# IDENTIFYING THE INFLUENCE OF THE LOCAL GEOLOGY IN CASE OF EARTHQUAKE FOR URBAN PLANNING: CASE STUDY IN BRUSSELS

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It is now widely admitted that the sub-surface geology is a crucial component when analyzing the seismic response in urban areas. Our project aims at mapping the seismic response of a pilot zone of Brussels in case of major earthquake scenarios. A detailed knowledge of spatial underground conditions is essential for an analysis of site effects. This is currently done in Brussels at the scale of 1/5000 through a 2D and 3D GIS model. Geological data, field measurements and numerical modeling results will be combined into a GIS to provide maps featuring the local seismic hazard.

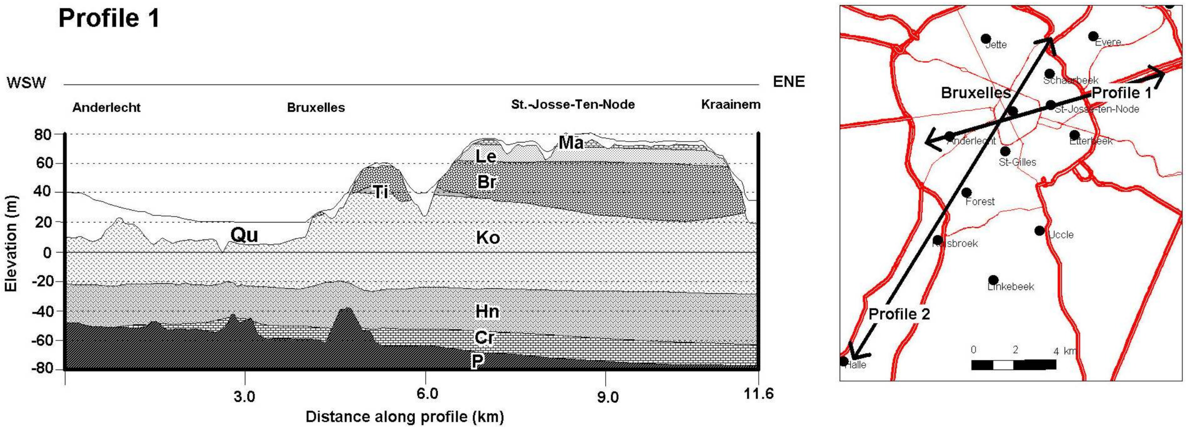
## Introduction

The NW-Europe is a zone of moderate seismic activity where large earthquakes could occur in the future (Camelbeeck and Meghraoui, 1996, 1998). The risk is presented as the convolution of the hazard (i.e. the phenomena and its probability of occurrence) and the vulnerability (i.e. the capability of various systems as buildings, lifelines, etc. to resist to the phenomena). The presented project aims at providing authorities with GIS-oriented and up-to-date maps of the seismic hazard taking into account the geological specificity of Brussels in order to define more risky zones. In September 18, 1692, the strongest earthquake ever known in northwestern Europe occurred near Verviers. Its magnitude is estimated close to 6.5 and damages were reported in all cities of Belgium but also far in UK, Germany and France (Alexandre, 1997 ; Alexandre et al., 2002). In 1352, 1504, 1580, 1449, 1696, 1755-56, 1828, 1878 and 1951, several others destructive magnitude greater than 5.5 events were reported (Alexandre and Vogt, 1994). The city of Brussels suffered also extended damages during the Nukerke event of magnitude 5.0 in June 11, 1938 (Somville, 1939) and weak damages in 1992 due to the Roermond magnitude 5.4 earthquake (Camelbeeck et al., 1994). Reported damages during those events are mainly fallen chimneys, cracks in the walls and minor damages in several patrimonial buildings. Panic in the population is often mentioned. Research on evidences of past seismic activities into recent deposits (Vanneste et al., 1999, 2001) and continuous weak seismic activity are good indicators to predict future large earthquakes in Belgium and surrounding areas (Camelbeeck et al. submitted). In addition, numerous large earthquakes in the world indicated that unconsolidated sediments from ancient lakes, rivers and glacial episodes often amplify ground shaking conducting in important spatial variation of damages in urban areas as most of them are built on such a recent deposits. Evidences of those effects have been also identified at specific sites in cities of Belgium (Nguyen et al., 2004). The conjunction of ground shaking amplification due to unconsolidated sediments and deteriorated built environment would then conduct to heavy damages in cities in case of important regional earthquakes. The non-preparedness of population and stakeholders would also disrupt the economical systems for a long period and increase monetary losses. The main objective of this collaborative project is to provide mapping tools and database to estimate the spatial variations of ground shaking into Brussels and other cities for future major earthquakes and then identify zones where the expected damages and risk would be the highest.

## 1. Geological settings

The Region of Brussels is located in the center part of the lower Paleozoic Brabant Massif that constitutes the seating for Tertiary and Quaternary deposits. The Quaternary is relatively thick with variable lithology whereas the tertiary formations have a more sub-tabular structure. Drilling data on the territory of Brussels indicates heterogeneous stratigraphic successions with strong lateral thicknesses variations (see cross-section in Figure 1).

Figure 1: Simplified geological profile across Brussels



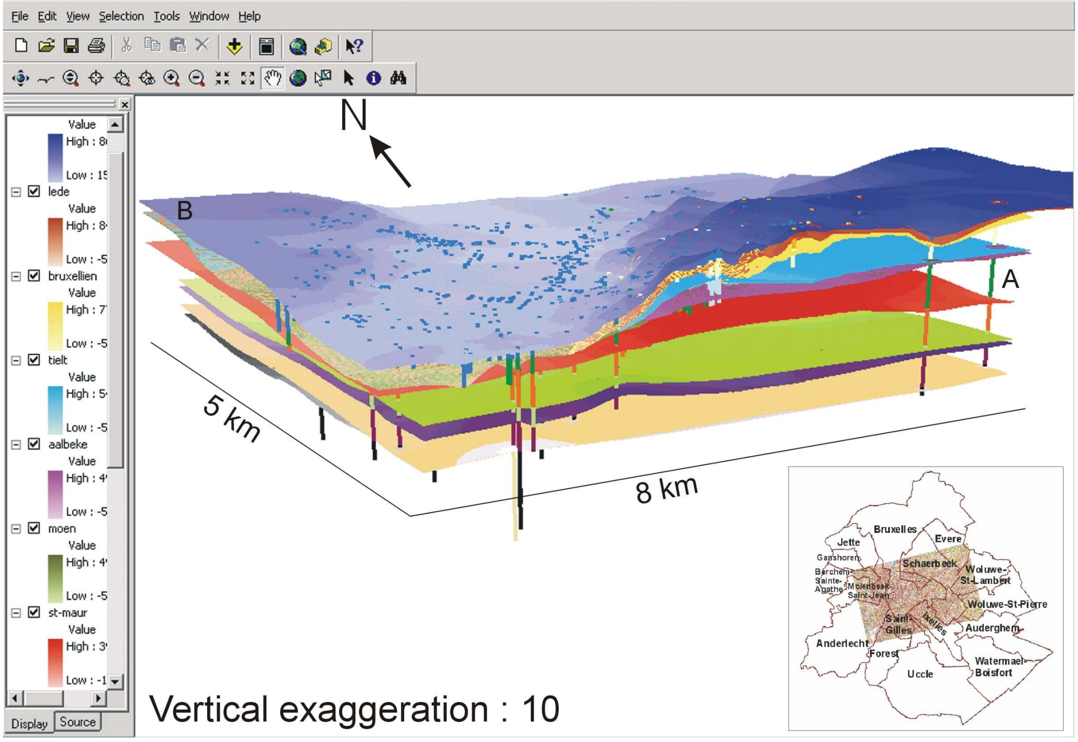
Main geological layers above the Paleozoic basement (P) are represented. Abbreviated name are briefly explained in chapter 1. The profile 1 is located on the map.

Anthropogenic backfills are present almost everywhere and have a thickness ranging from tens centimetres up to several meters. Quaternary deposits comprise the modern Holocene alluvial sediments essentially located in the Senne valley and the Pleistocene deposits (loess and fluviatile sediments) covering the whole area. Beneath the continental Quaternary sediments lie Tertiary marine formations from the upper Miocene down to the upper Paleocene. Miocene and upper Eocene sand deposits have been partly preserved from the erosion and form the top of the hills in the northern part of Brussels. The Maldegem Formation (Ma, Middle Eocene) is composed of a maximum of 21 m of grey to greenish clay and glauconitic sands. The Lede Formation (Le, Middle Miocene), generally 12 m thick, is mostly present in the hills of the north, east and southeast parts of Brussels. Five to twelve sandy calcareous banks are present in the lower part of Lede and have been actively exploited in underground in galleries connected to shafts since the Middle Age. The Brussels Formation (Br, Middle Eocene) is characterized by coarser sands and is 30-35 m thick but reaches a thickness of 70 meters in channel structures. The Gent Formation (Ge, Lower Eocene) reaches a thickness of 8 meters. Gent is only observed in the northwestern part of Brussels. The clay and fine sand of the Tielt Formation (Tt, Lower Eocene) are generally 20m thick. The Kortrijk Formation (Ko, Lower Eocene) is mainly composed of clay and sand reaching an average total thickness of 70 meters. The Upper Paleocene formation (Hannut, Ha) contains an upper sandy member and a lower greenish clay member. Cretaceous deposits are only present in the northern part of Brussels. Finally, the basement of Brussels corresponds to Paleozoic sandstones, quartzite and slate of Early Cambrian age.

## 2. Digital modeling of the subsurface geology

The ground response to seismic waves is strongly influenced by shallow deposits. Hence, a detailed spatial distribution of the soft deposits is of prime importance. Our study benefits from the on-going work in the frame of the Brussels Urban Geology program (Devleeschouwer and Pouriel, 2004, submitted). It concerns the development of a 2D and 3D GIS geological model of the Brussels subsoil using ArcView tools. An application with the ArcGIS desktop software is created with which all the information and available data gathered could be stored in a database and managed within an open, dynamic and visual GIS. Technically, this GIS application is based on the creation of two complementary modules: a relational database management system under Microsoft Access 2000 software for the descriptive data and a cartographic management system under ESRI ArcView 8.3 software for the raster and vectorial geographic data.

Figure 2: 3D geological model of the centre of Brussels.



The boreholes database is imported into ArcMap and each borehole, under ArcScene, is represented by a column shape or stick of various colours, each colour corresponding to a different geological formation. The length of the stick is proportional to the estimated thickness of the chosen geological formation (A on the right). The Inverse Distance Weighting interpolation method is then used to create a draped 3D model of the underground characterized by coloured layers. Each layer defines the roof of one geological formation (B on the left is the Quaternary layer for example). The location of the studied area is indicated on the bottom-right map.

The database and the ArcView software are connected through a geodatabase that avoids double data acquisition and facilitates the management of new information. Boreholes and cone penetration tests (CPT), constituting the background data and starting point of the program, were stored and managed in the same main database. Data come essentially from two sources: firstly, from the Geological Survey of Belgium (GSB) and constituted by all the geological information (boreholes, wells, outcrops, etc.) gathered by the geologists since

1896, date of the GSB creation. Secondly, from the archives of the Ministry for the Equipment and the Transport of the Walloon Region that collects boreholes and CPT carried out during major building sites (motorways, subway, industrial sites, etc.) since the fifties. The 3D model used the boreholes database to generate a set of interpolated geological layers corresponding to the main features in the Brussels area as shown in the Figure 2.

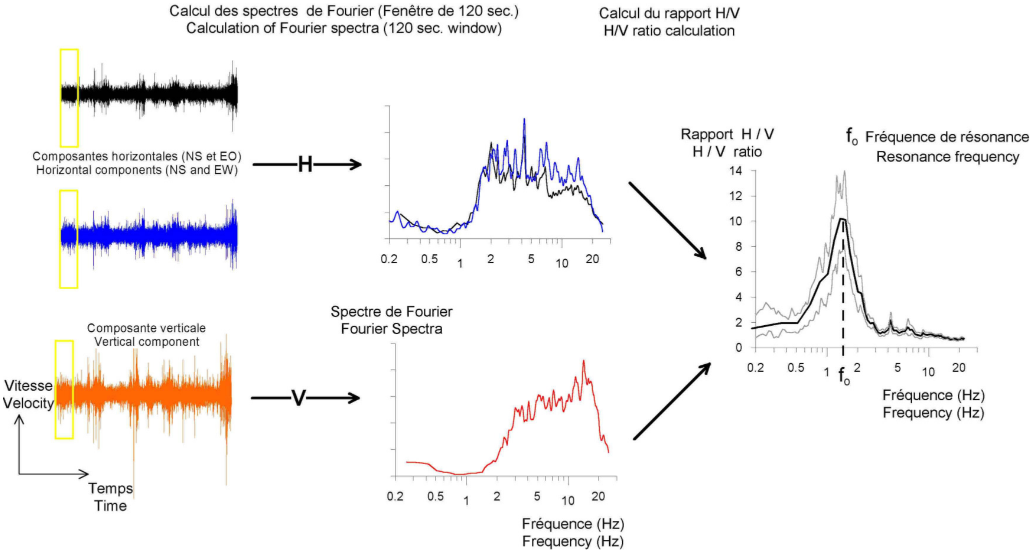
## 3. Empirical and analytical estimation of ground response

In order to estimate the local ground response due to a major earthquake in Brussels, two complementary methods of investigation have been used. One uses the recording of ambient noises to empirically estimate the resonance frequency of the soil (i.e. the frequency from which waves are preferentially amplified). It is well adapted in urban context, as it requires a minimum of instrumentation and time. 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.

### 3.1. Ambient noise recording

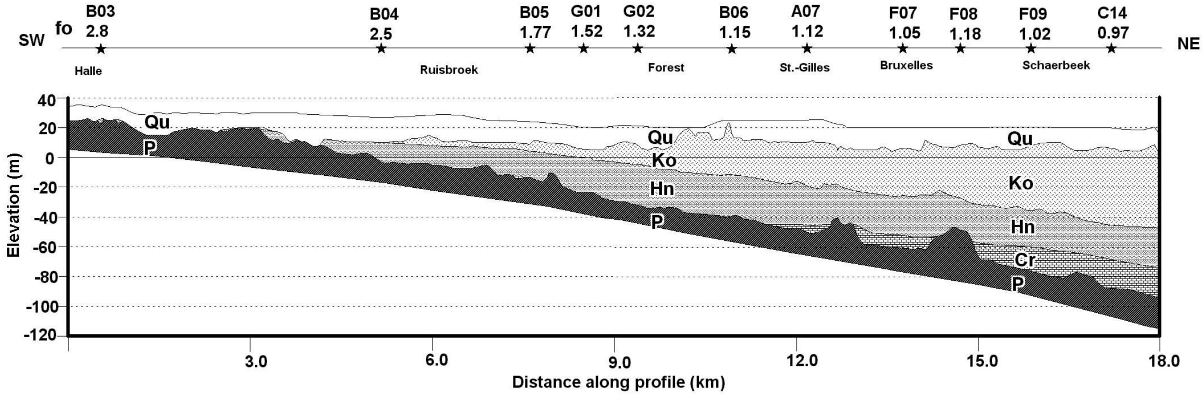
The signals of ambient noise are low-amplitude motions of the ground generated by surface sources such as traffic and other human activities, but also come from oceanic waves and wind-structure interactions. Noise associated with wind and human activities is predominantly below 0.1s while noise generated by near-shore oceanic waves and currents is at higher periods. The H/V method is a common tool used for site effect investigations (for further detailed see Bard, 1999). The horizontal (H) and vertical (V) components of ambient noises are simultaneously recorded at one single point. The spectral ratio of H over V generally exhibits a peak that corresponds more or less to the fundamental frequency $f_0$ of the site. The procedure for the analysis is illustrated in Figure 3. The H/V spectrum provides valuable information about the underlying structure as $f_0$ is related to the thickness h and shear waves velocity Vs of soft soil layers through a simple relation $f_0$=Vs/4h.

Figure 3. Procedure for ambient noise analysis



First results in Brussels show that thicker are the soils over the basement, lower is the resonance frequency $f_0$ as illustrated in a NS profile through the Brussels region in Figure 4.

Figure 4. Measured predominant frequency of resonance along a NS geological profile

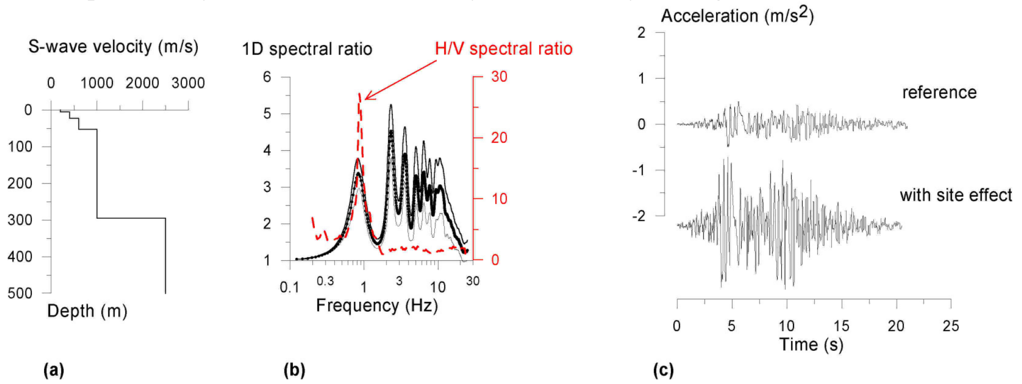


Abbreviated name of the different geological formation are briefly explained in chapter 1. The location of the profile correspond to the profile 2 indicated on the map of the Figure 1. Obtained resonance frequency $f_0$ with ambient noise records are given for few sites along the profile. Values are clearly correlated with the thickness of soils above the Palaeozoic (P) and are able to predict small variations in the shape of the basement.

## 3.2. Numerical analysis of ground response

A one-dimensional simulation approach is used to retrieve both frequencies and amplitude of the ground response. It is referred as an one-dimensional computation since the local geology is modeled with horizontal, infinite layers that is almost the case in Brussels. Each layers has its specific dynamic properties (namely the shear waves velocity, the density and an attenuation factor) and thickness. Calculations are performed considering incident shear waves at the base of the soils column. Uncertainties due to the lack of knowledge on layer properties are treated through a simplified Monte-Carlo approach. Results are given considering the mean calculated ground response and the standard deviation obtained with the set of hundreds of calculation for one site as shown in the Figure 5. The maximum amplification factor is around 2-3 and predominantly at a frequency of 1Hz.

Figure 5. Site response analysis for the site of the Royal Observatory of Belgium in Uccle



(a) Vertical profile based on the S-wave velocity (b) Predominant frequency of resonance calculated with the 1D model provided in (a) and measured with ambient noise (dash line). There is a good concordance between experimental and analytical value of $f_0$ (c) seismic scenario based on a reference signal scaled to a peak ground acceleration of 0.5 m/s$^2$ and related to the 1D spectral ratio of the figure (b).

The GIS-oriented approach will consist in the use of data provided by the 3D geological model to generate automatically input values for the 1D simulation program. The calculations will be performed into a regular grid of sites and resulting parameters will be interpolated over the investigated area. Calculated resonance frequencies could then compared with observed ones as often as possible (H/V method or spectral ratio on recorded earthquakes) and validated if values are similar. Amplitude of the ground response for different frequencies corresponding to resonance frequency of specific type building will be interpolated over the whole area of Brussels and scenarios for specific expected type of earthquakes will be presented.

## Conclusion

One of the objectives of the project is to develop a tool using GIS, database and calculation routines to generate maps featuring the seismic response at the scale of an urban area. The combination of seismological methods, GIS and database is a powerful mean to provide authorities with predictive maps related to local ground shaking that can be updated when new data are available. The spatial variation of ground response is estimated through field experimentation and numerical computation. First results show that the approaches are efficient in urban areas and that the thickness of recent and unconsolidated sediments plays a important role in the site response. In the future, additional data such as the cone penetration tests will help to improve the modeling of the Brussels subsurface geology and contribute to refine the seismic hazard maps of the city.

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