Updating Seismic Hazard Approach: Application to New Metropolitan Area

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SUMMARY
In this contribution, updating seismic hazard procedure is used to estimate seismic hazard at new metropolitan area at Aswan, Egypt. Seismic activity on Aswan area, which includes five active faults named Kalabsh, Seiyal, Gabal El-Barqa, Kurkr, and Khor El-Ramla fault system, has increased during the last decades with many strong events. These earthquakes resulted in major stress-drops on the western side of the Naser Lake. These fault segments were recently explored using bathymetric and reflection surveys. These recent findings helped to reshape the seismotectonic environment of the Aawan area which is a perplexing tectonic domain. Based on collected new information, seismic hazard of the Aswan region, particularly new Aswan metropolitan area and its vicinity were re-examined using a probabilistic and deterministic approaches. Alternate seismic source and magnitude-frequency relations combined with various indigenous and “foreign” attenuation relationships were adapted within a logic tree formulation to quantify and project the regional exposure on a set of hazard curves. The hazard curves show the peak horizontal ground acceleration and spectral acceleration at PGA, 0.1, 2.0, and 4.0 sec. These acceleration levels were computed for 2%, 5% and 10% probabilities of being exceeded in 50 years. Applying the deterministic approach, the ground motion was calculated at 50th, 84th percentile levels for the largest effective earthquake from nearest seismic source. Finally, the 5%, 10% and 20% damping median response spectra are provided for Aswan new city site based upon a stochastic simulation technique and on borrowed attenuation relationships.

Key words: probabilistic, deterministic and stochastic approaches, new Aswan metropolitan area

1. INTRODUCTION

In the last decade, a number of new urban communities and new cities have been constructed in successive generations in Egypt and others still under construction. The Egyptian Government decided to construct new urban settlements along Upper Egypt to develop all over the areas in south. These new communities aim to extend the density housing population concentrated in and around the Nile Valley, away from this narrow zone. In the current work, the light will be throw on one example of such newborn cities (Aswan new city) to supply all the seismological, and engineering information required for construction process. The area in which the site of interest was undertaken extends from latitudes 24.17 to 24.22 N and longitudes 32.84 to 32.86 E which is mainly located in the north south of Naser Lake (Fig 1.1). The site is a small part of the south Western Desert. The site of the city is about 10 km to the north of Aswan city on the western bank of Nile River. The area is about 5 km^2 bounded by the river at its eastern edge. The western parts are the highest with elevation around 160 m. The elevation decreases eastward to be about 130 m at its eastern part representing the eastern scarp which is higher and sharper than other scarps in the middle and to the west of the city. The new urban settlements must have zones for heavy industry besides the normal living houses. Unfortunately, serious problems have been took place in the building foundations such as cracks in the concrete, tilting of tall buildings, differential subsidence and the possibility of soil liquefaction under heavy buildings. These problems are related to the dynamic characteristics and the subsurface geologic features of the foundation beds at the areas of these cities. So, in the present research, a study of seismicity and seismic hazard assessment of one proposed new urban community in Upper Egypt that will be managed by Egyptian Government to construct in the future will be done to reduce and avoid all the above problems.

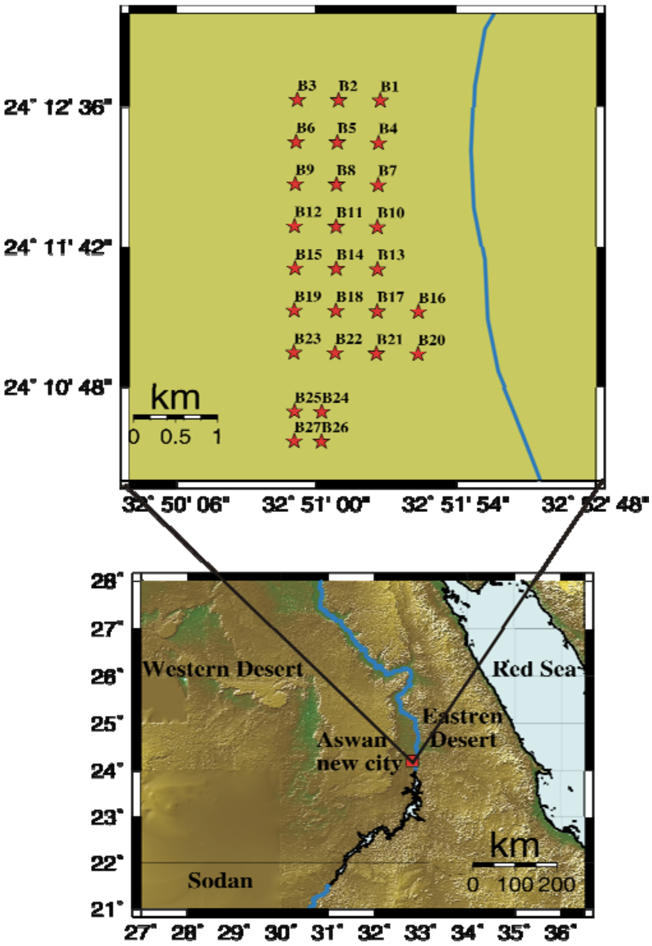

Figure 1.1. Location map of the studied area. The red stars in upper panel map indicate to boreholes.

In this paper, Seismic hazard analyses were conducted in detail in the new Aswan city. The objective was to evaluate the probability of exceedance for different levels of ground shaking not only due to earthquakes that may occur naturally but also due to earthquakes that may be triggered by the High Dam reservoir. The probability, deterministic and stochastic approaches are used to assess the seismic hazard of the study area.

2. METHODOLOGY

Seismic hazard assessment in the area of interest has been estimated by using the probabilistic and deterministic seismic hazard approaches followed by a stochastic simulation method for the most effective earthquake to the city. The probabilistic seismic hazard assessment (PSHA) is conducted because it is widely considered as seismology's most valuable contribution to earthquake hazard assessment (Reiter 1991; Bommer *et al.* 2004). The PSHA was first introduced by Cornell (1968) and has since then been widely adopted and modified. This technique uses the widest possible amount of data, combining seismological, geological and geophysical data to build up a model of the earthquake producing processes. The probability that the value Z will be exceeded within t years is given by the equation:

$$P_t(z) = \sum_{j=1}^{k} \int_{m=Mmim}^{m=M\max} P_t(m) \int_{r=R0}^{R\max} P(r)(P(A \geq Z)m, r)dmdr \qquad (2.1)$$

Where m denotes magnitude, r is the distance to the energy source and j is a seismogenic zone. $P_t(m)$ is the probability of occurrence of a magnitude m earthquake in zone j within t years. $P_t(m)$ is determined from equations (2.2). Equation (2.1) is based on the assumption that the random temporal occurrence of the earthquakes in zone j obeys Poisson distribution laws.

$$P_t(m) = 1 - \exp\left[-t/n(m)\right] \tag{2.2}$$

P(r) is the probability that the earthquake of magnitude m in zone j, will occur at a distance r from the analyzed site/geographical point. This probability is derived from the assumption that earthquake epicentres will be uniformly distributed within the area defining the seismogenic zone. There are currently sufficient data to accurately enough quantitatively characterize all linear sources (active faults) in the region. P(A≥Z) is the probability that given the magnitude of the earthquake and the distance to the source, the ground motions A at the site will exceed the level Z. P(A≥Z) is computed under the assumption that the uncertainty is estimating the expected ground acceleration is log normally distributed with a know standard deviation.

The deterministic seismic hazard analysis, in its most commonly used form, defines the seismic source or sources that might have an impact on the site of interest and then assesses the maximum possible earthquake magnitude for each of these sources. By assuming each of these maximum earthquakes to occur at a location that places the earthquake at the minimum possible distance to the site, the ground motion is predicted, mostly, utilizing an empirical attenuation relation. The deterministic calculations estimate ground motions (for the mean and specified fractiles of the ground motion dispersion) corresponding to the largest magnitude occurring on each seismic source at its closest approach to the site of interest. These results can be applied to various types of structural analyses. The stochastic method (Boore 2003) was applied to simulate the ground motion from the effective seismic source. The method employs a stochastic time-domain simulation and also uses general equations from random process theory. The total spectrum of the motion at a site is contributions from earthquake source, path, site, and instrument. In this way, the models easily account for specific situations or for improved information about particular aspects of the model. The general equation that involves all the terms, in the frequency domain, can be written as:

$$Y(Mo, R, f) = E(Mo, f)\, P(R, f)\, G(f)\, I(f) \tag{2.3}$$

where Y (Mo, R, f) is the Fourier amplitude spectrum of ground acceleration as a function of seismic moment and distance, E (Mo, f) is the earthquake source spectrum for a specific seismic moment, and P(R, f) is the path term that models the geometric spreading and the anelastic attenuation effects as a function of hypocentral distance R, and frequency f. The term G(f) accounts for the site effect and the term I(f) is in general, the instrumental transfer function.

3. DATA COLLECTION

The data used in this study includes updating earthquake catalogues, seismic field measurements and bathometric wells. The catalogues of earthquake recording are divided into an incomplete part (historic) and a complete part (instrumental). Instrumental earthquakes during the period 1900 to 2011 were collected from Mamoun et al. 1984, International Seismological Center Bulletin (ISC) (http://www.isc.ac.uk/), Preliminary Determination of Epicenters, online bulletin provided by the National Earthquake Information Center (NEIC) for the period from 1900 to 2007 (http://earthquake.usgs.gov/earthquakes/), Aswan seismic Bulletin, Egyptian Research Institute of Astronomy and Geophysics (NRIAG 2011) and Bulletins of the Egyptian National Seismic Network for events which occurred after 1997 in Egypt and its surrounding and the catalogue provided by the Aswan Regional Seismic Center starting from 1982. Additionally, published data on historical earthquakes was also considered (Ambraseys 2001; Ambraseys et al. 1994). The complete part of the catalogue can be subdivided into two groups. The first group (having a magnitude ≥4) covers the time interval from 1st December 1900 to 31 December 1980. The second group (with a magnitude threshold of 3.0) covers the time interval from 1 January 1981 to 31 December 2010. Since earthquakes with small magnitude can be neglected in the context of the present study, our analysis was limited to earthquakes with magnitude ≥3.0. All event magnitudes contained in both these sub-catalogues are in *Mw* scale. To ensure the homogeneity of the catalogue, all events for which moment magnitudes (*Mw*) were not reported were converted into this scale. The standard deviations on the two groups were assumed to be 0.11 and 0.25, respectively. Seismic data were collected for a region encircling within 300 km from the Aswan new city according to the geological setting, fault pattern space distribution, and seismotectonic studies of the region.

The Egyptian Geological Survey and Mining Authority (EGSMA 1991) had carried 50 vertical electrical soundings, 50 shallow seismic refraction profiles at Aswan new city site to explore a depth down to 50 m, and also a detailed geomagnetic study. In addition, 27 boreholes were drilled by the Engineering Consulting Center (BK 1994) to depths ranging from 10 to 20 m for defining the soil lithology and its different physical and engineering characteristics (Fig 1.1). We used all the available compiled field measurements data in our study to determine the geotechnical parameters of soil and bedrock at the study area.

4. TECTONIC SETTING AND SEISMICITY MODEL

The most important tectonic features in the study area are the Red Sea and the faults, which can be divided into three groups, Eastern Desert, Western Desert and Aswan faults. According to the spatial distribution of earthquakes that were located in and around the study area. Aswan zone is the closest and most hazardous zone. Ambraseys et al. (1994) showed no historical earthquakes in this area. Maamoun et al. (1984) showed two historical earthquakes with epicentral intensity VII almost at the same location of the 1981 earthquake. These two events occurred in 1210 BC and in 1854. The seismicity around the Aswan area shows a close association with the known faults, (Fig 4.1). This activity is limited primarily to the upper 25 km of the Earth's crust.

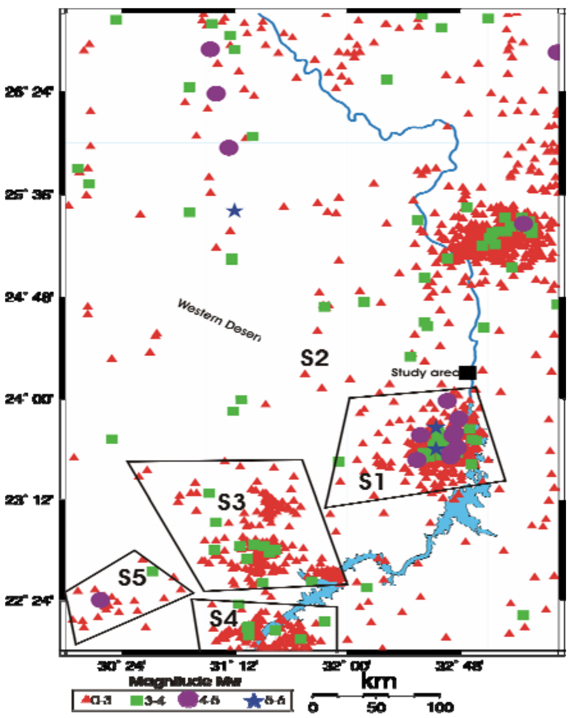

Figure 4.1. Western Desert seismic sources around Aswan new city. Five seismic sources were identified.

After the installation of the Egyptian National Seismic Network (ENSN) in 1997, many new regions with microseismic activity appeared. Among those is the microseismic activity in the southeastern part of the Eastern Desert (Fig 4.2). We divided the Red sea and Eastren Desert into 10 seismic sources as shown in Fig 4.2. The definition of the seismic zones in this area is based on the seismicity distribution and the change in the rate of the seismic activity.

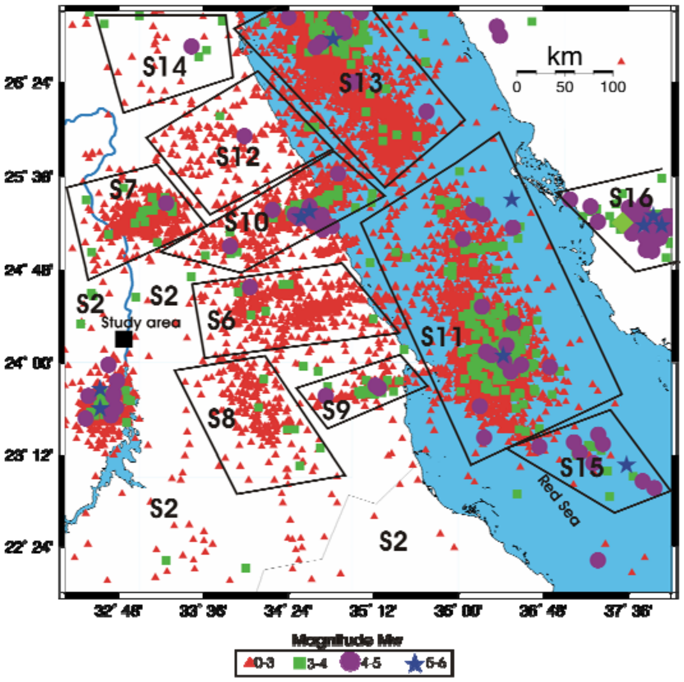

Figure 4.2. Eastern Desert and Red Sea seismic sources around Aswan new city

The seismotectonic settings around Aswan strongly suggest that medium to large earthquakes are possible, particularly along the Kalabsha, Gabal El-Barqa, Abu Derwa, Gazell, Kurkur, Khor El-Ramla and Seiyal faults (Fig 4.3). On 14 November 1981 an earthquake of magnitude *M*W = 5.3 occurred southwest of the Aswan city on E–W Kalabsha fault. Detailed investigations of the regional seismicity, nearby faults and the significance of the identified faults on the Aswan area were started directly after the occurrence of the 1981 earthquake by Woodward Clyde Consultants (WCC 1985) and a final report was submitted in 1985.

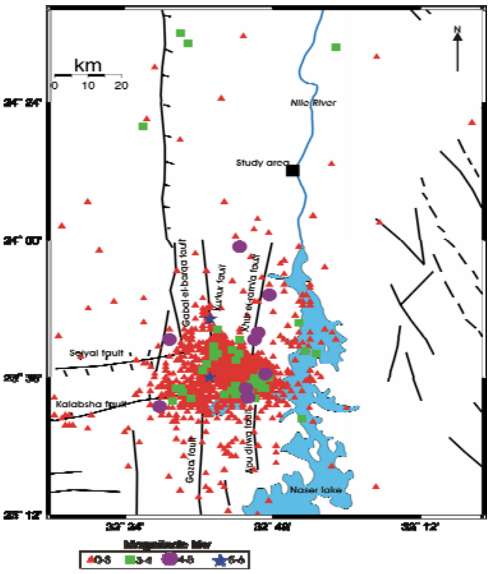

Figure 4.3. Line source model LSM around Aswan new city. Six effective faults were determined.

WCC (1985) estimated the maximum magnitude for the defined significant faults. Based upon the evaluation of the scarp features of the Kalabsha fault the maximum earthquake that was geologically recorded on the fault was interpreted to have a magnitude of Ms = 7.0. Due to the similarity between the Seiyal and Kalabsha faults, WCC (1985) judged the Seiyal fault to have a maximum magnitude of Ms = 7.0. The Gabal El-Barqa fault is the most prominent of the three significant north–south trending faults (Gabal El- Barqa, Kurkur, Khur El-Ramla). Two alternatives and competing seismic source models are proposed for the Aswan area to account for the probable epistemic uncertainty. The first model is the area source model ASM for natural and reservoir-induced seismicity includes 16 seismic sources as shown in Figs 4.1 and 4.2. The second model is the Line source model LSM which includes Seiyal fault, Kalabsha fault, El-Barqa fault, Kurkur fault and Khor El-Ramla fault (Fig 4.3).

5. RECURRENCE PARAMETERS ESTIMATION

Recurrence earthquakes are formulas relating the frequency of occurrence and the size parameter of the seismic event. The seismicity of a seismogenic zone is quantified in terms of the recurrence relationship

$$\log N(M) = a - bM, \qquad (5.1)$$

where N is the number of earthquakes of magnitude M or greater per unit time. The a value is the activity and defines the intercept of the above recurrence relationship (Gutenberg and Richter 1944) at M equals zero. The number of occurrences per year of a hazardous event (e.g. the annual frequency that the ground-motion parameter, X, at a site exceeds a specified value x) is defined as the annual frequency. The parameter b is the slope, which defines the relative proportion of small and large earthquakes. The methods available for estimating M_{max} can be classified according to four procedures: 1) in the case of the presence of paleoseismological studies, the results of these studies indicate the maximum magnitude; 2) when the seismic history is available, the maximum magnitude is estimated using the statistical procedure proposed by Kijko (2004); 3) when consistent data regarding fault type and its total length were available, it is assumed that portions from 20% to 40% of the total fault length could rupture in one earthquake and then the maximum magnitude is estimated; 4) in any remaining case, the maximum magnitude is estimated by adding 0.5 magnitude unit to the largest known magnitude in the zone. In this study, the procedures 3 and 4 have been used for estimating the maximum magnitude M_{max} for each seismic zone and fault. The maximum magnitude of the fault zones and area zones with known relationship to active faults were calculated based upon the expected rupture areas using the empirical relationships of Hanks and Bakun (2002). The full list of the identified seismic sources with their main characteristics is given in Table 5.1.

6. ACCELERATION ATTENUATION MODEL

Seismic hazards studies required the prediction of strong motion from earthquakes that pose a potential threat to public, either by injury or damage to property. Once the earthquake distributions have been calculated, the attenuation relationships are used to estimate the ground motion. Ideally, it is preferable to use a ground-motion scaling relationship derived from local data, but this is seldom possible except in regions of dense station coverage and high seismicity such as Japan and California. In view of lack of ground-motion acceleration records in Aswan makes it necessary to apply already developed ground-motion scaling relationships. Aleatory variability and epistemic uncertainty are terms used in seismic hazard analysis that are not commonly used in other fields, but the concepts are well known. In this study, the epistemic uncertainties are treated by taking alternatives for the ground motion attenuation relationships, which in turn implicate several different estimates of the ground motion. In total, three different ground motion models were considered following the guidelines proposed by Cotton et al. (2006). All of these models have been used extensively in hazard analysis throughout the world. These three attenuation models were taken for earthquake occurring within active shallow crustal zones. The ground motion models used for the active shallow crust zones are

Abrahamson and Silva (1997) and Campbell and Bozorgnia (2003) and Boore et al. (1997). We use equal weight for both ground motion models (i.e 50% for each equation) in seismic hazard schemes. All of these models were incorporated within a logic-tree framework.

Table 5.1. The identified seismic sources with their main characteristics.

Source Model	Region	Seismic Source	M_{max}	M_{min}	a	b	beta	Activity rate
ASM	Western Desert	S1	7.0	2.5	3.4	1.08	2.48	0.45
		S2	6.5	2.0	2.7	0.70	1.61	0.33
		S3	4.5	2.0	3.1	1.2	2.76	0.43
		S4	4.2	2.5	3.2	1.21	2.79	0.42
		S5	4.3	2.5	3.0	0.8	1.84	0.30
	Eastern Desert and Red Sea	S6	5.0	2.5	2.4	1.0	2.30	0.50
		S7	5.9	2.5	2.5	1.1	2.53	0.48
		S8	4.7	2.0	2.0	0.9	2.07	0.40
		S9	5.5	2.5	2.3	1.04	2.39	0.39
		S10	6.5	2.5	3.5	1.2	2.76	0.66
		S11	7.0	3.0	4.0	1.23	2.83	0.70
		S12	5.1	2.0	2.3	0.92	2.11	0.45
		S13	7.0	3.0	3.5	1.2	2.76	0.80
		S14	5.0	2.0	2.2	0.82	1.88	0.40
		S15	7.0	3.0	3.4	1.0	2.30	0.50
		S16	6.5	3.0	2.5	1.02	2.34	0.42
LSM	Faults around Aswan	Kalabsha	6.8	2.5	2.6	1.09	2.50	0.55
		Seiyal	6.5	2.5	2.2	1.07	2.46	0.51
		Khor El-Ramla	6.0	2.5	2.5	1.08	2.48	0.52
		Kurkur	6.1	2.5	1.7	1.08	2.48	0.50
		Gabal El-Barqa	6.3	2.5	2.4	1.09	2.50	0.51
		Abu Derwa	5.9	2.5	1.7	1.08	2.48	0.50

7. SEISMIC HAZARD ESTIMATION

Estimation of seismic hazard at Aswan new city was carried out using updating probabilistic, deterministic and simulation techniques as follow:

7.1. Probabilistic Hazard Estimation

In the current study, the probabilistic hazard approach (PSHA) is done applying EZ-frisk 7.52 software. The stochastic model used in this routine assumes that the generation of earthquakes in the time domain follows a homogenous Poisson process. EZ-frisk program allows the variability of the source boundaries and attenuation of ground motion. Uncertainties due to this variability were taken into consideration. Employing the same parameters and assumptions, hazard curves were calculated for the selected 27 site representing location of boreholes at Aswan new city. The uniform hazard spectrum (UHS) at Aswan new city is obtained by computing the hazard at a suite of spectral periods using response spectral attenuation relationships. The UHS for the site of borehole 14 (B14) is shown in Fig 7.1.

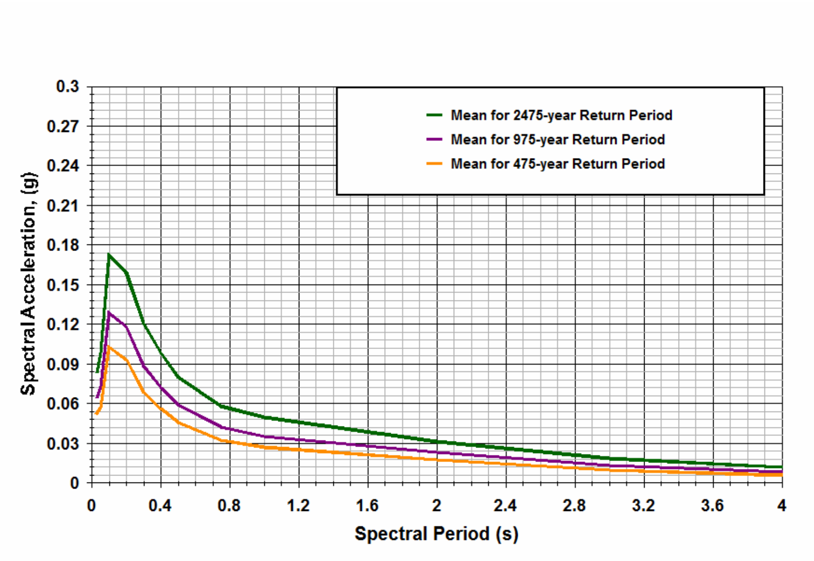

Figure 7.1. Uniform hazard spectra at site of borehole no 14 (B14). Hazard was calculated at 3 return periods.

7.2. Deterministic Hazard Estimation

Deterministic seismic hazard analysis (DSHA) requires definition of seismic sources and their distance from the site. The seismic sources and active faults in the area are identified and a maximum magnitude is assigned to each of the seismic sources and faults. The ground motion is then calculated using appropriate attenuation relationships for deterministic analysis. The deterministic approach is essentially based on the worst case scenario. The worst case scenario of Aswan new city site is of a maximum magnitude 6.5 earthquake occurring within an epicentral distance of 10 km with 10 km depth. The effect of this event was calculated at site of borehole no 14 (B14) and is expressed in terms of acceleration response spectrum. Fig 7.2 shows the 5% damping for the median value of horizontal acceleration response spectra at site of borehole no 14 (B14). The spectrum was calculated over the period range of 0.01–10 s. The ground motion was calculated at 50th percentile levels for the median peak ground acceleration.

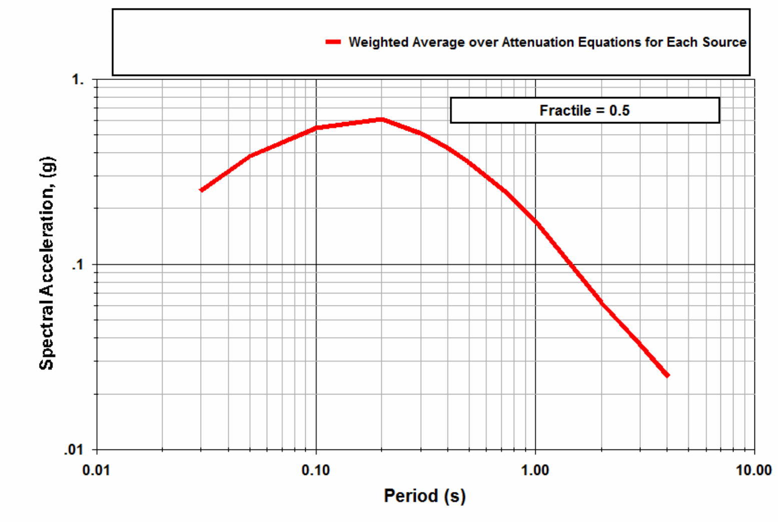

Figure 7.2. The median value of horizontal acceleration response spectra at site of borehole no 14 (B14).

7.3. Synthetic Seismogram of Largest Effective Earthquake

Evaluation of the seismic hazard at the investigated site requires the prediction of the strong ground motion that will be generated by the potentially dangerous earthquakes. For the area having limited seismic record, synthetic ground motion models is the alternative (as the study area lacks ground motion records). The seismological model by Boore (2003) is used for generation of synthetic acceleration-time response (Atkinson and Boore, 1995). This technique is known as the stochastic simulation of high frequency shear wave ground motion (Boore 2003). For more comprehensive summary about the method, refer to the work of (Boore 2003; Abd El-Aal 2008, 2010a, 2010b). Representative examples of the predicted time histories from largest expected earthquake at the surface at the location of borehole no 14 (B14) are shown in Fig 7.3. The response spectra (5%, 10% and 20% damped pseudo-acceleration) were simulated for the largest expected earthquake at B14 site in the area (Fig 7.4).

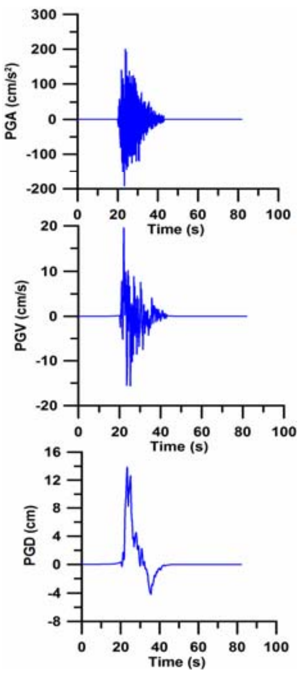

Figure 7.3. Time history of expected largest earthquake.

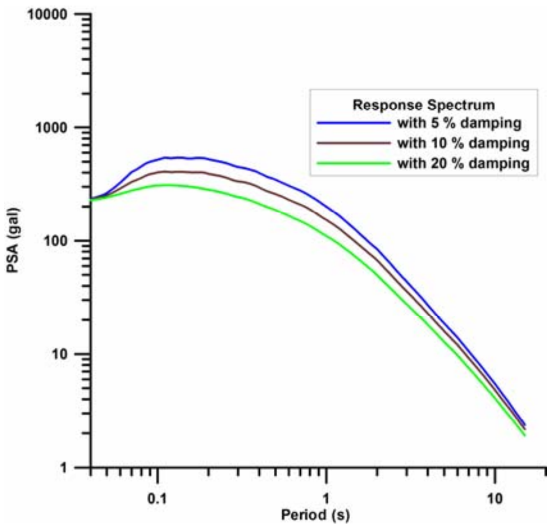

Figure 7.4. The PSA predicted at site B14.

8. DISCUSSION AND CONCLUSION

The aim of this study is to highlight the degree of hazards related to the earthquake activities associated with Aswan new city, in terms of speculating the possible future potentially damaging earthquakes. For this purpose, we presented and discussed a proposed seismic hazard assessment at site of Aswan new city that is based on spectral parameters. The proposed seismic hazard approach includes updating probabilistic, deterministic and stochastic hazard analysis. The PSHA build upon extensive research and database compilation. Uncertainty analyses have been incorporated in the seismic hazard model using a logic-tree framework. Progress was made in particular by using both the historical and instrumental earthquake database which is converted to a uniform moment magnitude scale. We used the new zoning, which takes into account an improved understanding of the seismotectonic framework of the region. On the other hand, to assess the seismic hazard in quantitative evaluation, we used a deterministic seismic approach followed by a stochastic PGA simulation. The deterministic seismic hazard assessment provides a quantitative evaluation of the nature of ground shaking in the investigated area that could be induced by future maximum earthquakes, in order to provide the engineers and planners with complete information on which they must base their decisions**.** There are similarities between computed amplitudes of ground motion in terms of their values and spatial distributions. The results obtained from the deterministic and stochastic approaches are comparable but higher than those obtained by probabilistic approach, this due to site effect and amplification factors on the ground motion are involved in case of deterministic and stochastic approaches. Moreover the deterministic approach uses a "conservative" earthquake magnitude at a closest distance which leads to a considerable increasing in their obtained values.

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