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ORIGINAL ARTICLE

Update earthquake risk assessment in Cairo, Egypt

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Abstract The Cairo earthquake (12 October 1992; m_b = 5.8) is still and after 25 years one of the most painful events and is dug into the Egyptians memory. This is not due to the strength of the earthquake but due to the accompanied losses and damages (561 dead; 10,000 injured and 3000 families lost their homes). Nowadays, the most frequent and important question that should rise is "what if this earthquake is repeated today." In this study, we simulate the same size earthquake (12 October 1992) ground motion shaking and the consequent social-economic impacts in terms of losses and damages. Seismic hazard, earthquake catalogs, soil types, demographics, and building inventories were integrated into HAZUS-MH to produce a sound earthquake risk assessment for Cairo including economic and social losses. Generally, the earthquake risk assessment clearly indicates that "the losses and damages may be increased twice or three times" in Cairo compared to the 1992 earthquake. The earthquake risk profile reveals that five districts (Al-Sahel, El Basateen, Dar El-Salam, Gharb, and Madinat Nasr sharq) lie in high seismic risks, and three districts (Manshiyat Naser, El-Waily, and Wassat (center)) are in low seismic risk level. Moreover, the building damage estimations reflect that Gharb is the highest vulnerable district. The analysis shows that the Cairo urban area faces high risk. Deteriorating buildings and infrastructure make the city particularly vulnerable to earthquake risks. For instance, more than 90 % of the estimated buildings damages are concentrated within the most densely populated (El Basateen, Dar El-Salam, Gharb, and Madinat Nasr Gharb) districts. Moreover, about 75 % of casualties are in the same districts. Actually, an earthquake risk assessment for Cairo represents a crucial application of the HAZUS earthquake loss estimation model for risk management. Finally, for mitigation, risk reduction, and to improve the seismic performance of structures and assure life safety and collapse prevention in future earthquakes, a five-step road map has been purposed.

Keywords Earthquakes · Hazards · Risk · Vulnerability · Risk profile · Risk matrix · Cairo · Egypt

1 Introduction

Cairo is the capital of Egypt and the largest city in the Arab world and Africa, and the 16th largest metropolitan area in the world. It was founded in the year 969 AD making it 1042 years old. It has long been a center of the region's political and cultural life. Cairo was founded by the Fatimid dynasty in the tenth century AD, but the land composing the present-day city was the site of national capitals whose remnants remain visible in parts of Old Cairo. Cairo is also associated with Ancient

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Egypt due to its proximity to the ancient cities of Memphis, Giza, and Fustat which are nearby to the Great Sphinx and the pyramids of Giza. Cairo is arguably the largest city in the Middle East and North Africa and is a chaotic megalopolis where life is characterized by extremes, both of tradition and of modernity. Although the size of the actual population is disputed, the official 2012 census puts the number at more than 19 million inhabitants. The current boundaries of Cairo consist of 27 (Fig. 1) districts, (El-Mosskey, Bab El-Shariya, Shubra, Abdeen, Bolaq, Rod El-Farag, Sayeda Zeinab, Wassat-center, El-Waily, Hadayek El-Qobba, El-Sharabia, El-Zawia El-Hamra, El- Sahel, Gharb, Manshiyat Naser, El-Zaitoon, Madinat Nasr Garb, Ain Shams, Masr El-Qadima, Maser–El-Gedida, El-Matariya, El-Khaleifa, El-Basateen-Dar El-Salam, El-Marg, Madinat El-Salam, El-Nuzha, Madinat Nasr Sharq).

Cairo is home to a number of historical districts and significant monuments that demonstrate the architectural wealth of the city, not only as a capital of the Islamic World but as a wonder of the human urban experience.

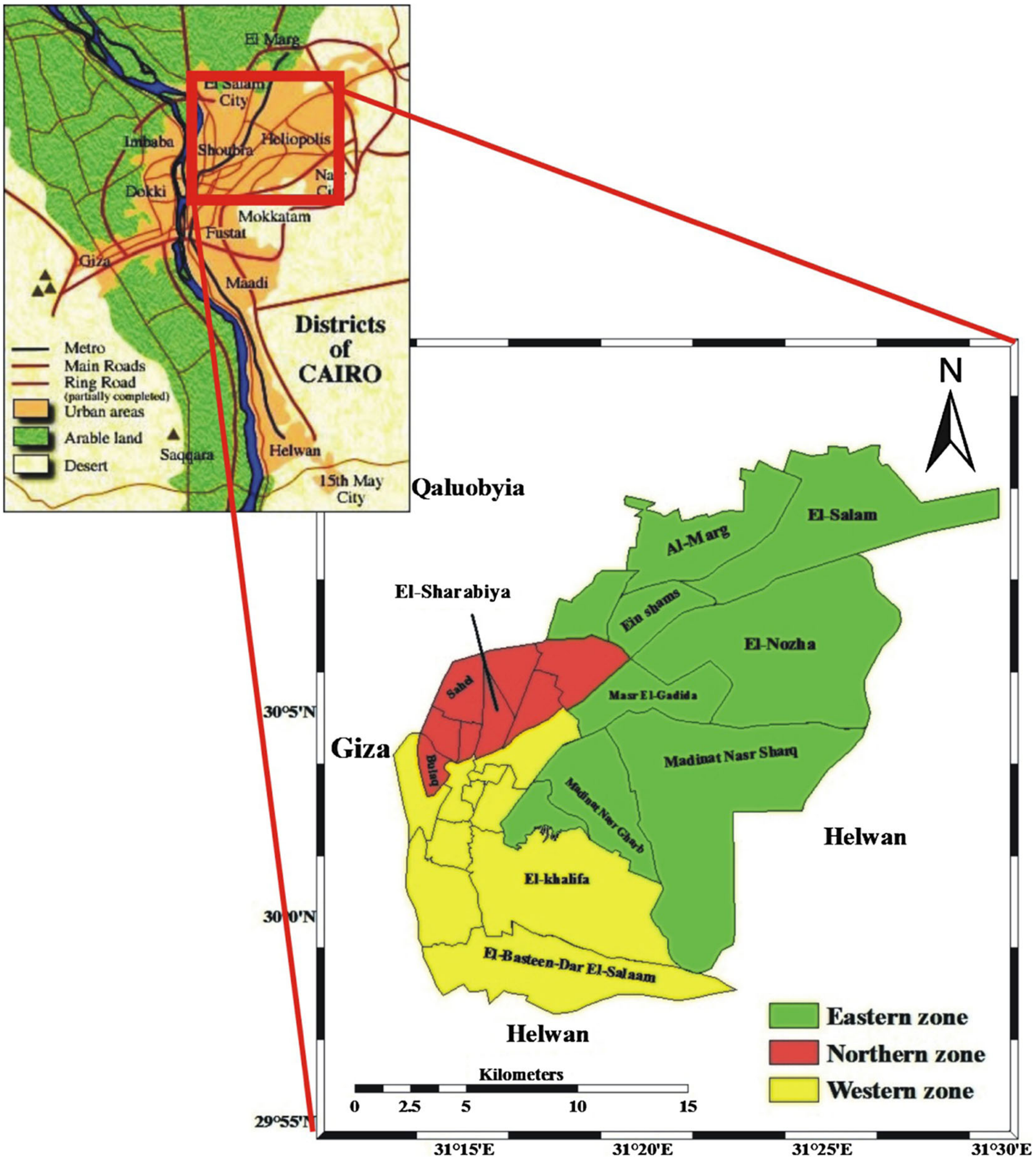


Fig. 1 Location map of the 27 Cairo's districts for this study

Cairo resides at the center of the largest metropolitan area in Africa and the 11th-largest urban area in the world. Cairo, like many other mega-cities, suffers from high levels of pollution and traffic.

Nowadays, the *P*robabilistic *S*eismic *H*azard *A*ssessment (PSHA) is widely applicable for earthquake hazard analysis (e.g., Reiter 1991; Frankel 1995; Woo 1996; Badawy 1998; Giardini et al. 1999; Bommer et al. 2004; Deif et al. 2009; El-Hussain et al. 2010). For Cairo, the seismic hazard has been estimated using the probabilistic seismic hazard approach (Badawy et al. 2016). PSHA is performed utilizing CRISIS 2007 software (Ordaz et al. 2007). The logic-tree frame work was used during the calculations. Epistemic uncertainties were taken into account by using alternative seismotectonic models and alternative ground-motion prediction equations. Seismic hazard values have been estimated within a grid of 0.1° × 0.1° spacing for all Cairo's districts at different spectral periods and four return periods (50, 100, 200, and 500 years). Moreover, the uniform hazard spectra have been calculated at the same return periods.

Many initiatives have been launched worldwide to assess and reduce urban vulnerability, such as HAZUS–MH, which is the Federal Emergency Management Agency's (FEMA) nationally applicable software program that estimates potential building and infrastructure losses from earthquakes, floods, and hurricane winds. HAZUS-MH loss estimates reflect state-of-the-art scientific and engineering knowledge and can be used to inform decision-making at all levels of government by providing a reasonable basis for developing mitigation, emergency preparedness, and response and recovery plans and policies.

HAZUS provides quantitative estimates of losses in terms of direct costs for repair and replacement of damaged buildings and lifeline system components, direct costs associated with loss of function, and casualties and people displaced from residences. To generate this information, the methodology includes classification systems for assembling information on the building stock, highway lifelines, demographic and economic data, methods for evaluating damage, and calculating various losses.

The HAZUS-MH Earthquake Model estimates earthquake damage and loss to buildings, essential facilities, and transportation and utility lifelines. It also addresses debris generation, fire-following earthquake, casualties, and shelter requirements. The Advanced Engineering Building Module (AEBM) permits the analysis of individual buildings to measure the effects of various mitigation actions.

HAZUS-MH is a standalone program that is used with ArcGIS© GIS software to map and display hazard data, the results of damage and economic loss analyses, and potential effects on area populations. HAZUS-MH analyses also can be run in real time to support response and recovery actions following a disaster event. Also, it was developed in conjunction with the National Institute of Building Sciences. The Program uses commonly available city information including the following: (1) inventory data collection based on census tract areas; (2) specify the magnitude and location of the scenario earthquake—in developing the scenario earthquake, consideration should be given to the potential fault locations; (3) using database maps of soil type, ground motion; (4) classifying occupancy of buildings and facilities; and (5) classifying building structure types.

In order to contribute to urban risk assessment in developing countries, we have carried out a simulation for Cairo governorate, using the HAZUS-MH program. The present work is aimed at evaluating the potential earthquake hazards, risks, and losses and to map out the geographic distribution of potential human and materials losses, in case an earthquake strikes. This work was carried out under an umbrella of bilateral cooperation between the Earthquake Division of the National Research Institute of Astronomy and Geophysics (NRIAG) and Federal Emergency Management Agency (FEMA), Region VIII, Denver, Colorado, USA.

2 Geologic and tectonic setting

The review of the geologic and topographic context shows that the geological conditions of the greater Cairo area were described by many researchers (e.g., Said 1962; Youssef 1968; El Shazly and Tamer 1977; Said 1981; and others) and may be summarized as follows: The basin-like area of Cairo is located on the tip of the Nile Delta (Fig. 2), and it is surrounded by uplands along the eastern and western sides. The sediments of the Quaternary period cover almost the whole area.

The area around Cairo has a basin-like topography, where it is surrounded by high mountains along the eastern and western sides and low relief in the central part, leading to significant landslide risk. Many

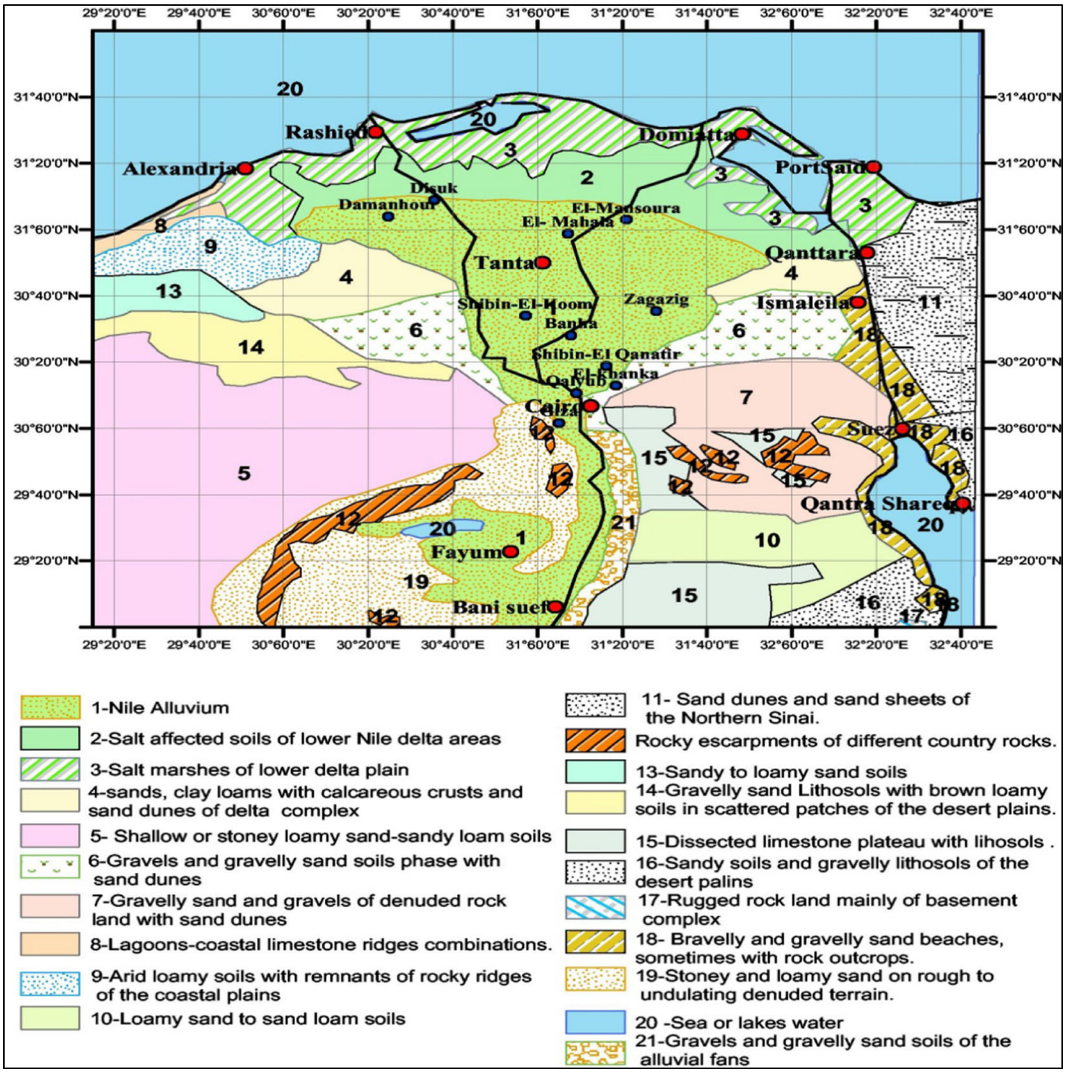


Fig. 2 Geological map of the Nile Delta and the surroundings (Issawi 1981)

structures have been built on very soft and soft sediments, placing them at great risk owing to possible site amplification effects.

The upper surface soil in the Cairo area is a result of sedimentation from the Nile. The basin, from which these deposits are formed, belongs to relatively old formations eroded by streams and rainfall. The Cairo area can be divided geologically into three regions: the cultivated valley, the eastern side of the Nile, and the western side of the Nile. The cultivated valley is the narrow strip that is penetrated longitudinally by the River Nile, made up of thick uppermost sedimentary layers overlying the Pliocene deposits. The Pliocene formation is found at depths decreasing from south to north and from the center of the valley to its embankments. Deep boring showed its existence at about 60-m depth east of the city (SAFER project, D4.39, NRIAG, 2009).

The eastern side of Cairo can be divided into three zones from north to south: It consists of massive variegated sands and gravels presumably deposited by the Oligocene River that drained southern Egypt, overlying the upper Eocene in the north. The central part of the eastern side is occupied by limestone rocks of middle Eocene age in its lower part and of upper Eocene age in the higher parts, forming a hill that borders the eastern part of Cairo. The southern part of the eastern side has a series of brownish beds of shales and sandstones overlaying the limestone rocks (SAFER project, D4.39, NRIAG, 2009).

The sedimentary layer is thick in the western side, and the region seems to be subjected to intensive compressional as well as tensional movements. The western side is characterized by surface structure that reflects part of the old tectonic activity. The compression may be attributed to a deep seated wedge-shaped, north westerly pointing tectonic unit that moved toward the northwest. There are three anticlines and synclines in this region that are affected by faults causing the elimination of a part of these structures. The faulting in this region began at the end of the Oligocene, with the main trend toward the northwest direction. Basaltic flows have also occurred along the fault and are distributed in this region to the north and to the west (SAFER project, D4.39, NRIAG, 2009).

Most of the Nile delta and its adjacent areas are covered with Nile alluvium deposits (clay and silty clay) of Holocene age. These are termed Neo Nile sediments (said, 1981). To the north (near the Mediterranean Sea), belts of sand dunes and vast areas of Sabkha are present. To the northwest of Cairo, plains of gravels and pebbles from the Oligocene, Pliocene, and Pleistocene extend to the Mediterranean Coast. The Nile cone of delta is composed mainly of classtic terrigenous sediments (Fig. 2).

3 Seismicity and seismic hazard analysis

Egypt is located near three major plate boundaries, namely, the African–Eurasian margin (including the Hellenic Arc), Gulf of Aqaba–Dead Sea (the Levant transforms) fault, and the Red Sea margin (Fig. 3). The Sinai sub-plate is partially separated from the African plate by spreading apart or rifting along the Gulf of Suez (Woodward-Clyde Consultants 1985; Badawy 1996; Badawy and Horvath 1999a, b). In addition to these plate boundaries, there is a megashear zone running from Southern Turkey to Egypt (Neev 1975 and Kebeasy 1990) marked by relatively moderate and scattered seismicity. The primary features of active plate tectonics in the vicinity of Egypt have been discussed in detail by many authors (McKenzie 1970, 1972; Neev 1975; Ben-Menahem et al. 1976; Garfunkel and Bartov 1977; Ben-Avraham et al. 1978; Sestini 1984; Meshref 1990; Badawy 1996; Badawy and Horvath 1999a, b).

Egypt is considered an area of relatively low to moderate seismicity, but it has experienced damaging earthquake effects throughout its history. The spatial distribution of earthquake epicenters (Fig. 3) indicates that Egypt has suffered from both interplate and intraplate earthquakes. Most earthquake activities have been concentrated in Northern Egypt, along the borders of Sinai subplate (Northern Red Sea and its two branches, Suez rift and Aqaba–Dead Sea transform fault). Away from this relatively active seismic zone, the inland seismic dislocations are also reported (Badawy 2005).

Cairo is relatively remote from any major plate boundaries, with the closest major source being the Suez Rift (El-Sayed et al. 2000), which forms part of the Suez trend, dominated by normal faults striking parallel to the rift. The Egyptian coastal dislocation trend defined by Maamoun and Ibrahim (1978) includes the seismically active region off the Egyptian Mediterranean coast. They attributed the activity of this trend to the continental shelf and the probable deep faults running parallel to the coast. This trend is considered to be the continuation of the subduction activity existing further to the north at the Hellenic and Cyprus arcs. It can be considered to begin from Cyrenaica (Libya) in the west to Alexandria and then north-eastward to Beirut Bay. Events attributed to this trend have a history of affecting Egypt, and mainly Alexandria. The most recent and prominent of these events is the 12 September 1955 earthquake having a surface wave magnitude of 6.5 (ISC bulletin).

The source of seismicity of the closest proximity to Cairo is the Eastern Mediterranean–Cairo–Fayoum trend, which is sometimes referred to as the Pelusiac trend. Kebeasy (1990) stated that this trend extends from the Eastern Mediterranean to the east of the Nile Delta and throughout to Cairo and the Fayoum region. Along this trend, small to moderate earthquakes are observed, the depths of which are confined to the crust and do not define any seismic plane. The zone extends parallel to the Syrian Arc system, where Maamoun and Ibrahim (1978) attributed its low seismicity to the neotectonic activity of the old dislocation zone (Syrian Arc system). Many of the events belonging to this trend occur in the Fayoum area SW of Cairo such as the well-known Dahshour earthquake of 12 October 1992, a fact that encouraged some researchers to consider the Fayoum area as a separate seismic zone (Abou Elenean 1997).

The most important examples of such events that have affected Cairo are the Ms. 5.8 event of 1847 (Ambraseys et al. 1994) and the Ms. 5.4 Dahshour

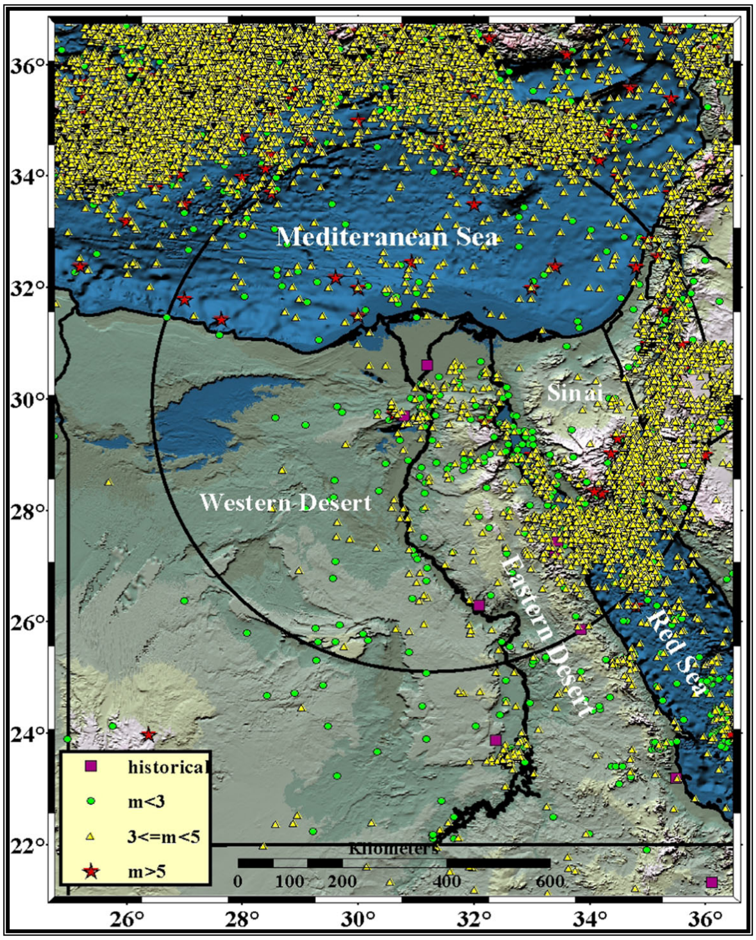


Fig. 3 Seismicity map of Egypt from 2200 BC to 2014 (Badawy et al. 2016)

earthquake of October 1992 (Badawy and Mourad 1994; Khater 1992). Both events originated from the seismically active area to the SW of Cairo at distances of 25 km from the center of the Cairo City. Larger earthquakes are expected to occur on seismogenic sources to the north and east, but their distances are such that the resulting ground motions in the capital are unlikely to be of importance. Another potential source of earthquake shaking is large events in the Hellenic arc, particularly a repeat of the event of 12 October 1856, for which Sieberg (1932) reported intensity in Cairo of VII–VIII. Sieberg's isoseismal map for this event is reproduced in Theodulidis (2002), who presented a rather unusual extended arm that indicates considerably higher intensity around Cairo than elsewhere along the North African coast, including locations closer to the earthquake epicenter. Ambraseys et al. (1994) did not report a magnitude for this earthquake, in contrast with the value of VII–VIII assigned by Sieberg (1932) and reported that only 20 houses have collapsed in the Egyptian capital, with another 200 dwellings ruined.

Probabilistic earthquake hazard analysis shows for Cairo (Badawy et al. 2016) that the eastern zone of Cairo (e.g., El-Nozha and El-Salam Districts) lies at relatively high hazard with PGA varying from 0.1 to 0.3 g in return periods 224 and 4745 years, respectively. However, both the northern Cairo's zone (e.g., El-Khalifa District) and western zone (El-Sharabiya District) are shown as relatively low earthquake hazard with PGA changing from 0.08 to 0.2 g at the same return periods respectively (for details, see Badawy et al. 2016).

However, given the poor quality of building construction and soil quality, an increased degree of intensity can be considered for some of the urban areas, including impacts to older buildings including the potential collapse of masonry buildings. Poor soils may also impact older buildings in smaller earthquake events.

4 Definition of the scenario

One of the components of a risk assessment study is to estimate the magnitude and locations of future earthquakes that are likely to hit Cairo. The study has sought to gauge the level of ground shaking that these earthquakes would create and determine potential life and monetary losses and the extent of damages to Cairo's buildings, vital lifelines, and critical infrastructure. The study came up with the following earthquake scenario that assumed to take place on the main earthquake dislocations around Cairo: NW Cairo (Dahshour) scenario.

- An event of the same hypo central parameters of 12 October 1992 (Mw = 5.6, depth 18 km) was used which is assumed to hit Cairo City.
- For victim estimations, we have simulated the results for the earthquake origin time at 2 p.m. and alternative time at 2 a.m.

The earthquake scenario is based on seismological and geological information to prepare and educate government authorities, emergency managers, and policy makers in case of disasters. The extent of damage to Cairo's buildings, vital lifelines, and critical infrastructure is provided in detail within Tables 3 and 4 for each district using the national census in 2012 and LANDSCAN 2012 Global Population Database for Egypt.

5 Results

The seismic vulnerability plays a key role in the evaluation and mitigation of earthquake risks. Generally, vulnerability estimates the impact and describes the effect of the hazard on the community. The vulnerability to the earthquake hazard is based on a variety of factors including proximity to active and inactive faults, the age of structures, the density of the population and development, the value of property and infrastructure, the construction materials used in residential and nonresidential buildings, and the location of critical facilities. Building vulnerability is given by methodologies which provide the probability of a given level of damage as a function of ground motion parameters (e.g., seismic intensity, peak ground acceleration (PGA)). Vulnerability analysis reveals the damage of structures under varying intensity or ground motion magnitudes. A mathematical relationship is defined in the form of a vulnerability curve (VC) to quantify this relationship. The four approaches that may be used to construct the VC are as follows: empirical, analytical, hybrid, and judgment-based methods.

To understand the vulnerability or damage of a structure, it is important to consider three key factors. The first key factor is the general structure of the building which includes the construction type, height, and age. The remaining two key factors are the quality of the construction and the occupancy of the structure. The structure type describes the makeup of the building. In defining the structure type, it is essential to have a good understanding of the specific construction materials used. This is important because different construction materials are more resistant to earthquake shaking than others.

Knowing the height of the building is crucial to estimate damage, as different structure heights respond differentially to ground motion frequencies. Additionally, the age of building is significant, as it will determine the type of construction method and building codes applied. The occupancy of structure significantly influences damage to contents and time element losses as well as damage to the building.

In this study, the building type identification is done by matching the specific criteria needed by HAZUS with those by the Egyptian building Census (2012) and the LANDSCAN 2012 Global Population Database for Egypt.

Classifying building structure type, examples of model building types are light wood frame, mobile home, steel braced frame, concrete frame with unreinforced masonry infill walls, and unreinforced masonry. Each model building type is further subdivided according to typical number of stories and apparent earthquake resistance (based primarily upon the earthquake zone where they are constructed). The model building types required for HAZUS are shown in Table 1.

For risk assessment in Cairo, we have designed an earthquake risk matrix (Table 2). This matrix comprises five risk levels that range from very low

Table 1 Structural building classifications (model building types)

No.	Label	Description	Height			
			Range		Typical	
			Name	Stories	Stories	Feet
1	W1	Wood, light frame (≤5000 sq. ft.)		1–2	1	14
2	W2	Wood, commercial, and industrial (>5000 sq. ft.)		All	2	24
3	SIL	Steel moment frame	Low-rise	1–3	2	24
4	SIM		Mid-rise	4–7	5	60
5	SIH		High-rise	8+	13	156
6	S2 L	Steel braced frame	Low-rise	1–3	2	24
7	S2 M		Mid-rise	4–7	5	60
8	S2H		High-rise	8+	13	156
9	S3	Steel light frame		All	1	15
10	S4 L	Steel frame with cast-in-place	Low-rise	1–3	2	24
11	S4 M	Concrete shear walls	Mid-rise	4–7	5	60
12	S4H		High-rise	8+	13	156
13	S5 L	Steel frame with unreinforced	Low-rise	1–3	2	24
14	S5 M	Masonry infill walls	Mid-rise	4–7	5	60
15	S5H		High-rise	8+	13	156
16	C1L	Concrete moment frame	Low-rise	1–3	2	24
17	C1M		Mid-rise	4–7	5	60
18	C1H		High-rise	8+	13	120
19	C2L	Concrete shear walls	Low-rise	1–3	2	24
20	C1M		Mid-rise	4–7	5	60
21	C2H		High-rise	8+	13	120
22	C3L	Concrete frame with unreinforced	Low-rise	1–3	2	24
23	C3M	Masonry infill walls	Mid-rise	4–7	5	60
24	C3H		High-rise	8+	13	120
25	PC1	Precast concrete tilt-up walls		All	1	15
26	PC2L	Precast concrete frames with concrete shear walls	Low-rise	1–3	2	24
27	PC2M		Mid-rise	4–7	5	60
28	PC2H		High-rise	8+	13	120
29	RM1L	Reinforced masonry bearing walls with wood or metal deck diaphragms	Low-rise	1–3	2	20
30	RM2M		Mid-rise	4+	5	50
31	RM2L	Reinforced masonry bearing walls with precast concrete diaphragms	Low-rise	1–3	2	20
32	RM2M		Mid-rise	4–7	5	50
33	RM2H		High-rise	8+	12	120
34	URML	Unreinforced masonry bearing walls	Low-rise	1–2	1	15
35	URMM		Mid-rise	3+	3	35
36	MH	Mobile homes		All	1	10

to very high risk. The obtained results are presented in numerical forms for buildings damages and casualties (Tables 3 and 4) and spatial distribution per districts (Figs. 4 and 5) and risk profiles in Figs. 6, 7, and 8, respectively.

5.1 Buildings damages estimations

Table 3 shows that almost all Cairo districts are severely affected by very high risk due to precode concrete buildings (Figs. 4 and 7) according to the

Table 2 Earthquake risk matrix for Cairo, Egypt

	Buildings	Severity-1	Severity-2	Severity-3	Severity-4
Very low	<5	<10	<5	<3	<1
Low	5–15	10–35	5–15	3–10	1–3
Medium	15–30	35–65	15–35	10–15	3–5
High	30–50	65–100	35–50	15–25	5–10
Very high	>50	>100	>50	>25	>10

designed earthquake risk matrix in this study (Table 2). However, the unreinforced buildings are very low affected only at Ain Shams, low risk level at two districts (El-Nozha and Al-Marg), medium risk level only at Rood El-Farag, and very high risk level at the rest of the 18 districts (Table 3 and

Table 3 The expected number of damaged buildings in the 27 Cairo's districts investigated in this study

Districts	Concrete			Districts	Unreinforced		
	No.	%	Risk level		No.	%	Risk level
El-Nuzha	73	0.88	Very high	Ain shams	4	0.18	Very low
El- Matariya	97	1.17	Very high	El-Nuzha	9	0.40	Low
Wassat (center)	132	1.59	Very high	Al-Marg	11	0.49	Low
Masr El-Gadida	141	1.70	Very high	Rood-El Farag	27	1.20	Medium
El-Mosskey	163	1.97	Very high	Bolaq	33	1.47	High
Manshiyat Naser	169	2.04	Very high	Bab El-Shariya	37	1.64	High
Bab El-Shariya	183	2.21	Very high	Shubra	44	1.95	High
Bolaq	223	2.69	Very high	Madinat Nasr Garb	46	2.04	High
Shubra	230	2.77	Very high	El-Mosskey	52	2.31	Very high
Rood-El Farag	238	2.87	Very high	El-Zawia El-hamra	54	2.40	Very high
El khalifa	247	2.98	Very high	El Sharabiya	55	2.44	Very high
Madinat Nasr sharq	253	3.05	Very high	Wassat (center)	69	3.06	Very high
Ain shams	262	3.16	Very high	El- Matariya	71	3.15	Very high
El-Zawia El-hamra	268	3.23	Very high	El-Waily	77	3.42	Very high
Aabdeen	280	3.38	Very high	Masr El-Gadida	89	3.95	Very high
El-Waily	289	3.49	Very high	El Sahel	91	4.04	Very high
Hdayek El-Qobba	333	4.02	Very high	Hdayek El-Qobba	93	4.13	Very high
El Zaitoon	363	4.38	Very high	El Zaitoon	94	4.17	Very high
El Sayeda Zeinab	411	4.96	Very high	Aabdeen	99	4.40	Very high
Al-Marg	433	5.22	Very high	El Sayeda Zeinab	101	4.48	Very high
El Sharabiya	436	5.26	Very high	Madinat Nasr sharq	140	6.22	Very high
Madinat Nasr Garb	498	6.01	Very high	El Basateen, Dar El-Salam	145	6.44	Very high
Gharb	512	6.17	Very high	Gharb	164	7.28	Very high
El Sahel	553	6.67	Very high	El khalifa	169	7.50	Very high
Masr El-Qadima	610	7.36	Very high	Manshiyat Naser	182	8.08	Very high
El Basateen, Dar El-Salam	895	10.79	Very high	Masr El-Qadima	296	13.14	Very high
Sum	8292	4.42 %			2252	1.20 %	

No. number, % percentage

Table 4 Number of deaths along the 27 Cairo's districts investigated in this study

Districts	2 a.m.			Districts *t* (center)	2 p.m.		
	No.	%	Risk level		No.	%	Risk level
Wassat (center)	1	0.12	Low	Wassat (center)	0	0	Very low
Manshiyat Naser	2	0.24	Low	Manshiyat Naser	1	0.29	Low
El-Waily	4	0.48	Medium	El-Waily	1	0.29	Low
Hdayek El-Qobba	6	0.72	High	Hdayek El-Qobba	3	0.88	Medium
El- Matariya	7	0.84	High	El- Matariya	3	0.88	Medium
El khalifa	7	0.84	High	El khalifa	3	0.88	Medium
Shubra	11	1.32	Very high	Shubra	5	1.47	High
El-Mosskey	13	1.56	Very high	El-Nuzha	7	2.06	High
El Sayeda Zeinab	18	2.15	Very high	El-Mosskey	7	2.06	High
El-Zawia El-hamra	19	2.27	Very high	El-Zawia El-hamra	8	2.36	High
El-Nuzha	22	2.63	Very high	Rood-El Farag	9	2.65	High
Rood-El Farag	23	2.75	Very high	El Sayeda Zeinab	9	2.65	High
Bab El-Shariya	23	2.75	Very high	Madinat Nasr Garb	10	2.95	Very high
Madinat Nasr Garb	24	2.87	Very high	El Sharabiya	11	3.24	Very high
El Sharabiya	25	2.99	Very high	Bab El-Shariya	11	3.24	Very high
Bolaq	30	3.59	Very high	Aabdeen	14	4.13	Very high
Al-Marg	32	3.83	Very high	Bolaq	14	4.13	Very high
Aabdeen	33	3.95	Very high	Al-Marg	14	4.13	Very high
El Zaitoon	36	4.31	Very high	El Zaitoon	15	4.42	Very high
Masr El-Gadida	37	4.43	Very high	Masr El-Gadida	16	4.72	Very high
El Basateen, Dar El-Salam	41	4.90	Very high	Masr El-Qadima	18	5.31	Very high
Masr El-Qadima	44	5.26	Very high	El Basateen, Dar El-Salam	18	5.31	Very high
Madinat Nasr sharq	63	7.54	Very high	Ain shams	22	6.49	Very high
Ain shams	64	7.66	Very high	Madinat Nasr sharq	24	7.08	Very high
Gharb	98	11.72	Very high	Gharb	41	12.09	Very high
El Sahel	153	18.30	Very high	El Sahel	55	16.22	Very high
Sum	836	0.01 %			339	0.004 %	

No. number, % percentage

Figs. 4 and 7). Building distribution in the census 2012 and landscan 2012 shows that about 9.87 % of total Cairo buildings are erected at Madinat Nasr sharq District. This increases the vulnerability of the district which may explain the obtained results.

The earthquake risk profile (Fig. 7) in damage of building by building type by precode (concrete) indicates that the highest number of affected constructions (5.88 %) is reported at Bab El-Shariya in first scenario, Gharb with (6.83 %) in the scenario of 1847, and El Basateen, Dar El-Salam with (7.04 %). Also (Fig. 7) in damage of building by building type by precode (unreinforced) indicates that the highest number of affected constructions (4.64 %) is reported at Al-Marg, El Basateen, Dar El-Salam with (5.49 %), and El Basateen, Dar El-Salam with (7.15 %).

It appears that Madinat Nasr sharq and Al-Marg Districts have the highest damage although it considered an area of high construction quality. These districts have the highest population density (5.25 %) and number of building (residential (9.48 %), nonresidential (5.53 %)). Manshiyat Naser has the highest damage and is considered a slum, consisting mainly of random construction of two or three floors, absence or bad conditions of infrastructure, and high percentage of people living below the poverty line. Moreover, buildings within informal settlements are mostly made of masonry, which is more vulnerable to seismic risk. Because of the bad

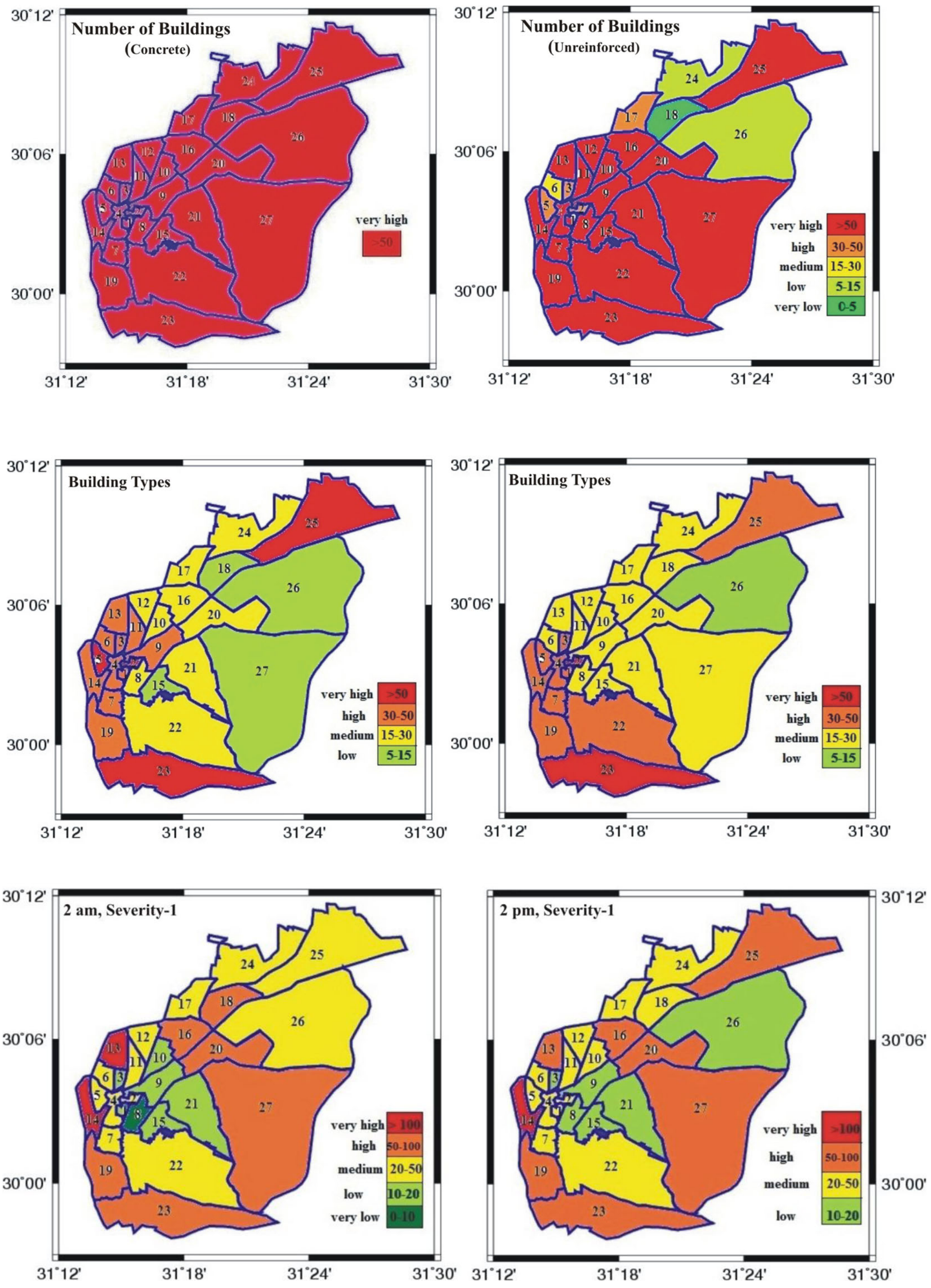


Fig. 4 Distribution of buildings damages per districts, according to the designed earthquakes risk matrix in this study (numbers refer to the 27 Cairo's districts as follows: *1* El-Mosskey, *2* Bab al-Sharia, *3* Shubra, *4* Abdeen, *5* Bulak, *6* Rod–El Farag, *7* Syada Zeinab, *8* Wassat-center, *9* El-Waily, *10* HadeqEl-Qubba, *11* El-Sharabia, *12* El-ZawiaEl-hamra, *13* El Sahel, *14* Gharb, *15* Manaashat Naseer, *16* El-Zeiton, *17* Madinat Naser Gharb, *18* Ain shams, *19* Masr El-Kadima, *20* Maser–El-Gadida, *21* Al-Mataria, *22* El-khaleifa, *23* El-Basteen–Dar El-Salam, *24* Al-Marg, *25* Madina El-Salam, *26* El-Nuzha, *27* Madinat Naser sharq)

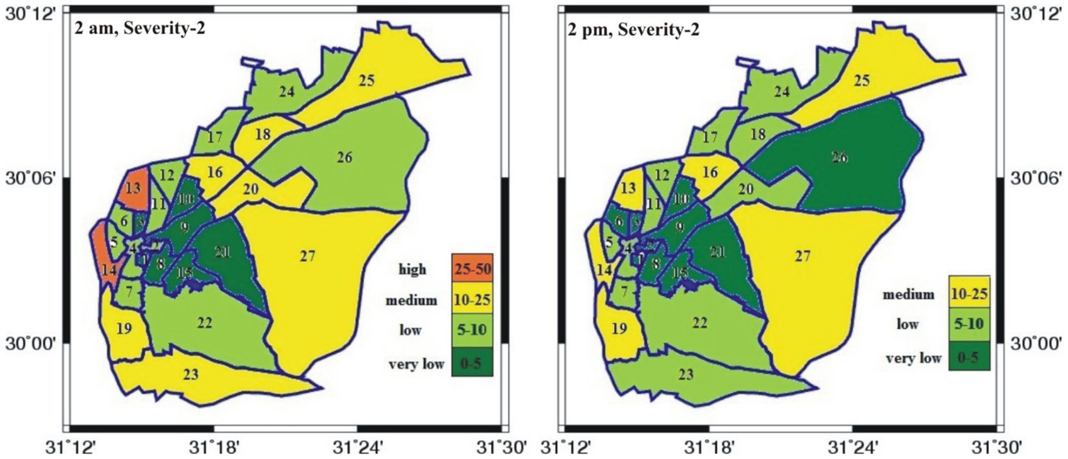


Fig. 5 Distribution of severity-1 and severity-2 at two alternative times, according to the designed earthquakes risk matrix in this study (numbers refer to the 27 Cairo's districts as follows: *1* El-Mosskey, *2* Bab al-Sharia, *3* Shubra, *4* Abdeen, *5* Bulak, *6* Rod–El Farag, *7* Syada Zeinab, *8* Wassat-center, *9* El-Waily, *10* HadeqEl-Qubba, *11* El-Sharabia, *12* El-ZawiaEl-hamra, *13* El Sahel, *14* Gharb, *15* Manaashat Naseer, *16* El-Zeiton, *17* Madinat Naser Gharb, *18* Ain shams, *19* Masr El-Kadima, *20* Maser–El-Gadida, *21* Al-Mataria, *22* El-khaleifa, *23* El-Basteen–Dar El-Salam, *24* Al-Marg, *25* Madina El-Salam, *26* El-Nuzha, *27* Madinat Naser sharq)

quality of construction and poor soil, these areas are also at high risk of earthquakes.

The main soil component in Cairo is also responsible for the damage in each district. By reviewing the map of soil type, we have found according to classification of soil deposits of boreholes in the study area according to the NEHRP provisions that the soil type in district of Masr El-Qadima belongs to class D (stiff soil with Vs(30) = 180–360 and SPT(N) = 15–50) and district of El Basateen, Dar El-Salam) belongs to class C(very dense soil with soft rock with Vs(30) = 360–760 and SPT(N)= > 50). The soil can be quickly converted from solid material into a liquid which has no strength to support structures that may rest on its surface when subjected to prolonged shaking.

However, the bad conditions of some of these buildings constitute an aggravating factor. Fast urbanization of the surrounding areas will further increase the vulnerability of the city, with the appearance of new urban patches on sites exposed to earthquake hazards and by the expansion of informal settlements in low-lying areas exposed to flood and earthquake risks.

5.2 Casualty estimation

The simulated results show that the expected impacts of the October 1992 scenario are twice than previously reported in the last destructive earthquake on 12 October 1992. We have studied the victims (injuries and deaths) through two alterative times at 2 a.m. and 2 p.m. The results show the number of injury through three items of severity: severity 1 (injuries will require medical attention but hospitalization is not needed), severity 2 (injuries will require hospitalization but are not considered life-threatening), and severity 3 (injuries will require hospitalization and can become life threatening if not promptly treated). For severity 1 at 2 a.m. and 2 p.m., the five earthquake risk levels of the designed matrix are presented (Fig. 5). The severity 2 at 2 p.m., only three risk levels (very low, low, and medium) are distributed along the studied 27 districts of Cairo City; however, at 2 a.m., four risk levels are reported (Fig. 5). For severity 3, only three risk levels are reported (Fig. 6).

For severity 4, which is a fatality, the total numbers of victims are of about 836 and 339 at 2 a.m. and 2 p.m., respectively. Two districts are low risk level, one medium; three high and 21 are very high risk level (Table 4 and Fig. 9).

These results explain that urban components within Cairo City, which are most vulnerable or sensitive to the impacts of earthquake disasters, are informal settlements or slum areas of high-density population. The earthquake risk profile indicates four districts (Al-Sahel, El Basateen, Dar El-Salam, Gharb, and Madinat Nasr sharq) that lie at high earthquake risks, while Manshiyat Naser, El-Waily, and Wassat (center) Districts are at relatively low earthquake risks.

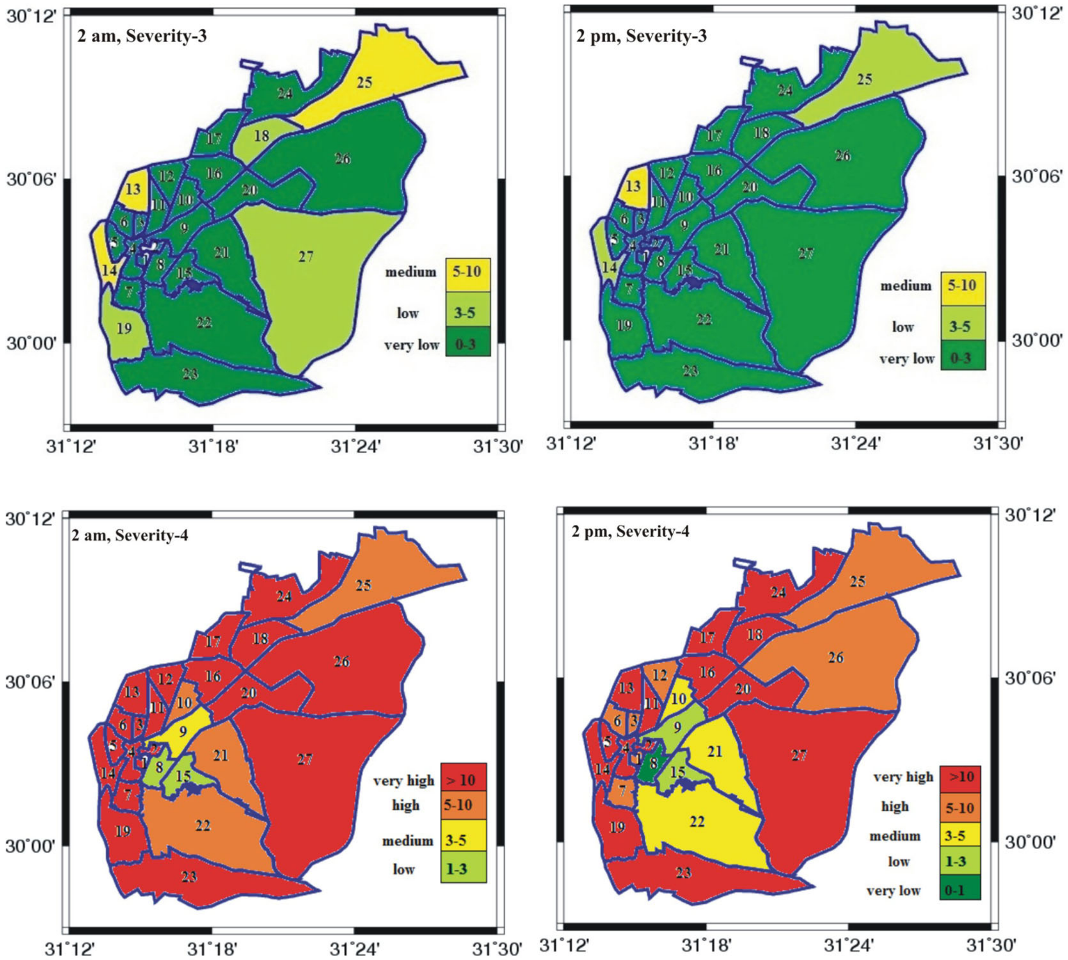


Fig. 6 Distribution of severity-3 and severity-4 at two alternative times, according to the designed earthquakes risk matrix in this study (numbers refer to the 27 Cairo's districts as follows: *1* El-Mosskey, *2* Bab al-Sharia, *3* Shubra, *4* Abdeen, *5* Bulak, *6* Rod–El Farag, *7* Syada Zeinab, *8* Wassat-center, *9* El-Waily, *10* HadeqEl-Qubba, *11* El-Sharabia, *12* El-ZawiaEl-hamra, *13* El Sahel, *14* Gharb, *15* Manaashat Naseer, *16* El-Zeiton, *17* Madinat Naser Gharb, *18* Ain shams, *19* Masr El-Kadima, *20* Maser–El-Gadida, *21* Al-Mataria, *22* El-khaleifa, *23* El-Basteen–Dar El-Salam, *24* Al-Marg, *25* Madina El-Salam, *26* El-Nuzha, *27* Madinat Naser sharq)

5.3 Socio-economic impacts

HAZUS can calculate both direct and indirect economic losses. The direct economic impacts are the economic cost of direct physical damages; however, the indirect is a longer term impact on different types of commerce (industry, mining, agriculture, tourist, etc.). For Cairo, we could not estimate the indirect economic impacts due to the lake of information. The direct economic losses are separated into two main categories: capital stock loss (direct physical damages) and income loss (losses in income due to building damages). Table 5 illustrates in detail that the total building-related economic loss estimations are about $49.3 billion. The capital stock losses and the income losses are $46.9 billion and $2.4 billion, respectively. Although the seismic retrofit solutions are available to overcome these seismic deficiencies of constructions in Cairo, implementation is hampered by complicated economic issues. In fact, earthquake experts are currently able to reasonably predict the intensity and model the temporal and spatial variation of earthquakes ground motions. They have also developed adequate structural models for the seismic response analysis of various types of buildings and appropriate guidelines for design and detailing of different structural elements. The already developed mathematical

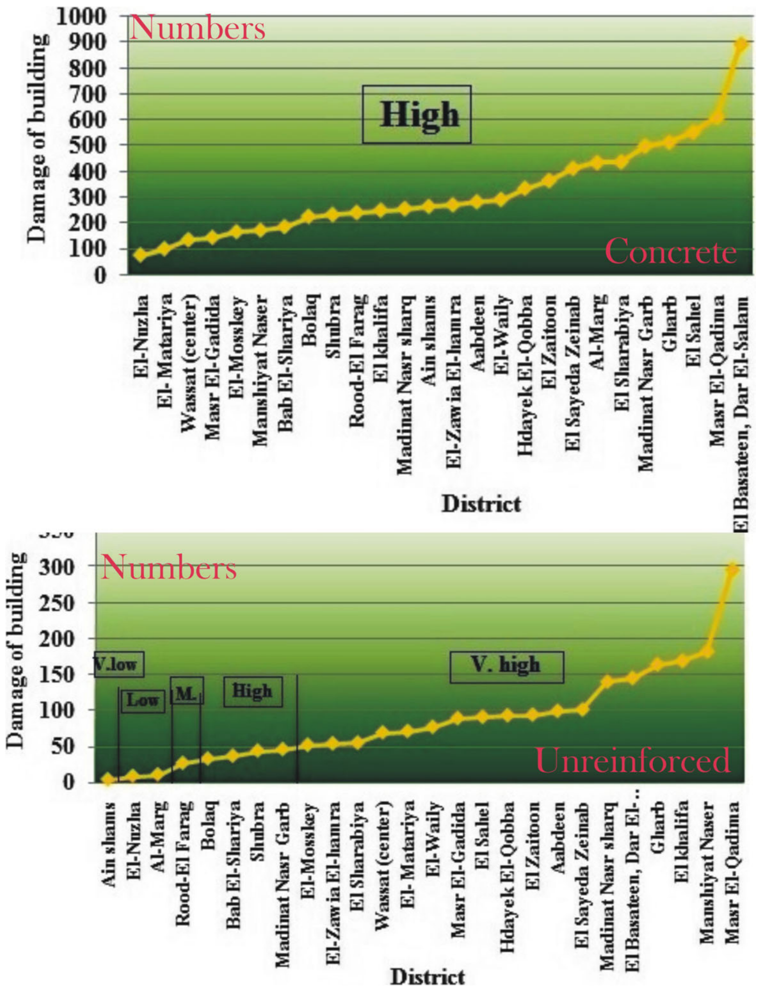


Fig. 7 Earthquake risk profile (damage of buildings–number of buildings) for Cairo's districts, according to the designed earthquakes risk matrix in this study

models and construction procedures that cover both new structures and already existing vulnerable ones requiring repair or strengthening. The authors believe that the present situation is more controlled by economic situation particularly in developing countries such as Egypt. In other words, technical issues may not be of major concern compared to economic perspective. In Cairo, as most of the building owners spent their lifetime savings in constructing their homes, they wish to ensure their homes are safe against possible future earthquakes, but are unable to pay the consulting fees and/or to finance the seismic upgrading of their homes, if needed. Most of these owners rely on home insurance. Therefore, it is necessary to seek some sort of national or international grants to fully or partially cover the expenses of seismic upgrading or replacement of vulnerable residential and school buildings in developing countries particularly for low-income areas.

Special attention and prompt response are crucial for school buildings as their safety is important to protect the students and teachers and for use as public shelters if people are forced to evacuate their homes. It is unfortunate that school buildings routinely collapse during earthquake shaking in most countries. In some Egyptian villages, people do not report noticeable structure defects in school buildings as this may lead to closing the school until the budget allows its repair, strengthening, or replacement. Another problem is created by the lack of knowledge and sensitivity to quality as related to safety and collapse and damage prevention among construction labors and site supervisors as many of them do not have any substantial engineering education or training. As a result, intense supervision of

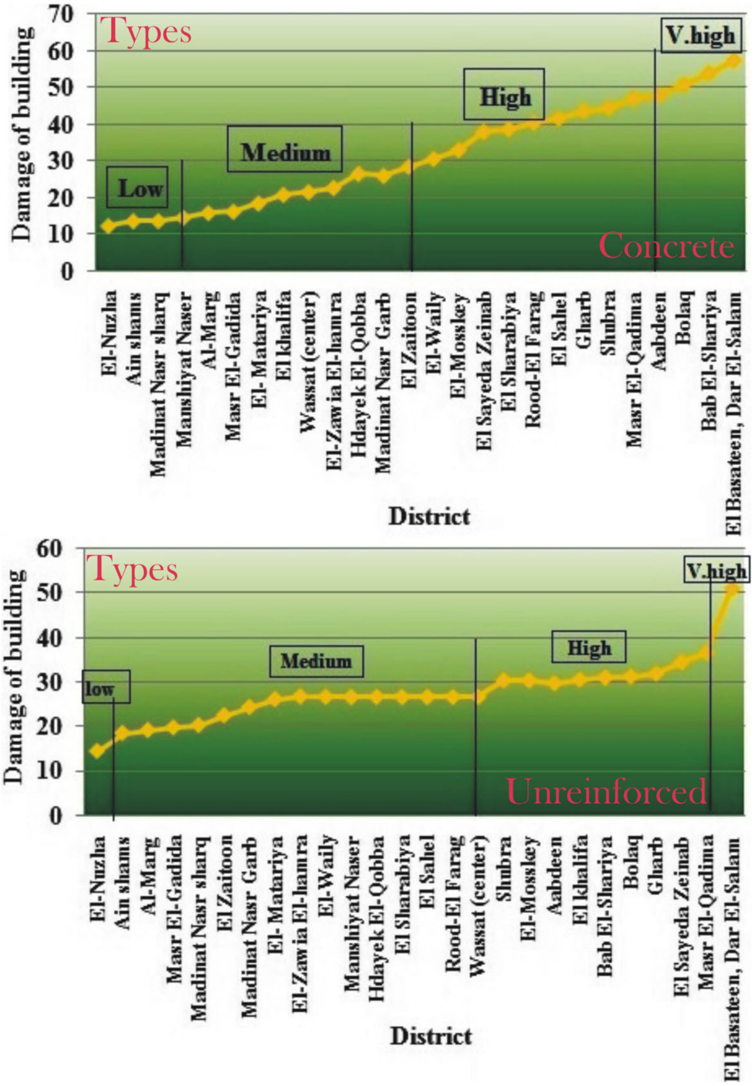


Fig. 8 Earthquake risk profile (damage of buildings–building type) for Cairo's districts, according to the designed earthquakes risk matrix in this study

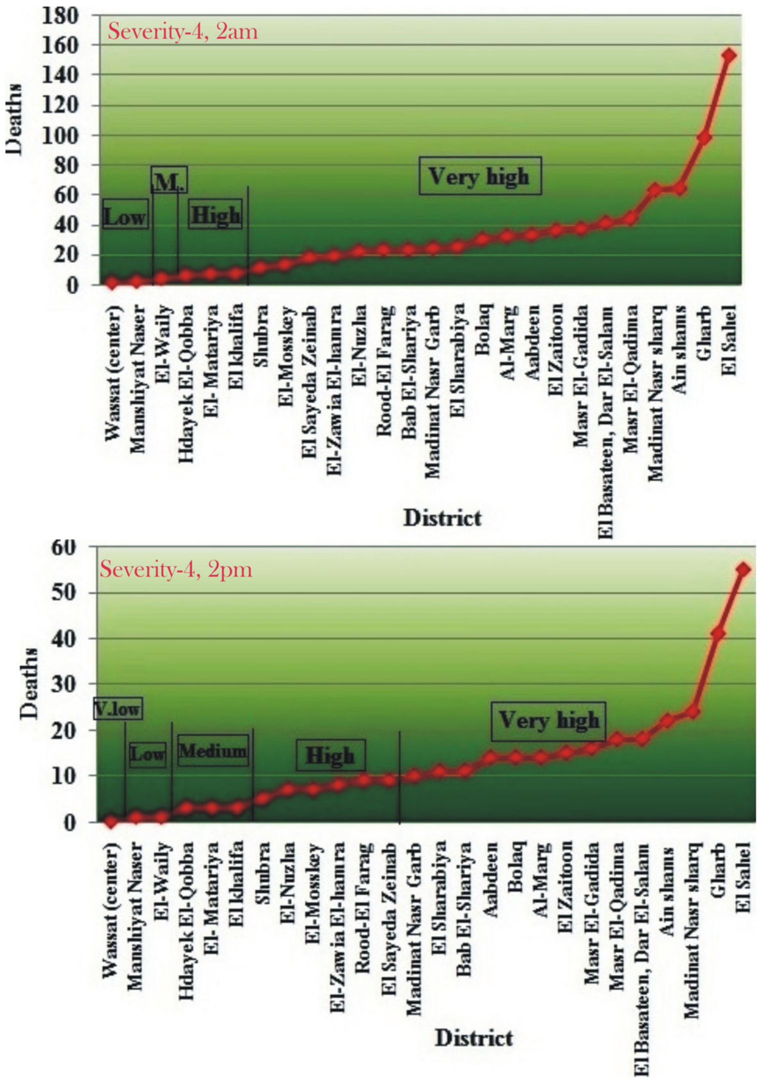
seismic upgrading works must be performed by experienced professional engineers.

Another milestone in earthquake risk reduction efforts is the public awareness. Indeed, the public is generally not trained on how to behave during and after earthquakes. Public awareness programs are needed to inform people about what to do in the event of a damaging earthquake. Emergency social services must be planned to make it possible to provide disaster victims with lodging, food, clothing, registration, and inquiry as well as personal services. With good preparation and sufficient training, emergency social service persons can shorten that the time survivors might have to wait for assistance and help people cope with pain and problems caused by earthquake disasters.

6 Discussion

Egypt is considered as a low to moderate seismicity country. From time to time, it has experienced few numbers of damaging earthquakes. However, in the absence of any seismic provisions in design codes until 1988, a large inventory of buildings is recognized to be seismically vulnerable. These include gravity-load designed reinforced concrete (RC) skeletal structures as well as unreinforced masonry (URM) buildings. Besides, there are few densely populated areas where some nonengineered buildings were constructed. The first seismic loading provisions were published by the Egyptian Society of Earthquake Engineering, 1988. However, due to

Fig. 9 Earthquake risk profile (no. of deaths) for Cairo's districts at two alternative times, according to the designed earthquakes risk matrix in this study

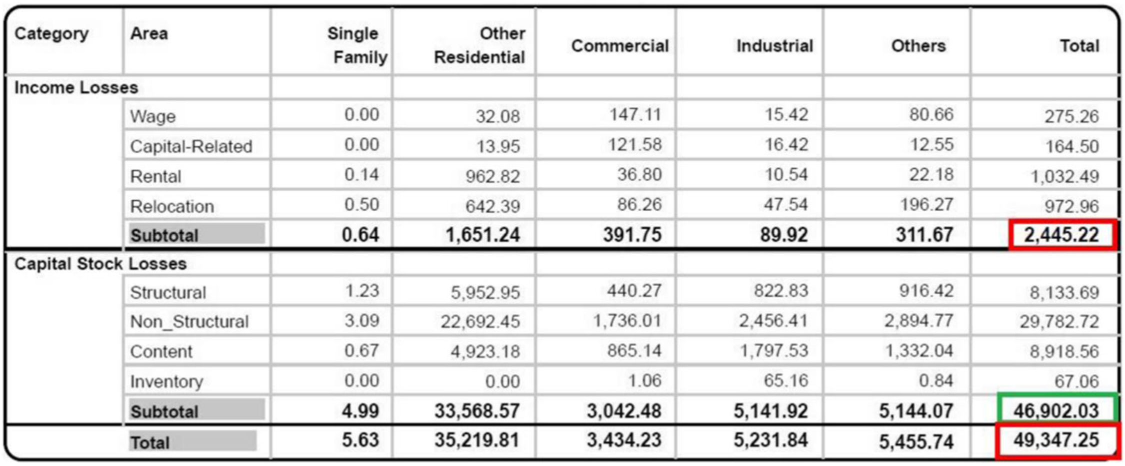


lack of official backing, it had minimal impact. The first code to include seismic loading was the Egyptian Code for Reinforced Concrete Construction, 1989, which included an equivalent static method with a minimum lateral load of 1 %. A similar method was defined in the Egyptian Load for Foundations, 1990, but with different seismic coefficients.

Since the occurrence of the SW Cairo earthquake in 1992, the building provisions and codes were dramatically developed. For instance, the reference to seismic loading in both codes was superseded by the Egyptian Code for Loads and Forces in 1994. This latter Code followed a procedure similar to UBC 85 to calculate the base shear for the equivalent static method. The Code stated that dynamic analysis is required for special and irregular buildings. However, it did not provide a response spectrum or criteria for time history records. The code for loads has recently been updated, and the current version follows a Euro-code format and minimizes the use of the equivalent static method. Seismic loads in the new code vary substantially from the older version and are generally higher.

Although seismic hazard in Egypt is considered low to moderate, seismic risk is relatively high due to the fact that most of the buildings were designed prior to the implementation of code regulations for seismic design. In addition, many structures suffer from lack of maintenance, which in turn reduces the strength and mechanical properties of construction

Table 5 The expected socioeconomic impacts of earthquake risk assessment in Cairo. Building-related economic loss estimates (Millions of dollars)



Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses							
	Wage	0.00	32.08	147.11	15.42	80.66	275.26
	Capital-Related	0.00	13.95	121.58	16.42	12.55	164.50
	Rental	0.14	962.82	36.80	10.54	22.18	1,032.49
	Relocation	0.50	642.39	86.26	47.54	196.27	972.96
	Subtotal	**0.64**	**1,651.24**	**391.75**	**89.92**	**311.67**	**2,445.22**
Capital Stock Losses							
	Structural	1.23	5,952.95	440.27	822.83	916.42	8,133.69
	Non_Structural	3.09	22,692.45	1,736.01	2,456.41	2,894.77	29,782.72
	Content	0.67	4,923.18	865.14	1,797.53	1,332.04	8,918.56
	Inventory	0.00	0.00	1.06	65.16	0.84	67.06
	Subtotal	**4.99**	**33,568.57**	**3,042.48**	**5,141.92**	**5,144.07**	**46,902.03**
	Total	**5.63**	**35,219.81**	**3,434.23**	**5,231.84**	**5,455.74**	**49,347.25**

materials. The majority of nonengineered buildings in Egypt were built in villages and rural areas prior to the 1990s, but similar constructions are also found at extremities of even major cities. The number of existing such buildings is large (for example in Cairo, about 36 % of the number of buildings susceptible to earthquake damage can be classified as nonengineered or of low engineering (Elnashai 1995). These buildings are mostly residential and school buildings presenting a very high risk to life safety in the case of damaging earthquakes. The construction of these buildings varies between adobe, URM, cut-stone, and lightly reinforced concrete (LRC). As nonengineered buildings were erected without seeking proper engineering advice and may have also been subjected to repeated alterations and/or extensions, including heightening, without any engineering consultation, their structural safety is questionable even under the effects of gravity loads. Consequently, these buildings are seismically highly vulnerable (Elnashai 1995).

7 Conclusions and recommendations

Disasters arise from the interactions among the earth's physical systems (hazard), its human systems (vulnerability), and its built infrastructure (exposure). A broad view, which encompasses all of these dynamic systems and interactions among them, can enable us to find better solutions for mitigation and protective plans.

Although Cairo is characterized by low to moderate earthquake hazard, it possesses a high earthquake risk. If the October 1992 earthquake occurred again, the expected losses and damages may triplicate the total cost of building repairing or replacement is about $49.3 billion. Numbers of victims at two alternative times (2 a.m. and 2 p.m.) are doubled. In all cases, the expected losses and damages are greater than the previous event.

Buildings within informal (Al-Sahel, Masr El-Qadima, Gharb, and El Basateen, Dar El-Salam Districts) settlements are mostly made of masonry, which are more vulnerable to earthquake risks. Fast urbanization of the surrounding areas and rapid population growth will further increase the vulnerability of Cairo City.

Based on these conclusions, we recommend the following measures and actions: The slum areas represent, not only in Cairo but also throughout the whole Egyptian lands, a time bomb due to natural hazards and the ability to recover or due to the spread of crime and poverty. Therefore, it has to be the face of this phenomena that spread through the Egyptian body by viable and applicable mechanisms. These mechanisms should include upgrading the existing constructions with required retrofitting and public awareness programs to train the residents how to behave during and after earthquakes. According to the Egyptian National Plan for Earthquake Risk Reduction (Badawy 2010), all these issues were clearly addressed. The chapter five of this national plan describes in detail with schematic illustrations what the residents can do in case of earthquake at different places (e.g., houses, schools, universities, factories, and streets) to reduce the associated risks. Moreover, the Egyptian National Strategy for public awareness for Crisis and disasters was published in 2010 (El-Gazar 2010, for more detail see PreventionWeb). This national strategy contains many action plans for raising public awareness for natural hazards (e.g., earthquakes, flash floods) with different communication messages with short-, medium-, and long-term evaluation of Key Performance Indicators (KPI's). These KPI's measure how much the progress of each item of the action plans.

El-Sahel and Gharb Districts specifically need planning in order to achieve a future reduction of earthquake risks. This can be done through the technical inspection of buildings and facilities to address the requirements of the seismic retrofits and raise the efficiency and resistance of these constructions and facilities in this district. Building codes, standards, and practices for earthquake hazards must be reevaluated in light of the goal for sustainable mitigation. Indeed, land use planning, earthquake hazard mitigation, and sustainable communities are concepts with a shared vision, in which people and property are kept away from hazards. The mitigative qualities of the natural environment are maintained, and the development is resilient in the face of earthquake hazards.

The Cairo governorate must collect, analyze, and store standardized data on damages and losses from past and current disasters, thereby establishing a database for comparison with future losses. This database should include information on the types of losses, their locations, their specific causes, and the actual dollar amounts, taking into account the problems of double counting, comparisons with gross domestic product (GDP), and the distinction between regional and local impacts. Given the low to moderate seismicity of greater Cairo and the vulnerable buildings and knowing that the seismic risk is the product of hazard and vulnerability, there is a relatively high Earthquake risk in Cairo. For mitigation, risk reduction, and to improve the seismic performance of structures and assure life safety and collapse prevention in future earthquakes, we suggest a five-step road map. These are (1) upgrade of the exiting constructions with suitable retrofit, (2) rebuilding better, (3) regular maintenance, (4) suitable site selection for new structures, and (5) public awareness and outreach to residence how to behave pre, during, and post-earthquakes.

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