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Seismic Risk Assessment at the Proposed Site of Gemsa Wind Power Station, Southwestern Coast of Gulf of Suez, Egypt

Kamal Abdelrahman[1,2*], Abdullah Al-Amri[1], Nassir Al-Arifi[1] and Enayat Abdelmoneim[2]
[1]Geology and Geophysics Department, King Saud University, Riyadh, Saudi Arabia
[2]Seismology Department, National Research Institute of Astronomy and Geophysics, Egypt
***E-mail:** *khassanein@ksu.edu.sa*

ABSTRACT

Gemsa has been chosen as the site for one of a new generation of power stations along the south-western margin of the Gulf of Suez. This site has been affected by a number of destructive earthquakes (M_w> 5), in addition to large number of earthquakes with magnitudes of less than 5. In this study seismic activities in the region were collected and re-evaluated, and the main earthquake prone zones were identified. It is indicated that this site is affected by the southern Gulf of Suez, northern Red Sea and Gulf of Aqaba source zones. The southern Gulf of Suez source zone is the nearest to the proposed site. The stochastic simulation method has been applied to estimate the Peak Ground Acceleration at the site of the proposed Gemsa power plant. It was noticed that the pseudo-spectral acceleration (PSA) reaches 175 cm/sec^2 resulting from the southern Gulf of Suez seismic source. In addition, the response spectrum was conducted with a damping value of 5% of the critical damping, and the predominant period reached 0.1sec at the site. These results should be taken into consideration by civil engineers and decision-makers for designing earthquake resistant structures.

INTRODUCTION

Egypt has suffered from a shortage of conventional energy sources in recent times, which has forced the country to reorient its power generation towards renewable sources in order to meet the needs of the population and the huge developmental and urban projects that country intends to implement. Recently, Egypt has launched a global competition for the construction of power station across the country through an ambitious plan including wind, solar and nuclear power.

Gemsa has been selected to be the site of one of wind power stations along the south-western coast of the Gulf of Suez, as shown in Fig.1. This site is characterized by relatively high wind speeds because it is an extended and broad area where there are no significant topographical changes that could affect the speed and direction of wind. The Suez rift extends northwest-southeast with a width of about 50-90 km and a length of about 350 km. Gemsa has been affected by number of damaging and destructive earthquakes both historically (before 1900) and instrumentally (1900 to 2014). These earthquakes resulted in extensive damage, especially at the southern opening of the Gulf of Suez, due to the complicated tectonic activities affecting this area.

Based on the above-mentioned context, it is necessary to evaluate the earthquake activities that may affect the proposed site and to conduct a seismic risk assessment in terms of pseudo-spectral acceleration (PSA) and response spectra which are very important for safety of constructions at the Gemsa site.

GEOLOGIC SETTING OF THE STUDY AREA

Tectonics of the Gulf of Suez

A sequence of great tectonic movements started in the Oligocene and continued until post-Miocene times (Khalil and McClay, 2001) to form the Gulf of Suez. The main configuration of the graben boundaries was controlled by tensional faults with considerable displacements. Within the confines of these boundary faults, the graben area is dissected into numerous pre-Miocene fault blocks of various sizes. It has been observed that the tilting of these blocks is oriented to the southwest in the northern and southern parts of the Gulf, but changes to the northeast in the central part (Said, 1962, Meshref, 1990; Bosworth and McClay, 2001) as seen from Fig.2.

The Red Sea – Gulf of Suez rift system was formed by divergent movements between the Arabian plate and the African plate (Coleman, 1974; Hempton, 1987; Khalil and McClay, 2001). This hypothesis is consistent with the near orthogonal rifting along the whole extent of the rift system. The Gulf of Suez rift is strongly segmented with alternating polarity due to the presence of the Zaafarana and Morgan accommodation zones (Younes and McClay, 2002) (Fig. 2). The Zaafarana accommodation zone defines the change in fault polarity from NE-dipping in the north to SE-dipping to the south (Moustafa, 1996). It matches with the location of the Wadi Araba anticline. The Morgan accommodation zone, meanwhile, illustrates the shifting in fault polarity from NE-dipping to the north to SW-dipping to the south (Moustafa and Fouda, 1988). It also corresponds to a noticeable southward spreading of the rift zone.

Geological Setting of Gemsa Area

According to the Egyptian General Petroleum Coorporation (1976), the surface geology for the Gemsa area composed of various sediments of sabkha, coralline limestone and alluvial wadi deposits (Fig. 3). Surface sediments cover the basement complex in the southern

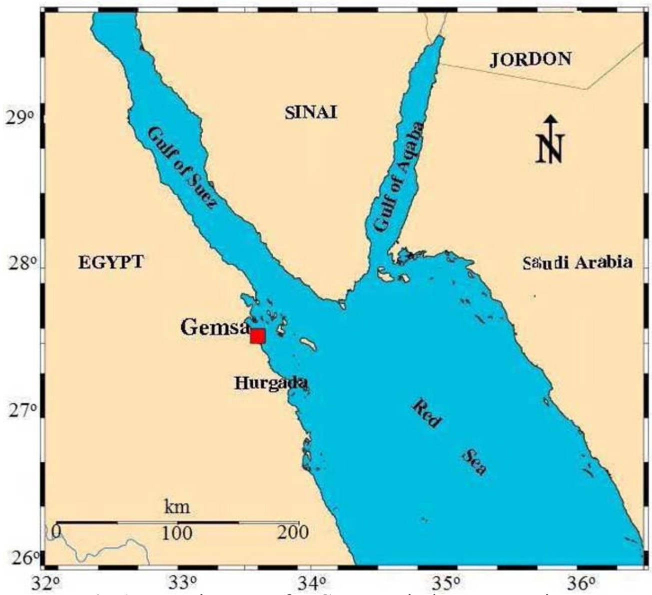

Fig.1. Location map for Gemsa wind Power station

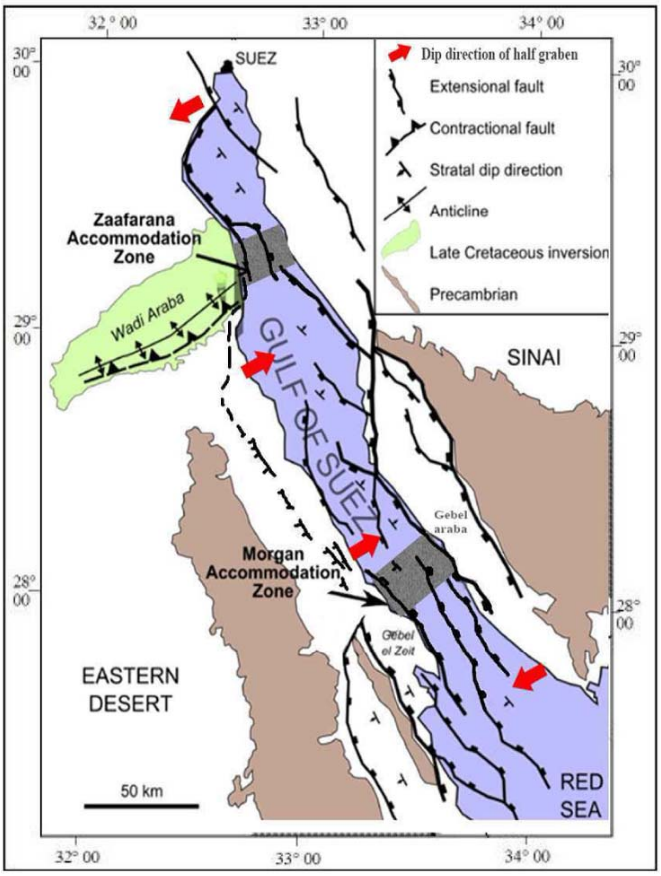

Fig.2. Tectonic setting of the Gulf of Suez (Younes and McClay, 2002).

part of study area. These sediments have been affected by different tectonic movements. Structural elements have been identified in the study area where they are oriented NW and NE parallel to the main tectonics of the Gulf of Suez and Gulf of Aqaba, respectively.

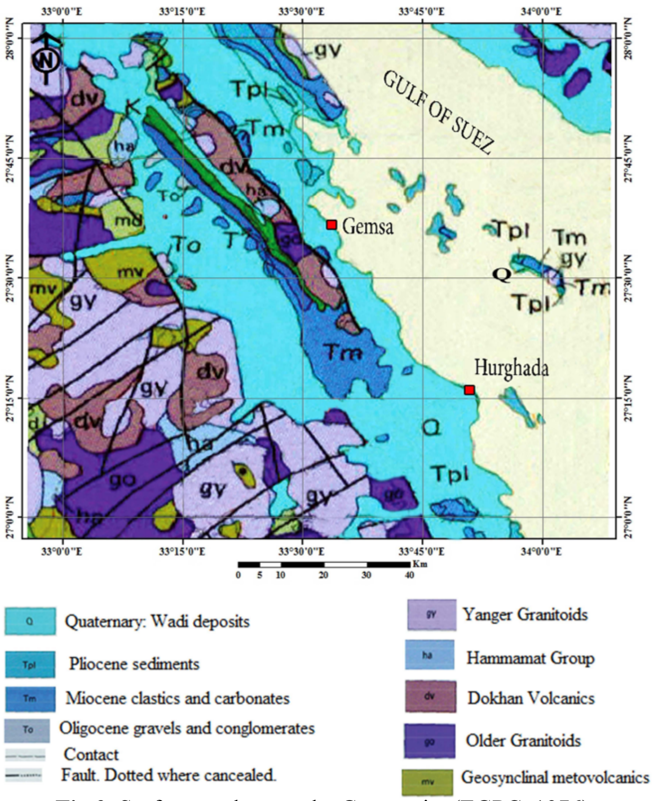

Fig.3. Surface geology at the Gemsa site (EGPC, 1976).

SEISMICITY AND SEISMIC SOURCES ZONES

Compiling the Earthquake Catalogue

Earthquake data for tens of centuries are available in Egypt. Historical Islamic, Arabic documents and literatures contain comprehensive depiction of damage including deformation due to earthquakes. The southern Gulf of Suez area has experienced large number of earthquakes with different magnitude ranges. The historical earthquakes (pre-1900) were collected from Ambraseys et al. (1994) and Riad et al. 2004 (Fig. 4), while the instrumental seismicity (from 1900 to 2014) affecting the Gemsa site was gathered from Maamoun et al. (1984) and the Egyptian National Seismic Network (ENSN) bulletins in a circle of radius 100 km. These data were then merged, reviewed and refined from duplicated events using the International Seismological Center (ISC); the National Earthquake Information Centre (NEIC) of United States Geological Survey and the European Mediterranean Seismological Centre (EMSC) earthquake catalogues. Different magnitude scales were converted into moment magnitude using Scordilis (2006) relationships. Foreshock and aftershock sequences were eliminated from the catalogue following Gardner & Knopoff's (1974) windowing procedure. Finally, the spatial distribution of the obtained earthquake catalogue was plotted on a map so as to construct an updated seismicity map around the Gemsa power station site (Fig.5).

It was found that the Gemsa site has been affected by a number of damaging and destructive earthquakes with magnitudes greater than 6 (as the following two earthquakes).

1969 March 31, Shedwan Island, Red Sea Earthquake

31 March 1969 Shedwan earthquake (M_w 6.9) and its aftershock sequence is considered as one of the strongest earthquakes to have affected the region. The Shedwan earthquake was also the closest one to the Gemsa site and hence represents the most hazardous threat for the power structures proposed at the site.

This was a destructive earthquake with an offshore epicentre in the southern entrance to the Gulf of Suez and affected the area of Shadwan Island (Fig.6) where the shock caused numerous rock-falls landslides, fissures and cracks. A maximum intensity of IX was assigned at Shedwan Island (Maamoun et al., 1984), where it was strong enough to throw people to the ground. Because of the desolate nature of the region, there was no damage to property. The lighthouse at the southern end of the island did suffer horizontal mortar cracks near its base. A zone of ground deformation, probably of non-tectonic origin, was noticed extending in a north-south direction for about 1 km showing a few centimetres of right–lateral displacement. At a

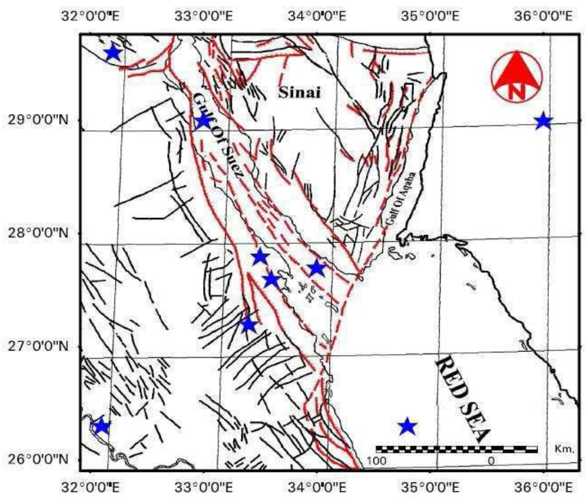

Fig.4. Historical seismicity around the Gemsa site (Ambraseys et al., 1994).

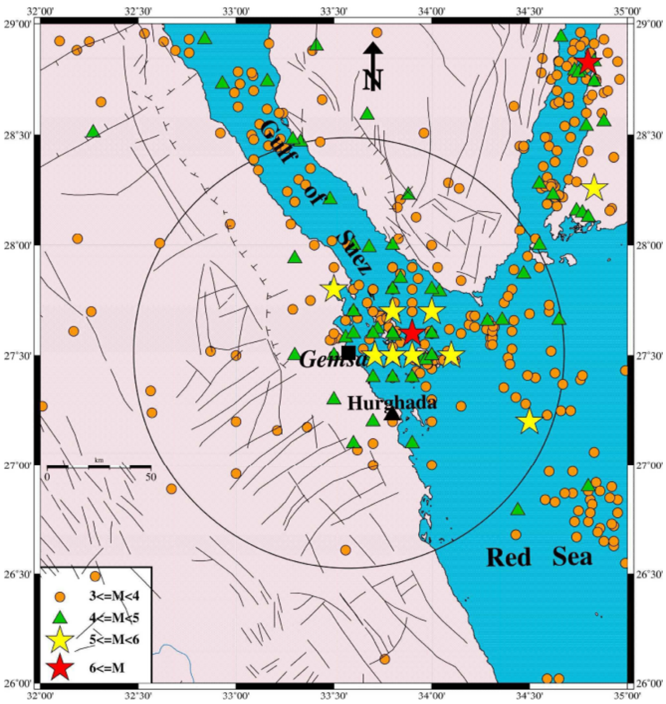

Fig.5. Earthquake activities affected Gemsa site (from 1900-2014).

distance of about 10 km west of this zone, in the sea, a coral reef was raised permanently above the sea-level confirming the dip-slip motion (Ben-Menahim and Aboodi, 1971).

Dead fish and some agitation of the sea were noticed after the main shock. At Gemsa itself the shock caused some damage, including cracks in the brick walls of a reinforced concrete power plant, and plaster cracks in two hotels. In the southern Sinai area, at Tur, a few dilapidated houses were damaged while the plaster in a building was cracked and partly fell from a ceiling at the monastery of St. Catherine's. Meanwhile, at Sharm al-Shaikh, the earthquake produced cracks along mortar in walls, articles fell from shelves and furniture was displaced. People ran outdoors and had difficultly standing. Light wooden houses remained intact, and overall damage to property was negligible. Rock-falls and talus slides triggered by the shock raised clouds of dust.

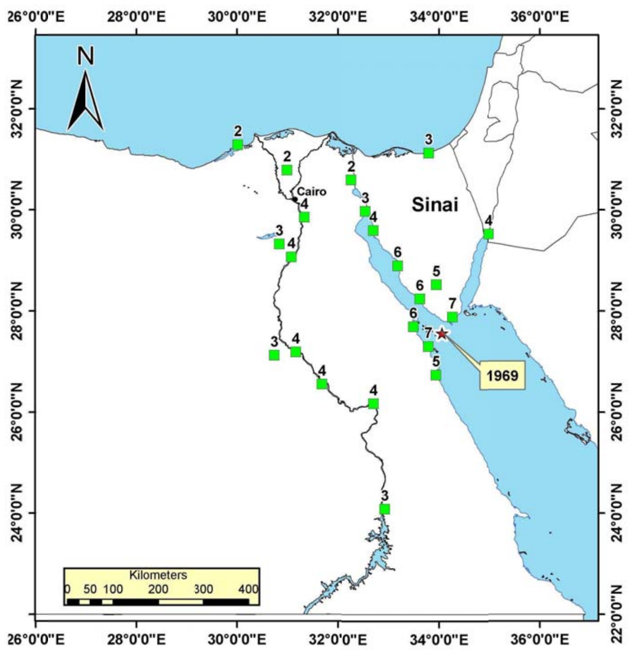

Fig.6. Intensity map for 31 March 1969, southern Gulf of Suez earthquake.

Gulf of Aqaba Earthquake (22nd November 1995, M_w 7.2)

On November, 22, 1995, the largest earthquake sequence of mainshock-aftershock started in the central part of the Gulf of Aqaba and continued until December 25, 1998. The main shock (Mw 7.2) had an origin time of 04:15 GMT and located at latitude of 28.76 N and longitude 34.63 E. This event was followed by more than seven thousands aftershocks (M_l > 1.5) within three months following the main shock. It is considered as the most serious earthquake, instrumentally, affected the entire Gulf of Aqaba region, producing panic, casualties and catastrophes in the epicentral area. The earthquake ruptured along the Gulf of Aqaba left-stepping fault segment (Freund et al., 1970; Ben-Avraham et al., 1979a&b; Garfunkel, 1981 and Ben-Avraham, 1985). Heavy damage caused by this earthquake was reported in the epicentral area along the western, eastern and northern coasts of the Gulf of Aqaba. At least 11 people were killed and 47 injured (Al-Tarazi, 2000). Its impact was extended over a wide area such as Lebanon, Sudan, southern Syria and western Iraq.

Identification of Seismic Source Zones

The seismic activity that surrounds Gemsa can be classified into three main seismic source zones (Fig. 7) which are as follows:

The Northern Red Sea Zone

The distribution of seismic activity in the northern Red Sea indicates the presence of recent tectonic activity (Daggett et al., 1986). These earthquake activities extend south-southeast of the southern Gulf of Suez into the median zone of the Red Sea. Earthquake spatial distribution is correlated with the spreading axis of Girdler and Styles (1976). In addition, some epicentres were recorded along the Red Sea margin with centre of earthquake foci along the Red Sea axial trough. Accordingly, the northern Red Sea zone has complicated tectonics reflecting the Sinai triple junction separating the Arabian and African plates from the Sinai sub-plate. Their focal mechanisms indicate different faulting characteristics.

The Southern Gulf of Suez Zone

This zone has noticeable seismic activity based on the occurrence of small, moderate and destructive earthquakes throughout the zone. Two swarms of earthquakes have been recorded from Shedwan and

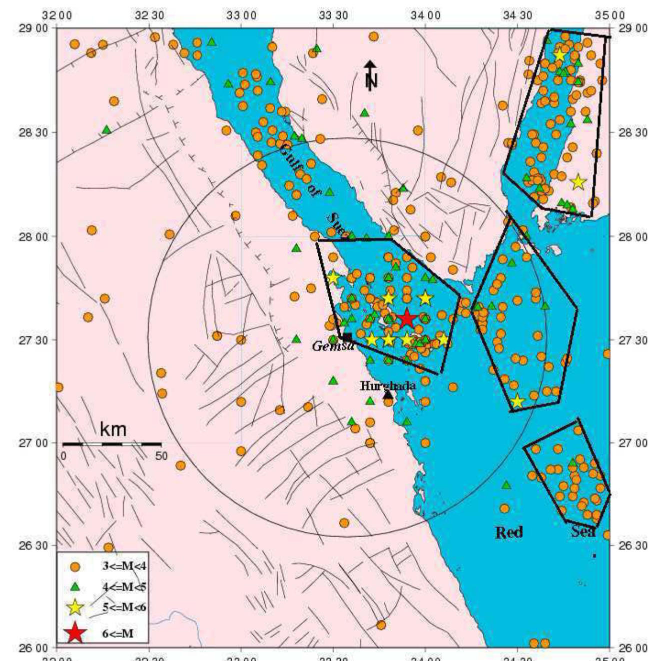

Fig.7. Seismogenic source zones affecting the Gemsa site.

Gubal Islands at the southern entrance of Gulf of Suez (Maamoun and El Khashab, 1978). The focal mechanisms of the 31 March 1969 Shedwan earthquake indicate normal faulting however, the Gubal Island swarm, to the north of Shedwan Island, show reverses faulting.

The Gulf of Aqaba Zone

The Gulf of Aqaba zone has one of the most active zones in the Middle East region during the last two decades. Earthquake activities are controlled by the major tectonics and structural elements as indicated by surface and sub-surface studies (Al-Amri et al., 1996 and Abdel-Rahman et al., 2009). Recent swarms that have occurred in 1983, 1991, 1993 and 1995 (with Mw 7.2) have illustrated the migration of earthquake epicentres north-eastward which, in turn, indicates the north-eastward continuation of the strike-slip faulting movement. Furthermore, an earthquake with magnitude 5.7 M_l was recorded on 8th of March 2000. This earthquake was felt over a large area, including the Sinai Peninsula, and extended to Gemsa.

GROUND MOTION SIMULATION AT GEMSA

Overview of the time domain simulation method

Owing to the absence of high frequency strong ground motion records in Egypt, simulation of ground motion characteristics has been used in this study (Boore, 2003). The stochastic approach that is presented by Boore (1983), as improved in Boore (2003), has been applied in this study. Brune's (1970) spectrum was adapted to eliminate frequencies exceeding a certain cut-off frequency. Boore (2003) breaks down the whole motion spectrum recorded at a site (Y(Mo, R, f)) into earthquake source (E), path (P), site (G) and instrument (I) contributions as:

$$Y(Mo, R, f) = E(Mo, f)\, P(R, f)\, G(f)\, I(f) \quad (1)$$

The earthquake source spectrum model is the w-square model. The earthquake source spectrum E (Mo, f) for the horizontal component is given by:

$$E\,(Mo, f) = C(2\pi f)^2 MoS(Mo,f) \quad (2)$$

where S(Mo, f) is the displacement source spectrum and C is a constant. $C = R_s VF/\,(4\pi\rho\beta^3 R)$, with R = 1.0 km, Rs = average shear wave radiation pattern (= 0.55), F = free surface effect (= 2.0), V = partition into two horizontal components (= 0.71), ρ = the density at the source and β is the shear wave velocity at the source.

The path P(R, f) in equation (1) is assumed by the multiplication of the geometrical spreading and Q function, as follows:

$$P(R, f) = Z(R)\, \exp[-\pi\, f\, R\, /\, Q\, (f)_{CQ}] \quad (3)$$

where CQ is the seismic velocity used in the determination of Q(f), and the geometrical spreading, Z(R), is given by a piece-wise continuous series of straight lines, as follows:

$$Z(R) = \begin{bmatrix} Ro/R & R \le R_1 \\ Z\,(R_1)\,(R_1/R)^{P_1} & R_1 \le R \le R_2 \\ Z(R_n)\,(R_n/R)^{Pn} & R_n \le R \end{bmatrix} \quad (4)$$

where R is generally the closest distance to the rupture surface.

Atkinson (1993b) and Atkinson and Boore (1995) stated that the duration ground motion (T_{gm}) is estimated by the sum of the source duration (T_o) and path dependent duration. The path dependent (bR) can be illustrated by a linked series of straight line segments. The value b is the slope of each segment of the three segments of relationships between the distance R and the duration. The Q model, derived by Moustafa (2002), representing an elastic attenuation factor has been used in this study which is as follows;

$$Q = 85.68f^{0.79} \quad (5)$$

Input Parameters

ρ_s and β_s are equal to 2.8 gm/cm^{3}and 3.78 km/sec, respectively. The reference distance R_o= 1 km. The seismic moment and the stress drop are 7.2x10^{26} dyn.cm and 39.5 bar (Hussein et al., 1998), respectively. The path effect is divided into geometrical spreading and in elastic attenuation effect. The geometrical spreading relationship of Atkinson and Boore, (1995) is used in this study.

Results

The time history of PGA, peak ground velocity (PGV) and peak ground displacement (PGD) at the Gemsa power station site, resulting from the Shedwan earthquake, which is the closest source for the station, was simulated (Fig. 8). The simulated PGA, PGV and PGD at the site are about 45 cm/sec^2, 2.75 cm/sec and 3.1 cm, respectively.

Response Spectra

Jennings (1983) defined response spectra as the response of a single degree of freedom damped oscillator to the earthquake acceleration. The response spectrum of an accelerogram has the dual function of illustrating the ground motion as a function of frequency and of being a tool for calculating earthquake resistant design criteria.The response spectra were estimated with a damping value of 5% of the critical damping for the Gemsa wind power station site (Fig. 9). The pseudo-spectral acceleration (PSA) reached 175 cm/sec^2 at the predominant period of 0.1 sec.

DISCUSSION AND CONCLUSION

The earthquake catalogue in a circular radius of 100 km around Gemsa station has been updated from different data sources. This catalogue illustrates that most of the events affecting Gemsa station have small-moderate magnitudes while the strong earthquakes are limited with lengthy recurrence interval even their hazardous impact. In the light of absence strong ground motion records, the stochastic hazard approach used in this work to simulate the time history for the

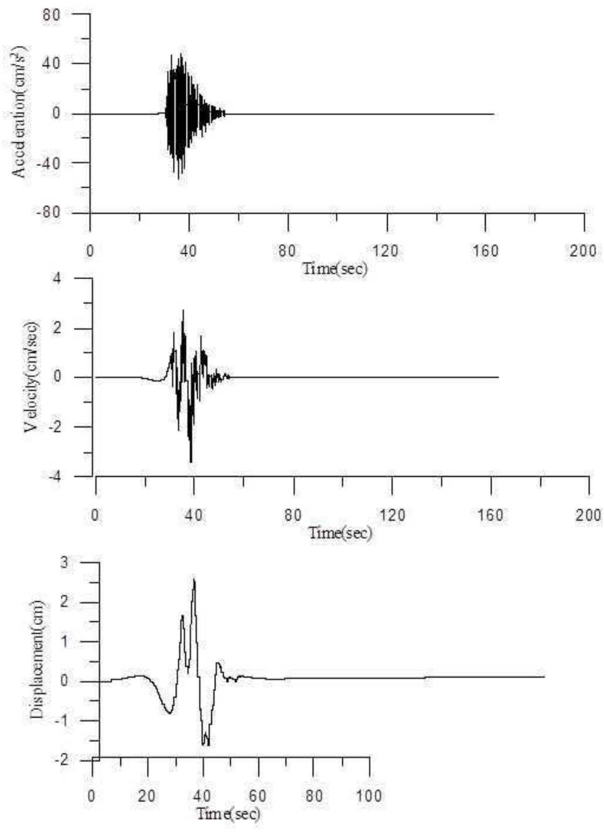

Fig.8. Simulated time history for PGA at Gemsa site produced from Shedwan earthquake.

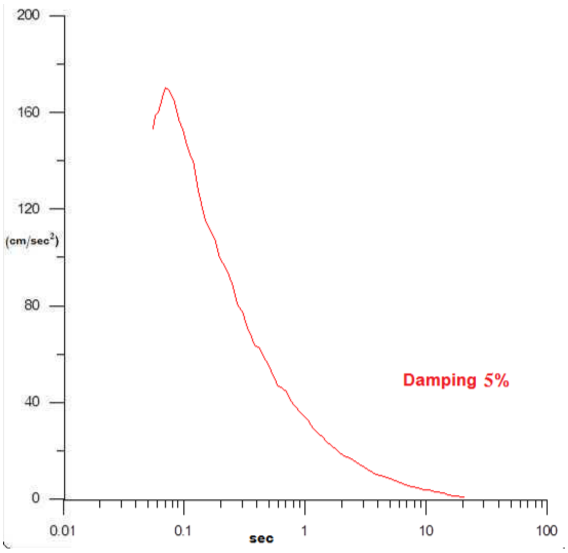

Fig.9. Response spectra at Gemsa site produced from Shedwan earthquake.

peak ground acceleration, peak ground velocity and peak ground displacement at the selected site for Gemsa station. The maximum pseudo-spectral acceleration and site response spectrum have assigned from different sources that show; Shedwan earthquake is the credible earthquake where its PGA reached was calculated as 175 cm/sec^2 at 0.1 sec predominant period. Although 22nd Nov. 1995 earthquake has magnitude greater than that of Shedwan one, it occurred at greater distance and its impacts is less than that of Shedwan earthquake. In view of our results, seismic hazard at Gemsa station is mainly dominated by local earthquakes which, in turn, should be considered in computing the realistic design response spectra for Gemsa power station. In light of the tectonic environment of the selected site, conducting paleoseismic investigation is recommended for safety requirements.

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