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Chapter VI

Magnitude-intensity and intensity-attenuation relationships for Atlas and Algerian earthquakes

1. Introduction

This chapter presents the results of a study of the magnitude-intensity and intensity-attenuation relationships for earthquakes in the Atlas zone and Algeria.

Despite the increase in numbers of strong-motion accelerographs, intensity continues to be a necessary measure of the size of ground shaking in earthquakes. When evaluated consistently for large enough number of earthquakes to represent the seismic activity of a region, macroseismic intensity, as other semi-empirical measures, may disclose regular isoseismal models which can be taken as a simple radiation pattern associated with a point source. This approach remains very practical for an efficient evaluation of the interaction between earthquakes and environment, and thus seismic hazard and risk. The attenuation of intensity with epicentral distance constitutes the cornerstone parameter when assessing seismic hazard at a given site. Also, the spatial distribution of intensity may be used to assign magnitudes to earthquakes without instrumental data, but for which isoseismal radii and intensities are known. Both relationships, namely intensity-attenuation and magnitude-intensity, are obtained by deriving empirical correlations between intensity, magnitude and epicentral distance for earthquakes for which instrumental magnitude as well as isoseismal maps are available. For this purpose an earthquake data set sample for the area was completely revised.

2. The data

The data used in the analysis are based on a selection not only of the most important from the human point of view, but also the most revealing earthquakes to have occurred in the Atlas region during the twentieth century and for which instrumental and macroseismic information are available (see Chapter III). These events, which are listed in table I, are considered as a representative sample of the seismicity in the region under consideration, they cover fairly well the seismic activity of the Atlas region in this century. Most of these events have had their macroseismic data completely reevaluated using primary sources of information (see Appendix B). Intensity has been re-estimated according to the Medvedev-Sponheuer-Karnik – MSK – 1981 intensity scale and the surface-wave magnitudes M_S have been determined by using instrumental data.

The data sample includes 32 selected isoseismal event maps; among these, 24 were constructed anew in this study: 23 isoseismal event maps for Algerian earthquakes and one a Moroccan event. In order to obtain a more representative sample for the

Table 1. Selected data of the events used in the regression analysis for the determination of magnitude-intensity and intensity-attenuation relationships in the Atlas and Algeria.

Event N.	Date	Epicentre		M_S	Mean radius (km) of isoseismals (MSK)								Site
					D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	
1	1903 Sep. 23	36.00N	2.83E	5.60	–	–	–	34	–	–	–	–	Moudjebeur. AL
2	1908 Aug. 4	36.41N	6.61E	5.23	–	–	–	–	21	13	–	–	Constantine. AL
3	1922 Aug. 25	36.40N	1.30E	5.10	98	56	–	–	18	7	–	–	Tenes. AL
4	1924 Mar. 16	35.40N	5.80E	5.35	–	–	–	–	21	8	–	–	Mac-Mahon. AL
5	1924 Nov. 5	36.60N	3.00E	4.80	86	53	32	20	14	6	–	–	Ben Chabane. AL
6	1928 Aug. 24	35.90N	0.90E	5.40	113	–	42	–	–	9	–	–	Inkermann. AL
7	1934 Sep. 7	36.30N	1.70E	5.10	100	60	42	28	9	–	–	–	Carnot. AL
8	1936 Oct. 14	32.00N	6.20W	4.90	–	52	43	30	–	–	–	–	Tilougit. MO
9	1937 Feb. 10	36.40N	7.50E	5.20	103	48	52	35	22	0	–	–	Guelma. AL
10	1943 Apr. 16	35.90N	4.00E	5.30	–	–	–	–	20	9	–	–	Mansoura. AL
11	1946 Feb. 12	35.70N	4.82E	5.55	125	–	51	–	28	13	–	–	Berhoum. AL
12	1947 Aug. 6	36.31N	6.68E	5.00	67	45	32	24	17	8	–	–	Constantine. AL
13	1949 Feb. 17	36.52N	5.24E	4.74	77	48	34	20	9	–	–	–	Kherrata. AL
14	1950 May. 10	32.70N	5.50W	5.30	165	119	71	26	–	–	–	–	Kerrouchen. MO
15	1954 Sep. 9	36.31N	1.47E	6.70	280	–	138	–	48	34	24	15	Orléansville. AL
16	1955 May. 8	36.53N	1.46E	4.75	95	57	–	22	11	–	–	–	Boucheral. AL
17	1955 Jun. 5	36.31N	1.50E	5.31	104	–	45	27	–	–	–	–	Beni Rached. AL
18	1959 Nov. 7	36.38N	2.55E	4.90	110	68	40	24	16	9	–	–	Bou Medfaa. AL
19	1959 Dec. 12	35.72N	0.56W	4.55	84	53	28	18	11	–	–	–	Oran. AL
20	1960 Feb. 21	36.04N	4.17E	5.12	80	–	40	–	22	13	–	–	Beni Ilman. AL
21	1960 Feb. 29	30.45N	9.62W	5.70	242	178	97	22	14	10	–	–	Agadir. MO
22	1960 Dec. 5	35.58N	6.54W	4.70	–	–	30	–	–	–	–	–	Atlantic Coast. MO
23	1964 Nov. 15	34.85N	5.47W	4.50	75	54	18	–	–	–	–	–	Ouezzane. MO
24	1965 Jan. 1	35.61N	4.40E	5.45	121	79	56	36	–	13	–	–	M'Sila. AL
25	1968 Apr. 17	35.24N	3.73W	4.80	75	48	30	–	–	–	–	–	Boudinar. MO
26	1970 Apr. 7	34.87N	3.90W	4.50	–	36	22	–	–	–	–	–	Adjir. MO
27	1977 Jan. 19	36.56N	8.43E	4.60	55	41	23	15	6	–	–	–	Ain Soltane. TU
28	1980 Oct. 10	36.16N	1.40E	7.45	425	257	203	130	70	44	21	–	El-Asnam. AL
29	1985 Oct. 27	36.34N	6.92E	5.70	125	95	60	38	20	9	–	–	Constantine. AL
30	1986 Jan. 28	31.98N	5.39W	4.90	127	66	21	–	–	–	–	–	Khenifra. MO
31	1988 Apr. 9	31.44N	9.75W	4.20	46	31	22	–	–	–	–	–	Atlantic Coast. MO
32	1989 Oct. 29	36.78N	2.44E	5.68	153	112	56	43	19	9	–	–	Chenoua Mount. AL

AL: Algeria; MO: Morocco; TU: Tunisia.

correlation, 9 other isoseismal event maps were adopted from existing maps (Cherkaoui, 1991 and Rothé, 1980). The average radius of each isoseismal was determined from the radii measured in 20 directions at 18° intervals of the compass. Isoseismals with no reliable data were disregarded for the regression analysis. The mean epicentral radii D_i for selected isoseismals of the 32 events used in the regression analyses are given in table I.

3. Magnitude-intensity relationships

The magnitude-intensity relationships model and procedure used in this study are based on the form of expression proposed by Ambraseys (1985b). This model is selected because it has been tested for north-west European, Turkish and Balkans earthquakes by Ambraseys (1985b, 1987 and 1992). The general form of the magnitude-intensity correlation is expressed by:

$$M_{sc} = A1 + A2\,(I_i) + A3\,(R_i) + A4 \log (R_i) \pm \sigma P \qquad (3.1)$$

where M_{sc} is the predicted macroseismic magnitude, R_i is the focal distance that corresponds to the average epicentral radii $D_i = (R_i^2 - h_0^2)^{1/2}$, in km, of isoseismal of intensity I_i and h_0, which represents the mean focal depth for the whole data set used, is a constant determined by searching to minimize the sum of squares of the residuals. σ is the standard deviation of M_{sc} and the constant P takes a value of zero for 50 percent probability that the predicted parameter will exceed the real value and one for 84 percent probability. Where A1, A2, A3 and A4 are constant.

One of the results of the revision of the data set in table I is the derivation of a relationship from which the surface-wave magnitude can be estimated from macroseismic information. This can be achieved by fitting the pairs I_i and R_i with their corresponding surface-wave magnitude M_S to eq. (3.1), using regression analysis routine (Sarma, 1993).

The result of the regression analysis of the data set of the Atlas region which consists of 32 events and 123 pairs of I_i, D_i is:

$$M_{sc} = -2.36 + 0.596\, j^{-1} \sum_i^j (I_i) + 0.0016\, j^{-1} \sum_i^j (R_i) + 2.71\, j^{-1} \sum_i^j \log (R_i) \pm 0.22\, P \qquad (3.2)$$

where $j \geq 1$ is the number of isoseismals available for the determination of the mean value of the equivalent surface-wave magnitude M_{sc} of a particular earthquake and $R_i = [D_i^2 + (2.96)^2]^{1/2}$ in km. The curves of macroseismic magnitudes M_{sc} predicted by eq. (3.2) for intensities III, IV, V, VI and VII, and distance are shown in fig. 1. A comparison between the surface-wave magnitude M_S calculated from instrumental data for the Atlas events and the values of M_{sc} predicted from eq. (3.2) is shown in fig. 2, *i.e.* $M_S = -0.14 + 1.03\,(M_{sc})$ with a standard deviation of 0.13 and a high coefficient of correlation of 0.96.

Using the same procedure, eq. (3.1) is now fitted to the selected Algerian earthquake data set listed in table I, 91 pairs of (I_i, D_i) corresponding to 22 events. The regression analysis gives the following results:

$$M_{sc} = -3.20 + 0.63\, j^{-1} \sum_i^j (I_i) + 0.0014\, j^{-1} \sum_i^j (R_i) + 3.12\, j^{-1} \sum_i^j \log (R_i) \pm 0.17\, P \qquad (3.3)$$

with $R_i = [D_i^2 + (5.64)^2]^{1/2}$.

Figure 3 shows the curves of macroseismic magnitudes M_{sc} predicted from eq. (3.3) for intensities III, IV, V, VI and VII,

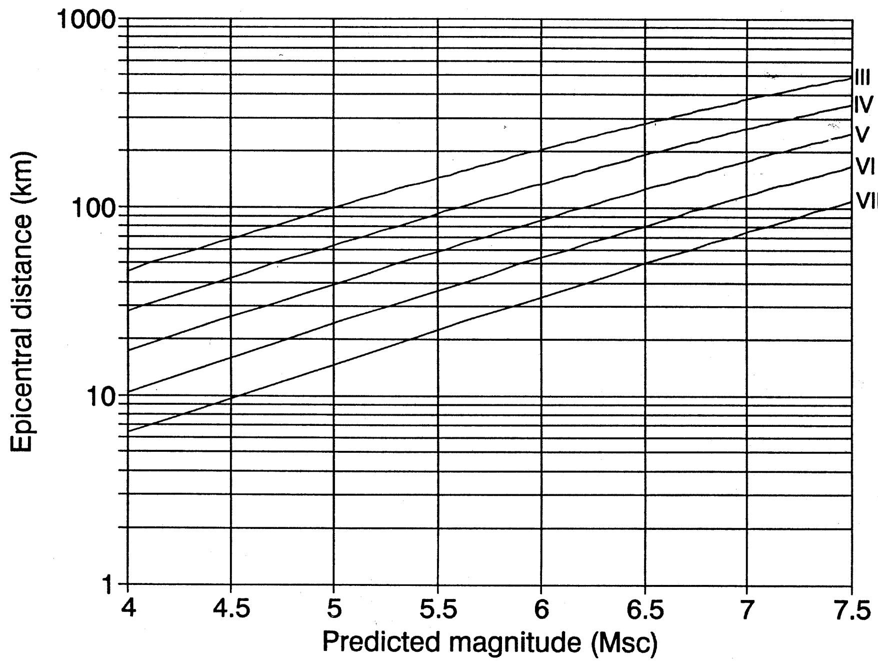

Fig. 1. Magnitude-intensity relationships for the Atlas region, plotted for intensities I = III to VII.

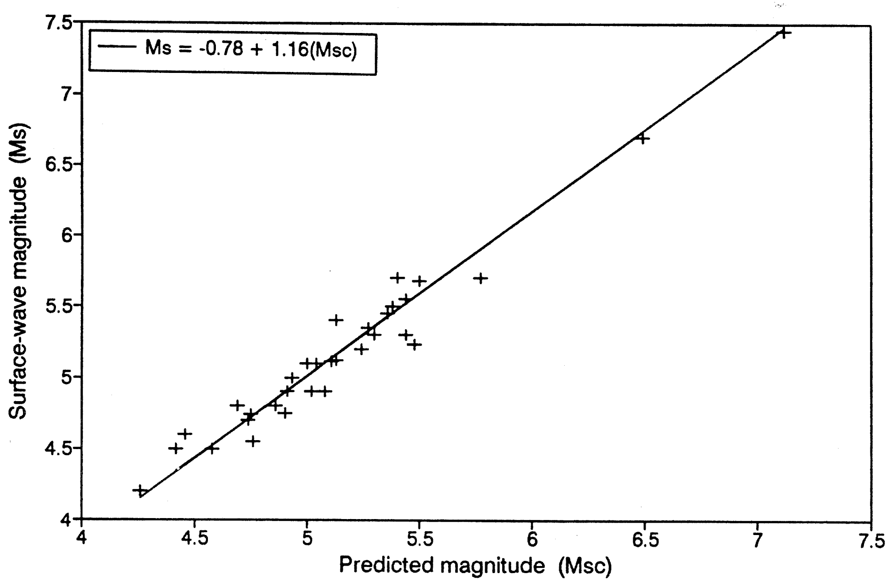

Fig. 2. Surface-wave magnitudes M_S calculated from instrumental data versus macroseismic magnitudes M_{sc} predicted for the Atlas.

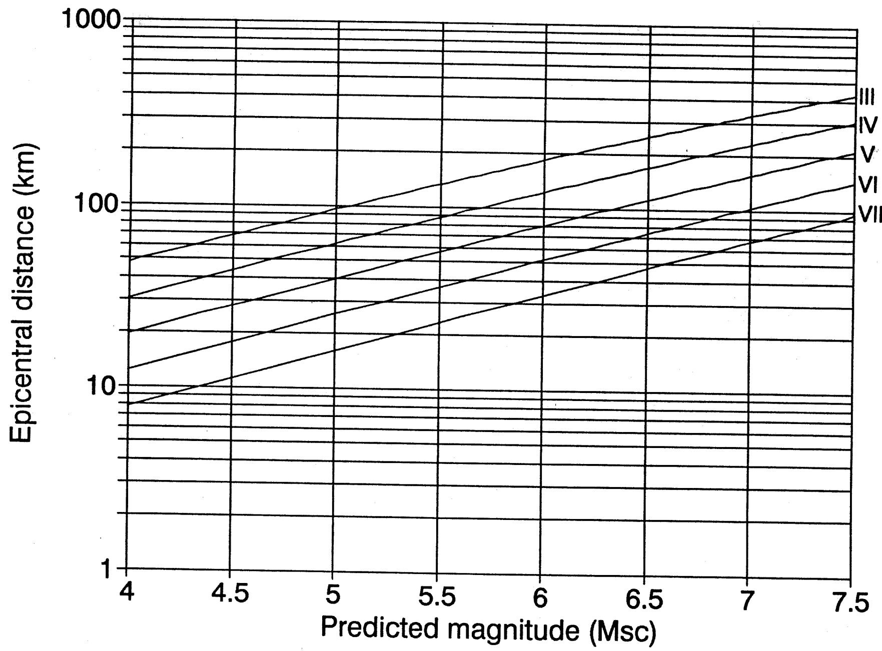

Fig. 3. Magnitude-intensity relationships for Algeria, plotted for intensities I = III to VII.

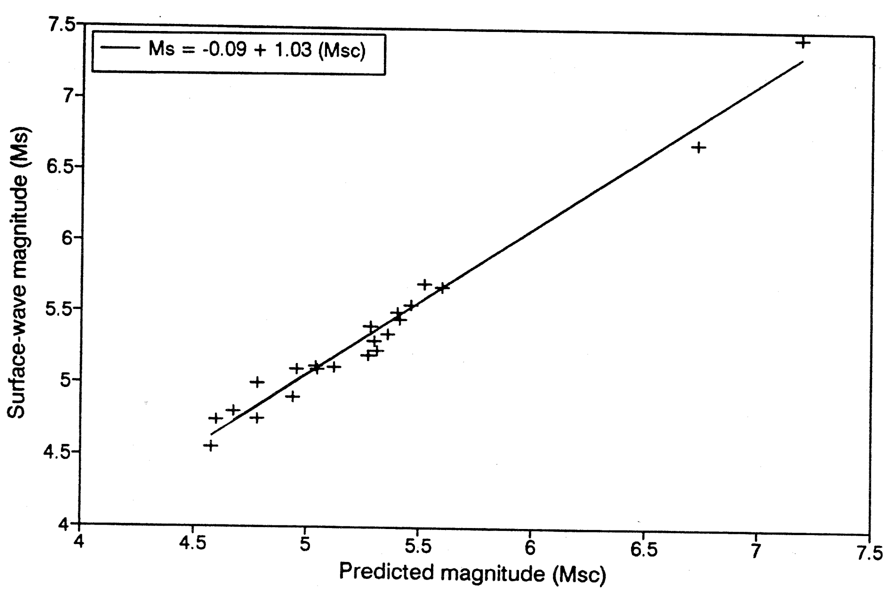

Fig. 4. Surface-wave magnitudes M_S calculated from instrumental data versus macroseismic magnitudes M_{sc} predicted for Algeria.

and epicentral distance. A comparison between the surface-wave magnitude M_S calculated from instrumental data for the Algerian events and the values of M_{sc} predicted from eq. (3.3) is shown in fig. 4, *i.e.* $M_S = -0.09 + 1.03\ (M_{sc})$ with a standard deviation of 0.09 and a coefficient of correlation of 0.97.

A comparison of the magnitude-intensity relationships in Algeria and the Atlas zone with that in the Balkans, derived by Ambraseys (1992), for intensities IV, V and VI respectively are plotted in figs. 5a-c which show that the correlations are similar. This may be explained by the fact that the three geographical regions belong to the same tectonic zone, *i.e.*, the Alpine zone.

4. Intensity-attenuation relationships

The attenuation relationships for MSK intensity with distance in the Atlas block and Algeria are estimated. Using the same earthquake data set listed in table I, the attenuation expression may also be derived by solving eq. (3.1) for the intensity I. Thus, the intensity, I, may be expressed in the general form:

$$I = \mathrm{B1} + \mathrm{B2}\ (M_S) + \mathrm{B3}\ (R) + + \mathrm{B4} \log (R) \pm \sigma P \qquad (4.1)$$

where B1, B2, B3 and B4 are the coefficients to be determined, M_S is the re-calculated surface-wave magnitude, R is the focal distance that corresponds to the mean epicentral radius $D_i = (R_i^2 - h_0^2)^{1/2}$ of isoseismal I_i in km and h_0, σ and P are as defined previously in section (3.3). Equation (4.1) is a general form of expression used for the attenuation of peak ground acceleration, a_{max}, where log (a_{max}) is replaced by the intensity I, as in Joyner and Boore (1981), or Ambraseys and Bommer (1991).

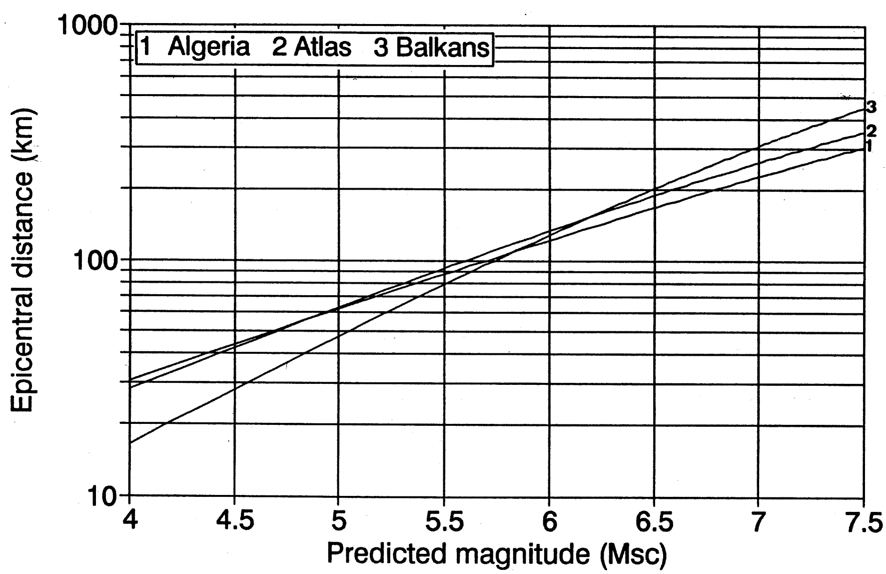

Fig. 5a. Comparison of magnitude-intensity curves in Algeria, Atlas and the Balkans for intensity I = IV.

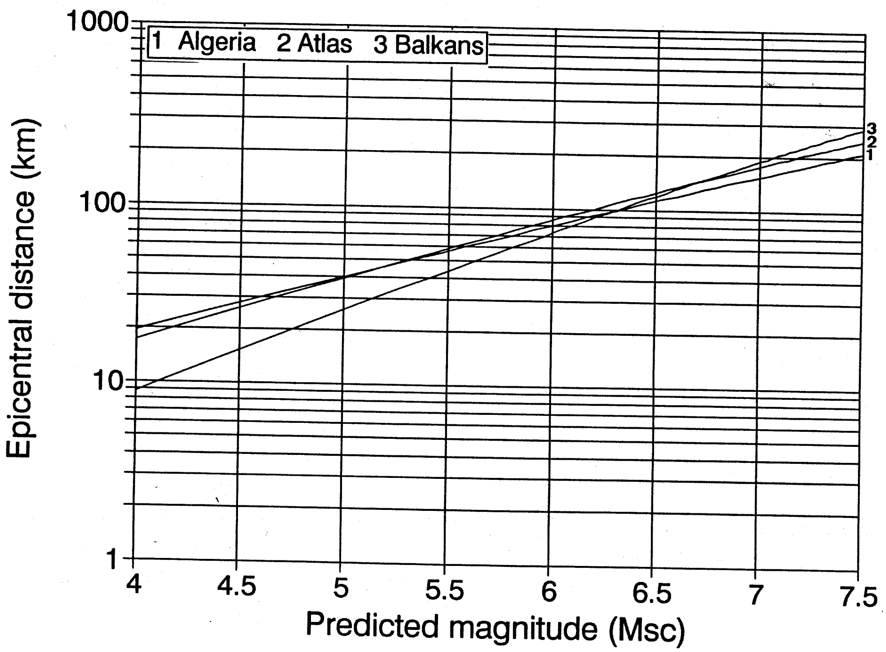

Fig. 5b. Comparison of magnitude-intensity curves in Algeria, Atlas and the Balkans for intensity I = V.

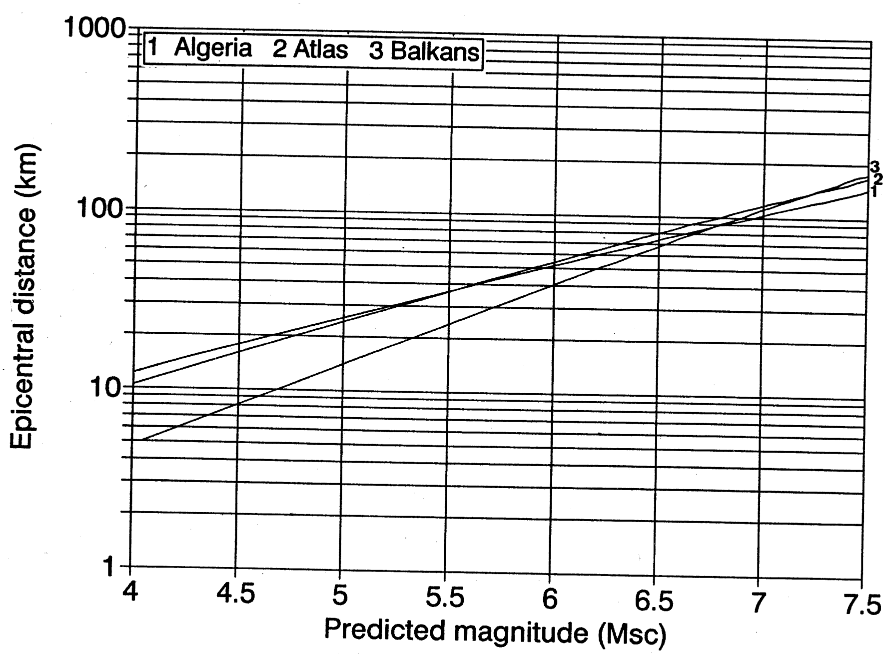

Fig. 5c. Comparison of magnitude-intensity curves in Algeria, Atlas and the Balkans for intensity I = VI.

The coefficients B1, B2, B3 and B4 are determined by fitting eq. (4.1) to the earthquake data set M_S and the selected (I_i, D_i) pairs listed in table I; a two-stage regression analysis is used.

The regression analysis for the Atlas data set, which consists of 123 (I_i, D_i) pairs corresponding to 32 events, gives the following mean attenuation expression:

$$I = 5.16 + 1.48\,(M_S) - 0.00074\,(R) + - 4.73\,\log\,(R) \pm 0.35\,P \qquad (4.2)$$

with $R = [D^2 + (4.82)^2]^{1/2}$.

Next, considering the Algerian data set, which consist of 91 pairs of (I_i, D_i) corresponding to 22 events, a regression analysis for these data resulted in the mean expression:

$$I = 6.29 + 1.43\,(M_S) - 0.0004\,(R) + - 5.245\,\log\,(R) \pm 0.24\,P \qquad (4.3)$$

with $R = [D^2 + (6.82)^2]^{1/2}$.

In fig. 6, the data set (I_i, D_i) of the Agadir 1960 earthquake is plotted against the mean intensity-attenuation curve in the Atlas; the data points show some scatter about the mean regression line, but look very similar in the trend. In figs. 7a-c, the data sample (I_i, D_i) of three events used in the regression analysis are plotted against the mean attenuation curve in Algeria, respectively the Ben Chabane 1924, the Orléansville 1954 and the El-Asnam 1980 earthquakes. The data points for these three Algerian earthquakes show a good agreement with the proposed intensity-attenuation relationships in Algeria.

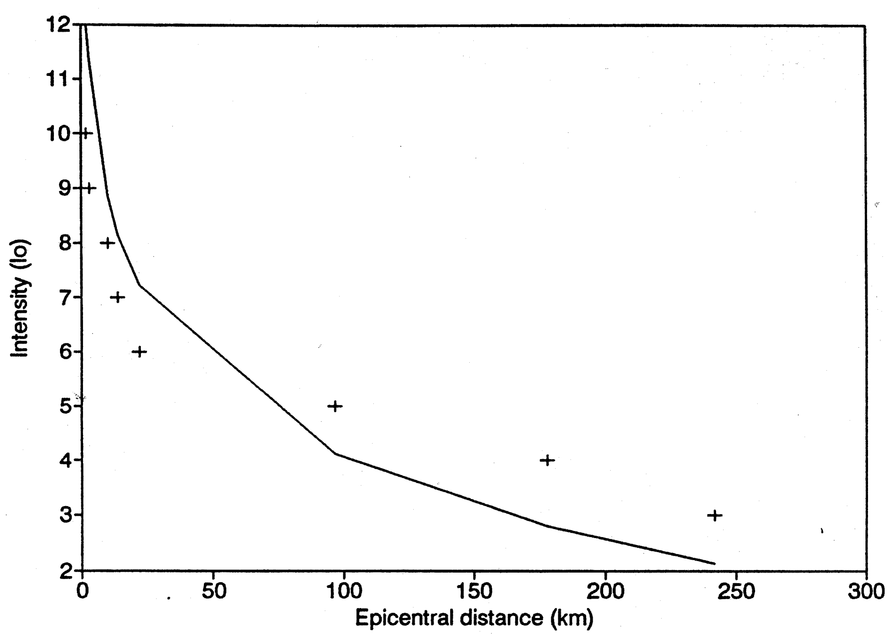

Fig. 6. Plot of isoseismal (I, D) data for the Agadir 1960 earthquake and mean intensity-attenuation curve in the Atlas.

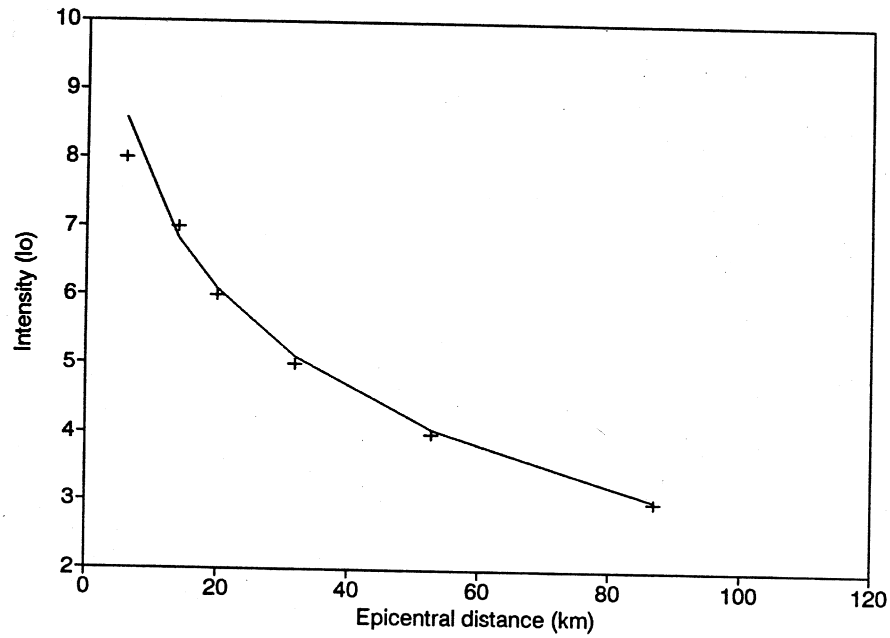

Fig. 7a. Plot of isoseismal (I, D) data for the Ben Chabane 1924 earthquake and mean intensity-attenuation curve in Algeria.

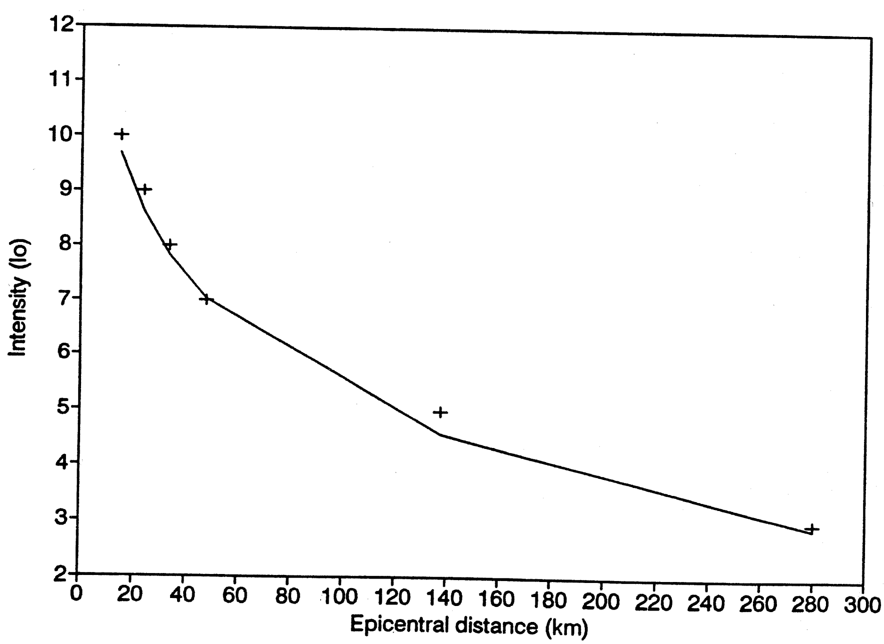

Fig. 7b. Plot of isoseismal (I, D) data for the Orléansville 1954 earthquake and mean intensity-attenuation curve in Algeria.

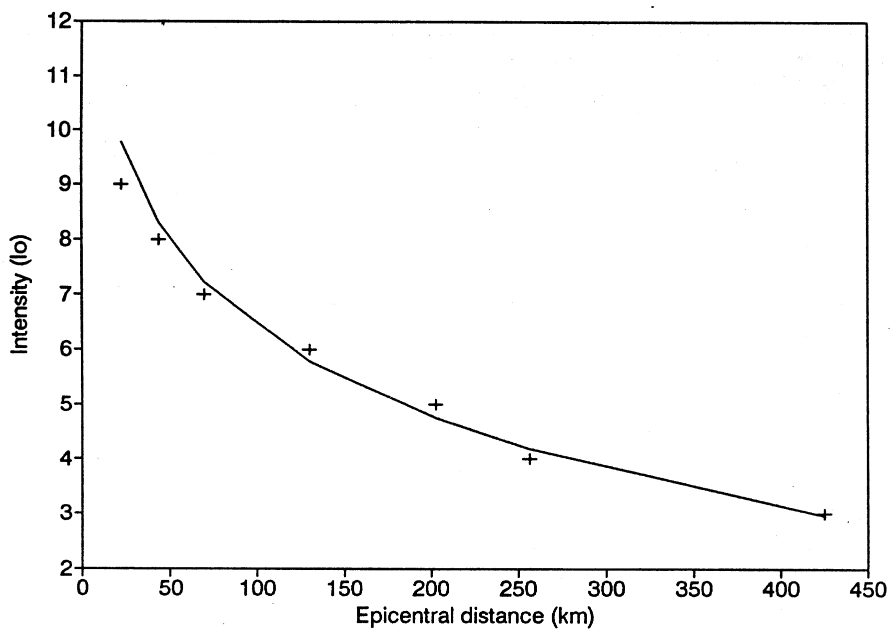

Fig. 7c. Plot of isoseismal (*I, D*) data for the El-Asnam 1980 earthquake and mean intensity-attenuation curve in Algeria.

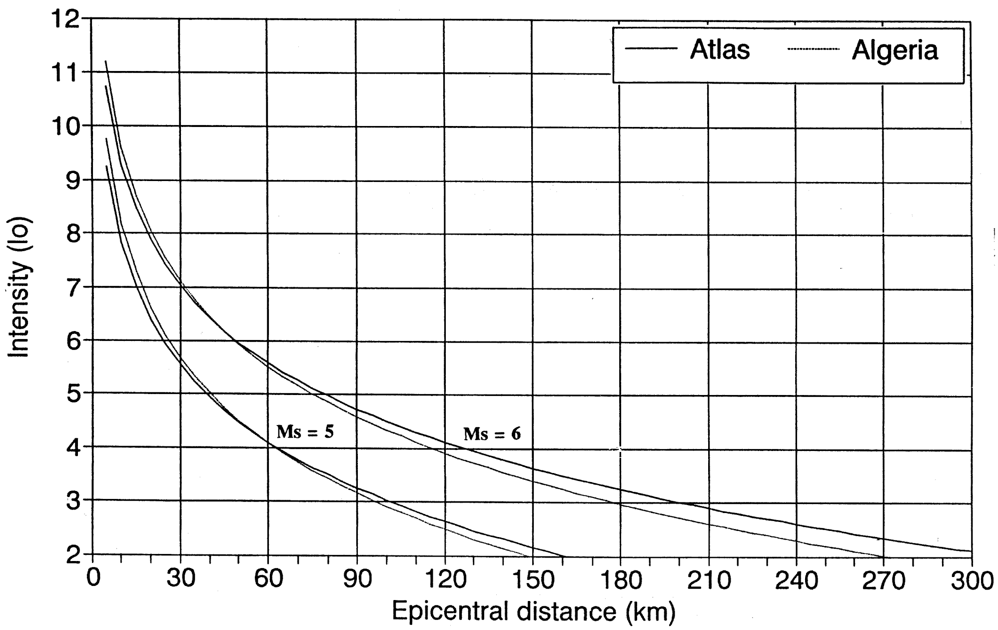

Fig. 8. Comparison of intensity-attenuation curves in the Atlas and Algeria, plotted for surface-wave magnitudes M_S = V and M_s = VI.

A comparison between the Atlas and Algerian earthquake intensity-attenuation relationships, plotted for magnitudes V and VI, is shown in fig. 8. It is clear that this figure shows that the two intensity-attenuation curves are very similar, particularly for an epicentral distance, *D*, less than 100 km.

5. Conclusions

The earthquake data sample used in this analysis was completely revised. The derived relationships for the two ares (3.2) and (3.3), which represent the equivalent surface-wave magnitude, M_{sc}, in terms of felt effects, may be used to assign magnitudes to early Atlas and Algerian events which have no instrumental data but for which isoseismal radii and intensities are available. These expressions are found to be very similar to that in the Balkans; this may be explained by the fact that they belong to the same tectonic zone, *i.e.*, the Alpine zone. Also, it was found that the intensity-attenuation models in the Atlas zone and Algeria, eq. (4.2) and (4.3), fit the macroseismic data quite well. However, it must be kept in mind that these relationships were derived using earthquakes with surface-wave magnitudes in the range $4.2 \leq M_S \leq 7.5$ and distances $D_i \leq 450$ km; therefore, they should be used with a certain caution near the limits of these ranges.

The advantage of the use of eqs. (3.2), (3.3), (4.2) and (4.3) is that epicentral intensities are not needed, and that magnitude-intensity relationships may be used to assign magnitudes to off-shore events or to earthquakes in regions of sparse population.

Although all the relationships derived in this chapter show a certain consistency with the data set, it is clear, however, that more data are needed before a final conclusion about the intensity-attenuation rate in the Maghreb region can be drawn. It is of interest to mention that the region under consideration has a long history of intermittent high seismicity which needs to be studied as Ambraseys and Vogt (1988) have achieved for the region of Alger (Capital of Algeria).