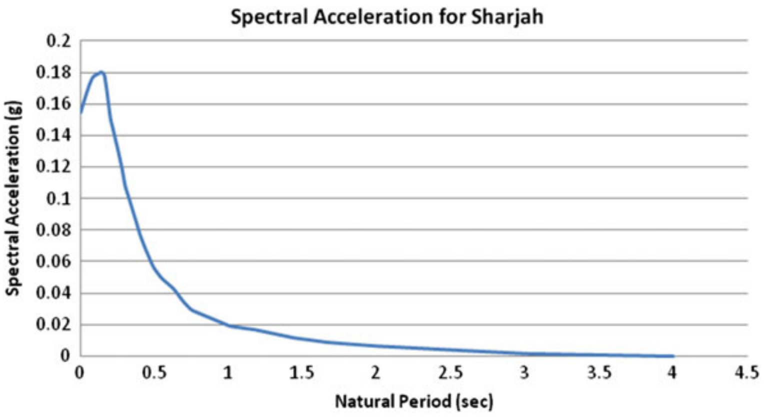

Fig. 9 Spectral acceleration for (M = 5) Sharjah for 50 years' exposure time and 0.1 probability of exceedance [22]

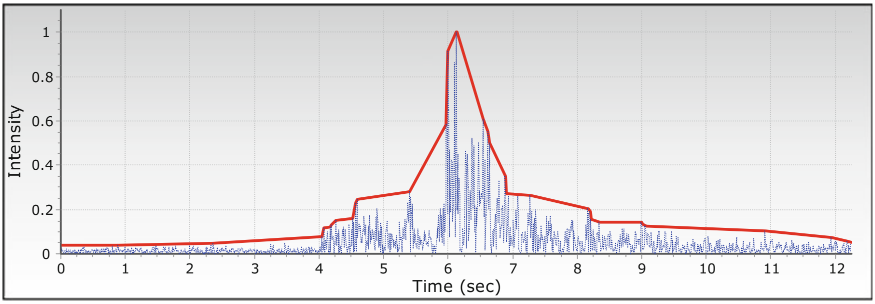

Fig. 10 Masafi, 2002 earthquake envelope

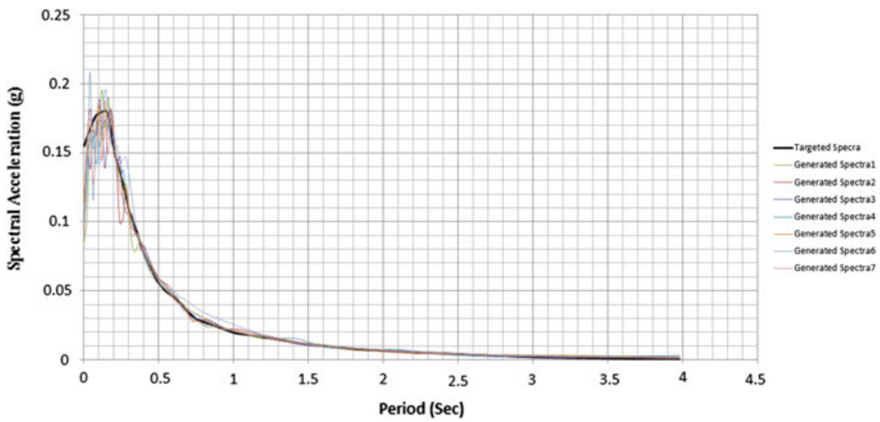

Fig. 11 Performing spectral matching of candidate earthquake records to the target rock spectrum

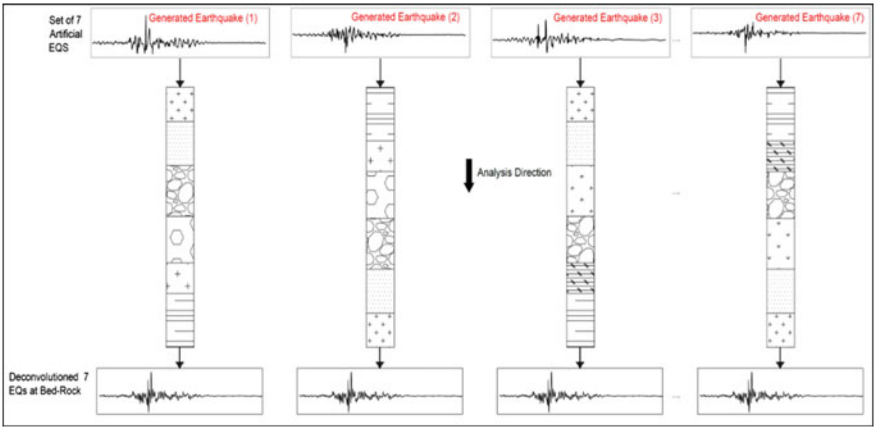

Fig. 12 Deconvolution of the generated earthquakes through generic boreholes

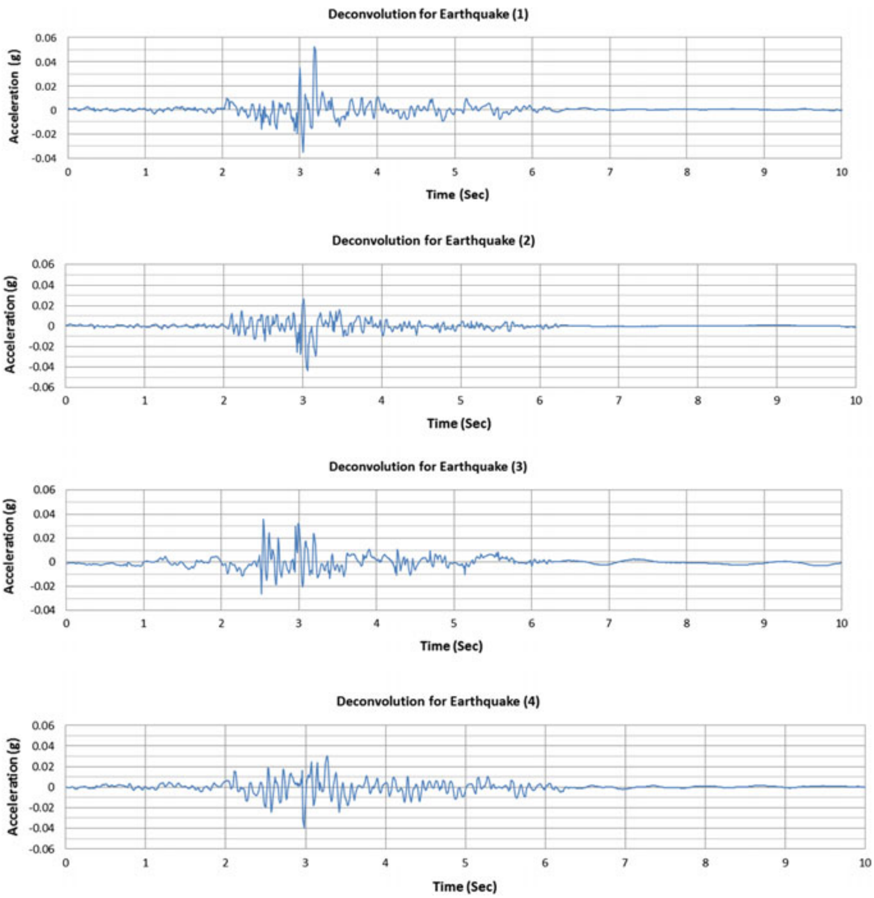

Fig. 13 Time history for deconvolution earthquakes

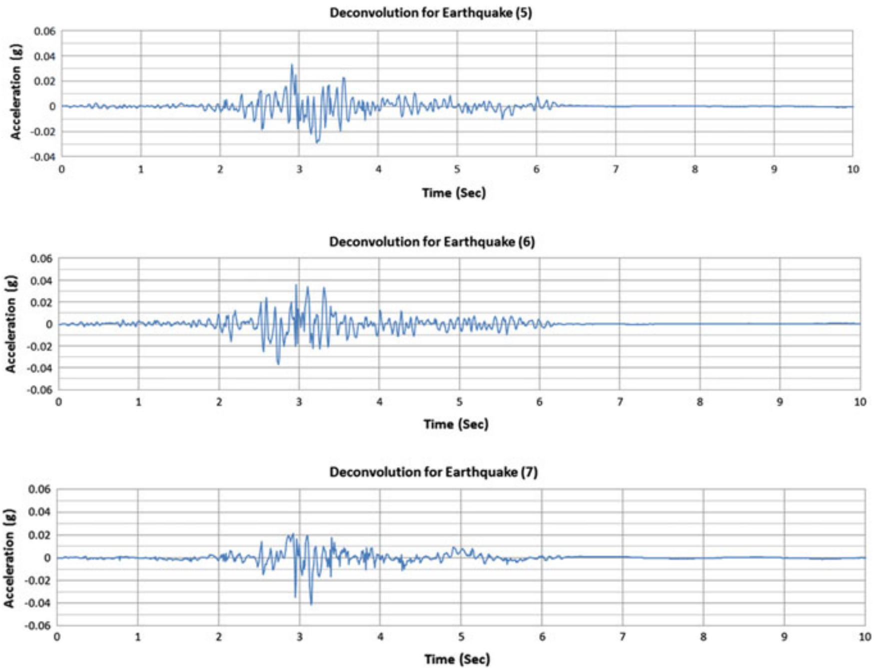

Fig. 13 (continued)

4 Results and Discussions

The estimation of soil amplification in this work is based on shear wave velocities, site periods, and amplification factors. A $V_{s(30)}$ map, site period and amplification factor maps were produced for the upper 30 m depth, in addition to peak ground acceleration at bedrock and surface maps. All maps were done depending on the average shear wave velocity to a depth 30 m.

4.1 Peak Ground Acceleration at Surface

PGA is the largest estimation of horizontal acceleration obtained from an accelerogram of that component. It is the most normally utilized measure of amplitude of a particular ground motion because the dynamic forces induced in structures closely related to the parameter PGA Value in this study is 0.15 g as discussed previously.

The PGA value at bedrock level amplified based on the soil profile at various locations. The acceleration-time histories at various depths obtained as output from SHAKE analysis. The peak acceleration value at the surface obtained for each

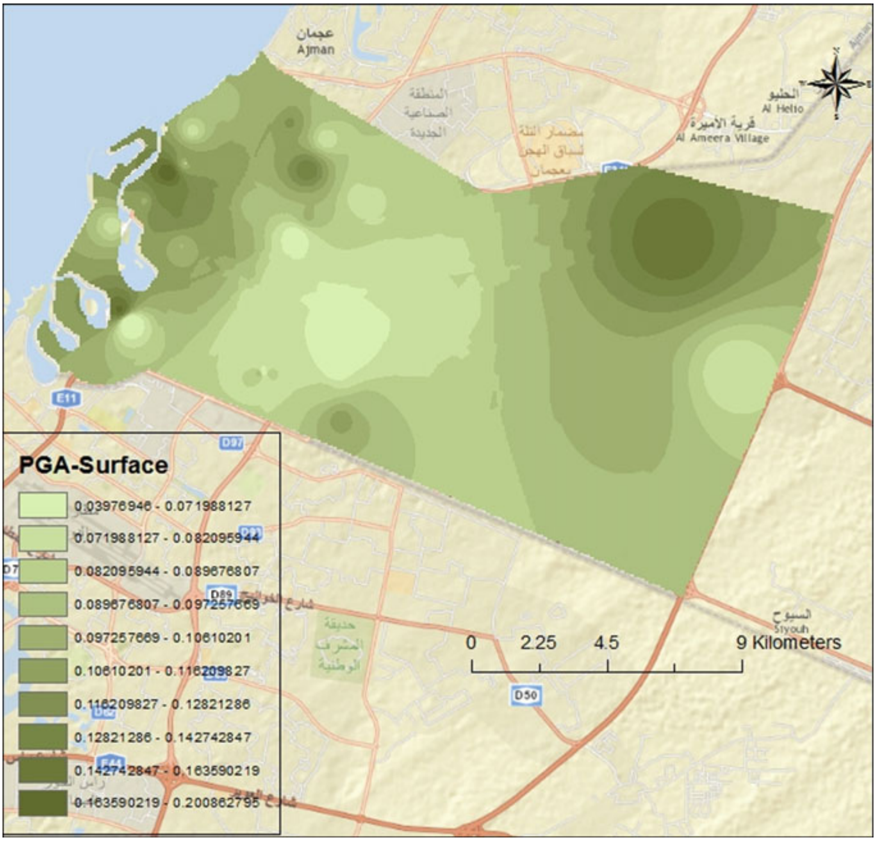

Fig. 14 PGA at surface

location plotted to obtain the Peak Ground Acceleration (PGA) map at ground surface as shown in Fig. 14. This PGA value at surface varies from 0.039 to 0.2 g and irregularly distributed due to variation in the soil profile at various locations.

4.2 *The Shear Velocity Distribution*

The elastic properties of materials located near the surface and their effect on the spread of seismic waves are critical in earthquake engineering. The increasing amplitude in soft-layered soils is one of the most influential parameters responsible for the amplification of an earthquake motion. For soil amplification and site response studies, the 30 m average shear wave is considered sufficient [14] and $V_s(30)$ can be obtained by the following relationship:

$$V_{s(30)} = \frac{30}{\sum_{i=1}^{N} \frac{d_i}{v_i}}, \tag{2}$$

where d_i and v_i represent ith layer's thickness and velocity.

Shear waves velocity distribution down to a depth of 30 m shown in Fig. 15. The determined average shear wave velocities categorized with respect to the NEHRP site classes and a map has been generated using ArcMap. Based on this, the study area is considered to consist of one class for seismic local site effects, which is site class C (180 m/s < $V_{s(30)}$ < 360 m/s) that refers to Table 1 [15]. The map in Fig. 15 shows the average shear wave velocity distribution to a depth of 30 m.

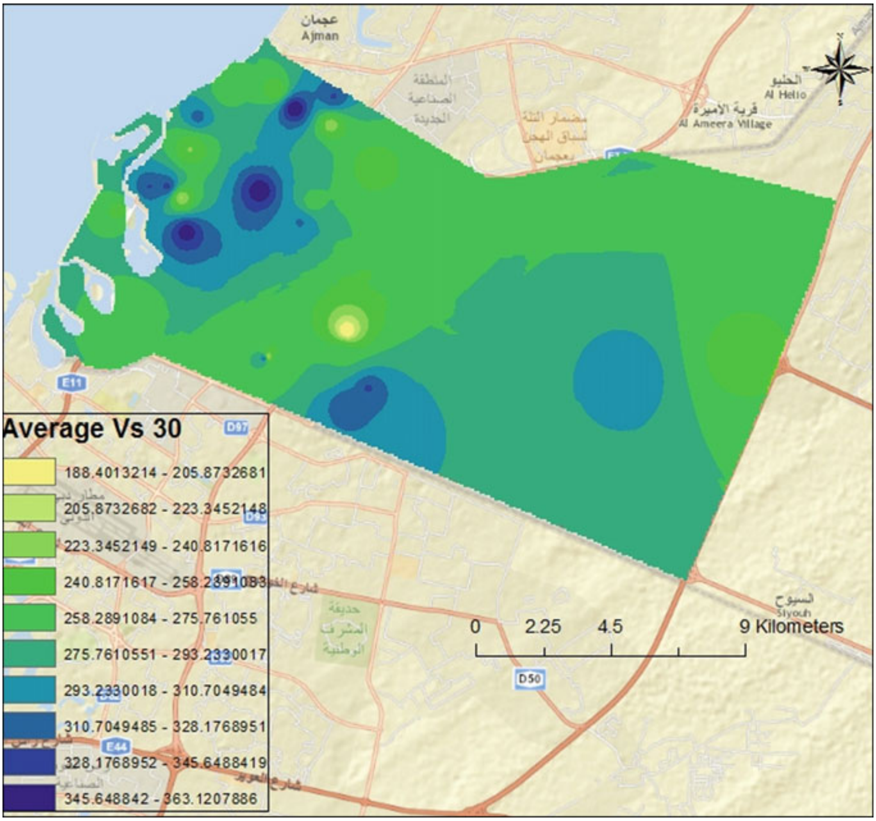

Fig. 15 $V_{s(30)}$ distribution map

Table 1 Site classes [15]

Site class	V_s in upper 30 m
A	>750/s
B	360–750/s
C	180–360/s

4.3 Amplification Factor

Amplification factor is a parameter that specifically identified with the seismic risk of the region. Initially, maximum factors of amplification obtained within the acceleration, velocity, and displacement controlled regions, which presented, generally, in such format in seismic design standards. The outcomes demonstrated that there was no genuine pattern with depth or shear wave velocity of the site when the amplification factors were obtained in such a manner. This is because the magnitude of the amplification factor highly depends on the shear wave velocity, while the location of the amplification is highly dependent on the site's period.

The amplification factor for specific period range is a function of $V_{s(30)}$. For periods greater than 0.5 s, the amplification factors are not very sensitive to period but are much greater than the short period amplification factor for the period less than 0.5 s. Two sets were used to calculate the amplification factors; one set for short periods ($T_s < 0.5$ s) and another set for long periods ($T_s > 0.5$) [16]. In the present study, the range of site period belongs to the short periods ($T_s < 0.5$). The period-dependent amplification factor was calculated using the following formula:

$$\mathrm{AF} = \left(\frac{997}{V_{s(30)}\ \mathrm{m/s}}\right)^{0.36}, \tag{3}$$

where V is the average shear wave velocity to 30 m depth measured in m/s.

Based on this relation, the amplification factors for the study are shown in Table 2.

As it is seen in the graph below, there is inversely proportional relation between amplification factors and shear wave velocity values. That means, as the shear wave velocity increases the value of amplification factor also decreases and vice versa Fig. 16.

The calculated amplification factor in this study ranges from 1.44 to 1.83. The quantitative amplification factors obtained and these results were used to prepare the amplification factor map using ArcMap. The value of amplification factor for the study area is larger, where the value of $V_{s(30)}$ is low.

The site amplification factor map based on equations for the area is presented in Fig. 17. This map indicates that the north, northwestern, south, and southeastern (yellowish green to light green color) are characterized by low amplification factor values ranging between 1.44 and 1. The central part shown in dark green indicates medium amplification factor values; the range of this value is between 1.85 and 1.61. The third category is the light to dark blue colored part exposed in the central part of the area, where the amplification factor is high or more than 1.63.

Figure 18 shows amplification factor map for the area from SHAKE2000, slightly different in the amplification factor between equations and software, following Table 3 shows the results.

Table 2 Amplification factor values for each $V_{s(30)}$

$V_{s(30)}$ (m/s)	Amplification factor	$V_{s(30)}$ (m/s)	Amplification factor
363.6	1.44	267.3	1.61
359.2	1.44	265.1	1.61
357.2	1.45	265.1	1.61
333.0	1.48	263.5	1.61
332.8	1.48	260.1	1.62
330.4	1.49	258.0	1.63
329.9	1.49	253.6	1.64
329.3	1.49	251.0	1.64
323.9	1.50	250.8	1.64
317.1	1.51	242.7	1.66
315.1	1.51	242.6	1.66
312.1	1.52	230.6	1.69
304.6	1.53	221.7	1.72
287.5	1.56	215.3	1.74
286.3	1.57	212.0	1.75
286.1	1.57	206.1	1.76
286.0	1.57	194.0	1.80
274.4	1.59	188.2	1.82

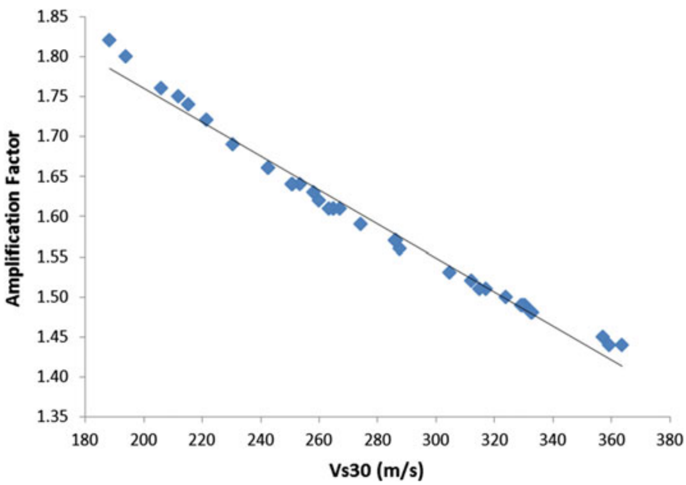

Fig. 16 $V_{s(30)}$ versus amplification factor

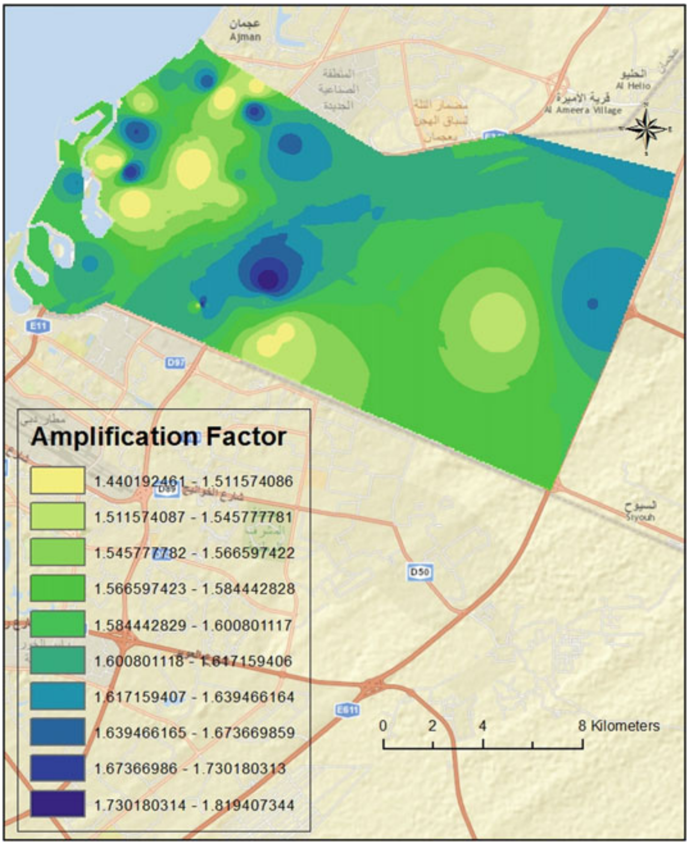

Fig. 17 Amplification factor map based on equations

4.4 Variability in Amplification Factors

Amplification factor varies as the value of $V_{s(30)}$ varies. Figure 19 plots amplification factor versus period for each of the $V_{s(30)}$ values. The factors of amplification for a given $V_{s(30)}$ are highly scattered. The amount of scatter varies with $V_{s(30)}$ and period.

4.5 Soil Liquefaction

It generally acknowledged that only recent sediments or fills of saturated, cohesionless soils at shallow depths would liquefy due to earthquake. The conditions required for liquefaction to occur are [17]:

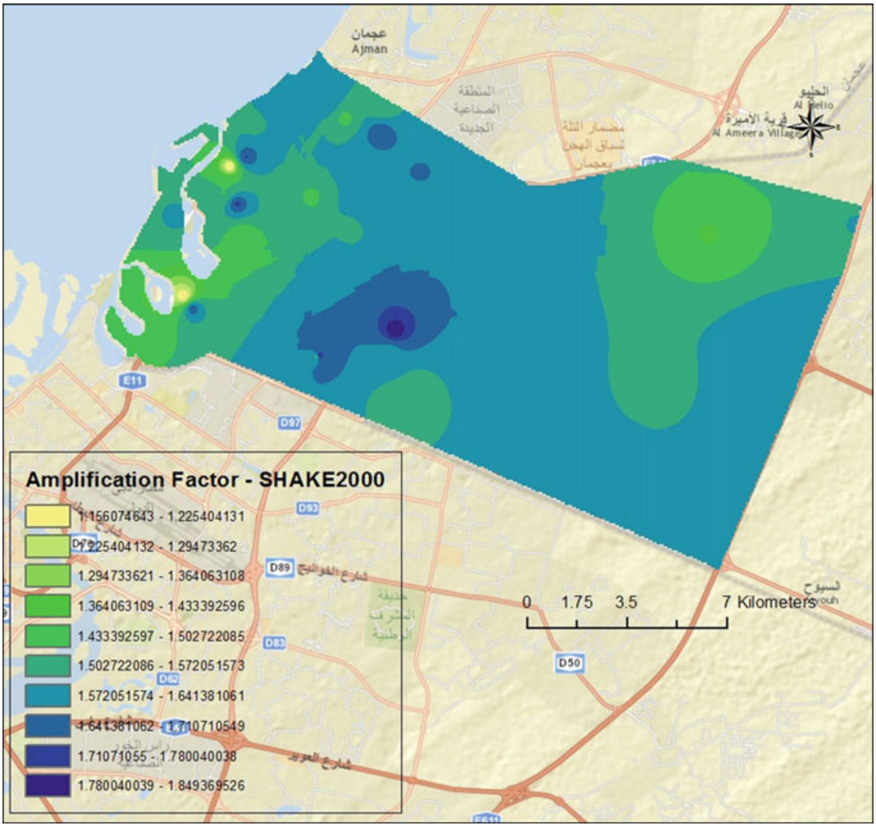

Fig. 18 Amplification factor map—SHAKE2000

a. the soil deposit is sandy or silty soil;
b. the soil is saturated or nearly saturated (usually below groundwater table);
c. the soil is loose or medium compact;
d. the soil is subjected to seismic stress (such as from earthquake, blast, etc.).

Earthquakes magnitude scaling factor (MSF) was taken 0.73 corresponding to highest earthquake magnitude $M_w = 8.5$, according to studies done for Dubai and Abu Dhabi [2, 6]. The safety factors figured along the entire profundity of the borehole for all liquefiable soil layers considering the accessible SPT-N blow count numbers utilizing the surface peak ground accelerations determined using site response analysis. For each borehole, the liquefaction potential was determined using the variation of the safety factors with depth. The factor of safety against liquefaction was grouped into four groups as shown in Table 4.

Microzonation maps in terms of the liquefaction for Sharjah city developed based on different method developed by researchers.

Table 3 Amplification factor equation versus SHAKE2000

AF (equation)	AF (SHAKE2000)	Difference	AF (equation)	AF (SHAKE2000)	Difference
1.57	1.17	0.40	1.49	1.57	−0.08
1.61	1.15	0.46	1.19	1.59	−0.40
1.69	1.5	0.19	1.82	1.63	0.19
1.52	1.43	0.09	1.41	1.65	−0.24
1.14	1	0.14	1.64	1.62	0.02
1.51	1.48	0.03	1.57	1.61	−0.04
1.49	1.44	0.05	1.56	1.68	−0.12
1.80	1.5	0.30	1.64	1.63	0.01
1.74	1.5	0.24	1.75	1.64	0.11
1.44	1.52	−0.08	1.50	1.66	−0.16
1.49	1.53	−0.04	1.72	1.6	0.12
1.45	1.51	−0.06	1.48	1.63	−0.15
1.48	1.52	−0.04	1.63	1.65	−0.02
1.51	1.56	−0.05	1.61	1.71	−0.10
1.61	1.55	0.06	1.44	1.73	−0.29
1.41	1.55	−0.14	1.66	1.75	−0.09
1.57	1.56	0.01	1.59	1.8	−0.21
1.76	1.6	0.16	1.66	1.81	−0.15
1.64	1.59	0.05	1.62	1.83	−0.21
1.53	1.58	−0.05	1.61	1.85	−0.24

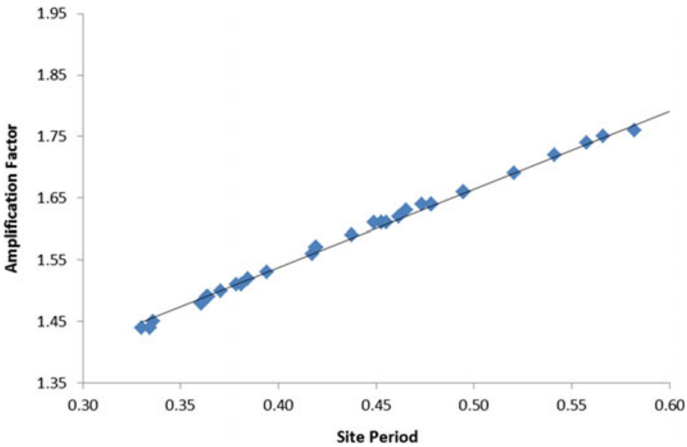

Fig. 19 Site period versus amplification factor graph

Table 4 Factor of safety against liquefaction groups [23]

Group	Factor of safety range	Severity index
1	<1	High
2	1–2	Moderate
2	2–3	Low
4	>3	Nil

Method Developed by Seed et al. [18]. Following Fig. 20 shows Liquefaction Safety Factor values based on Seed et al. for Sharjah City. The calculated safety factor following this method ranges between 0.56 and 6.42; refer to Table 4, most parts of the area is in the moderate range which is shown in orange color in the map, some parts of the area have nil liquefaction index displayed by yellow color, high severity index displayed by red color which quit few areas.

Method Developed by NCEER [19]. Figure 21 shows map of Safety factor against liquefaction based on NCEER [19]. This map indicates the north, northwest, and northeast (reddish orange color) characterized moderate severity index and low value of safety factor between 1 and 2. The south part of the area shown by yellow

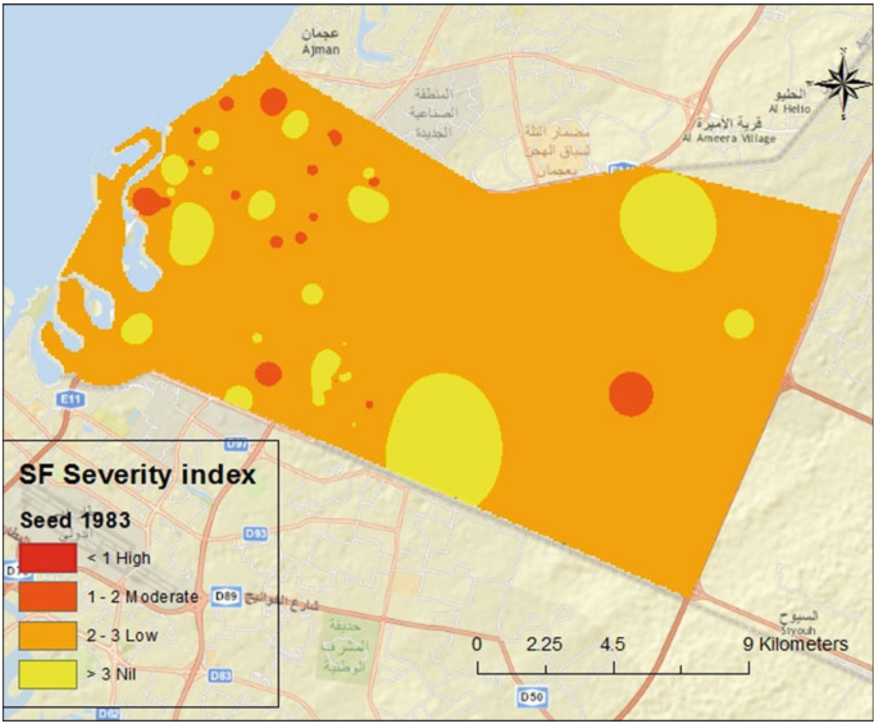

Fig. 20 Safety factor based on [18]

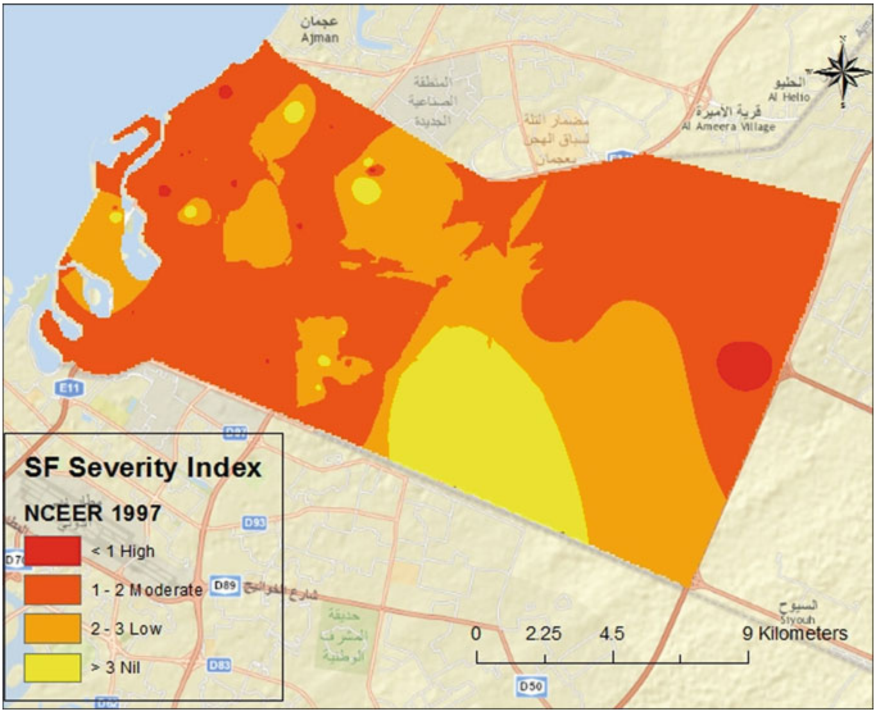

Fig. 21 Safety factor based on [19]

color indicates nil severity index and safety factor more than 3, some parts covered by orange color have low severity index and safety factor between 2 and 3.

Method Developed by Boulanger and Idriss [20]. Figure 22 indicates map based on Boulanger and Idriss [20] the south parts (yellow color) characterized nil severity index and high values of safety factor more than 3. The other parts of the area presented by reddish orange color indicates high to moderate severity index and maximum safety factor value of 2.

Vancouver [21]. Safety factor severity index map for the area is presented in Fig. 23. This map indicates that the north, northeastern, southeastern, and some parts of east (reddish orange color) are characterized by moderate severity index values of safety factor vary between 1 and 2. The central part shown in orange indicates low severity index and safety factor values between 2 and 3. The third category is the yellow colored part exposed in the south part of the area where the site safety factor against liquefaction is more than 3 which showed zero severity index.

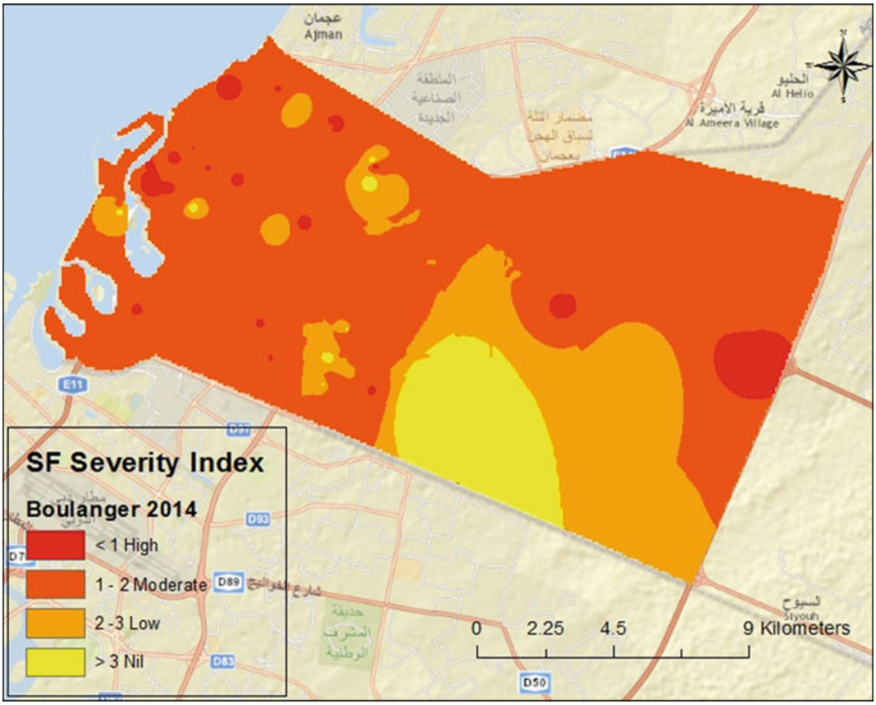

Fig. 22 Safety factor based on [20]

Combination of four methods. In this map, shown in Fig. 24, the previous four methods were used to prepare a map based on average of the four methods.

This map indicates that the north, northeastern, and southeastern (reddish-orange color) are characterized by moderate severity index values of safety factor which varies between 1 and 2. The central part shown in orange indicates low severity index and safety factor values between 2 and 3. The yellow colored part exposed in the south part of the area, where the site safety factor against liquefaction is more than 3, shows nil severity indexes. The following Table 5 shows a sample of soil liquefaction values of the previous methods.

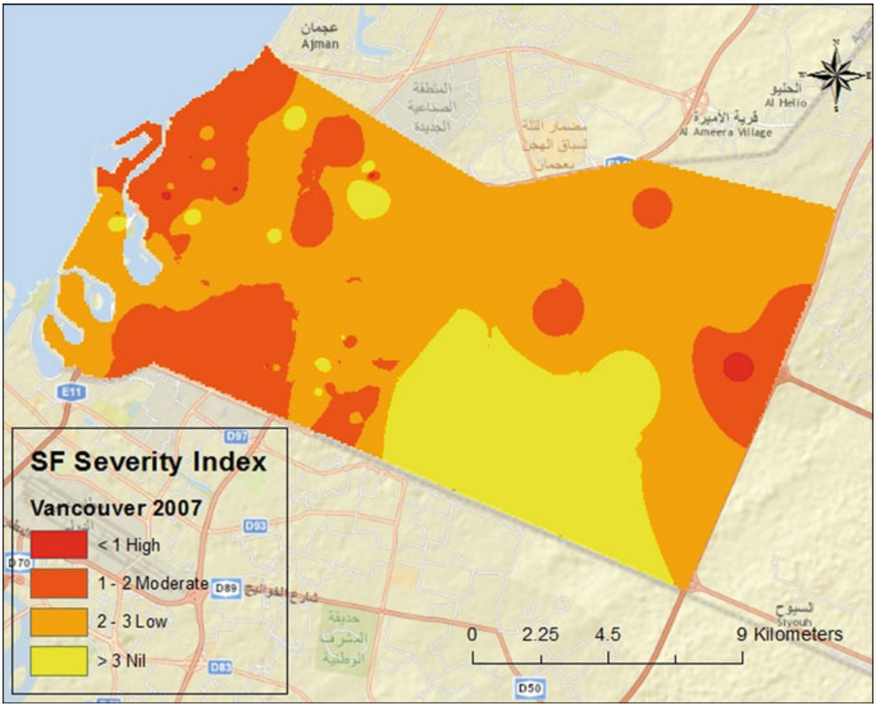

Fig. 23 Safety factor based on [21]

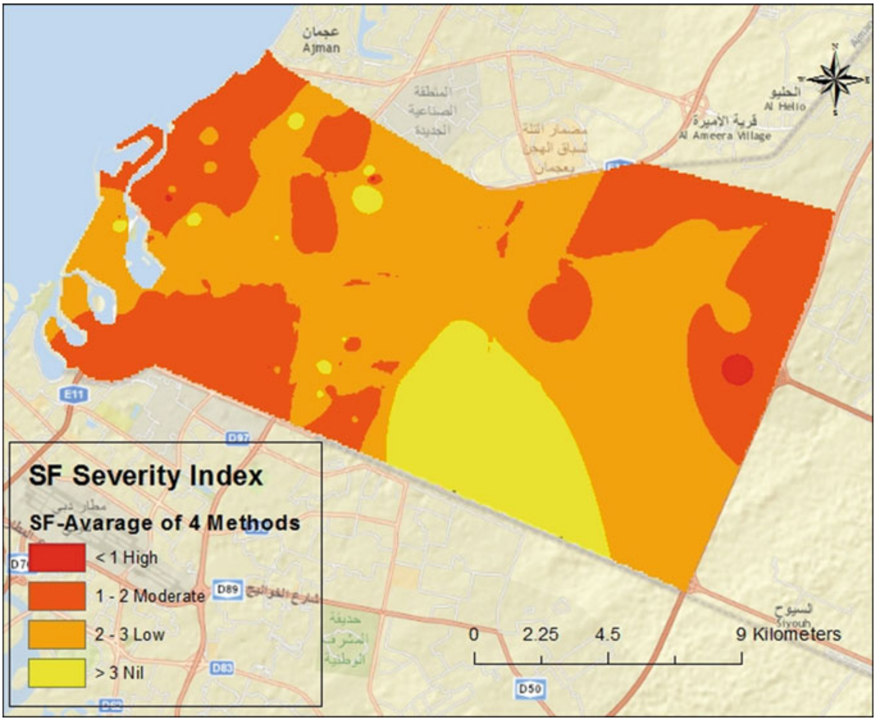

Fig. 24 Safety factor based on average of four methods

Table 5 Sample of soil liquefaction values of previous methods

BH_NO	NCEER workshop [19]	Boulanger and Idriss [20]	Vancouver task force [21]	Seed et al. [18]	Average
7	5.88	5.37	6.1	4.8	5.54
14	5.68	5.67	5.68	5.68	5.68
15	2.84	2.83	2.84	2.84	2.84
16	0.47	0.62	0.47	1.03	0.65
23	0.46	0.61	0.46	0.93	0.61
24	0.41	0.58	0.41	0.94	0.59
31	5.65	5.61	5.65	5.65	5.64
32	5.62	5.6	5.62	5.62	5.62
34	5.57	5.53	5.57	5.57	5.56
41	5.89	5.28	5.89	4.53	5.4
42	5.22	5.46	5.22	5.1	5.25
43	5.07	3.87	5.07	3.63	4.41
52	0.96	0.97	0.96	1.46	1.09
53	0.88	0.92	0.88	1.38	1.01
64	0.42	0.6	0.42	0.94	0.59
65	0.26	0.42	0.26	0.81	0.44
71	2.17	2.28	2.26	3.16	2.47
72	5.68	5.63	5.86	5.86	5.76
74	0.6	0.74	0.6	1.16	0.78
76	0.6	0.73	0.6	1.15	0.77
82	1.46	1.48	1.46	2.08	1.62
83	1.91	2.12	1.91	2.67	2.15
93	1.87	2.04	1.87	2.65	2.11
112	0.38	0.54	0.38	0.98	0.57
115	1.66	1.74	1.66	2.35	1.85

5 Conclusion

Soil amplification of the site expressed in terms of amplification factor. The calculated value of amplification factor for the site ranges from 1.44 to 1.83. The higher values of the amplification factors are located in the central portions and in these parts, the higher amplification factor shows high amplification potential and high seismic hazard. Lower values of amplification factor are found in all other parts of the study area. In these sites, the lower amplification factor indicates low amplification potential of the soil and relatively low seismic hazard. The damage due to seismic hazard is much higher on the unconsolidated soils than on solid rocks.

Soil liquefaction studies were carried out in Sharjah City. Soil liquefaction of the site was expressed in terms of safety factor. The calculated value of safety factor for the site was divided into four categories, safety factor less than 1 indicates high severity index, SF value between 1 and 2 indicates moderate severity index, SF value between 2 and 3 indicates low severity index, and more than 3 indicates nil severity index. The low values of the safety factors against liquefaction are located in the north, northeastern, and southeastern portions and in these parts, the lower safety factor shows high liquefaction potential and high seismic hazard. Higher values of safety factor found in central and toward south central parts of the study area. In these sites, the higher safety factor indicates low liquefaction potential of the soil and relatively low seismic hazard. The damage due to seismic hazard is much higher on the unconsolidated soils than on solid rocks.

References

1. TC4-ISSMGE: Manual for Zonation on Seismic Geotechnical Hazard. Revised edition, Technical Committee For Earthquake Geotechnical Engineering (TC4) of International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE), p. 209 (1999)
2. Assessment of Seismic Hazard and Risk in Emirate of Abu Dhabi Municipality (2011)
3. Borcherdt, R.D.: Estimates of site dependent response spectra for design (methodology and justification. Earthq. Spectra **10**(4), 617–654 (1994)
4. Youd, T.L., Idriss, I.M., Andrus, R.D., Arango, I., Castro, G., Christian, J.T., Dobry, R., Finn, W.D.L., Harder, Jr., L.F., Hynes, M.E., Ishihara, K., Koester, J.P., Liao, S.S.C., Marcuson, III., W.F., Martin, G.R., Mitchell, J.K., Moriwaki, Y., Power, M.S., Robertson, P.K., Seed, R. B., Stokoe, II., K.H.: Liquefaction resistance of soils: summary report from the 1996 NCEER and 1998 NCEER/NSF workshops on evaluation of liquefaction resistance of soils. ASCE J. Geotech. Geoenviron. (2001)
5. Idriss, I.M., Sun, J.I.: Shake91, a computer program for conducting equivalent linear seismic response analysis of horizontally layered soil deposits. Modified based on the original SHAKE program Published in December 1972 by Schnabel, Lysmer and Seed (1992)
6. Ansal, A., Kurtulus, A., Tönük, G.: Assessment of Seismic Hazard and Risk in Dubai. Department of Earthquake Engineering, University Istanbul, Turkey, UAE (2008)
7. Iwasaki, T., Tokida, K., Tatsuoka, F., Watanabe, S., Yasuda, S., Sato, H.: Microzonation of soil liquefaction potential using simplified methods. In: Proceedings of the 3rd International Conference on Microzonation, Seattle, vol. 3, pp. 1319–1330 (1982)
8. Omar, M., Shanableh, A., Balwan, M., Fattah, M.Y., Hamad, K.: Influence of local soil conditions on ground response—site amplification Sharjah, United Arab Emirates. Int. J. Mod. Eng. (IJME) **13**(2), 34–40 (2013) (ISSN: 2157-8052)
9. Jamal, A., A-Homoud, A.S.: Seismic hazard assessment of United Arab Emirates and its surroundings. J. Earthq. Eng. **8**(6), 817–837 (2004) (Imperial College Press)
10. Lyisan, R.: Correlations between Shear wave velocity and in-situ penetration test results. Teknik Dergi J. **2**(2), 1187–1199 (1996)
11. Halldorsson, B., Papageorgiou, A.S.: Calibration of the specific barrier model to earthquakes of different tectonic regions. Bull. Seism. Soc. Am. **95**, 1276–1300 (2005)
12. Bartlett, S.F., Ostadan, F., Abghari, A., Farnsworth, C.: Development of design spectra for deep and soft soil sites. www.civil.utah.edu/~bartlett/CVEEN6330/spectra.pdf
13. Baroud, M.: One Dimentional Dynamic Nonlinear Site Response Analysis. Sharjah City, United Arab (Case Study) (2016)
14. Kanli, A.I., Tildy, P., Prónay, Z., Pınar, A., Hermann, L.: VS30 mapping and soil classification for seismic site effect evaluation in Dinar region, SW Turkey. Geophys. J. Int. **165**(1), 223–235 (2006)

15. Boore, D.M., Joyner, W.B., Fumal, T.E.: Estimation of response spectra and peak accelerations from western North American earthquakes: An interim report (1993)
16. Ishihara, K.: Perspectives on earthquake geotechnical engineering. In: Geotechnical, Geological and Earthquake Engineering, 45 pp (2015)
17. Xiao, M.: Geotechnical Engineering Design. Wiley, United Kingdom (2015)
18. Seed, H.B., Idriss, I.M., Arango, I.: Evaluation of liquefaction potential using field performance data. J. Geotech. Eng. ASCE **109**(3), 458–482 (1983)
19. Youd, T.L., Idriss, I.M.: Proceedings of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils. Technical Report No. NCEER-97-0022, 31 Dec 1997
20. Boulanger, R.W., Idriss, I.M.: Evaluating the Potential for Liquefaction or Cyclic Failure of Silts and Clays. Report No. UCD/CGM-04/01, Center for Geotechnical Modeling, Department of Civil and Environmental Engineering, University of California, Davis, Calif (2004)
21. Vancouver Task Force Report: Task Force Report, Geotechnical Design Guidelines For Buildings on Liquefiable Sites in Accordance with NBC 2005 for Greater Vancouver Region, 8 May 2007
22. Malkawi, A.I.H., Barakat, S., Shanableh, A., Al Bdour, W., Omar, M., Altoubat, S.: Seismic Hazard Assessment and Mitigation of Earthquake Risk in the United Arab Emirates. Published Jointly by Jordan University of Science and Technology and the Deanship of Research and Higher Studies, University of Sharjah, United Arab Emirates (2007)
23. Sitharam, T.G., Anbazhagan, P., et al.: Seismic Hazarad Studies Using Geotechnical Borehole Data and GIS, pp. 23–24 (2005)