Two seismological approaches to the Benavente earthquake (1909): from the network of citizens to the network of instruments

J. Ferreira
IHC – Grupo CEHFCi (Ciência) da Universidade de Évora, Portugal

ABSTRACT: The 23rd April 1909 earthquake (Benavente Earthquake - BE), with catastrophic effects in Ribatejo, including Benavente, relatively close to Lisbon, was the subject of two coeval studies according to different approaches that in the conceptual framework of tectonics can be considered pioneers in the Portuguese seismology: the official one, according to dedicated questionnaires and based on a network of human observers, and the one of private initiative, according to the only seismogram registered in the Portuguese continental territory (Coimbra), but limited by the absence of a (reclaimed) network of instruments. These two studies are described with attention to the protagonists, the contexts and the contributions to the Portuguese seismology, and despite the different approaches, both claim for more instruments and the setting of a desired and necessary national network of seismic stations.

1. INTRODUCTION

The earthquake of April 23, 1909 (Benavente Earthquake - BE), with catastrophic effects in Ribatejo, including Benavente, relatively close to Lisbon, was studied according to two approaches dependent on networks: the official study (Choffat & Bensaúde 1912), according to dedicated questionnaires and directed to a network of human observers, and the study of private initiative (Diniz 1911), according to the seismogram obtained in the only seismographic station operating in Portuguese continental territory (Coimbra), but limited by the absence of a seismic instruments network. These two studies are analysed (see more information in Ferreira 2014) in order to highlight how they contributed to the development of the Portuguese seismology.

Seismic networks were then claimed for the need to have comparable data on the propagation of the earthquake throughout an extensive shaken area, for the location of the epicentres and for the study of the Earth's interior. The British engineer John Milne (1850-1913) promoted an early network of seismographic stations among the British community, based on a seismograph designed by himself, and the Company of Jesus established on its own a network of seismographic stations distributed throughout the world, with precision devices and standard procedures, in the early 20th century, long before the World Wide Standard Seismograph Network (WWSSN). The establishment of networks required a cooperative effort, which resulted in the creation of the International Seismological Association (1905).

Another network seismological approach (with human observers) was initiated by the Marquis of Pombal following the 1755 earthquake in Lisbon, which solicited priests throughout the Kingdom to report on the effects of the earthquake, although the questionnaire was distributed more for reasons of reconstruction (Oldroyd 2007). One that can be considered the first scientific "field" study on intensity was carried out after the earthquake that occurred in southern Italy in December 1857 by Robert Mallet (1810-1881), based on testimony and detailed cataloguing of damage to buildings and land surface. This study is contemporaneous with early seismographic instruments, such as that of Luigi Palmieri (1856), used in Italy and Japan. Mallet and many of his British, Italian and Japanese colleagues then choose the instrumental approach.

The problems that the first instruments revealed, not resolved before the beginning of the twentieth century, led the Swiss to consider the human observers most reliable and inexpensive for the study of local earthquakes. The first commissions for the study of earthquakes began between 1878 and 1880, in Switzerland, Italy and Japan, but only the Swiss commission would have volunteer citizens for this purpose, whose observations were collected through questionnaires or postcards. Citizens were trained in the observation of earthquakes, and communication with scientists was based on standard definitions and accessible language. A seismic activity that is often

felt, but without great destructive effects, made Switzerland suitable for a seismological study based on this type of network (Coen 2013).

2. THE STUDY OF THE BENAVENTE EARTHQUAKE THROUGH A NETWORK OF CITIZENS (CHOFFAT & BENSAÚDE 1912)

Following the BE, two commissions were appointed by the Ministro das Obras Públicas, one related to the reconstruction of settlements and the other for the scientific study of the earthquake. This commission met once and included an exhibition of the Swiss geologist Paul Choffat (1949-1919) on the intensity of the earthquake evaluated with information collected in the newspapers. The study that was later carried out would have been influenced by the education of this Swiss geologist who was working for the Portuguese Geological Services, and by the very own approach to seismology (with the citizens as observers) in Switzerland. Unsurprisingly, the commission decided to distribute to citizens across the country a questionnaire on the effects of the earthquake. The task of this commission was carried out by Paul Choffat, as a contracted geologist, and Alfredo Bensaúde (1856-1941) who had served in the Geological Services as a petrographer.

The corresponding official report of this study, prepared by the two geologists, was published in French (language adopted by the International Association of Seismology), with some delay in its printing and the translation to Portuguese was done only in 1912. The first part of the report had preliminary information and considerations, and it was of Paul Choffat's responsibility. The second, on the earthquake of April 23, 1909, included various observations by Alfredo Bensaúde and the examination of the effects of the quake by natural regions, by Paul Choffat. The third and last part, dedicated to the aftershocks, was in charge of Alfredo Bensaúde.

At the beginning of the report, Paul Choffat explained that the questionnaire was drawn up on the basis of that used by the Swiss Seismological Commission. In addition to questions about the observer, the time at which the observation was made, the location and nature of the ground where it was located, it included questions about the elements that characterize the earthquake, the noises accompanying the quakes, and the effects of the earthquake on furniture, buildings and others. There was a delay in printing the questionnaire and the answers were not given in due time, a situation that took out part of its value, according to Choffat. In addition, the answers: […] certainly, contain large gaps and misunderstandings because most respondents have never focused on these issues. Many of the questions were often misunderstood […][1]

Even before the report was published in Portuguese, Choffat had stated that the answers to the questionnaires on the BE that the commission decided to apply were too contradictory to allow any conclusion on hour, duration and direction of the shakes (*Revista de Obras Públicas e Minas* 1912).

The questionnaires were distributed by postage and the return was free of charge. The percentage of returned respondents was 25% (out of 240) in Lisbon and 58%, (out of 897) in provinces, of whom 91 were telegraphers from the districts of Lisbon and Santarém. Provincial administrators, ecclesiastics, teachers and postal and telegraph employees were the main recipients of the distributed questionnaires. Choffat notes that for some professions more questionnaires were answered than those distributed, attributing this fact to recipients having passed the questionnaires to other individuals. Poverty and lack of "instruction", at a time when about three-quarters of the Portuguese population could not read or write, justify that Choffat would suggest the distribution of questionnaires "by the competent people" (Choffat & Bensaúde 1912, 11).

The lack of information concerning locations for which the questionnaires were not answered was, to a certain extent, offset by the reports sent by the correspondents of the newspapers. Choffat lamented, however, the lack of accuracy in the information provided, referring to the classification of shakes as "strong" or "violent", words that, explained the geologist, may have different meanings depending on who writes it. Choffat points out that newspaper correspondents tend to "exaggerate" (Choffat & Bensaúde 1912, 11) the effects of the shakes. The report also takes into account the intensity scales, integrating the assessment of the duration of the earthquake or the effects on the buildings, and the considerations produced are also in the sense that the empirical observations give rise to "very uncertain data" (Choffat & Bensaúde 1912, 20).

The report includes an extensive list of the BE aftershocks found in the Tagus Valley (the last one included was on February 5, 1910), but according to Alfredo Bensaúde, the list would be more extensive if newspaper correspondents reported on all shakes. He also considered the known number of premonitory tremors lower than what had happened and that this knowledge had been obtained through the newspapers. Still without instrumentation was the information about observations at sea, obtained from the questionnaires, newspapers and personal survey

[1] "[…] contêm certamente grandes lacunas e enganos devido a que a maior parte dos respondentes nunca fixara a sua atenção sobre estes assuntos. Muitas das perguntas foram com frequência mal compreendidas […]" (Choffat & Bensaúde 1912, 11).

(conducted on-site). As they were not perceived on board of the ships anchored in ports, these observations are interpreted as repercussions of an earthquake originated on land, a conclusion that coincides with the interpretation from the seismogram recorded in Coimbra (see next section).

In relation to the observations on the state of the atmosphere on April 23, 1909, it was possible to take into account the instrumental approach, using the sheets and automatic records of the Observatories Infante D. Luís (Lisbon) and University of Coimbra. Alfredo Bensaúde verified that no sudden change occurred, calling into question some information resulting from non-instrument observations. Also, the study of the effects of the earthquake in Lisbon is called into question, since most of the people did not answer or the questionnaires were filled "in haste and in an incomplete way". Even using newspapers and collecting data verbally, this situation implied, according to Bensaúde, a "deficient" (Choffat & Bensaúde 1912, 39) basis for the study of the seismic phenomenon.

The results of the analysis and interpretation of the answers to the questionnaire were presented at the ordinary session of the Associação dos Engenheiros Civis Portugueses, held on December 18, 1911. Paul Choffat lamented the uncertainty of the data collected and claimed the establishment of a network of devices not very sensitive, without "deteriorating", specifically to "accuse" macroseisms occurring in the national territory(*Revista de Obras Públicas e Minas* 1912, 52). The commission appointed to study the BE also reported being desirable to set several recording devices across the country "through which the empirical observations can be interpreted and rectified" (Choffat and Bensaúde 1912, 20). It was demanded access to more instrumentation that should be set in network.

3. THE STUDY OF THE BENAVENTE EARTHQUAKE BASED ON A SEISMOGRAM (DINIZ 1911) AND THE DEMAND FOR A NETWORK OF SEISMOGRAPHS

The instrumental seismology offered the opportunity to compare earthquakes worldwide, whether they were felt in inhabited regions or not. John Milne was an important protagonist who directed the first scientific organization dedicated to the seismological studies, the Seismological Society of Japan, and in 1894 conceived a compact and simple to use seismograph (Ben-Menahem 1995) that was known by his name, capable of detecting seismic waves that propagated several thousand kilometres from their origin. The records of the observatories with Milne instruments were published through a bulletin and served to make world maps of the earthquake's distribution.

The first seismographic observations in Portuguese territory occurred in 1902, from seismographs installed in the Azores, but at the date of BE was located in the Observatório Magnético-Meteorológico of the University of Coimbra (COI station) the only seismograph in the country that "operates regularly" (*Apêndice ao Diário do Governo* nº495 – 1909, 451). Acquired in 1901, it operated continuously since 1903 (Custódio et al. 2012). The apparatus which drew up the register was precisely a horizontal pendulum of Milne, the same type used in the John Milne British network. The earthquake covered an extensive area and was recorded by other European stations, but the use of the seismogram obtained in Coimbra by Ferreira Diniz (1878-19--) was an early approach in the Portuguese seismology. This study of the author's initiative was completed in December 1909 (about eight months after the BE), being mentioned in the report produced by the official commission that studied the earthquake.

A significant part of Ferreira Diniz' text is dedicated to the main earthquakes, with emphasis on the earthquake of 1755 and a series of earthquakes in 1903, to prove that Portugal is a seismic region. Accompanying the text are five intensity charts and the effects on the constructions are illustrated by the photos in 18 figures (the first figure is the seismogram). The author regretted that the country was not equipped with the devices that allowed the recording of unfelt earthquakes and the "rigorous study of earthquakes" (Diniz 1911, 342), with the exception of the Milne horizontal pendulum existing at the University of Coimbra, where Diniz had graduated (in Philosophy).

In the introduction, Ferreira Diniz emphasized the study of the propagation of the seismic movement, which allowed the conclusion of the existence of longitudinal, transverse and surface waves, existence confirmed by seismograms obtained using better devices, especially for long distance shakes, where three vibration phases corresponding to the three types of waves were distinguished. For seismic waves to propagate within the planet, he stated that the nucleus would have to be "stiffer than steel", highlighting the importance of the seismological study for the knowledge of the Earth's interior.

Despite the few elements available, the author stated his use of the instrumental approach:

Now the seismogram of Coimbra without prophase shows that the earthquake came from an approximate region. It tells us little more, for it is not easy to study the amplitudes and periods of the movement, however, knowing […] a magnitude of 10 millimetres corresponds to a dangerous shock and a magnitude greater than 20 millimetres to a destructive concussion; it appears from the graph that the

corresponding quake can be included in the second category.[2]

Although a "fairly confusing" chart, interpreted as a result of the proximity to the epicentral region, Diniz takes into account the seismogram obtained in Coimbra in five parameters (time, duration, intensity, epicentral region and aftershocks) when interpreting the BE (see table 1). Other elements taken into account are the extension, direction of movement, depth and noise. And when he analyses the intensity, he regrets (again) the lack of a network of seismological stations.

Table 1. Ferreira Diniz' interpretation of the BE based on the Coimbra seismogram.

Parameter	Observations and interpretation
Time	17 hours, 6 minutes and 30 seconds, in Coimbra (horizontal pendulum of Milne)
Duration	The information collected is "discordant" but, based on the seismogram, the duration "should not go beyond 30 seconds" (p.345).
Intensity	According to the seismogram, Coimbra (intensity VII) would be close to the epicentre (p.353). Five zones of intensity in Portugal, with maximum intensities (IX and X) in alluviums areas.
Epicentral region	The sudden movement of the pendulum and the absence of preliminary phases "prove well that the shake emanated from the vicinity of the station", but also "the distribution of intensity in the shaken area" (p.357).
Aftershocks	The main quake was followed by "numerous small shakes" (p.358). But the horizontal pendulum of Coimbra registered nothing, being to reject the testimonies of small shakes in regions other than the maximum intensity.

Compared with previous earthquakes, Ferreira Diniz notes that the study of the BE revealed a new seismic focus, which would be a "large hydrographic basin, where successively in horizontal layers came to deposit the Tertiary and the Quaternary" (Diniz 1911, 360) and not one around the western coast. The BE would thus have its origin in a "vertical movement which occurred along a line […] passing through Salvaterra, Benavente and a little east of Samora" (Diniz 1911, 360-361), a tectonic nature origin that the author has no doubt and close to the epicentre, as was evidenced by the seismogram.

Ferreira Diniz used the registration of the University of Coimbra Observatory (COI station), even saying "little", to support his estimations in five of the parameters he considered to study the quake, following an early approach in national seismology based on different vibration phases of seismic waves recorded in seismograms. Although he was dependent on an instrument for the observation of the seismic event, which was still not very precise, the author did highlight the need to develop this approach, claiming the widening of the seismic (instrumental) network, for the rigor of the seismological study.

4. FINAL REMARKS

The official seismological study carried out following the 1909 earthquake in Benavente (BE) was supported by information collected through a network of human observers, inspired by the approach of the Swiss Seismological Commission. The absence of a culture of observation of the seismic event in Portugal, giving rise to "uncertain" data, contributed to Alfredo Bensaúde and Paul Choffat claim the development of the instrumental approach and a seismic network, the same claim that Ferreira Diniz, author of the personal initiative study supported by the seismogram recorded in Coimbra (COI station), did.

At a meeting held in January 1910, by royal convocation, the directors of the observatories and meteorological services, as well as the referred geologists of the commission appointed to study BE, were in charge of choosing venues for observatories and seismic stations. The commission determined that the Infante D. Luís Observatory (Lisbon) became the central Portuguese seismology station, but despite this attempt to organize the seismological observation service after the BE, a network of seismographic stations covering the entire continental territory was only materialized after the earthquake of February 28, 1969.

5. REFERENCES

Ben-Menahem, A. 1995. A Concise History of Mainstream Seismology: Origins, Legacy, and Perspectives. *Bulletin of the Seismological Society of America* 85(4): 1202-1225.

Choffat, P. & Bensaude, A. 1912. *Estudos sobre o sismo do Ribatejo de 23 de Abril de 1909* (versão do original francês). Lisboa: Imprensa Nacional.

Coen, D. R. 2013. *The Earthquake Observers. Disaster Science from Lisbon to Richter*. Chicago and London: The University of Chicago Press.

Custódio, S., Battló, J., Martins, D., Antunes, F., Narciso, J., Carvalho, S., Lima, V., Lopes, F. C., Ribeiro, P., Sleeman, R., Alves, E. I. & Gomes, C. R. 2012. Station COI: dusting off an Old Seismic Station. *Seismological Research Letters, Historical Seismologist* 83 (5): 863-869.

[2] "Ora o sismograma de Coimbra sem prófase mostra-nos que o sismo proveio de uma região aproximada. Pouco mais nos diz, pois não é fácil estudar nele as amplitudes e períodos do movimento, no entanto sabendo-se […] uma amplitude de 10 milímetros corresponde a um abalo perigoso e uma amplitude superior a 20 milímetros a um abalo destruidor; parece pelo gráfico que o sismo correspondente pode ser incluído na segunda categoria" (Diniz 1911, 353-354).

Diniz, J. O. F. 1911. Contribuição para o estudo dos tremores de terra em Portugal. O abalo sísmico de 23 de Abril de 1909. *Revista de Obras Públicas e Minas* XLI: 305-361.
Ferreira, J. 2014. *Da sismicidade à ciência dos sismos*: *para a história da sismologia em Portugal.* Tese de Doutoramento em História e Filosofia da Ciência) – Évora: Universidade de Évora.
Oldroyd, D.; Amador, F.; Kozák, J.; Carneiro, A.; Pinto, M. 2007. The study of earthquakes in the hundred years following the Lisbon earthquake of 1755. *Earth Sciences History* 26(2): 312-370.
Other sources:
Apêndice ao Diário do Governo, nº495–1909 (11 dezembro): 451-470.
Revista de Obras Públicas e Minas XLIII (1912): 31-54.