Earthquake Engineering, Tenth World Conference © 1994 Balkema, Rotterdam. ISBN 90 5410 060 5

Seismicity of the Strait of Gibraltar during 1991

Aomar Ibenbrahim, Idrissi Dafali & Driss Bensari
National Research Center of Morocco Rabat, Morocco

ABSTRACT: This study summarizes our present knowledge on the seismicity of the Strait of Gibraltar with a particular emphasis on data collected by a newly installed network. The area of study is confined to the rectangle extending 34-38° N and 4-8°W. Even though this area has not suffered from any large magnitude earthquake in this century, it has been historically known as a region which suffered a great deal from large magnitude events such as the 1755 Lisbon earthquake. The seismicity of this area for the period 1900-1989 shows that this region is characterized by three alignments of seismicity:

- a N-S trend of seismicity bet 35-37°N at 5°W,
- a NE-SW alignment of seismicity in southern Spain,
- and a NW-SE direction of seismicity in northern Morocco,

The Strait of Gibraltar is in itself very quiescent seismically. Furthermore, seismic risk studies have shown that the area north of 35°N is subject to high risks from earthquakes of magnitudes > 5.5.

In order to accomplish a more refined study of the seismicity of the area of the Strait of Gibraltar, two networks specifically designed for this purpose were installed in northern Morocco and in southern Spain in 1989. The Moroccan network consists of six short-period telemetered seismic stations, while the Spanish network consists of nine. The data are available in both digital and analog forms. In this study we invert travel-time P and S-wave data for the hypocentral locations of the events recorded in 1991. In our data processing, we include readings from stations of the national networks as well.

The analysis of the 1991 seismic data shows two major trends of seismicity: a NE-SW trend in southern Spain and a NW-SE trend in northern Morocco, the Strait of Gibraltar remaining very aseismic during this period. Those results are in good agreement with the previously reported ones for the period 1900-1989. Moreover, we find that the events recorded in southern Spain have magnitudes that vary between 1.0 and 3.5, while those in northern Morocco vary between 2.0 and 3.8. In general, the events occurring in northern Morocco have relatively stronger magnitudes, but are deeper. They occur at a depth around 30 km, while the events in southern Spain are very shallow with depths around 5 km.

While the new networks have substantially helped in reducing the error on hypocentral locations, the threshold of detected events in northern Morocco remains relatively high. It is therefore suggested to rearrange the configuration of the Moroccan network and to add a three-component digital seismic station. This would help decrease the thresholds of magnitudes to an estimated magnitude of 1, and will equally allow us to calculate the spectral response from both local and remote earthquakes.

1. INTRODUCTION

The purpose of this paper is to study the seismicity of the area of the Strait of Gibraltar using data collected at a newly installed network in this region. This work is part of a major feasibility study initiated by both the Moroccan and the Spanish governments for the establishment of a fixed link between Morocco and Spain.

The method used in this study consists of inverting travel-time P and S-wave data to invert for hypocentral locations of the recorded seismic events. The data used in this study cover the year of 1991 only, and consist, not only of events recorded by the Strait of Gibraltar networks, but also of readings from the national Moroccan and Spanish networks as well. The Spanish data are taken from monthly reports of the "Real Instituto y Observatorio de la Armada" of Spain and from the Earthquake Data Reports (EDR) published by the USGS.

In this paper, we briefly review the historical seismicity and seismic risk studies. The seismicity patterns for the 1991 events are analyzed as well as their depth distribution. Finally, the results of this short-term study are used to give suggestions to improve the quality of the data acquisition.

2. HISTORICAL SEISMICITY AND SEISMIC RISK.

The Strait of Gibraltar is situated in the centre of a zone of N-S convergence between the African and Eurasian plates. This compression is partly accommodated by an E-W opening along normal faults in the Alboran sea, which enables some of the materials to be squeezed out of the area (Buforn et al., 1991)[1]. Farther to the west of this area, a triple junction connects the Mid-Atlantic ridge to the Ibero-Moghrebian region by a play of transform faults (Mezcua et al., 1991)[2].

Historically, the Strait of Gibraltar has been inactive seismically. Yet, this area suffered a great deal from large magnitude earthquakes which originated mostly in the eastern Atlantic region. Among these, is the so-called Lisbon earthquake of November 1, 1755, which had an estimated magnitude of 9 (Ben Sari, 1981)[3], and occurred in the Gorringe bank area.

Various studies concerning the seismicity of this area in the twentieth century have shown that the Strait of Gibraltar region is subject to three main tectonic trends:

- A N-S alignment of seismicity around 5°W between 35°N and 37°N (Ben Sari, 1981)[3].
- A NE-SW trend of seismicity in southern Spain, extending from (36.5°N, 5°W) to (38°N, 1°W) (Ben Sari, 1981)[3].
- A third trend of seismicity was reported by Ait Brahim et al., (1987)[4] in Northern Morocco with a NW-SE direction.

All published seismicity maps (e.g. Ramdani et al., 1992)[5] concerning this region show that the Strait of Gibraltar is itself very aseismic.

Seismic Risk studies (Tadili and Ramdani, 1982[6]; Ramdani et al., 1982[7]; Ben Sari, 1981[3]) show that there is a high probability that the area between 34°-38°N and 2°-6°W experiences an earthquake of magnitude higher that six, with a period of recurrence of 75 years, while the area between 6°-9°W has a very weak seismicity (Figure 1).

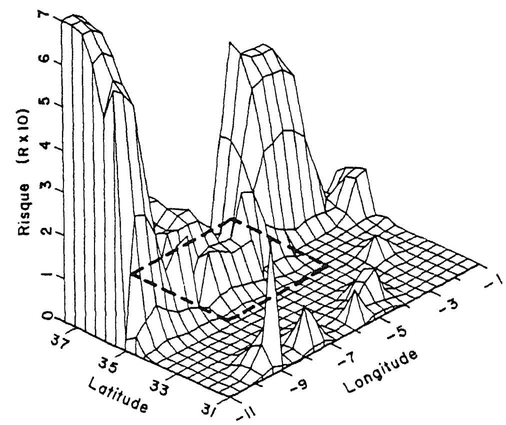

Figure 1. Seismic risk vs latitude and longitude. Three-dimensional representation for magnitudes > 7.0. Dashed lines delimit area of study (Tadili,1991).

3. NETWORK DESCRIPTION

The network installed in Northern Morocco for the study of the seismicity of the Strait of Gibraltar consists of six short-period seismic stations (Table 1,Figure 2). Five of these stations are connected by UHF radio to the regional station of Cap Spartel, where the data are mixed and transmitted by telemetry to the central recording station in Rabat. In Rabat, these data are recorded both in analog and digital forms. The geophones used are the SS-1 Kinemetrics type with a central frequency of 1 Hz.

In parallel with the seismic array, a network consisting of four accelerographs is deployed at stations CPS, BMD, BIT and STY. These

TABLE 1: Moroccan seismic network for the Strait of Gibraltar.

STATION CODE	STATION NAME	LATITUDE (N)	LONGITUDE (W)	TYPE
TSY	Tnine Yamani	35.373	5.970	V,S
DKH	Dar Kharkour	35.492	5.361	V,S
CPS	Cap Spartel	35.790	5.910	V,S
BMD	Beni Massoud	35.780	5.700	V,S
BIT	Ibn Batouta	35.643	5.734	V,S
SAR	Sarsar	34.930	5.930	V,S

V = vertical component; S = short-period.

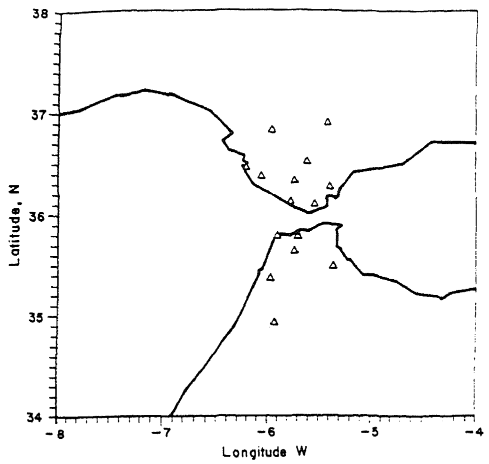

Figure 2. Seismic Network for the Strait of Gibraltar.

accelerographs are three-components and the recording is triggered by accelerations of 0.06g or more. The Spanish network of the Strait of Gibraltar consists of nine stations (Table 2, Figure 2). Together, the Moroccan and the Spanish networks provide a relatively good azimuthal cover of the Strait of Gibraltar.

4. DATA PROCESSING

A slightly modified version of Hypo71 (Lee and Lahr, 1975)[8] is used to locate the hypocenters of seismic events recorded by the Moroccan and Spanish Seismic Networks. The modifications concern mainly the input/output of the program. These were changed to suit the type of data being handled as well as the empirical formula for magnitude calculation. Only P- and S-wave phases are used to locate the events.

The velocity model used to invert for the hypocentral coordinates (Table 3, Figure 3) is derived from the results of deep seismic soundings carried in Morocco, the Alboran sea and Spain (Ben Sari, 1987)[9]. This velocity model consists of an upper and a lower crust which are 15 km thick, and a Moho at a depth of approximately 30 km.

5. RESULTS AND DISCUSSION

During the year of 1991, 50 events were located in the area defined in figure 1. Since most of these events are of small magnitudes, many of them are recorded by one network only, either the Spanish or the Moroccan network. However, a number of events were recorded by both.

Most of the events recorded during this time span occurred in southern Spain, along a NE-SW direction of seismicity (Figure 4). On the other hand, the events recorded in northern Morocco are dispersed along a NW-SE direction of seismicity (Figure 4). Both of these seismic trends were reported by previous seismicity studies of northern Morocco and southern Spain (e.g. Ramdani et al., 1992[5]; and figure 8 of Ben Sari, 1987[9]). Only few events are located in the Alboran sea and the Atlantic ocean side of this area. Furthermore, no seismic events are recorded in the Strait of Gibraltar.

The absence of events in the strait is also in agreement with previous work covering the period of 1900-1989, thus providing further evidence of the lack of seismicity of the Strait of Gibraltar. Most of the events in southern Spain are shallow, with only few occurring at a depth around 30 km. A NE-SW cross-section along the south of the Iberian peninsula shows

TABLE 2: Spanish network for the Strait of Gibraltar.

STATION CODE	REGION (CADIZ)	LATITUDE (N)	LONGITUDE (W)
ALJ	ALGIBE	36.519	5.611
GIBL	GIBRALBIN	36.833	5.958
CNIL	CONIL	36.374	6.055
LIJA	LIJAR	36.908	5.419
MOMI	MOMIAS	36.331	5.728
OJEN	OJEN	36.100	5.544
PLAT	PLATA	36.129	5.774
SFS	S. FERNANDO	36.469	6.209
SRQ	SAN ROQUE	36.271	5.388

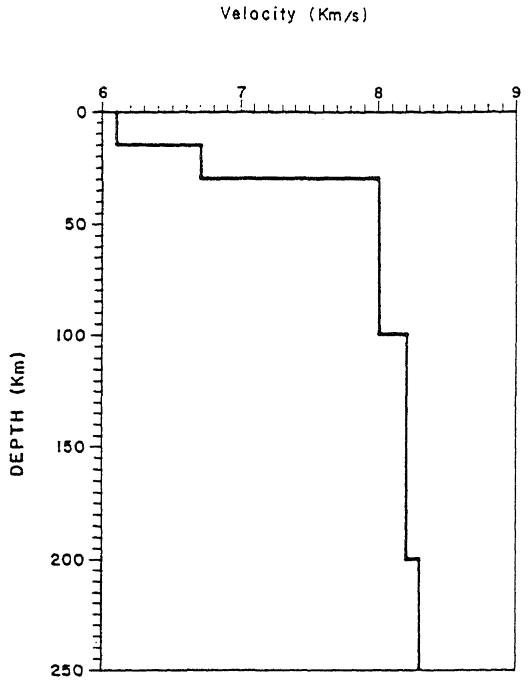

Figure 3. Velocity-depth model used to locate events recorded at the Moroccan seismic network

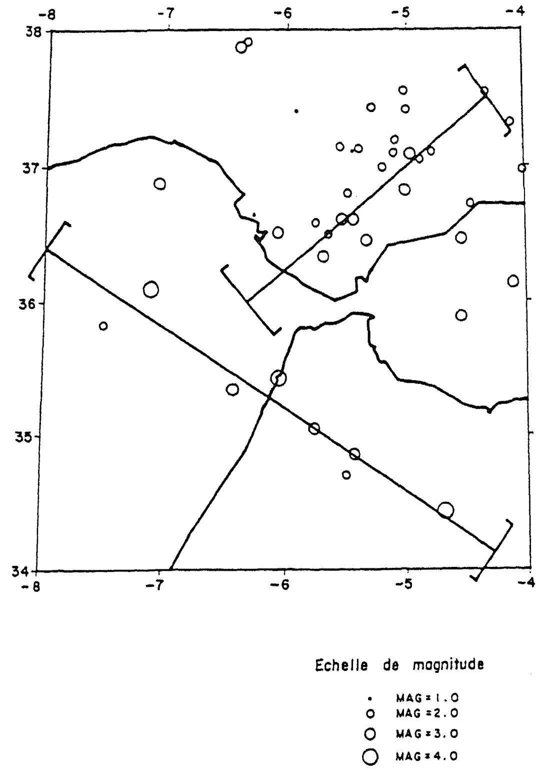

Figure 4. Seismicity map of the Strait of Gibraltar during 1991 showing the location of cross-sections in Figures 5 and 6. The Strait of Gibraltar remained aseismic during 1991.

TABLE 3: Velocity Model used in the hypocentral determinations

LAYER	DEPTH (km)	P-VELOCITY (km/s)
1	0 - 15	6.1
2	15 - 30	6.7
3	30 - 100	8.0
4	100 - 200	8.2
5	200 - 250	8.3

the presence of two seismic zones (Figure 5). A zone of shallow seismicity extending from the surface to a depth of approximately 10 km, and a deeper zone at around 30 km depth, with no seismicity in-between. On the other hand, a NW-SE cross-section in northern Morocco shows that most of the seismicity occurs at a depth of 30 km (Figure 6). The depth control on these events is not very good, and they may have greater depths, thus suggesting that these quakes are probably sub-Moho events. The magnitudes of the events located in southern Spain in 1991 vary from 1.0 to 3.5, while those recorded in northern Morocco vary between 2.0 and 3.8. In general the events which occurred in southern Spain have smaller magnitudes than those in northern Morocco. Yet, they are shallower. However, the magnitudes used in this report are still heterogeneous, since some of them are mbLg magnitudes taken from the earthquake data reports of the USGS, while others are MD (duration) magnitudes. An effort is being done to homogenize these magnitudes.

Our results show that the newly installed networks for the study of the Strait of Gibraltar have substantially improved the determination of the hypocentral coordinates by reducing the errors on them, and has equally helped improving the threshold of the detected events. For the events in southern Spain the lowest detected event has a magnitude of 1.0, while for those in northern Morocco the lowest magnitude is 2.0. This is probably due to the higher density of stations in Spain. Therefore, it is imperative to increase the number of seismic stations in northern Morocco.

6. CONCLUSIONS AND SUGGESTIONS

Although the results of this 12-month seismicity study of the Strait of Gibraltar area are not representative of

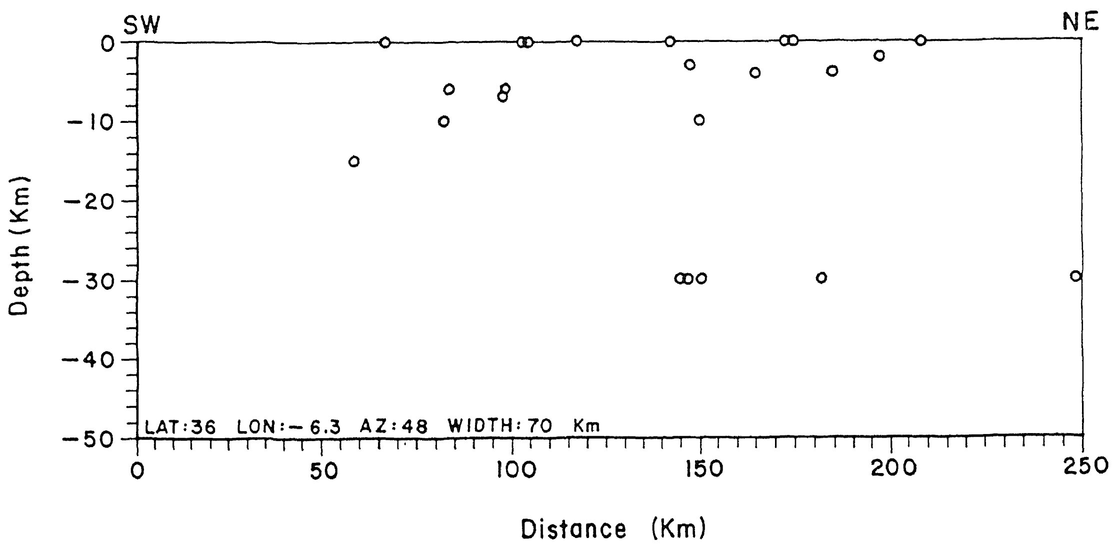

Figure 5. NE-SW cross-section in Southern Spain, showing a shallow zone of seismicity and a deeper one at 30km depth.

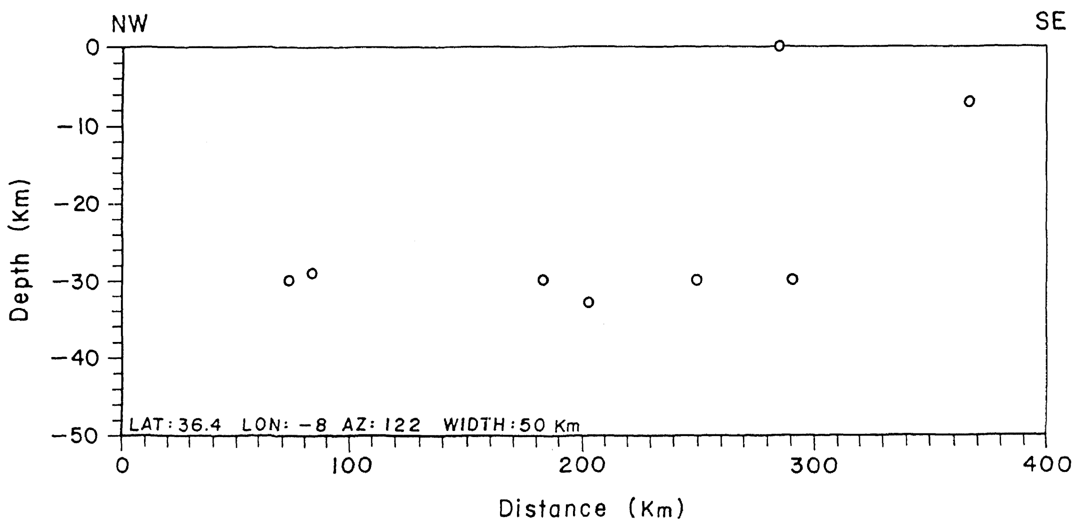

Figure 6. NW-SE xsection in northern Morocco. Most of the events occur around 30 km depth.

the long-term seismicity, they, however, confirmed and revealed a number of important findings. First, these results confirmed the presence of two seismicity trends in our study area: a NE-SW alignment of seismicity in southern Spain and a NW-SE trend in northern Morocco. While the earthquakes in Spain are mostly near-surface events, those in Morocco are probably sub-Moho events. The Strait of Gibraltar itself did not manifest any seismicity during this period.

Furthermore, our results, obtained using two networks specifically designed for this project, show that the determined hypocenters have a better accuracy and depth control than those determined using the national networks. Although the threshold of the detected events has improved, it still remains unsatisfactory for the Moroccan network. It is therefore suggested to rearrange the Moroccan network for the Strait of Gibraltar, and to add two more stations. This new configuration of the network should provide a better azimuthal coverage of the area, will help decrease the threshold of the detected events, and hopefully allow a better depth control. It is is also suggested to add a three-component digital seismic station in both Morocco and Spain. Such stations will make it possible to perform spectral studies of both local and regional events.

ACKNOWLEDGMENTS:-

Mohamed Kassimi helped in the installation and the operation of the Moroccan seismic network for the study of the Strait of Gibraltar. Ahmed Boutaleb actively participated in processing the data, while Ouafa Sebbata helped in gathering the data.

REFERENCES:-

[1] Buforn E. and A. Udias (1991), ***Focal Mechanisms of earthquakes in the Gulf of Cadiz, southern Spain and Alboran sea***; in Seismicity, Seismotectonics and Seismic Risk of the Ibero-Maghrebian region: Monografía Num. 8 (ed. by The Instituto Geográfico Nacional, Spain, 29-40).

[2] Mezcua J., J. Rueda and J.M. Martínez Solares (1991), ***Seismicity of the Ibero-Maghrebi region***; in Seismicity, Seismotectonics and Seismic Risk of the Ibero-Maghrebin region: Monografía Num. 8 (ed. by The Instituto Geográfico Nacional, Spain).

[3] Ben Sari D. (1981), ***Données Géophysiques du Détroit de Gibraltar***; in Symposium sur la géologie du Détroit de Gibraltar et la liaison fixe Europe Afrique (ed. by SNED, Société Nationale d'Etudes du Détroit), 87-123.

[4] Ait Brahim, L. P. Chotin, M. Ramdani and B. Tadili (1987), ***Carte sismotectonique du Maroc Nord (Rif)***; Rapport SISMO/CNRN 2/1987, convention de coopération CNR-CNRS, 1-39.

[5] Ramdani M., B. Tadili, L. Ait Brahim, D. Ben Sari and M. Barazangi (1992), ***Carte de sismicité du Nord du Maroc, période de 1900 à 1989***, (ed. by Centre National de Coordination et de Planification de la Recherche Scientifique et Technique, Rabat, Morocco).

[6] Tadili B. and M. Ramdani (1982), ***Risques sismiques dans la région Bético-Rifaine et la mer d'Alboran***; Bull. Inst. Sci., Rabat, 6.63-71.

[7] Ramdani M., G. Herquel and B. Tadili (1982), ***Etude du risque sismique au Maroc***; Data Proc. in Geochem. and in Engin. Geol., Nancy, 23, 103-114.

[8] Lee W. H. K. and J.C. Lahr, HYPO71 (revised), ***A computer program for determining hypocenter, magnitude and first motion pattern of local earthquakes***; U.S Geol. Surv., open file report 75-311, 1975.

[9] Ben Sari D., ***Connaissance Géophysique du Maroc***; ed. by Centre National de Coordination et de Planification de la Recherche Scientifique et Technique, 52, Avenue Omar Ibn Khattab, Rabat, Maroc, 1987.