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Original article

Seismic hazard assessment for the proposed site of electric power plant: Comprehensive approach

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ABSTRACT

Al-Sokhna area has been selected for installation one of the electric power plants along the Cairo-Suez Road. Unfortunately, this area lies within small-moderate seismicity area where some destructive earthquakes (>5), great number of earthquakes with magnitudes of less than 5 have been recorded. Through this work, earthquake events within a circle of 300 km radius around the selected site have been gathered, refined, and the affecting earthquake prone zones were recognized as; southern Gulf of Suez, Dahshour and Gulf of Aqaba source, Beni Suef and Sohag-Assuit zones however Dahshour zone is the nearest to the proposed site. The values of Peak Ground Acceleration have been assessed using deterministic and stochastic hazard approaches as 37.63 and 38.4 cm/sec^2 respectively. Moreover, the pseudospectral acceleration (PSA) reaches 142, 96 and 74 cm/sec^2 at damping values of 2%, 5% and 10% of the critical damping where the predominant period about 0.1 s at the selected site. These results have to be considered by policy and decision-makers to design more earthquake resistant structures at the selected site.

1. Introduction

Earthquakes affecting all human-beings and facilities where their impact could be heavily aggravated. Accordingly, the higher safety levels for critical facilities against earthquake hazardous effects is of utmost importance for properly designed against the earthquake threat. Several studies have been applied world-wide to assess the hazard potential for the power stations (Liu et al., 2004; Salman and Li, 2017; Omidvar et al., 2017; Katona and Vilimi, 2017; Hossain et al., 2018; Jamil et al., 2019; Ziggy et al., 2019).

Recently, Egypt has a great expanding economical and industrial plan that are, in turn, dependent on the availability of reliable, low-cost and sustainable electric power. In order to meet the forecasted demand, the Ministry of Electricity & Energy (MEE) estimates that an additional 19,000 MWe of new generating capacity will be required during the next ten years. In order to achieve the highest levels of safety for these stations, the government recommended earthquake hazard assessment for these areas and take it into account for designing these stations. Then, this study aims to assess the earthquake hazard at Al-Sokhna Power Plant station through deterministic and stochastic approaches.

Al-Sokhna Power Plant is situated on the northwestern coastal zone of the Gulf of Suez (Fig. 1). The site belongs to the great developing industrial zone about 1-km south of the Al-Sokhna marine Port which is a major commercial harbor facility along the Gulf of Suez.

2. Seismicity and seismotectonics of Al-Sokhna area

The earthquake catalogue is the focal point for earthquake hazard assessment. The available earthquake catalogue for the proposed site includes the historical observations (pre-1900) of events that occurred over a period of about 4000 years and comprehensive instrumental data for different magnitude ranges. The earthquakes data from 1900-July 2020 have been collected from Maamoun et al. (1984), Ambraseys et al. (1994) and International Seismological Center (ISC) as well as the bulletins of the Egyptian National Seismic Network (ENSN). Fig. 2 represents the distribution of the earthquake activity around the site of interest within 300 km. There are great number of earthquakes with magnitude < 3 recorded close to the site. In addition, there are various earthquakes with magnitude ranges from 3 to 4.9 occurred around the

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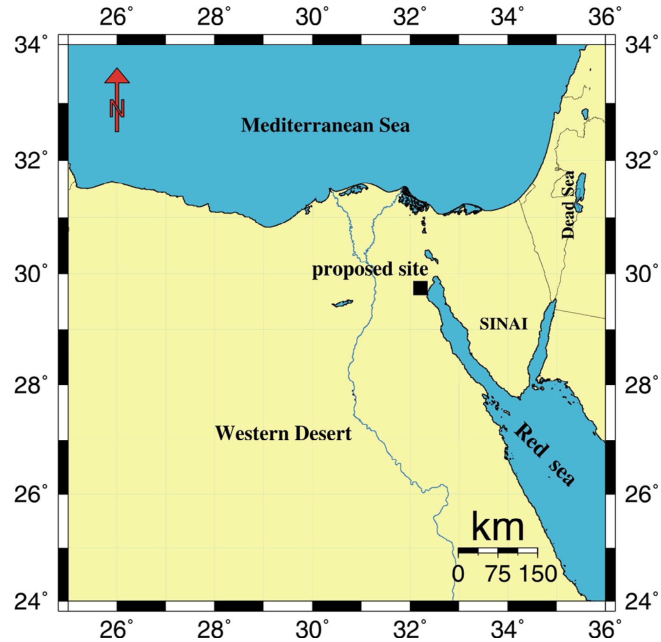

Fig. 1. Location map of Al-Sokhna Power Plant proposed site.

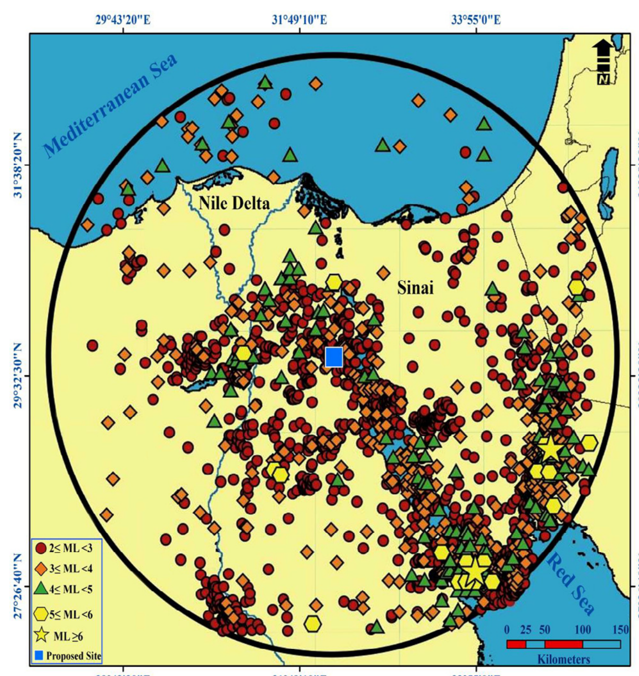

Fig. 2. Seismicity of 300-Km circle around Al-Sokhna site.

site, while the site is affected via earthquakes with magnitudes greater than 5.

The distribution of small-moderate to large earthquakes approve the closed relationship between earthquake activity tends and seismically active belts and trends (Abdel-Rahman et al., 2009; Abdelrahman et al., 2017). Based upon the spatial distribution of earthquakes, major tectonic trends in northern Egypt (Fig. 3, Modified after Barazangi et al., 1993; Salamon et al., 1996; Guiraud and Bosworth, 1999; Abdel Aal et al., 2000; Gamal, 2013), maximum possible or expected earthquake, maximum expected acceleration, present day stress, and correlation of earthquake epicenters with

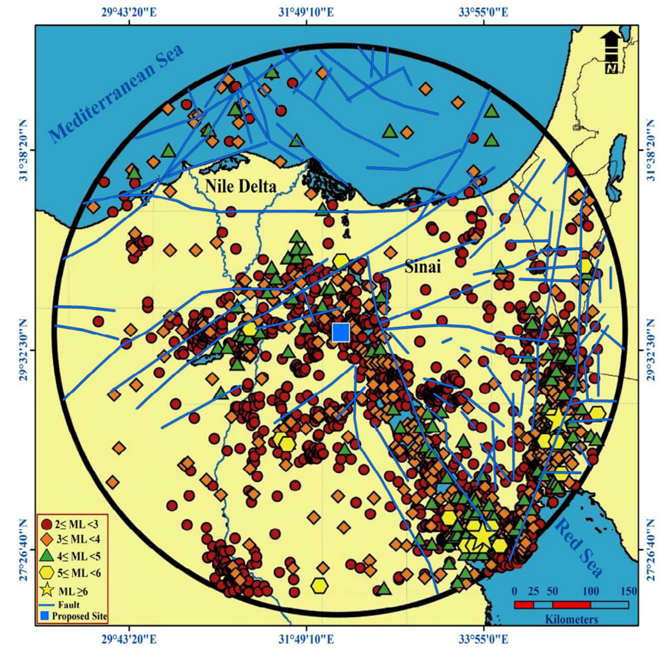

Fig. 3. Seismotectonics of Al-Sokhna area within a circle of 300 km radius around the site, the tectonics modified after Barazangi et al., 1993; Salamon et al., 1996; Guiraud and Bosworth, 1999; Abdel Aal et al., 2000; Gamal, 2013).

the tectonic data, the seismic sources of the area around the site of interest are defined as; Gulf of Suez and Eastern Desert source, Gulf of Aqaba, Southwest Cairo (Dahshour) seismogenic source, Beni Suef seismogenic source and Sohag-Assuit source. These areas have special seismotectonic characterizations than the rest areas of Egypt (Fig. 4).

3. Seismic hazard assessment

3.1. Deterministic seismic hazard approach

There are certain published relationships are applied globally based on the fault rupture length (L). Deif and Ali (2001) found such relation to be represented by the following equation:

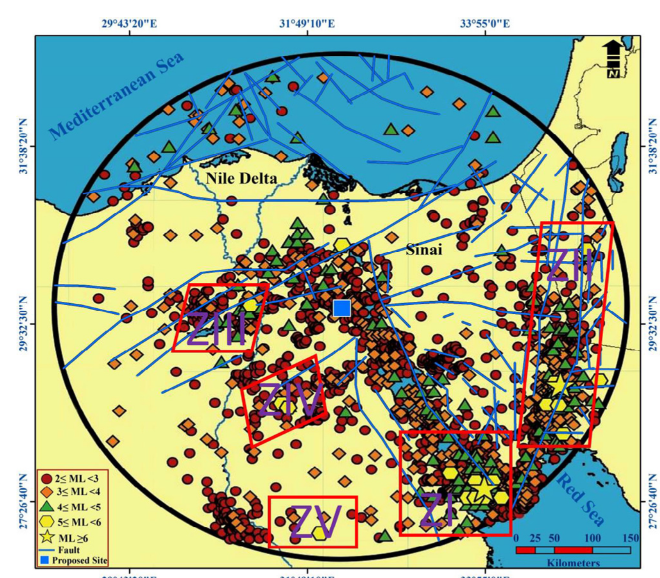

Fig. 4. The identified seismotectonic source zones affecting the Power Plant.

$$\text{Log}\,(M_o) = 2.8348\,\log\,(L) + 12.3836 \quad (1)$$

Based on the tectonic setting prevailing at the selected site (Fig. 3) it has been noticed that the site of interest located along active faults which should be taken into consideration during the establishment of construction facilities at the site; 2) Another accepted approach based on the increasing of magnitude of the historical earthquake with 0.5 to estimate the maximum earthquake. This technique is applicable, mostly, in the regions where their fault information is inattentive.

The results of the above methods are expressed in terms of maximum expected seismic moment. The resultant maximum seismic moment could be transferred to the surface wave magnitude values using the following relationship:

$$Log(M_o) = 1.44(\pm 0.051)Ms + 16.375(\pm 0.293) \quad (2)$$

3.1.1. Maximum earthquake magnitude calculation

The identified seismotectonic zones have different levels of seismic activity. Southwestern of Cairo seismic zone initiated the most hazardous earthquake in the twentieth century in October 12, 1992 with seismic moment magnitude 5.8. The maximum instrumentally observed magnitude in the Eastern Desert zone was 5.0 at Abu-Hammad region. By integration of Eqs. (1) and (2), the maximum surface wave magnitude (*Ms*) of this zone is 6.31. The historical technique is used for the rest of seismic sources (Table 2). Depending on this table, Dahshour source zone represents the nearest source for earthquakes to the site of interest.

3.1.2. Maximum possible acceleration at the proposed site

It is found that the seismic source of the southern southwest Cairo is expected to be the most hazardous one on the site of Power Plant. The maximum earthquake hazard based on the peak ground acceleration at the selected site is found to be 37.63 cm/sec^2 resulting due to earthquake with magnitude 6.31 occurrence at distances (R) of 105.527 km at Dahshour area using the attenuation model defined by Abdel-Rahman (1999).

$$\text{Log}(a) = -0.4499\text{Ln}(R + 25) + 0.436Ms + 1.013 \quad (3)$$

Accordingly, Dahshour source zone has the most hazardous effect for the selected site.

3.2. Stochastic simulation of ground motion

The synthetic ground motion model by Boore (1986), Boore (2003) [SMSIM-program] was used to determine rock level Peak Ground Acceleration (PGA) and to generate a synthetic acceleration-time history (Atkinson and Boore 1995). The value of stress drop taken as 30 bars for PGA calculations of the selected site. The whole-path attenuation is governed by the frequency dependent quality factor Q. Geometrical spreading factor is $1/r$ for r < 100 km and equal to $1/10\,\sqrt{r}$ for r > 100 km, where, r is the hypocentral distance.

Distance dependent duration, which is a function of the path as well as the source, is given by

$$T = 1/fc + br \quad (4)$$

where, the first part $1/fc$ is the source duration and the second part are a distance dependent term that accounts for dispersion. The value of b was taken to be 0.05.

The shear wave velocity models to 30 m depth (Vs30) for equivalent rock-type sites with density used from four boreholes drilled in this study (Fig. 1). From these data, the average shear wave velocity was estimated at each site. Site amplification [A(f)] at the assumed engineering rock level was determined using quarter-wavelength method.

Where Vs30 represents the average shear wave velocity at each site, the average kappa factor for the rock site in the compensated district was obtained as 0.019. In the scaling factor, a reduction factor (H) of 0.71 was taken to represent the partitioning of the S-wave energy into two horizontal components. For radiation pattern ($R\vartheta\phi$) a value of 0.55 was used (Atkinson and Boore, 1995).

Based on the soil classification at the site of interest as alluvial sediments, the amplification factor at this site will be 3.9 (Borcherdt and Gibbs, 1976). The parameters of sedimentary section through shear wave velocity profiles where, four boreholes have been drilled through the study area (Table 1). The weighted shear-wave velocities were computed according to the following formula:

$$V_{s(av)} \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{v_{si}}} \quad (5)$$

where d_i and V_{Si} denote the thickness (in meters) and the shear-wave velocity (in m/s) of the *i-th* layer, in a total of n layers, existing in the same type of stratum (d_i and V_{Si} were determined by borehole measurements).

The amplification factor is calculated based on the following equation (Midoricawa, 1987) and (TC4, 1999); $A = 68.\ Vs^{-0.6}$. While Borcherdt et al. (1991) show a strong correlation between shear wave velocity and Average Horizontal Spectral Amplification (AHSA) as $AHSA = 701/V_s$ where, Vs is the local shear wave velocity in m/s averaged over the soil profile.

Table 1
Moderate earthquakes in the area of 300 km around site of interest from 1900 to 1/7/2020.

Year	Mon.	Day	Hr.	Min.	Sec.	Long. (E)	Lat. (N)	Depth (km)	Magnitude Mb
1906	12	26	17	45		34.00	27.70	20	5.5
1969	3	8	10	31	54	33.80	27.50	24	5.1
1969	3	24	11	34	14	33.90	27.50	16	5.2
1969	3	24	12	50	51	33.80	27.50	13	5.3
1969	3	31	7	15	54.4	33.90	27.60	20	6.1
1972	6	28	9	49	33	33.80	27.70	15	5.6
1992	10	12	13	9	55.5	31.144	29.78	21	5.9
1993	8	3	12	54	6.3	34.777	28.60	10	5.1
1995	11	22	4	15	11.9	34.799	28.83	10	6.4
1996	2	21	4	59	51.2	34.783	28.80	10	5.1
1999	6	13	4	20	9.7	34.83	28.26	5	5.2
1999	10	5	5	44	33	35.25	28.89	33	5.6
1999	10	11	20	39	34.6	31.51	28.63	28.4	5.1
1999	10	28	15	39	15.8	35.10	30.43	25	5
2000	3	8	14	22	26.3	34.73	28.87	7	5.7
2003	6	4	9	14	49.2	31.97	27.08	10.7	5.1
2006	11	8	4	32	10	31.59	28.58	3	5.2

Table 2
The maximum expected magnitude for different sources.

Seismic Source	Maximum magnitude	Distance to the site (km)
Southern Gulf of Suez	7.34	289.811
Gulf of Aqaba	7.63	270.401
Southwestern Cairo (Dahshour)	6.31	105.527
Beni Suef	5.6	144.051
Sohag-Assuit	5.6	297.097

According to Table 3, it could be concluded that; *Vs(avg)* ranges from 287 to 291 m/s; Amplification factor varies from 2.24 to 2.3 (Midoricawa, 1987 and TC_4, 1999), and from 2.39 to 2.44 (Borcherdt et al., 1991). Both values are correlated well. This in the case of dray soil, but in the case of wet soil the porosity of soil will be increased and shear wave velocity will be decreased with about 30%, and the amplification characteristics may be reach about 3.7.

Table 3
Amplification characteristics for dry and wet soils.

Borehole	In case of Dry soil			In case of Wet soil		
	V_s(average) (m/s)	Relative amplification Midoricawa, 1987	Relative amplification Borcherdt et al. 1991	V_s(average) (m/s)	Relative amplification Midoricawa, 1987	Relative amplification Borcherdt et al. 1991
BH 1–2	291	2.3	2.4	194	2.88	3.6
BH 1–3	287	2.28	2.44	191	2.9	3.7
BH 1–4	296	2.24	2.39	197	2.85	3.6
BH 1–5	290.5	2.26	2.41	193	2.89	3.65

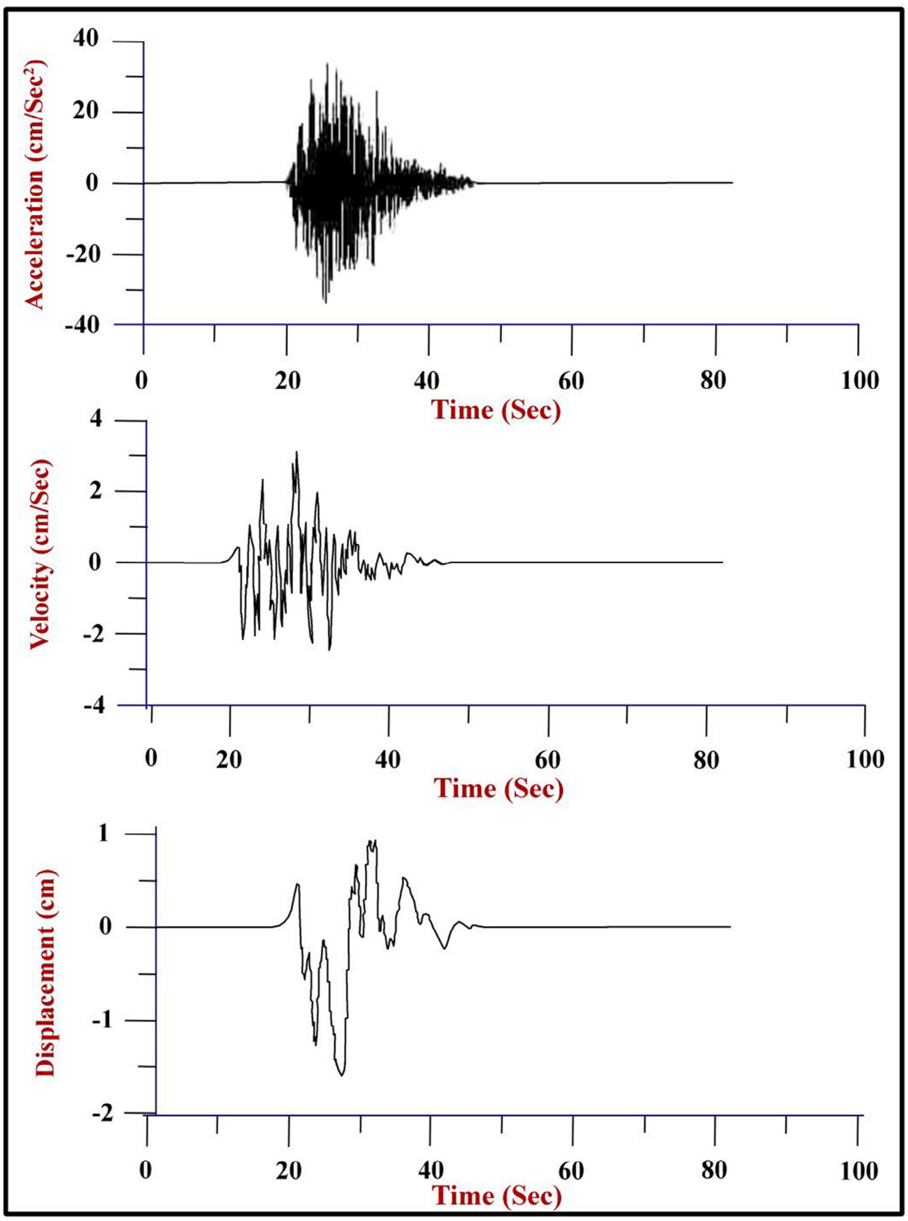

Fig. 5. Simulated time history of the maximum PGA, PGV and PGD at Al-Sokhna Power Plant resulted from Dahshour zone.

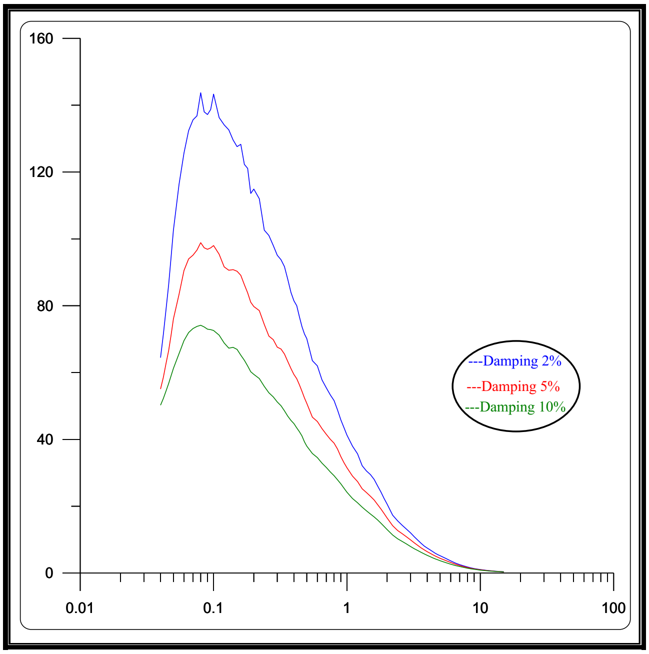

Fig. 6. Response Spectra for Pseudo-Spectral Acceleration at Al Sokhna Power Plant.

PGA has been calculated at four boreholes sites within the proposed site using synthetic ground motion models of earthquakes from Dahshour seismogenic source taken the relative amplification of the soft soil (Table 3) into consideration. The resulted PGA as 38.4 cm/sec^2 (Fig. 5). The ground surface response spectra were determined at 2%, 5% and 10% of critical damping (Fig. 6). According to this figure, it is noticed that the PSA reached 70, 102 and 173 cm/sec^2 at 2%, 5% and 10% of critical damping respectively at 0.1 s fundamental period.

4. Conclusions

Based on the collection of a complete earthquake data set within 300-Km around Al-Sokhna Power Plant it is indicated that the southwest Cairo (Dahshour) seismic source has the largest effect upon the site. The maximum earthquake that may occur in this source is estimated to be with 6.31 moment magnitude. Depending on the deterministic seismic hazard approach, the PGA at the site is found to be 37.63 cm/sec^2 resulting from the occurrence of an earthquake with magnitude 6.31 at distances of 105.5 km. Moreover, the simulated Peak Ground Acceleration equals 38.4 cm/sec^2 at the site of interest. Also, the response spectra are calculated. It is indicated that both of the maximum expected accelerations calculated by the deterministic approach and by the stochastic model are very close to each other which clarifies that both approaches are good of earthquake hazard assessment for sites of the critical value.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jksus.2021.101360.

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