MAPPING THE LOCAL SEISMIC HAZARD AND ITS INFLUENCE ON BUILT ENVIRONNEMENT : CASE STUDY IN THE MONS BASIN (HAINAUT - BELGIUM).

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Seismic risk is defined as the convolution of the seismic hazard and vulnerability. In the Mons Basin, the conjunction of strong ground motions and the deteriorated state of the built environment could result in a high seismic risk. Our study aims at defining the level of ground motions at local scale and investigating the vulnerability of typical buildings in the historical center of Mons to produce maps indicating the damage rate of buildings. This information could facilitate urban planning and preservation of cultural heritage.

Introduction

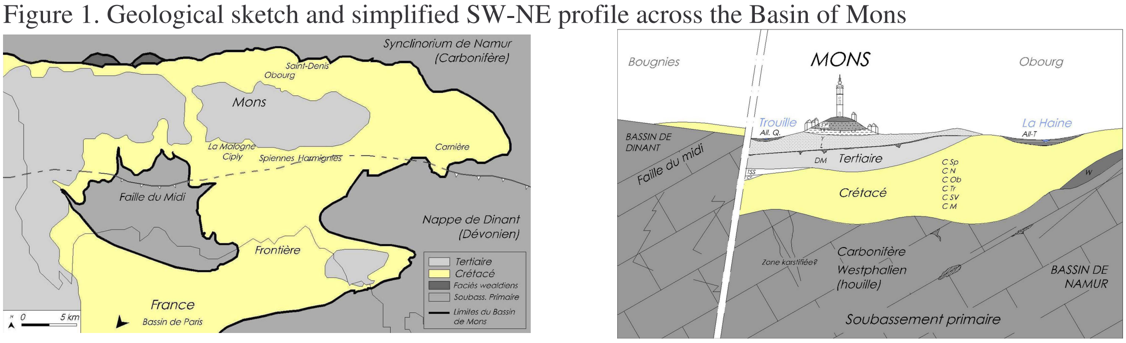
Earthquakes and their implication in terms of risk for the population and the economy is more often neglected in the preparedness plan for natural catastrophes in Belgium. One of the tasks of the Royal Observatory of Belgium (ROB) is to make available information concerning past and present seismic activity in and around Belgium and to promote studies on the potential hazard and risk for the different regions of Belgium. The Basin of Mons is one of them where the hazard is the largest as attested by past and actual earthquakes. Studies conducted by the ROB on the local hazard also show that the recent geological deposits of the Basin could potentially amplify seismic waves and increase the ground motions. It is obvious that the conjunction of a deteriorated state of buildings and a high level of ground motions could produced a catastrophic scenario in case of a major earthquake in the region. A collaborative work with seismologist, geologists and architects is in progress in order to develop a methodology that include a local seismic hazard mapping and an estimation of the seismic vulnerability of buildings. At the end, one should able to provide with maps including the damage rate of buildings for the expected ground motions

1. The Mons Basin

1.1. 3D Geological model of the Basin

From a geological point of view, the basin of Mons constitutes the Northern prolongation of the basin of Paris. This basin is long about fifty kilometers and has a width of approximately 10 kilometers (Figure 1). Cretaceous and Tertiary sediments fill a synforme of East-West axis limited Northward by the synclinorium of Namur and southward by the synclinorium of Dinant. The maximum thickness is about 400 meters. The past mining activities of this area have justified numerous studies on the evolution of the subsidence and its particular relation with deposits of the Basin of Paris (i.e. Marlière, 1970; Dupuis and Robaszynski, 1986). Sedimentation processes are mainly controlled by the climate and the sea level. The Basin is a complex succession of episodes without sedimentation or with mainly a marine sedimentation. To simplify, one can distinguish two phases, a first one with mainly carbonate sediment (chalks and marl) until the Maastrichtian (74.0-65.0 Ma) and a second one with detritic sediment (clay and sand) after the Danian (65.0-60.5 Ma) expressing a prolonged denudation. During the Quaternary (1.64 Ma to present), pet and alluviums from the Haine river were deposited. Concomitantly, the evolution in the structure of the Basin was mainly controlled by subsidence and faulting at all geographical scales.

Figure 1. Geological sketch and simplified SW-NE profile across the Basin of Mons



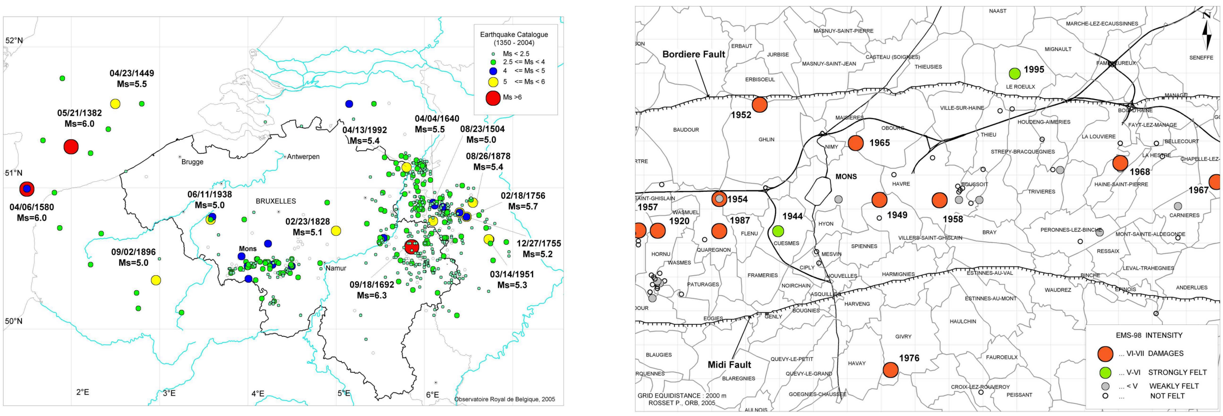
Cretaceous formations are various types of chalks (Cxx) overlying limestone of the Palaeozoic basement. Tertiary layers are mainly sand and clay.

An extensive compilation of geological data has been achieved in order to elaborate a simplified 3D geological model later use for the estimation of the local seismic response.

1.2. Spatial distribution of earthquakes in and out of the basin

The seismic activity in the Basin of Mons is recent and represents a significant part of the overall seismic activity in Belgium. Most of the epicenters are localized in a zone limited to the North by the Bordière fault of the Brabant Massif, in the south by the Midi fault (Camelbeeck, 1994) as shown in Figure 2.

Figure 2. Historical and recent earthquakes in Belgium and in the Hainaut zone



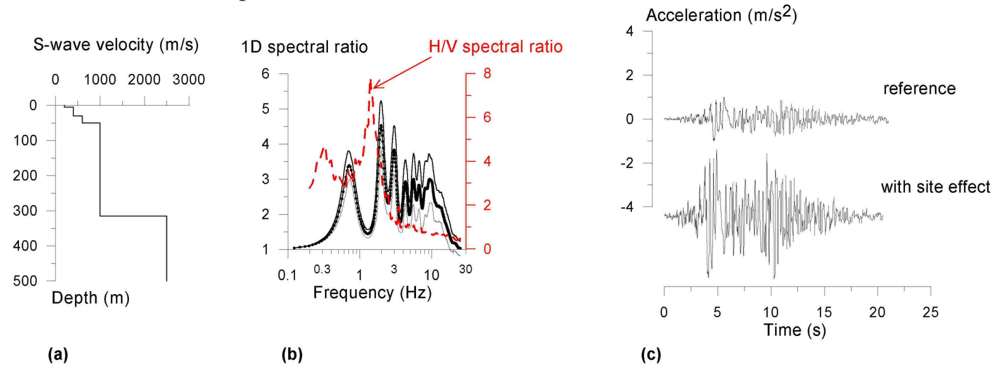
(left) Seismicity in and around Belgium since 1350 expressed in terms of magnitude. (right) Location of earthquakes felt in the region of Mons. The estimated intensity is based on reported damages after each earthquake.

Since 1900, nine earthquakes with M_L magnitude higher than 4.0 occurred, the Havré (April 3, 1949) and the Carnières (March 28, 1967) ones were the most damaging. Seismic studies show that the events of the Hainaut zone are characterized by 1) a high epicenter intensity compared to their magnitude which attest a low focal depth, the seismogenic zone is limited to the first 7 km of the crust 2) an activity in the form of swarms with precursors and aftershocks. The analysis of about fifteen focal mechanisms (Camelbeeck et al., 2005 submitted) shows various fault solutions that indicate the not-homogeneous pattern of the stress field in this zone. Their relationships with local geology are not yet established. The tectonics of the basin from the late cretaceous and the beginning of the Paleocene seems to be related to the pull-apart subsidence and linked with the dextral strike-slip movements of the shear zone of the Northern Artois (Dupuis and Vandycke,1989 ; Vandycke, 2002). More distant earthquakes located in the Massif of Brabant (as the Nukerke event of June 11, 1938, Ms=5.0) or in the Ardennes region (as the Verviers one of November 18, 1692, Ms=6.0-6.5) stroke the Basin of Mons. These earthquakes are typical regional events which are considered for the local seismic hazard analysis.

2. Influence of the local geology on the seismic response

Recent destructive earthquakes have demonstrated that the spatial distribution of damages is not only related to the distance from the seismic source but also to the local geology of the sites. Damages occurred during the Liège earthquake of November, 8, 1983 (Ms=4.6) have clearly shown that recent river and glacial deposits amplified to a factor of 5 to 10 the seismic waves (Jongmans and Campillo, 1990). Another analysis also shown that the effect of soft sediments in the Brabant Massif is related to the depth of the cretaceous seating (Nguyen et al., 2004). An analysis of one site in Mons has indicated that amplification could be large due to the influence of thick "soft" deposits as chalk, sand and clay from cretaceous to quaternary ages. An extensive analysis of the seismic response for the overall basin is on-going (Rosset and Camelbeeck, 2004).

Figure 3. Calculated seismic response and scenario for the center of Mons



(a) S-wave vertical profile in the center of Mons. The thickness of the soft sediments is about 320m. (b) Predominant frequency of resonance given by 1D and H/V spectral ratio. The calculated 1D response is based on the 3D geological model with 6 different soil layers as shown in (a). A randomised set of 500 calculations per site are provided to deal with soil parameters uncertainties. The H/V peak amplitude around 2 Hz corresponds to the second peak of the 1D modelling. (c) Earthquake scenario based on a real seismic record scaled to a maximal acceleration of 1.0 m/s^2 (reference) including site effect provided by the calculated transfer function of (b).

Two methods are used in a complementary manner to estimate the influence of soft deposits on ground shaking. One uses the recording of natural and man-made vibrations to empirically estimate the resonance frequency of the soil (i.e. the frequency from which waves are preferentially amplified). It requires only one seismic instrument and less than 30 mn per site. The other method is referred as a one-dimensional, linear elastic approach and provides the frequency of resonance and an estimation of the amplification factor. It is also a good alternative to instrumental ones as it uses data from boreholes and drilling that are often available in urban areas. Details concerning methodological aspects could be found in another paper of this series (Rosset et al., 2005). Those methods provide information in terms of resonance frequency and amplification factor as illustrated in Figure 3 for the investigated area in the historical center of Mons. Information provided by the 3D geological model allow the calculation on a regular grid of the seismic response and the mapping of its spatial distribution in the basin which is later used for damage estimation

3. Analysis of the vulnerability of buildings

3.1. Typology of buildings

The vulnerability of a group of buildings is evaluated by classifying them according to the characteristics that influenced their behavior towards earthquakes. A compilation of existing data on building (structural, historical and all relevant information) and a detailed screening of each building are performed. Based on those data, buildings can be classified following different typologies : a global typology which describes the house itself. In this case, it is mainly masonry houses with wooden floors often including an opened commercial ground floor. A town-planning typology that considers an house in its global built environment. For instance, buildings in the middle of a series are differentiated from those located in an angle. A typology based on the front wall is also used as shown in Figure 4. These typologies are then used for comparison and for a fast screening method to analyze the vulnerability.

Figure 4: Front wall typologies of the rue de la coupe.

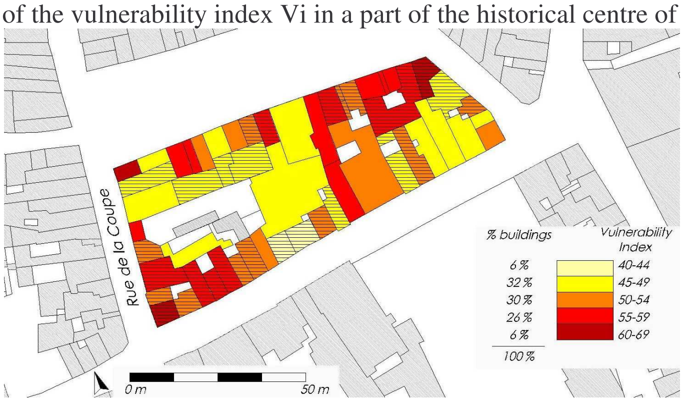
The classic typology is divided into 3 types according to the width and the composition of the piers, for example, because it is one important element for the resistance towards shear movements.

3.2. Analysis of vulnerability for typical buildings in the historical center of Mons

There are two kind of approaches to analyze the vulnerability of buildings: the analytic and the probabilistic ones. The analytic methods use model-building and numerical simulation. The probabilistic methods are based on damages inventories during past earthquakes and their statistical extrapolation for a range of seismic intensity. The latter approach leads to a fast evaluation of the vulnerability at the scale of a district, as the analytic one is more adapted for a block of buildings. In our study, a probabilistic method for rapid diagnosis has been proposed based on an index of vulnerability including 11 parameters of major influence for building resistance. These parameters have been adapted to the Belgian built specificities (Barszez, 2005 ; Jongmans and Plumier, 2000) from the Italian expertise (GNDT, 1998). In a first step, a basic vulnerability index (Vi) is determined based on the typologies of a building.

In a second step, particular characteristics not always observable from outside of the buildings have been investigated. The sum of the basic index and the penalties based on those particular characteristics is then calculated to estimate the vulnerability index. The analysis in a district of the historical centre of Mons is shown in Figure 5.

Figure 5: Determination of the vulnerability index Vi in a part of the historical centre of Mons.

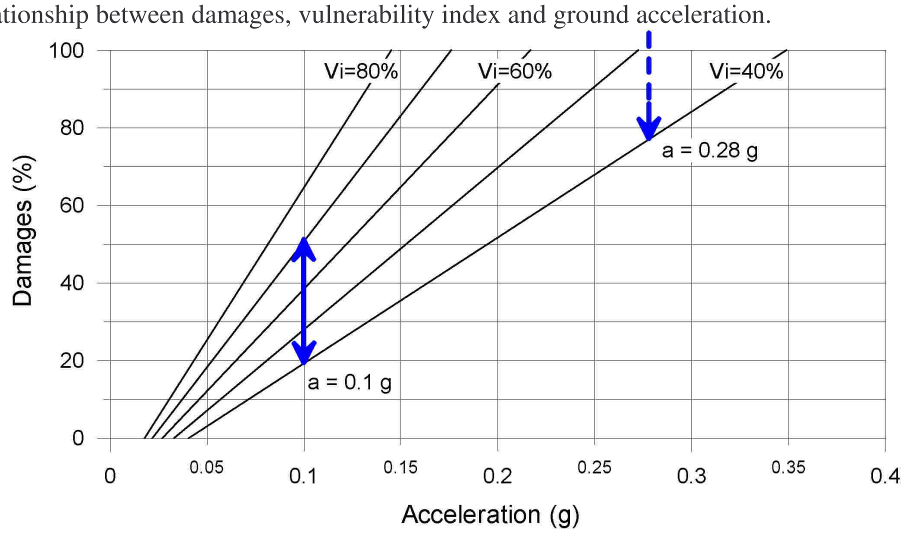


The spatial distribution of the index indicates that the highest values (i.e. more vulnerable) correspond to angle houses, slender houses and weakened front wall. A comparison of front wall typologies indicates the classic ‘1’ typology of the figure 4 is the less vulnerable.

4. GIS-oriented seismic risk analysis

The evaluation of the seismic risk in urban areas need to estimate the level of damage that could happen on constructions, i.e. the ratio between reparation costs and replacement costs. One means is to combine vulnerability indexes of masonry buildings as given in the Figure 5 with expected ground motions as calculated in Figure 3 (here acceleration), to give degrees of damages using the graph of the Figure 6.

Figure 6: Relationship between damages, vulnerability index and ground acceleration.



The evaluation of damages is compared to vulnerability index Vi and calibrated with past earthquakes in Italy (Faciolli et al., 1999). For a ground acceleration of 0.1 g (1.0 m/s^2) given by the seismic code for the Mons area (NAD, 2000) and the vulnerability indexes of the investigated area shown in Figure 5 (40-70 %), most of the houses would suffer 20 to 50% of damages. If site effects calculated in Figure 3 are considered in the analysis, a ground acceleration of 0.28g would conduct to percentage of damages higher than 70%.

By combining the information in terms of ground acceleration provided by seismic hazard analysis and site effect assessment with the building vulnerability, one are able to map the spatial distribution of damages.

Conclusions

Presented results constitute a first attempt to integrate local seismic hazard analysis and a fast screening of the vulnerability for typical buildings in the historical center of Mons. They point out the important level of damages for buildings when using the ground acceleration provided by the seismic code. The latter increases when considering local geological effects. The spatial variation of the hazard and vulnerability is then of prime importance to provide authorities with maps indicating the highest level of risk. The investigation of the local geological effects remains tricky and uncertainties inherent to the geological model are often a limitative factor. The hypotheses and uncertainties associated to the statistical approach of vulnerability are also limitative. It is then important to produce a set of maps indicating the range of expected ground acceleration values including site effects and its associated damage rates to buildings.

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