Copyright © 1996 Elsevier Science Ltd
Paper No. 1721. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

A METHODOLOGY FOR THE RE-EVALUATION OF THE SEISMICITY. A CASE STUDY: THE MAGHREB REGION

D. Benouar

USTHB, Civil Engineering Institute, BP 32 EL-ALIA, Bab Ezzouar, Alger, Algeria

ABSTRACT

This paper presents a methodology used to re-evaluate the seismicity of a given country and adjacent regions This requires (1) the retrieval and revision of both macro seismic and instrumental information, (2) the development of a methodology for the assessment of seismicity, (3) the application of techniques of completing the homogenised available data, (4) the establishment of a homogeneous and complete earthquake catalogue for the region under survey, (5) the geographic distribution of the earthquakes in order to define the seismic source zones in the region, (6) the calibration of the earthquakes in the region under survey and (7) the derivation of intensity-attenuation relationships in the region considered This methodology and the consistency process of the available data, particularly magnitude determination and intensity estimation, ensure a high degree of homogeneity, completeness and accuracy for the whole period under investigation. As a consequence, this earthquake data sample has been used in seismic hazard evaluation in this region As a demonstration of the use of this work, the assessment of seismic hazard in the Maghreb region, the Atlas block, Algeria and at eight major urban cities in Algeria has been carried out

KEY WORDS

Maghreb Region, Earthquake Catalogue, macroseismic information, Instrumental data, Seismicity, Seismic Hazard

INTRODUCTION

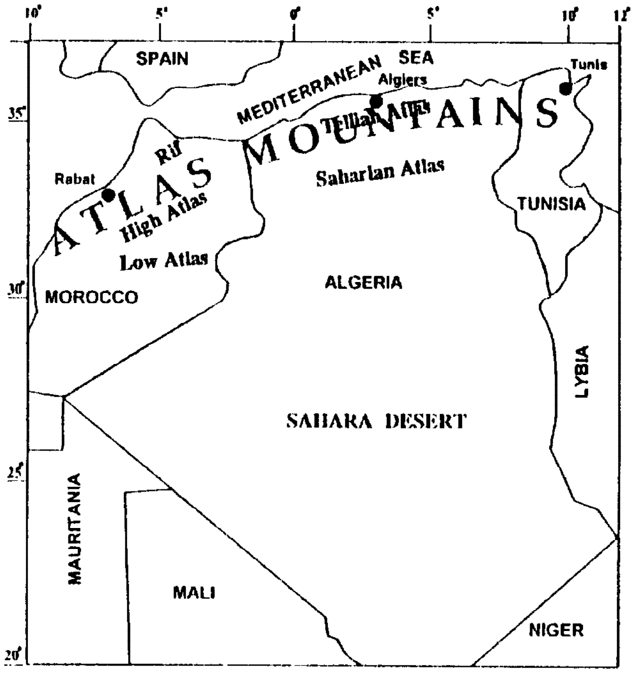
The main purpose of this work is to present a methodology to establish a uniform catalogue of all earthquakes reported in the Maghreb region, which satisfies the conditions of homogeneity, and to derive from this basic data set the general laws governing the space and time distribution of earthquake occurrences in the seismic source zones and to evaluate the seismic hazard

For the Maghreb region, as in many other region of the world, earthquake hazard constitutes a constant threat to human life and property, sometimes causing major economic losses and disruption. The rapid urbanisation, development of critical engineering works such as dams, nuclear power plants, industrialisation of cities with modern types of buildings and the concentration of populations living or settling in hazardous areas are matters of growing concern, as they contribute to heavier loss of life and increase considerably the cost of disaster damage. The environment concerns and an increased official and public awareness of earthquake hazards have, in the last decade, led to a rapid rise of interest in seismicity and, seismic hazard and risk evaluations in many countries.In order to assess the seismic hazard with a certain degree of reliability, an earthquake data of the region under survey which are as complete, homogeneous and accurate as possible are needed. For this purpose, and from the point of view of long term prediction and seismic hazard assessment, it is imperative that input data in the catalogues of many countries be revised and homogenised.

DEFINITION OF THE REGION UNDER SURVEY

By "the region under survey" it will be meant hereafter the main country to investigate and adjacent zones. Actually, for the evaluation of seismic hazard of any country it is necessary to take into consideration also the seismic sources which lie outside its borders, but which can affect its territory. Thus, the investigation will cover also earthquakes, the epicentral areas of which do not fall within the country of interest but which may affect its seismic hazard evaluation.

The region under consideration, which is defined as the Maghreb, includes Algeria, Morocco, Tunisia and the south Iberian Peninsula, it is limited by the 20°N and 38°N and 10°W and 12°E, and shown in Map 1. The term Maghreb is used here to illustrate the extent of the interest of the project, although Algeria constitutes the main concern. For the Maghreb region, as well as for other regions of the World, it is imperative to look beyond the boundaries of each country when evaluating seismic hazard. In fact, there are various reasons for investigating beyond the boundaries of each country and looking rather into the north African-south Iberian Peninsula region, designated as the Maghreb in this study, as a unit and for evaluating the final seismic hazard of the entire zone under similar criteria: (1) Similar geological process: the countries limiting the western part of the Mediterranean Sea and its adjacent continuation in the Atlantic Ocean have had, since hundred million years ago, the same tectonic process marked by a relative motion alternating between left and right lateral along the border of the African and Eurasian plates; (2) Similar present compressional state of stress: the actual state of stress in the whole zone is dominated by a compression with a principal axis along the NNW-SSE direction. (3) Similar historical development: the historical development of the countries in the region shows many common factors, such as cultural background, which lasted for several centuries and are still apparent today. Similarities in population settlements, building stock characteristics and socio-economic and demographic conditions, etc..., are very important parameters in the whole process of seismicity studies in the zone under consideration. The selection of this area allows investigation of any earthquake, affecting although not occurring in a specific zone of the Maghreb, which may influence the seismic hazard assessment in any particular site of the region. The term Atlas is used here to define the block containing the Atlas mountains along the whole north Africa (Map 1.).



Map. Limit of the region under study

PERIOD OF CONSIDERATION

The period before 1900 is to be extended as back in time as far as the data allow. The problem of timing in this period, which is carried out by historical records, is usually expressed according to various calendars or time-systems.

The period between 1900 and 1990 deals with the twentieth century which is characterised by a rapid development on instrumental seismology and by adequate seismological services operating in and around countries of the Maghreb. It has been found that during this period of time, homogeneous data for earthquakes above a certain magnitude can be obtained for the entire region under survey. However, the overall detection capability was significantly reduced for long periods of time during the unstable years between 1914 and 1922, 1940 and 1947 and again between 1954 and 1963 for Algeria as a result of permanent or temporary suspension of some stations and services.

GENERAL METHODOLOGY

The procedure which was used to re-evaluate the seismicity in a given country and surrounding regions is given by the flow-chart in Fig 1. It is clear that for historical earthquakes (pre-instrumental events) and even for twentieth century earthquakes for which there are no instrumental data, but for which intensities and radii are available, their magnitudes are calculated from macro seismic data (calibration relationships).

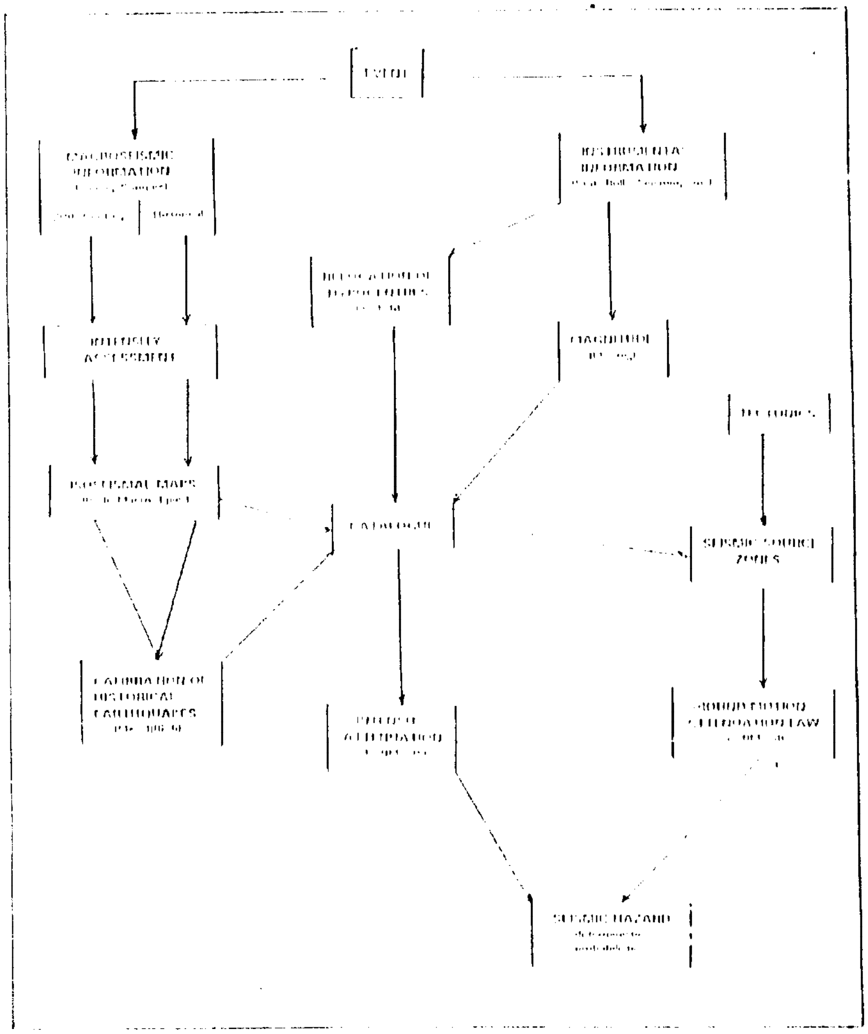


Fig. 1: Flow-chart of the general methodology of re-evaluation of seismicity and assesement of seismic hazard

Instrumental Information

Earthquake instrumental recordings in and around the Maghreb region, as in many regions in the world, started late in the last century. Most of the seismographic stations covering the Maghreb countries were operating in southern Europe, thus all to the north, resulting in a narrow range of azimuthal distribution of stations. Stations such as those at Cairo (Egypt) and Ksara (Lebanon) give some additional east-west control. For a better understanding of the instrumental data in the Maghreb countries, it is important to know about the historical development of seismographic station network in and around the region.

Seismological Bulletins

Monthly bulletins of various seismological stations and international organisations have been used along the study of the seismicity of the Maghreb region for checking the event itself. completing and/or determining missing characteristics of the event, summarised in Table 1. They may be used to re-evaluate hypocentral locations, origin time and exceptionally to determine source mechanism.

SOURCES	TIME COVERAGE (1900 – 1950 – 1990)	(*)
+Hee (1925)	11——24	I/M
+Sieberg (1932)	——28	I/M
Hee (1932)	11——31	I/M
+Rodriguez (1932-40)	——33	I/M
+Roux (1934)	——33	I/M
+Hee (1950)	——11	I/M
+Rothe (1950)	——48	I/M
Debrach (1952)	33——51	I/M
Grandjean (1954)	40——50	I/M
Gutenberg et al.(1954)	04——52	I/M
+Ben Osman (1960)	——55	I/M
+Ambraseys (1962)	——58	I/M
+Munuera (1963)	——62	I/M
+Rothe (1980)	——77	I/M
Duverge (1969)	18——67	I/M
Karnik (1969)	01——55	I/M
Rothe (1969)	53——61	I
Benhallou et al.(1971)	51——70	I
+Roussel (1973)	——70	I/M
Ben Sari (1978)	01——80	I/M
Hatzfeld (1978)	72——75	I
Frogneux (1980)	73——78	I
+Mezcua et al.(1983)	——80	I/M
+Woodward-Clyde (1984)	——81	I/M
+Benhallou (1985)	——80	I/M
Cherkaoui (1988)	01——84	I/M
ISS (1913-63)	13——63	I
BCIS (1950-63)	50——63	I
ISC (1964-82)	64——82	I
NEIS(1983-90)	83——	I

+: catalogue including earthquake data from pre-1900 period.
I: Instrumental catalogue
M: Macroseismic catalogue
I/M: Instrumental and Macroseismic catalogue

Table 1: main sources used in the establishement of the Maghreb earthquake catalogue during the twentieth century.

Seismograms

Seismograms are the fundamental observational records to study earthquakes and earth's interior. They are recorded at seismographic stations all over the world and are usually stored locally. The relocation of hypocentral location will be mostly accomplished using original seismograms as well as bulletin data if wave forms are missing.

Relocation of Hypocentres

The relocation of hypocentres is a fundamental problem in seismological observations and research. In regions well covered with seismographic stations, it is believed that instrumental locations are more precise than macro seismic epicentres. However, this is not the case of the Maghreb countries where neither the quality of the data nor the azimuthal distribution and number of stations is suitable for an accurate epicentral location, particularly before 1960. Whenever, the instrumental data permits, it is imperative that earthquakes before 1960 be relocated, using the present ISC location procedure, to obtain a reliable geographical distribution of epicentres which may lead to a better seismotectonic interpretation so that hidden features be revealed. In the study of the seismicity of the Maghreb region, some Algerian earthquakes have been relocated to show the degree of accuracy of the British Association for the Advancement of Science (BAAS: 1899-1917) and the International Seismological Summary (ISS: 1918-1963), presented in Table 2. It is found that the location error reaches values about an average of 16 km, still remains important since it represents about 2 to 3 times the radius of the meizoseismal area, in comparing relocated positions and macro seismic ones, where it is an average about 65 km between relocated and ISS epicentres which is a significant improvement.

Date	ISS (1)	relocated (2)	Macroseismic (3)	(1-2) (km)	(2-3) (km)
1910 Jun. 24	36.0°N 4.0°E	36.3°N 3.7°E	36.23°N 3.43°E	47	30
1922 Aug. 25	36.5°N 1.5°E	36.4°N 1.3°E	36.42°N 1.20°E	25	11
1924 Mar. 16	35.0°N 6.0°E	35.4°N 5.8°E	35.42°N 5.90°E	50	11
1924 Nov. 5	35.3°N 3.5°E	36.6°N 3.0°E	36.64°N 2.91°E	154	11
1928 Aug. 24	34.3°N 1.3°E	35.9°N 0.9°E	35.94°N 0.88°E	183	5
1934 Sep. 7	36.0°N 1.1°E	36.2°N 1.6°E	36.30°N 1.70°E	60	16
1937 Feb. 10	36.6°N 7.5°E	36.4°N 7.2°E	36.38°N 7.52°E	40	35
1943 Apr. 16	36.1°N 4.6°E	35.9°N 4.0°E	36.00°N 4.48°E	70	57
1946 Feb. 12	35.7°N 4.8°E	35.7°N 4.8°E	35.70°N 5.00°E	2	20
1959 Nov. 7	36.4°N 2.5°E	36.4°N 2.5°E	36.41°N 2.48°E	6	8

(1-2) Location error between ISS and relocated epicentres
(2-3) Location error between relocated and Macroseismic epicentres

Table 2: Comparison of original ISS, relocated macroseismic epicentres for some Algerian earthquakes

Determination of Magnitudes

Magnitudes are recalculated from world-wide stations bulletins and, when possible, from original seismograms. An important phase of the efforts in establishing the earthquake data catalogue is the attribution of a uniform magnitude to each seismic event.

Body-wave magnitude m_B is calculated using Gutenberg and Richter formula:

$$m_B = \log(A/T)_{max} + Q(D,h) + S$$

where $(A/T)_{max}$ is the maximum amplitude-period ratio in the wave classes (PV, PH, PPH and SH) and Q(D,h) is a calibrating function which depends on epicentral distance D, focal depth h and wave type. Surface-wave magnitude M_S is calculated using the Prague formula given by:

$$M_S = \log(A/T)_{max} + 1.66\log(D) + 3.3$$

where $(A/T)_{max}$ is the maximum value of the ratio of the ground displacement amplitude in microns, T is the corresponding period in seconds and D is the focal distance in degrees.

For the early years of this century, when Milne seismographs were operating, M_S is calculated using the calibrating Ambraseys and Melville formula given by:

$$M_S = \log(2A_t) + 1.25\log(D) + 4.06$$

where $(2A_t)$ is the double trace ground displacement amplitude (peak-to-peak) in millimetres and D is the focal distance in degrees

For a variety of reasons, many earthquakes in the Maghreb region, as in many other regions of the world, remain without surface-wave magnitudes or simply without any type of magnitude. To solve this problem, M_S are estimated when possible from semi-empirical relationships, derived from the newly compiled earthquake data bank, between M_S and m_b or M_S and M_L or by using the number of stations that reported the event to the ISS or ISC. M_S for historical earthquakes, may also be estimated from the radius of perceptibility (r_3) which is defined as the mean epicentral distance of an area within which the shaking was felt with an intensity equal to or greater than III (MSK) by using a relationship between M_S and r_3, or by using the relationship between M_S and I_O.

Macro seismic information (literary sources)

Documentary source materials are essential for a retrospective reconstruction of the macro seismic field data of past earthquakes. However, it is clear that the results of any study based mainly on an inventory of data available from various sources is subject to the quality and completeness of the information. Thus, the earthquake data available today will determine the accuracy of this work and the significance of the conclusions drawn. Sources of information are found in local and European documentary materials, newspapers, administrative records, special studies, scientific reports, private diaries and various books. Such materials are found to be available in libraries and archive centres across the Maghreb countries and the Mediterranean European countries such as Spain, Italy and, particularly France.

Catalogues

Although catalogues or listings of earthquakes in the Maghreb region are generally available, they cover different time periods, incomplete at a given region, and are grossly deficient in several respects, particularly in magnitude, depth and location. For some events, especially those prior to 1960, epicentral locations, magnitudes and other pertinent earthquake characteristics are inaccurate or simply not available. They are also inhomogeneous with respect to how earthquake parameters were assigned from macro seismic data; therefore, the quality of the catalogue could be increased by evaluating earthquake parameters according to standard procedures. Today, methodologies for calculating earthquake parameters are well presented for instrumental data, but not for macro seismic information. With reference to the problem of the analysis of macro seismic information, a study of the actual procedures of earthquake parameter determination from macro seismic information should be carried out and the most convenient one will be adopted when assessing seismic hazard.

The first task was to make an inventory of all existing catalogues covering the whole region or parts of it and period under investigation, shown in Table 1, and to compare and combine their entries. The number of estimates inventoried for the Maghreb reached 12,447 for 7,724 earthquakes reported of which 2,061 have surface-wave magnitude equal to or greater than 3.0. This methodology has allowed the estimation of the accuracy of the various catalogues and, in particular, the identification of the sources consulted in their compilations as well as the procedures used in the determination of the earthquake parameters. These catalogues, despite their incompleteness and inhomogeneity, constitute important references, in terms of both felt and recorded seismic activity, and should be considered as the starting point for the revision of the seismicity of the region under consideration. Additional macro seismic information, collected during the re-evaluation of the seismicity, are used to answer ambiguities among previous catalogues.

Contemporary Accounts

These documentary sources could be classified under two general headings which are: the official reports and the general public information (local and foreign newspapers). The first type includes published and unpublished scientific works, official reports, administrative correspondence, private letters and military records. The second type of document, although written for public consumption, generally presents the effects of the event according to the geographical and political circumstances. Some of these reports contain detailed information, mentioning names of damaged cities, villages, hamlets and even buildings, houses and streets, behaviour of the population and animals, effects on nature, relief operations, photographs and interviews with people. This type of archives has played a major role in the revision of the knowledge of the seismicity of the Maghreb. From his accounts, generally, one is able to retrieve the historical context during which the earthquake occurred

Other Documentary Sources

Another new source of information appearing during the twentieth century is unpublished technical reports related to the construction of large engineering structures. Most of these reports contain invaluable information accumulated in situ by engineers or geologists after an earthquake or in specific studies made to evaluate local seismic hazard.

INTENSITY ASSESSMENT

Intensity assignment presents also one of the main reasons for inhomogeneity. Intensity value is usually attributed in terms of different scales, sometimes even unspecified. Newly retrieved data should be re-assessed according to one suitable scale and correlate the old data with it.

Intensities, in the re-evaluation of the seismicity of the Maghreb region, are re-assessed with reference to the Medvedev-Sponheuer-Karnik -MSK- (1981) intensity scale, using standard criteria and macro seismic information retrieved from various sources mentioned earlier.

For a wise analytical study of past earthquakes, and better understanding of the information contained in the contemporary sources, one should take into account the political, socio-economic and demographic conditions, times of peace or war, cultural and religious backgrounds as well as the building stock characteristics of the period concerned. From these factors that may influence the macro seismic information, the buildings play a major role in the frame of intensity estimations. Because the building stock in the Maghreb countries, as that in many other regions in the world, has numerous variable characteristics such age, building materials and structural systems, an extensive investigation was carried out in order to reveal what type of constructions were exposed and what state they were in during the period of the concerned earthquake.

In the study of the seismicity of the Maghreb region, Intensities IX (MSK) and higher are assigned to the sites where destruction was complete (intensity depending of the nature of buildings) and there was great loss of life. Broadly, this means that within the area containing the fault-breaks associated with the earthquake, masonry and adobe structures were totally destroyed, many of which collapsed completely, causing casualties. Intensities VI to VIII (MSK) are consistent with a rigid interpretation of the MSK intensity scale. Lower intensities IV to V (MSK) were attributed solely on felt effects and on evidence of lack of damage to low-quality types of constructions. For the very low intensities II to III (MSK), negative reports were also taken into account; generally in the absence of very low intensity observations, intensity III^+ (MSK) is assumed to be the boundary of the felt area.

ISOSEISMAL MAPS

From intensity data when enough, an isoseismal map has been constructed and a macro seismic epicentre located for each studied earthquake. Radii (R_i) and intensity (I_i) should be better reported in the catalogue.

The location of macro seismic epicentres is of great value, in terms of tectonic feature determinations, particularly during the first half of this century when instrumental data were still unreliable.

CALIBRATION OF HISTORICAL EARTHQUAKES

From the isoseismal map using the pairs I_i and R_i with their corresponding surface-wave magnitude M_S, a relationship $M_S = f(R_i, I_i)$ can be easily derived. For the Atlas block, the data set used consists of 32 events and 123 (I_i, R_i) pairs.

The derived relationship, which represents the equivalent surface-wave magnitude, M_{SC}, in terms of felt effects, could be used to assign magnitudes to historical and even to 20th century earthquakes which have no instrumental data but for which isoseismal radii and intensities are available.

INTENSITY ATTENUATION

From the catalogue, the Atlas data which consist of 123 (I_i, R_i) pairs corresponding to 32 events is used to derive an intensity-attenuation relationship $I = f(M_S, R_i)$ for the Atlas Block. This model is found to predicted quite accurately the fall-off of intensity with distance. The rate at which intensity die-out with distance is of great importance for the assessment of the seismic intensities to be expected at a given site as a result of an earthquake. Intensity distribution may be used to estimate focal depth and together with other parameters, to estimate the size of an event.

TECTONICS

It is generally agreed that earthquakes have occurred along faults. Thus, the first step is to identify and classify the tectonic and geological faults. The identification of the tectonic process plays an important role in modelling earthquake occurrences.

SEISMIC SOURCE ZONES

The definition of seismic source zones is based upon the interpretation of geological, geophysical and seismological information. The configurations of individual sources could be point source, line source, area source or volume source, depending upon the type of source chosen and the ability to define its geologic space.

GROUND MOTION ATTENUATION LAW

Ground motion attenuation laws depend on the concerned region. Very often, due to the absence of strong motion data for the region under study, an attenuation law is selected from a region of similar tectonic process. The ground motion attenuation law is given in the form of $a = f(M_S, d_i)$. Figure 2 shows the Algerian strong motion data fitted to Attenuation derived for Europe by Ambraseys and Bommer (1991) which is used in the evaluation of seismic hazard in the Maghreb region.

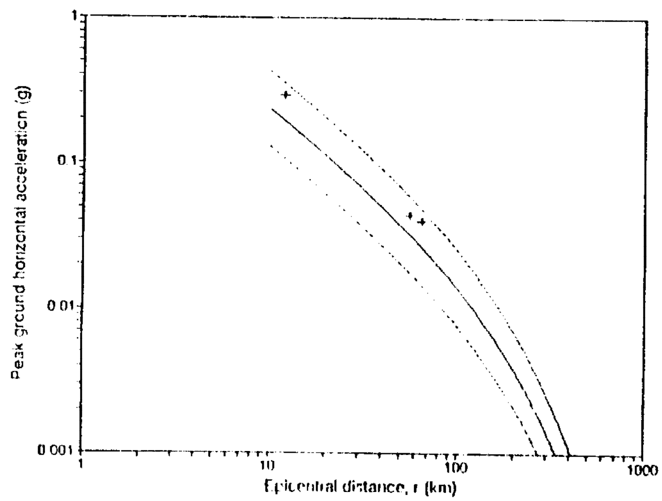


Fig 2: Relationships between peak values of recorded horizontal accelerations and distance r in Chenoua 1989 earthquake. The solid line shows the values predicted by the equation of Ambraseys & Bommer (1991) and the dashed lines are 84-percentile value of this prediction.

SEISMIC HAZARD EVALUATION

- In deterministic seismic hazard analyses, seismic sources are assigned maximum earthquakes which are assumed to occur at the location, within the source, closest to the site of interest. This approach uses the ground motion attenuation to estimate the ground motion parameter at a given site.

$$a = f(M_S, d_i)$$

- The probabilistic seismic hazard analysis allows the use continuous events and models. This consists of the evaluation of the probability of occurrence of an earthquake strong enough to cause damage within a given region or site and in a given time interval.

$$P(a > A / M_S, d_i)$$

To illustrate this approach in this research work:

(1) The seismic hazard is evaluated using Gumbel type I asymptotic distribution in the Maghreb region, shown in Figure 3.

(2) The estimation of modal magnitude return periods using Gumbel type I distribution at major urban cities in Algeria is presented in Table 3.

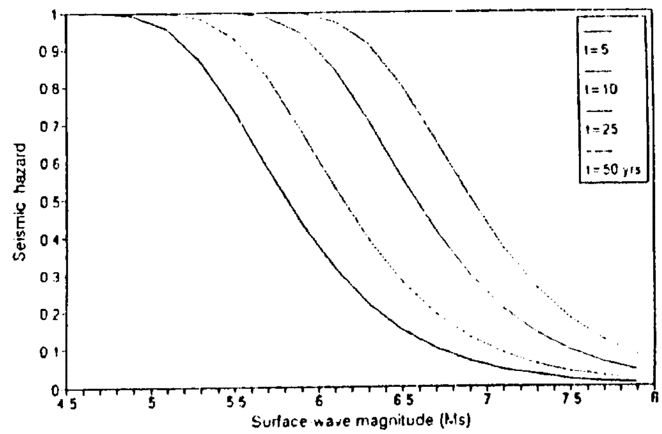


Fig. 3: Seismic hazard for a sample of earthquake magnitudes and return periods in the Maghreb region.

City	Parameters		Magnitudes for		Mean return Period For Magnitudes (Years)			
	U	B	50-	100-yr RP	4.5	5.0	5.5	6.0
Alger	4.37	0.64	6.8	7.3	1.2	2.5	5.8	12.7
Oran	3.98	0.58	6.2	6.6	2.4	5.8	13.7	32.5
Annaba	4.24	0.51	6.2	6.6	1.6	4.4	11.8	31.5
Constantine	4.25	0.48	6.1	6.4	1.7	4.8	13.5	38.0
Chlef	4.18	0.64	6.7	7.2	1.6	3.6	7.8	17.1
Setif	4.27	0.53	6.3	6.7	1.5	4.0	10.2	26.2
Mascara	4.09	0.50	6.0	6.3	2.3	6.2	16.8	45.6
Msila	4.32	0.57	6.5	6.9	1.4	3.3	8.0	19.1

Table 3: Results of seismic hazard analysis for eight cities in Algeria.

CONCLUSION

This methodology and the consistency process of the available data, particularly epicentre locations, magnitude determinations and intensity estimations, ensure a high degree of homogeneity for the whole period under investigation. This has led to a homogeneous and complete earthquake catalogue for the Maghreb region which can be used in seismic hazard and risk evaluations in this region. The catalogue compiled in this work is stored as a computer file for ease of use. However, this research clearly demonstrates that in order to investigate the pattern of current tectonic activity or to evaluate long term seismic hazard in a certain region, seismic information should go back in time as far as possible.

REFERENCES

Annuaires et Annales de l'Institut de Physique du Globe de Strasbourg (France) publiés de 1920 à 1972 sous la direction de E. Rothé puis J.P. Rothé.

Ambraseys, N.N., 1962. The seismicity of Tunis. Ann. di Geofisica. Vol. XV. No. 2-3, 233-244.

Ambraseys, N.N., 1971. Values of historical records of earthquakes. Nature, 232, 374-379.

Ambraseys, N.N., 1981a. Le Tremblement de Terre d'El-Asnam du 10.10.1980. In Actes des Journées Scientifiques sur le Séisme d'El-Asnam Alger, 15-16 Juin.

Archives Gouvernement General, Alger., 1900-onwards. (unpublished).

BAAS, British Association for the Advancement of Science. Seismological Investigation Reports 1899-1917, London, UK

Benhallou, H., 1985. Les Catastrophes Séismiques de la Région d'Echéliff dans le Contexte de la Séismicité Historique de l'Algérie. Thèse de Doctorat Es-Science, IST-USTHB, Alger.

Benouar, D., 1993. The seismicity of Algeria and adjacent regions during the twentieth century. PhD thesis, Imperial College of Science, Technology and Medicine, University of London, pp 712.

Cherkaoui Maknassi, M.T., 1991. Contribution à l'étude de l'aléa sismique au Maroc. Thèse de Doctorat, Université Joseph Fourier de Grenoble. France.

International Seismological Centre (ISC), Newbury, Berkshire, 1964-onwards.

International Seismological Summary (ISS), Kew observatory, Richmond, 1918-1963.

Meghraoui, M., 1988. Géologie des Zones Sismiques du Nord de l'Algérie (Paléosismologie, Tectonique Active et Synthèse Sismotectonique). Thèse de Doctorat d'Etat. Université de Paris-Sud, Centre d'Orsay. France.

Meghraoui, M., 1991. Blind reverse faulting system associated with the Mount Chenoua-Tipaza earthquake of 29 October 1989 (north-central Algeria). Terra Nova, 3, 84-93.

Mezcua, J. and Martinez, J.M., 1983. Sismicidad Del Area Ibero Mogrebi. Seccion de Sismologia, Inst. Geogr. Nacional. Madrid.

Munuera, J.M., 1963. Datos basicos para un estudio de sismicidad en la area de la peninsula Iberiic (seismic data). Memorias del Instituto Geographico y Catastral, tome XXXII, Madrid, pp.93.