PotSis'92, PotSis'94 and PotSis'99 GPS campaigns to improve the knowledge of seismic potentiality in the Eastern Pyrenees.

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Abstract

A GPS network of 24 points was established at both sides of the Eastern Pyrenees as an important part of the PotSis project which is a long term multidisciplinary collaboration between Spanish and French teams to study the present-day tectonic deformations through seismic, neotectonic and geodetic measurements. The expected rate of deformation is of the order of *1 mm/yr*. To mesure such low rate, the network is periodically observed (up to now it has been observed in 1992, 1994 and 1999). These campaigns and their results are presented and discussed.

Introduction

Although the current seismicity of the eastern Pyrenees is moderate, a destructive seismic crisis took place in the Middle Ages (1427-1428) which seems to indicate that periods of low seismic activity are interrupted by destructive earthquakes, probably with long repetition intervals. In fact, there is not enough historical information to estimate the duration of this interval. The interdisciplinary workgroup PotSis was created in 1991 to carry out this research. The PotSis workgroup is composed by the Servei Geològic de Catalunya (ICC), GEOTER (Montpeller), Unitat de Geodèsia (ICC), GEOÏD (Montpeller), Institut de Protection et de Sûreté Nucléaire (Paris), Observatoire Midi-Pyrénées, Groupe de Recherche de Géodésie Spatiale (Toulouse), Université Scientifique et Technique du Languedoc (Montpeller), Universitat de Barcelona.

Current tectonic deformations

The study of the distribution of current tectonic deformations originated by the regional stress field is very important in investigating which are the most likely areas of future destructive earthquakes, and which are their return periods. Analysis of historical and instrumental seismicity data, together with research into the deformations (folds and faults) that have affected recent geological formations (Plioquaternary), enables an initial qualitative approximation of recent tectonic deformations to be made.

Historical seismicity.

Historical seismicity data are fundamental in the study of seismic potentiality as it tells us of the existence of important earthquakes and of the areas most affected in relation to the epicentral area of the earthquakes. These data have an important limitation due to the fact that the information period (in many cases of the order of 1000 years) is insufficient for the study of earthquakes with longer return periods. The eastern Pyrenean region is a good example of this problem. In fact, a large number of mediaeval documents have permitted us to know about the destructive crisis of 1427-1428 with great precision. Recent investigations have enabled the effects produced by the different quakes in the crisis to be separated: there were two earthquakes wich caused damage in 1427, one on March 15th and another on May 15th. The area of maximum damage was located on the Amer-Olot axis. Another quake, the most important, took place on February 2nd 1428 and was felt over a wide area from the Pyrenees to Barcelona. The results of the present investigation will enable a more precise definition of the epicentral area to be obtained. Since this crisis the area has suffered no further destructive earthquakes. Nor is there any information about possible previous earthquakes. From this data it is not possible to determine the return period of destructive earthquakes.

Instrumental seismicity

Seismic information based on seismograph readings is available for the eastern Pyrenees, in a very imprecise way, from the start of the century through to the 1970s. The recent development of the seismic network of Catalonia, carried out by the Servei Geològic de Catalunya (SGC), and in particular of the seismic network of the eastern Pyrenees, in collaboration with the Observatoire Midi-Pyrénées (OMP) of the Toulouse, has permitted the detection and location of quakes, including even those of small magnitude, which define with precision the areas of current fragility. The distribution of epicentres corresponding to the period 1977-1997 *[30]* shows a marked concentration of seismic events of small magnitude at the two extremes of the NW-SE direction fault system -the system in which the areas of damage of the two 1427 earthquakes is concentrated- and very little activity on these faults. From these observations we can see that it is very difficult to differentiate between potentially seismic areas and those which are not.

Deformations in sediments of the Plioquaternary age

Field studies carried out have permitted the analysis of numerous indications of recent deformations (affecting formations of the post-Miocene age), from one side to the other of the mountain range axis *[10,26]*. All of these observations suggest the presence of faults with recent activity, liable to be able to concentrate nowadays the regional tectonic deformations.

Analysis of these deformations indicates the existence of different Plioquaternary reverse faults of NW090 to N130 direction, with maximum compression axes of N-S to NE-SW direction.

All of these observations carried out on post-Miocene age formations are compatible with a regional stress pattern typified by a compression of approximately N-S direction, that would give grounds for the manifold observations of compressive motion, accompanied by an extension of E-W direction, responsible for the distensive structures.

The use of GPS measurements for the study of crustal motion

The average convergence velocity between the African and European plates is approximately 1 cm/year in the western part of the Mediterranean. Part of this deformation corresponds to the motion between the European and Iberian blocks at the Pyrenees. This value, of the order of a few millimeters per year, can be spread in a more or less uniform manner over the 100 km width of the range from north to south. This is, on average, equivalent to a motion of the order of a few tenths of a millimeter per year between two points separated by a distance of 10 km. However, both the seismicity and the neotectonic data indicate that the deformation is not distributed uniformly and the areas exist where it is concentrated in such a way that one can expect to find much higher values, of the order of 1 mm/year/10 km. These areas correspond to fault systems which are susceptible to reactivation under the effect of the current forces. The deformation is concentrating around probable fracture areas, where the energy will be dissipated in the form of future earthquakes.

As we have seen, knowledge of the current deformations is incomplete and we should also bear in mind that seismicity is the manifestation of only a part of the tectonic deformations. In order to be able to quantify the distribution of current deformations the use of geodetic techniques is necessary. The measurement of crustal motion in regions of substantial tectonic activity is increasingly being conducted with very precise positioning techniques, such as those provided by GPS satellites (a synthesis of the use of geodetic techniques for the study of crustal deformations can be found in *[22]*). For regions with moderate deformations the utmost care must be taken in all the processes which are involved in the measurements, from the construction of the fixed measuring points to the measuring itself. Furthermore, the measurements must be repeated over the required period of time so that the deformations of the network are significant with respect to the intrinsic measuring errors.

As for vertical deformations, conventional techniques such as precision levelling *[10]* could be more accurate, in particular for research at regional or local scale.

The PotSis GPS network

In 1992 a network of 24 points was set up covering an area of 80 km x 100 km. The mean distance between neighouring points is about 17 km and the maximum variation in altitude between two neighbouring points is 850 m. The maximum variation in altitude is 1280 m, which restricts the vertical accuracy of the network, but our main interest is to determine horizontal movements.

The sites were selected according *[8,15]* to the following criteria below: first, the points are sited around faults presenting evidence of recent activity. Once the areas were selected using the above criterion, the best network geometry was taken into account so as to achieve the best precision and reliability in data analysis. Then all the points are situated on hard and stable bedrock with an easy accessibility by vehicle and with a good visibility of 15 degrees above the horizon in all directions. On the other hand, the residents and local councils, informed of the project, have received it with interest.

Great care was taken in the design and construction of the geodetic monument as they have to allow the rapid and very precise installation of the GPS antennas at the time of measuring and to avoid confusing pillar movements with tectonic ones. Above all they need to possess great stability over time if one bears in mind the fact that the measurements must be repeated over a period of 10-20 years. Because of this the pillars are made of concrete, with an iron framework anchored to solid bedrock. They are 1.60 m high in order to ensure maximum visibility.

For the attachment of the receiving antennas, the French posts have fitted aluminium base with three grooves and a hole. The Catalan posts contain an embedded bolt to which the antenna is fitted thanks to a finely-calibrated metal part.

In addition, some reference points have been placed near the posts in order to be able to locate them accurately, should it be necessary and 4 levelling benchmarks were set up on the pillar base to monitor any inclination of the pillars. All of them were measured in 1992-1993. Although the initial idea was to check the stability of the pillars in case a significant movement was detected, some of the pillars have been already checked and no local movements have been detected.

PotSis'92, PotSis'94 and PotSis'99 campaigns

The PotSis network has been observed in 1992, in 1993 and in 1999. All the descriptions about each campaign is shown in Table 1. Teams formed two groups, one with the Trimble receivers and the se\-cond one with the Ashtech receivers. The occupation strategy was signed to minimize the distance between receivers in the same group.

	PotSis'92	**PotSis'94**	**PotSis'99**
# teams	10	10	11
DOY	195-199	180-185	179-183
Session	10:30-4:00	12:30-6:00	11:00-4:00
Receivers	4 TGP	4 TSSE	3 TSSI
	3 AP12	3 AZ12	1 TSSE

	2 ALDXII	3 ALDXII	7 AZXII3
	1 ALMXII		
Antennas			DMchoke
ITRF	1991	1992	1996
Remarks	IGS	180 add.	
	EPOCH'92	T Team	

Table 1. Observation strategy for each PotSis campaign. TGP: Trimble Geodesist P; AP12: Ashtech P-12; ALDXII: Ashtech LD-XII; ALMXII: Ashtech LM-XII; TSSE: Trimble 4000SSE; AZ12: Ashtech Z-12; TSSI: Trimble 4000SSI; AZXII3: Ashtech Z-XII3; DMchoke: Dorne Margolin chokering

The processing of the campaigns has been carried out by the Institut Cartogràfic de Catalunya (ICC) and at the Observatoire Midi-Pyrénées (OMP).

At the ICC, in a first step, baselines have been computed using the Bernese software *[27]*. For modelling the troposheric delay only a few parameters have been estimated for each station. The ambiguities have been succesfully solved in most of the cases *[13,29]*. Finally, a least-squares adjustment has been done for each campaign using the ICC GeoTeX software *[2]*.

At the OMP, the computation has been done using GAMIT *[20]*. Tropospheric estimates have been also determined and most of the ambiguities have been succesfully solved *[23,25]*.

Ashtech and Trimble data have been processed independently, as if they were from different sessions in order to avoid antenna fixing problems. The data processing of PotSis'99 campaign is now being carried out by ICC and OMP.

Once the campaigns have been computed, they have been combined to estimate the velocity field and its uncertainty. Two different approaches have been used: at the OMP the GLOBK software *[18,19]* is used; at the ICC, GeoTeX software is used to estimate station velocities and a set of datum transfer parameters between two campaigns.

Theoretically, the reference frame of the PotSis adjusted networks should be the one provided by the precise orbits used. So, the datum transfer parameters should be well known and not need for its estimation. GeoTeX introduces the datum transfer estimates in order to avoid apparent distortions due to changes in the reference frame imposed by the orbits. Similarly, the GLOBK introduces large stochastic variations in the orbits. Both approaches separate the reference frames at the two epochs, minimizing any distorsion. Otherwise, the distorsion could be as large as 1 mm over 10 km *[21]*.

The evaluation of movements between PotSis'92 and PotSis'94 are shown in *[29]*. The results suggest that the level of noise between surveys separated by two years is comparable to that between two sequential days of measurements recorded by a permanent station. The evaluation of movements from PotSis'99 campaign is now being carried out.

Conclusions

A synthesis of the most important results of the PotSis workgroup has been presented. We have seen how seismicity research make clear the past existence of destructive earthquakes and a current period typified by moderate or weak seismicity. In order to know the location of future earthquakes, as well as their interval of repetition, the areas where the deformations are concentrated, and their rates, must be worked out. The rate of current deformation can only be worked out in a quantitative way by using geodetic techniques. For this reason, a network of 24 fixed points, in the form of concrete pillars, has been constructed from one part to the other of the eastern Pyrenees, which has been measured in 1992, 1994 and 1999 using GPS receivers.

The lessons learned on the processing of PotSis'92 and PotSis'94 have allowed us to improve the methodology for the next campaigns. An optimal geodetic arrangement consists of a set of permanent stations providing high temporal resolution data and a geodetic network of high spatial resolution tailored to the geographical distribution of tectonic faults. The first results of these measurements are promising, in the sense that the regulation of the network has enabled us to obtain coordinates of the points with a milimetrical accuracy in planimetry, which approaches the values hoped for from this type of network, and we can therefore expect that the measurements repeated in the future will permit the detection of current horizontal tectonic deformations and, in consequence, the interval of repetition of possible future destructive earthquakes in the eastern Pyrenees.

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