Workshop: Results of the European Project
SHARE: Seismic Hazard Harmonization in Europe

Development of seismic hazard maps for Belgium

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ABSTRACT:

We first provide a brief overview of the evolution of seismic hazard assessment in Belgium, followed by a comparison of the current official seismic hazard map used to define the seismic zonation of Belgium in the framework of Eurocode-8 with the corresponding map from the European SHARE project. The general pattern of the PGA spatial distribution is similar in the two maps, but although the differences are lower than 0.02 g in a large part of the Belgian territory, they locally reach 0.08 g. This comparison suggests that seismic hazard in Belgium should be re-evaluated using current state-of-the art methods as developed in the frame of SHARE and Global Earthquake Model (GEM) projects, but also taking into account the most recent studies of the regional seismic activity that have not been taken into account in the SHARE computations.

In the second part of the paper, we present the most important advancements made during the last years by the Royal Observatory of Belgium (ROB) on the assessment of seismic hazard for sites in Belgium. Most of these developments follow the guidelines and experiences provided by the SHARE and GEM projects. For the specific cases of sites in the northern part of the country, we also discuss why it is relevant to use hard-rock ground motion prediction equations.

Keywords: seismic hazard, eurocode-8, SHARE-project, ground motion prediction equation

1 Introduction

The first investigations in Belgium to provide ground motion levels for the safety of new buildings date from the 70ies at the occasion of the construction of the first nuclear reactors at the sites of Tihange and Doel. Nevertheless, despite the interest in the seismicity in Belgium resulting from these engineering projects, it was not until the 90ies when the first seismic hazard map for the whole Belgium territory was drafted as a part of the Global Seismic Hazard Project (GSHAP) for Central, North and Northwest Europe (Grünthal et al. [1]).

In 2000, cooperation between the Liège University and the Royal Observatory of Belgium (ROB) resulted in a new probabilistic seismic hazard map (Leynaud et al. [2]) that served as the basis for the Eurocode-8 (EC8) zonation in Belgium. Although it is based on data and concepts (see below) that are mostly outdated, this map is to this date the only map that has been published specifically for Belgium, and it is still considered as the official seismic hazard map for Belgium.

Between 2009 and 2012, ROB participated in the European SHARE project which aimed to homogenize seismic hazard across the whole of Europe based on common datasets and state-of-the-art methodologies, and which resulted in a new European seismic hazard map in 2013 (Giardini et al. [3]).

In parallel, ROB has conducted a number of site-specific seismic hazard studies for sensitive constructions (storage facility for nuclear waste, stress tests for Belgian nuclear power plants, …) since 2008. This required a more sophisticated analysis, including a.o. improvement of the earthquake catalog, more elaborate processing of the earthquake catalog, development of alternative models to characterize seismicity, implementation of new methods such as smoothed seismicity, evaluation of more recent GMPEs, application of logic trees, deaggregation, characterization of bedrock, host-to-target adjustments, and modelling of site effects.

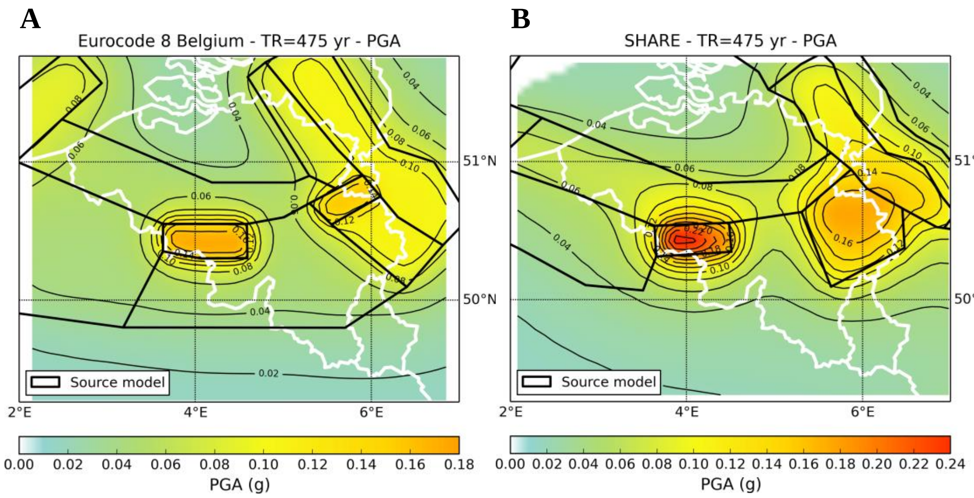
In the first part of this paper, we compare the map obtained for the Belgian territory by the SHARE project with the map which is at the base of the official EC8 Belgian zonation map. This comparison is useful because it can be considered as a kind of uncertainty evaluation of the "official" seismic hazard levels on the Belgian territory. The differences between the two maps can be attributed to differences in the applied methodologies, but also to regional characteristics of the seismic activity not necessarily considered in SHARE. These differences are significant enough to necessitate a re-evaluation of seismic hazard in Belgium using the present-day state of the art methods, but also taking into account the most recent studies on the regional seismic activity. In the second part of the paper, we present specific aspects of hazard assessment that were specifically developed since 2008 at the ROB for that purpose.

2 Comparison of EC8 and SHARE seismic hazard for Belgium

Since 1 January 2012, EC8 should be applied in Belgium for the construction of new buildings. The zonation map published in the EC8 Belgian official document has been based on the hazard map of Leynaud et al. [2]. This map was based on a single area-source model, one magnitude-frequency distribution for each source, and one GMPE (Ambraseys et al. [4]) with a 2 σ truncation, and was computed for PGA only. The computations were originally done with the SEISRISK III software

(Bender and Perkins [5]), and later re-implemented in CRISIS (Ordaz [6]). Figure 1a presents the PGA corresponding to 10% probability of exceedance in 50 years. We compare these results with the corresponding hazard map of the SHARE project (Figure 1b).

For most of the Belgian territory, the difference between the two maps is less than 0.02 g (Figure 1c). In general, the PGA values in the SHARE map are lower than in the EC8 map for the northern and southern parts of the territory. The PGA difference is reversed in the central part of Belgium, with two spots with larger differences in the Hainaut zone and in the eastern Ardenne (denoted as “HAIN” and “HFAG”, respectively, in Figure 4a). In those areas, the SHARE values are 0.04 to 0.08 g higher than the ones in the EC8 map. In the map of the relative differences (Figure 1d), the pattern is relatively similar, except that the two spots of maximum difference are shifted compared to the map with absolute differences. This is because the spots of maximum absolute difference coincide with zones where the PGA values are also highest. This is particularly the case for the Hainaut zone, where PGA values are around 0.16 g in the EC8-map, quickly dropping to 0.06 g in the surrounding areas. The decrease is slightly less abrupt to the north, as a result of which the spot of maximum relative difference is displaced in that direction.



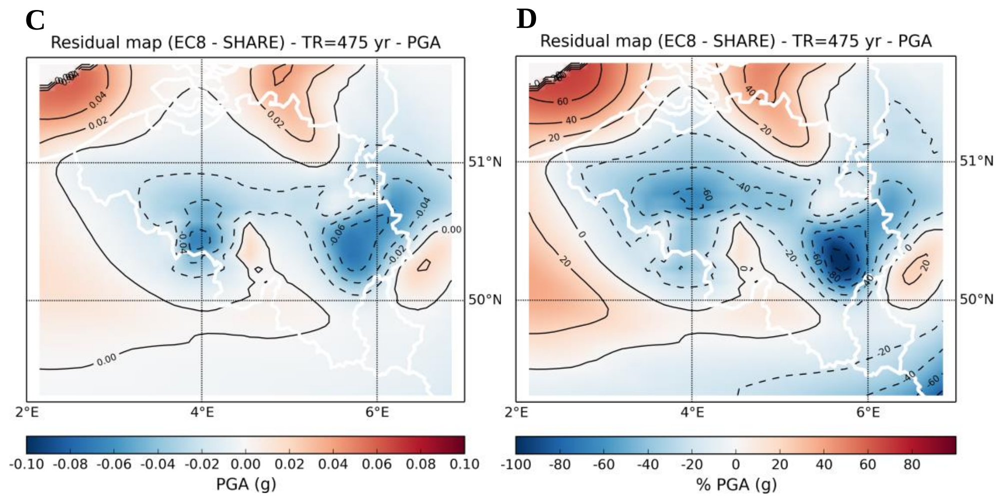


Figure 1 - Comparison of seismic hazard maps (PGA, 10% probability of exceedance in 50 years) for Belgium. A) Hazard map used for EC8 (Leynaud et al. [2]); B) Hazard map resulting from the SHARE project (Giardini et al. [3]); C) Absolute differences between EC8 and SHARE maps; D) Relative differences between EC8 and SHARE maps. Black lines in A and B delineate area-source model

The large discrepancies in these two spots do not have the same cause. In the Hainaut zone, the earthquake activity is very shallow and the differences appear to be essentially due to the fact that the Ambraseys et al. [4] GMPE used by Leynaud et al. [2] is independent of earthquake focal depth and predicts lower PGA than the GMPEs used in SHARE. In either case, the hazard evaluation for this region does not seem realistic and appears too high compared to the local extension of damages caused by the 20th century shallow earthquakes that occurred in the area. Providing a better hazard assessment for this seismic zone will require establishing a specific GMPE for the area. In the second case, the large difference in the eastern Ardenne is related to differences in the geographical limits of this seismic source (compare Figure 1a and 1b), which have an important impact on the computed seismic activity rates.

3 Methodologies, databases and input data for seismic hazard assessment in Belgium

In this section, we briefly present the main databases, input data and methodologies used and developed at the ROB for seismic hazard assessment.

3.1 Earthquake catalogues

ROB developed its own earthquake catalogue for the region extending from 49°N to 52°N and 1°E to 8°E. As is the case for most other seismic catalogs in the world, this catalog is heterogeneous, and consists of two different types of data:

- Historical data: concern the period from about 1350 to 1910, for which only local reports about damage and felt effects (i.e. intensity) of earthquakes are available. The magnitudes of these events are inferred from macroseismic radii, and correspond to M_S;
- Instrumental data: concern the period from 1911 onward, the year continuous seismic recordings in Belgium started, to the present day. For earthquakes during this period both intensity data (from macroseismic enquiries with the local authorities and, since 2000, on the internet) and seismic recordings are available. The magnitudes of these events are mostly M_L and, if macroseimsic information is available, M_S.

The ROB catalog is constantly updated and improved. Recently, a revision work has been undertaken to provide M_W for all the earthquakes in the list and to include the most recent investigations on historical earthquakes.

We also use the CENEC (Grünthal et al. [6]) and SHEEC earthquake catalogues (Stucchi et al. [8]). CENEC is a unified catalogue for central, northern and northwestern Europe with unified M_W for events with $M_W \geq 3.5$ in the time frame 1000-2004. It is based on national earthquake catalogues. The SHEEC catalogue, developed in the framework of different European projects and finalized during SHARE, covers the time period 1000-1899 and has been established using the same methodological background to evaluate earthquake location and magnitude from intensity data points in the different parts of Europe (Stucchi et al. [8]).

3.2 Models of seismic sources

In addition to the existing seismic source models defined in the GSHAP and SHARE projects and the one defined by Leynaud et al. [2] (Figure 2A) for the hazard computation in the framework of Eurocode 8, we developed three seismic source models:

- The first model, called “Seismotectonic model” (Figure 2B), results from an integrated analysis of all available geologic, tectonic, geophysical and seismological data (Verbeeck et al., [9]). The model contains 14 zones that cover the whole Belgian territory and a considerable area around it, in order to include all earthquakes that could have an impact in Belgium.
- An alternative model is the “Two-zone model” (Figure 2C), consisting of the Roer Valley Graben (RVG) and a so-called “Single Large Zone” (SLZ), which includes the entire region outside of the RVG. This model is motivated by the observation that the RVG, which is the only area in Western Europe where active faults are evidenced, is characterized by

rather continuous seismicity, whereas in the region outside, the temporal and spatial distribution of seismicity is diffuse.

- In the frame of the SHARE European database of seismogenic sources, we have devised a seismic-source model for the RVG consisting of so-called composite seismic sources (Figure 2D, Vanneste et al., [10]). These are fault sources that may encompass one or more fault segments, but it is considered unlikely that a segment would extend across more than one source. We distinguish 15 such fault sources with a total length of more than 560 km based on major stepovers, bifurcations, gaps, and important changes in strike, dip direction, or slip rate along the different faults of the Lower Rhine Embayment.

As an alternative to these source models, we are also investigating a zoneless approach using smoothed seismicity.

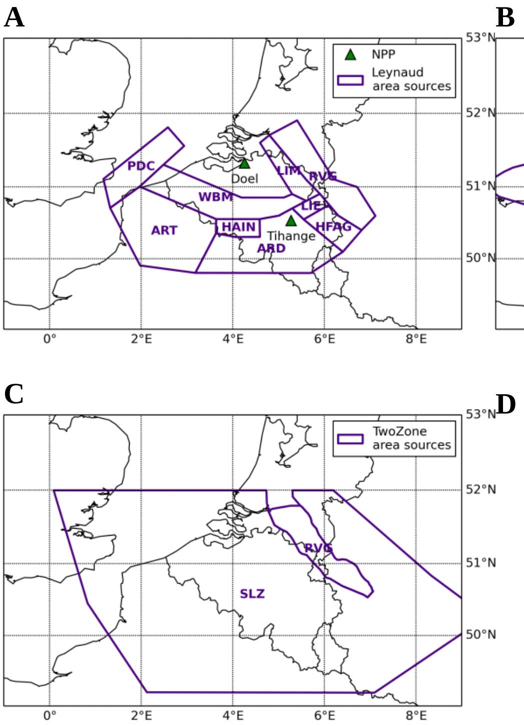


Figure 2 - Source models developed for seismic hazard assessment in Belgium: A) Leynaud et al. [2] model used for EC8 hazard map; B) Seismotectonic model; C) Two-zone model; D) RVG fault model.

3.3 Ground-motion prediction equations

Belgium and surrounding regions are classified as a "Stable Continental Region". Therefore, the choice of the GMPEs in the hazard assessment should consider GMPEs valid for this seismotectonic context. Nevertheless, some experts also consider the RVG as an "active region" and propose to combine GMPEs valid for active and stable regions when evaluating the impact of this zone.

Most of the classical GMPEs used in Europe are based on empirical data and have a validity domain for standard rock conditions (V_{S30} in the range 800 to 1200 m/s). These standard rock conditions are met in the southern part of Belgium. Therefore, for sites located in this area, we consider the models that have been selected for this part of Europe by the experts in the SHARE project (Delavaud et al. [11]).

The northern part of Belgium corresponding to the geological unit of the Brabant Massif is characterized by bedrock with higher shear-wave velocity. Although the geological bedrock corresponds to the Palaeozoic units, the strongest impedance contrast, which is considered as the seismic bedrock, occurs at the limit between the upper Mesozoic-Cenozoic sedimentary column and the Cretaceous strata with V_S = 1700 – 1800 m/s. Therefore, for the northern part of Belgium, it appears more advisable to partly use GMPEs determined for hard-rock conditions and obtained by stochastic modelling in parallel with GMPEs valid for standard rock conditions. For both of these GMPE types, it is necessary to consider host-to-target adjustments to adapt them to the real V_S and kappa factor of the studied site.

Below is a list of GMPEs we currently consider for the two different geological conditions in the case of stable or active source regions as discussed in this section:

- Standard site conditions (southern Belgium)

Stable regions	Active regions (with known active faults)
Toro et al. [12] adapted to V_{S30}=800 m/s by SHARE [13]	Zhao et al. [19]
Campbell [14] adapted to V_{S30}=800 m/s by SHARE [13]	Bindi et al. [20]
Atkinson and Boore [15] modified by Atkinson and Boore [16]	Boore and Atkinson [21] modified by Atkinson and Boore [16]
Akkar et al. [17]	
Faccioli et al. [18]	

- Sites characterized by hard rock below a thick sedimentary cover (central and northern Belgium)

Stable and active regions
Toro et al [12]

Campbell [14]
Rietbrock et al [22]
Atkinson and Boore [15] modified by Atkinson and Boore [16]

3.4 Software - engine

The hazard engines mainly used at ROB are CRISIS and OpenQuake. CRISIS is a Visual Basic program with an intuitive graphical user interface developed by M. Ordaz [6] from UNAM, Mexico. It is fast, but it runs only on Windows, and is difficult to extend. Logic trees have to be implemented outside CRISIS in order to generate input files corresponding to logic-tree samples that can be batch-processed with CRISIS. The development cycle and versioning system are not very clear. OpenQuake (OQ) is a hazard engine written in Python and developed by GEM (Silva et al. [23]). It is open source (source code freely available from internet repository with versioning system), and its development process is subjected to unit testing. On the downside, OQ requires a Linux server and lacks a graphical user interface, which results in a steeper learning curve. However, its core library, oq-hazardlib, is platform independent, and can be easily extended. The hazard maps of the SHARE project were computed with OQ.

Over the years, we have developed a number of Python routines for various parts of the PSHA chain, which we have organized in a module, named rshalib (ROB seismic hazard assessment library). The module extends classes defined in oq-hazardlib, but also defines higher-level classes not found in oq-hazardlib. Rshalib enables us to extend the code to our needs, and at the same time take advantage of the latest advancements made by the OQ developers. Using rshalib, we can build simple PSHA models or complex logic trees, run them in either OpenQuake or CRISIS, and analyze and visualize the results.

4 Perspectives and conclusion

The differences in ground motion levels between the official hazard for Belgium and the map of the SHARE project are significant enough to necessitate a re-evaluation of seismic hazard in Belgium using the present-day state of the art methods, but also taking into account the most recent studies on the regional seismic activity.

While seismic hazard assessment in Belgium has seen a strong evolution in the last years, several issues still have to be addressed. Already started is the work on the M_W determination of the catalog, in order to avoid the use of magnitude scale relations. Also important is the translation of several specifications in SHARE and GEM to a more site-specific context (e.g. Mmax). Most work however will be concentrated on ground-motion models. A consensus has to be reached about the relevant GMPEs to use, and for some regions new models have to be developed taking into account region-specific source and path effects (e.g. Hainaut zone). This work includes also a better characterization of the regional bedrock, and the adjustment of existing GMPEs accordingly, combined with the establishment of a map reporting the soil types and depth to the bedrock or natural frequencies. In the end, new hazard maps for Belgium will be computed based on a logic tree incorporating multiple source models, seismicity models and GMPEs, and for multiple spectral periods. These computations can then be used for a revision of EC8.

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