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SYNOPSIS An up-to-date seismic hazard maps for Jordan and conterminous areas have been developed based on probabilistic approach. Such maps are intended to show the Peak Ground Acceleration (PGA) with 90% probability of not being exceeded in a life time of 50, 100, and 200 years, respectively. The computer program FRISK was used for estimating the PGA. A suitable attenuation equation reported in the literature, along with up-to-date earthquake catalogue including all the earthquake events that occurred in Jordan and neighboring countries, were considered in this study. Altogether, ten seismic zones as potential of earthquake activities are identified in the assessment of the seismic hazard maps. These are Aqaba Gulf fault, Wadi Araba fault, Dead Sea fault, Northern fault, SE-Mediterranean fault, Farah and Carmel faults, Wadi Sirhan fault, Karak-Fayha fault, Suez Gulf fault, and Cyprus zone fault.

INTRODUCTION

Seismic hazard analysis plays an important role in making decisions of constructing various civil engineering facilities, such as dams, buildings, nuclear power plants facilities and industrial plants. The assessment of seismic hazard is based generally upon two different approaches: deterministic and probabilistic approach. The deterministic approach does not account for the uncertainties in the size, location, occurrence and time of seismic events and other characteristics of future earthquakes. On the contrary, it adopts the most conservative values for these factors which entail extremely conservative design requirements. Considering the randomness of earthquake occurrences with respect to time, magnitude and the various sources of uncertainties, a probabilistic approach appears to be more appropriate.

The aim of this study was to produce seismic hazard maps for Jordan by utilizing the current probabilistic procedures. These maps will contain probabilistic evaluation of the peak ground acceleration (PGA) (for a given return period and a certain life time of the structure) and they will be used to form the basis for the assessment of seismic hazard for public facilities in Jordan. The computer program FRISK for seismic risk analysis using faults as earthquake sources will be adopted herein after some modifications.

TECTONICS OF JORDAN

The tectonics of Jordan is mainly related to the tectonics of the Middle East and Eastern Mediterranean region. According to the tectonic plate theory, the tectonics of Jordan are controlled mainly by the African, Eurasian, and Arabian plate movement. The movements between the Arabian and African plates mainly occur along the Jordan Dead Sea transform fault system.

Tectonically, the Dead Sea fault of 1000 Km length, is the most conspicuous element influencing the seismic activity of Jordan and surrounding areas. It strikes in a N-NE direction, and extends from the Aqaba Gulf northward along the Wadi Araba, Dead Sea and Tiberias to central Lebanon, and terminates in southern Turkey.

UPDATED EARTHQUAKE CATALOGUE

Jordan is a unique example of an area for which information and documentation of historical earthquakes covering almost 2000 years are available. One of the oldest sources of documentation is the Bible, in which we find distant echoes of tectonic events as far as 2000 B.C. In Jordan, interest in seismicity started in 1966 when work on the Khalid Bin El-Walid dam on Yarmouk river began, and afterwards on King Talal dam on Zarqa river in 1972. The first permanent seismic station in Jordan was installed in the Jordan University in Amman in June 1981.

HISTORICAL EARTHQUAKES

In order to take full advantage of strong earthquake events for statistical analysis, records were collected for a period dating back to 1900 when earthquake events were first recorded instrumentally in this region. Also, historical earthquakes which shook ancient cities were taken into account. During the last two thousand years many destructive earthquakes affected this region, some with disastrous consequences in large areas. These historical earthquakes have been published in many catalogues in this century. All of the earthquakes which occurred in the Jordan-Dead Sea transform area between the latitudes of 27.00 and 35.50 N and the longitudes of 32.00 and 39.00 E were collected. All catalogues and historical data reports were used, (e.g. Abou-Karaki, 1987 and Al-Tarazi, 1992, Husein (Malkawi) et al. (1994).

Earthquake monitoring in the Jordan Dead Sea transform area has progressed gradually in this century. Many lists and catalogues of instrumentally recorded earthquakes have been compiled, e.g. Ben-Menahem (1979), Abou-Karaki (1987), Al-Tarazi (1992), and Husein (Malkawi) et al. (1994).

All the instrumentally recorded earthquakes which occurred in this study area (latitudes of 27.00^{o} and 35.50^{o} N and longitudes from 32.00^{o} to 39.00^{o} E) were considered. The first covers the time period 1900-1989 (Al-Tarazi, 1992), the second covers the period 1990-1991 (Husein "Malkawi" et al. 1994). This catalogue was updated in this study to cover all events occurred in 1992. All available catalogues, bulletins and lists containing instrumental earthquakes data, the bulletins of the International Seismological Summary (ISC), the Jordan Seismological Observatory (JSO), the Institute for Petroleum Research and Geophysics (IPRG), and the monthly listing of the Preliminary Determination of Epicenters (PDE), published by the National Earthquake Information Service (NEIS) were utilized.

IDENTIFICATION OF SEISMIC SOURCES

Based on seismic maps shown in Figs. 1 and 2, and according to previous studies of Ben-Menahem et al. (1982), Abou-Karaki (1987), Arieh (1991), Al-Tarazi (1992), and the regulations of the International Atomic Energy Agency in Vienna (1972) and of the U.S. Atomic Energy Commission (1973), ten seismic faults have been identified in order to analyze the seismic hazard in Jordan and its vicinity. These faults are shown in Figs. 3 and 4. The historical seismicity of these faults is demonstrated in Fig. 3. Figure 4 shows the instrumental seismicity of the area. It is observed that there is high seismic activity along the faults Nos. 1, 3, 4, 5, 6, 7, and 10.

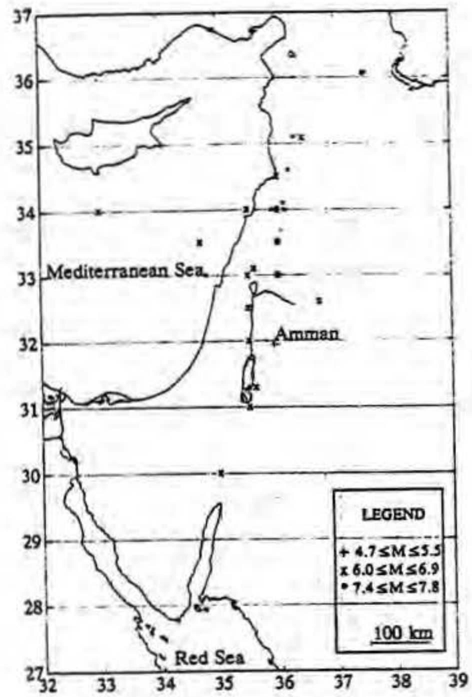

Fig. 1. Historical earthquakes (52 events) After Al-Tarazi, 1992.

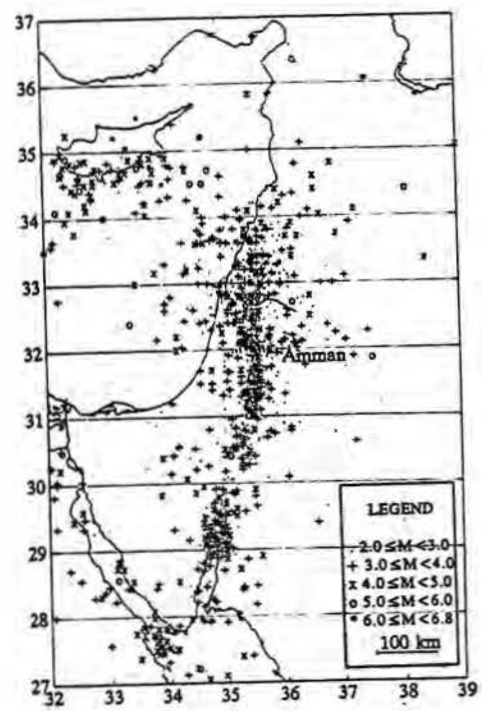

Fig. 2. Instrumentally recorded earthquakes (1291 events)

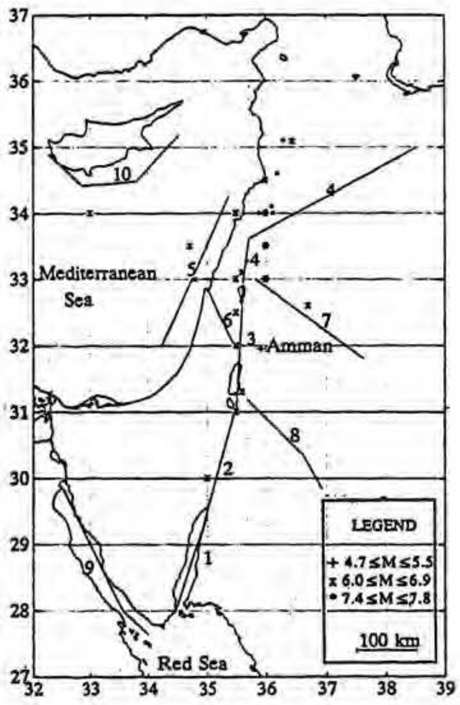

Fig. 3. Ten Faults Considered in this study accompanied with historical Earthquake events

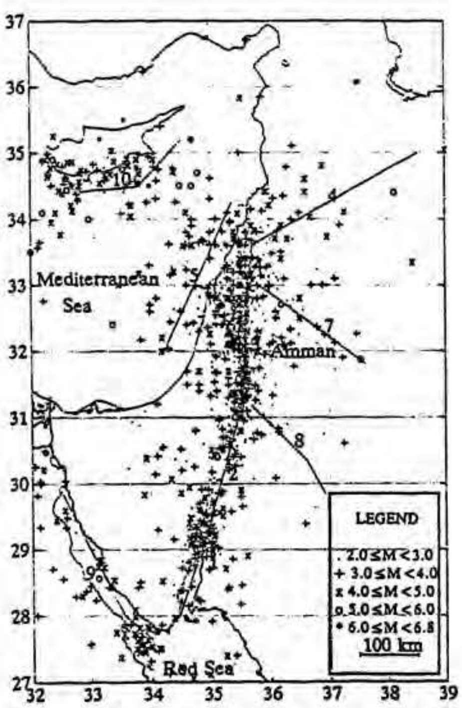

Fig. 4. Ten Faults Considered in this study accompanied with Instrumentally recorded Earthquakes

A brief description of the identified seismic faults affecting the study area is follows: I) Aqaba Gulf Fault (No.1). II) Wadi Araba Fault (No.2). III) Dead Sea-Jordan River Fault (No.3). IV) The Northern Faults (No.4). V) The South East Mediterranean Fault (No.5). VI) The Wadi Farah-Carmel Faults (No.6). VII) The Wadi Sirhan Basalt Area (No.7). VIII) Karak-Fayha Fault (No.8). IX) Suez Gulf Fault (No.9). and X) The Cyprus Zone Fault (No.10)

SEISMIC HAZARD PARAMETERS

The seismic hazard parameters include the b-parameter in the Gutenberg-Richter relationship, the annual activity rate of earthquake λ, and the maximum regional magnitude (m_1). These parameters were determined using the Kijko and Sellevoll (1992) methodology. The methodology determined the relevant parameters utilizing information of the strong events contained in the historical part of the catalogue as well as that contained in the complete instrument catalogue. In this study, the method was used to evaluate the seismic parameters using both historical (extreme) and Instrumentally recorded earthquake events catalogue (complete).

According to the analysis by Kijko Sellevoll program, the faults parameters used in seismic hazard analysis is presented in Table 1. The table also contains the following parameters the annual activity rate of earthquake λ_4, β-parameter (β=bln10), the upper bound magnitude (m_1) with the standard error showing the uncertainties of the maximum observed magnitude. The threshold magnitude (m_0) for the seismic faults is considered to be 4.0. The focal depth is taken here to be the average of the focal depths of the earthquakes occurred in each source.

Table 1. Seismic Hazard Parameters determined in this study (Modified after Husein (Malkawi) et al. 1994).

Fault Name	b-parameter	β-value	λ_4	m_0	m_1	Focal Depth (KM)
Aqaba Gulf	0.64±0.06	1.52±0.12	0.202±0.06	4.0	5.30	15.0
Wadi Araba	0.79±0.05	1.85±0.12	0.155±0.04	4.0	6.75	15.0
Dead Sea-Jordan River	0.89±0.03	2.06±0.07	0.310±0.03	4.0	7.50	15.0
Northern Faults	0.69±0.03	1.60±0.06	0.260±0.05	4.0	7.60	15.0
SE-Mediterranean	0.58±0.05	1.33±0.12	0.110±0.03	4.0	7.26	15.0
Farah & Carmel	0.78±0.04	1.80±0.10	0.190±0.06	4.0	5.70	10.0
Wadi Sirhan	0.79±0.06	1.88±0.13	0.054±0.01	4.0	7.50	10.0
Karak-Fayha	0.30±0.10	0.68±0.34	0.010	4.0	4.15	10.0
Suez Gulf	0.70±0.08	1.64±0.18	0.370±0.06	4.0	6.50	24.0
Cyprus	0.57±0.10	1.31±0.23	0.790±0.13	4.0	7.50	30.0

SEISMIC HAZARD MAPS FOR JORDAN

Using the parameters extracted from Kijko and Sellevol method presented in Table 1 and the available seismicity of the faults information, the analyses to assess the seismic hazard for Jordan were carried out using the computer program FRISK (McGuire, 1978). To ease the work, the FRISK output was modified in order to fit the requirement input of the Matlab™ program.

The most suitable attenuation equation for Jordan is the one presented by Esteva in 1974, which was developed based on strong motion data of the West Coast of U.S.A and East Coast of Mexico. The Esteva equation is given as:

$$PGA = \frac{b_1 e^{(b_2 m)}}{(R_h + b_4)^{b_3}} \qquad (1)$$

where:

PGA - Maximum Peak Ground Acceleration on the bed rock in cm/sec^2

R_h - Hypocentral distance from source to site in km

m - the earthquake magnitude

b1, b2, b3, and b4 are constants and their values are 5600, 0.8, 2.0 and 40, respectively.

To describe the rupture length-magnitude relationships for the previously mentioned faults, the Ambraseys and Barazangi formula (1989) is used herein. The formula stated below is derived based on earthquakes data for the Middle East region.

$$M_s = 4.63 + 1.43 \log_{10}(L) \qquad (2)$$

where M_s is surface magnitude, L is the rupture length (KM).

The software (Matlab™) is used to present the output in a form of figures including the local map of Jordan and the peak ground acceleration (PGA) in contour maps form. Three different maps were developed for three different life times of structures (mainly 50, 100, 200 years).The above mentioned maps are presented in Figs. 5, 6, and 7.

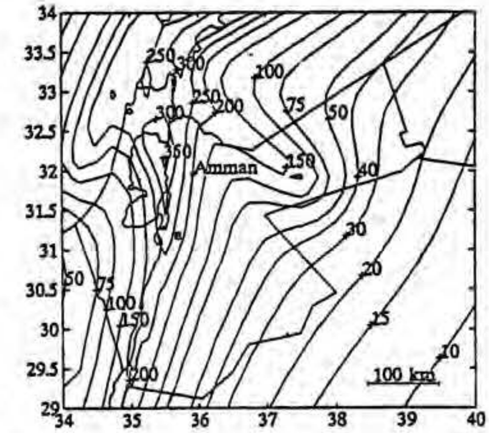

Fig. 5. Maximum Peak Ground Acceleration (cm/sec^2) with 90% probability of not being exceeded in a life time of 50 years.

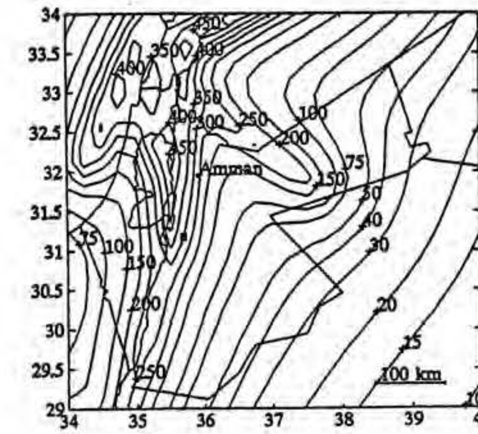

Fig. 6. Maximum Peak Ground Acceleration (cm/sec^2) with 90% probability of not being exceeded in a life time of 100 years.

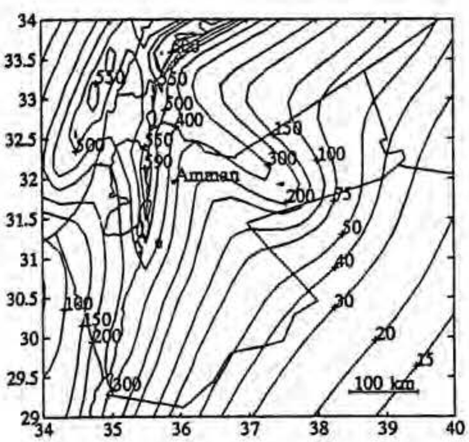

Fig. 7. Maximum Peak Ground Acceleration (cm/sec^2) with 90% probability of not being exceeded in a life time of 200 years.

SUMMARY AND CONCLUSIONS

A probabilistic method was used to assess the seismic hazard of Jordan. Updated earthquake catalogues, which include all the earthquakes that occurred from 1 A.D. to 1992 A.D. in Jordan and adjacent areas, more specifically between latitudes 27.0°-35.5°N and longitudes 32.0°-39.0°E, were used in this study. The seismic sources were identified. These are Aqaba Gulf fault, Wadi Araba fault, Dead Sea fault, Northern fault, SE-Mediterranean fault, Farah and Carmel faults, Wadi Sirhan fault, Karak-Fayha fault, Suez Gulf fault, and Cyprus zone fault.

The Peak Ground Acceleration (PGA) was selected as a measure of the ground motion severity. A suitable attenuation equation reported in the literature was selected for PGA computations. The computations were carried out using FRISK computer program. The seismic hazard maps corresponding to 90% probability of not being exceeded were presented for a life time of structures (i.e., 50, 100, and 200 years)

The major hazard level in the area under study is due to the Dead Sea fault, where it was found that the peak ground acceleration (PGA) for life time of structures of 50 years is in the range of 0.3g to 0.34g. For 100 years life of structure the PGA is in the range of 0.4g to 0.44g and for 200 years life of structures the PGA is in the range of 0.54g to 0.58g.

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