Assessment of Seismic Structural Risk for Model Buildings in the City of Sharjah, UAE

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ABSTRACT

Thirteen model building types were used to represent the building stock in Sharjah city, United Arab Emirates (UAE) in terms of structural system, height and use. Fourteen representative real ground motion records were scaled and used to assess the potential seismic structural risk of the model buildings. Time history analyses were performed on the 13 model buildings and fragility curves relating the probability of reaching or exceeding four predefined damage states to peak ground acceleration (PGA) were established for the 13 model building types. The fragility curves were then used to assess the structural risk of the model buildings and estimate the associated human and economic losses for various earthquake scenarios. Finally, indicative GIS-seismic risk-based maps were produced for Sharjah city for the various risk scenarios.

KEYWORDS: Seismic risk, Earthquakes, Representative building, Pushover, Time history, Fragility curves, Loss estimation, GIS risk maps.

INTRODUCTION

The United Arab Emirates (UAE) is located in the Arabian Peninsula, southwest of Asia. The Peninsula is known to be seismically stable; however, the UAE is subject to local seismic activity and to impact of strong earthquakes at the southern coastline of neighboring Iran. In March 2002, the Masafi area earthquake (Mb5, 25.24°N 56.15°E, 16 km deep) shocked the north-eastern part of the UAE, alarming the population and changing the perception of the absence of significant local seismic activity. Moreover, earthquakes exceeding Mb6 are common in neighboring Iran. Some of them originate from the southern shores of Iran in Bander Abbas and Qeshm Island in Hurmuz Straits, less than 100 km away from the northern parts of the UAE. During the past decade, the impacts of earthquakes have been felt more than ever before in the UAE due to the construction of high-rise buildings along the shores of the Arabian Gulf facing Iran. In a relatively recent event in 2005, people evacuated tall buildings in Dubai and Sharjah due to an Mb5.9 earthquake in the Iranian Qeshm Island, which is about 180 km away from the two cities.

The main objective of this study was to assess the structural seismic risk of buildings in Sharjah city and the associated risk to the inhabitants of the buildings. The work involved assessing the resistance of the structural systems to earthquakes through establishing fragility curves for the different types of buildings in the city (Barakat et al., 2012).

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Buildings and Population in Sharjah

Researchers have used a variety of classification schemes for buildings (see for example, Ramamoorthy, 2006; Tantala et al., 2007; Erdik et al., 2004). The standardized methodology used by the US Federal Emergency Management Agency (FEMA) for estimating potential losses resulting from earthquakes (HAZUS) was used in classifying the building stock in Sharjah according to height, use and structural system. In addition, the buildings were classified according to their use, which is necessary to assess the potential impact of earthquakes on the users of buildings. A GIS-database containing the distribution of Sharjah buildings and their features was collected from Sharjah Department of Planning and Surveying.

Classification of Buildings Based on Their Use

Sharjah city has three major urban zones, as shown in Fig. 1. The commercial zone is located in the northwestern part of the city and consists of 25 areas. The residential zone is located in the northeastern and southeastern parts of the city and consists of 44 areas. The industrial zone is located in the southwestern part of the city and consists of 15 areas. In terms of numbers, most of the buildings in Sharjah are residential buildings. In percentages, 60% of the buildings are residential, 31% are industrial and only 9% are commercial. However, based on floor area of buildings, 30% of the total floor area is commercial, 39% residential and 31% industrial. The difference in classification based on building numbers and floor area is because most commercial buildings are mid-rise or mostly high-rise buildings, while residential building are mostly one-or two-story buildings. Moreover, during daytime, an estimated 56% of the population is concentrated in commercial buildings, 30% in residential buildings and 14% in industrial buildings.

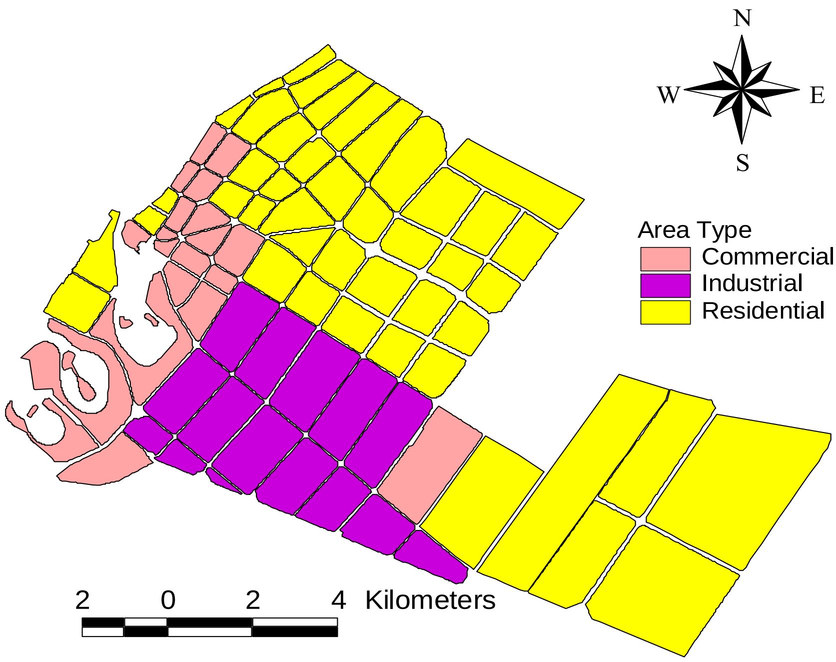

Figure (1): Sharjah city land use zones

Classification of Buildings Based on Their Structural System

The structural system of buildings determines their response to earthquakes. The US Federal Emergency Management Agency (FEMA) established a standardized methodology for estimating potential losses resulting from earthquakes. The FEMA's system for classifying buildings was used in this study for classification of the buildings in Sharjah based on their use, structural system and height.

Using the FEMA methodology, the following types were identified in Sharjah (Fig. 2):

- Concrete frame with unreinforced masonry infill wall (C3) buildings.
- Concrete shear wall (C2) buildings.
- Steel frame with unreinforced masonry infill walls (S5) buildings.

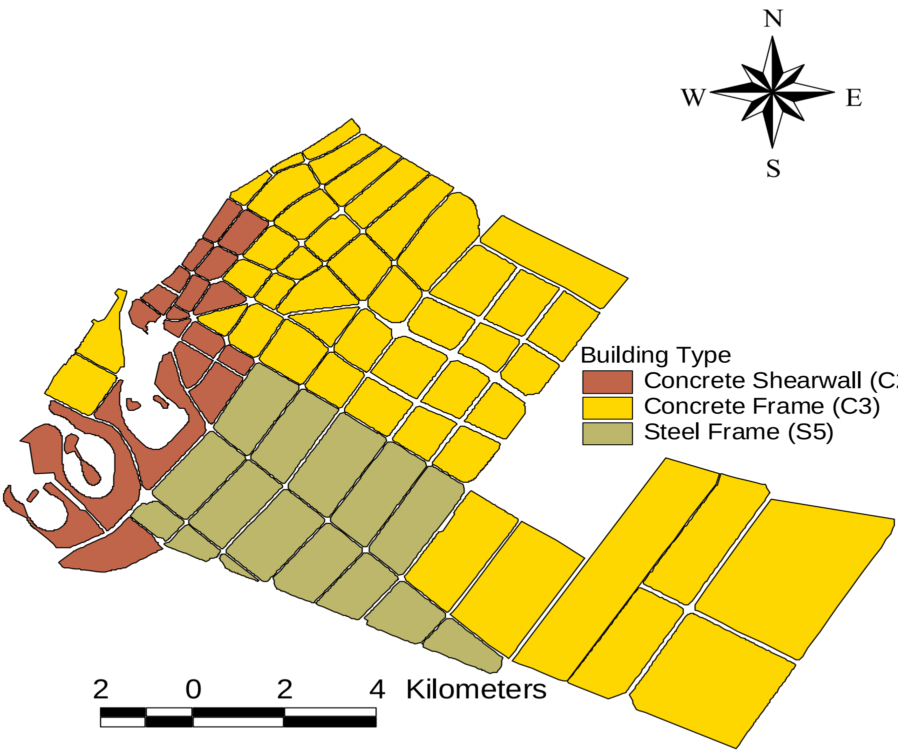

Figure (2): Structural systems of building in Sharjah city

In terms of percentage distribution, 61% of the buildings in Sharjah are concrete frame buildings with unreinforced masonry infill walls (C3), 31% are steel frame buildings with unreinforced masonry infill walls (S5) and 8% are concrete shear wall buildings (C2). In terms of floor area, however, building type C3 was 38%, 31% building type C2 and 31% building type S5. During the day, 58% of people were in buildings of type C2, 28% in buildings of type C3 and 14% in buildings of type S5.

Classification of Buildings Based on Their Height

The FEMA loss estimation methodology classifies buildings in terms of height into three categories: low-rise buildings (1–3 stories), mid-rise buildings (4–7 stories) and high-rise buildings (8 stories and above). A database of building heights was obtained from the Sharjah Department of Planning and Surveying. The buildings in the various parts of the city were classified according to height, as shown in Fig. 3. The commercial zone was dominated by mid-rise buildings, with a few low-rise and high-rise building areas. The residential industrial zones were mostly low-rise buildings. In terms of percentage distribution, 92% of the buildings in Sharjah are low-rise, 6% are mid-rise and only 2% are high-rise buildings. However, in terms of floor area, 68% were low-rise buildings, 18% mid-rise buildings and 14% high-rise buildings. Similarly, for the inhabitants of the buildings, 42% lived in low-rise, 32% in mid-rise and 26% in high-rise buildings. Although most buildings in Sharjah city were low-rise, the population was nearly equally distributed among the three height categories. The distribution of buildings in Sharjah is presented in Fig. 4. The percentages of Sharjah buildings categorized according to their type are shown in Fig. 5.

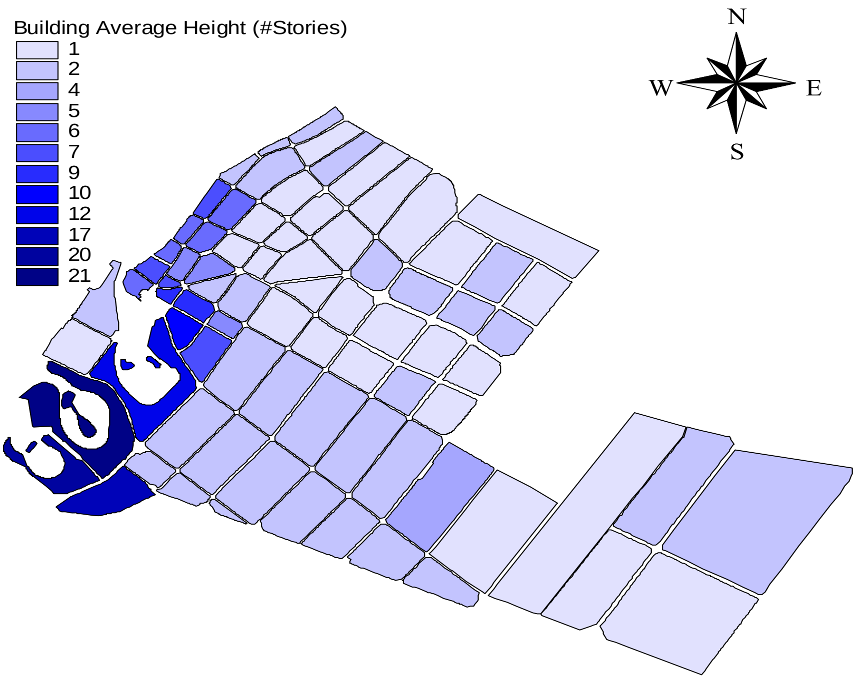

Figure (3): Distribution of buildings according to number of stories

Representative Buildings in Sharjah

Following classification of the building stock in the city according to their use, height and structural system, representative buildings were selected for the various areas.

A single building representing the average characteristics of the buildings in each area, in terms of height and structural system, was selected and designed using the applicable seismic code in Sharjah. In total, 13 building types (Table 1) were considered representative of the building stock in Sharjah. For simplicity and taking the distribution of buildings and floor areas into consideration, the 13 representative model buildings were assumed to have three equal 6-m bays in the longitudinal and transverse directions (i.e., 18 m x 18 m) with a typical story height of 3 m.

Demographic Information

The distribution of the population in the city of Sharjah is shown in Fig. 6. The highly populated areas represent the older parts of the city and the parts with high-rise buildings.

Building Fragility

The next step is to assess the vulnerability of each of the thirteen representative buildings.

Seismic Hazard

The seismic hazard of the United Arab Emirates was assessed by a number of researchers (Abdalla and Al-Homoud, 2004; Al-Bdour, 2005; Sigbjornsson and Elnashai, 2006; Aldama-Bustos, 2009; Shama, 2011; Khan et al., 2013; Mwafy, 2013; Mwafy et al., 2014). In this study, the seismic hazard scenarios produced by Al-Bdour (2005) were used to assess the seismic risk in Sharjah.

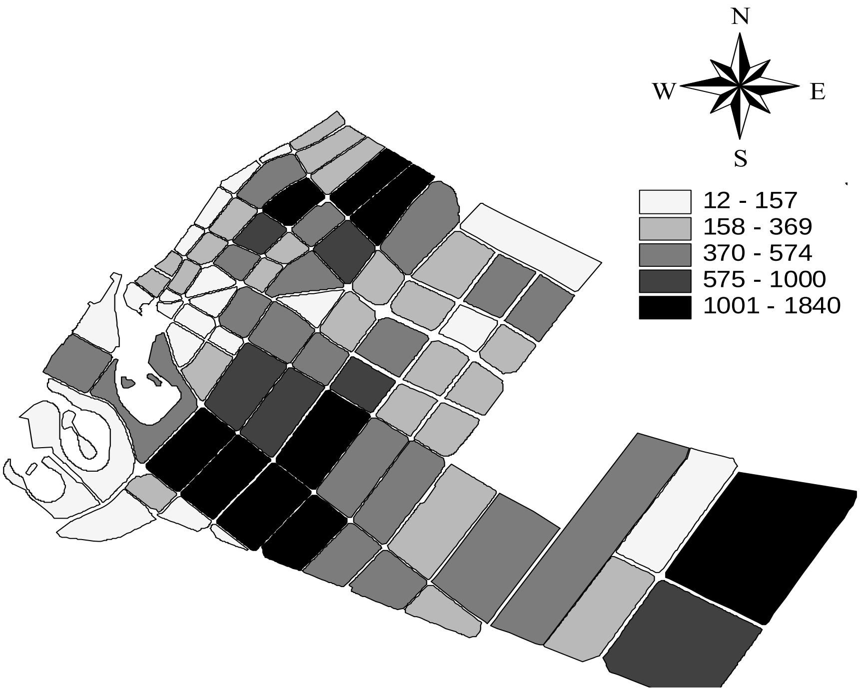

Figure (4): Distribution of numbers of buildings in Sharjah

Al-Bdour (2005) produced a variety of seismic hazard maps for the UAE using ground motions taken from the Iranian Strong Motion Network (ISMN). The local seismic records are generally weak and do not have enough energy to analyze the seismic fragility of buildings.

Therefore, a group of 14 time history motion records were obtained from ISMN and used to analyze the fragility of the 13 model buildings used to represent the building stock in Sharjah. Each of the 14 ground motion records was scaled 15 times to yield records with maximum shaking levels ranging from 0.01g up to 2.00g. In Fig. 7, the response spectra for the 14 ground motion records show the variation of the chosen ground motion records and their contents.

The site amplification factors shown in Fig. 8 were taken from a study conducted by Balwan (2008) on Sharjah using a database of borehole records.

Table 1. Model buildings used to represent Sharjah Buildings

Building Height		Structural System
Category	**Floors**	
Low-Rise	1	C3
	2	C3
	2	S5
Mid-Rise	4	C3
	5 to 7	C2
High-Rise	9 to 21	C2

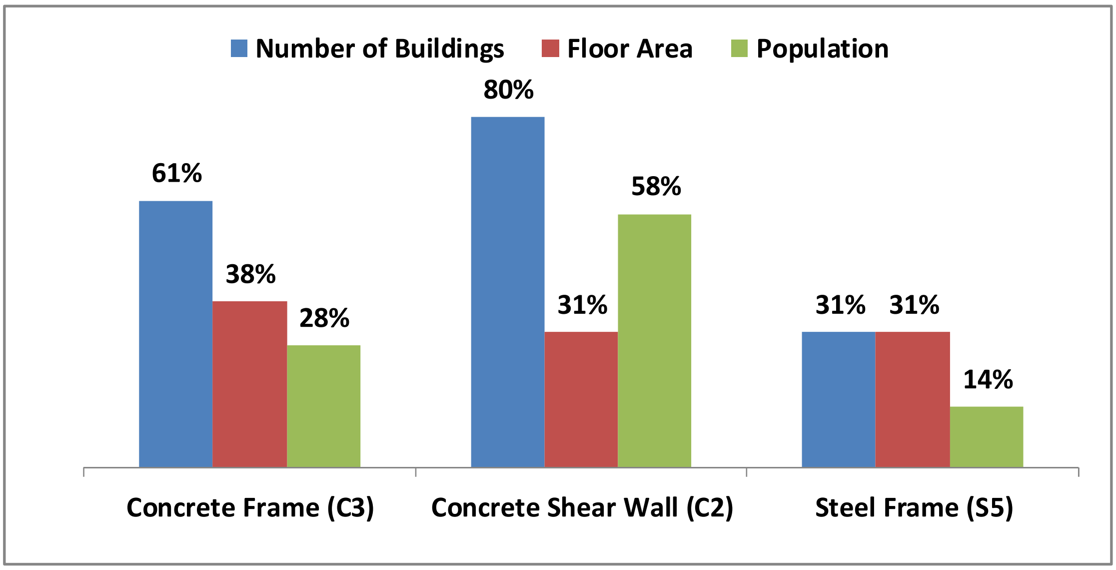

Figure (5): Percentages of Sharjah buildings categorized according to their type

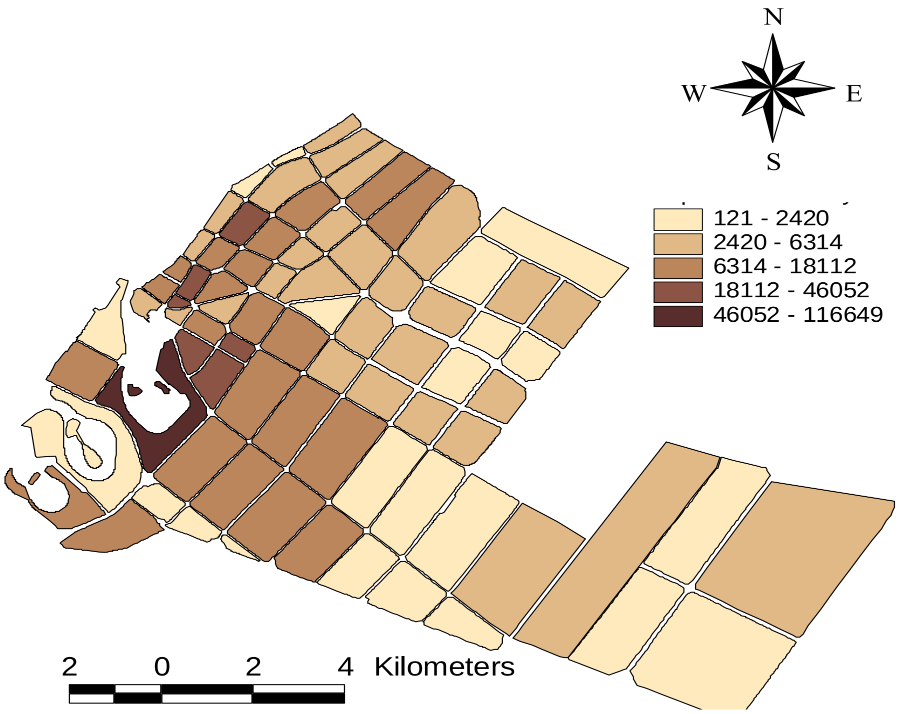

Figure (6): Distribution of population in Sharjah city

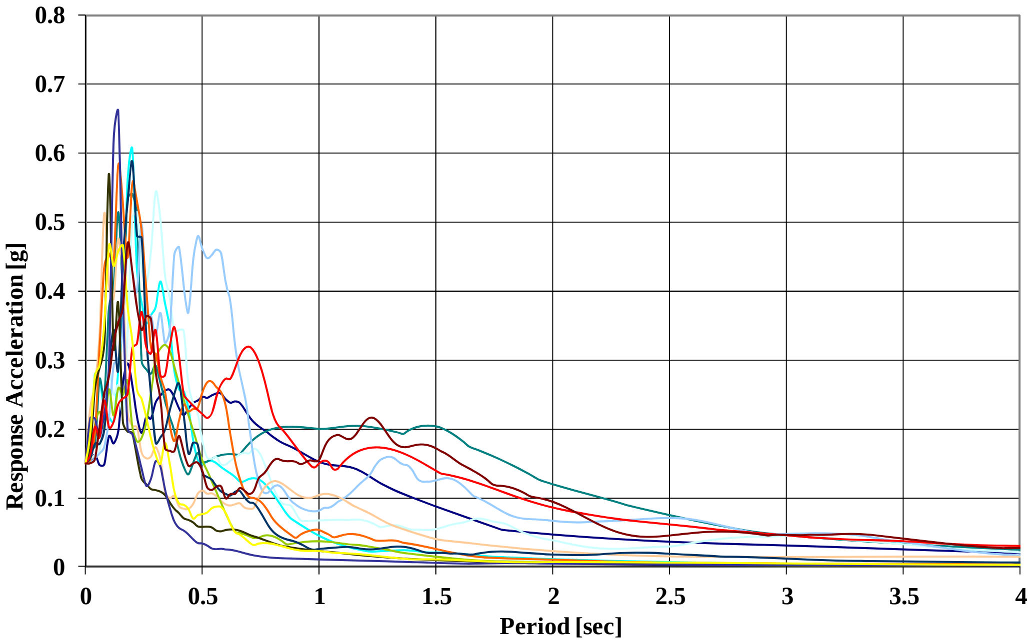

Figure (7): Response spectra for 14 ground motion records scaled to 0.15 g

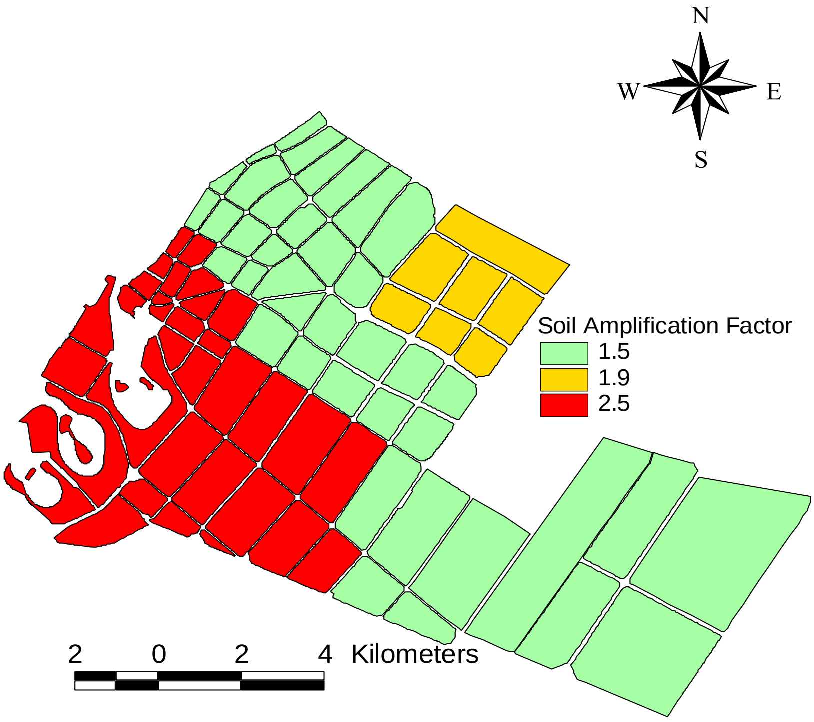

Figure (8): A GIS-based map showing soil amplification factors for Sharjah city

Time History Analysis

The above fourteen ground motion records were each scaled to 15 different PGA values ranging from 0.01g up to 2.0g (Alimoradi et al., 2004; Al Bdour, 2005). To assess the vulnerability of the 13 representative types of building, the buildings were modeled and designed using ETABS to meet the standards applicable in Sharjah city. These standards include: ACI-318-11 code for concrete buildings, AISC-LRFD for steel buildings and IBC 2011 for lateral load design. It should be noted that buildings with less than 5 stories are not designed to resist lateral loads in Sharjah. Then, using ETABS, incremental time history analysis was performed to develop the fragility curves for the different types of building. The maximum inter-story drift was determined and recorded for each analysis. The inter-story drift represents the maximum displacement of one floor relative to an adjacent floor divided by the story height. Inter-story drift represents the ability of a structure to resist P-Δ instability and collapse and is closely related to plastic rotation demand, or drift angle demand, on individual beam-column connection assemblies.

Damage States

The buildings' damage states were based on FEMA classification of damage states; slight (S), moderate (M), extensive (E) or complete (C). The basis for classifying the damage states was the FEMA inter-story drift limits listed in Table 2.

Table 2. Inter-story drift ratios used to define the damage states

Building Type	Structural Damage State			
	S	M	E	C
C2	0.004	0.008	0.020	0.050
S5, C3	0.003	0.006	0.015	0.035

Fragility Curves

The fragility curves are lognormal functions that describe the probability of reaching or exceeding specific damage states, P (R or E) for a given PGA. These curves take into account the variability and uncertainty associated with capacity curve properties, damage states and ground shaking. Figures (9-12) provide examples of fragility curves for different building types used in this study.

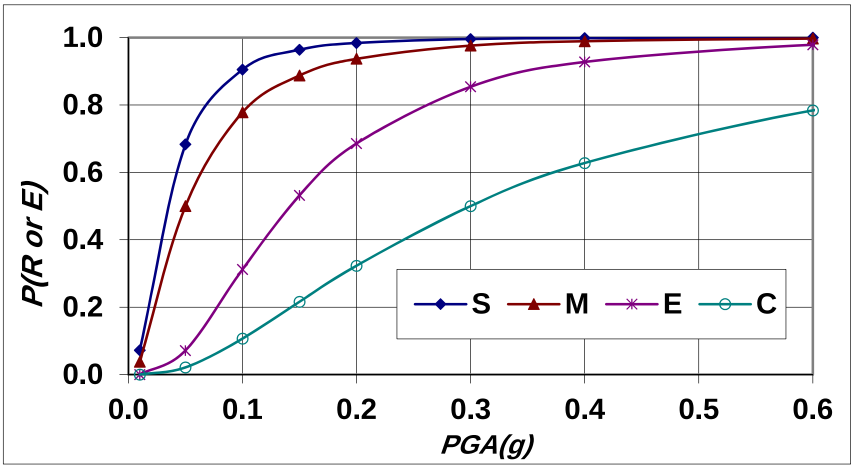

Figure (9): Sample fragility curves for 2-story (C3) concrete frame building

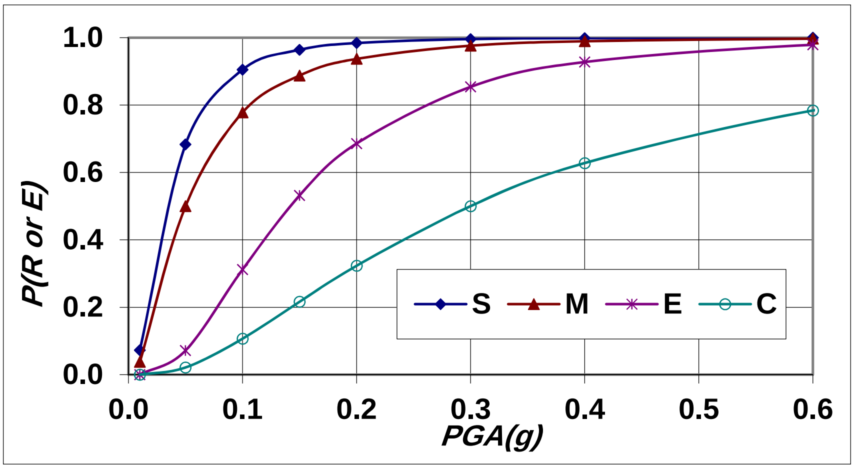

Figure (10): Sample fragility curves for 2-story steel frame (S5) building

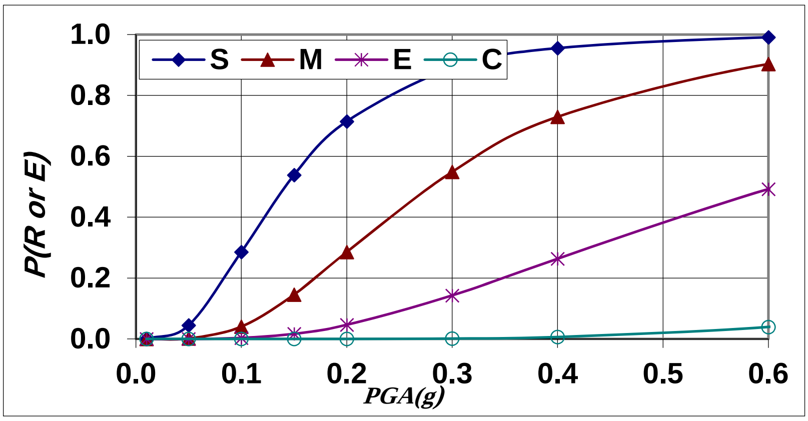

Figure (11): Sample fragility curves for 6-story (C2) concrete shear wall building

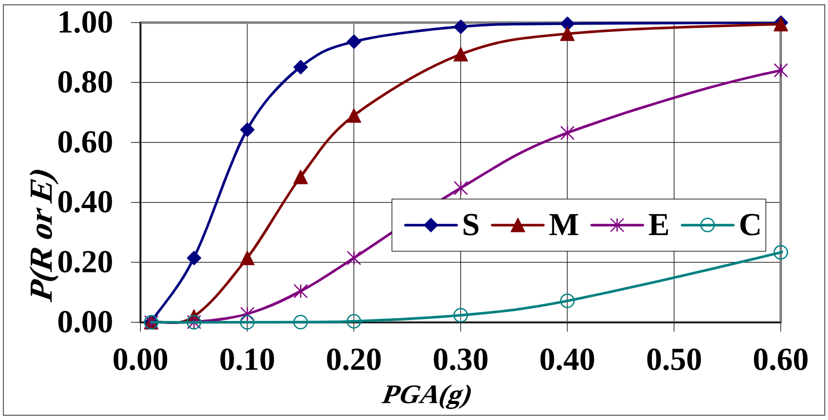

Figure (12): Sample fragility curves for 20-story (C2) concrete shear wall building

Loss Estimation

Potential human losses include injuries and deaths and structural losses can be represented by the replacement costs. The potential rates of human and structural losses used in this study were based on ATC-13, as summarized in Tables 3 and 4.

Table 3. Injury and death rates used in this study, derived from ATC-13

Damage State	Damage %	Minor Injuries	Serious Injuries	Deaths
None	0	0	0	0
S	10	3/10,000	1/25,000	1/100,000
M	30	3/1,000	1/2,500	1/10.000
E	60	3/10	1/25	1/100
C	100	2/5	2/5	1/5

Table 4. Cost of damage state (Source: Cortés-Areizaga, 2006)

Item	Damage State			
	S	M	E	C
Mean Loss Ratio	0%	10%	50%	100%
Mean Loss Rate [$/SF]	$0.0	$2.5	$12.5	$25.0

The distributions of different losses based on building height, building use and building type were investigated. Summaries of these distributions, presented as average values from all earthquake scenarios, are given in Table 5.

The above results show that low-rise buildings in Sharjah are potentially responsible for about 75% of the total structural and human losses. This is because most people live in low-rise buildings, being the dominant type of building in Sharjah city, but such buildings are not designed for lateral load resistance (the local regulations require seismic design only for buildings with 5 stories and taller).

Table 5. The distribution of all structural and human losses among the different building categories

Building Categories		Struc. Losses	Injuries		Deaths
			Minor	Serious	
Height	LR	72%	65%	74%	75%
	MR	14%	14%	9%	8%
	HR	14%	21%	17%	17%
Use	Res.	53%	38%	41%	41%
	Com.	28%	41%	35%	35%
	Ind.	19%	21%	24%	24%
Type	CF-(C3)	54%	40%	45%	45%
	CSW-(C2)	27%	39%	31%	31%
	SF-(S5)	19%	21%	24%	24%

Using the methodology described above, combined with the database of the population and buildings, the total losses for Sharjah city areas were estimated and incorporated into the GIS database. Using the loss rates in Tables 3 and 4, the potential losses based on 10% probability in 50 years earthquake scenario were estimated and presented in the form of GIS maps (Figs. 13 - 16). These GIS maps show the areas that are susceptible to more damages than the others for a given earthquake scenario. The darker the color, the more the potential losses the area has. Therefore, emergency systems and plans can be better prepared taking the most vulnerable areas into account.

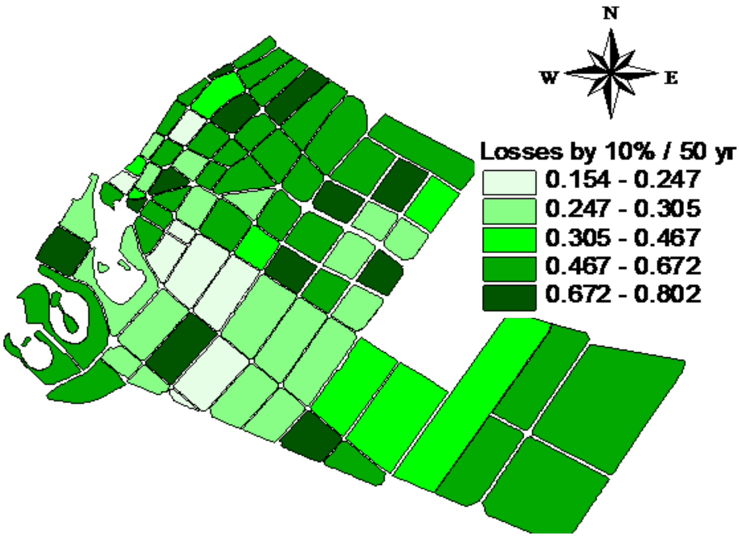

Figure (13): Distribution of potential structural losses (total losses = 6 billion USD)

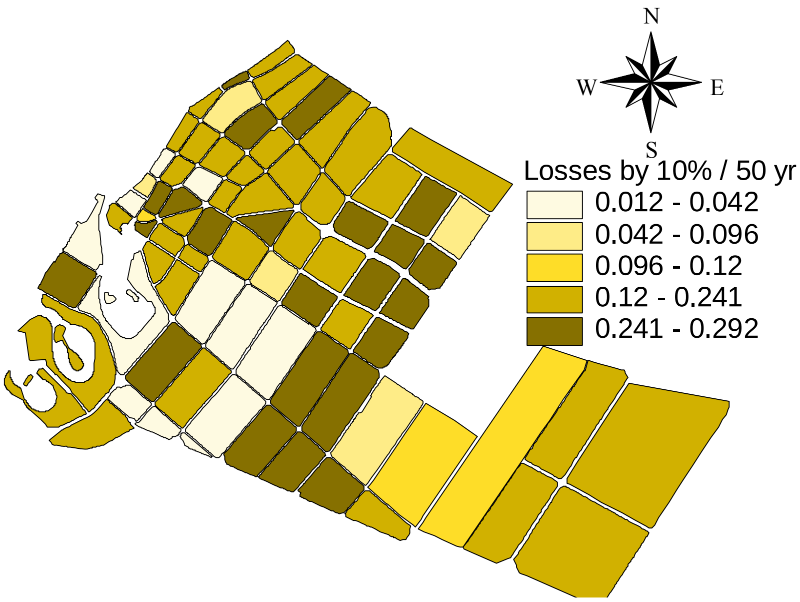

Figure (14): Distribution of potential minor injuries (14% of the population)

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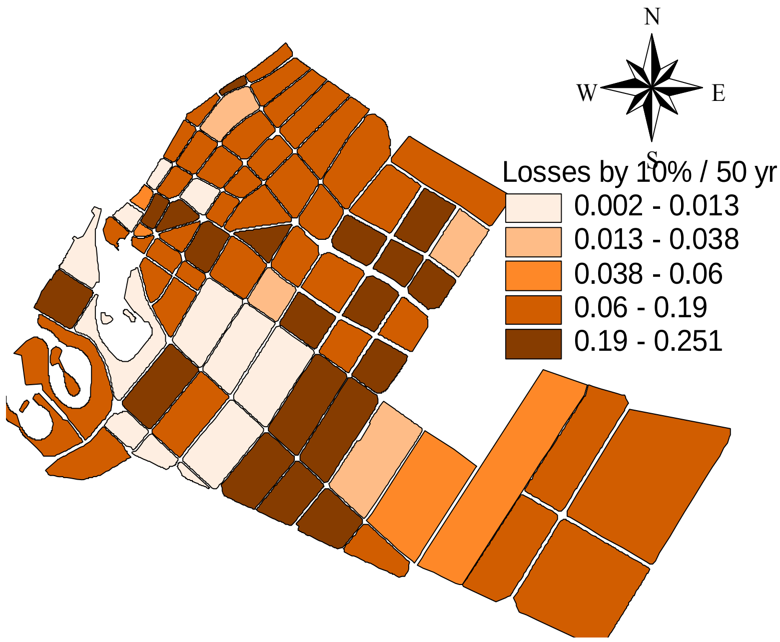

Figure (15): Distribution of potential serious injuries (9% of the population)

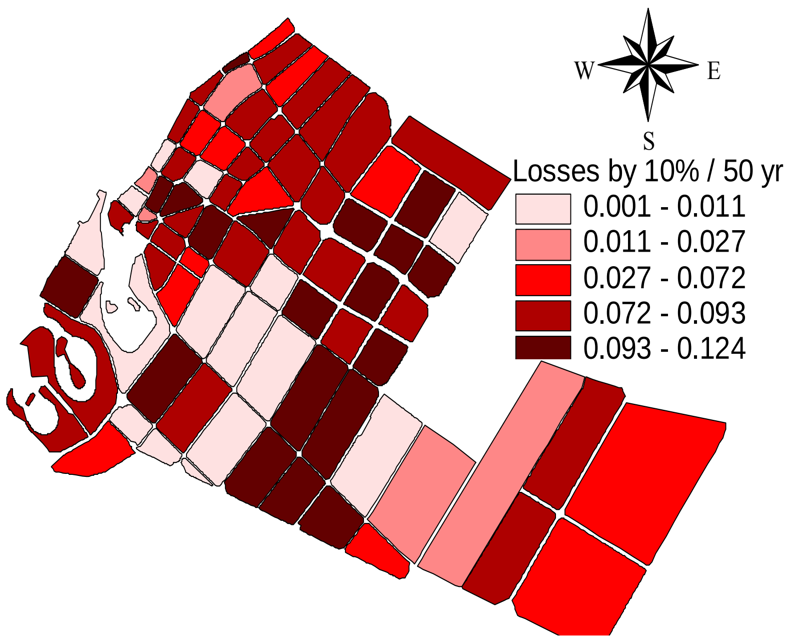

Figure (16): Distribution of potential deaths (5% of the population)

SUMMARY AND CONCLUSIONS

The seismic risk assessment for buildings in Sharjah city was performed. Sharjah buildings were classified and the necessary information was collected about them. A group of 13 representative buildings were modeled to represent, in an average sense, all building types, heights and uses in Sharjah city. Time history analysis was performed on these buildings using 14 real ground motion records from Iran, which were the basis of a seismic hazard assessment previously performed for Sharjah city, UAE. The results of the analysis were used to establish the fragility curves for the buildings. The performance of each building under different seismic hazard scenarios was determined and the losses were calculated. Seismic risk GIS-based maps were produced for different earthquake scenarios. These maps can be used to guide the preparation of emergency systems and plans. Most of the buildings in Sharjah city are low-rise concrete frame buildings with unreinforced masonry infill walls, which are not designed for seismic loading. Not surprisingly, most of the projected losses were due to these buildings. The local regulations do not require buildings with less than 5 stories to be designed for lateral load resistance and the seismic design starts from 5-story buildings and taller. This study confirmed that this gap in the design could have significant impacts on the behavior and the performance of unprotected low-rise buildings. The results of this comprehensive study were integrated into a GIS database that allows quick and visual inspection of high- and low-risk areas in the city. The results are helpful for developing the seismic hazard zones and seismic protection code in the UAE.

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