SEISMIC HAZARD ZONATION AND DYNAMIC SITE PERIODS MAPPING FOR GREATER AMMAN MUNICIPALITY

BÜYÜK AMMAN BELEDİYESİ İÇİN DEPREM TEHLİKESİ BÖLGELENDİRME ÇALIŞMALARI VE ZEMİN PERİYODU HARİTALARI

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ABSTRACT

Seismic hazard maps were developed for the capital of Jordan Amman. These maps show the Peak Ground Acceleration (PGA) of bedrock for 90% probability of not being exceeded for an economical life time of 50, 100 and 200 years, respectively. The probabilistic PGA values were calculated based on the line source model incorporated in the computer program FRISK (McGuire, 1978). Ten distinctive seismic sources are identified in Jordan and vicinity. The pertinent parameters of each source, are determined from two sets of seismic data: the historical earthquake records and the instrumentally recorded earthquake data. Earthquake data used in this study have been extracted from several earthquake catalogues on the seismicity of Jordan and the neighbouring countries. An earthquake catalogue covering the period from 1 A.D. to December, 1992 was used. Acceleration attenuation relationship given by Esteva (1974) was used to estimate the peak ground acceleration. A rupture relationship based on empirical relationships of historical fault ruptures derived by Ambraseys and Barazangi (1989) was used.

Maps of dynamic site periods for Amman were developed by using the computer program SHAKE (Schnabel et al., 1972) in which several selected acceleration time histories were used, also analyses of local site effect was carried out for several selected soil columns.

INTRODUCTION

This study aims at developing seismic hazard maps for Greater Amman Municipality in Jordan, using micro-zonation analysis and utilizing the current probabilistic procedures. These maps include probabilistic estimates of Peak Ground Acceleration (PGA) for specified return periods. Furthermore dynamic site period maps were also being developed for Amman. The one-dimensional wave propagation program SHAKE (Schnabel et al., 1972) was used for this purpose.

Tectonics of Greater Amman

Amman is located on the Amman-Hallabat compressional structure belt, which runs from Siyagha on the NE corner of the Dead sea an area over looking the valley of Jordan named after

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the famous ancient church, to Qaser El-Hallabat, an ancient Ommayyad castle located 50 km east Amman, up to Ruseifa town. Greater Amman area lies, geologically speaking, between the high lands in the west next to the Jordan Rift. In this site, further increase in the stress is caused by continuous geologic and tectonic effect of the Arabian plate movement.

Seismic Hazard Assessment

Probabilistic seismic hazard assessment, generally, requires multi-disciplinary inquiry, on national, regional and site specific scales, with particular emphasis on the modelling of seismic sources, determination of magnitude-frequency relationships, determination of appropriate attenuation laws and probabilistic estimate of peak ground acceleration for specified return periods. McGuire (1978) developed a computer program named FRISK that allows incorporation of the above mentioned items. FRISK is based on the line source model (LSM). It has the capability of computing the probabilistic seismic hazard at sites affected by fault rupture during an earthquake event. Important uncertainties such as, magnitudes of future earthquakes, rupture length magnitude, maximum expected magnitude on the fault are incorporated. This program is used in this study. Following is description of relevant items related to the current study.

Identification of Seismic Sources

Identification of potential seismic sources is basically based on local geology, tectonic history and seismicity. Earthquakes in Jordan and vicinity has focal depths less than 30 km. Both historical and recent earthquake data of the area remarkably illustrate the close correlation between the geostructural setting with earthquake epicentral distribution. In fact, a close relation between earthquakes and active faulting on the surface is present. The association of earthquakes with well-defined faults forms a very important basis for identifying line sources.

Taking into consideration the available literature (Shapira et al. 1986 and Arieh 1991) and considering the regulations of the International Atomic Energy Agency in Vienna (1972), ten seismic sources have been identified which are relevant to the seismic hazard in Jordan and the vicinity. These sources are Aqaba Fault (No.1); Wadi Araba (No.2); Dead Sea-Jordan River (No.3); The Northern Fault (No.4); The South-East Mediterranean Fault (No.5); Wadi Fara'a-Carmel Fault (No. 6); The Wadi Sirhan Basalt Area (No.7); Al-Karak Fayha Fault (No.8); Suez Gulf Fault (No.9) and The Cyprus Seismic Source (No.10) and shown in Fig.1.

Rupture Length Magnitude Relation

In the Line Source Model (LSM) calculations, an essential factor to be considered is the amount of rupture length which results from an earthquake. A well accepted empirically determined equations, that is used in this study, was published by Ambraseys and Barazangi (1989) for Middle East region, this is as follows

$$M_s = 4.63 + 1.43 \log_{10} L \qquad (1)$$

where: M_s - is the surface magnitude; L - is the rupture length in km.

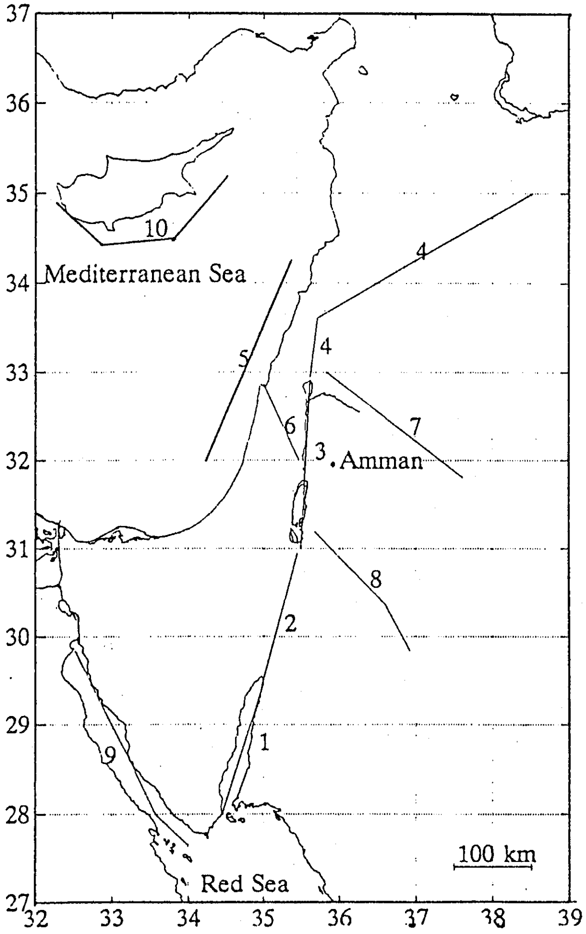


Fig. 1 10 Faults Considered in this Study to Assess the Seismic Hazard of Grater Amman Municipality.

Earthquake Catalogue

Earthquakes activities covering almost 2000 years, have been collected by several researchers. Yücemen (1985) compiled data up to 1980. Al-Tarazi (1992) compiled data on seismicity of Jordan up to 1989 A.D. In this study the assessment of seismic hazard in Jordan is based on the accumulated data on earthquake activities in Jordan and vicinity up to 1992 (Husein (Malkawi) et al. 1994). Historically recorded earthquake catalogue covering the period from 1 to 1900 A.D. and instrumentally recorded earthquakes covering the period from 1900 -1992 A.D. are compiled. These data are used to estimate the seismicity parameters for the identified faults in the studied area.

Estimation of Seismic Hazard Parameters

Seismic hazard parameters are estimated by using the method developed by Kijko and Sellevoll (1989) with an assumed threshold magnitude $m_o = 4.0$. The method gives the β ($\beta = b\,ln10$) or b parameter of the Gutenberg-Richter formula (Gutenberg and Richter, 1965), the annual rate of earthquakes λ_4, and the upper bound magnitude m_1. The method combines data from the largest historical earthquakes with complete instrumental data of variable threshold magnitude. Table (1) summarizes the results of the analysis so that the required parameters can be obtained. These parameters are used in the analysis as part of the input information for the computer program FRISK (McGuire, 1978).

Table 1 Seismic Hazard Parameters Used in This Study.

Name	b-value	β-value	λ_4(yearly)	m_o	m_1	Focal depth (km)
Wadi Araba	0.79	1.85	0.155	4.0	6.75	15
Aqaba Gulf	0.64	1.52	0.202	4.0	5.3	15
Dead Sea-Jordan River	0.89	2.06	0.31	4.0	7.5	15
Northern Fault	0.69	1.60	0.26	4.0	7.6	15
SE-Mediterranean	0.58	1.33	0.11	4.0	7.26	15
Farah & Carmel	0.78	1.8	0.19	4.0	5.7	10
Wadi Sirhan	0.79	1.88	0.054	4.0	7.5	10
Karak-Fayha	0.30	0.68	0.01	4.0	4.15	10
Sues Gulf	0.70	1.64	0.37	4.0	6.5	24
Cyprus Fault	0.57	1.31	0.790	4.0	7.5	30

Iso-Acceleration Maps

The Poisson model, is adopted in the analysis of the data. In addition, consideration are given to various types of sources surrounding a given site, their corresponding magnitude-frequency relationships, the maximum magnitude assigned to each source, the location and focal depth and the attenuation pattern characterizing the region under study. Then for a given probability of exceedence, specific hazard level, the PGA values can be computed. For the purpose of computation of PGA for the territory of Jordan, the region bounded by latitudes 29.0°N and 34.0°N and longitudes 34.0°E and 40.0°E was divided into a grid of squares. The accumulative probability distribution of PGA at each node of the grid is evaluated using the program FRISK. By interpolation of the PGA values of the closest points and by connecting the points of equal acceleration, the so-called acceleration contour lines are obtained. The maps obtained in this way represent the distribution of equal ground accelerations, that is, the seismic hazard at a given time and the probability that certain ground acceleration level would not be exceeded.

Attenuation of Peak Ground Acceleration

Due to the unavailability of strong motion records for the territories of Jordan. Several attenuation relationships were considered. The Esteva, (1974) attenuation relationship based on data collected from the west coast of the USA is adopted in this study as it gives conservative results in the near field ($R \leq 30$ km) compared to others investigated attenuation laws and is valid for the far field based on a study by Idriss (1978) who concluded that at increasing distances from the earthquake source the calculated PGA tends to give similar results regardless of the relationship used. The Esteva (1974) equation is given as:

$$PGA = \frac{b_1 e^{(b_2 m)}}{(R_h + b_4)^{b_3}} \tag{2}$$

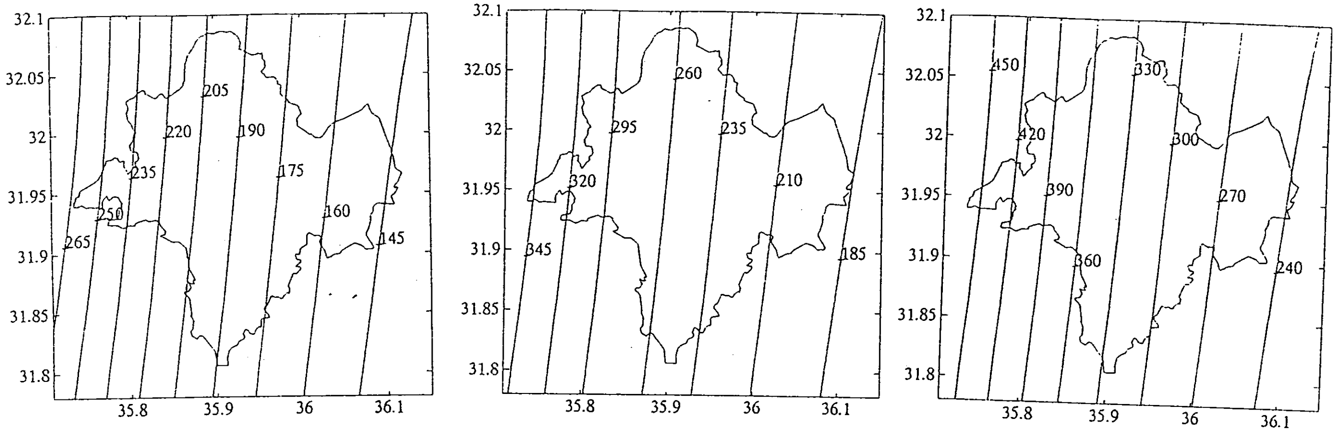
where:

PGA - Maximum Peak Ground Acceleration in cm/sec^2 on rock;
R_h - Hypocentral distance from source-to-site, in km;
m - is the earthquake magnitude;

b_1, b_2, b_3 and b_4 are constants derived by fitting a best-fit line to a set of data points collected in California, their values are 5600, 0.8, 2.0, and 40 respectively (Esteva, 1974). This attenuation equation is adopted for the calculation of PGA for each site specified and it is used to generate the iso-acceleration maps for the territories of Jordan.

Seismic Hazard Maps of Greater Amman Municipality

Maximum Peak Ground Acceleration maps with 90% probability of not being exceeded in a life time of 50 years, 100 years, and 200 years were evaluated (see Fig. 2).



(a)

(b)

(c)

Fig. 2a,b,c Maximum Peak Ground Acceleration (cm/sec^2) with 90% Probability of Not Being Exceeded in A Life Time of 50, 100 and 200 Years.

Local Site Effect Analysis

Geotechnical Data of the Studied Areas

Geotechnical data of the Greater Amman Municipality were evaluated in this study based on over 300 boreholes. These data are available from investigations carried out by the Natural Resources Authority (NRA), the Royal Scientific Society (RSS) and the Ministry of Energy and Mineral Resources in co-operation with the Federal Institute for Geo-sciences and Natural Resources, Hanover. Fig.3 shows some of the location of these boreholes.

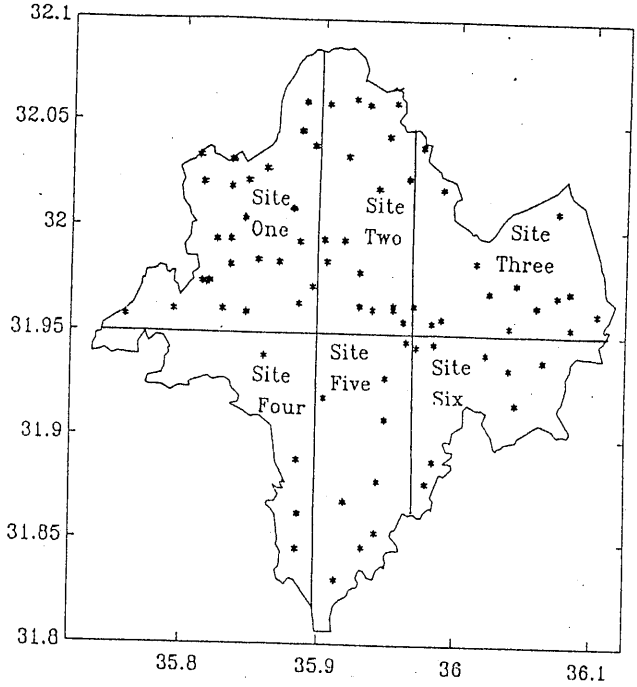


Fig. 3. Local Map of Greater Amman Municipality Divided into Six Zones Showing Location of Selected Boreholes.

Due to unavailability of data on cross-hole shear wave velocity, standard penetration test results were used in this study to evaluate the shear wave velocity. N-value, and the soil type were extracted from the boring logs of each borehole. Applying the empirical equations developed by Ohta and Goto (1979), the shear wave velocity V_s (m/sec) was evaluated. The empirical equations require the N-value, the soil type, and the depth of soil layering in meter.

Typical geological profiles of soil columns showing shear wave velocity variation with depth are given in Fig.4 for Greater Amman Municipality.

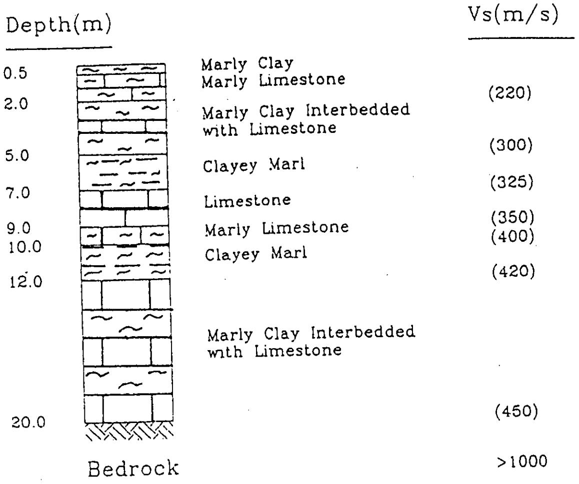


Fig. 4. Soil Column with Values of Shear Wave Velocity for Greater Amman Municipality, Sites 1 and 6 respectively.

Earthquake Input Motion

Dynamic Analysis requires time history of an earthquake as input to the computer program SHAKE. As strong motion time histories for the region under study and strong earthquakes from different parts of the world were selected, these earthquakes were of strike slip origin that is similar to the mechanism of the major earthquake source in Jordan (i.e. Dead Sea Fault). The earthquake time histories used in this study were the 1940 Imperial Valley Earthquake (El-Centro N-S), 1952 Taft Earthquake, and the 1992 Erzangan Earthquake (N-S).

Results of Dynamic Site Period

Maps showing the distribution of dynamic site period for Greater Amman were evaluated for all four input motions. The difference in the maps for different input motion represent the effect of frequency content on the distribution of dynamic site period. However, for each city an overall composite dynamic site period map was prepared. The composite map combines the results of the four maps corresponding respectively to the four strong motion earthquakes considered in this study. Fig.5 shows the composite dynamic site period maps for Greater Amman Municipality.

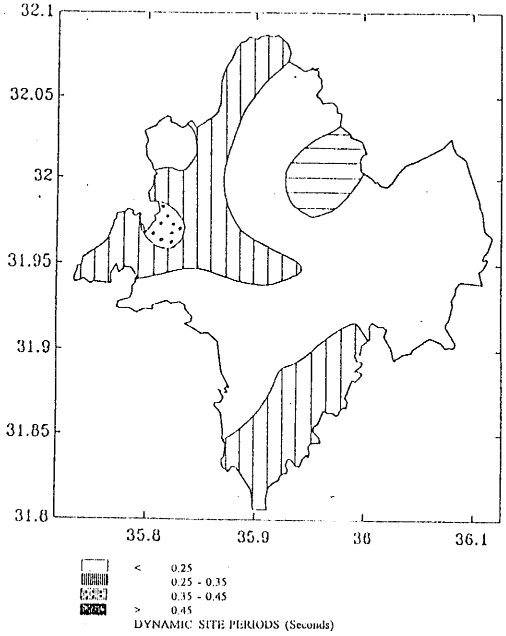


Fig. 5 Composite Dynamic Site Period Map for Greater Amman Municipality.

CONCLUSIONS

Probabilistic seismic hazard analysis has been carried out for Greater Amman, using the line source model developed by McGuire (1978). An updated earthquake catalogue was used covering the period from (1 A.D to 1992 A.D) including all earthquakes that occurred in Jordan and adjacent areas, more specifically between latitudes 27.0°-35.5° N and longitudes 32.0° -39.0° E.

Data sets of the historical earthquakes and the instrumentally recorded earthquakes, were used to estimate the seismic hazard parameters i.e., b parameter of Gutenberg-Richter relationship, the annual activity rate of earthquake λ_4, and the upper bound magnitude m_1, were evaluated for every seismic zone using the KS method (Kijko and Sellevoll 1989). These parameters were used as input in the computer program FRISK.

Based on the geologic, tectonic and seismological data and for the purpose of seismic hazard analysis, ten seismic sources have been identified. Attenuation equation developed by Esteva (1974) was used to compute the Peak Ground Acceleration using FRISK program. Results of seismic hazard analysis are presented in the form of seismic hazard maps. Seismic hazard maps corresponding to 90% probability of not being exceeded were presented in this study for 50, 100, and 200 years a life times of structure.

Maps of dynamic site period for Greater Amman were developed using the computer program SHAKE (Schnable, 1972) based on local geological and geotechnical data. Four strong motion earthquake records were used as input motion. The developed maps were obtained by combining the results corresponding to each of the four strong motion records.

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REFERENCES

1. Al-Tarazi E. (1992) "Investigation and Assessment of Seismic Hazard in Jordan and Vicinity", Berichte des Instituts Für Geophysik der Ruhr-Universität Bochum, Reihe A, Nr. 34, November.
2. Ambraseys, N. N. and Barazangi, M., (1989) "The 1759 earthquake in the Bekaa Valley: Implications for earthquake hazard assessment in the eastern Mediterranean region", J. Geophys. Res., vol. 94, pp. 4007-4013.
3. Arieh, E., (1991) "Refinement of earthquake hazard assessment in Israel", Annual meeting, Israel Geological Society.
4. Esteva, L., (1974) "Geology and probability in the assessment of seismic risk", Proc. at the 2nd International Congress of the International Association of Engineering Geologists, p. 14, Sao Paolo.
5. Gutenberg, B. and Richter, C. F., (1965), Seismicity of the Earth, 310pp., Hafner, New York and London.
6. Husein (Malkawi), A.I.; A.S. AL-Homoud; and R.Y. Liang (1994)"Seismic hazard mapping of Jordan" Quarterly Journal of Engineering Geology, 27, 39-50.
7. Idriss, I. M., (1978), "Characteristics of Earthquake Ground Motions", Proc. Specialty Conf. on Earthquake Engng. and Soil Dyn. ASCE. Pasadena, California, June.
8. International Atomic Energy Agency, (1972) "Earthquake guidelines for reactor siting", Tech. Reports, Series No. 139, pp.25, Vienna.
9. Kijko, A. and Sellevoll, M. A., (1989) "Estimation of Earthquake Hazard Parameters from Incomplete Data Files. Part I. Utilization of Extreme and Complete Catalog with different Threshold Magnitudes", Bull. Seis. Soc. Am., vol. 79, pp. 645-654.
10. McGuire, R.K., (1978) "FRISK- A Computer program for Seismic Risk Analysis", U.S.Dept. of Interior, Geological Survey: Open -File Report 78-1007.
11. Ohta, Y. and Goto, N., (1979) " Empirical Shear Wave Velocity Equations in Term of Characteristic Soil Indexes", Earthquake Engineering and Structural Dynamics, Vol. 6, pp. 167-187.
12. Schnabel, P. B., Lysmer, J., and Seed, H. B., (1972), "SHAKE-A Computer Program for Earthquake Analysis of Horizontally Layered Sites", EFRC 70-10, University of California, Berkeley, CA.
13. Shapira, A.; Manor, O.; Oman, D., and Sheshinsky, R. (1986) "The empirical relation of earthquake epicentres to mapped faults in Israel", Israel J. of Earth Sciences, Vol. 35, pp. 149-157.
14. Yücemen, M. S. (1985), "A Probabilistic Assessment of Seismic Hazard in Jordan: Preliminary Results", Second Jordanian Geological Conference, 22-24 April, Amman, Jordan.