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EARTHQUAKE HAZARD ZONATION OF EASTERN ARABIA

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SUMMARY

This paper presents seismic hazard assessment and seismic zoning of United Arab Emirates and its vicinity based on the probabilistic approach. The studied area lies between 50°E - 60°E and 20°N - 30°N and spans several Gulf countries. First, the geology and tectonics of the area and its surroundings is reviewed. An updated catalogue, containing both historical and instrumental events, is used. Seismic source regions are modeled and relationships between earthquake magnitude and earthquake frequency is established. An attenuation relation for Zagros is used. Seismic hazard assessment was carried out for 25 km interval grid points. Seismic hazard maps of the studied area based on probable Peak Ground Acceleration (PGA) for 10% probability of exceedance for time-spans of 50 and 100 years is shown. Peak ground acceleration for selected cities and seismic zone map for a 475-year return period are shown.

INTRODUCTION

Seismic hazard zoning studies were conducted for different countries of the Arabian Peninsula, that include: (1) Saudi Arabia [1]; (2) Iran [2]; and (3) Jordan and surrounding countries [3] and others. In spite of this there are very few published seismic hazard studies for the Arabian Gulf counties. In fact none of the countries in this region is included in the global review of hazard assessments published by IASPEI and ESC [4]. The eastern portion of the Arabian Peninsula, including Bahrain, Kuwait, Qatar, Northern Oman and United Arab Emirates, is one of the few areas that are not covered by the Global Seismic Hazard Assessment Programme (GSHAP). Grunthal et al. [5] compiled a seismic hazard map for Europe, Africa and Middle East from individual area studies in these regions that were carried out as part of GSHAP. The region of UAE is not covered by individual studies and the hazard was mapped by simulating the attenuated effect of the seismic hazard activity in the Zagros province of Iran [5]. This extrapolation resulted in hazard levels that reach almost 0.5g at the northern most part of the UAE and that are greater than 0.2 g in most of the country. These mapped values can be confidently rejected as having a very weak scientific basis and being grossly over-conservative.

A more reliable study is the seismic hazard assessment for the Kingdom of Saudi Arabia carried out by Al-Haddad et al. [1]. Their study actually considers seismic hazard throughout the Arabian Peninsula. The seismic source zones defined by Al-Haddad et al. [1] that lie within Saudi Arabia are mainly on the western side and along the Red Sea and Gulf of Aqaba. There are no seismic source zones defined in

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eastern Saudi Arabia or in Oman and the UAE, all of which are considered to be devoid of appreciable earthquake activity. The only source of earthquake activity identified by Al-Haddad et al. (1994) that could significantly affect hazard levels in the UAE is their Source zone 11 in southern Iran, for which a maximum magnitude of 7.5 is assigned. The shortest distance between the boundaries of this source zone and Dubai for example is of the order of 125 km.

Al-Haddad et al. [1] produced a map of iso-accelerations with a 10% probability of exceedance in 50 years, which is equivalent to a return period of 475 years. The hazard level in Dubai and Sharjah, according to this study, is significantly below 0.05 g. The attenuation relationship used by Al-Haddad et al. [1] is the one developed for Western USA. Such attenuation relationship may not be appropriate for the region under consideration.

Reference is made here also to the most recent seismic hazard study for Iran [2, 6]. It is clear from this study that the largest earthquakes and most intense activity in the Zagros are concentrated along or close to the line of the main thrust fault. The activity becomes more diffuse to the southwest through the Zagros folded belt. This study is intended to improve on previous work and include areas that were not covered previously by seismic hazard assessment of the region.

GEOLOGY, TECTONICS AND SEISMICITY OF UAE

Geographically, United Arab Emirates is bordered in the north by the Arabian/Persian Gulf, to the east by the Gulf of Oman and Sultanate of Oman, to the south by Saudi Arabia and Sultanate of Oman and to the west by Qatar and Saudi Arabia.

Geologically, the features of UAE follow that of the Arabian Platform. The rocks in the Arabian Platform accumulated on stable marine-to-fluviatile shelf. Uplift and collapse of arches and basins, movements on fault blocks, and migration of shoreline backward and forward across this shelf resulted in the interactions and migrations of sandstones, siltstones, carbonates and salt basin that characterized the region [7, 8].

Tectonically, UAE is situated in the South-Eastern part of the Arabian plate. The Arabian plate is one of the youngest plates that make up the surface of the earth. The plate comprises a crystalline basement of Precambrian continental crust about 40-50 km thick, an overlaying basement of sequence of younger Phanerozoic sedimentary rocks that range in thickness from zero to 10 km, in addition to basalt and oceanic basin. The separation and splitting of the Arabian Plate from the African Plate along the Red Sea and the Gulf of Aden axes followed by drift of the Arabian Plate to the north and northeast, lead ultimately to a collision with the Eurasian plate that resulted in the formation of the Zagros fold belt. Zagros fold belt is the major source of earthquakes in the eastern border of the Arabian plate [7].

There are several major fault systems that surround the Arabian Plate. The northwest boundary of the Arabian Plate is the left-lateral Dead Sea Fault Zone. The southeast boundary of the Arabian Plate is the Owen Fracture Zone (OFZ) in the northwestern Indian Ocean [9, 10]. The western boundary of the Arabian Plate is the Red Sea Rift and Sheba Ridge systems. The seismicity of few of these directly affects the seismicity of UAE. As shown in Figure 1, Zagros Fold and Thrust Belt and Makran Subduction Zone are the only two fault systems that have direct effect on the seismicity of UAE. An overview of the characteristics, geometry, tectonic positions and seismic activity of these two fault systems will be presented.

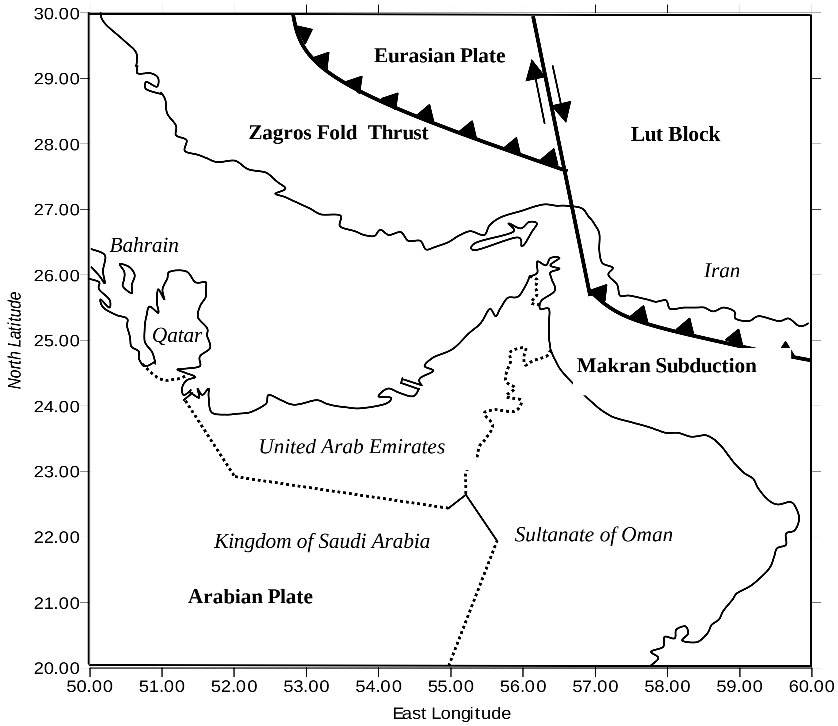

Figure 1. Tectonics of UAE and its vicinity.

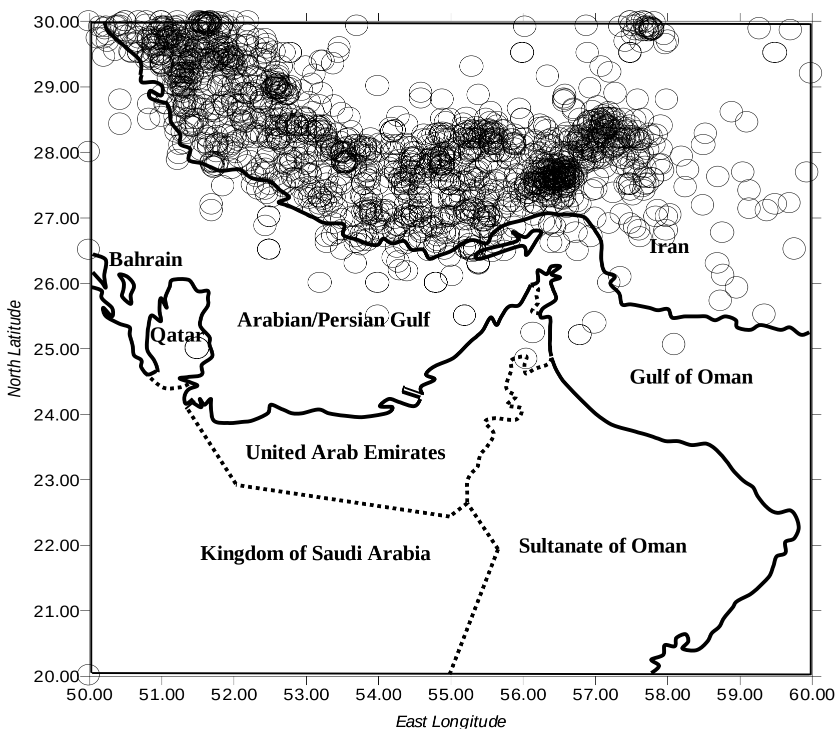

Figure 2. Seismicity of UAE and its vicinity.

Zagros Fold and Thrust Belt

The Zagros fold and thrust belt forms the boundary between the Arabian and Eurasian plates. Zagros belt is one of the most active fault zones in the world and extend a distance of over 1500 km in NW-SE direction along the northeastern part of Iraq and the western part of Iran which extends passing from Turkey in the north to Oman in the south [11]. The Zagros belt zone is about 200 km wide and most seismic activities take place in the coastal part of the Arabian Plate that underlies the Zagros Folded Belt. This highly active seismic region forms the boundary between the Arabian and Eurasian plates and results in numerous damaging earthquakes [12]. The Zagros fold and thrust belt is highly active seismic region. Shoja-Taheri and Niazi [13] identified the Zagros as the second most seismically active region in Iran, after the Hindu Kush region. However, they also identified large b-values for the recurrence relationship in the Zagros, which implies that far more small and moderate magnitude earthquakes occur than large magnitude events.

Makran Subduction

The Makran subduction is the region where the Gulf of Oman is continue to subduct under the southern region of the Eurasian plate. It differs from other subducting segments of the Arabian Plate in that it is an oceanic crust rather than continental crust that is being subducted beneath Eurasian Plate. This oceanic crust extends eastward to Owen Fracture Zone (OFZ) along the Indian Plate boundary. This is a region that can produce great earthquakes. Byrne et al. [14] identify a very distinct difference between the western and eastern parts of the Makran, with no evidence for large earthquakes in the western portion during the instrumental or historical periods. The eastern Makran, where great earthquakes can happen, is far from the UAE and therefore has negligible effect.

EARTHQUAKE CATALOGUE CLEAN UP AND COMPLETENESS

There are several catalogs available for the region of interest. These mainly include: The National Earthquake Information Center (NEIC), International Seismological Center (ISC), International Institute for Seismology and Earthquake Engineering (IISEE), British Geological Survey (BGS), National Oceanic and Atmospheric Administration (NOAA) and others. This catalogue is completed and cleaned from heterogeneities by IIEES [15]. The moment magnitude in the catalogue is used.

SEISMIC HAZARD ASSESSMENT

Modeling Of Seismic Source Regions In Uae And Surroundings

There are several types of seismic source modeling. Mainly, point source, and line or plane source and area source. In this investigation area source region model is adopted and assumed to have homogenous seismicity. UAE and most of its surrounding has been divided into seven seismic source regions, as shown in Figure 3. A background seismicity, with b = 0.8, M_{min} = 4 and M_{max} = 5, is used to model the random occurrence of small and moderate size events for areas outside these seismic source regions [16]. As indicated in Figure 3, the seismic source regions are: Source Region I; Main Zagros Thrust Region; Source Region II; North East Arabian Gulf Region; Source Region III; Northern Emirates Region; Source Region IV; Lut Region; Source Region V; Central Iran Region; Source Region VI; Makran Region; and Source Region VII: South East Arabian Gulf Region.

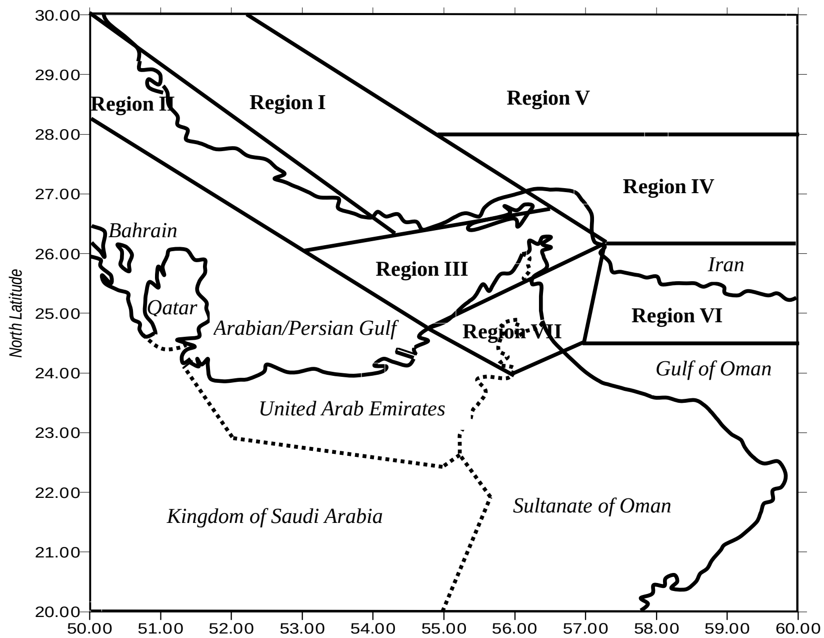

Figure 3. Seismic source regions of UAE and its surrounding (for M≥4 from 1964-2002 and for M≥6 from 1900-1964)

Recurrence And Attenuation Relations

The recurrence relation used in this study is that of Gutenberg and Richter (G-R formula) for seismic hazard analysis [17] and is given by:

$$\log N = a - bM \quad (1)$$

where, N is the number of earthquakes having magnitude greater than M, M is the earthquake magnitude, a and b are constants depend on the source area and they have physical meaning. The a-values and b-values have been calculated for each source region based on events extracted from the catalogue. Table 1 shows the computed a-values and b-values for each region. These values are considered reasonable for the purpose of this study since they are generally within the range reported for Zagros Region [18] and its vicinity. A uniform hypocentral depth of 25 km was assumed for all source regions of this study. Calculated b-values for regions III, VI and VII were too small due to insufficient data. Therefore the b-values for these regions have been replaced with assumed values of 0.8. No significant difference in the final seismic hazard result was observed.

Table 1. **Seismic hazard parameters for the seven regions**

Source Region No.	Total No. of Events (N)	Minimum Magnitude (M_w)	Maximum Magnitude (M_w)	b-Values	a-Values
I	866	4.0	7.0	1.22	10.17
II	106	4.0	6.0	0.94	6.99
III	30	4.0	6.0	0.80	5.22
IV	369	4.0	6.8	1.11	9.01
V	140	4.0	7.2	0.89	7.34
VI	6	4.0	6.7	0.80	2.74
VII	29	4.0	7.5	0.80	4.88

One of the important elements in seismic hazard assessment is the attenuation relationship which defines the reduction in peak ground acceleration (PGA) or intensity (I) with distance from the epicenter (R) for an earthquake of given magnitude (M). There are several factors that affect the attenuation relationship [19] such as: (1) damping of transmitting media; (2) magnitude of earthquake; (3) type of fault rupture mechanism; (4) distance of site from earthquake hypocenter; and (5) soil characteristics of the site. An attenuation relation that resulted from calibration and adjustment of constants to reflect the region characteristics such as transmission path, soil type, source, etc., developed by IIEES [18] is used in the current study. The general form of the attenuation equation is as follows:

$$\log a = C_1 M + C_2 R - \log R + c_i S_i + (\sigma) P \quad (2)$$

Where a is the peak ground acceleration (PGA cm/sec^2), M is the earthquake magnitude (moment), R is the hypocentral distance measured in (km), C_1, C_2 and C_3 are constants. S_i is the site condition, c_i is the site class (c_1 for rock, c_2 for hard alluvium, c_3 for soft alluvium and c_4 for soft soil), σ is the standard deviation and P is a constant. P = 0 (for average PGA), P = 1 (for average PGA plus standard deviation). For Zagros horizontal component, the following values have been calculated: $C_1 = 0.399$, $C_2 = -0.0019$, $C_3 = 1.0$ (for homogeneous space), $\sigma = 0.329$, $c_1 = -1.047$ (site class for bedrock).

However, recording of strong motion at different locations in the UAE as a result of major earthquakes occurring along Zagros Faulting System will enable the development of an accurate attenuation relation that takes into consideration attenuation of earthquake waves across the Arabian/Persian Gulf.

RESULTS AND DISCUSSIONS

Seismic hazard assessment models have been developed by several researchers [20, 21]. In this study probabilistic seismic hazard analysis for the regions was performed using the computer code EQRISK [21]. Details of the probabilistic seismic hazard assessment are shown in Abdalla et al. [22]. The input parameters for EQRISK consist of Richter parameters, geometry of source regions, rate of occurrence, annual probability of exceedance, and coordinates of location where the seismic hazard is required. In this study the whole area of interest was subdivided into a grid of approximately 25x25 km, an input file is prepared for EQRISK program and seismic hazard analysis is carried out for the region. The output of the program was the anticipated peak ground acceleration in with a 10% probability of being exceeded during time spans of 50, 100 and 200. The result of the seismic hazard analysis is graphically shown in Figures 4 and 5. It is observed that the maximum PGA occurs in Zagros region where Central Iran, Lut and North Eastern Arabian regions also show, respectively, high PGA. Northern Emirates, Makran and Southeast Arabian regions show moderate to low PGA. The result of the seismic hazard analysis is graphically shown in Figures 4 and 5. It is observed that the maximum PGA occurs in Zagros region where Central Iran, Lut and North Eastern Arabian regions also show, respectively, high PGA. Northern Emirates, Makran and Southeast Arabian regions show moderate to low PGA. Figure 6 shows PGA for selected cities within the Arabian/Persian Gulf area.

The seismic hazard analysis carried out in this investigation assumed an ideal bedrock case, and therefore no influence of local soil conditions is taken into consideration. The contour lines obtained can be used to divide UAE and its surrounding into macro-seismic zones. The zones specify regions of anticipated PGA from 0 to 3 as commonly used in most building codes including the UBC [23]. The seismic zone map is generated based on probable Peak Ground Acceleration (PGA) with 10% probability of exceedance in a 50 years time period, which corresponds to a 475 years return period. Figure 7 shows the proposed seismic zone map for UAE and its surroundings based on the probabilistic seismic hazard assessment presented in this investigation.

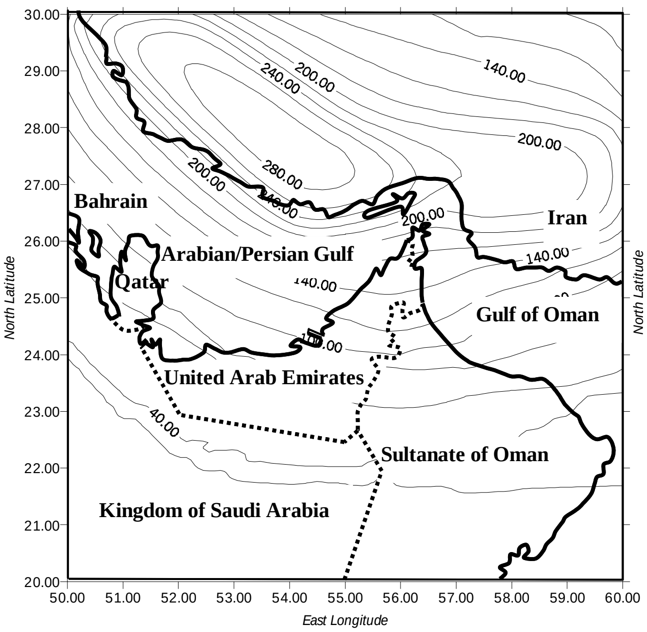

Figure 4. PGA (cm/sec^2) for 50 years time span.

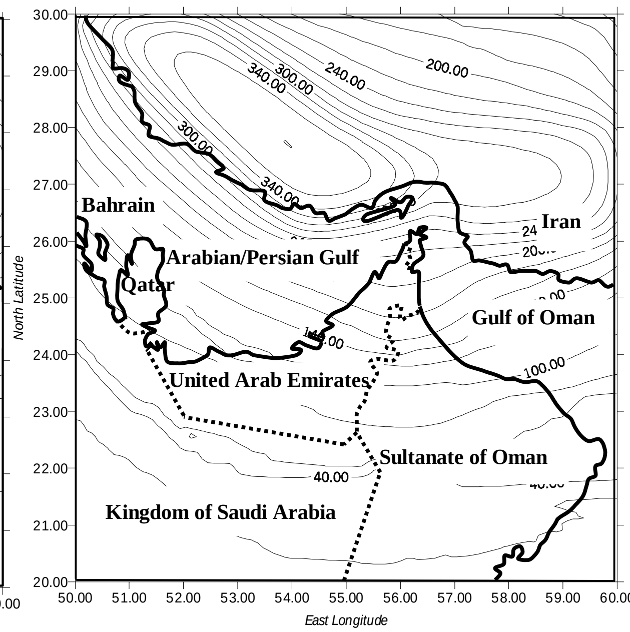

Figure 5. PGA (cm/sec^2) for 100 years time

It is observed that large parts of UAE, specifically Southern UAE, lie within Zone Zero where the PGA in 50 years time period (corresponds to 475 years return period) does not exceed 50 , i.e., 0.05 of the gravitational acceleration (0.05g). Greater Abu Dhabi area lies within Zone 1, where the PGA is between 0.05g and 0.10g, i.e., with an average of 0.075g. Zone 2A, where the PGA is between 0.10g and 0.20g, i.e., with an average of 0.15g, covers Greater Dubai, Sharjah and Ajman area where the highest PGA in Fujaira area approaches 0.2g. No part of UAE lie within Zone 2B or Zone 3. The delineation of zones for UAE and its surrounding are clearly marked in Figure 7.

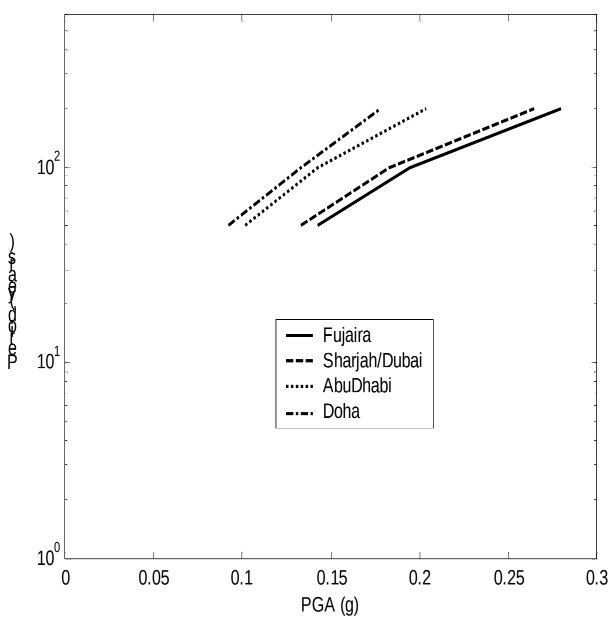

Figure 6. PGA (cm/sec^2) for different time span

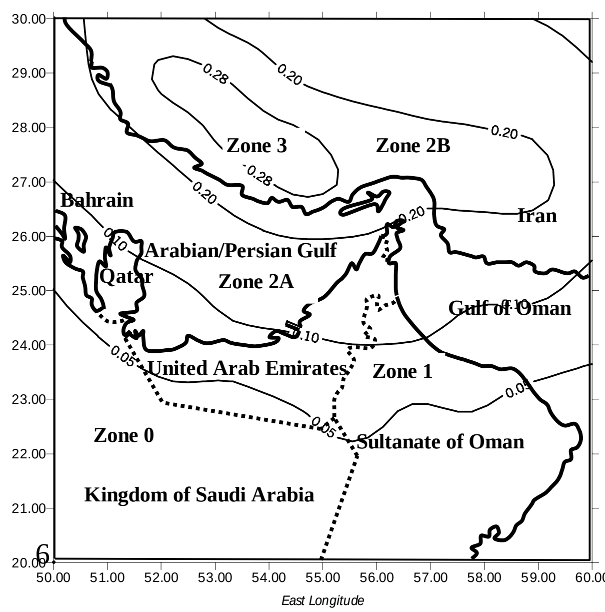

Figure 7. Seismic zoning map of UAE and its vicinity for 475 years return period showing five zones (0,1, 2A, 2B and 3)

CONCLUSION

This paper investigated seismic hazard and seismic zoning of UAE and its surroundings based on probabilistic approach as the first step toward developing an earthquake resistant design code. The significant results of this investigation are: (1) generation of seismic zone map that can be used, however with caution, as a guide for determining the design earthquake; and (2) review of tectonics and seismotectonics of the studied area.

The results of the seismic hazard assessment indicated that UAE has moderate to low seismic hazard levels, nevertheless high seismic activities in the north part of UAE warrant attention. The Northern Emirates is the most seismically active part of UAE. The PGA in this region ranges between 0.22g for a return period of 475 years to 0.38g for a return period of 2400 years. This magnitude of PGA, together with amplification from local site effect, can cause structural damage to key structures and lifeline systems.

Besides the inherent uncertainties in seismic hazard assessment, the results obtained in this study have some other limitations and therefore future research in some key areas is needed as follows: (1) The hazard assessment is done for an ideal bed-rock condition, therefore care should be taken when using the results for sites with special local conditions. In such cases, evaluation of local site effects should be considered for microzonation of mega cities. (2) The attenuation relation used in this investigation is for Zagros fold zone. Attenuation relations for the region should be developed when sufficient strong motion data become available.

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