The seismic activity in stable continental Europe

CAMELBEECK, Thierry
Royal Observatory of Belgium, avenue circulaire 3, B-1180 Brussels

VANNESTE, Kris
Royal Observatory of Belgium, avenue circulaire 3, B-1180 Brussels

VAN CAMP, Michel
Royal Observatory of Belgium, avenue circulaire 3, B-1180 Brussels

Abstract

We provide a synthesis of the long-term earthquake activity in the region of Northwest Europe between the Lower Rhine Embayment and the southern North Sea. Historical seismic activity in stable continental Europe shows patches of activity, with $M \geq 5.0$ earthquakes, separated by relatively inactive regions. The activity in most of these patches is sporadic in time, showing inactive periods of hundred to some hundreds of years followed by more active periods. Only the Lower Rhine Embayment shows relatively permanent activity. An important observation is that nearly all $M \geq 5.0$ earthquakes inside the different patches occurred at different locations. Therefore, we can suspect that the next earthquakes in each of these patches will occur at a location not yet affected during historical time. Because in plate interiors the present seismic activity does not necessarily reflect past and future activity, we discuss the necessity to use the geologic record to infer long-term earthquake activity. Thus, we discuss paleoseismic investigations in the Roer Graben that provide evidence that large earthquakes with magnitude 6.5 to 7.0 occurred since the late Pleistocene.

Introduction

In the most seismically active regions of the world, earthquake prevention can be based on the experience of recent destructive earthquakes and on seismic hazard assessed by a multidisciplinary methodology combining earthquake seismology, geodesy and earthquake geology. Within many regions at the interior of lithospheric plates, it is more difficult to evaluate the risks associated to the earthquake occurrence simply because very destructive earthquakes have not been experienced recently and the known seismic activity is not necessarily representative of the future seismic activity due to its limited period of observation.

Nevertheless, during the last decade, authorities in countries like United States, Canada or France begun to take into consideration that earthquake risks can be high in these regions of low seismic activity when they are densely populated and (or) highly industrialized. The recent damaging earthquakes of Liège (Belgium on November 8, 1983 – M_S=4.7) and Roermond (The Netherlands on April 13, 1992 – M_S=5.4) provide examples of the high vulnerability of northwest Europe in the case of small or moderate earthquakes. Therefore, scientists focus on the necessity to better understand the seismic activity and the potential for large earthquakes in this part of intra-plate Europe but also to evaluate correctly our vulnerability to such earthquakes, which is essential to adopt adequate prevention measures.

Recently, new basic information has been collected on the seismic activity and risks in northwest Europe. In Belgium, numerous studies have been conducted to improve our knowledge on strong historical earthquakes, to develop methodologies to evidence active faults and study their recent activity. These works have been supported by the Belgian Science Policy and by the European Community (projects PALEOSIS, SAFE and SESAME). In this note, we present the main results of these studies.

Seismic activity in northwest Europe

The implication of professional historians in the study of earthquakes having occurred in the past is relatively recent. It induced major changes in the quality and reliability of the knowledge of seismic activity in Europe. Indeed, these works published during the 80^{th} have shown that most of the studies on northwest European historical earthquakes used up to that time were compilations obtained without any source criticism. Thus, it is dissuaded to use those compilations and historical earthquake activity studies have to be based on the search of original written sources able to furnish contemporaneous information on the seismic events. Since that time, methodologies have been also developed to evaluate intensity with historical data and also to quantify and calibrate macroseismic data to evaluate source parameters of historical earthquakes.

The earthquake epicenters from 1350 to 2004 in the region concerned by this note are plotted on figure 1. All the reported earthquakes come from the earthquake catalogue of the Royal Observatory of Belgium, which is based on different sources which can be considered as confident in terms of historical source criticism. The catalogue includes the earthquakes reported in the works of Alexandre [1] for the continental earthquakes before 1259, the Alexandre list of events in Camelbeeck [2] for the earthquakes felt in Belgium before 1910, and Ambraseys and Melville [3] for the earthquakes in England before 1800. The earthquakes that occurred since 1910 have been studied by Camelbeeck [2]. The magnitudes of the strongest earthquakes in northwest Europe since 1800 have been provided by Ambraseys [4] [5]. Lambert and Levret [6] completed the seismic activity data since 1800 in the French part of the studied area. The reliability of the information in the earthquake catalogue is strongly depending on the considered epoch (Alexandre and Vogt [7]).

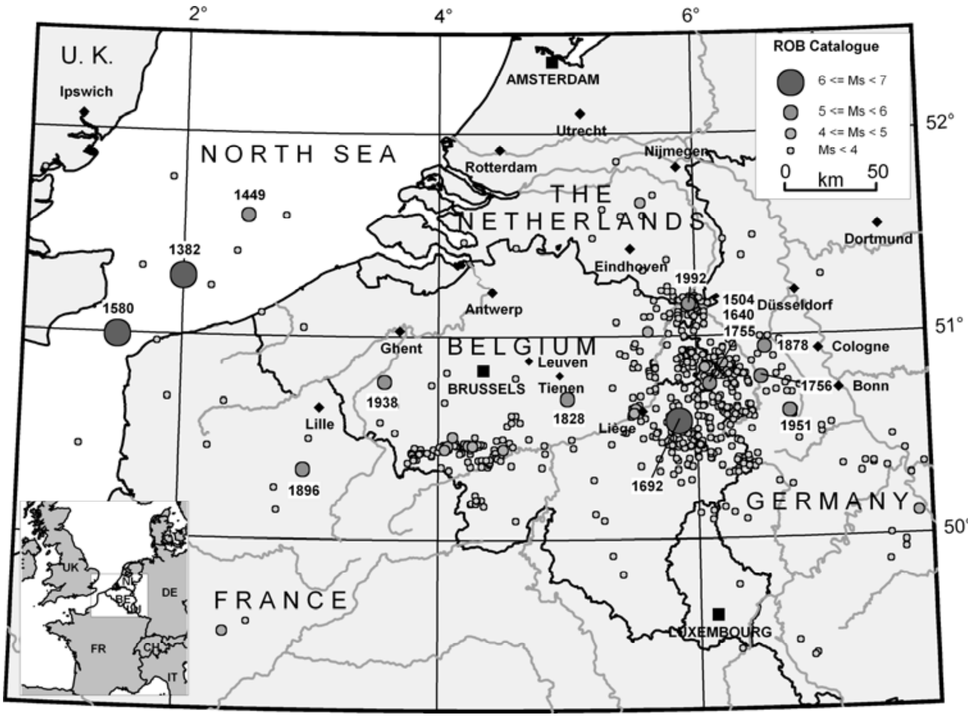

Figure 1 – Seismic activity in northwest Europe from 1350 to 2007

The most active region of the studied area (figure 1) is the bordering region between Belgium, The Netherlands and Germany. This tectonic region is often calling «Lower Rhine Embayment». A part of it, the Roer Graben area appears as the most active area with several earthquakes with M≥5.0, the strongest being the 1756 Düren event (Germany) with a M magnitude estimated around 5 ¾. The most important recent ones are the 1951 Euskirchen earthquake (Germany, M_S=5.3) and The Netherlands, M_S=5.4 1992 Roermond event (van Eck and Davenport [8]). To the west of the Roer Graben, a notable activity exists also in the Hautes-Fagnes and Eifel mountains. The strongest known seismic event of the studied region as a whole occurred there on 18 September 1692. Its magnitude has been evaluated to 6 ¼ (Alexandre et al. [9]). The 1692 earthquake provides a unique example of a large earthquake in northwest Europe for which the impact can be studied. In the near region of Liège, the activity is less important, but on 8 November 1983, a M=4.7 earthquake caused many damages in the city. There is also a concentration of earthquake activity in the Hainaut region (figure 1), but up to now, the magnitude of these events does never exceed M=4.5. In the other parts of northwest Europe, the earthquake activity is more diffuse and sporadic with time. The best example is given by the southern North Sea and the Strait of Dover, where the activity is very weak since the XVIIth century but was more important beforehand with the occurrence of two earthquakes in 1382 and 1580 (Melville et al. [10]) that have an estimated magnitude greater than or equal to 6.0.

Past large earthquakes in the geological record

Paleoseismology, which is the methodology to identify and study past large earthquakes in the morphology and the geological record, is a discipline which has been developed in seismically active regions of the world. In continental intraplate Europe with low tectonic deformation, surface coseismic deformations or ruptures were up to very recently unknown and considered to be improbable. Active faults remain largely unidentified and the potential for large earthquakes unknown. There, to evaluate this potential the problems to solve are different to that encountered in seismically active zones. To identify active faults is a difficult problem mainly because their morphological expression is often not clear due to the low level of deformations, the climatic regime and the strong anthropic activity. On the other hand, the interpretation of deformation and their dating are very complex due to the probable long duration of the seismic cycle which produces an intercorrelation between tectonic and climatic events.

In the framework of the european projects PALEOSIS (1998-2000) and SAFE(2001-2004) and some Belgian research projects, new approaches in paleoseismology were proposed and developed to study active normal faults in intraplate context. In an initial phase, active faults are identified by combining very detailed geomorphic and geologic investigations. Then, geophysical methods are used to locate precisely the faults and obtain their image near the ground surface. Finally, the fault activity and the possible related paleoearthquakes can be studied in trench exposures.

In the Lower Rhine Embayment, Ahorner [11] established already the relationship between the seismic activity and normal faults dislocating Quaternary deposits by up to 175 m. Based on high-precision geodetic levelling, Ahorner postulated also that a-seismic creep movements play a prominent role in the neotectonic deformation of the Lower Rhine Embayment. He did not consider the possibility of co-seismic surface rupturing, and inferred that the largest earthquakes should be similar in importance to the largest historical earthquakes, corresponding to M around 5.5. Our investigations (Camelbeeck and Meghraoui [12] [13], Vanneste et al., [14] [15]) since 1995 in the Roer Graben contradict these conclusions and provide evidence that large surface rupturing earthquakes occurred along the border faults of the Roer Graben during the Holocene and the late Pleistocene. These results, that have been synthetized by Camelbeeck et al. [16], evidenced also the relevance of active faulting studies to assess long-term seismic activity in this part of northwest Europe.

Where and when will occur the next large earthquake?

As suggested by recent investigations on strong historical earthquakes and our paleoseismic investigations in the Roer Graben, there is no doubt that large earthquakes with magnitude M greater than 6.0 occurred in the past and will occur in the future in northwest Europe. The main questions are to delineate the possible locations and to evaluate the magnitude and the return period of these future events.

To locate the seismogenic structure where they could occur is not easy. The earthquake catalogue already shows that the stronger historical earthquakes occurred generally at different locations. Thus, it is very likely that the next one could occur in an unexpected site. For that reason, we consider that it is important not only to map known seismogenic structures linked to known geologic and seismic activity, but also to map what we called capable faults, which are faults that have crustal dimension but for which there is presently no evidence of very recent geological activity. The known seismogenic structures can be classified in two categories. They can be associated with strong historical earthquakes with estimated magnitude greater than M_S=5.0 or with active faults evidenced by specific studies evaluating also their seismogenic character. In contrast to active regions where it is supposed that all the potential seismogenic sources can be evidenced, only a few of them can generally be identified in intra-plate context. Therefore, we intend to establish a relationship between the known seismogenic sources representative of $M \geq 5.0$ earthquakes and geological structures with the purpose of delineating other similar geological structures in the same region which could be considered as capable faults (potential seismogenic sources). In a second step, it will be necessary to establish that the considered structures are active faults and thus real seismogenic sources.

The maximum credible earthquake can be defined as the largest earthquake that appears capable of occurring along a fault or in a specific region considering the existing tectonic stress environment. Its magnitude is defined as Mmax. Following our definition of seismogenic sources, the maximum credible earthquake should correspond to the earthquake associated with the largest seismogenic source in the considered region. The problem is relatively easy to solve in well-studied seismic active regions where most of the active faults are identified and where historical seismicity already provided examples of major events which can be considered as the maximum credible earthquake. In intra-plate tectonic environments the major problem is the identification of the possible seismogenic sources and the evaluation of their dimension.

Despite the possibility to define the maximum credible earthquake in regions where large historical earthquakes occurred or the rare locations where active faults have been identified and well studied, information is lacking in many intra-plate regions. This is not only the case for areas where seismic activity is unknown or weak and diffuse, but also for areas where seismic activity is noticeable but has characteristics which do not allow to clearly infer seismogenic sources. The Hainaut and Liège zones are two typical examples in northwestern Europe. These seismic zones have been defined from their specific characteristics which appeared as different from the earthquake activity in the neightbouring regions. The known seismic activity in the Hainaut and Liège regions is characterized by relatively shallow hypocenters and magnitudes not exceeding 4.5 and 4.7 respectively. It is important to note that all the listed activity is relatively recent and has occurred since the beginning of the 20^{th} century. No known historical earthquakes originated from these two regions. Extensive coal mining activity during the last 200 years stopped in these areas during the years 1970-1980. Earthquake activity clearly occur at depth greater than that of the mining activity and the seismic activity can be of pure tectonic origin, but up to now, there is no scientific study demonstrating that the earthquake activity cannot be (at least partly) due to local stress modification caused by the extensive rock volume removed from the underground. This explain partly why it is not evident Therefore, in these regions, it appears more adapted to consider a variable definition of the maximum credible earthquake in relation to the purpose of the evaluation. Mmax could be defined as the magnitude of the largest possible earthquake to occur with a specified probability during a specified exposure time, or of the largest earthquake considered likely to occur in a “reasonable” amount of time (lifetime of facility involved?).

References

[1] Alexandre, P., 1990, Les séismes en Europe Occidentale de 324 à 1259: nouveau catalogue critique: Série Géophysique, Observatoire Royal de Belgique, 267 p.

[2] Camelbeeck, T., 1993, Mécanisme au foyer des tremblements de terre et contraintes tectoniques : le cas de la zone intraplaque belge [Ph.D. thesis]: Université Catholique de Louvain, 295 p.

[3] Ambraseys, N.N., and Melville, C., 1983, Seismicity of the British Isles and the North Sea: London, SERC, Marine Technology Centre, 132 p.

[4] Ambraseys, N.N., 1985a, Magnitude assessment of Northwestern European earthquakes: Earthquake Engineering and Structural Dynamics, v. 13, p. 307-320.

[5] Ambraseys, N.N., 1985b, Intensity-attenuation and magnitude-intensity relationships for northwest European earthquakes: Earthquake Engineering and Structural Dynamics, v. 13, p. 733-778.

[6] Lambert, J., and Levret-Albaret, A., 1996, Mille ans de séismes en France : Catalogue d'épicentres – paramètres et références: Nantes, Ouest Editions, Presses Académiques, 80 p.

[7] Alexandre, P., and Vogt, J., 1994, La crise séismique de 1755-1762 en Europe du Nord-Ouest, *in* Albini P. and Moroni A., eds., Historical investigation of European earthquakes, materials of the CEC project: review of historical seismicity in Europe: Milano, CNR, v. 2, p. 37-76.

[8] Van Eck, T., and Davenport, C.A., guest eds., 1994, Special Issue, Seismotectonics and seismic hazard in the Roer Valley Graben; with emphasis on the Roermond earthquake of April 13, 1992: Geologie en Mijnbouw, v. 73 (2-4), 441 p.

[9] Alexandre P., Kusman D., Petermans T., Camelbeeck T. in press, The 18 September 1692 Earthquake in the Belgian Ardenne and its aftershocks. In press in J. Fréchet, M. Meghraoui and M. Stucchi (eds.), Modern Approach in Historical Seismology: Interdisciplinary studies of past and recent earthquakes, Springer, Series: Modern Approaches in Solid Earth Sciences

[10]Melville C., Levret A., Alexandre, P., Lambert, J., and Vogt, J., 1996, Historical seismicity of the Strait of Dover-Pas de Calais: Terra Nova, v. 8, p. 626-647.

[11]Ahorner, L., 1975, Present-day stress field and seismotectonic block movements along major fault zones in Central Europe: Tectonophysics, v. 29, p. 233-249.

[12]Camelbeeck, T., and Meghraoui, M., 1996, Large earthquakes in northern Europe more likely than once thought: EOS, Transactions, American Geophysical Union, v. **77**, p. 405-409.

[13]Camelbeeck, T., and Meghraoui, M., 1998, Geological and geophysical evidence for large palaeoearthquakes with surface faulting in the Roer Graben (northwestern Europe): Geophysical Journal International, v. 132, p. 347-362.

[14]Vanneste, K., and Verbeeck, K., 2001, Paleoseismological analysis of the Rurrand fault near Jülich, Roer Valley graben, Germany: Netherlands Journal of Geosciences, v. 80, p. 155-169.

[15]Vanneste, K., Meghraoui, M., and Camelbeeck, T., 1999, Late Quaternary earthquake-related soft-sediment deformation along the Belgian portion of the Feldbiss fault, Lower Rhine Graben system: Tectonophysics, v. 309, p. 57-79.

[16] Camelbeeck, T., Vanneste, K., Alexandre, P., Verbeeck, K., Petermans, T., Rosset, P., Everaerts, M., Warnant, R. and Van Camp, M., 2007, Relevance of active faulting and seismicity studies to assess long term earthquake activity in Northwest Europe, Continental Intraplate Earthquakes: Science, Hazard, and Policy Issues. Geological Society of America, S. Stein and S. Mazzotti (eds.) Special Paper 425, 193-224, 2007