Egyptian Geophysical Society
EGS Journal, vol. 6, No. 1, 115-123 (2008)

VULNERABILITY STUDIES AND RISK ANALYSIS FOR CRITICAL AND HIGH COST BUILDINGS IN GREATER CAIRO AND ITS SURROUNDINS

M.A.H. Abdel Aziz and S.A.M. Al-Gohary

National Center for Nuclear Safety and Radiation Control, Cairo, Egypt.

دراسات لقابلية الإنجراحية وتحليل للمخاطر السيزمية للمنشآت الحرجة والعالية التكاليف

بمدينة القاهرة الكبرى والمناطق المتاخمة لها

الخلاصـة: يحكم عملية تحليل المخاطر الزلزالية ثلاث عوامل رئيسية هى الخطورة الزلزالية، قابلية الإنجراح والتكاليف الاقتصادية للمنشأة. ويتوقف العامل الأول (الخطورة الزلزالية) على الوضع التكتونى والزلزالى بالمنطقة بينما يعتمد كل من العامل الثانى والثالث على درجة تعليم ومعرفة وخبرة الانسان، وبالتالى تتحكم العوامل الثلاث فى الحد من الخطر الناتج أو تعظيمه.

تهدف هذه الدراسة إلى تحليل المخاطر المصاحبة لحدوث الزلازل بمدينة القاهرة وما حولها وقد أوضحت الدراسات التكتونية أن مدينة القاهرة تقع عند التقاء اتجاهين من الاتجاهات السيسموتكتونية المؤثرة على مصر. وقد عكس النموذج السيسموتكتونى تأثر القاهرة بثلاث نطاقات سيسموتكتونية وهى شرق المتوسط، غرب المتوسط والفيوم. وقد تم حساب المعاملات السيزمية للنطاقات الثلاث واستخدامها فى حساب الخطورة الزلزالية كأحد العوامل الثلاث الضرورية لحساب المخاطر المصاحبة لحدوث الزلازل وتم التعبير عن الخطورة الزلزالية المتوقعة عن طريق خرائط تعكس توزيع عجلة التسارع الزلزالى المتوقعة عند ٥٠ ، ١٠٠ ، ٢٠٠ سنة كعمر منشأ باحتمالية ٩٠% عدم تجاوز تلك القيمة.

وقد عكست الخرائط قراءات عالية لعجلة التسارع الزلزالى شمال وشرق منطقة الدراسة مقارنة بالمناطق الجنوبية والغربية لذلك توصى الدراسة بأن المنشآت التى تقام فى المناطق الشمالية والشرقية لابد أن تتميز بقيم للقابلية الإنجراحية المنخفضة وكذلك يجب أن تكون تكلفتها الاقتصادية منخفضة أيضاً لاختزال محصلة الخطر الناتج كما توصى الدراسة بإقامة المنشآت الحرجة والمبانى ذات التكلفة العالية فى المناطق الجنوبية والغربية.

ABSTRACT: *Risk analysis process is controlled by three main parameters which are the earthquake hazard, vulnerability and economic asset. The first parameter can not be controlled and based mainly on the tectonics and seismicity of the area and its surroundings. The second and third parameters are based on man's education, knowledge and experience. So, they are controlled and hence they play a role in reduction of generated risk. Cairo lies at the intersection of two main seismo-tectonic trends; North Red Sea-Gulf of Suez-Cairo-Alexandria Clysmic trend and East Mediterranean-Cairo Fayum Pelusiac trend. The seismo-tectonic model governed the greater Cairo and its surroundings has been constructed consisting of three main seismo-tectonic provinces which are named East Mediterranean, West Mediterranean and Fayum seismo-tectonic source zones. The expected hazard in the form of peak ground acceleration with 90% probability of not being exceeded through 50, 100 and 200 year exposure times has been estimated. The maps show high ground acceleration in the northern and eastern parts compared with the southern and western parts. This means that the buildings and facilities located in the northern and eastern areas of Cairo may be subjected to high vibratory ground motion values compared to the southern and western parts. So, the buildings in the northern and eastern parts should be characterized by low vulnerability and low economic assest to minimize the net risk. Meanwhile, the critical and high risk buildings should be located in the southern and western parts.*

INTRODUCTION

The critical and high cost buildings like nuclear power plant, research laboratories, radioactive waste repositories, traditional power plants, etc. should be located in sites of low tectonic and low seismicity to mitigate and reduce the associated risk. During the past decades, natural hazards such as earthquake, land slides, high winds, river and coastal flooding have caused major loss of human lives and livehoods, the destruction of economic and social infrastructure, as well as environmental damage. Losses from natural disasters caused by natural hazards will continue to increase unless there is a shift towards proactive solutions. One of these solutions is vulnerability to hazards.The outcome of the World Summit on Sustainable Development (WSSD) in Johansperg in 2002 brought more relevance and commitment towards disaster reduction and a multi-hazard approach to reduce risk and vulnerability, within the context of sustainable development.

Egypt is more vulnerable to natural hazards. This is due to high rates of population growth. Poverty and social and economic pressures such as migration from the villages to the cities, unemployment and illegal land tenures practices, make people vulnerable by forcing them to live in dangerous locations, often on unsafe lands and in unsafe shelters or buildings. In buildings sector, the last earthquake in 1992 highlights other key deficiencies and trends in the approach to disaster risk reduction.

Disaster reduction strategies are aimed at enabling societies at risk to become engaged in the conscious management of risk and the reduction of vulnerability.The vulnerability assessment will provide a framework for developing risk reduction options and associated costs.

The design of new development projects and buildings, should take risk assessment into account at the appraisal stage. Environmental impact assessment should systematically include a section on hazard proneness and consider disaster reduction measures where appropriate, with particular regard to the protection of lifeline infrastructures and critical facilities.The land use and mapping tools should be used to determine the level of risk and to identify the most suitable use of vulnerable areas.

RISK ANALYSIS AND RISK MANAGEMENT

Risk is defined as a combination of the the probability that can event will occur and the consequences of its occurrence. According to the department of U.S. Homeland Security risk can be expressed as follows;

Risk = Threat rating × Vulnerability × Asset value

So, Risk assessment is the process to determine the nature of extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability/ capacity that could pose a potential threat or harm to people, property, livehoods and the environment on which they depend.

Meanwhile, risk management is the liklihood that a threat will harm an asset with some severity of consequences and deciding on and implementing action to reduce it.

It is clear that, three main elements constitute seismic risk which are earthquake threat, vulnerability and asset value or economic cost. In the following we discuss these elements showing how to evaluate each one, its effect on the total risk and as a case study how to minimize the seismic risk for critical and high cost buildings in Greater Cairo and its surroundings.

SEISMIC HAZARD

Hazard versus Risk

Unfourtunately, many specialists use the two terms hazard and risk interchangeably although there is a difference between them. In general, hazard is potentially damaging physical event, phenomenon and/or human activity which may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. Accordingly, seismic hazard describes the potential for dangerous earthquake related natural phenomenon such as ground shaking, fault rupture or soil liquifaction. This phenomenon could result in adverse consequences to society such as the destruction of buildings or the loss of life. Seismic risk is the probability of occurrence of these consequences.

The output of a seismic hazard analysis could be a description of the intensity of a nearby earthquake or a map which shows levels of ground shaking in various parts of the country that have an equal chance of being exceeded. The output of a seismic risk analysis could be the probability of damage (in dollars) from a nearby magnitude of an earthquake or the probability of fatalities due to seismically induced nuclear power plant accidents. So, seismic hazard is needed in order to calculate seismic risk. If not already known, defining the seismic hazard becomes part of the risk estimation process (Reiter, 1991).

Probabilistic Seismic Hazard Methodology

Two main types of seismic hazard analysis are probabilistic and deterministic (Reiter, 1991). The two methods are similar with some major differences.It is recommended to use probabilistic seismic hazard analysis in case of critical buildings siting like nuclear power plant (IAEA,1979).The methodology used in most probabilistic hazard analysis was first defined by Cornell (1968). It consists of four main steps;

Step (1): The definition of earthquake sources. Seismic source can be expressed as point, line or an area according to the available data. Sources are explicity of uniform earthquake potential, that is, the chance of an earthquake of a given size occurring is the same throughout the source.

Step (2): The definition of seismicity recurrence characteristics for each source. Each source is characterized by an earthquake probability distribution or recurrence relationship. A recurrence relationship indicates the chance of an earthquake of a given size occurring anywhere inside the source during a specified period of time. Each source is characterized by upper and lower magnitudes. The recurrence curve in this simple case is;

$$\text{Log } N = a - bM$$

where N is the cumulative number of earthquakes of a given magnitude or larger that are expected to occur during a specified period of time.

(a) is the log of the number of earthquakes of magnitude zero or geater expected to occur during the same time, and (b) is the slope of the curve which characterizes the proportion of larger earthquakes to small earthquakes.

Step (3): Estimation the earthquake effect. The range of earthquake sizes considered requires a family of earthquake attenuation or ground motion curves, each relating a ground motion parameter, such as peak ground acceleration to distance for an earthquake of a given size.

Step (4): Determining the hazard at the site. The effects of all earthquakes of different sizes, occurring at different locations in different earthquakes sources at different probabilities of occurrence are integrated into one curve that shows the probability of exceeding different levels of ground motion levels at the site during a specified period of time. With some assumptions this can be written as;

$$\mathrm{E}(z) = \sum_{i=1}^{N} \alpha\, i \int_{m_o}^{m_u} \int_{r=0}^{r=\infty} fi\,(m)\; fi\,(r)\, P\,(Z > z \mid m\,, r)\;\, dr\, dm$$

where;

E(z) is the expected number of exceedance of ground motion level (z) during a specified time period (t).

α_i is the mean rate of occurrence of earthquakes between lower and upper bound magnitudes (m_o and m_u) being considered in the source.

f_i(m) is the probability density distribution of magnitude (recurrence relationship) within source (i).

f_i(r) is the probability density distribution of epicentral (or source) distance between the various locations within source (i) and the site for which the hazard is being estimated and ;

P(Z >z|m,r) is the probability that a given earthquake of magnitude (m) and epicentral distance (r) will exceed ground motion level (z).

Application of Probabilistic Seismic Hazard

The estimation of seimic hazard at Greater Cairo and its surroundings requires the studying of general geologic and tectonic setting of the Geater Cairo and its surroundings. Beside the forementioned data, up to date seismological catalogue should be used to fit the geologic and tectonic data. The collected geologic, tectonic and seismological data are very important in constructing the seismo-tectonic model affecting the concerned area.

Geologic Setting of Greater Cairo

Cairo is bounded from the eastern part by Gebel Mokattem Mountain. Gebel Mokattem is the subject of studies by a larger number of workers among them, Cuvillier (1924 and 1930), Awad et al. (1953), El-Shazly et al., (1980), and Swedan (1991). The strata displayed in the cliff behind the citadel differ widely, the two-thirds consists of white limestones, while the upper part is red-brown in colour and is characterized by the presence of numerous beds of clastics. This marked topographical and lithological separation led Zittel (1883) to subdivide these strata into the lower and upper Mokattam units. He dated them as middle Eocene. Later paleontological work on the continued faunas has shown that the lower Mokattam unit (Mokattam Formation) is of middle Eocene age in its lower part and of upper Eocene age in its higher parts whereas the upper Mokattam unit is of upper Eocene age. At the type locality near citadel, Mokattam Formation consists of from top to bottom Nummulitic limestone with gastropodes, Cairo building stone horizon with gypsum containing shark teeth and a white compacted limestone unit.

To the south of Mokattam in the eastern cliffs of Helwan, there some units became increasingly thicker. Farag and Ismail (1959) have recently subdivided the succession in this area into the following units: El-Qurn Formation which consists of chalky and marly limestone alternating with sandy marls, Observatory Formation which consists of yellowish to white hard chalky limestone and Gebel Hof Formation that contains Nummulites, Velotes and others.

On the western side of the Nile, the topography is somewhat subdued and the Eocene succession is thinner in the pyramids of Gizeh plateau. The succession has a 25m thick grey to yellowish limestone bed at the base. This is followed by a 15m thick unit best exposed in the sphinx ditch and in the quarry along the Fayum road. The whole succession rests unconformably and with conglomerate at its base, over the Senonian chalk exposed to the south at the southern limb of Abu Roash anticline. This latter structure was probably active during the deposition of the Mokattam Formation.

At Gebel Al-Ahmar, east of Cairo, a massive variegated sands and gravels presumbly deposited by an Oligocene river that drained southern Egypt, overlie the upper Eocene beds with an angular unconformity.

The marine Pliocene exposures around Cairo area occur as a strip along the cultivation edge. They are especially well developed between Abu Sir and Gizeh on the western bank of the river. At Kom El-Shelul, Pliocene sediments overlap the upper Eocene with angular unconformity. They have a 10m thick coquinal limestone at the base, followed by a 2m thick marl bed. Upon this lies a sandstone bed of half a meter thick.

SEISMO-TECTONIC MODEL

Based on the investigations of seismo-tectonic trends and the distribution of earthquake epicenters from 1900 to 2002 affecting Egypt, it could construct the seismotectonic model affecting the capital Cairo and its surrounding as shown in Fig.(1). The model consists of four seismotectonic source zones

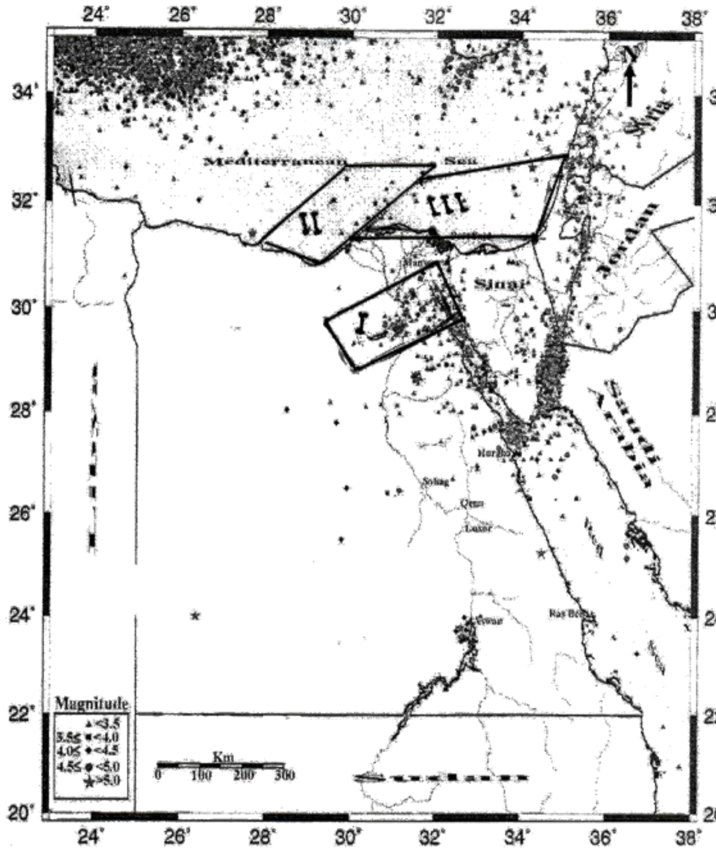

Fig (1): Seismcity map of Egypt and Seismo-tectonic model of the concerned area (after NRIAG, 2003).

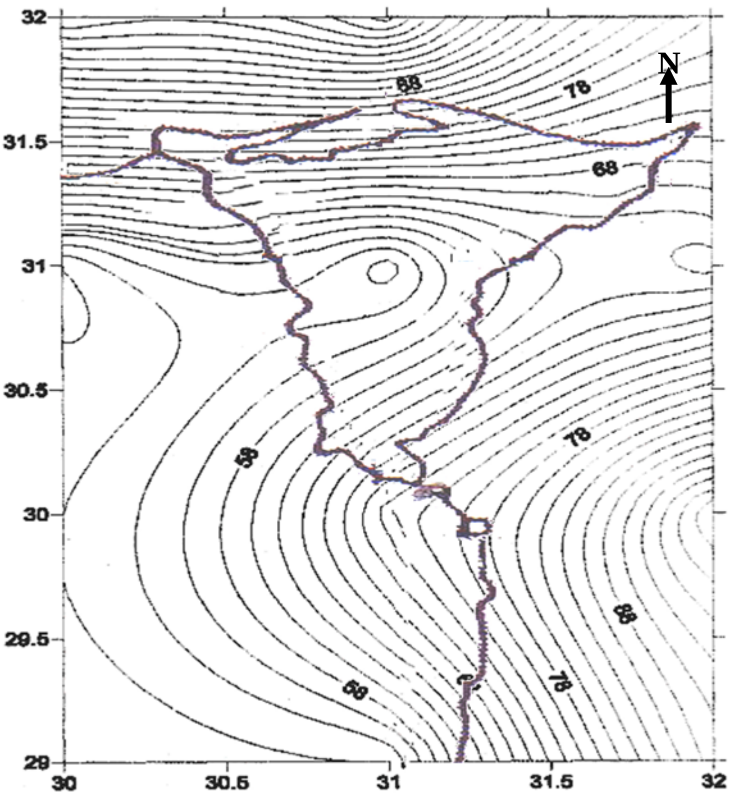

Fig (2) : Peak ground acceleration in gals with probability 90% of not being exceeded corresponding to 50 years exposure time

a- Seismo-Tectonic Source 1

The earthquake activity in this source is attributed to a set of geologic structures taking different directions; extension of Syrian Arch System, a set of faults along the Cairo-Suez Road and wrench faults giving the Nile Valley direction. This source is subjected to a number of historical earthquakes among them 2200 B.C. with maximum intensity VII, Fayum earthquake in 1303 with magnitude 7 and Nile Valley earthquake in 1847.

b- Seismo-Tectonic Source 2

This source is marine and its tectonic cause not clear and its seismicity low as shown from the instrumental earthquake catalogue of past ninety five years. The largest earthquake in this zone occurred in 306 A.D. with Ms=7.2.

c- Seismo-Tectonic Source 3

This source witnessed many historical earthquake occurrences. The largest one occurred on 2 June 1201 with magnitude above 7.5. The largest recorded earthquake in this zone tooke place on 16 March 1956 with M=6.

Estimated Seismic Hazard

The application of the probabilistic earthquake hazard analysis approach was carried out using EQRISK computer program developed by McGuire in 1976. The results are mapped as shown in Figs 3, 4 and 5. The maps reflected the expected hazarad in the form of peak ground acceleration with 90% probability of not being exceeded in 50, 100 and 200 years exposure times.These maps show high ground acceleration in the northern and eastern parts compared with the southern and western parts. This means that the buildings and facilities located in the northern and eastern areas may be subjected to high vibratory ground motion values compared to the southern and western parts.

VULNERABILITY ESTIMATION

Vulnerability may be estimated in several ways including those listed below.

a) The vulnerability may be obtained from experience in many different locations, involving many different populations, with a total number of people at risk (No), of which (Nx) would suffer the consequences of failiure if an event of magnitude x occurs (Plate, 1996). That is, Vi (x) = Nx/No.

b) The vulnerability of the structures may be determined by computer simulation of structural damage resulting from an event of magnitude (x). This approach is a central component of minimum life cycle cost design of earthquake resistant structures.

Factors Affecting the Sesimic Vulnerability of Buildings

There is a number of different factors affect the overall vulnerability of a structure besides the construction type. These factors are generally applicable to all types of structures and they include: quality and workmanship, state of preservation, regularity, ductility, position, strengthening, earthquake resistant design (ERD) and site condition

Example of Different Vulnerable Buildings

The design of new development projects and buildings, should take risk assessment into account at the appraisal stage. According to Khaled and Hays (2003), the vulnerability of a building is based mainly on its design, building elevation, locations of potential failure, floor plan and potential problems. They gave vulnerability scale from 1 to 10 since the number 10 refers to extreme vulnerability and vice versa. In the following, some buildings with different designs and different vulnerability values will be presented.

-Pyramid shape buildings: This building shape is characterized by extremely low or non-vulnerability value (equal unity). If attention given to foundation and non structural elements, the vulnerability is reduced. Rocking may crack foundation (Fig.5a).

-Box building: This building shape is characterized by very low vulnerability value between 1 to 2. The building may be of non vulnerability. If attention is given to foundation and non structural elements, the vulnerability will be nil. Rocking may crack foundation (Fig.5b).

-Multiple setbacks buildings: It is characterized by low vulnerability value between 2-3 as shown in Fig.5c. The vertical transition in mass, and damping may cause failure at foundation and transition points at each floor.

-Overhang building: This building design is chaaracterized by medium vulnerability rangeing between 4-5. Top heavy asymmetrical structure may fail at transition point and foundation due to rocking and overturning (Fig.5d).

-L-shaped building: It is also characterized by medium vulnerability but much higher than the case before (vulnerability between 5-6) as shown in (Fig.5e) . Asymmetry and transition in mass, stiffness and damping may cause failure where lower and upper structures join.

-Partial soft story: The design is characterized by medium to high vulnerability between 6-7 as shown in Fig.5f. Horizontal and vertical transition in mass and stiffness may cause failure on soft side of first floor and overturning.

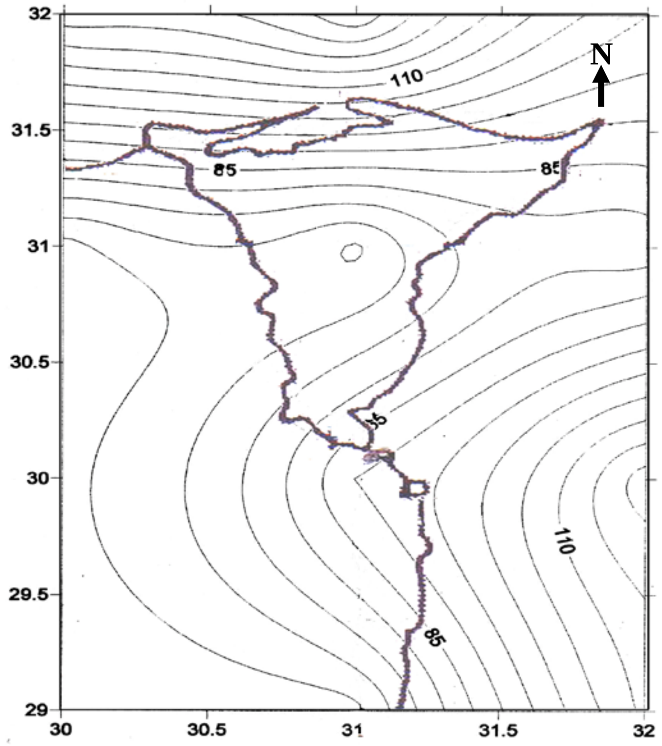

Fig. (3) : Peak ground acceleration in gals with probability 90% of not being exceeded corresponding to 100 years exposure time.

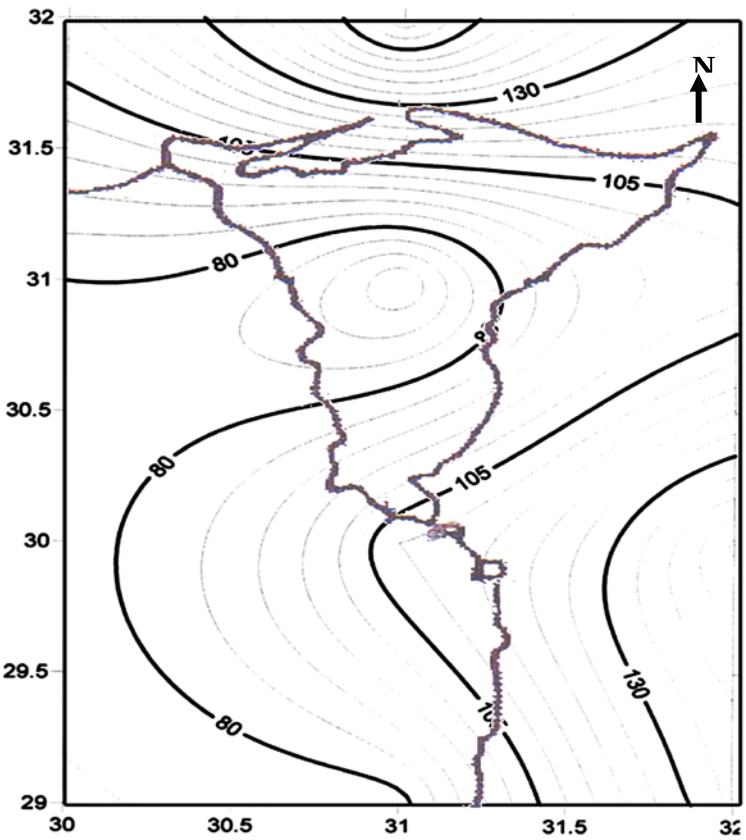

Fig. (4) : Peak ground acceleration in gals with probability 90% of not being exceeded corresponding to 200 years exposure time.

-*"Soft" first floor:*This building shape is characterized by very to extremely high vulnerability between 8 and 10 as shown in Fig.5g. Vertical transition in mass and stifness may cause failure on transition points between first and second floors.

-*Combination of "soft" story and overhang:* Such a design is characterized by very to extremely vulnerability between 9-10 as shown in Fig.5h. Vertical transition in mass and stiffness may cause failure on transition points and possible overturrning.

-*Building on sloping ground:*Such a building is characterized by extremely high vulnerability equals 10 as shown in Fig.5i. Horizontal transition in stifness of soft story columns may cause failure of columns at foundation and/or contact points with structure. .

ECONOMIC ASPECTS OF VULNERABILITY (ASSET VALUE)

Vulnerability is defined as the degree of loss (from 0 to 100 percent) resulting from a potentially damaging phenomenon. Two categories of damages are considered: direct and indirect damage. Direct damages include property damage, injuries and loss of life, whereas indirect damages refer to the disruption of economic activity.

Direct Damage

1) Structures and contents

Potential damage to structures and their contents are typically estimated through a combination of field surveys of structures in the area that would be affected by potentially damaging phenomena and information obtained from post disaster surveys of damage.

The US Army Corps of Engineers (USACE) has developed a detailed procedure for estimating the potential damage to structures and their contents resulting from flooding. A similar procedure could be applied to determine potential damages from other types of natural hazards: such as earthquakes, volcanoes, etc.

The value of contents is specified as a fraction of the value of the structure. This approach is similar to the approach normally applied by residential casually insurers in setting rates and contents for home owners insurance. The USACE (1996) has summarized the claims records of the flood insurance administration for various categories of residential structures.

The ratio of the value of contents to the value of residential structure is:

- 0.434 for one story structure without a basement,
- 0.435 for one story structure with a basement,
- 0.402 for two story structure without a basement,
- 0.441 for two story structure with a basement,
- 0.421 for split level structure without a basement,
- 0.435 for split level structure with a basement,
- 0.636 for mobile homes.

The value of contents found in any structure is highly variable because it represents the wealth, income, tastes and lifestyle of the occupants for residential structures. On the other hand, it is also highly variable in different types of structures. As example the ratio for commercial structures in Mexico City is 0.5 and in Tokyo is 0.4. These values are examples of typical magnitudes of the ratio.

2) Value of life and cost injuries

Estimating of the value of human life and, thus, the value of lives saved by risk- mitigation measures used for decision making is difficult and controversial. Numerous methods have been proposed to estimate the value of human life including those based on the following:

a) life insurance coverage;
b) court awards for wrongful death;
c) regulatory decisions;
d) Calculations of direct out of pocket losses associated with premature death;
e) Examination of how much people are willing to pay to reduce their risk of death;

Methods based on data derived from (d) and (e) are most commonly applied in the literature on public decision making.

Indirect Damages

Indirect damages are determined from multiplier or ripple effect in the economy caused by damage to infrastructures resulting from a natural disaster. In particular, damage done to lifelines, such as the energy distribution network, transportation facilities, water supply systems and waste management systems, can result in indirect financial losses greater than the direct financial damage to these systems and a long term drain on the regional or national economy.

SUMMARY AND CONCLUSION

- Three main elements constitute the total output of risk are seismic hazard, vulnerability and asset value. The first element cannot be controlled because it is connected with the tectonic and seismological setting of the site where the facility will be located. The other two elements can be controlled and based on man's knowledge and experience and with a good site selection man can reduce the risk and avoid the undue consequences.

- The expected seismic hazard at Greater Cairo and its surroundings is represented by the distribution of peak ground acceleration with 90% probability of not being exceeded in 50, 100 and 200 years exposure times.

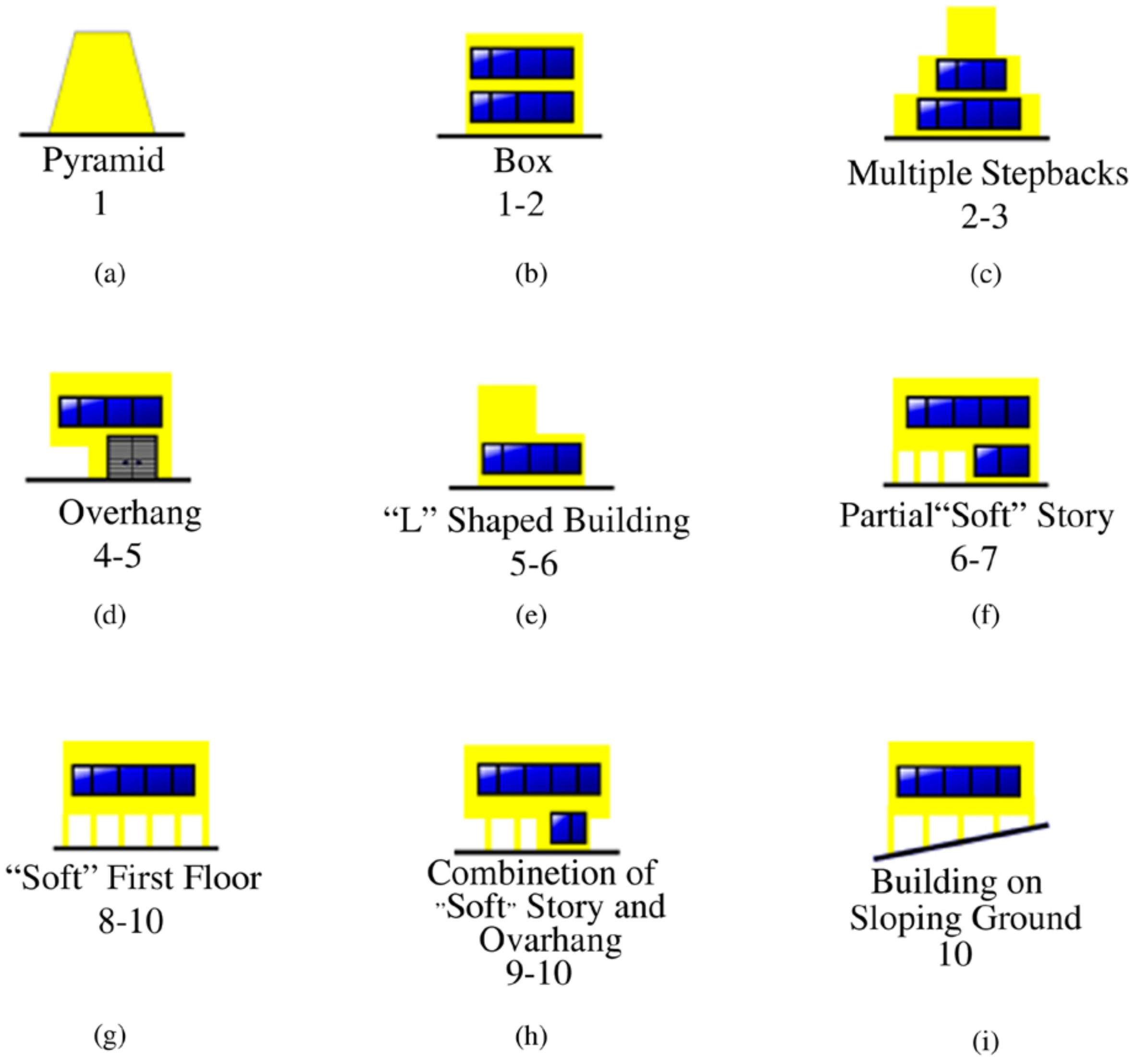

Fig (5): Examples of estimated vulnerability for some Engineering building (after Khaled and Hays, 2003).

They reflect that both the northern and eastern parts of the Greater Cairo generated maps may expose to peak ground accelerations higher than those that may affect the western and southern parts. So, buildings and facilities in the northern and eastern parts should be characterized low vulnerable and low cost values to reduce the total risk in case of seismic event occurrence with considerable magnitude. Also, it is recommended that the critical and important buildings and facilities should be located in the southern and western parts of Cairo.

- Further studies should be conducted related to the estmation of numerical values of both the vulnerability and asset value of buildings in Greater Cairo districts to define the associated risk with the calculated hazard.

REFERENCES

Awad, G.H., Faris, M.I., and Abbas, H.L.; 1953: Contribution to the the stratigraphy of the Mokattam area east of Cairo. Extrait Bull. Inst.Desert D'Egypte 3(2),3.

Bachmann H.; 2003: Seismic Conceptual Design of Buildings – Basic Principles for engineers, architects, building owners, and authorities, Swiss Federal Office for Water and Geology Brotbeck Corporate Design, Beil, Switzerland.

Cuvillier, J.C.; 1927: A conglomerate in the Nummulitic formation of Gebel Mokattam near Cairo.Geol. Mag.London 64, 522-523.

Cuvillier, J.C.; 1927: Revision du nummulitique Egyptien. Mem. Inst. Egypt 16, le Caire.

El-Shazly, E.M., El-Ghawaby M.A., Salman, A.B., Khawask, S.M., El-Amin, H., El-Rakiaby, M., El-Assay,I.E., Abdel Megid, A.A. and Mansour, S.L.; 1980: Geological map of Egypt. Remote Sensing Center, Academy of Scientific Research and Technology, Cairo, Egypt.

Farag, I.A.M., and Ismail, M.M.; 1959: A contribution to the stratigraphy of the Wadi Hof area (northwest of Helwan).Bull.Fac.Sci.Cairo Univ. 34, 147-168.

IAEA, 1979: "Earthquakes and associated topics in relation to nuclear power plant siting". Safety series No.50-SG-S1, IAEA, Vienna.

Khaled K. And Hays W.; 2003: "Analysis of vulnerability" workshop on living with risk: hazards, insurance and sustainability in the Mediterranean region. Egypt-Cairo 6-11 Dec.,2003.

NRIAG, 2003: "egyptian seismological bulltein". Issued by National Research Institute of Astronomy and Geophysics, Vol.III

Cornell, C.A.; 1968: "Engineering seismic risk analysis.,Bull. Seismol. Soc. Am., vol.58, 1583-1606.

Reiter L.; 1991: Earthquake hazard analysis., Columbia University Press, New York.

Swedan, A.H.; 1991: A note on geology of Greater Cairo area. Survey of Egypt, Ann. Geol. Survey Egypt 17,239-251.

World Meteorological Organization; 2006: Comprehensive risk assessment for natural hazards, WMO/TD No.955, Switzerland.

Zittel, A.K.; 1883: Beitrage zur geologie and paleontologie der Lybischen Wuste and der angrenzenden gebiete.Paleotographica 30(1)1-12.