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Strong motion simulation at Abu Zenima city, Gulf of Suez, Egypt

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Abstract Earthquake hazard assessments are an important task for the design of earthquake resistant structures and insurance industry. Such assessments get more importance when the site of interest is located near an active earthquake zone. Such situation is present for the location of Abu Zenima city. The city is characterized by the presence of industrial and Maritime platform in addition to other Oil production facilities. These industrial facilities motivated the present work.

The simulated earthquake ground motion time histories are conducted using stochastic technique. The magnitude used for simulation is obtained using both probabilistic and deterministic approaches. An analysis using both approaches shows that moderate earthquakes in the vicinity of the site could have the largest effects on the area. Thus an earthquake of magnitude 4.5 at a distance of 21 km is chosen as design earthquake.

The simulated ground motions are presented in terms of acceleration, velocity, and displacement time histories. In addition the response spectra are also presented that may be used for engineering purposes.

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1. Introduction

Seismic hazards assessments have become more and more important for the design and building of earthquake resistant

structures. The basic goal of assessment is to define the so called design or credible earthquake (Reiter, 1990), that has the maximum expected ground motion at the site of interest for a certain period of time. Such parameter is obtained following either probabilistic or deterministic approaches (Cornell, 1968; Bender and Perkins, 1987). The definition of the characteristic earthquake of the region enables the evaluation of the maximum peak ground motion (acceleration, velocity, and displacement) together with the response spectra of a single degree of freedom system. These are the necessary parameters for the design of earthquake resistant structures.

The area under investigation is located at a longitude of 29.037°N and longitude of 33.129°E. From the geographic

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point of view the site is located at the shoreline of the Gulf of Suez in an area characterized by the presence of oil fields and industrial facilities (Fig. 1).

Seismically, the Gulf of Suez is considered as the relatively high active region together with the seismicity of the Gulf of Aqaba. The largest recent earthquake to take place in the Gulf of Suez occurred at the entrance of the Gulf on 31st March, 1969, with magnitude M_s of 6.9. Tectonically, the Suez Gulf is subdivided into three basins separated by two NE-SW fault sets. In general each basin is characterized by uplifted and subsided faulted blocks. At the separating faults, the dip of the faulted blocks is reversed. From the distribution of earthquake foci it is readily observed that seismicity at the southern basin is the highest. It is also observed that the seismic activity decreases northward.

The methodology used for hazard assessment throughout this work adopts two approaches; namely the probabilistic and deterministic approaches. The probabilistic approach employs a probability model that evaluates the maximum expected ground acceleration with a probability of 90% not being exceeded in periods of 50, 100, and 500 years. The deterministic approach, on the other hand, evaluates the effects of the largest earthquakes that took place near the site of interest, then choosing the earthquake that produced the largest peak ground acceleration at the site. The design earthquake is thus obtained by adding an increment of 0.5 to its magnitude. The design earthquake is thus used to synthesize the ground acceleration time history and response spectra.

2. Overview on the seismicity and seismotectonics of Egypt

The seismotectonics of Egypt are mainly related to the regional tectonics of the Red Sea and Mediterranean seas. The active tectonic zones were and are still in focus of several seismologists due to the development plans carried out in the country (Maamoun and Ibrahim, 1978; Maamoun et al., 1980; Kebeasy et al., 1981; Ibrahim, 1985; Albert, 1987; Kebeasy, 1990; Degg, 1990; Abu-Elenean, 1993). The space distribution of the epicenters yields a delineation of the active tectonic province as follows:

- (1) Red Sea, Gulf of Suez, province, with evidences of repeated activities along the so-called Clysmic trend.
- (2) Levant-Aqaba trend.
- (3) The Nile delta province between the Pellusic line and Wadi Natrun fault including the Mediterranean Zone.
- (4) Cairo-Fayoum province, where earthquakes are occasionally very damaging.
- (5) Kalabsha-Lake Nasser province.
- (6) East Mediterranean trend.

In addition, other zones with remarkable seismic activity do exist such as Gaghboub-siwa and Gilf Elkebir-Bahariya zones in the Western desert, and Abu dabbab, Hurghada-Wadi Qena and Wadi Hagoul zones in the Eastern desert.

Egypt experienced earthquakes throughout its entire history. Most of the seismic activities occur at the north eastern

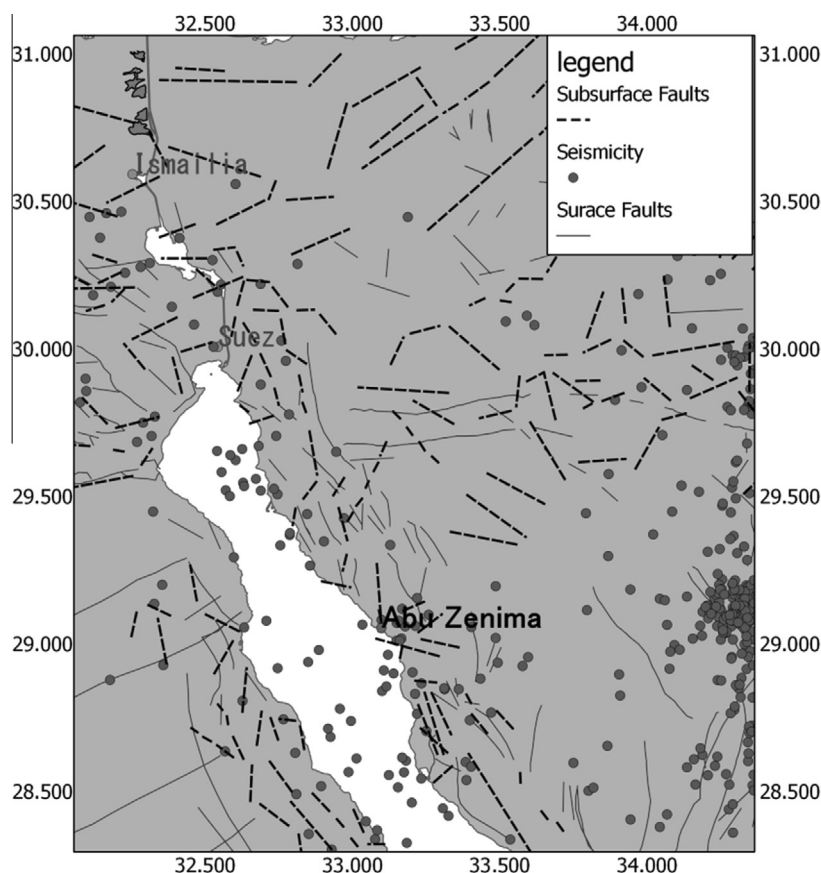


Fig. 1 Location map of Abu Zenima city showing the seismic activities and the distribution surface and subsurface faults.

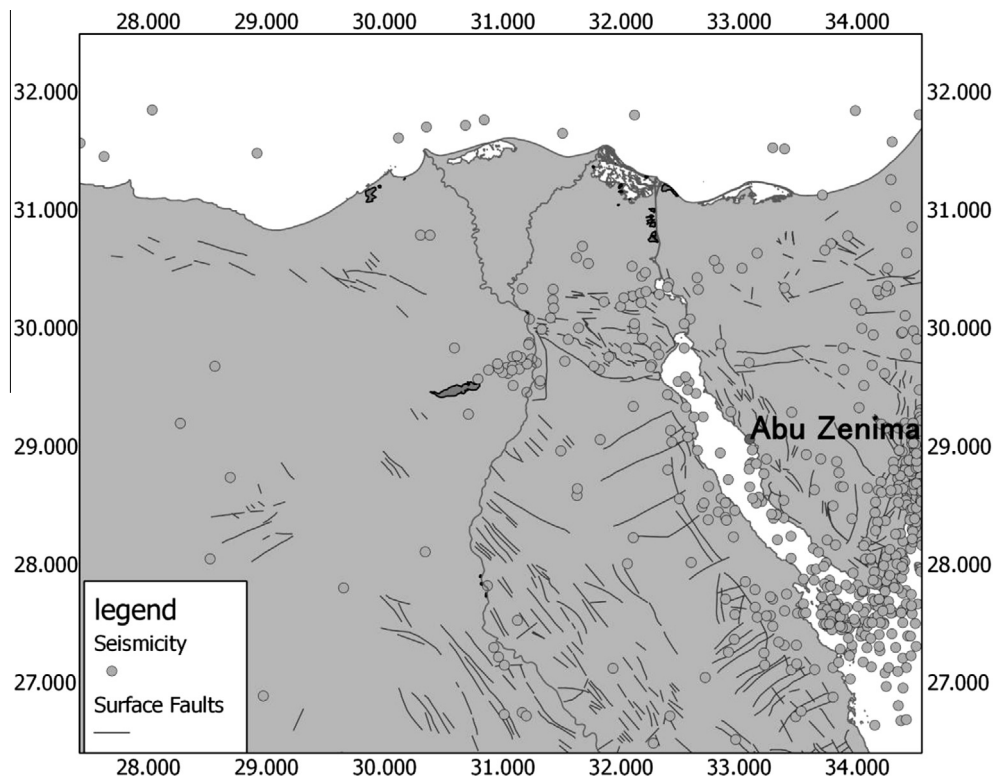


Fig. 2 Map showing the epicenter distribution of instrumental earthquakes and surface faults at lower Egypt.

part of the country. The hottest seismological regions are the Gulf of Suez and the Gulf of Aqaba. At earlier days of the last century, most of the attention was given to the seismic activities of the Gulf of Suez. The interest was initiated by the occurrence of Shedwan earthquake on March 31st, 1969 with a magnitude of 6.9. This earthquake was considered as the largest instrumental earthquake to hit the Egyptian territories till 1995. The location of this event took place at the entrance of the Gulf of Suez near Shedwan island. The damages encountered due to this event were focused on the nearby areas at Hurghada and south Sinai. With this large magnitude, the earthquake was felt at great distances with reported minor damages to old buildings in Cairo. The Gulf of Suez region is still tectonically active as proven from earthquake activities there.

On November 22nd, 1995, the largest ever earthquake shocked the Egyptian territories near the city of Nuweiba at south Sinai. The magnitude of such an event was 7.2. The damages encountered due to this event was restricted to cities in its vicinity namely Nuweiba, Aqaba, Haql, etc. Most of the damages were reported in the neighboring countries. The event was felt all over the region reaching as far as Lebanon.

In addition to the above zones other seismic activities were reported at south west Cairo (Dahshour area), east Cairo (Belbeis, Khankah, and Abu Zaabal), offshore Mediterranean, and isolated seismic activities at Wadi Hagol. The most damaging earthquake that took place in Egypt is the Cairo earthquake in 1992 despite the fact that the magnitude of this event is moderate. The magnitudes of the earthquakes that occur in other places like Belbeis, Abu Zaabal, El Khanka, and Wadi Hagol seldom exceed the magnitude of 4.5.

Other seismic zones are also present but their effects are negligible on the site due to both its long distances and magnitude levels. As an example of such zones are the activities at Aswan and Offshore Mediterranean. The location of the epicenters of the instrumental seismicity is shown in Fig. 2.

In addition to this, the historical data indicate that some events took place at both sharqiya province and east Cairo. The magnitudes of these events are about 5.5 (Khalil, 1998). A map showing the distribution of historical earthquakes in Egypt is shown in Fig. 3.

3. Probabilistic seismic hazard assessment

In this section the probabilistic seismic hazard assessment of the site is reviewed. The method is basically an application of probabilistic model suitable for the distribution of seismic data to determine the maximum expected peak ground acceleration. Usually, the expected peak ground acceleration is predicted with a probability of 90% not being exceeded in a certain period of time.

The calculation conducted here is performed using SEISRISK III software (Bender and Perkins, 1987). SEISRISK assumes that seismicity within a seismic source is of normal distribution, this allows some earthquakes that previously would have occurred within the zone to occur outside the zone permitting a smooth change of seismicity at the border. The program calculates probabilistic ground motions at all sites resulting from earthquake in a single source, before proceeding to the next source. This requires retaining intermediate calculations for each site to accumulate ground motions from successive sources.

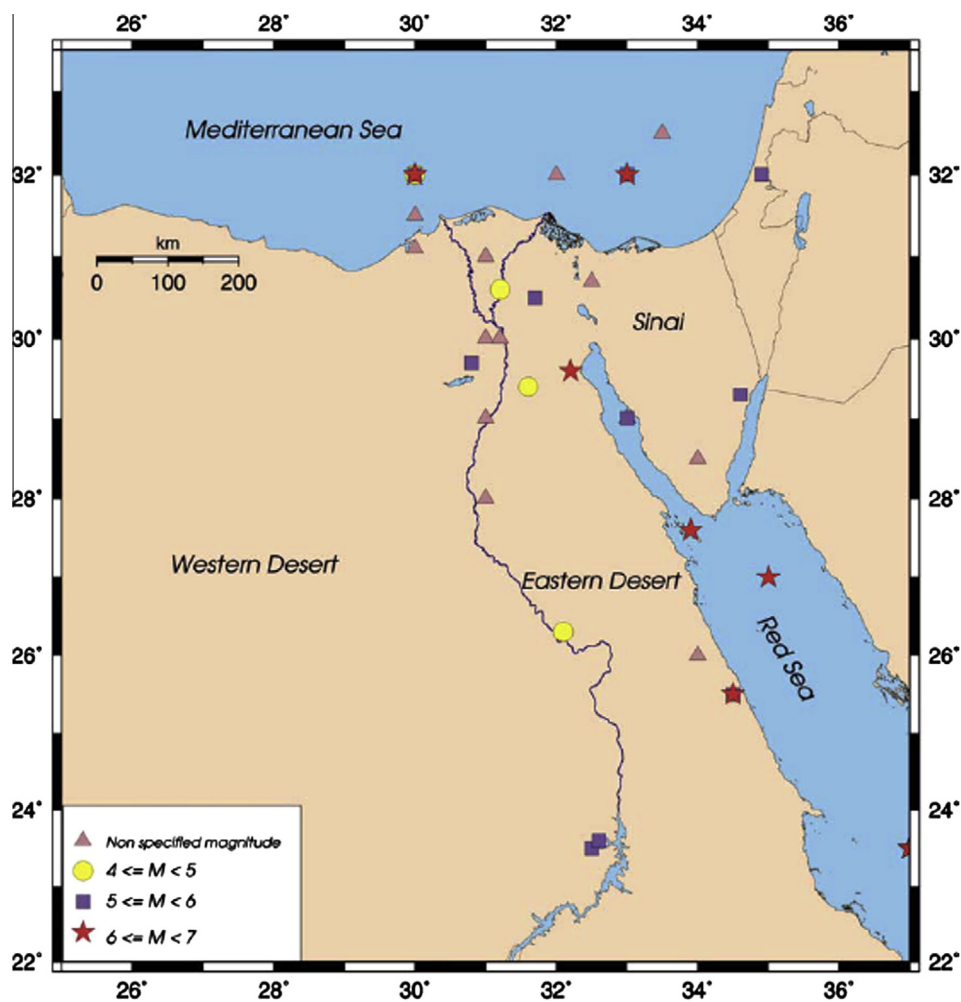


Fig. 3 Map showing the historical earthquakes in Egypt (after NRIAG, 2004).

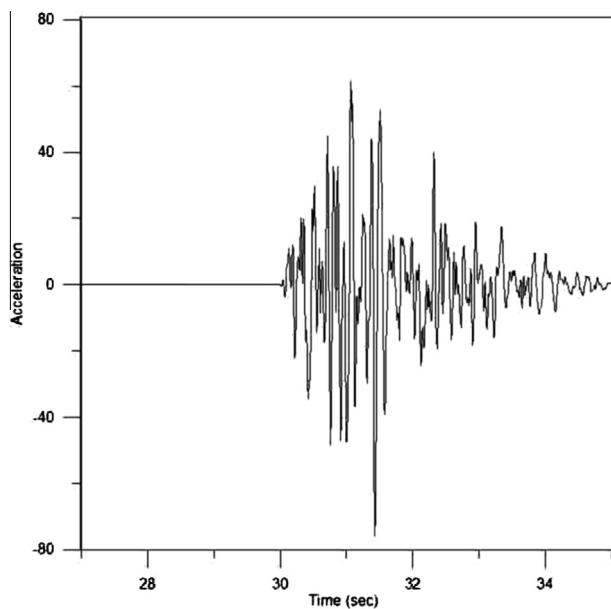


Fig. 4 Simulated acceleration time series of the design earthquake with magnitude 4.5 and a distance of 21 km.

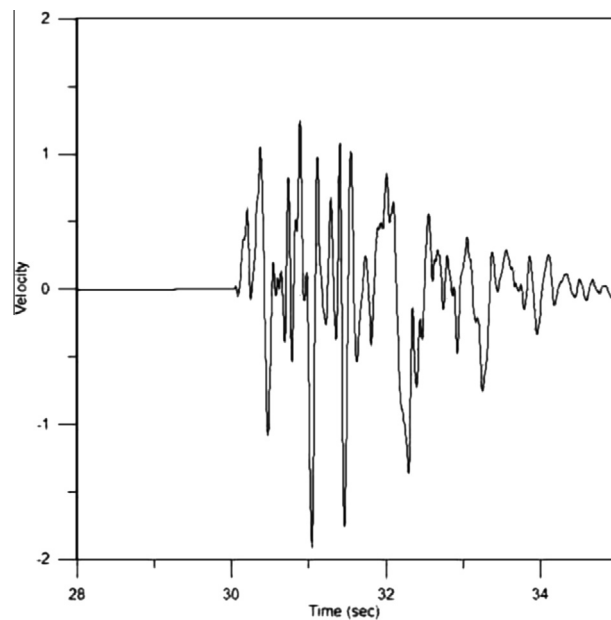


Fig. 5 Simulated ground velocity time histories of design earthquake.

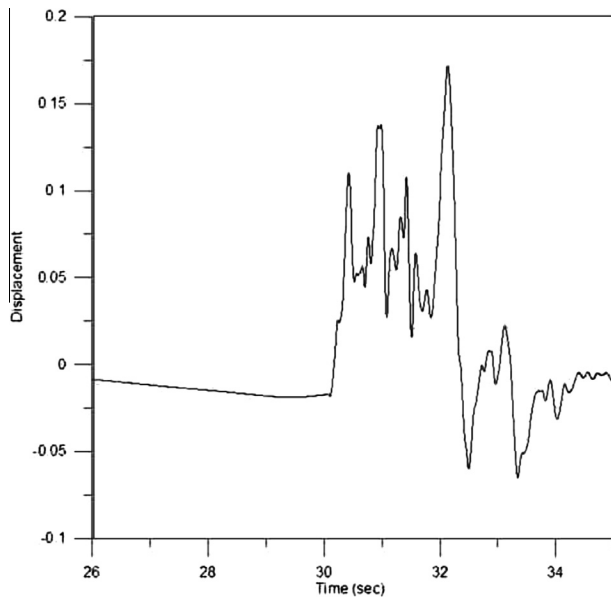


Fig. 6 Simulated displacement time series of design earthquake.

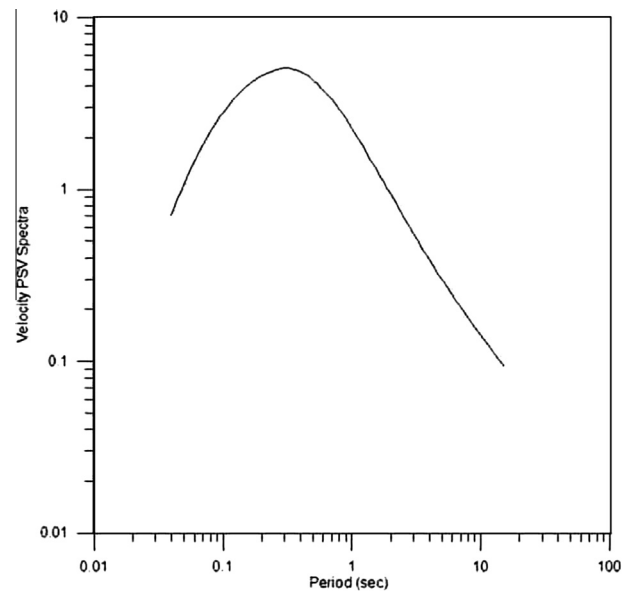


Fig. 8 Velocity response spectrum PSV of design earthquake.

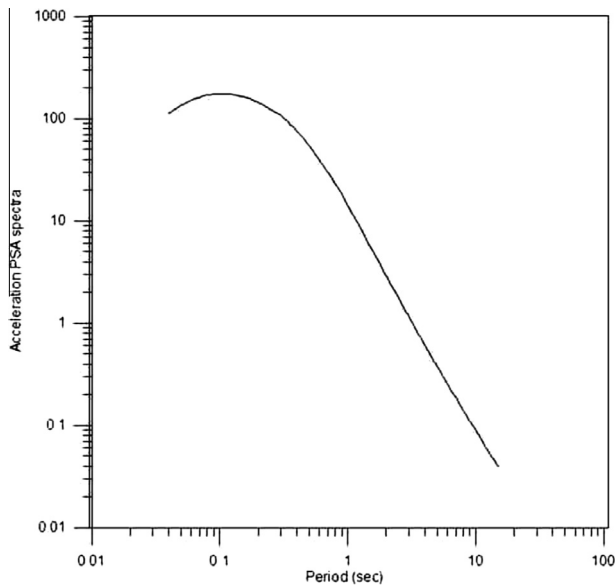


Fig. 7 Acceleration response spectrum of design earthquake.

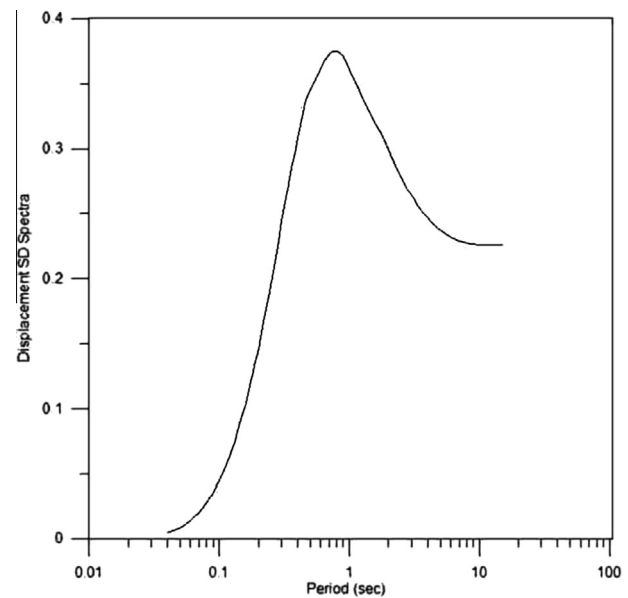


Fig. 9 Displacement response spectrum SD of design earthquake.

The input parameters to the program are both the attenuation relation and source zone parameters. The attenuation relation is used by the program to account for the attenuation of seismic energy with distance. The source zone parameters include the borders of the zone, number of earthquake, and the rate of occurrence of each magnitude intervals or subclasses.

The seismicity of Egypt is subdivided into 11 source zones. The subdivision is carried out based on geologic settings, seismological characteristics, geodetic measurements, etc. The analysis indicated that the seismic source zone at the Gulf of Suez, Gulf of Aqaba and eastern Desert have about the same effect on the site of interest. The analysis yielded that the expected peak ground acceleration PGA of 25, 34, 57 gals

(cm/s^2) was in the period range of 50, 100, and 500 years respectively.

4. Deterministic hazard assessment

The deterministic seismic hazard assessment may be summarized simply as following:

- Selecting all earthquakes that occur at a distance range less than or equal to 80 km.
- Selecting earthquakes with magnitudes above 4.5 to a distance range of 350 km.

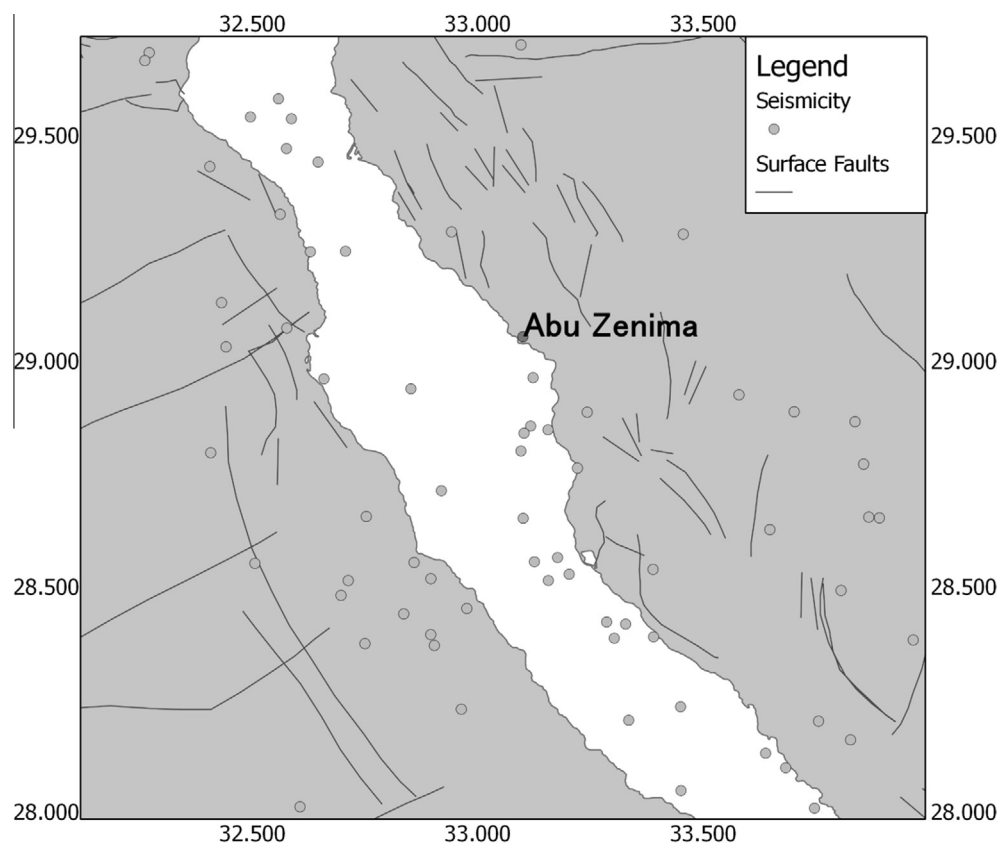


Fig. 10 The study area is marked by a triangle with the occurrence of earthquake epicenters and fault trace.

- Using appropriate attenuation relation to determine the peak ground acceleration due to the selected earthquakes at the site of interest.
- Determining the earthquake with highest peak ground acceleration.
- Adding an increment of 0.5 to such earthquake to determine the magnitude of design earthquakes.

The above steps are applied to the Egyptian seismological catalog collected from local and international sources. The analysis yielded that three earthquakes have nearly the same effects on the site. These earthquakes are the Aqaba earthquake on 22/11/1995, and an earthquake of magnitude 4 that took place at a distance of 21 km. Due to its proximity the last earthquake is selected as the design earthquake and was scaled to be of magnitude 4.5.

5. Simulation of strong ground motion

The simulation of strong motion is carried out using the stochastic technique. A description of the method is given in Boore (1983, 2009). The method assumes that the radiation from a fault is distributed randomly over a time interval whose duration is related to the source size and possibly the distance from the source to the site.

The ground motion can be obtained via time-domain (TD) simulation, from which peak parameters such as peak acceleration and response spectra can be obtained (mean values of the parameters require a Monte Carlo simulation with many realizations for a given set of input parameters). The peak

parameters also can be obtained directly using the random-vibration (RV) theory. This is a much quicker way of obtaining the peak parameters, but it is not useful if time series are needed in the analysis. In addition, there are assumptions in the random-vibration theory that are not present in the time-domain simulations. For this reason, the time-domain simulations can be considered “truth”; many simulations are needed (on the order of 50 or more), however, in order for the square-root of n reduction of noise to provide accurate estimates of the peak parameters. In general, the random-vibration simulations seem to be good estimates of the ground motions in almost all cases, at greatly reduced computer time.

The computation of PGA and the response spectra due to the design earthquake yielded the following parameters:

- The PGA of the design earthquake with magnitude of 4.7 at a distance of 21 km of 76 gals, which is consistent with the probabilistic analysis. In addition, the peak ground velocity and displacement were estimated as 1.9 cm/s and 0.172 cm respectively. Figs. 4, 5 and 6 show the simulated ground motion time series for acceleration, velocity, and displacement.
- The response spectra were also calculated for a single degree of freedom structure with damping ratio of 0.05. The plots of the response spectra are shown in Figs. 7, 8 and 9.

6. Summary and conclusion

The seismic hazard assessments are an important task for the establishment of earthquake resistant structures. The notable

seismological activities, although of moderate size, clearly explain the importance of seismic hazard assessments. The site of interest is characterized by both moderate seismic and tectonic activities nearby. Fig. 10 shows that not only earthquake activity is present but also a surface trace of probable active faults as well.

The assessments were calculated using probabilistic and deterministic approaches. The results of both approaches are in good agreement with each other. The probabilistic approach computation yielded that the activities of the seismic zones of the Gulf of Suez and Gulf of Aqaba are of about equal effects on the site with expected PGA of probability of 90% of not being exceeded in 50, 100, 500 years as 25, 34, and 57 respectively. Such results were obtained using SEISRISK III code.

The deterministic approach, on the other hand, also indicated that a design earthquake with a magnitude of 4.5 at a distance of 21 km has the highest effect on the considered site. The calculations were carried using SMSIM program to obtain simulated acceleration, velocity, and displacement time series in addition to the response spectra of displacement, velocity, and acceleration. The simulated time histories indicated that the peak ground acceleration is 76 gals which is in good agreement with probabilistic results. The peak ground velocity and displacement are 1.9 cm/s and 0.172 cm respectively.

The information presented throughout this work represent the necessary information for the design of earthquake resistant structures and should be taken into considerations.

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