A Comparative Earthquakes Risk Assessment Approach Applied to the United Arab Emirates

Samer A. Barakat [1]***, Abdallah Shanableh*** [1] ***and Abdallah I. Husein Malkawi*** [2]

[1] Department of Civil Engineering, University of Sharjah, P.O.Box 27272, Sharjah, United Arab Emirates, sbarakat@sharjah.ac.ae, shanableh@sharjah.ac.ae
[2] Department of Civil Engineering, Jordan University of Science and Technology, P.O. Box 3030, Irbid 22110, Jordan, mhusein@just.edu.jo

ABSTRACT

This paper presents the preliminary results of a long research project on the assessment and mitigation of seismic risk in major cities in the UAE. UAE's earthquake activity has long been recognized as one of the lowest in the world. All cities have experienced moderate earthquakes in the past, and will again do in the future. Recent earthquakes in Iran (e.g., Bam in 2003, --- in 2005) have killed thousands of people. Because of the different design and construction practices, different population density concentrations and economic activities in the UAE, different damages and losses are likely to be experienced.

The impact of an earthquake is not limited to direct losses, such as the loss of life, loss of structures and business interruptions. Earthquakes also cause indirect losses by producing supply shortages and demand reductions in various economic sectors. In a country such as the UAE, which is undergoing an unprecedented construction-based development with high-rise buildings being the main feature, a large earthquake in a major city can actually cause a considerable economic loss.

In this study, a framework for assessing and comparing the risk associated with the adverse consequences of earthquakes in the UAE is presented. The framework is based on a simple risk-characterization model that is used to assess the health risks associated with toxic chemicals. The model: $\boldsymbol{Risk} = \boldsymbol{D} \times \boldsymbol{RF} \times \boldsymbol{Pop} \times \boldsymbol{ER}$, adopted to fit our purpose of estimating the risk associated with the consequences of earthquakes, the various parameters in the above mentioned model are translated as follows: Dose (***D***)= seismic "force" at a specific location or weighted for an area; Response Factor (***RF***) = degree of damage or losses per unit "force"; Population (***Pop***) = a factor representing exposed population. Equivalent populations may also include exposed environment or exposed infrastructure. Emergency Response (***ER***) = effectiveness of available emergency response programs to reduce risk immediately as the adverse effects take place. It should be noted that emergency response in this case is different than deliberate risk management.

First, the earthquake hazard and risk in the UAE, including the estimation of the amplitudes of the ground motion parameters, is stochastically assessed. Then the comparative risk framework to assess the relative impacts on people and buildings in the seven emirates and the major cities of the UAE is applied. The result is a ranking system for risk that is being integrated within a geographic information system (GIS). The database is intended for detailed development to maximize benefits to the various stake holders in the community.

KEYWORDS: Seismic hazards, Adverse consequences of earthquakes, Risk to people, Risk to buildings, United Arab Emirates, Comparative risk assessment.

Accepted for Publication on 1/4/2008.

INTRODUCTION

Earthquakes have claimed hundreds of thousands of lives in the past 100 years and improvements in technology have only slightly reduced the death toll. Most of the biggest urban disasters are due to earthquakes. Past earthquakes have shown that the socio-economic impact of a large, urban earthquake can be huge and widespread. After a huge Asian Tsunami and earthquake on 26 December 2004, 280000 people lost their lives and more than one million people were displaced. The economic damage measured by the aid commitments to Tsunami affected countries, as of 21-February 2005 was about $6317.5 million.

The United Arab Emirates (UAE) is undergoing high levels of development that represent high level of financial investments and high densities of populations. Designing, constructing and maintaining high rise buildings are the major challenges, especially in the presence of ground motions due to earthquakes that might subject the structures to complex force distribution. These forces should be carefully calculated and accounted for in the design process. The hazard assessment of Dubai for close and distant earthquakes reported by Sigbjornsson and Elnashai (2006) explored the implications of the hazard from near and far earthquakes.

UAE is located at the eastern coast of the Arabian Peninsula (Figure 1). The UAE is geographically, geologically and geophysically situated in a unique location. Facing the subduction boundary just across the waters of the Arabian Gulf, the tip of the country lies opposite to the Hurmuz Straits, north of which one of the most notorious seismically active zones in the world is situated. This situation necessarily implies that the U.A.E is not only exposed but is ultimately vulnerable to excessively large strong earthquake ground motions originating not too far a distance on the southern shores of Iran.

Till recently, the general conception about UAE is that there is little or no earthquake activity. However, the M_b5 (March 2002) earthquake, which shocked the Masafi area, north east of the UAE, with its epicenter at (25.24°N 56.15°E) and at 16 km depth is alarming. The strong motions which were recorded on 10 Dec. 2002 and on 25 April 2003, and the several small earthquakes which have been recorded since that time, represent a sufficient evidence of the existence of considerable seismic activity in the UAE (Abdalla, 2003).

Seismic risk is the probability of losses due to an earthquake. Earthquake damage can be devastating and wide spread, affecting human lives and health, environmental health, buildings and infrastructure, in addition to business and economic activity. Although each earthquake has a unique magnitude (of a specific type), its effects vary greatly according to distance, ground conditions, construction standards and other factors.

Figure (1): Location of the United Arab Emirates within its region, (Source: Google Earth, Downloaded September, 2005).

The significance of the present research program lies in presenting a systematic approach for risk assessment and in its comparative results and parametric products (e.g., maps, sections, plots, spectra, relative risk assessment,… etc.) that can directly and effectively be used by national and local governments, decision makers, geoscientists, engineers, planners, designers, emergency response specialists, building contractors and universities in order to improve and upgrade methods and procedures for land-use, building design and construction, emergency disaster preparedness plans as well as socio-economic planning and forecasting.

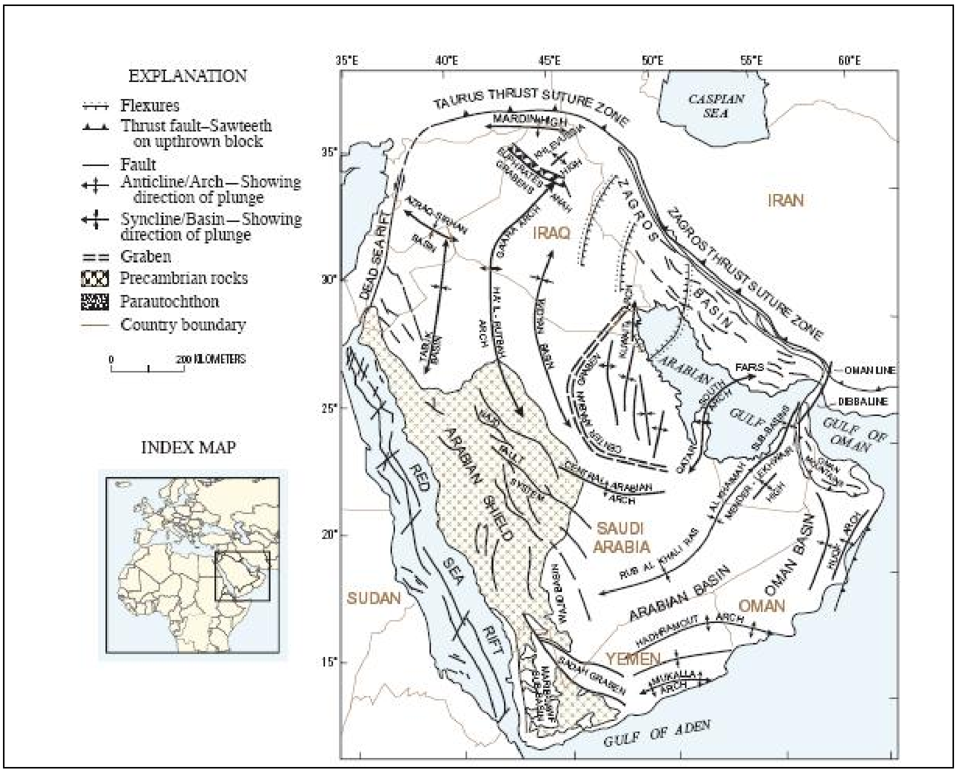

Figure (2): Tectonic and geologic structure of the Arabian plate with Zagros folded belt (Reported by Wassel, 2005 based on James E. Fox and Thomas S. Ahlbrandt, *U.S. Geological Survey Bulletin*, 2002).

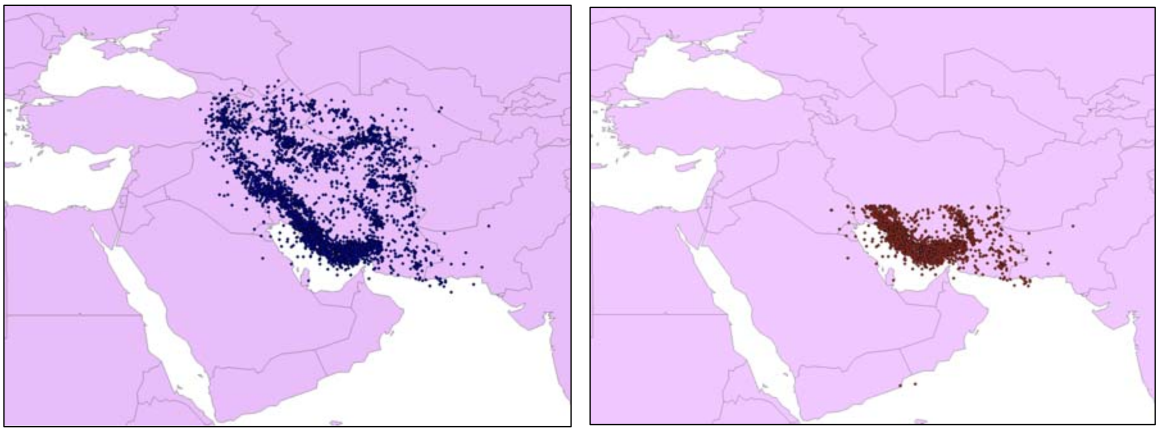

Figure (3): Seismogenic zone taken as the whole area for seismicity results from the subduction zone activity (Sources I and II).

BACKGROUND

The seismic activity in the UAE may be attributed to the regional geologic settings and local geology of the UAE, as follows (Abdalla, 2003; UNESCO, 1983):

- Major faults of unknown activity level have been mapped as transecting the UAE.
- The horn formed by the territory of the UAE penetrates into the plate- boundary of collision between the Arabian Peninsula and Asia; thus accumulating stresses.
- The Zagros Mountain is a folded belt that extends for about 1500 km in northwest-southeast direction along the western part of Iran and the northeastern part of Iraq from Oman in the southeast to the Turkish borders in the northwest, as shown in Figure 2. The occurrences of earthquake events in the Zagros province define a zone, about 200 km wide, which runs parallel to the folded belt. The majority of the earthquakes occur in the crustal part of the Arabian plate that underlies the Zagros folded belt because it is one of the most active faults in the world. For example, a recent study of the historical seismicity of Iraq shows that most of the moderate to large historical events occurred in eastern Iraq along the Zagros folded belt.
- Makran subduction zone: the area of Oman Gulf subduction under the Eurasian plate. It is an oceanic crust, which extends eastwards to Owen fracture zone along the Indian plate boundary. This oceanic crust descends below the continental crust along Makran subduction trench. This zone is capable of producing very strong earthquakes.

Using data from neighboring countries, Wassel (Malkawi et al., 2007) conducted a UAE study to assess, stochastically, the earthquake hazard and risk, including the estimation of the seismic parameters; produce seismic hazard maps utilizing probabilistic procedure; forecast the events magnitude recurrence during the time of exposure at diverse specific levels; develop hazard curves for 15 major cities of the UAE; develop spectral response curves for 15 major cities of the UAE, based on ground motion predicted for 50 years exposure time and 10% probability at 5% damping level; and systematize and represent the results in scientific and applicable manner.

In order to take steps to reduce risks posed by natural hazards, individual property owners, developers, insurers, emergency management personnel as well as local governments need to know the location of hazard-prone areas. Maps of earthquake hazard areas should be available. Wassel (Malkawi et al., 2007) used a probabilistic approach to assess seismic hazard and risk within the UAE to account for the uncertainties in earthquake magnitude, which is reflected in amplitude, location and return period. Methods developed by researchers (Kijko and Graham, 1998; Kijko and Sellevoll, 1989; Kijko and Sellevoll, 1992; Kijko and Graham, 1999) were used for determining the parameters of seismogenic zone, including the mean rate of seismic activity, return periods and the maximum regional earthquake. Using of a suitable attenuation equation and ground motion parameter seismic activity and seismic zoning was introduced. Seismic sources vary; due to both near-surface and deeply-buried fault systems. Two seismogenic sources were used as shown in Figure 3.

A FRAMEWORK FOR COMPARATIVE RISK ASSESSMENT

Risk assessment follows a systematic procedure that involves (Figure 4): hazard identification; assessment of exposure to hazards; assessment of relationship between hazard quantity and severity of consequences; and finally risk characterization. Having defined earthquakes as the hazard of concern (i.e., step 1 in risk assessment), the next step in risk assessment is to define exposure through first defining who or what is at risk, how are they exposed to risk, and by how much. Exposure to earthquake risk can involve the following at risk categories: human lives and health; buildings and infrastructure; the environment; and businesses. Earthquake exposure is widespread and is directly related to ground movement and indirectly to some of the consequences of earthquakes, including damage to buildings, fires, floods and other earthquake consequences.

In this section, we develop a framework for comparative risk assessment. The system is based on a simple risk-characterization model adopted from the health industry. The model is represented in Equation 1:

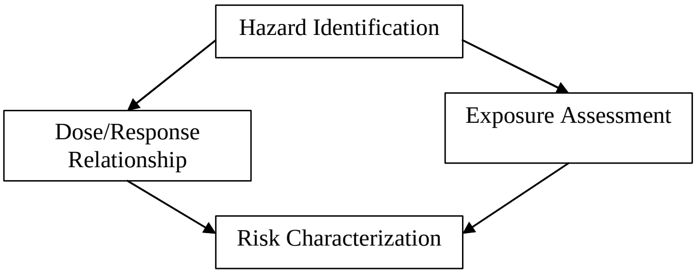

Figure (4): Risk assessment steps.

Table 1. Earthquake dose conversion scale adopted for purposes of this study (Fahmi and Malkawi, 1998).

Zone Damage State	PGA (xg)	MMI	Magnitude Range M
Insignificant	0.005-0.010	4-5	3.4-4.0
Minor	0.011-0.050	5-6	4.0-4.6
Moderate	0.051-0.150	6-7	4.6-5.3
Strong	0.151-0.300	7-8	5.3-5.8
Very Strong	0.301-0.500	8-10	5.8-7.0
Destructive	>0.5	>10	>7.0

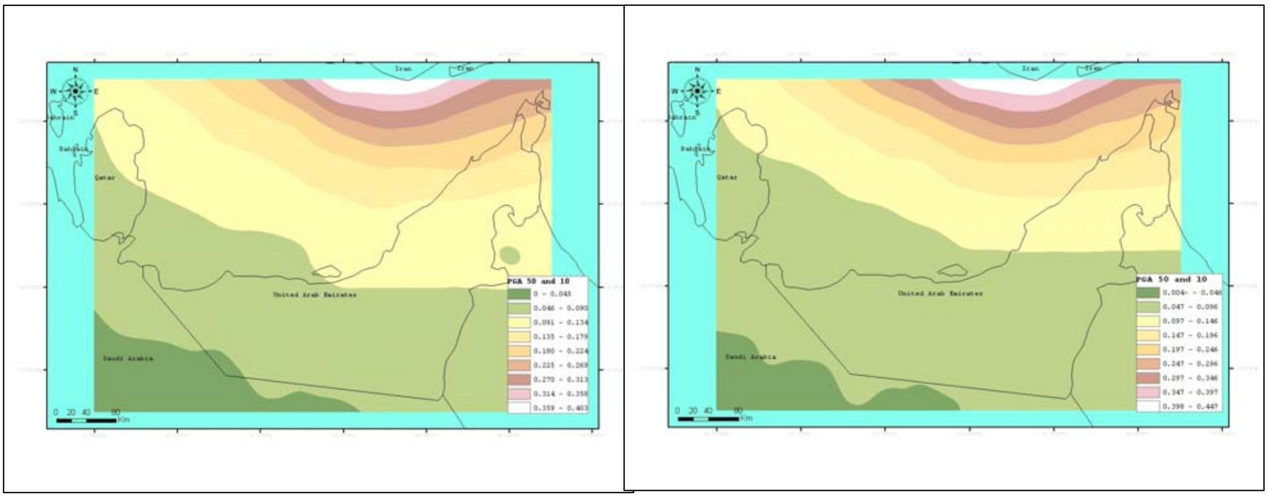

Figure (5): Generalized seismic hazard map for the UAE. Maps show peak ground accelerations (in % gravity) with a 10% probability of being exceeded in 50 years for sources I and II.

Risk =Dose x Response Factor x Equivalent Population x Emergency Response Factor (1)

Adopted to fit our purpose of estimating seismic risk, the various parameters in the above mentioned model are translated as follows: Dose= equivalent seismic force; Response = degree of damage per unit force; Equivalent Population = a factor representing exposed population, exposed environment or exposed infrastructure; and

Emergency Response = effectiveness of available emergency response system to reduce risk immediately after the event. It should be noted that the emergency response in this case differs from long-term risk and consequences management.

Exposure Assessment

The earthquake "*dose*" in this case is reflective of a variety of factors, including earthquake magnitude, distance, depth, type of faulting and characteristics of geologic material. Wassel (Malkawi et al., 2007), supervised by one of the coauthors (Malkawi, 2005), generated probable peak ground acceleration (PGA) contours for the UAE using various scenarios of return periods and probabilities of exceedance. The shaking-hazard maps were also prepared. Each of these maps shows the severity of expected earthquake shaking for a particular level of probability. For example, the map may show the level of earthquake shaking that have a 1-in-10 chance of being exceeded in a 50-year period (typical design life span of most infrastructure, such as buildings and bridges)**.** Local governments across the country should rely on such continuously updated maps to establish the seismic design standards in building codes. The output of a seismic hazard analysis are maps that show levels of ground shaking intensity (in acceleration), in different parts of the UAE that have a certain probability of being exceeded by an expected earthquake. The seismic hazard maps presented in Figure 5 are examples of seismic hazard assessment.

For comparison purposes, the scale presented in Table 1 was used to assess the earthquake dose, as listed in Table 2. The data in Table 2 and Figure 5 suggest that most of the UAE land is relatively at a low risk of major earthquake damage, however the north-eastern horn, which constitutes only a small part of the UAE land and is closest to Iran, is relatively at an increased level of risk. The PGA distribution in Figure 5 provides examples of *"dose"* distribution across the UAE.

Dose-Response Relationship

Fortunately, the history of serious earthquake damage in the UAE has not been written. As such, site-specific earthquake force versus damage relationships do not exist. To estimate dose-response relationships for the various parts of the UAE, one may rely on existing data for areas with similar characteristics. Until recently, the buildings in the UAE generally have been designed and constructed without proper attention to earthquake resistance provisions (Abdalla, 2003). More recently, earthquake resistant buildings are being constructed; however, the design codes and guidelines may not be based on detailed analysis of seismic hazard in the UAE.

Wyss and Al-Homoud (2004) developed scenarios of seismic risk in the UAE, including approximate estimates of deaths, injuries, building damage, degree of damage and economic loss for selected settlements. These scenarios, whether plausible or not, were reportedly based on analysis of prototype cities with similar characteristics with respect to fragility of buildings (five fragility classes used). Buildings were distributed into fragility classes derived from the prototype cities after adjusting for number of inhabitants, degree of industrial development and cultural profile. Figure 6 presents hypothetical dose-response relationships for Dubai based on Wyss and Al-Homoud (2004). Assumptions behind the scenarios and the validity of assumptions in relation to the published material (Wyss and Al-Homoud, 2004) must be carefully considered.

Considering the fragility of buildings, buildings' age, design practices, building materials, buildings' height, degree of building code enforcement, degree of development, industrial and economic activity, living standards, ground conditions and similar factors, and statistical analysis of dose-response relationships from earthquake stricken settlements, we adopted a relative unit-response scale (0-1) for purposes of risk comparisons. In this scale, highly developed cities and economies with a good proportion of new and modern earthquake resistant structures like Dubai and Abu-Dhabi receive the lowest response factors (*RF=0.9*) and smaller, less developed cities like Al-Fujaira receive higher response factor (*RF=1*). For absolute, non-comparative dose-response relationships, the work of Wyss and Al-Homoud (2004), should be reviewed with caution.

Table 2. Selected probabilities for seismic activity in the UAE.

Return Period (Yrs)	Prob-ability (%)	Source	PGA Range and Average			MMI	Magnitude M	
			Lower Limit	Upper Limit	Average	Range	Range	Weighted Average
50	10	I	0.046	0.091	0.0685	6-7	4.6-5.3	4.95
			0.091	0.135	0.113	6-7	4.6-5.3	4.95
			0.135	0.18	0.1575	7-8	5.3-5.8	5.55
			0.18	0.224	0.202	7-8	5.3-5.8	5.55
100	10	I	0.303	0.359	0.331	8-10	5.8-7.0	5.9
			0.359	0.416	0.3875	8-10	5.8-7.0	5.9
			0.416	0.472	0.444	8-10	5.8-7.0	5.9
			0.472	0.528	0.5	8-10	5.8-7.0	5.9
100	50	I	0	0.024	0.012	4-5	3.4-4.0	3.7
			0.024	0.046	0.035	5-6	4.0-4.6	4.3
			0.046	0.069	0.0575	6-7	4.6-5.3	4.95
			0.069	0.091	0.08	6-7	4.6-5.3	4.95
			0.091	0.113	0.102	6-7	4.6-5.3	4.95
200	10	I	0.097	0.191	0.144	6-7	4.6-5.3	4.95
			0.191	0.287	0.239	7-8	5.3-5.8	5.55
			0.287	0.383	0.335	8-10	5.8-7.0	5.9
			0.383	0.478	0.4305	8-10	5.8-7.0	5.9
50	10	II	0.004	0.047	0.0255	5-6	4.0-4.6	4.3
			0.047	0.096	0.0715	6-7	4.6-5.3	4.95
			0.096	0.146	0.121	6-7	4.6-5.3	4.95
			0.146	0.196	0.171	7-8	5.3-5.8	5.55
			0.196	0.246	0.221	7-8	5.3-5.8	5.55
100	10	II	0.006	0.069	0.0375	5-6	4.0-4.6	4.3
			0.069	0.142	0.1055	6-7	4.6-5.3	4.95
			0.142	0.216	0.179	7-8	5.3-5.8	5.55
			0.216	0.291	0.2535	7-8	5.3-5.8	5.55
			0.291	0.365	0.328	8-10	5.8-7.0	5.9
100	50	II	0.002	0.024	0.013	5-6	4.0-4.6	4.3
			0.024	0.048	0.036	5-6	4.0-4.6	4.3
			0.048	0.074	0.061	6-7	4.6-5.3	4.95
			0.074	0.098	0.086	6-7	4.6-5.3	4.95
			0.098	0.123	0.1105	6-7	4.6-5.3	4.95
200	10	II	0.009	0.098	0.0535	6-7	4.6-5.3	4.95
			0.098	0.204	0.151	7-8	5.3-5.8	5.55
			0.204	0.31	0.257	7-8	5.3-5.8	5.55
			0.31	0.416	0.363	8-10	5.8-7.0	5.9
			0.416	0.52	0.468	8-10	5.8-7.0	5.9

Comparative Risk Characterization

With the earthquake dose estimated, we turn to the distribution of population and development in the UAE. A quick view of the population and developed areas of the UAE is shown in Figures 7-9. The data in Figure 7 approximate the populated areas and population densities. The current total population of the UAE is estimated to be about 5 millions. As we prepare this article, a thorough census is being conducted in the UAE with the results expected to be released in December 2005. The previous census was in 1995 with estimates of population distributions up to the year 2003 provided.

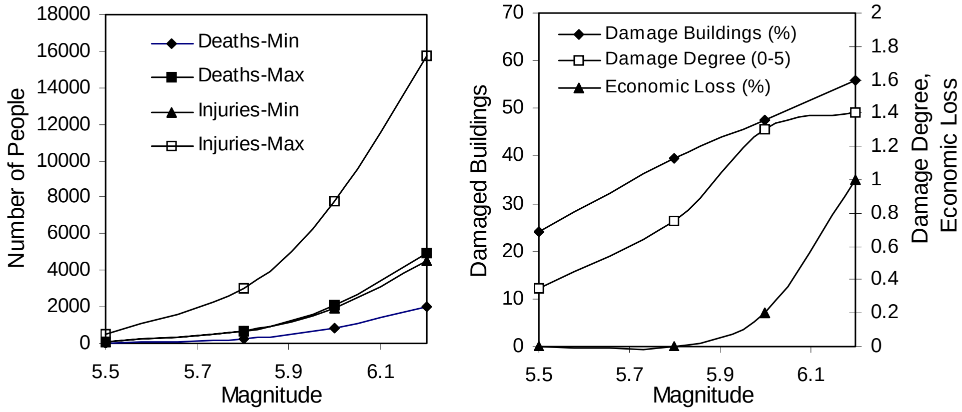

Figure (6): Hypothetical dose-response relationships for Dubai (based on hypothetical scenarios by (Wyss and Al-Homoud (2004)).

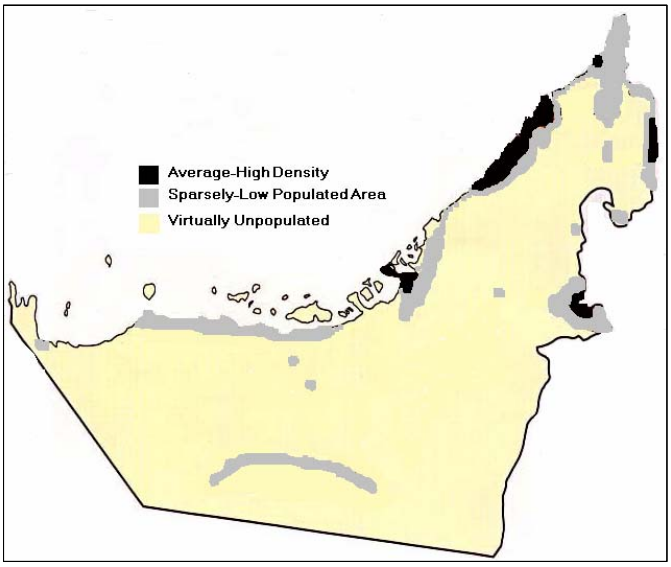

Figure (7): Map showing an overview and gross approximation of populated areas and population densities inland of the UAE (islands excluded).

The UAE is comprised of seven emirates (Figure 9), the largest of which is Abu-Dhabi. The city of Abu-Dhabi is the capital of the country. The estimated 2003 population and buildings' distribution among the seven emirates are listed in Table 3.

Comparative Risk Assessment – Population and Buildings

In this section, we integrate the various data presented in the previous sections to generate normalized comparative risk scores for each of the seven emirates and for the major cities of the UAE. The comparison scale is from 0 to 1, with 1 being the highest risk score. Given the location of each of the seven emirates and major cities and the population estimates, we estimated a relative risk score for each emirate and for the major cities. The results are shown in Figure 10.

Figure (8): Major cities of the United Arab Emirates.

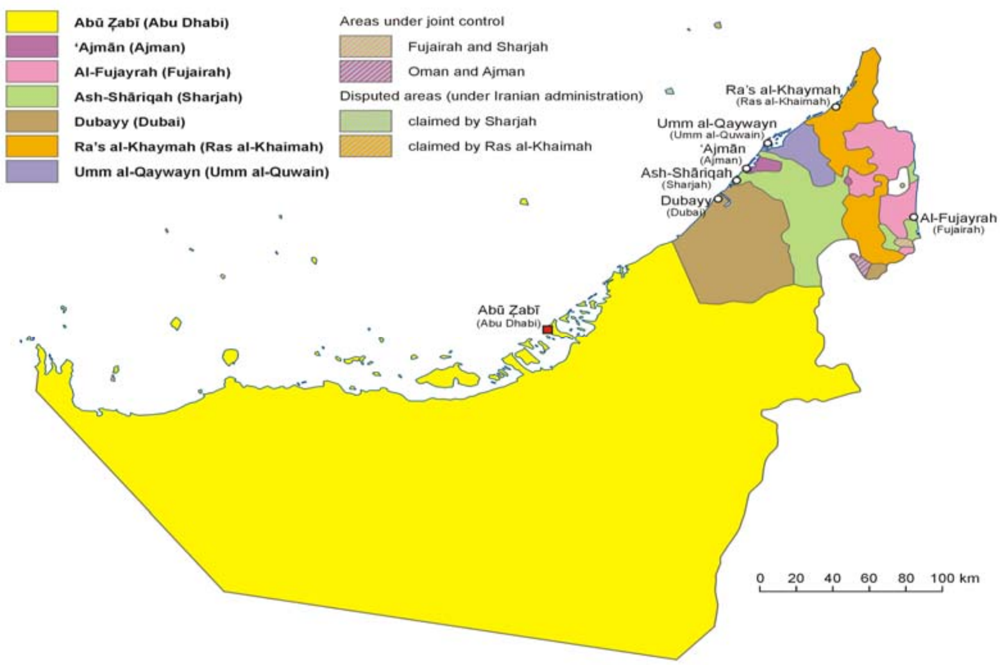

Figure (9): The seven emirates of the United Arab Emirates.

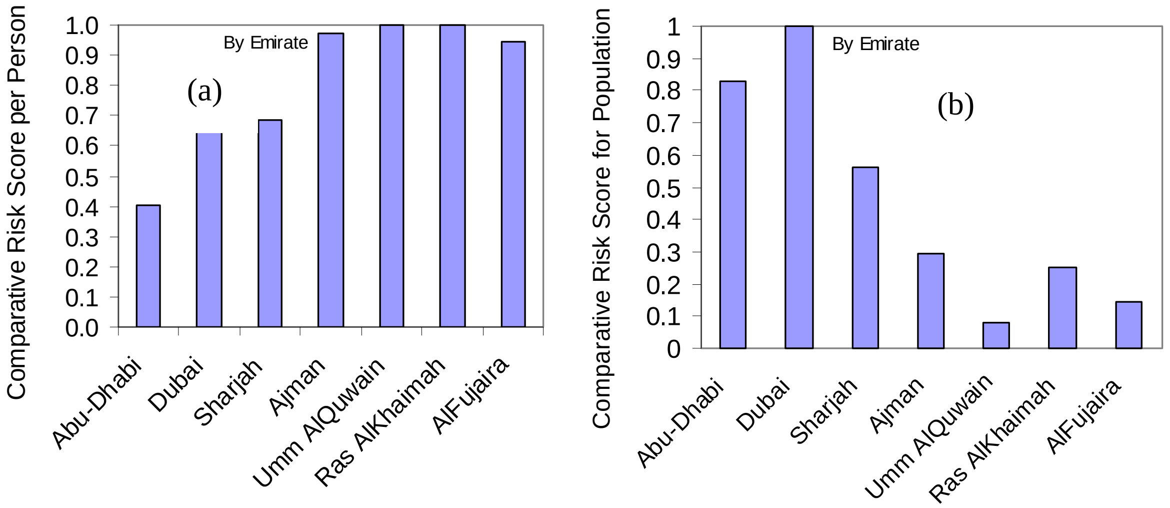

Figure (10): a) Normalized risk scores (i.e., risk per unit population) for the seven emirates.
b) Comparative risk scores for the populations of the UAE seven emirates.

Table 3. Population and buildings of the seven UAE emirates in 2005 and major cities in 2003.

Emirate (Figure 9)	Population	No. of Buildings	Major City (Figure 8)	Population
Abu Dhabi	1399484	455083	Abu-Dhabi	552000
Dubai	1321453	390236	Al-Ain	348000
Sharjah	793573	294770	Dubai	1171000
Ajman	206997	79562	Sharjah	519000
Umm Al-Quwain	49159	21967	Khor-Fakkan	32000
Ras Al-Khaimah	210063	102480	Ajman	225000
Al-Fujaira	125698	48824	Umm Al-Quwain	38000
Total	**4106427**	**1392922**	Ras Al-Khaimah	102000
			Al-Fujaira	54000
			Total	**3041000**

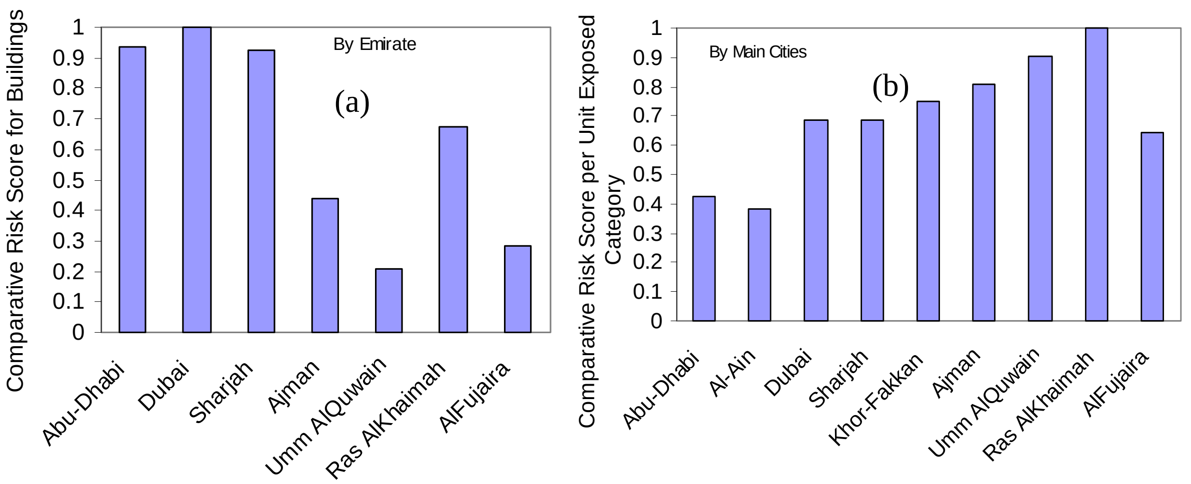

Figure (11): a) Comparative risk scores for the buildings of the UAE seven emirates.
b) Normalized risk scores (i.e., risk per unit equivalent population) for the major UAE cities.

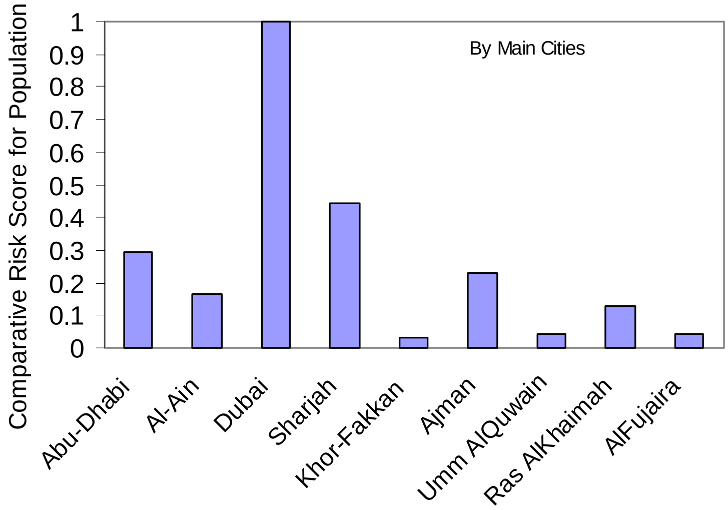

Figure (12): Comparative risk scores for the population of the major UAE cities.

The comparative risk scores per person living in any of the seven emirates of the UAE are shown in Figure 10-a. These scores reflect the dose multiplied by the response factor in Equation 1. The data clearly show that a person in the emirates of Ras Al-Khaimah and Umm Al-Quwain is subject to the highest levels of risk; while a person living in the emirate of Abu-Dhabi is subject to the lowest risk. This assessment and ranking of risk reflect proximity to the source in addition to our estimate of the response factors based on considerations of factors, such as the fragility of buildings, buildings' age, design practices, building materials, buildings' height, degree of building code enforcement, degree of development, industrial and economic activity, living standards, ground conditions and similar factors. The "*dose*" factor was based on the weighted average PGA values for the land of each of the emirates. In our estimates, the emirates of Dubai, Abu Dhabi, Sharjah and to some extent Ajman, are more developed with more established economies than Ras Al-Khaimah, Al-Fujaira and Umm Al-Quwain.

While the risk per person in Figure 10 is highest for an emirate like Umm Al-Quwain, the risk for the total population in each emirate is lowest for the emirate of Umm Al-Quwain. The data in Figure 11 is derived from the data in Figure 10 after multiplying the values by the number of people who live in each of the seven emirates (i.e., 2003 population in Table 3). In this case, the risk for the whole community is highest for the more populated emirates of Dubai, Abu Dhabi and Sharjah. Similarly, the data in Figure 11 show the comparative risk scores for all of the buildings estimated to exist in 2003 in each of the seven emirates. The correlation between the risk of damage to buildings and the population risk is straightforward, damaged buildings and structures cause most of the causalities of earthquakes, especially if earthquakes happen while the majority of people are indoors, during night-time for example.

The comparative risk scores per person and comparative risk scores for the whole population of the major cities of the UAE are shown in Figures 11 and 12. In terms of risk per person, Ras Al-Khaima city ranks highest and Al-Ain city ranks lowest. Taking the population of each city into account (i.e., 2003 population estimates in Table 3), the risk posed to Dubai city ranks the highest, well above the other cities.

The above examples illustrate the simplicity, yet the value of the comparative risk ranking framework established for purposes of screening the risk posed by earthquakes. The trends established by the comparisons make good sense. The uncertainties are being dealt with through data collection and model adjustments. The data collection phase is anticipated to go on for years to come allowing us to cover many layers of risk estimates not only for buildings and humans, but also to the environment and economic activity.

SUMMARY AND CONCLUSIONS

The seismic risk that involves the expected consequences or losses of future seismic events (measured in lives, injuries and damaged buildings) is comparatively performed. Comparative probabilistic expression of the product of seismic hazard and its consequences is carried out, and then, by assessing the vulnerability of different regions under these ground motion parameters, the relative seismic risk for the UAE emirates/cities is estimated.

The risk characterization framework developed and presented in this article proved to be a simple yet a highly useful tool for organizing the UAE earthquake hazard database based on a simple mathematical function adopted from the health industry. The application of the model and framework was illustrated on a comparative basis: risk posed to each of the seven emirates and risk posed to each of the major cities. The data collection phase for purposes of developing and updating the database is still on-going and is expected to continue indefinitely. Simultaneously, the model will be developed further to allow for discontinuous and non-linear dose-response relationships.

The results of applying the risk assessment framework and the generated estimated risk scores for each of the seven emirates and the major cities make good sense comparatively, in terms of rank or order. The higher risk scores mean higher risk and *vice versa*. However, these scores can not be translated into absolute numbers in terms of potential deaths, injuries and damage. As more data is gathered and analyzed critically, the comparative risk assessment framework can be further refined both in terms of scale and absoluteness of predictions.

In conclusion, the following statements can be made:

A. Although less frequent, there is an evidence for recurring large earthquakes and the potential for many more, especially in the eastern-northern regions. The strong motions recorded on 10 Dec. 2002 and 25 April 2003, and the several small earthquakes which have been recorded since that time represent a sufficient evidence of the existence of considerable seismic activity in the UAE.

B. The average population density is higher in the northern UAE than in the southern UAE. Combined with the lower attenuation of ground motion in that part of the UAE, a greater number of people theoretically would be affected by an earthquake occurring in the northern UAE relative to an earthquake in the southern UAE.

C. There is an abundance of weak, vulnerable infrastructure with little to no seismic protection, and the seismic design practice in the UAE is still immature. Although the practice is evolving, seismic design standards and their applications are relatively new.

D. There is a great deal of "human inertia". That is, because earthquakes are not frequently felt, there is more resistance to exercising mitigation and preparation measures – an "out-of-sight-out-of mind" type attitude. However, the rapid development of the country is contributing towards decisive and rapid change, as is the case in Dubai.

E. The United Arab Emirates (UAE) is undergoing a high level of high rise developments that represent high level of financial investments and high densities of population. In the presence of earthquakes, one of the major challenges in designing and maintaining high-rise structures is to account for the earthquake induced forces and displacements. Therefore, a more detailed risk assessment approach should be developed.

ACKNOWLEDGEMENT

This research is part of an on-going research program entitled: "Collaboration and Capacity Building in Seismology – Methodology for Assessing Earthquake

Impacts on Health, Environment and Infrastructure in the UAE". The investigation is jointly funded by the University of Sharjah (UAE), through the Research and Studies Center Grant No. 110301, and Jordan University for Science and Technology (Jordan) through the Scientific Research Deanship Grant No. 158/2004. The Authors from the University of Sharjah are members of the Energy and Environment Research Group and the Intelligent Systems and Infrastructure Research Group.

REFERENCES

Abdalla, J.A. 2003. Towards an Earthquake Resistant Design Code for the United Arab Emirates, Emerging Technologies in Structural Engineering, *Proceedings of 9^th^ Arab Structural Conference*, Nov 29- Dec 1-2003 Abu Dhabi, UAE, 371-378.

Fahmi, K.J. and Malkawi, A.I.H. 1998. Dynamic Site Response Evaluation of the Port City of Aqaba (Jordan) Employing the Equivalent Linear Method, *Canadian Geotechnical Journal*, 35: 961-975.

Kijko, A. and Graham, G. 1998. Parametric-historic Procedure for Probabilistic Seismic Hazard Analysis. Part I: Estimation of Maximum Regional Magnitude m_{max}, *Pure Appl. Geophys.*, 152: 413-442.

Kijko, A. and Graham, G. 1999. Parametric-Historic Procedure for Probabilistic Seismic Hazard Analysis. Part II. Assessment of Seismic Hazard at Specified Site. *Pure Appl. Geophys*, 154: 1-22.

Kijko, A. and Sellevoll, M.A. 1989. Estimation of Earthquake Hazard Parameters from Incomplete Data Files. Part I: Utilization of Extreme and Complete Catalogs with Different Threshold Magnitudes, *Bulletin of the Seismological Society of America*, 82 (1): 120-134.

Kijko, A. and Sellevoll, M.A. 1992. Estimation of Earthquake Hazard Parameters from Incomplete Data Files. Part II: Incorporation of Magnitude Heterogeneity, *Bulletin of the Seismological Society of America*, 79 (3): 645-654.

Malkawi, A.I.H., Barakat, S., Shanableh, A., Al Bdour, W., Omar, M. and Altoubat, S. 2007. Seismic Hazard Assessment and Mitigation of Earthquake Risk in the United Arab Emirates (UAE), Published Jointly by Jordan University of Science and Technology and the Deanship of Research and Higher Studies, University of Sharjah, United Arab Emirates.

Sigbjornsson, R. and Elnashai, A.S. 2006. Hazard Assessment of Dubai, UAE, for Close and Distant Earthquakes, *Journal of Earthquake Engineering*, 10 (5): 749-773.

UNESCO. 1983. for AFESD and IDB, Assessment and Mitigation of Earthquake Risk in the Arab Region, 1-50.

UNESCO. 1983. for AFESD and IDB, Program for Assessment and Mitigation of Earthquake Risk in the Arab Region, 10-30.

Wyss, M. and Al-Homoud, A. 2004. Scenarios of Seismic Risk in the United Arab Emirates, an Approximate Estimate, *Natural Hazards*, 32:375-393.