Seismic Hazard Assessment and Spectral Accelerations for United Arab Emirates

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SUMMARY:
The accelerated schedule driven projects in United Arab Emirates (UAE) are compelling designers to use values of seismic hazard from disagreeing studies. Moreover, not all estimates of a seismic hazard analysis such as mapped spectral accelerations, representative hazard spectra, and deaggregation that covers all parts of UAE are available. Most studies for UAE either focused on few cities or did not provide all the necessary information. Considering substantial development in UAE, a more comprehensive seismic hazard analysis is urgently required. This study reviews the previous studies and presents new findings. The hazard curves, deaggregation of hazard are also presented. Moreover, the breakdown of the range of spectral accelerations ($S_{0.2}$ and S_1) is proposed to form the basis for the development of site amplification factors in subsequent studies. The results indicate slightly larger values of seismic hazard compared to some recently published studies and smaller values compared to some earlier studies.

Keywords: UAE, Seismic Hazard Analysis, Deaggregation

1. INTRODUCTION

United Arab Emirates (UAE) has experienced significant economic growth in recent years. The accelerated schedule driven projects are compelling designers to use values of seismic hazard (ground motion) that present significant variation. Moreover, not all estimates of a seismic hazard analysis such as mapped spectral accelerations, representative hazard spectra, and deaggregation that covers all parts of UAE are available. Most studies that have attempted to define the seismic hazard in UAE provide different results and they either focused on few cities or did not provide additional information such as deaggregations and/or uniform hazard spectra (UHS). Previous studies, (e.g., Grunthel et al. 1999, Abdalla and al Hamoud 2004; Peiris et al. 2006; Malkawi et al. 2007, Al Dama et al. 2009) presents estimates of seismic hazard for specific parts of UAE with large range of variability. The variability in their results could be attributed to the use of different source zonation, activity parameters based on developing catalogue of events, and different ground motion prediction equations (GMPE).

This study is based on the use of a homogenized catalogue of various degrees of completeness for temporal distribution of events (Surface magnitudes, Ms), activity parameters based on doubly bounded magnitude-frequency relationships, modified zonation of area sources, and next generation of ground motion prediction equations. The study provides seismic hazard values for all parts of UAE that will provide designers with Hazard curves, values of peak ground accelerations (PGA), spectral accelerations at 0.2s and 1s (S0.2 and S1), Uniform Hazard Spectra (UHS), and deaggregation of seismic hazard. The results are generally provided for a return period of 2475 years (2 % probability of excedance in 50 years) in conformance to and compliance with the provisions given in most modern building codes. The results presented in this paper correspond to rock sites classified as Site Class B according to International Building Code (IBC 2009).

2. REVIEW OF PREVIOUS STUDIES

The earliest study of seismic hazards analysis for the Arabian Peninsula including UAE was performed by Al-Haddad et al. (1994). That study used ground motion prediction equation (GMPE) with coefficients adopted from Thenhaus et al. (1986). The seismic source model presented in the study contained a single large area source that combined Zagros and Makran regions. The results of this study indicated that the PGA value corresponding to a return period of 475 years for the cities of Abu Dhabi and Dubai are less than 0.05g.

A Global Seismic Hazard Assessment Project (GSHAP) was completed in 1999 for generating the PGA maps (return period of 475 years) for Europe, Africa and Middle East (Grunthel et al. 1999). The results of this study suggested values of PGA of 0.32g and 0.24g for Dubai and Abu Dhabi, respectively.

Abdalla and Al Homoud (2004) performed the first seismic hazard assessment for United Arab Emirates and its surroundings. This study used attenuation equation from Zare (2002). The PGA for a return period of 475 years for Dubai and Abu Dhabi were reported to be 0.15g and 0.10g respectively.

Sigbjornsson and Elnashai (2006) performed a seismic hazard study for Dubai. The source model used in their study was based on zonation of Tavakoli and Ghafori - Ashtiany (1999). They used attenuation equations by Ambraseys et al. (1996) and Simpson (1996) for all the sources in the seismic source model. The PGA for a return period of 475 years for Dubai was reported to be 0.16g. The study included West Coast Fault (WCF) in the analysis.

Peiris et al. (2006) performed seismic hazard assessment for the Arabian Gulf including Dubai and Abu Dhabi. The seismic source model in that study was similar to source model suggested by Al Haddad et al. (1994) and Tavakoli and Ghafory-Ashtiany (1999). They used the prediction equations suggested by Dahle et al. (1990) and Atkinson and Boore (1997) for the Arabian stable craton and equations of Ambraseys et al. (1996) and Sadigh et al. (1997) for Zagros and Makran region. They reported PGA of 0.06g and 0.05g for Dubai and Abu Dhabi respectively for return period of 475 years.

The paper by Musson et al. (2006) presented results of seismic hazard assessment of UAE. Zagros region in the seismic source model is similar to that of Peiris et al. (2006). Attenuation equations of Ambraseys et al. (1996) were used for the computation of spectral accelerations, whereas Ambraseys (1995) was used for predicting Peak Ground Acceleration (PGA). The results of the study were similar to those of Peiris et al. (2006).

Malkawi et al. (2007) presented seismic hazard assessment for major cities of UAE. The seismic source model of this study consists of a single source which includes the Makran Region, Zagros Region and parts of the Arabian Craton. Ground motion prediction equation of Atkinson and Boore (1997) was used. The PGA for a return period of 475 years for Dubai was reported to be larger than 0.2 g.

Study by Aldama et al. (2009) concentrates on three major cities of Dubai, Abu Dhabi and Ras Al Khaymah. The seismic model consists of many seismic sources and seven ground motion prediction equations including a Next Generation Attenuation (NGA) equation. The results are in agreement with the findings of Pieris et al. (2006) and Musson et al. (2006).

Shama (2011) presented a seismic hazard assessment for a site in Dubai. This study used many attenuation models for different seismic sources. Many local faults such as Dibba Fault and the controversial West Coast Fault were considered as very active and hence included in this study. The study presented values of 0.17g and 0.33g for return periods of 475 and 2475 years respectively for Dubai.

Table 1 presents a summary and comparison of results from different studies in terms of PGA in

Dubai for a return period of 475 years. The results of these studies indicate a wide range of variability in results and level of disagreement that justifies re-examination of seismic hazard for UAE. The variability in these results could be attributed to many factors as previously indicated that include source model, activity parameters, catalogues and prediction equations, among others.

Table 1. Comparison of results for Dubai from previous hazard studies.

Study	PGA (475 years)
Al-Haddad et al. (1994)	< 0.05g
Grunthel et al. 1999	0.32 g
Abdalla and Al Homoud (2004)	0.14g
Sigbjornsson and Elnashai (2006)	0.16g
Peiris et al (2006)	0.06g
Musson et al. (2006)	0.05g
Aldama et al. (2009)	< 0.05g
Shama 2011	0.17g

3. EARTHQUAKES CATALOGUE AND SOURCE MODEL

UAE is located to the Northeast in the Southeast corner of the Arabian plate which is considered as stable (Platform) continental region (Fenton et al. 2006). Significant crustal deformations and recorded seismic events are rare within the Arabian peninsula (Vita-Finzi 2001). Although the Arabian plate is bounded by many active tectonic boundaries, major contribution to the seismic hazard in UAE is from Zagros fold and thrust belt, the Zindan-Minab transitional fault and the Makran region subduction zone. The separation of the Arabian plate from the African plate creates a subduction zone with the Eurasian plate. The Arabian plate is moving north at a rate of approximately 21 mm/year (Vernant et al. 2004) and slight rotational movement also creates subduction zone at the boundary of Makran (Farhoudi and Karig 1977). Movement of Arabian plate is also associated with the formation of Zagros fold and thrust belt in Iran that extends to the edge of the Persian Gulf (Jackson and McKenzie 1984). In addition to Zagros and Makran regions, the active tectonic structures present in the Oman Mountains (Dibba fault) can also contribute significantly to the seismic hazard in UAE especially in the north and east of the country (Johnson 1998).

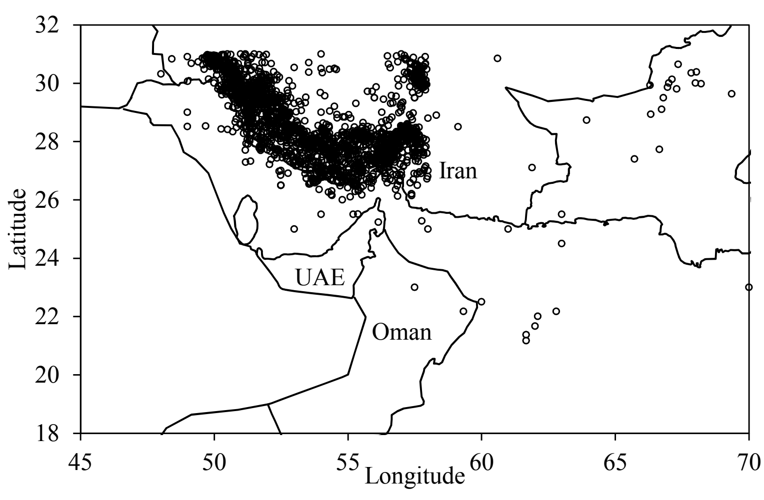

Figure 1. Earthquake Catalogue of instrumented events for last 50 years

Different databases from sources such as United States Geological Survey (USGS) and National Geosciences of Iran were used to develop a seismic earthquakes catalogue for the sources around UAE. Events with magnitude greater than four ($M_w > 4$) and dated between 1900 and 2010 were selected as the basis of catalogue to identify the sources. The catalogue was cleaned using standard protocols of removing duplicated events (declustering) and aftershocks and for completeness using methods suggested by Knopoff (2000). Historical records of earthquakes in the region were especially considered and were given due consideration in selecting the upper bound magnitudes. The conversions of the magnitude scales were performed by using global conversion equations (Scordilis 2006). Figure 1 presents the homogenized (M_s) seismicity catalogue of only instrumentally recorded events.

The development of seismic source model is based on the work of Aldama et al. (2009). Seven distinct seismic source models have been adopted for the current study as shown in Figure 2. The southern boundary of South Zagros has been extended into the Persian Gulf instead of being along the Iranian coast due to uncertainty associated with constraining the boundary. Moving the boundary of South Zagros further northward can increase the seismicity of stable Arabian Craton with potentially higher hazard levels in the southern and central cities such as Abu Dhabi and Dubai.

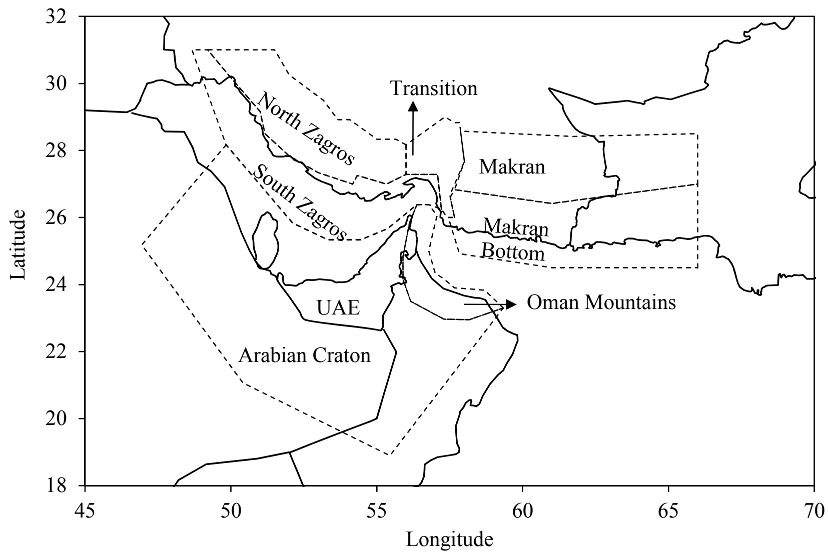

Figure 2. Proposed seismic source model

The parameters for all the source zones were calculated using the doubly bounded exponential distribution (McGuire and Arabasz 1990). The activity parameters (λ. at M_{min} and β) for Oman mountains were computed by using the model proposed by Youngs and Coppersmith (1985). The slip rates and shape of the Dibba fault in Oman Mountains was used to estimate the seismic moments and then the magnitude-recurrence relationship to determine the activity parameters following the methodology presented by Hanks and Kanamori (1979). An uplift rate of 0.28 mm/yr and a dip slip rate of 0.51 mm/yr were used for the characterization of Oman Mountains.

Table 2. Activity parameters of different source zones modeled in this study.

Seismic Source	Fault Mechanism	Mw_{min}	Mw_{max}	λ at Mw_{min}	β	b
North/High Zagros	Reverse	4	7.1	16.27	2.253	0.978
South Zagros	Reverse	4	7.1	2.056	1.960	0.851
Oman Mountains	Strike Slip	4	7.0	0.625	2.500	1.086
Makran Top	Intra-slab	4	6.8	1.070	1.630	0.708
Makran Bottom	Interface	4	7.9	2.000	1.796	0.780
Zagros Makran Transition	Strike slip	4	7.0	5.045	1.998	0.868
Arabian Craton	Reverse	4	6.5	0.116	1.156	0.502

For Arabian Craton, the β parameter was obtained from seismicity of the source. Previous studies (Fenton et al 2006) indicate a larger value of this parameter. The value of 1.16 was selected because subsequent analysis of hazard with different β parameter for the region indicated insignificant effect on the total hazard due to larger contribution of other dominant sources. The upper bound magnitudes (Mw_{max}) were selected as the maximum of historical seismicity, instrumented seismicity, and computation using relationships by Wells and Coppersmith (1994) for known geometry of faults. The parameters for doubly bounded Gutenberg-Richter relationships for all source zones are presented in Table 2. Equivalent linear regression was used to achieve the fit and minimum coefficient of determination of 0.96 was achieved.

4. GROUND MOTION PREDICTION EQUATIONS

Since, there were no established seismograph networks in UAE until recently established by the governments of Dubai and Abu Dhabi; therefore, ground motion prediction equations (GMPEs), specific to UAE, are not available. All previous seismic hazard analysis performed for UAE used GMPEs developed for other geographical areas. The choice of these equations often is based on guidelines proposed by Cotton et al (2006). Alternatively, equations (Next Generation Attenuation Equations) that were developed after the analysis of worldwide seismicity are increasingly being used.

A total of seven different GMPEs were used in this study including NGA equations. Different seismic sources were assigned at least two GMPEs except for the Arabian Craton along with conversion to geometric mean wherever applicable. Three NGA equations of Boore and Atkinson (2008), Abrahamson and Silva (2008), Campbell and Borzognia (2008) and one by Abrahamson and Silva (1997) were assigned to sources of Zagros and the Oman Mountains. For the Makran region, Atkinson and Boore (2003) and Youngs et al. (1997) were used due to their suitability for earthquakes generated in subduction zones. The equation by Atkinson and Boore (2006) was assigned to the Arabian Craton. In the GMPE of Atkinson and Boore (2006), a stress of 140 bars was used as the base value in the equation with variation in the estimation of ground motion adjusted by changing the coefficients of stress adjustment factors automatically in the software.

During the selection process of GMPEs, several other relationships were also considered (e.g. equations by Chiou and Youngs (2008), Akkar and Bommer (2010), and Zare (2002)). The choice of the three NGA models was not based on superior predictive capabilities of any model as the models of Chiou and Youngs (2008) and Akkar and Bommer (2010) would have produced similar results. Moreover, the selected NGA models were already built in to the software.

5. RESULTS AND DISCUSSIONS

Commercially available software 'EZFRISK' (Risk Engineering Inc.) was used in this study which represent an application of the total probability theorem (Kramer, 1996). All results correspond to 2% probability of excedence in 50 years on rock sites unless stated otherwise.

Figure 3 present the contours of mapped peak ground accelerations (PGA). Results presented in Fig. 3 indicate higher seismicity towards the east and northeast of the country with relatively little difference in seismicity level within the southern part (Emirate of Abu Dhabi). The seismic hazard along the western coast is generally dominated by the Zagros fold and thrust belt; whereas Oman Mountains contribute largely to the hazard on the eastern side. These results are in line with the general expectation of hazard distribution in UAE due to the presence of active sources towards the North and East. The contour maps of short and long period shaking generally follow the same trend as the contour map of PGA.

The dots on the plots represent the main cities of Ras Al Khaimah (RAK), Um Al Quwain (UAQ), Ajman (AJM), Sharjah (SHJ), Dubai (DUB), Fujaira (FUJ), Al Ain (AAN), and Abu Dhabi (ABD).

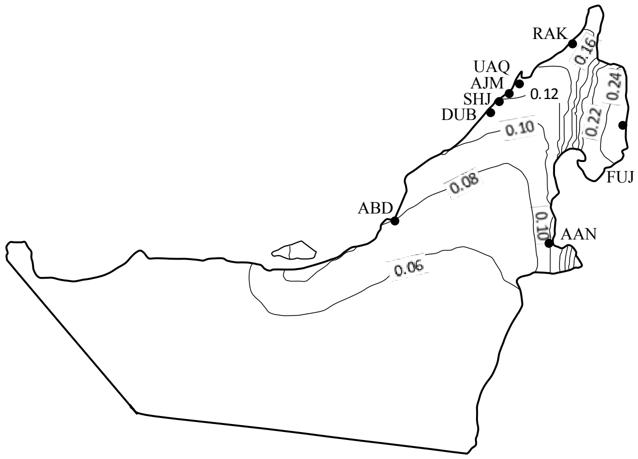

Figure 3. Mapped peak ground accelerations in units of "g" (2475 years return period)

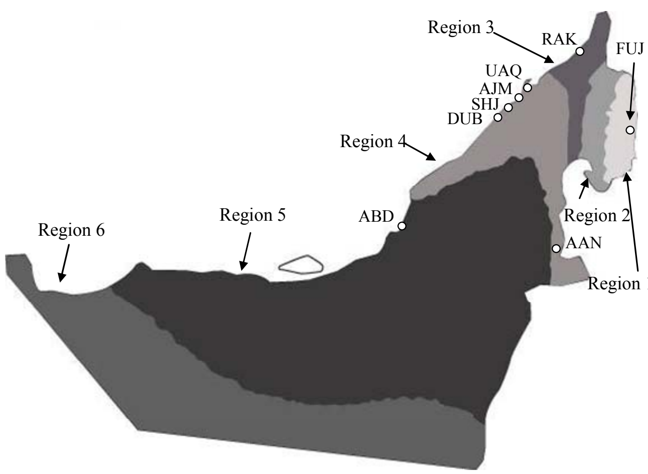

Figure 4. Proposed regions of UAE based on equal increments of mapped hazard

Modern building codes provide site amplifications factors for different site classes based on different levels of mapped spectral accelerations at short and long periods (e.g. IBC 2009). The provisions in the building codes are not adequate for the development of site amplification factors specific for UAE due to low values of maximum spectral accelerations at short and long periods. As a result, the breakdown of spectral accelerations for the UAE is proposed in Table 3.

Table 3. Mean mapped acceleration for different regions in units of "g". The IBC 2009 Suggested values for the six regions (or whatever available) needed to be added to the table for comparison and supporting the above highlighted conclusion.

	Region 6	Region 5	Region 4	Region 3	Region 2	Region 1
$S_{0.2}$	< 0.1	0.15	0.25	0.35	0.45	> 0.55
S_1	< 0.05	0.06	0.09	0.12	0.13	> 0.14
PGA	< 0.03	0.06	0.11	0.16	0.21	> 0.23

The proposed breakdown of spectral range for UAE is based on the regions of UAE presented in Figure 4. Each region represents an approximately equal change in mapped hazard as presented in Table 3. The proposed distribution of mapped spectral accelerations will provide the basis for subsequent studies of site response analyses for the development of amplification factors.

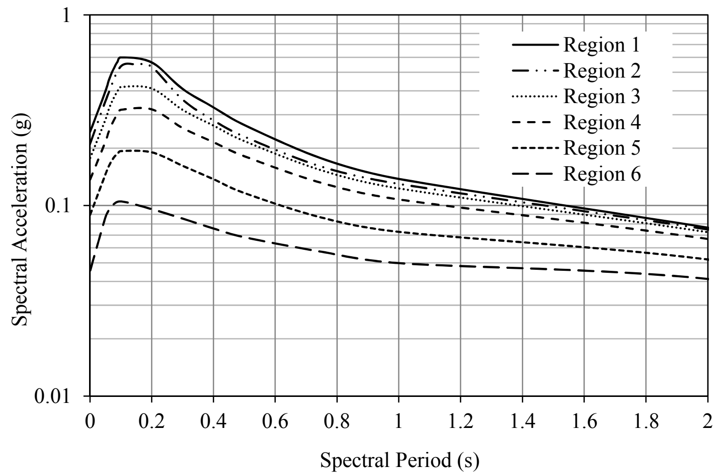

Figure 5. UHS representing the proposed regions of UAE (2475 years)

The UHS for return period of 2475 years representing proposed regions (Figure 4) and ranges (Table 3) of spectral accelerations are presented in Figure 5. The UHS are provided to aid designers in selecting appropriate UHS depending on the location of the site. Smaller cities of UAE are also growing at a considerable pace and Figures 4 and 5 is an attempt to address the requirements of these areas.

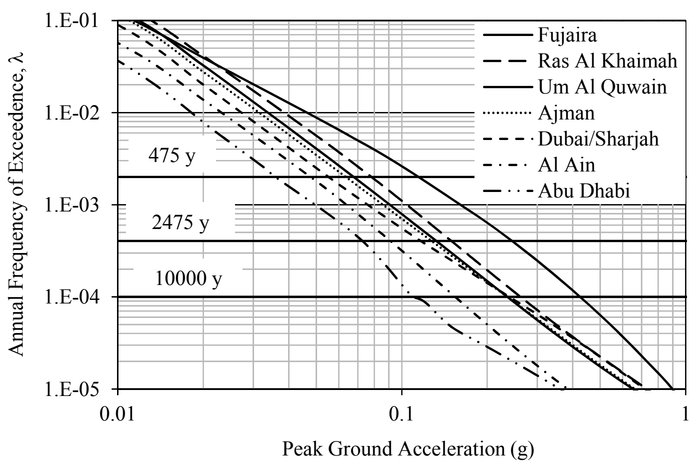

Figure 6. Seismic hazard curves for the major cities of UAE

The hazard curves for the selected cities are presented in Figure 6. The horizontal lines on the figure represent three different return periods of 475, 2475, and 10000 years. The PGA corresponding to these return periods can be determined from the plot if required for different cities. Figure 6 presents high resolution hazard curves in a narrow band of ground motion parameter to elaborate the comparison of the hazard curves for different cities.

Table 4. Mapped spectral accelerations for major cities for return period of 2475 years**.**

City	PGA (g)	0.2s (g)	1s (g)
ABD	0.074	0.178	0.075
AJM	0.122	0.300	0.113
SHJ	0.120	0.285	0.109
FUJ	0.250	0.565	0.131
DUB	0.118	0.251	0.100
RAK	0.154	0.356	0.126
UAQ	0.135	0.314	0.113
AAN	0.097	0.250	0.088

The PGA and spectral acceleration for major cities in UAE are presented in Table 4. The table provides ordinates of UHS spectra for the cities for a return period of 2475 years. The largest hazard is observed for Fujaira (0.25g) and the lowest hazard is calculated for Abu Dhabi (0.074g). The seismic hazard at a specific site represents the total effect of different combinations of earthquake magnitudes and distances. The choice of magnitude and distance is aided by a technique called deaggregation that presents (e.g., Figure 7) earthquake–distance combinations that contributes to the total hazard at a site (Bazzurro and Cornell 1999).

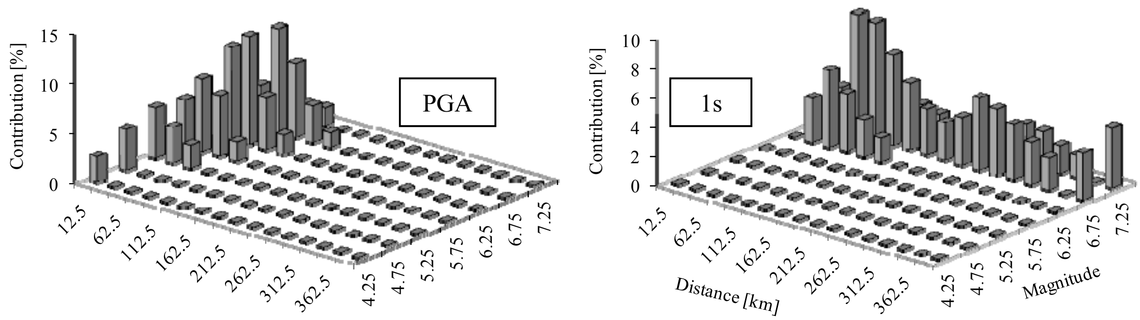

Figure 7. Deaggregation of hazard for Dubai (2475 years return period)

Deaggregation of hazard (at S_1) for Dubai (Figure 7) for example, indicates two possible magnitude-distance scenarios. The spectral matching of the UHS at long periods for Dubai should consider an earthquake with mean magnitude of 7 occurring at mean distance of 60 km and then at 300 km. The short and long distance earthquakes represent the events occurring in Zargos and Zindan-Minab transition respectively.

6. CONCLUSIONS

The results of this study indicate slightly larger values of seismic hazard compared to some recently published studies. The variation in the results of seismic hazard studies including current study can be attributed to use of different source models, mislocated events in the seismic catalogue, and different prediction equations.

The Arabian Craton contributes mostly to the hazard in southern part of UAE. The contribution of other sources increases as one move towards the North. The west of the country is dominated by seismicity from Zagros whereas the east is affected by seismicity from Oman Mountains. The hazard in the northern parts of UAE is influenced equally by seismicity in Zagros and Oman Mountains.

The deaggregation of seismic hazard at different spectral periods indicates a strong earthquake occurring at long distance is the most likely scenario for southern region of UAE. The influence of medium to strong earthquakes occurring at shorter distance increases as one moves to the north.

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