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SITING OF HIGH RISK INDUSTRIAL FACILITIES: THE REGIME OF NATURAL PHENOMENA SUCH AS EARTHQUAKES

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الخلاصة: يختص هذا البحث بوصف الطرق المستخدمة لتعريف معاملات الأمان النووى للمفاعلات النووية وتطبيقاته على المناطق ذات الصناعات عالية الخطورة على البيئة فى مصر. وتم ذلك بدراسة المخاطر ألزلزالية وحساب معاملات الأمان للمفاعلات النووية وتطبيقها على المناطق الزلزالية فى مصر. وقد تم استخدام طرق الاحتمالات لعمل خريطة لحساب أشد المناطق فى منطقه الدلتا ومصر العليا. ومقارنة النتائج بنتائج الوكالة العالمية للطاقة الذرية وأمريكا واليابان وألمانيا وايطاليا.

ABSTRACT: *This work deals with a description of the methodology for the definition of the design earthquake and associated topics for Nuclear Power Plants (NPPS) and applied it on high risk industrial facilities in Egypt.*

New Probabilistic strong ground motion maps at Delta and Upper Egypt are derived by applying the "Cornell-McGuire" method to 27 earthquake source zones in the Nile Delta area and Upper Egypt. The design basis of earthquakes is estimated for Egypt.

A comparison of the results of design basis earthquakes (operation basis earthquakes and safe shutdown earthquakes) with equivalent estimates made in International atomic Energy Authority (IAEA) , Italy, USSR, USA, Japan and Germany.

INTRODUCTION

The methodology for the definition of the design earthquake and associated topics for Nuclear Power Plants, is described in the IAEA Safety Guide 50 SG S1 Revision 1, (for which the Authors has worked for many years), and is briefly summarized by Serva (2004).

In selecting a site particular attention should be paid to two categories of earthquake-related features (Serva 2004):

Category (1): features that can have direct influence on the acceptability of the site

Category (2): features that can substantially influence the severity of the design basis earthquakes.

Category (1) features

It is active, capable faults at the site and/or potential for the occurrence of other unforeseeable geological hazards such as large landslides, liquefaction phenomena, karst collapses. If engineering solutions are not available or, if available, the cost of applying them is such that the project becomes economically infeasible, another site should be recommended. This is usually the case when a site is near one or more capable faults. A fault is considered capable if it shows evidence of past movement (significant deformation and/or dislocation) of a recurring nature within such a period that it is reasonable to infer that further movement can occur at, or near the surface. In highly active areas, where both earthquakes and geological observations consistently reveal short earthquake recurrence intervals, periods of the order of tens of thousands of years may be appropriate for the assessment of capable faults. In less active areas, it is likely that much longer periods may be required. When faulting is known or suspected, investigations should include detailed geological geomorphological mapping, topographical analyses, geophysical (including geodesy, if necessary) surveys, trenching, boreholes, determining ages of faulted sediments or rocks, local seismological investigations and any other appropriate techniques, to ascertain when the last movement occurred.

Category (2) features

Category (2) features define the parameters of the ground motion of the design-basis earthquakes. To reach this goal, it is necessary to compile a specific and complete database for the construction of a seismotectonic model from which the potential earthquakes affecting the site can be derived. These earthquakes are then used to define the nature of earthquakes used as a basis for design of the facility. Thus, it is essential to obtain an integrated geological and seismological database. The elements of this database should be studied in greatest detail in the region close to the site where it will be more complete. In this connection, four scales of investigation are appropriate:

- Regional, near regional, the vicinity of the site, and the immediate area of the site. The main purpose of the regional studies is to provide knowledge of the tectonic framework of the region and its general geodynamic setting and to identify and characterize those seismological features that may influence the seismic hazard at the site. The main purpose of the near regional investigations is to characterize the more important seismological structures for the assessment of seismic hazards.

- Investigation of the site vicinity, as already mentioned, is designed to define in greater detail the history of faults with the special purpose of resolving the possibility of surface faulting at the site (fault capability) and identifying sources of potential instability (Class 1 features).
- Investigations at the site area should emphasize the definition of the physical properties of the foundation materials and the determination of their stability and response under dynamic earthquake.

DETERMINATION OF THE DESIGN BASIS GROUND MOTIONS

At least two levels (SL-l and SL-2) of design basis ground motion are evaluated for each plant. The SL-2 level corresponds directly to ultimate safety requirements. This level of extreme ground motion will normally have a very low probability of being exceeded during the lifetime of the plant and represents the maximum level of ground motion to be used for design purposes. Its evaluation will be based on the seismotectonic model and a detailed knowledge of the geology and engineering parameters of the strata beneath the site area. The SL-l level corresponds to a less severe but more likely earthquake load conditions with safety implications that differ from those of SL-2. In some IAEA Member States, licensing authorities require only one level, the SL-2, which corresponds to a level with a probability of 10-4 per year of being exceeded. In other Member States, SL-1 corresponds to a level with a probability of 10-2 per year of being exceeded. The assessment of appropriate ground motion levels for SL-2 and SL-1 may involve analyses based on deterministic and/or probabilistic considerations.

DETERMINISTIC TECHNIQUES

As applied to the evaluation of SL-2, deterministic techniques involve:

(1) Reducing the seismotectonic model derived by the integration of the four scales of geological and seismological data, into seismogenic structures

(2) Identifying the maximum earthquake potential associated with each seismogenic structure.

(3) Performing the evaluation as follows:

(a) For each seismogenic structure the maximum potential earthquake should be assumed to occur at the point on the structure closest to the site area taking into account the physical dimensions of the source. When the site is within the boundaries of a seismogenic structure, the maximum potential earthquake shall be assumed to occur under the site. In this case special care should be taken to demonstrate that the seismogenic structure is not capable.

b) An appropriate attenuation relation should be used to determine the ground motion level which each of these earthquakes would cause at the site, with consideration of the local site conditions.

PROBABILISTIC TECHNIQUES

The probabilistic technique involves the following steps:

(1) Refining the seismotectonic model in terms of source type (e.g. volume, area, linear, point sources), geometry and depth.

(2) For each source, identification of the following parameters (including their uncertainties):

- Magnitude-frequency or intensity-frequency (recurrence) re1ationships
- Maximum (or cut -off) magnitude or maximum intensity
- Attenuation relationships.

(3) Choice of appropriate stochastic models (e.g. Poisson, Markov, cluster, renewal).

(4) Evaluation of the best estimate hazard curve, with appropriate confidence intervals, Illustrating the dispersion.

(5) Use for design purposes of those levels of ground motion at which probabilities of being exceeded meet the safety standards set by the Member State.

The characteristics of the design basis ground motions for SL-1 and SL-2 level earthquakes is expressed in terms of response spectra for a range of damping values and compatible time histories. Several methods can be used to generate the design response spectra: Standard response spectrum, Site-specific response spectrum, Uniform confidence response spectrum. In selecting the damping values to be used for the design response spectra for SL-1 and SL-2, it is important to bear in mind both the damping values associated with structures for which the response spectra will be used and the level of strain/stresses be induced in these structures. Time histories corresponding to both SL-l and SL-2 are developed for use in applications such as studies of non-linear behavior of structures, soil-structure interaction, and equipment response. These time histories should reflect all of the prescribed design ground motion parameters including duration.

EARTHQUAKES DATA

The historical records differ worldwide greatly in their period, completeness and quality of the earthquake histories. Egypt is one of the few regions in the world where evidence for the occurrence of historical earthquakes have been recorded. Although Egypt is an area of relatively low seismicity, it has experienced some damaging shocks. Figure (2) shows the epicenteral distribution of earthquakes in El-Dabaa area and its vicinity. The basic parameters of these earthquakes are listed after Maamoun et al. (1984) and Ambraseys et al.(1994) The earthquake data were taken from the earthquake catalogues (Ambraseys et al. (1994), Poirer & Taher (1980), the seismological Bulletin of Israel, seismicity of Egypt (Maamoun et al. 1984) and international Seimological Bulletin data base).

METHODS

Earthquake Source Model:

The seismic source model produced for this study contains fourteen source zones. The principles on which it is constructed are the subdivision of the study area into component tectonic features, while reflecting the distribution of seismicity. The basis of the source zonation was the work accomplished by El-Sayed, (1996), Penza et al.(1999). Some effort was required to arrive at a single, usable zonation model for the whole region. While it was obviously desirable to keep as much as possible the idea expressed in the references above, some alterations was needed for the following reasons:

- To reconcile interpretations where differences existed;
- To insure that the zonation adequalty reflected the seismicity pattern;
- To eliminate zones too small to be analyzed;
- To obtain a seamless coverage over the entire study area;
- To make such simplifications as were necessary for the production of a hazard map.

The zonation is shown in Fig. (2) and the tectonic map is shown Fig. (1). The Gutenberg-Richter parameters *a* and *b* were calculated by list square method. Uncertainties in *a* and *b* values were also calculated (Table 1).

Geologic and Tectonic Setting:

1- Nile Delta Source Region

The structure of northern Egypt evolved during Oligocene and early Miocene times and has remained since almost inactive except the older lines. Although, the Nile passes through a seismo-active zone, no evidence of volcanic activity or major faulting is known for northern Egypt later than the Early Miocene. (Said,1964).

2- Mediterranean Sea Area

This area shows major faults affecting Mediterranean sea (after Said, 1981) and the epicentral distribution of earthquakes are located in our area.

3-Fayoum Area

Along this trend, small to moderate historical and recent earthquakes are observed and earthquakes focal are conformed within the crust and don't define any seismic plane. The moderate and first instrumentally recorded events in the Gilf El-Kebir area in 1978 may form the extension of this trend into the southwestern parts of the Western Desert although there are few earthquakes between the Fayoum and Gilf El-Kebir areas.

4- Southwest of Aswan Trend

The activity of this area is very local nature. There are sets of faults in an east-west direction in the Kalabsha area. The epicenters of earthquakes are located near a considerably wide area of the Lake

Attenuation:

A reliable evaluation of seismic hazard in a region requires the knowledge and understanding the seismicity and attenuation of strong ground motion. Therefore, the attenuation of strong seismic ground motion has received a relatively high attention in Egypt. The first study by Maamoun et al., 1984 used the available isoseismal maps to provide attenuation estimates for Egypt. The values of intensity were taken along a profile perpendicular to the long axis of isoseismal elliptical shapes. Applying a theoretical intensity-acceleration relationship, Maamoun et al. (1984) could transform their attenuation relationship to be in terms of peak ground acceleration**.**

PGA:

Ground motion acceleration usually plays the main role with regard to the structural damage in earthquakes and one of the basic parameters which is used to define earthquake ground motion (Giardini , 1999). Deif (1998) used the data obtained from the database of the European strong motion records, which were published by Ambraseys and Boomer (1991-1). Their data set contains the records of earthquakes in the region extending from Azores in the west to Pakistan in the east. All of the used records were taken from rocky or soil sites. A subset of the data for the Eastern Mediterranean region was extracted from the whole data set. The produced attenuation model is used in this study.

The model proposed by Joyner and Boore (1981) is adopted in his study. This model was selected because it is the most widely used attenuation law in Europe where the majority of the data set was recorded. The basic form of the attenuation model can be expressed as:

$$\log(a) = \alpha + \beta M - \gamma \log R + bR + \sigma \qquad (1)$$

where: a is the peak ground acceleration in (g) and M is its magnitude; R is the hypocentral distance assuming an average depth of 20 km of the used earthquakes and α, β, γ, and b are the model parameters. σ is the standard deviation of log (a).

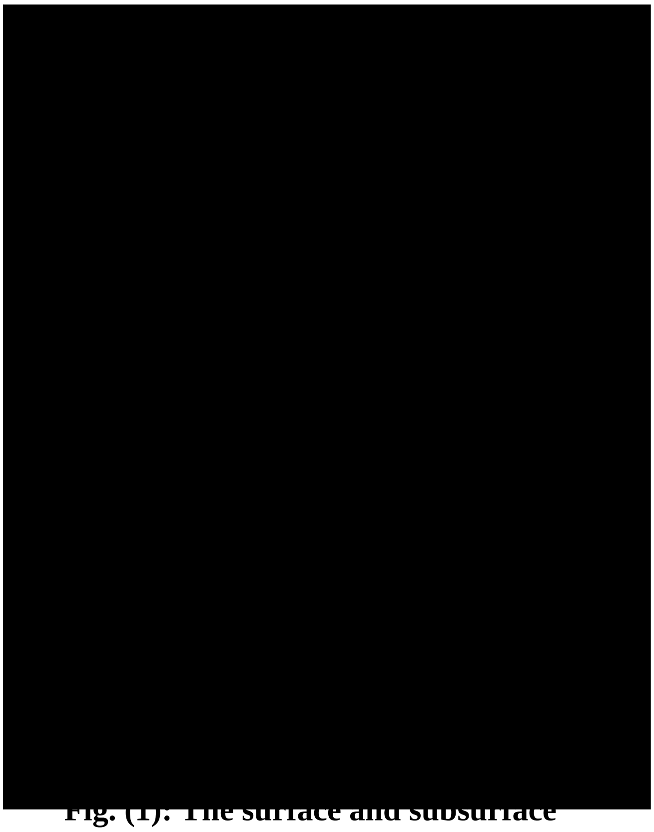

Fig. (1): The surface and subsurface faults of (After EGSMA, 1981)

Fig. (2): Selected seismotectonic source zones at Egypt study area.

Table (1): The a and b values for the selected seismic zones

Seismic Source	b-value	a-value	Seismic Source	b-value	a-value
Zone 1	-0.75	3.00	Zone 15	-.065	1.63
Zone 2	-0.85	2.35	Zone 16	-.057	1.35
Zone 3	-0.678	2.481	Zone 17	-0.76	2.33
Zone 4	-0.828	2.15	Zone 18	-0.85	4.61
Zone 5	-0.825	2.14	Zone 19	-0.89	3.21
Zone 6	-0.90	2.22	Zone 20	-0.75	2.85
Zone 7	-0.95	3.0	Zone 21	-0.890	2.409
Zone 8	-0.754	208	Zone 22	-0.75	2.85
Zone 9	-1.27	4.24	Zone 23	-0.75	2.53
Zone10	-1.064	3.87	Zone 24	-0.67	2.79
Zone 11	- 0.805	3.957	Zone 25	-0.847	2.829
Zone 12	-0.65	2.43	Zone 26	-1.00	4.06
Zone 13	-0.56	2.26	Zone 27	-1.00	3.68
Zone 14	-0.83	3.75	Back ground	-0.97	4.12

The above equation is a linear function of magnitude and of distance dependent terms. The first term represents the geometric losses and it is constrained to spherical spreading from a point source, while the second term accounts for anelastic losses (Ambraseys and Boomer, 1991-1).

Ambraseys and Bommer (*1991*-2) criticized the use of the two stages regression method due to the elimination of the earthquakes recorded in one station only. They stated that “mathematically, the optimum least squares fit on the data will be found by direct regression of equation (1) rather than the two stages regression. Applying the one step regression for equation (1), Deif (1998) found the attenuation model in terms of body wave magnitude as:

$$\log(a_h) = -1.86 + 0.385mb - \log R \qquad (2)$$

RESULT AND DISSECTIONS

Using the source zones, recurrence models, attenuation model and the hazard model of Bender and Perkins (1987), the seismic hazard map for Delta and upper Egypt is produced.

The contouring map is based on the estimated accelerations for a grid of 0.25 degree. Fig's (3-4) show the calculated peak ground acceleration at each grid point with probability 90% of not being exceeded in the next 50 and 100 years for the attenuation model of Deif (1998).

The overall view of these figures has a similar pattern. They define areas of high seismic hazard in terms of maximum expected ground acceleration. These

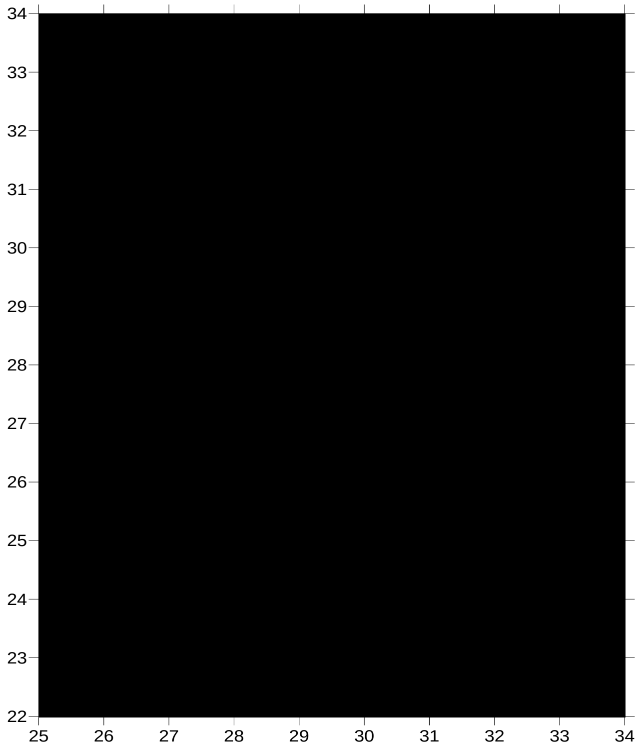

Fig. (3): Peak ground acceleration (gal.) with probability 90% of not being exceeded in the next 50 years.

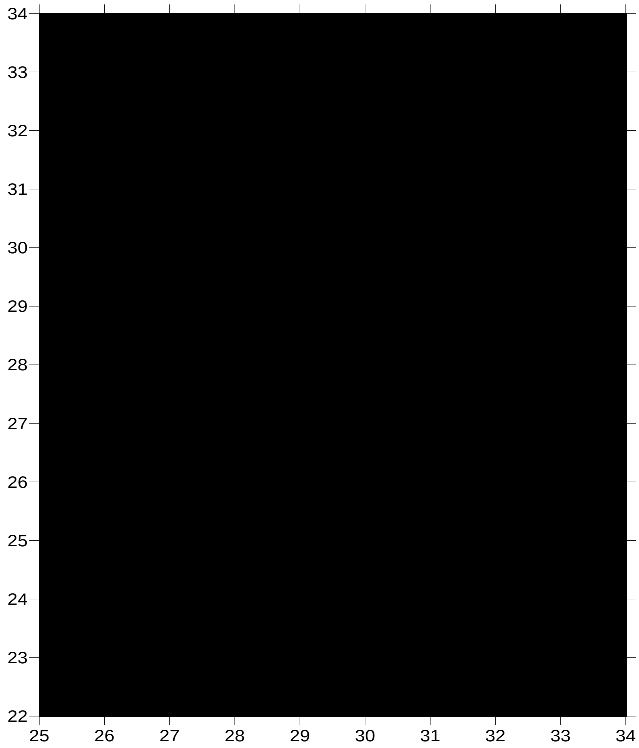

Fig. (4): Peak ground acceleration (gal.)with probability 90% of not being exceeded in the next 100 years.

Table 2: Minimum requirements and exclusion criteria for NPP's , iting and design (Serva 1993 & and modified by adding Egypt).

Code	Exclusion criteria	Minimum requirements
IAEA	Presence of capable fault at the site	Minimum SL2=0.1 g anchored to a site specific response spectrum
Egypt	Presence of capable fault at the site	Minimum SL2=0.16 g anchored to a site specific response spectrum
Italy	Area of historically observed intensity equal to (X) MCS (MMI or MSK) or greater. Presence of Capable fault at the site.	Minimum SSE=0.18 g anchored to a wide band standard response spectrum
Former USSR	Sites having a potential for intensity IX MSK or greater. In other words: NPP cannot be designed for more than 0.2 g.	Bearing capacity of the foundation soil > 0.2 kg/cm2
USA		Minimum SSE=0.1 g anchored with a wide band response spectrum
Germany	Presence of capable fault at the site	Minimum peak ground acceleration =0.05g
Japan	Sites having capable faults or close to faults having Quaternary slip-rate higher than 1 mm/y.	Foundation must be on sediments not younger than Tertiary. S2 shall withstand a near field earthquake (minimum distance 10 km) having M = 6.5

are the areas around El-Fayoum and the area around Aswan. The PGA values of maximum accelerations at 10% probability level for next 50 years are of about 120, 110 gals respectively. From the same contour maps the rest of the area under study is considered as an area of small seismic risk, as the values of the expected ground acceleration with probability 90% of not being exceeded in the next 50 years do not exceed 100 cm/sec^2 (gal).

The above two areas are the studied area where an acceleration of more than 0.15g expected to be maximum acceleration with 10% probability level in next 100 years

The results obtained with the probabilistic are similar to those from deterministic by (El-Sayed et. al. 2001). The considerable difference in some area may be related to the following factors: the probabilistic methods are very sensitive to the completeness of the catalogues and use simple attenuation laws that oversimplify the wave propagation phenomena

The Safe Shutdown Earthquakes (SSE) within Egyptian territory can generate ground acceleration to 0.12 & 0.14 for Delta area and Aswan respectively. The (SSE) for Western desert, Mediterranean Sea Coast and Red Sea area, 0.08, 0.1 & 0.16g., respectively (El. Fnawy et al. 2004). These values are extremely high for the area within a capable fault. Table 1 summarizes exclusion criteria and minimum seismic design for NPPs of some important Nations in nuclear industry. Data are taken from Serva, (1993). We can add Egypt to Serva table.

The quick look of this table (Serva2004) indicates that exclusion criteria depend mainly on the availability of suitable sites in a country, sensitivity of the technical and scientific community to the earthquake risk phenomenon and design restrictions against seismic loads for nuclear power plant. For example the exclusion criterion of intensity IX or over (MSK) in the former USSR (in other words, nuclear power plants were not designed for a seismic input exceeding 0.2 g) is obviously linked to the large availability of sites and to design restriction type reactors for coping high seismic loads. The minimum ground motion used as the basis for design at the site may be based on a near field or far field earthquake (or both). In the case of the near field earthquake, this is considered the maximum value of the random (floating) event, which in Japan can be as high as M=6.5. In Japanese practice however, it is assumed that this earthquake is not associated with surface faulting if in the site are present unfaulted terrains not younger than Tertiary (Serva, 2000). In Egypt, The same assumption is not appropriate when the value reaches IX MSK because such earthquakes should always be associated with structures detectable by state-of-the-art methods of geology and geophysics.

CONCLUSION

The main purpose of the present work is to provide guidance on the determination of the design basis ground motions for nuclear power plant. It has been described and commented because it looks the more appropriate one for using in the seismic design of the industrial plants. This is because this approach gives to the specialist a global view of the problem, pushing him to judge the level of information that is sufficient for making a reliable assessment, of the plant he is dealing with, taking into account its position (hazard level at the site) and cost. In other words, the detail required on the database (quality, quantity and type of geological, geophysical, seismological and engineering data) should be strictly linked to the level of risk/environmental impact of the plant under analysis. However a requirement that should remain the same is the Quality Assurance of the whole process in terms of data and their treatment (Serva, 2000).

This study deals with two parts, the first is estimate the (SSE) for Delta and Upper Egypt, as well as the (SSE) which calculated by (El-Adham &El-Hemamy,2004 and Hefnawy, et.al, 2004) to estimate the minimum seismic design for NPPs. Therefore, two maps of seismic hazard at different return periods for a Delta and Upper Egypt were constructed. These maps with the other maps at Red Sea and El-Dabaa area (El-Hefnawy et. al 2004) were used as a general guideline to regional distribution of seismic hazard in terms of peak acceleration values over the general area. They can also be used to calculate the (SSE). A comparison of the results of design basis earthquakes (operation basis earthquakes and safe shutdown earthquakes) with equivalent estimates made in IAEA, Italy, USSR, USA, Japan and Germany.

The second parts, applied these estimation on high risk industrial zone in Egypt, It is evident that there are no plants having the same level of risk of a NPP. However an industrial area containing different type of plants including some dealing with very toxic substances (Table 2) in the Author opinion, should be treated only a little less than an NPP. For some aspects, also a single plant dealing with very toxic material located in an intensively populated (e.g. downtown) area and a significant dam should be treated in a similar way Serva (2000).

The quick look of the methodology one can say it should be similar to the NPPs when we are dealing with a system of plants for which an accident can cause relevant risks on man and/or natural environment in term of a real extend and level of contamination (Serva 2004). A similar concept is expressed also by Gurpinar, 1997. In such a case, as for the nuclear, we should define, as design earthquake SL2 (SL1 in Seava,s, (2000) opinion is not necessary), the maximum potential earthquake, i.e. the ten thousands years return period earthquake. The engineering treatment of this earthquake can be significantly different from one defined in the nuclear and this theme is not treated here. Category 1 features should be analyzed in same detail of the nuclear

Table 2: Most hazardous industrial Plants (Serva, 2000)

For Man Large	Large VLPG storage plants. Large Chlorine storages. Phosgene storages and process users.
For Environment	Large diesel oil or fuel oil tank farms.

REFERENCES

Adham, K.A and El-Hemamy, S.T: Modeling of Seismic Hazard for El-Dabaa Area, Egypt, under pupliction, (2004)

Ambraseys, N. N., and Bommer, J. J. (1): Data base of European strong motion records, European Earthquake Eng., Vol. 5, No. 2 (1991).

Ambraseys, N. N., and Bommer, J. J. (2): The attenuation of ground accelerations in Europe, Earthquake Eng. struct. Dyn., Vol. 20, 1179-1202, (1991).

Ambraseys, **N. N., Melville, C.P., and Adams, R.D.:** The seismicity of Egypt, Arabia and the Red Sea, a historical review, King Abdul Aziz City for Science and Technology, Cambridge Univ. Press, Amsterdam, 1-137, (1994)

Bender, B., and Perkins, D.: SEISRISK III, A computer program for seismic hazard estimation, U. S. Geological Survey Bulletin, 1772, (1987).

Bender, B., and Perkins: DSEISRISK III, A computer program for seismic hazard estimation, U. S. Geological Survey Bulletin, 1772, ; 1987 .

Cornell, C.A.: Engineering seismic risk analysis, Bull. Seismol. Soc. Am., vol. 58, 1583-1606, (1968).

Deif, A.,: Seismic Hazard Assessment in and around Egypt in relation to plate tectonics, Ph.D. thesis, Ain Shams Univ., Cairo, Egypt, 1998

El -Adham, K. El-Hemamy, S.T.: Modeling of Seismic Hazard for El-Dabaa Area, Egypt**,** under Publication, (2004)

El-Hefnawy, M., El-Deaf, M, El-Hemamy & Mahmoud, M.: Probabilistic Assessment Earthquake Hazards at Sinai**,** under Publication, (2004).

El-Sayed , A. Seismic Hazard of Egypt, ph.d thesis, Seismological Department Uppsala University, Sweden, (1996).

El-Sayed, F.Vaccari and G.F. Penza, Determinestic seismic hazard in Egypt, geophys, J.Int., pp555-567, (2001)

Egyptian Geological Survey and Mining Authority: Geological map of Egypt, (1981)

International atomic Energy Authority; Earthquake and Associated Topics in Relation to Nuclear Power Plant Siting, IAEA, Safety Guide 50-SG-S1, Revision 1, Vienna, (1991).

Giardini D., 1999. The Global Seismic Hazard Assessment Program (GSHAP) – 1992/1999, Annali di geofisica, 42, 957-976

Gurpinar, A., A review of seismic safety considerations in the life cycle of critical facilities. Journal of Earthquake Engineering, Vol.1, pp. 57-76. Imperial College Press, London, U.K.(1997)

Joyner, **W. B., and Boore, D. M.; 1981:** Peak horizontal acceleration and velocity from strong motion records including records from 1979 Imperial Valley, California, Bull. Seism. Soc. Am., Vol. 71, 2011-2038.

Maamoun, M., Megahed, A. and Allam A., 1984, *Seismicity of Egypt*, Bullatin of the Helwan Institute of Astronomy and Geophysics. IV. pp 109-162

Panza, G.F, Romanelli, F. and Vaccari, F.; Seismic wave propagation in laterally heterogeneous anelastic media: theory and application to the seismic zonation. Advances in Geophysics, 43, 1-95. Academic Press, (2001

Poirier, J. P., and Taher, M. A.; 1980: Historical seismicity in the Near and Middle East, North Africa, and Spain from Arabic documents (VIIth-XVIIth century), Bull. Seism. Soc. Am., Vol. 70, 2185-2201.

Said, R.: Egitto. Encyslopedia of Petrolum, Rom 4: 8-75, (1961).

Said, R. the geological evaluation of the River Nile. Tspringer, 151pp, (1981).

Serva, L: An analysis of the major regulatory guides for NPP seismic design (a guideline for high risk. facilities). ENERGIA NUCLEARE, Anno 10, n° 2, Maggio-Agosto PP 77-96, Roma, (1993).

Serva, L, Blumetti,A.M., Guerrieri, L., Michetti, A.M.: The Apenninic intramountain basino: the results of repeated strong earthquakes over a geological time interval. Atti del Convegno: Evoluzione geologica e geodinamica dell'Appennino-In memoria del Prof. Giampaolo PIALLI. Foligno, 16-18 febbraio (2000).

Serva, L.: Siting of high risk industrial facilites**,** the role of natural phenomena such as earthquakes, internet, (2004).