SEISMIC HAZARD AND SEISMIC DESIGN REQUIREMENTS FOR THE ARABIAN PENINSULA REGION

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ABSTRACT :

This paper presents the results of a regional seismic hazard assessment undertaken for the Arabian Peninsula region. This area includes a number of major regional tectonic features including the Zagros and Makran regions to the north and east, the Dead Sea and Red Sea to the west and the Gulf of Aden and Owen Fracture Zone to the south and southeast, with the stable continental Arabian Plate in the centre of the region. An earthquake catalogue has been compiled and critically reviewed for this region and seismic source zones and their associated magnitude recurrence parameters defined. Attenuation relationships have been selected based on the tectonic character of the source zones. The uncertainty in each element of the hazard assessment has been included in the assessment using logic tree methodology. The seismic hazard results are presented in the form of peak ground motions and uniform hazard response spectra for selected cities in the region. The paper also discusses how these results compare with design values typically used for seismic design purposes in the region.

KEYWORDS: seismic hazard, ground motion, Arabia, United Arab Emirates

1. INTRODUCTION

Until quite recently, the seismic hazard in the Arabian Gulf states was considered to be negligible. For example, UBC (1997) and Al-Haddad *et al.* (1994) classify Dubai, Abu Dhabi, Bahrain and Doha to be in Zone 0, i.e. no seismic design requirements. In contrast, the publication of the Global Seismic Hazard Assessment Program (GSHAP) map (Shedlock *et al.*, 2000) as well as the recent occurrence of locally felt earthquakes, such as the March 11, 2002 Masafi event, have led to a perceived need for revision of this assessment.

There are currently no well established seismic code requirements for structures in the Arabian Peninsula states. However, both the Abu Dhabi and Dubai Municipalities recommend that for buildings of five or more storeys the Zone 2A design criteria in UBC 1997 should be employed. Further recommendations on seismic hazard levels in the Arabian Peninsula can be found in the “Guide to Design of Concrete Structures in the Arabian Peninsula” prepared by the Concrete Society (2007) which indicates moderately low seismic hazard for most of the cities in the Arabian Gulf region.

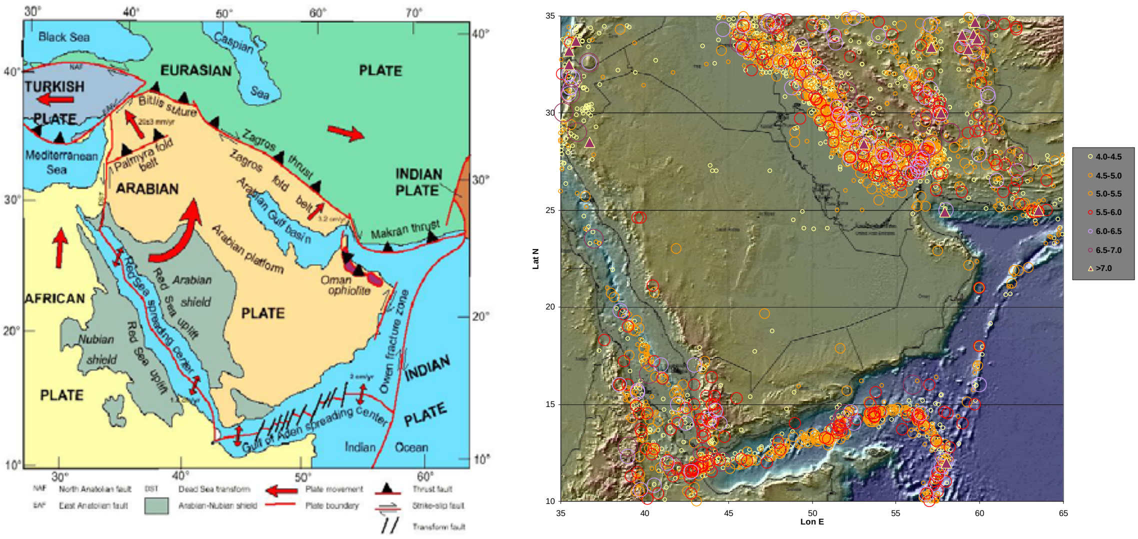
A seismic hazard assessment has therefore been undertaken to determine seismic ground-motion parameters for seismic design of facilities located in the Arabian Gulf region. This study represents an update to that produced by Peiris *et al.* (2006). The study area for this assessment extends from 10°N to 35°N and 35°E to 65°E. This area is centred on the stable continental Arabian Plate with major active tectonic features forming the boundaries to this stable plate; the Zagros Fold Belt and Makran subduction zone to the north and northeast, the Red Sea Rift and Dead Sea Rift to the northwest and west and the Gulf of Aden and Owen Fracture Zone to the south and southeast.

An earthquake catalogue extending back over 2000 years has been compiled and critically reviewed for the study area. A seismic source model has been developed based on the regional geology and tectonics, the historical and recent seismicity, and taking into consideration hazard models developed by other researchers for the region. The Next Generation of Attenuation (NGA) equations have been used for those seismic sources characterized by shallow crustal earthquakes.

The results of the seismic hazard assessment are presented in terms of peak ground acceleration (PGA) and uniform hazard response spectra (UHRS) for 475 year (10% probability of exceedance in 50 years) and 2475 year (2% probability of exceedance in 50 years) return periods for rock sites (Vs ≥ 760 m/s). Seismic ground-motion parameters are presented for the cities of Dubai, Abu Dhabi, Kuwait City, Bahrain, Doha, Muscat and Jeddah. It is also illustrated how the ground motion parameters determined compare with those in a range of current international building codes; the Uniform Building Code 1997, Eurocode 8 and the International Building Code 2005.

2. REGIONAL TECTONIC SETTING

The study area is centred on the Arabian Plate which is considered to be a stable continental region (EPRI, 1994). The Arabian Plate is currently separating from Africa at a rate of approximately 10 to 20 mm/year. This separation is due to the spreading along the Dead Sea transform fault zone and the opening of the Red Sea and the Gulf of Aden with Arabia rotating anticlockwise toward the north-northeast. In addition, Africa is moving north relative to Eurasia at a rate of approximately 15 to 20 mm/year. The Arabia-Eurasia convergence is almost entirely absorbed within the broad deformation zone extending from the Makran subduction zone through the Zagros Fold Belt and through Iran and up to Turkey in the northwest. To the south-east, the Arabian Plate is separated from the Indian Plate along the Owen Fracture Zone (see Figure 1a).



(a) (b)

Figure 1 (a) Regional tectonic map (Johnson, 1998); (b) Earthquake catalogue

3. SEISMICITY

3.1. Earthquake Catalogue

The study area for compilation of the earthquake catalogue is bounded by latitudes 10°N to 35°N and longitudes 49°E to 55°E (see Figure 1b). The earthquake data comprises historical and instrumental data from various sources. Historical data has been obtained from Ambraseys & Melville (1982), Ambraseys & Adams (1986), Ambraseys *et al.* (1994), Ambraseys & Jackson (1998), the National Earthquake Information Center

(NEIC) and the Iranian Institute of Earthquake Engineering and Seismology (IIEES). These catalogues present all the known historical events that have occurred in the past 2000 years. Instrumental earthquake data has been obtained from Ambraseys & Melville (1982), Ambraseys & Adams (1986), Ambraseys *et al.* (1994), Ambraseys & Jackson (1998), Ambraseys (2001), Engdahl & Villasenor (2002), the Global Seismic Hazard Assessment Program (GSHAP) East African Rift (1999), the International Seismological Centre (ISC) and the National Earthquake Information Center (NEIC).

3.2. Catalogue Processing

The reliability and quality of earthquake data sources have been investigated and considered for the catalogue compilation when conflicting information and duplicates have been encountered. Foreshock and aftershock sequences have been removed from the catalogue using the windowing procedure proposed by Gardner & Knopoff (1974).

3.3. Magnitude Scale

The moment magnitude scale M_w has been used for the catalogue. For events for which a surface wave magnitude (M_s) is reported, the following equations proposed by Ambraseys (2001) have been used:

$\text{Log } M_o = 19.08 + M_s$ for $M_s \leq 6.0$
$\text{Log } M_o = 16.07 + 1.5*M_s$ for $M_s > 6.0$
Where $M_w = 2/3*\log M_o - 10.73$ (Kanamori, 1977)

For events with a reported body-magnitude (m_b) the following conversion equations have been adopted:

- *for events in Europe and Middle East:* $M_w = 1.203*m_b - 1.14$ (Ambraseys, 1990)
- *for events in Iran:* $M_w = 0.62*m_b + 2.3$ (Ambraseys & Melville, 1982)

3.4. Catalogue Completeness

The earthquake catalogue dates back approximately 2000 years but cannot be considered to be statistically complete due to inconsistent reporting of earthquake data of different magnitudes over different time intervals. The statistical completeness of the catalogue has been assessed using two methods: the conventional magnitude recurrence relationship proposed by Gutenberg and Richter (1965); and the Stepp (1972) methodology (see Figure 2). Based on these two methods, the earthquake catalogue has been considered complete for the following time periods and corresponding minimum magnitudes; 1998 to 2006 for $M_w \geq 4.0$; 1978 to 2006 for $M_w \geq 4.5$; 1964 to 2006 for $M_w \geq 5.0$; 1900 to 2006 for $M_w \geq 5.5$; 1850 to 2006 for $M_w \geq 6.0$. It has not been possible to investigate the completeness of the catalogue within sub-regions.

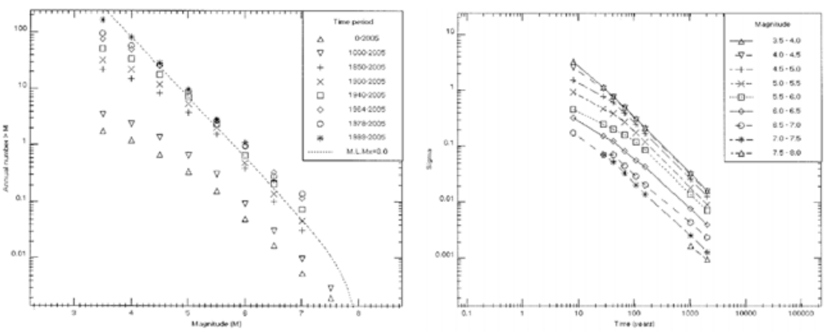


Figure 2 Magnitude completeness

4. SEISMIC HAZARD ASSESSMENT

The seismic hazard assessment has been carried out following the probabilistic methodology (Cornell, 1968; Reiter, 1990) using the program SISMIC. This methodology combines seismic source zoning, earthquake recurrence and ground motion attenuation to produce hazard curves in terms of ground motion and an associated annual frequency of exceedance.

4.1. Seismic Source Zones

The analysis has been undertaken using a seismic source model based upon the distribution of historical and recent seismicity and the interpretation of regional tectonics (see Figure 3). The area zone boundaries are generally consistent with the existing model for Saudi Arabia by Al-Haddad *et al.* (1994) and the model for Iran developed for the GSHAP by Tavakoli and Ghafory-Ashtiany (2006). In addition, a fault model is defined to represent the subduction within the Makran zone. The rate of occurrence of earthquakes is described in terms of truncated exponential distributions of magnitude recurrence.

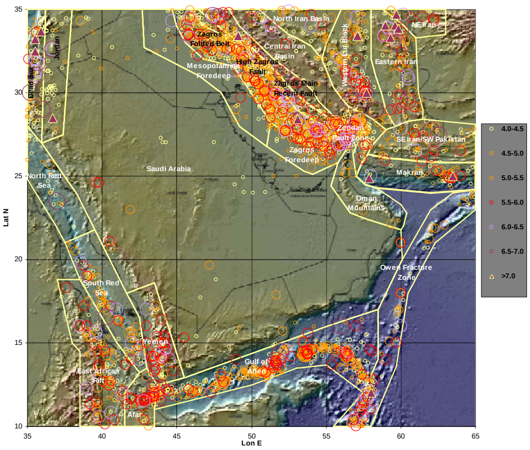


Figure 3 Seismic Source Model

Table 4.1 shows the “a” and “b” values and maximum magnitude values derived for each seismic source zone. The maximum magnitude of each zone has been determined by rounding the largest recorded magnitude upward to half a magnitude unit. A minimum magnitude of 4.0 M_w has been adopted.

Table 4.1 Magnitude-recurrence and maximum magnitudes for each source zone

Source Zone	Area Name	Area (km^2)	b-value		Activity rate, a (N>4.0/year)	Maximum Magnitude	
			Actual Mean	Assumed Mean ± SD	Mean	Recorded	Assumed
Iran	SE Iran/SW Pakistan	166,810	0.80	0.90±0.15	1.70	6.7	8.00±0.3
	Eastern Iran	180,117	0.76		2.30	7.6	
	Western Lut Block	194,090	0.91		4.32	7.6	
	Northern Iran Basin	80,773	1.07		1.40	6.4	
	NE Iran	50,081	0.81		0.26	7.6	
	Central Iran Basin	161,105	1.14		0.90	6.4	
	Zendan Fault Zone	47,497	1.06		3.69	6.7	
Zagros	Zagros Folded Belt	215,281	1.10	1.00±0.15	30.92	7.0	7.50±0.3
	High Zagros Fault	70,822	1.11		6.96	7.0	
	Zagros Main Recent Fault	81,400	1.06		3.28	7.3	
Gulf Region	Oman Mountains	119,997	0.65	0.85±0.15	0.16	6.4	7.00±0.3
	Zagros Foredeep	82,566	0.64		1.12	6.7	
	Mesopotamian Foredeep	194,305	0.92		0.71	6.4	
Saudi Arabia	Saudi Arabia	3,092,926	1.02	1.00	2.42	6.4	6.50
Rift Zones	North Red Sea	147,225	1.64	1.00±0.15	1.14	6.7	7.50±0.3
	South Red Sea	211,252	0.98		3.62	6.7	
	East African Rift	293,312	0.92		3.94	6.7	
	Afar	72,521	0.78		2.32	6.7	
	Yemen	133,416	1.09		1.06	6.4	
	Gulf of Aden	387,702	0.93		17.32	6.7	
	Owen Fracture Zone	292,682	0.74		3.50	7.0	
Dead Sea & Jordan	Dead Sea	86,116	1.07	1.00±0.15	3.12	7.0	7.50±0.3
	Jordan	131,982	0.83		2.74	7.3	
Makran (Shallow)	Accretion Zone	153,595	0.93	0.90±0.15	0.69	8.06	6.50
Makran (Fault)	Subduction Zone	180,689	-	1.00	0.69		8.50

4.2. Ground-Motion Prediction Equations

The ground motion prediction equations have been selected according to the tectonic regime associated with the earthquakes in each source zone. The model of Youngs *et al.* (1997) has been used for the Makran subduction zone. Akkar & Bommer (2007) and Campbell & Bozorgnia (2007) have been used for active shallow crustal sources (i.e. Iran, Zagros, Gulf Region, Dead Sea & Jordan, shallow Makran seismicity). The Campbell & Bozorgnia (2007) attenuation equation is one of the Next Generation of Attenuation (NGA) equations. Although the NGA database includes earthquakes recorded worldwide, the majority of the data is from earthquakes in Western North America. However, a study by Stafford *et al.* (2007) demonstrated, through comparisons of the NGA model of Boore & Atkinson (2007) and the European model of Akkar and Bommer (2007) that, for spectral ordinates and peak ground velocity, the NGA equations provide suitable predictive equations for a database of European earthquake records. The Atkinson & Boore (2006) model has been used for stable continental region (i.e. Saudi Arabia). The attenuation equation of Spudich *et al.* (1999) has been used for extensional zones in the Red Sea and the Indian Ocean.

4.3. Logic Tree

Uncertainties in the “b” value, maximum magnitude and slip rate of each source zone have been taken into account by assigning weights of 60% and 20% to the mean and to the mean ± 1 standard deviation values, respectively. The logic tree framework also incorporates the alternative ground motion models for those seismic sources associated to more than one ground motion model.

5. SEISMIC HAZARD ASSESSMENT RESULTS

5.1. Peak Ground Acceleration

Bedrock horizontal peak ground accelerations (PGA) for rock sites ($V_s \geq 760$m/s) have been derived from the probabilistic seismic hazard assessment for two return periods (475 years and 2475 years) for various cities in the Arabian Peninsula: Dubai, Abu Dhabi, Kuwait City, Bahrain, Doha, Muscat and Jeddah. Figure 4 shows the best estimate hazard curves for these cities. The hazard curves and PGA values (see Table 5.1) indicate a generally low seismic hazard in the Arabian Peninsula, with slightly higher hazard for cities close to the subduction Makran source and more seismically active zones.

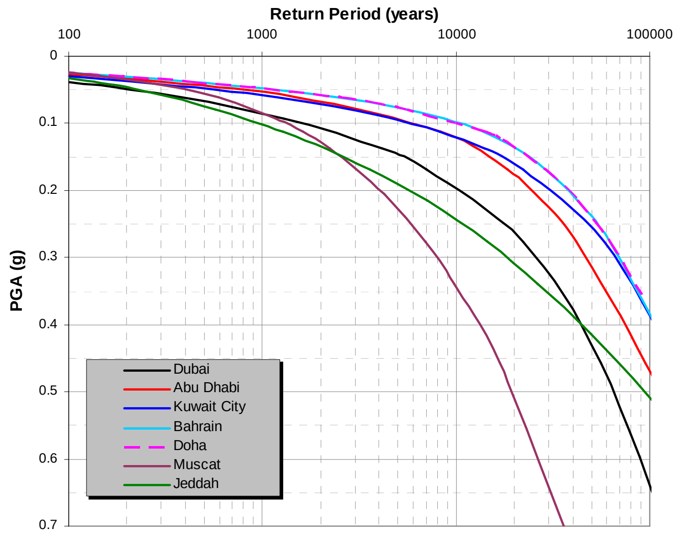


Figure 4 Best estimate hazard curves for PGA (rock site) for cities in the Arabian Peninsula

5.2. Uniform Hazard Response Spectra

Values of horizontal spectral acceleration (5% damping) for 0.2s (short period), 1.0s and 2.0s (long period) are presented in Table 5.1 for 475 year and 2475 year return periods for the selected cities in the Arabian Peninsula.

As for the PGA values, higher spectral accelerations are expected for those cities close to the Makran subduction zone or to the more seismically active regions. Figure 5 compares the bedrock horizontal uniform hazard response spectra (UHRS) for 475 year and 2475 year return periods for rock site in Dubai with the UHRS presented fro Dubai in Peiris *et al.* (2006). The updated probabilistic seismic model indicates spectral accelerations at short periods higher than those obtained in the Peiris *et al.* model, whereas slightly lower spectral accelerations are observed at longer periods.

Table 5.1 PGA and spectral accelerations at 0.2s, 1.0s and 2.0s for 475 year and 2475 year return periods

Location	PGA (g)		0.2s SA (g)		1.0s SA (g)		2.0s SA (g)	
	475year	2475year	475year	2475year	475year	2475year	475year	2475year
Dubai	0.06	0.11	0.160	0.277	0.056	0.097	0.022	0.041
Abu Dhabi	0.04	0.07	0.102	0.173	0.039	0.068	0.015	0.028
Kuwait City	0.05	0.08	0.113	0.186	0.044	0.070	0.017	0.028
Bahrain	0.04	0.06	0.092	0.149	0.037	0.057	0.013	0.023
Doha	0.04	0.06	0.090	0.145	0.045	0.056	0.013	0.022
Muscat	0.05	0.15	0.125	0.338	0.045	0.118	0.017	0.054
Jeddah	0.07	0.15	0.182	0.374	0.041	0.102	0.020	0.049

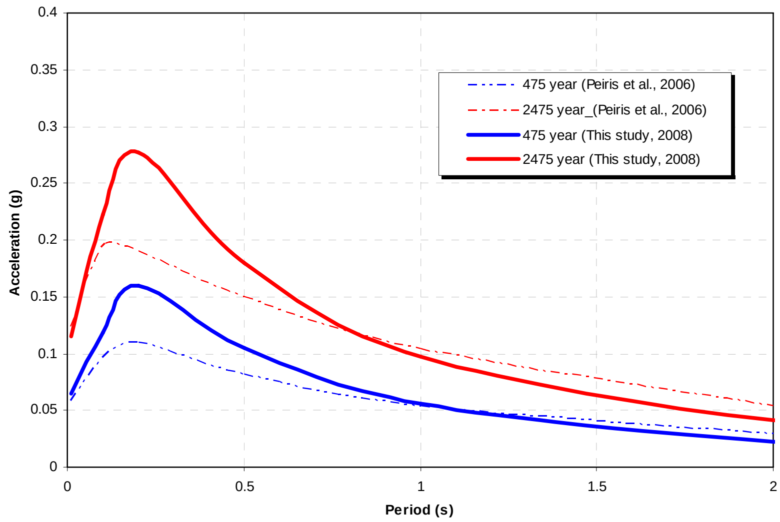


Figure 5 Bedrock UHRS for Dubai (5% damping) for 475 year and 2475 year return periods

7. SEISMIC DESIGN REQUIREMENTS

There are no specific seismic code requirements for building structures in the Arabian Peninsula states. However, the Abu Dhabi and Dubai Municipalities currently specify UBC97 Zone 2A design criteria for buildings of five or more storeys. A comparison between the seismic hazard assessment results in terms of UHRS and the internationally used seismic design codes is presented for Dubai in Figure 6. It can be observed that all codes are conservative both at short and long periods. In particular, UBC97 Zone 2A design spectrum is highly conservative with values far greater than both the 475 year and 2475 year UHRS accelerations. The EC8 gives a good match to the 475 year UHRS, in particular beyond 1.0s spectral period, i.e. in the long period range; whereas, a good match can be observed at short as well as long periods between the IBC2005 (MCE) spectrum and the 2475 year UHRS accelerations.

A discussion of seismic site response and appropriate requirements for consideration at site specific ground conditions and other related seismic hazards is not provided in this paper due to limitation of space.

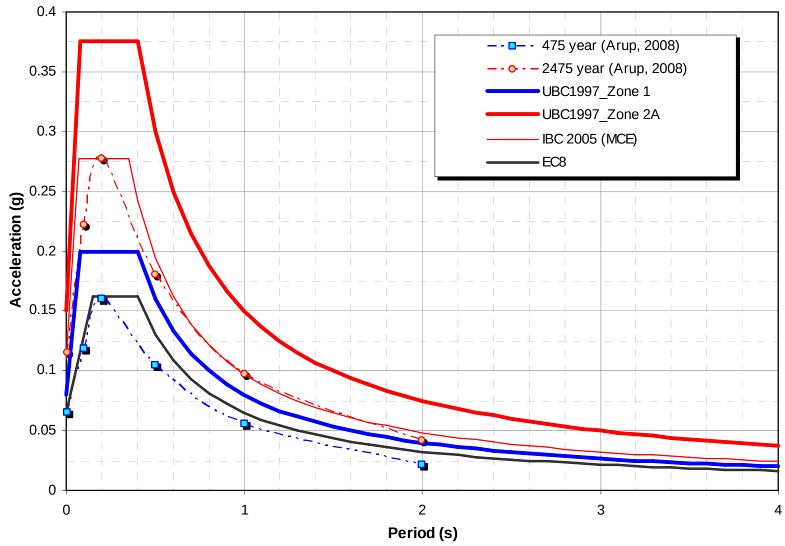


Figure 6 Comparison Code Spectra with UHRS for Dubai (rock site, 5% damping)

8. CONCLUSIONS

Results of a probabilistic seismic hazard assessment undertaken for the Arabian Peninsula region are presented in terms of ground motions in rock and spectral accelerations at short and long periods for various cities in the region. Uncertainties in seismic sources and ground motion models have been incorporated in the seismic hazard model using a logic-tree framework. The study shows that the seismic hazard level is low with expected bedrock horizontal PGA in the range 0.04 to 0.06g for 475 year return period and 0.06 to 0.11g for 2475 year return period with slightly higher values for those cities close to the more seismically active regions. These results generally agree with recent seismic hazard studies carried out for the Arabian Gulf region (e.g. Peiris *et al.*, 2006; Aldama-Bustos *et al.*, 2007).

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