Seismic fragility assessment of model buildings in Sharjah, United Arab Emirates

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Abstract

The United Arab Emirates (UAE) is located near an active seismic zone; the Zagros folded belt and the Makran subduction zone in Iran. The M\textsubscript{w}5 earthquake on 11 March 2002 in Masafi in the UAE highlighted the potential risk posed by local seismic sources. However, the seismic hazard is generally considered to be low to moderate in the UAE, depending on the proximity to the seismic sources. The objective of this study was to assess the fragility of buildings in Sharjah City when subjected to the probable seismic hazard. Sharjah City was divided into areas, and the buildings and the population data were collected for each area. The buildings were then classified according to their usage, heights and structural systems. The buildings were classified and model representative buildings were assigned for each of the different areas in Sharjah. Seismic fragility analysis was performed for each representative building to assess its performance under the probable seismic hazard using time history analysis and the fragility curves were prepared for each building type. The results of the study showed that the buildings that were not designed for earthquake resistance were most venerable. Finally, probable losses were estimated using available loss functions and a GIS database was developed for the city.

Keywords: seismic risk, Sharjah City, United Arab Emirates, building seismic fragility, GIS

1 Introduction

The risk posed by earthquakes to the buildings and infrastructure in the United Arab Emirates (UAE) has gained considerable attention during the past decade due to the rapid development and widespread construction of high-rise buildings, including some of the tallest buildings in the world. Particularly, the 2002 local M\textsubscript{w}5.5 Masafi earthquake, on the north eastern side of the UAE and the more recent earthquakes in the nearby Qeshm Island in Iran highlighted the importance of the local seismic risk. The M\textsubscript{w}5.9 Qeshm Island earthquake in Iran in 2005 was felt by the local people, especially in high-rise buildings which were evacuated, although little damage if any was reported. The above statements highlight the need for objective assessment of the seismic risk in the UAE.

2 Seismic hazard

The seismic hazard of the United Arab Emirates (UAE) was investigated by few researchers (Abdallah and Al-Hmoud, 2004, Malkawi et al., 2007). The probabilistic seismic hazard study by Malkawi et al. (2007) was based on assessing two seismic sources and provided six scenarios for each
seismic source with different return periods. Each scenario gave a certain peak ground acceleration (PGA) value for Sharjah City. The minimum value was (0.08 g) and the maximum value is (0.528 g).

2.1 Ground motion time-history records

For the purpose of the fragility analysis, ground motion records were collected from nearby seismic monitoring stations in Iran, the only available resource for strong ground motion records. A suite of 42 real ground motion records were collected in order to use them in the time history analyses. Each one of these ground motion records was scaled from (0.01 g) up to (2.00 g), to cover the amplified peak ground acceleration (PGA) values provided by the seismic scenarios. The response spectra for the 42 records is shown in Figure 1.

![Response spectra for the 42 ground motions scaled to 0.15 g](image)

Figure 1. Response spectra for the 42 ground motion records scaled to 0.15 g with the UBC97-Zone2A response spectrum

3 Inventories

The distribution and density of buildings in Sharjah City is shown in Figure 2. To cover all buildings of Sharjah City, the city was divided into areas according to land use and it was found that the city has 22 commercial areas, 44 residential areas, and 15 industrial areas. The common buildings structural system used in each area was investigated, and three structural system types prevailed; concrete frame system (C3), concrete shear wall system (C2); and steel frame system (S5). Moreover, the average building height in each area was estimated, and it was categorized under one of the three height levels; low-rise buildings (1-3 stories), mid-rise buildings (4-7 stories), and high-rise buildings (+8 stories). After filtering all the data of the buildings, a group of thirteen (13) representative buildings were chosen to represent the buildings stock in Sharjah. The model buildings were designed and detailed according to the local requirements, which do not require lateral load resistance design for
buildings below five (5) stories, but for buildings with five (5) stories or higher. This gap in the design had significant impacts on the behavior and the performance of the buildings, as was revealed in this study.

Figure 2. A GIS-Based map of the distribution of the buildings of Sharjah City

4  Fragility analysis

The fragility analysis of the 13 representative model buildings was performed using time history analysis and statistical analysis. For each model building, the 42 ground motions were applied by the time history analysis. Each ground motion was scaled into fifteen (15) levels of peak ground acceleration (PGA) from (0.01 g) up to (2.00 g). The maximum inter-storey drift (i.e., relative lateral displacement of stories when subjected to lateral loads) of each model building at each time history analysis was recorded. These values were compared with a predefined damage-states' limits for inter-storey drift. Using simple statistical analysis, the probability for each model building to reach or exceed a certain damage-state was estimated. Moreover, by fitting a curve to each group of points of certain damage-state, the log-normal function of each damage-state was defined. Fragility curves for all of the thirteen (13) representative model buildings were constructed (e.g. Figure 3), and the associated probability matrices, that showed the performance of these buildings under the probable seismic hazard scenarios, were also established.
5 Loss estimation

The associated human and structural losses were estimated for each seismic hazard scenario. Loss functions were developed using loss rates provided by ATC-13 for minor injuries, serious injuries, and dead. Structural losses were based on the replacement cost of each building and the damage percentage. The potential losses were estimated for the various seismic risk scenarios, which ranged from the 50% with 100 return period to 50% with 2079 return period all combined with the local site response factors. The results of this study showed that the probable structural losses for these scenarios ranged between 38% - 85% of the total replacement cost of all the structures, 7% - 29% of the population are minor injuries, 4% - 25% of the population are serious injuries, and 2% - 12% of mortality.

In depth, more than have of the total losses were due to the low-rise concrete frame (C3) buildings. Theses buildings were not designed, originally, for any lateral load resistance. These type of buildings are the common in Sharjah and house most of the population. A trial was made to see how the results would differ and what would the benefits gained be if the low-rise buildings were designed for lateral load resistance. The results showed that the losses would decrease dramatically by about 75% compared with the losses estimated without designing such buildings for earthquake resistance.
6  Seismic risk maps

All of the data and results of this study were compiled in a GIS-based database. Each type of data and results were modeled in a separate layer and presented by a well-formatted seismic risk GIS-based map. These maps show the distribution of the properties under consideration; either data (population density, building height, soil amplification factor, … etc) or results (structural losses based on 10% / 50 yr scenario from source (I) (Figure 4), Serious Injury population losses based on 10% / 50 yr scenario from source (II)). These maps, beside the above conclusions, can help in the strategic planning of the city. Moreover, they may help in the planning and management of the construction of structures and infrastructures projects, and prepare good emergency systems and plans in Sharjah City.

Figure 4. A GIS-Based map of the structural losses distribution (%) of the buildings of Sharjah City
7 Conclusion

The buildings stock in Sharjah city was represented by 13 model building types according to their heights, use and structural systems. Seismic fragility analysis was performed for each building type and the associated fragility curves were prepared. The fragility curves were used to estimate the seismic potential losses in Sharjah city for a wide range of seismic risk scenarios. The results revealed that the low-rise buildings would be responsible of more than half of the total human and structural losses in Sharjah. This result could be attributed two reasons; that these buildings were not designed to resist any lateral load; and that closeness of the periods of these buildings and the period of the ground motions used in the study. The study highlighted the need for objective seismic risk assessment in Sharjah.

References


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