Classification and Idealization of the Building Stock in the UAE for Earthquake Loss Estimation

A.M. Mwafy
United Arab Emirates University, PO Box 17555, Al Ain, UAE

15 WCEE
LISBOA 2012

SUMMARY:
This paper addresses essential components for predicting earthquake losses in the highly populated area in Dubai, UAE, namely the compilation, classification, design and idealization of the building inventory. Collecting the characteristics of the large and diverse building stock in Dubai is a challenging task. This is achieved using satellite images and confirmatory site visits. A GIS data of the urban development is also used to verify the collected data. The building inventory is classified according to four criteria, namely the building height, function, construction date and the population intensity of the construction site. A wide range of reference structures with various characteristics is selected to represent the building stock. The selected buildings are fully designed and idealized to represent pre-code, contemporary and critical facilities with different characteristics. This enables the derivation of a wide range of vulnerability relationships prepared for integration with a loss estimation system for the UAE.

Keywords: Buildings inventory, structural classification, loss estimation system, UAE, vulnerability curves

1. INTRODUCTION

Given the large investments in the infrastructure and construction sector in the United Arab Emirates, investigating and planning for earthquake risk in urban areas should be undertaken in order to effectively predict and mitigate earthquake losses. Earthquake hazard information should be combined with a realistic building inventory and vulnerability relationships to reliably assess seismic risk. The latter component, which is also referred to as fragility curves, involves the assessment of the seismic performances of reference structures representing the inventory when subjected to potential earthquake scenarios (Mwafy 2012). Impact of different seismic events on the building inventory can be evaluated from the vulnerability functions and translated into monetary and human losses through an earthquake loss estimation system. This system is also an effective mean for mitigating seismic risk by assessing the effectiveness of the seismic design provisions of new structures and retrofit approaches of existing buildings (Calvi et al. 2006). The anticipated losses can be compared with the cost of improving the seismic resistance through increasing seismic design loads or retrofit schemes, which provide the authorities with a tool to compare between the cost and risk.

The UAE seismicity is characterized by earthquakes originated from different seismic sources, namely long-distance events from Southern Iran along with earthquakes from local seismic faults (e.g. Mwafy et al. 2006). Although no significant human and monetary losses were reported from recent earthquakes, the repeated reports of seismic activities in the UAE reflect the pressing need to investigate seismic risk in this region. The multi-story buildings in the highly populated areas in the UAE are the most significant inventory since they represent concentrated economic and human assets. Emergency and critical facilities such as hospitals, fire stations and schools also play an important role in the recovery period following an earthquake. It is noteworthy that a comprehensive regional earthquake assessment and mitigation strategy requires an interdisciplinary framework that includes the hazard definition, physical damage, and social and economic consequences. Physical damage should be assessed for the building inventory, critical facilities, transportation networks and lifeline systems (e.g. Elnashai et al. 2008).

The compilation, classification, design and idealization of the building inventory in Dubai, UAE, are discussed in this paper. This area was selected due to its high population and vulnerability to near- and far-field seismic events (e.g. Mwafy et al. 2006). The adopted approach for collecting the structural characteristics of the building stock in Dubai using satellite images, GIS data of the existing construction and urban development, and confirmatory site visits is presented. The design and idealization approach of a wide range of reference structures which are selected to represent the building stock are also discussed. This study enables the derivation of a wide range of vulnerability relationships for the building stock prepared for use in a loss estimation system for the UAE.

2. LOSS ESTIMATION AND MITIGATION FRAMEWORK

The main driving engines of regional seismic risk systems are: (i) seismic hazard; (ii) inventory of the exposed systems (e.g. transportation network) or elements (e.g. a building); and (iii) vulnerability relationships (e.g. Kwon and Elnashai 2006). The results can be improved by adding socio-economic consequences to the loss assessment components. These components are integrated in a loss estimation platform to enable bridging the gap between researchers, practitioners and policy-makers. A framework for earthquake loss estimation in the UAE is depicted in Figure 1.

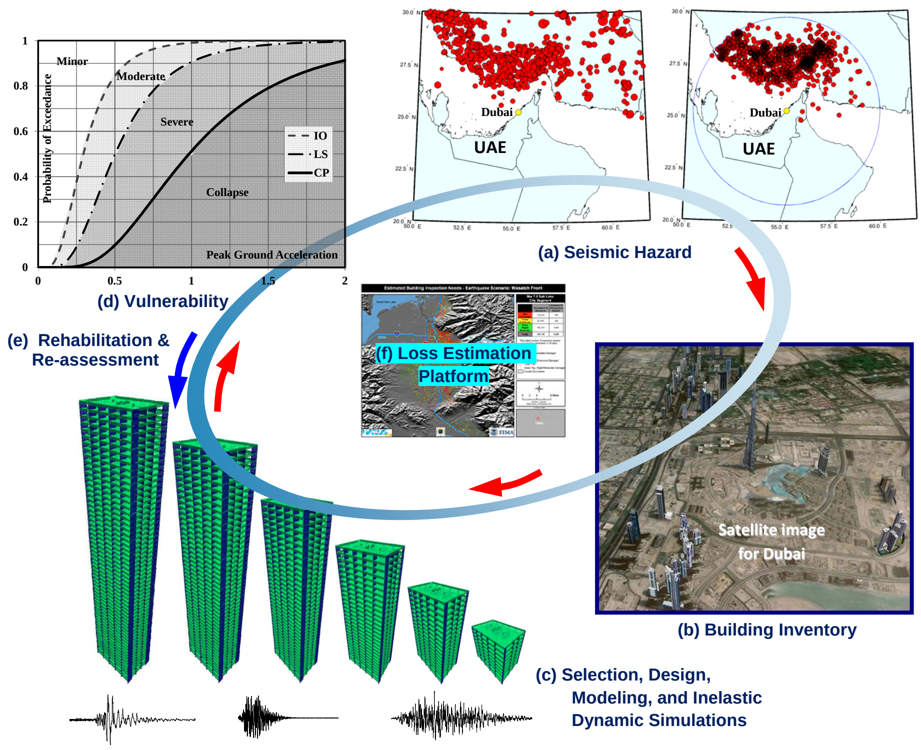

Figure 1. Framework for earthquake loss estimation in the UAE

The seismic hazard of the UAE has been addressed in number of recent studies (e.g. Abdalla and Al-Homoud 2004; Mwafy et al. 2006; Aldama-Bustos et al. 2009; Shama 2011). It was concluded that the earthquake hazard in the UAE is dictated by the seismicity of Southern Iran alongside inland earthquakes originated from local seismic faults. The seismic events occurred within or near to the UAE over the period 1924-1999 are 49 (0.65 events per year), three of which are located inland within the Arabian Peninsula. Considering the time span from 2000-2006, 18 events were recorded (3.0 events per year), six of which are inland and two just offshore (Aldama-Bustos et al. 2009). This increase in the rate of seismic events highlights the need for the reliable representation of different seismic scenarios to arrive at an accurate estimate of earthquake losses in the UAE. The distribution of earthquakes in the UAE for the period 734 to 2004 is shown in Figure 1-a (Mwafy et al. 2006). In the present study, the seismic design criteria and most important earthquake scenarios are considered according to the conclusions of recent seismic hazard studies related to the UAE (e.g. Abdalla and Al-Homoud 2004; Mwafy et al. 2006; Shama 2011). The ground motion uncertainty is accounted for in the vulnerability analysis using a wide range of natural and synthetically generated input ground motions that conform to the latest understanding of the tectonic setting and regional seismicity of the UAE. The real earthquake recordings were selected from the Pacific Earthquake Engineering Research Centre database (PEER 2012) and the European strong-motion database (Ambraseys et al. 2004). In order to allow for a more effective matching with uniform hazard spectrum (UHS) and the design spectrum of Dubai, the study of Mwafy et al. (2006) also recommended the use of artificial accelerograms developed using available geophysical information. Figure 2 shows the response spectra of 20 earthquake records selected to represent long period earthquakes, which is a seismic scenario applicable to Dubai.

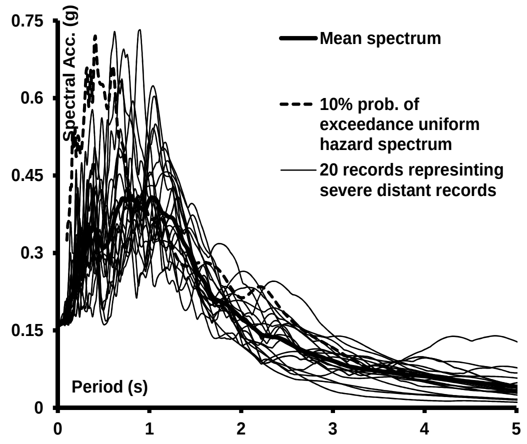

Figure. 2. Response spectra of 20 earthquake records representing a critical seismic scenario in Dubai

The reliable description of the built environment at risk is a fundamental input in loss assessment systems. Collecting a reliable inventory database for a large area is one of the major challenges in loss assessment studies due to the lack of detailed surveys and the rapid changes in the exposed inventory (e.g. Cagnan et al. 2008). Accordingly, official local surveys, high-resolution satellite images and supplementary field surveys were utilized in previous studies to collect data regarding the distribution of the building inventory (e.g. Moharram et al. 2008). The present study focuses on the building stock in the UAE, including critical and emergency response facilities, since they are the most significance in the potential consequences from natural hazard events.

Vulnerability relationships relate the probability of exceeding damage states to a ground motion intensity, as shown in Figure 1-d. These functions account for the uncertainty and variability associated with capacity and demand. Fragility curves are therefore significant for the estimation of monetary loss and seismic retrofit decisions. A number of possible approaches for collecting damage information can be used to derive fragility curves, including observational, analytical, and hybrid techniques (Calvi et al. 2006). Although the observational approach is the most realistic since the entire inventory is taken into consideration with site characteristics, it is practically difficult to collect an observation-based data for the UAE. Generating damage data through extensive analytical simulations is the most realistic and cost-effective option, and therefore is adopted in the current study. Several techniques for deriving vulnerability relationships based on analytically simulated structural damage statistics have been adopted by researchers, with a variety in analysis methods, structural idealizations, and seismic hazard and damage models. Most of these techniques are computationally demanding since a large number of analyses are required to fully represent the ground motion and structural uncertainties (e.g. Jeong et al. 2012). This is particularly true when adopting inelastic multi-degree-of-freedom dynamic simulations for deriving the vulnerability relationships, which is the most reliable technique, and therefore is adopted in the present study.

Finally, different technologies are available for visualizing the seismic risk. The Federal Emergency Management Agency’s HAZUS software can be used to integrate the loss assessment components and provide the required visualization (Kircher et al. 2006). The Mid-America Earthquake Center’s MAEviz system is also an open source environment that provides capabilities to develop risk reduction strategies and implement mitigation plans to minimize the impact of earthquakes (Elnashai et al. 2008). Several research projects have been undertaken to satisfy the needs of loss assessment process (e.g. Cagnan et al. 2008; Elnashai et al. 2008). However, very few studies have been directed to the built environment in the middle east (e.g. Moharram et al. 2008). This brief review reflects the pressing need for developing a realistic loss estimation and mitigation system for the UAE. In the following sections, the collection of a building inventory database in Dubai is discussed. Classifying the building stock and the selection, design, and idealization of reference structures to describe the seismic damage through fragility curves provide a tool for formulating risk reduction policies in this region.

3. BUILDING INVENTORY

Assembling a database for the existing building stock in Dubai is a major challenge due to the lack of census surveys and the rapid changes of the exposed inventory. Although some governmental institutions maintain partial inventory databases, they do not include all required structural information needed to properly categorize buildings for seismic risk assessment. Therefore, the building data is collected using high definition satellite images as well as site visits. Some information about the building inventory was obtained in a geographic information system (GIS) format from Dubai Municipality. This geo-referenced database of the existing building stock in Dubai includes some useful features and characteristics such as height limitations according to enforced regulations. The GIS data of the existing urban development has been used to verify the data collected using satellite images and site visits. Figure 3 depicts the adopted process for collecting a building database for Dubai, which includes collecting high resolution satellite images, dividing the study area to zones and sub-zones, site visits, assembling data of different zones using both site visits and satellite images, and finally confirming this data using the official GIS data by comparing height ranges and number of building in different zones. The studied area is divided into seven zones, each has common characteristics and features, as shown in Figure 3-b. Each of the seven zones is divided into a number sub-zones to facilitate collecting the required data from satellite images and site visits. Figure 4 shows satellite images of the seven zones with their sub-areas. The number of buildings in these areas are counted and classified to different categories, as discussed below.

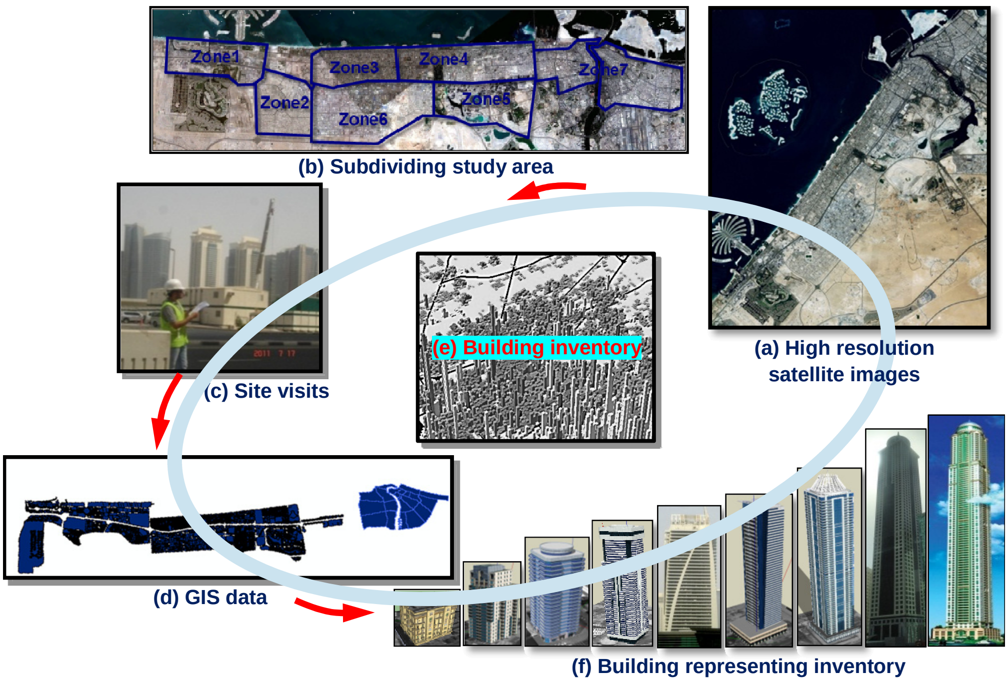

Figure 3. Developing building inventory and selecting representative reference structures for Dubai.

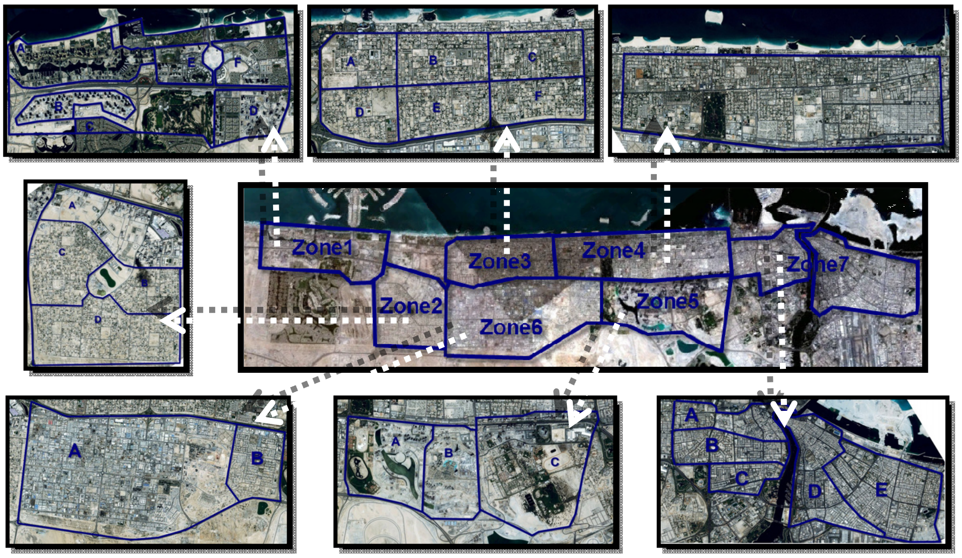

Figure 4. Dividing study area to zones and sub-areas

4. CLASSIFICATION OF THE BUILDING STOCK

Due to the significance of the classification criteria of the exposed building stock in risk analysis, the building inventory of Dubai is classified according to four criteria, namely the building height, function, construction date and the population intensity of construction site, as discussed below. In total 29729 buildings were counted from the seven zones shown in Figure 4 and classified to different categories.

4.1. Building Height

Building height is one of the most significant criterion that should be considered when classifying the inventory. Ten categories based on the number of stories are selected, namely 1-4, 5-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-70, 71-90 and 91-100 stories. Figure 5 depicts the percentage of buildings in different zones, while Figure 6 shows a sample of the classification of the buildings according to number of stories in Zone 1. The large and diversity of the building stock in Dubai is clear from the results presented in Figures 3-6. The distribution of buildings between different zones according to their heights is depicted in Figure 7. It is shown that, although most of the building stock comprises of buildings ranging from 1-10 stories, the inventory includes a diverse range of structures that exceed 100-story high. This reflects the significance of selecting a wide range of reference structures to reliably represent this diverse building stock.

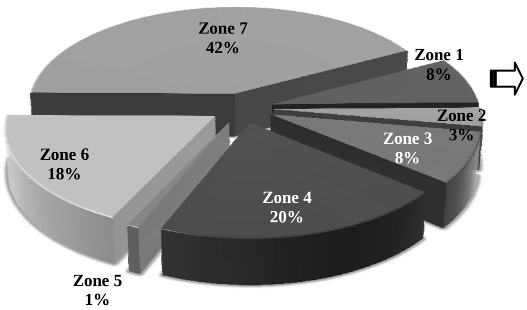

Figure 5. Percentage of buildings in different zones

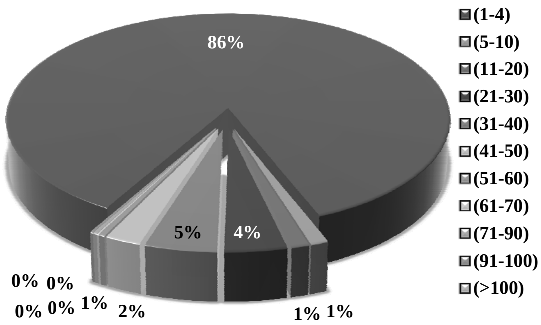

Figure 6. Sample of the building classification in Zone 1 according to height

4.2. Function

In addition to covering the residential and office building stock in Dubai with different heights, an emphasis is given to essential and emergency facilities. These facilities play an important role in the recovery period following an earthquake. Essential and emergency facilities include hospitals, police stations, fire stations and schools, which may serve as emergency shelters. The functionality of these buildings after earthquakes is important in order to ensure an effective emergency response. In the present project, buildings are classified to four categories according to their occupancy (ASCE 2010), namely I, II, III and IV. Figure 8 depicts the distribution of buildings in different zones according to their nature of occupancy. It is clear that the majority of the building stock (80%) is for buildings with standard occupancy (II), which corresponds to residential and office buildings. 19% of the inventory, mainly in Zones 6 and 7, is for buildings that represent a low risk to human life in the event of failure (occupancy category I). Less than 0.5% of the buildings stock is for buildings with occupancy categories III and IV.

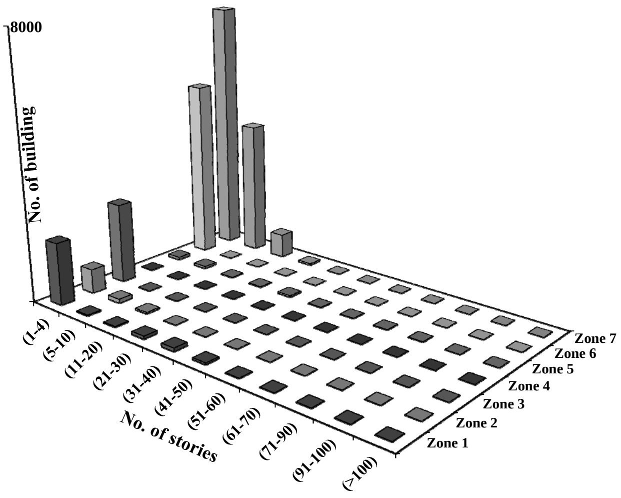

Figure 7. Building classification according to height

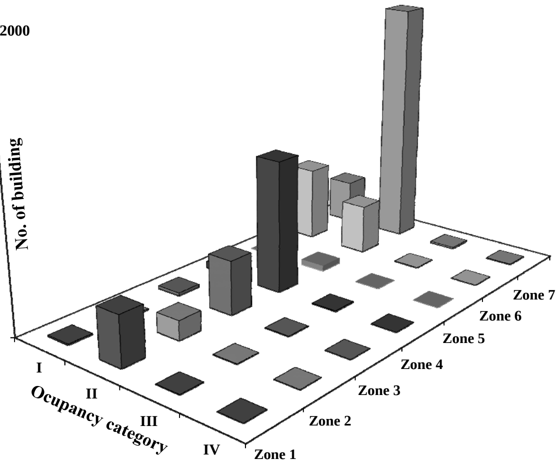

Figure 8. Building classification according to occupancy category

4.3. Construction Date

Dubai includes a large number of buildings that were designed and constructed in accordance with different building codes. Old buildings were likely designed to primarily resist gravity loads. The buildings stock is therefore classified into two categories based on their construction date, namely before 1991 and after 1991. This enables classifying the large number of buildings in the study area to ‘engineered’ and ‘pre-code’. The buildings in the ‘engineered’ subclass were designed according to modern design codes and therefore will have adequate structural capacity in terms of strength and ductility. Good material quality and good supervision result in reliable seismic performance for these buildings. The ‘pre-code’ structures were not designed to effectively resist earthquake loads. The latter subclass of buildings may include construction, detailing and design deficiencies. Figure 9 illustrates the buildings classification according to their construction date in different zones. It is clear that the majority of the building stock represent engineered buildings, while about one third of the structures are pre-code.

4.4. Population Density

Significant losses are anticipated wherever the areas of high population density and high seismic hazard come together. This emphasizes the significance of the correlation between the building stock and population density. The distribution of population between the seven study zones is estimated through the total number of buildings in different sub-areas. Figure 10 shows the relative population distribution between different zones. These results are consistent with the official population statistics of the UAE (Yearbook 2009). It is clear from Figure 10 that most of the population in the study area is concentrated in Zone 7, where most of the buildings are located.

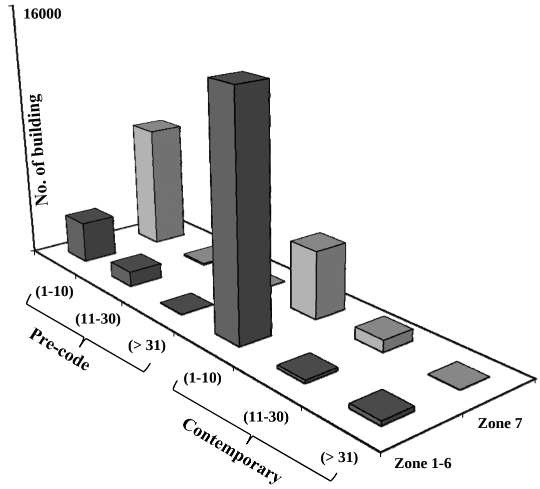

Figure 9. Buildings classification according to their construction date

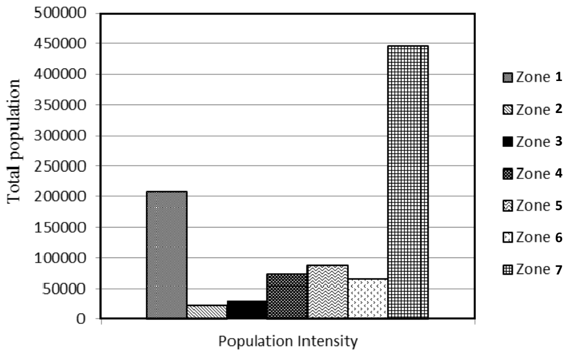

Figure 10. Distribution of population between zones

5. SELECTION AND DESIGN OF REPRESENTATIVE BUILDINGS

A wide array of structures representing the building stock in Dubai are selected from the collected building database for the derivation of fragility relationships using incremental dynamic analysis (IDA). The buildings are selected based on different classification criteria, as discussed above. Due to the diversity of the building inventory, the selected reference structures include a wide range of buildings of different characteristics. Table1 summarizes the characteristics of the selected reference structures. Ten of the selected buildings represent modern structures (engineered) with different heights, ranging from 2 to 100 stories. Moreover, four buildings are selected to represent essential and emergency facilities, while five buildings with different heights are selected to characterize pre-code structures. It is clear from the discussion presented above that the buildings stock is fairly represented in the set of reference structures shown in Table 1.

Table1. Selected reference structures to represent building stock according to classification criteria

No.	Building reference	Selection criteria		Buildings description
1	B-H-004	Height	(1-4)	2-story RC MRF
2	B-H-010		(5-10)	8-story RC MRF
3	B-H-020		(11-20)	18-story RC bearing walls
4	B-H-030		(21-30)	26-story RC bearing walls
5	B-H-040		(31-40)	40-story bearing walls
6	B-H-050		(41-50)	50-story bearing walls
7	B-H-060		(51-60)	56-story bearing walls
8	B-H-070		(61-70)	66-story bearing walls
9	B-H-090		(71-90)	80-story frame tube
10	B-H-100		(91-100)	100-story frame tube
11	B-F-PS	Function	Police station	2-story RC MRF
12	B-F-FS		Fire station	2-story RC MRF
13	B-F-HO		Hospital	6-story RC MRF
14	B-F-SC		School	3-story RC MRF
15	B-O-004	Construction date	Pre-code	2-story RC MRF
16	B-O-010			8-story RC MRF
17	B-O-020			18-story RC bearing walls
18	B-O-030			26-story RC bearing walls
19	B-O-040			40-story bearing walls
1 to 10	B-H-004 to B-H-100		Modern (engineered)	As shown in buildings 1-10

Detailed three-dimensional (3D) finite element models are developed for the selected buildings that represent the building inventory of Dubai using the structural analysis and design software ETABS (CSI 2011), which is commonly used in the design industry due to its capabilities in handling complex building models. The selected multi-story and high-rise buildings are fully designed and detailed particularly for this study according to the building codes adopted in the UAE. Figure 11 depicts the 3D finite element models of the buildings that represent contemporary structures. All design information are stored in spread sheets and AutoCAD drawings. This design information is used to idealize the buildings for multi-degree-of-freedom inelastic simulations, which enable the derivation of a wide range of fragility relationships representing the building inventory.

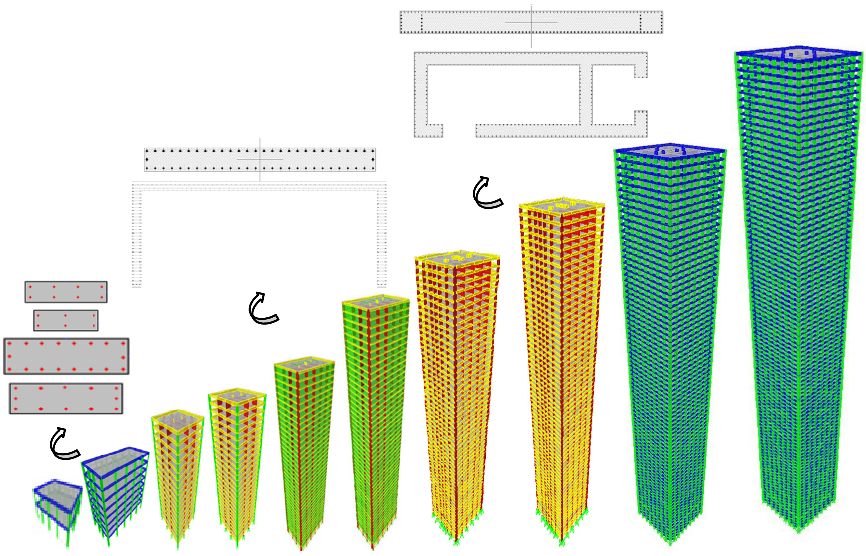

Figure 11. Three dimensional finite element models developed to represent the contemporary building stock

6. NUMERICAL MODELING FOR INELASTIC ANALYSIS

Detailed numerical idealizations of the reference structures for inelastic analysis are carried out using Zeus-NL (Elnashai et al. 2012). This platform is capable of predicting the large displacement behaviour of structures under static and dynamic loading, taking into account both geometric nonlinearities and material inelasticity. Several research projects covering complex structures have adopted this verified analysis platform (e.g. Mwafy 2012). Each structural member is assembled in the present study using a number of elasto-plastic frame elements capable of representing the spread of inelasticity within the member cross-section and along the member length via the fibre modelling approach. This idealization enables modelling different arrangements of reinforcing steel along the member length as specified in design. Several cross-sections are used from the ZEUS-NL library to model slabs (RC rectangular section), beams (RC T-section), shear walls (RC flexural wall section), cores (RC hollow rectangular section) and rigid arms (Rectangular solid section). The element cross-sections are divided into a number of fibres, which enable the geometric definition of the steel, confined and unconfined concrete regions within the section. The appropriate material stress-strain relationships are applied for each fibre, and strains and stresses are monitored. The response of cross-sections is assembled from the response of different fibres. The concrete response is represented using a uniaxial constant confinement concrete model, which includes enhanced cyclic degradation rules, inelastic strain and shape of unloading branches. An elasto-plastic model is also selected to represent the reinforcing steel. The mean (expected) material strength values are used in the inelastic analysis. Self-weight of structural members and superimposed dead loads are calculated and applied in the inelastic analyses before seismic actions. Masses are calculated in a manner consistent with gravity loads and are represented by lumped mass elements. Columns and walls are considered to be fixed at the foundation level (ASCE 2010). In response history analysis, the reference structures are subjected transient loads, which consist of accelerations that vary in the real time domain.

7. DERIVATION OF FRAGILITY RELATIONSHIPS

A large number of incremental dynamic analyses (IDAs) are conducted to derive the vulnerability relationships of the reference structures. Figure 12 presents a sample of IDA results obtained from two ground motion scenarios along with the power law used for deriving the fragility relationships. The two seismic scenarios represent far-field (Scenario A) and near-field (Scenario B) seismic events. A total of 280 peak ground acceleration-interstory drift values obtained from inelastic response history analyses are plotted for each building. It is clear that the differences in seismic demands obtained from the two seismic scenarios are quite significant. Different limit states (i.e. immediate occupancy 'IO', life safety 'LF', or collapse prevention 'CP') are observed at significantly higher PGAs under the effect of Scenario B compared with Scenario A. This is attributed to the high spectral amplifications of the latter ground motions, which match the first and/or second mode periods of the reference structures. The presented sample results confirm the vulnerability of the buildings in the UAE to severe distant earthquakes (Mwafy 2012), and highlight the pressing need to investigate the anticipated seismic risk of other types of structures in this region.

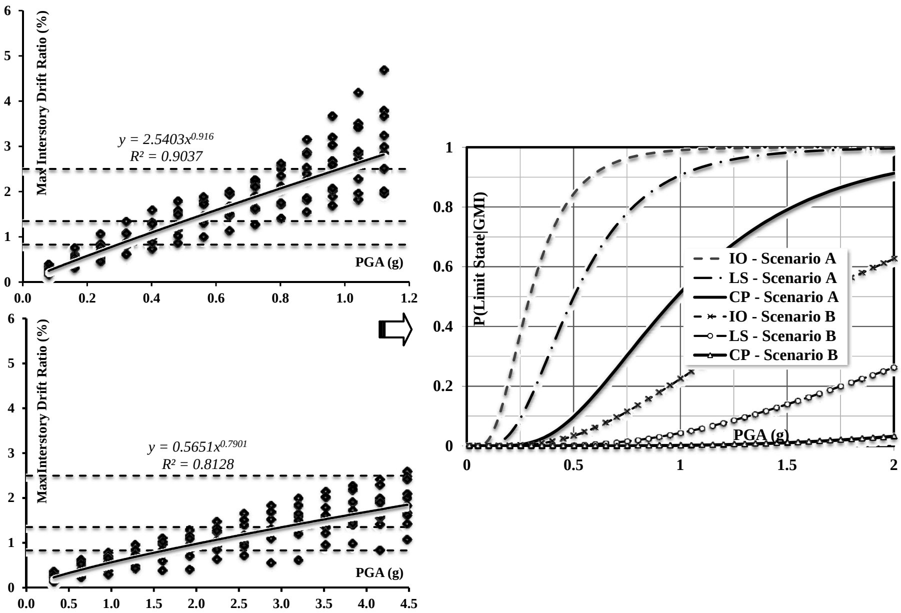

Figure 12. Fragility relationships of a 50-story building obtained from IDAs using two ground motion scenarios

8. CONCLUSIONS

Given the large investments in the construction sector and repeated seismic activities in the UAE, investigating and planning for earthquake risk should be undertaken in order to effectively mitigate earthquake losses. The main driving engines of regional seismic risk systems were reviewed in this paper with an emphasize on the UAE. Essential components for predicting earthquake losses in the highly populated area in Dubai were discussed. The adopted approach for collecting the characteristics of the large and diverse building stock in Dubai was presented. This included dividing the study area to zones and sub-zones, assembling data of different zones using both satellite images and confirmatory site visits, and finally confirming this data using official GIS data of the urban development. The building stock was classified according to four criteria, namely the building height, function, construction date and population intensity. The inventory was arranged to ten categories based height, four categories according to occupancy, and two categories based on construction date. This collected building database and classification criteria supported the selection of nineteen reference structures to represent contemporary, pre-code and critical facilities. Owing to the diversity of the building inventory, the selected reference structures included a wide range of buildings with different heights (2 to 100 stories), functions (standard and critical), and construction date (contemporary and pre-code). The reference structures were fully designed and detailed according to the building codes adopted in the UAE. The design information was used to idealize the reference structures using the fiber modelling approach for incremental dynamic analysis (IDA). A large number of IDAs are being undertaken to derive a wide range of vulnerability relationships prepared for integration with a loss estimation system for the UAE. The presented sample fragility curves confirm the vulnerability of the buildings to severe distant seismic events, and highlight the pressing need for formulating earthquake loss assessment and mitigation strategy for this region.

AKCNOWLEDGEMENT

This work was supported by the United Arab Emirates University under research grant RSA-1108-00163, fund code 31N007. This support is appreciated. The author would also like to thank Dr. Mwafag Ghanma, UAEU, and two research assistants, Amr Abdel Havez and Abdel Rahman Ashri, for their contribution to this study. The author is also indebted to the Geographic Information System Department, Dubai Municipality, for providing some information regarding the building inventory in Dubai.

REFERENCES

Abdalla, J.A. and Al-Homoud, A.S. (2004). Seismic hazard assessment of United Arab Emirates and its surroundings. *Journal of Earthquake Engineering* **8: 6**, 817-837.

Aldama-Bustos, G., Bommer, J.J., Fenton, C.H. and Stafford, P.J. (2009). Probabilistic seismic hazard analysis for rock sites in the cities of Abu Dhabi, Dubai and Ra's Al Khaymah, United Arab Emirates. *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards* **3: 1**, 1-29.

Ambraseys, N.N., Douglas, J., Sigbjornsson, R., Berge-Thierry, C., Suhadolc, P., Costa, G. and Smit, P.M. (2004). *Dissemination of European strong-motion data, vol. 2, using strong-motion datascape navigator, CD ROM collection*, Engineering and Physical Sciences Research Council, Swindon, UK, Feb. 2004

ASCE (2010). *Minimum design loads for buildings and other structures, ASCE Standard ASCE/SEI 7-10*, American Society of Civil Engineers, Reston, VA

Cagnan, Z., Sesetyan, K., Zulfikar, C.A.N., Demircioglu, M.B., Kariptas, C., Durukal, E. and Erdik, M. (2008). Development of earthquake lossmap for Europe. *Journal of Earthquake Engineering* **12: 2**, 37-47.

Calvi, G.M., Pinho, R., Magenes, G., Bommer, J.J., Restrepo-Velez, L.F. and Crowley, H. (2006). Development of seismic vulnerability assessment methodologies over the past 30 years. *ISET journal of Earthquake Technology* **43: 3**, 75-104.

CSI (2011). *ETABS - Integrated building design software*, Computers and Structures, Inc., Berkeley, California

Elnashai, A.S., Cleveland, L.J., Jefferson, T. and Harrald, J. (2008). *Impact of earthquakes on the Central USA*, Mid-America Earthquake Center Report 08-02, Univ. of Illinois at Urbana-Champaign, Urbana, IL

Elnashai, A.S., Hampton, S., Lee, J.S., McLaren, T., Myers, J.D., Navarro, C., Spencer, B. and Tolbert, N. (2008). Architectural overview of MAEviz–HAZTURK. *Journal of Earthquake Engineering* **12**, 92-99.

Elnashai, A.S., Papanikolaou, V. and Lee, D. (2012). *Zeus-NL - A System for Inelastic Analysis of Structures - User Manual*, , Mid-America Earthquake Center, Univ. of Illinois at Urbana-Champaign, Urbana, IL

Jeong, S.H., Mwafy, A.M. and Elnashai, A. (2012). Probabilistic seismic performance assessment of code-compliant multi-story RC buildings. *Engineering Structures* **34**, 527-537.

Kircher, C.A., Whitman, R.V. and Holmes, W.T. (2006). HAZUS earthquake loss estimation methods. *Natural Hazards Review* **7: 2**, 45–59.

Kwon, O.S. and Elnashai, A.S. (2006). The effect of material and ground motion uncertainty on the seismic vulnerability curves of RC structure. *Engineering Structures* **28: 2**, 289-303.

Moharram, A.M., Elghazouli, A.Y. and Bommer, J.J. (2008). A framework for a seismic risk model for Greater Cairo. *Soil Dynamics and Earthquake Engineering* **28: 10-11**, 795-811.

Mwafy, A.M. (2012). Analytically-derived fragility relationships for the modern high-rise buildings in the UAE. *Structural Design of Tall and Special Buildings*, In Press (published online).

Mwafy, A.M., Elnashai, A.M., Sigbjornsson, R. and Salama, A. (2006). Significance of severe distant and moderate close earthquakes on design and behavior of tall buildings. *The Structural Design of Tall and Special Buildings* **15: 4**, 391-416.

PEER (2012). *PEER NGA database*, Pacific Earthquake Engineering Research Center, University of California, Berkeley, California

Shama, A.A. (2011). Site specific probabilistic seismic hazard analysis at Dubai Creek on the west coast of UAE. *Earthquake Engineering and Engineering Vibration* **10: 1**, 143-152.

Yearbook, U.A.E. (2009). Trident Press Ltd., London, UK