



Seismic Design Criteria for the South Sinai Red Sea Rift Zone

A. I. Salama

Lecturer, Faculty of Engineering of Shoubra Zagazig UniversityEgypt.

Abstract

The Red Sea rift zone is an area of medium to high seismic hazard, with many medium and large magnitude earthquake recorded historically and very recently. On the other hand, the shoreline in South Sinai and on the Egyptian mainland has undergone unprecedented development with tens of new mini-towns and tourist resorts. Detailed and verified seismic design criteria and sample input motion have not been derived before this important area. In this paper, all available historical and instrumental records of earthquake activity are reviewed, and a definitive catalogue assembled. Conventional probabilistic seismic hazard analysis was undertaken, whilst ensuring the homogeneity of the data used. Levels of ground motion for seismic design are derived as a function of probability of being exceeded, and for different return periods. It is concluded that a level of PGA of about 0.175g (rock-stiff sites) is a conservative value recommended for design. Contrary to the recommendations of the Egyptian seismic code, the levels of excitation for low-rise structures is significant and should not be ignored. Moreover, the possible deterministic earthquake scenarios for the area are discussed. These are used to select recorded ground-motion accelerations from seismotectonic environments similar to the South Sinai area. The average spectra from the selected suite of records is compared to the EC8 spectral model, and shown to be reasonable, though well below EC8 in the long period range. The conclusions and recommendations of this paper are an important contribution to the study of seismic hazard and risk in an area not elaborately studied before and is of interest to both practitioners and researches who are concerned with earthquake issues in this part of the Middle East.



Introduction

This paper describes the assessment of seismic hazard and design criteria on the coast of the Sinai Peninsula at the mouth of the Gulf of Aqaba. The area lies between the co-ordinates of (34°49'N 29°29'E - 32°42'N 27°58'E), 3736660 Hectares area. The study focuses further on the area of Sharm el Sheikh, one of the South Sinai cities with major construction projects. It lies at the co-ordinates of (27.95°N, 34.40°E). Soil conditions in the area are in general of rocky ground while in some special areas it is covered with a layer of 2-5 meters of sand. The paper assesses the hazard in terms of peak ground accelerations (PGA) and associated probabilities of exceedance. The seismic hazard is also represented in terms of design earthquake scenarios for which appropriate strong-motion accelerograms are provided.

Preliminary Assessment of Seismic Hazard

An initial assessment of the seismic hazard in the region can be obtained from the study of Lomnitz¹, in which the Sinai Peninsula and Egypt are considered as relatively low seismicity areas on a global scale. Nonetheless, there is an appreciable earthquake activity in this region and therefore the seismic hazard cannot be disregarded. In the seismic zoning map of Egypt that appears in the regulations for earthquake-resistant building design (IAEE²; Ibrahim³), the entire coast of the Sinai Peninsula is located within Zone 3, which is the zone of highest hazard. Ibrahim also reports the results of an earlier study (Ibrahim & Hattori⁴) which gives a PGA of about 0.04g for a return period of 600 years in the area. Sobaih *et al*⁵ present a series of seismic hazard maps for Egypt, each map corresponding to a different exposure time and probability of exceedance, each intended for application to a different type and use of building. The hazard level most widely used for earthquake-resistant design is 10% probability of exceedance in 50 years, which corresponds to a return period of 475 years. Converting the exposure times and exceedance probabilities to return periods for the accelerations and interpolating for the 475-year hazard level, the study gives a corresponding PGA of about 0.095g.

1. Tectonic Setting

The Eastern Mediterranean region is affected by the intersection of three important tectonic plates: the Eurasian plate and the African and Arabian plates that are converging onto the former. This plate boundary defines the major seismic zones of southern Europe and the Middle East. The Sinai Peninsula is defined and bounded by two important and active tectonic structures. The Red Sea rift zone, that extends along the entire length of the Red Sea from the Gulf of Aden to the Gulf of Suez, forms the boundary between the African and Arabian tectonic plates, which are diverging from each other along this spreading ridge. The Sinai is actually considered as a microplate spreading at

the ridge of the Red Sea rift and is estimated at about 0.5 cm/year⁶. This spreading rate is thought to increase locally to about 0.6 cm/year at the northern end of the Red Sea where the rift is intersected by the active Aqaba rift. The Aqaba rift extends along the entire length of the Gulf of Aqaba and actually forms the southern end of the Dead Sea rift, which is a left-lateral shear zone. The slip rate in the Dead Sea rift has been estimated at 0.15-0.35 cm/year⁷.

2. Historical Seismicity

The seismicity of the Red Sea and surrounding areas has been studied in detail by Ambraseys *et al*⁸. Using a window of 600 km x 600 km centred on the area under study, the following historical (pre-1900) earthquakes, for which an estimate of the magnitude is available, were extracted from the Ambraseys catalogue: (Table 1).

Year	Mn	Day	TIME	LAT	LONG	M _s	Distance (km)
112				31.0	35.0	6.2	343
1068	3	18	08:30	28.5	36.7	7.0	233
1212	5	1	05:00	30.0	35.2	6.7	240
1293	1			31.0	35.6	6.6	358
1458	11	12		31.0	35.5	6.5	355
1588	1	4	13:00	29.0	36.0	6.7	195
1588	4	7	06:00	29.4	31.6	4.7	317
1710	8	27	08:00	29.0	33.0	5.4	180
1778	6	22	18:00	26.3	32.1	4.8	292
1814	6	27	22:00	29.0	33.0	5.4	180
1879	7	11	18:00	29.0	33.0	5.9	180
1895	12	7	02:40	30.6	31.2	4.9	427

Table 1: Historical Earthquakes about 450 km around the region

It is worth noting that while some significant earthquakes are shown in the Dead Sea rift zone, none of these occur within the Gulf of Aqaba. The earthquake of 18 March 1068, which was reported by Kebeasy⁹ to have occurred at the northern end of the Gulf of Aqaba, is re-located by Ambraseys *et al*⁸ in the Hejaz region of Saudi Arabia. The catalogue was also used for seismicity for this century within the same 600 x 600 km window. The earthquakes for the period 1900-1992 extracted from this catalogue are presented in Fig.1, which confirms the dominant sources of activity being the Red Sea-Gulf of Suez rift and the Gulf of Aqaba-Dead Sea rift. The same general trends are also seen in Fig.2 which shows the events extracted from the catalogue of the International Seismological Centre (ISC) for the period from 1964 to 1987

3. Important Recent Earthquakes in the Area

Various earthquakes took place in this century, only two events were recorded between 1900 and 1992, while a series of shocks took place in 1993 and 1995

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within the same area. Only two events between 1900 and 1992 with $M_s > 6.0$ are reported by Ambraseys *et al*⁸. The first of these occurred on 6 March 1900 towards the north of the Gulf of Suez (29°N, 33°E) with magnitude $M_s = 6.2$. The second event occurred on 31 March 1969 at Shedwan Island (27.6°N, 33.9°E), with magnitude $M_s = 6.6$. Ambraseys *et al* also report that at Sharm al-Shaikh the earthquake produced cracks along mortar joints in walls, articles fell from shelves and furniture was displaced, but that overall property damage was negligible. As detailed earlier, it is worth mentioning that at the time Sharm al-Shaikh was little more than a military observation post. However, at the present time it is a very densely populated area with large developmental projects. Osman & Ghobarah¹⁰ report events in the Gulf of Aqaba after 1992. Firstly, a series of shocks between July and August 1993, the largest of which was reported to have a magnitude $M_L = 5.9$. These events were located between Dahab and Nuweiba. Another earthquake, which produced appreciable damage, occurred in the same general area on 22 November 1995, the epicentre of which was located midway between Dahab and Nuweiba. The National Earthquake Information Service (NEIS) reported a magnitude $M_s = 7.2$ for this event and a shallow focus. Reports (Sobaih *et al*.¹¹; Osman & Ghobarah¹⁰) indicate that the earthquake was associated with left-lateral rupture over 40-60 km on a fault trending NNE along the Gulf of Aqaba, which is entirely consistent with the tectonic framework explained previously. Heaviest damage occurred around the northern end of the Gulf of Aqaba, particularly in Nuweiba where one hotel collapsed and three others were damaged. Also in Nuweiba, two of the four berths in the port were severely damaged and there was extensive liquefaction. The port terminal suffered column shear failure and extensive damage was inflicted on a brand new electricity generation complex. The Dahab-Nuweiba earthquake of 22 November 1995 was an exceptional event, without historical precedent and associated with very long return periods. Ben-Menahem¹² reports that large earthquakes in the Dead Sea rift ($M_L > 6.8$) have return periods between 600 and 800 years.

Probabilistic Seismic Hazard Analysis

Probabilistic Hazard analysis is undertaken showing the levels of ground motion and the effects of soil conditions.

1. Levels of Ground motion

An important attenuation relation applicable to this region is that of Thenhaus *et al*¹³ for Saudi Arabia which is reported by Al-Haddad *et al*¹⁴. This equation was obtained by adjusting an equation from another part of the world rather than actually being based on a regional data set of strong-motion records. For the same reason the equation is not accompanied by a measure of the dispersion and Al-Haddad employed an assumed value in their hazard study for Saudi Arabia. The equation chosen for application in this study is that of Ambraseys & Bommer¹⁵ which is based on a data set of more than 500 accelerograms from

Europe and surrounding regions, including the Middle East. The equation for predicting mean values of PGA (g) is as follows:

$$\log(\text{PGA}) = -1.09 + 0.238M_s - \log(r) - 0.00050(r) \quad (1)$$

Where M_s is the surface-wave magnitude, $r^2 = d^2 + 36.0$, where d is the horizontal distance between the earthquake source and a selected site on the area in kilometres. The standard deviation associated with the equation is 0.28. Comparison of the values of acceleration predicted by this Eurasian equation agree reasonably well with those given by the Saudi Arabian equation of the Thenhaus *et al*¹³ for a magnitude 6 earthquake in the distance range from 10 to 100 km the maximum difference between predicted values is less than 10%. The Dahab-Nuweiba earthquake of 22 November 1995 triggered strong-motion instruments in Eilat and Aqaba where maximum recorded accelerations were 0.09g and 0.10g respectively¹⁰ Assuming unilateral rupture over 50km, extending NNE from the epicentre, both recording areas are located at about 40km from the earthquake source. For the $M_s=7.2$. Equation 1 predicts a peak acceleration of 0.10g, which confirms the applicability to this region. A probabilistic seismic hazard analysis for the area has been performed using the method of Cornell¹⁶. The first stage in the analysis is the definition of seismogenic zones that could affect the region. These zones define the two main tectonic features that affect the area discussed, the Red Sea-Gulf of Suez rift system (Zone A) and the Gulf of Aqaba-Dead Sea Rift (Zone B). There is very little evidence of significant seismic activity in the southern portion of the Gulf of Aqaba and this is therefore a somewhat conservative approach since it implies that a major earthquake of the type that occurred in 1995, could occur at any location along Zone B. The catalogue of Ambraseys *et al*⁸ for the period since 1900 was used as the basis for the evaluation of the recurrence rates in these zones and in order to accommodate conservatively possible location errors those events located outside but close to the limits of the zones were included. A lower magnitude limit of $M_s = 4$ was applied since smaller events are not of engineering interest and also because the catalogue is more likely to be complete above this level. Performing regressions on the earthquake data for each zone, the following cumulative recurrence relationships of the type proposed by Gutenberg & Richter¹⁷, for the number of earthquakes, N , with magnitude $> M_s$ were found:

Zone A	$\log(N) = 3.82 - 0.60M_s$	(2)
Zone B	$\log(N) = 3.40 - 0.61M_s$	(3)

In order to apply these magnitude-frequency relationships in seismic hazard analysis it is also necessary to define the associated value of M_{\max} , which is the size of the largest credible earthquake associated with each zone. The approach adopted for Zone A is the standard practice of adding an increment of 0.5 to the largest earthquake in the seismic catalogue (the event of 31 March 1969), which results in a value of $M_{\max} = 7.1$. For Zone B the application of a similar



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approach would be over-conservative since the largest event in the catalogue is the 22 November 1995 earthquake and no other events are even close in size to this magnitude $M_s = 7.2$ event. Furthermore, an element of conservatism has already been introduced by the extension of Zone B to the junction of the Red Sea and Gulf of Aqaba systems. Therefore, for Zone B a value of $M_{\max} = 7.2$ is adopted, taking the 1995 earthquake as an example of the extreme event. The hazard analysis was performed using the standard program EQRISK (McGuire, 1976¹⁸).

2. Interpretation of Results

For a probability of exceedance of 10% in 50 years, the associated peak ground acceleration is 0.23g. This hazard level can be considered as reasonably conservative in view of characteristics of the assessment. It was clear that: (a) the seismogenic source zones were extended to be close to the area, (b) many events located outside the source zones were included in the determination of the recurrence relations, and (c) the scatter in the attenuation relation was fully incorporated into the hazard determination. However, it has long been recognised that the peak ground acceleration does not reflect the strength of the motion and that design spectra should be anchored to a measure of "effective" acceleration. Nacim & Anderson¹⁹ suggest the use of a factor of 0.76 to convert peak ground acceleration to effective peak acceleration. Applying this factor, the design acceleration for the area is 0.175g.

3. Effect of soil conditions

The presence of layers of soils overlying the bedrock at the area can modify the strong motion caused by earthquakes. Depending upon the type of deposit, its thickness and the contrast between its characteristics and those of the underlying rock, as well as on the nature of the ground shaking, the effects of a soil layer may include the following increase of the amplitudes of the ground-motion, shift to lower frequency (higher period) content of the ground-motion and an increase in the duration of the shaking.

Earthquake Scenarios & Smoothed Spectra for Modal Analysis

1. Definition of Earthquake Scenarios

In order to select appropriate acceleration time-histories for design it is necessary to define earthquake scenarios on the basis of the preceding hazard assessment. It is not appropriate to simply adopt the maximum magnitude earthquake associated with each zone and locate it as close to the area as possible within the source, since this would represent such a special case as to be unduly conservative. Three different scenarios are considered. The first is a major earthquake in the Gulf of Suez, for which the maximum magnitude of 7.1 is assumed, but the location would be similar to that of the earthquake of 31 March 1969. There is clear evidence to suggest that the major earthquakes in

this zone are associated directly with the rift, while only smaller events occur towards the limits of Zone A. The position of the 1969 Shedwan earthquake is quite unfavourable to the area under study; thus, there would be no justification for locating such a large event any closer to the area. According to equation (1), a magnitude 7.1 earthquake in the same location as the 1969 event would generate a peak acceleration of 0.06g. The second scenario would be a major event in the Gulf of Aqaba, which would be a repeat of the November 1995 event. The Dahab-Nuweiba earthquake of 1995 was an exceptional event and on the basis of the limited data available it is not possible to discard the possibility of a similar earthquake occurring elsewhere along the Gulf of Aqaba rift. To locate such a scenario event adjacent to the area would be extremely conservative, so a reasonable assumption would be for a repeat of the 1995 earthquake within a distance of 20-30 km from the area. According to equation (1) these scenarios would generate accelerations between 0.197g and 0.133g. The third possibility to be considered is a small, local earthquake in close proximity to the area. For this it is assumed that there is a repeat of an earthquake that occurred on 23 March 1982 with co-ordinates 28.0°N, 34.4°E, within about 6 km of the area. The magnitude of this event was only $M_s = 4.6$ and this event has no clear association with any major tectonic feature. According to equation (1) the peak acceleration that this earthquake would have generated at the area is 0.118g, which is smaller than that caused by the scenario earthquake associated with the Gulf of Aqaba rift. Furthermore, because of the small magnitude of such an event, the resulting motion would be of such short duration as to be of little engineering importance.

From the above it is clear that the dominant scenario is that of an earthquake of similar characteristics to the Dahab-Nuweiba earthquake of November 1995 occurring towards the south of the Gulf of Aqaba, within about 20-30 km of the area. Such an event would generate peak acceleration at the area comparable to the design level of 0.175g.

2. Selection of Earthquake Time Histories

The earthquake scenario defined above is a magnitude $M_s=7.2$ event at a distance of 20 to 30 km from the area. Therefore a search was made for appropriate accelerograms, using a magnitude range from 6.9 to 7.4 and distances from 20 to 40 km. The records identified in this search are listed in Table 2.

Earthquake	Y	M	D	Time	M_s	Distance(km)	PGA/(g)	Station
Montenegro	1974	4	15	06:19	7.0	29	0.255	Herceg-Nov
Caldiran	1976	11	24	12:22	7.3	44	0.098	Maku
Imperial Valley	1979	10	15	23:16	6.9	24	0.167	Cerro Prieto
Messina	1983	1	17	12:41	7.0	23	0.165	Argostoli
Kobe	1995	1	17	05:23	7.2	30	0.224	Abeno

Table 2: Earthquake accelerograms selected for design scenario.

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The spectra of the five selected records, scaled to the design acceleration of 0.175g, were generated for 5% of critical damping. These spectra are shown in Fig.3 and the average of the five spectra is shown in Fig.4 together with the spectrum for rock sites according to Eurocode 8, anchored to the same effective design acceleration. The EC8 spectrum, with a maximum amplification of 2.5, fits the data very well and is slightly higher at most periods.

Seismic Demand According to the Egyptian Building Code

Red Sea shores are considered as zone 3 (highest Risk Zone) according to the Egyptian code for seismic design (loading code). This calls for a Zone factor of $Z=0.30$. All seismic design criteria are considered in the Egyptian code as for: (I) (Importance factor); (K) factor to represent the level of ductility in the structure; (C) factor to represent the dynamic response of the structure and the Soil factor to represent various types of soils. The seismic design equation and procedure are similar to the UBC88. Nevertheless, a few restrictions and modifications were applied to adapt the local construction practice. One of the suggested revisions or modifications is not to exempt the twelve meter height structures (beam and slab type) from seismic design. This is due to the failure of an eleven meters height Hotel in the 22 November 1995 earthquake (Baracuda Hotel). Therefore it is not sufficient to assume that a rigid skeleton from beams and columns with minimum percentage of reinforcement is enough to resist the existing seismic hazard. However, it was proved from dynamic analyses of structures with Limited heights, that seismic demand will exceed the strength supply from minimum strength ratios mentioned earlier.

Concluding Remarks

The seismic hazard analysis has shown that there is an appreciable hazard in the area and seismic design is therefore required. The design acceleration, making relatively conservative assumptions in the analysis, is 0.175g and while this is significant, such a level of hazard does not make it necessary to undertake time-history analysis. The earthquake records that have been presented have been selected primarily to derive spectra for seismic analysis. In view of the huge investment in projects being constructed in the area, and due to its strategic importance, it is recommended to thoroughly apply structural studies for the construction projects in order to ensure a reasonable seismic safety level. This is suggested for all buildings, including the low-rise structures to avoid risk in the area.

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Fig 1 – Instrumentally recorded earthquakes from 1990 – 1992

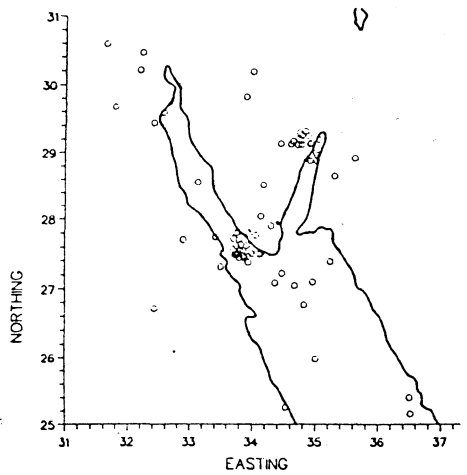


Fig 2 – Instrumentally recorded earthquakes from '64-'87 reported by International Seismology Center

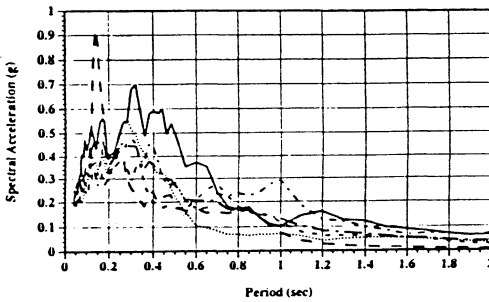


Fig – 3 Absolute acceleration response spectra for 5% damping of 5 accelograms for the earthquake scenario, normalized to a peak acceleration of 0.175 g

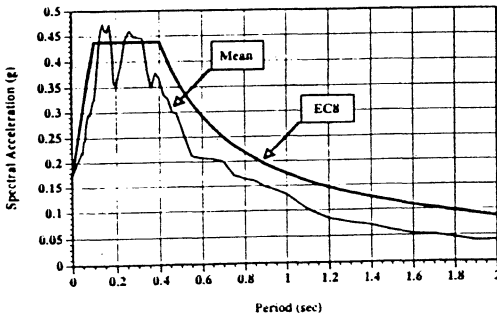


Fig – 4 Average of the 5 response spectra in fig 3 and the recommended elastic design spectrum