Seismic Risk in Belgium for Ordinary Buildings: Methodological Aspects and Study Cases.

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Abstract.

Belgium is located in a region in which damaging earthquakes exist. Assessing the risks for the society caused by this seismic activity is complex but useful.

We propose in this paper the concept of a general tool for a first level assessment of seismic risks aiming a rapid identification of problematic buildings in a given area. General methodological aspects are presented. For a building, the risk is represented by a volume in a multi-dimensional space. This space is defined by axes representing the main parameters that have an influence on the risk. We are

especially developing the assessment of the Belgian buildings vulnerability. We also express the importance of including a parameter to consider the specific value of cultural heritage.

Then we apply the proposed tool to analyze and compare methods of seismic risk assessment used in Belgium. They differ by the spatial scale of the studied area. Study cases for the whole Belgian Territory and for parts of cities in Liège and Mons (Be) aim also to give an overview of the overall risk in Belgium.

Introduction

Recent damaging earthquakes of Liège (8 November 1983, M = 4.6 – figure 1) [1], Roermond (13 April 1992, M = 5.4) [2] or in the Lincolnshire (27 February 2008, M = 4.6) suggest that northwest Europe is a region in which damaging earthquakes exist. Therefore, assessing the risks for the society caused by this seismic activity appears as very useful.

Figure 1 - Damages on a house caused by the 1983 earthquake in Liège.

Unfortunately, this is not an easy work based on exact science. There are a lot of factors to consider and many of them are poorly known. Moreover, such an assessment depends also on the specific aim of the evaluation. Nevertheless, it is important to develop a general methodology that is able to consider the different risks linked to the earthquake occurrence.

We propose a general tool for a first level assessment of seismic risks. We use it in the specific problematic of identifying the most sensitive buildings in a certain area. We illustrate both the proposed tool and the level of seismic risk for ordinary buildings in Belgium through study cases in Belgium.

Definition of a seismic risk assessment tool

Context

Seismic Risk is generally defined as a “probability that social or economic consequence of earthquakes will equal or exceed specified values at a site, at several sites, or in an area, during a specified exposure time” [3]. This definition makes seismic risk a relatively complex, abstract and theoretical concept. It brings into play numerous and various aspects: seismological, geophysical, geological, architectural, engineering, economic, sociological ….
Seismic risks assessment has been studied all over the world and different methods have been established to quantify it (for instance, the European RISK-UE methodology [4]). All methods tend to schematize the complex reality, with some hypothesis and inaccuracies. In high seismic areas, the perception of the risks is based on the experience gained during recent large earthquakes. At the opposite, the experience in low seismic areas is based on moderate earthquakes because the large earthquakes, for which the risks are highest, are rare. Therefore, the risk assessment is more uncertain and based on assumptions that shall be controlled after future destructive earthquakes.

General Principles

Within this context, we aim to develop a general tool to approach seismic risks, not as an absolute value, but as a relative one. We will explain the general idea by considering the risk of damage for a given building, including its value as a cultural heritage. Our practical objective in this example is to provide a tool for a rapid diagnosis. As shown on figure 1, we express it in a multidimensional space. This space is constituted by different axes representing the different parameters contributing to this specific seismic risk. For a given building and based on its location and own characteristics, we have to define a specific value for each of these parameters. These values are points on mathematical axes. The risk is represented by the volume of the polyhedron for which the summits correspond to these points. In brief, larger is the volume of the polyhedron, higher is the risk. [5]

To this day, we have identified the risk axes for the establishment of our tool (figure 2). We adopt a definition of the risk as the convolution of seismic hazard and exposure. The quantification part is in development. Axes have to be scaled properly and the relations between them have to be determined in order to make more explicit the influence of these parameters on the risk and the relations between them.

Seismic hazard at a given site represents the characteristics of earthquake strong ground motions to consider in the risks evaluation. Generally, only terms related to a level of hazard on the bedrock on one hand, and to site effects on the other hand are considered [6]. In our tool (figure 2(b)), these are each represented by one axis.

Exposure represents the value and the sensibility of buildings and people facing the risk. The influence of exposure on risk depends more precisely on the material and immaterial importance of the exposed elements but also on their vulnerability. Importance of exposure (figure 2(b) - 2 axes) depends on material and immaterial features. This last aspect is notably introduced to consider the architectural heritage, which has a high historical value. Indeed, immaterial value accounts for a fundamental most of all for historical cities, but is often neglected element of the risk. Vulnerability represents the capability of a construction to resist earthquake action. Vulnerability depends notably on construction materials, on their application and on geometry (dimensions, height, form, architectural features …). Seismic vulnerability is here expressed by using an index with a constant part due to the typology (figure 2(b) - 1 axis ‘v’) and a variable one linked to minor building properties (figure 2(b) - 1 axis ‘p’).

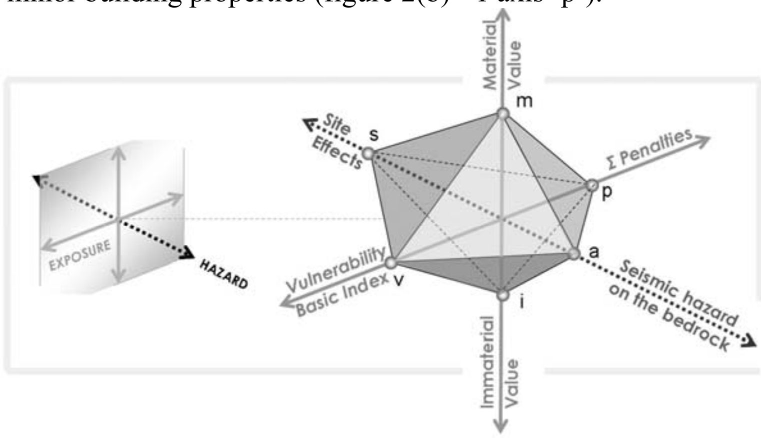
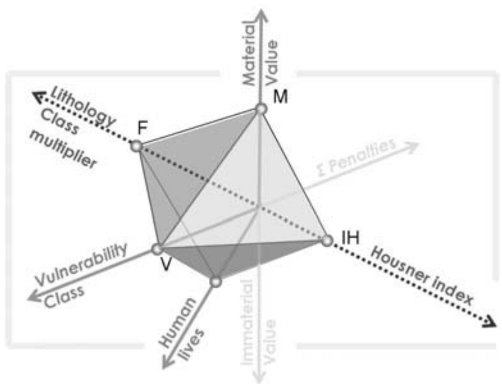


Figure 2 - Seismic risk as a volume in a multi-dimensional space

This representation of the risk provides a direct visualization of its importance, and of the most contributing parameters. The ‘general’ character of the tool makes it evolving and adaptable to evaluate other kinds of risk. Axes can be added and modified in function of the parameters to take into account. Finally, when the axes will be well calibrated, this tool should allow us to roughly estimate the effect of reinforcement on a building or to help in earthquake-resistant design. To validate this new approach, it is notably important to analyse and compare existing methods of risk assessment.

Application of the tool to study cases in Belgium

In the recent years, two main methods for seismic risk assessment have been developed in Belgium. They concern ordinary buildings which constitute the majority of the stock and are then the most representative. The first method aims a probabilistic loss estimate [7] for the whole Belgian Territory. An estimation of the annual frequency with which earthquake losses to residential buildings in Belgium will exceed different values and estimates of the annual average loss at different locations has been performed by Probabilitas. Partial results were presented by Van Dyck and Suys, [8]. The second one aims to predict damage level in a defined area for a given earthquake scenario. It was applied in a part of the city of Liège (4 km²), particularly affected by the 1983 earthquake [9]. We applied our tool to represent seismic risks for these two different kinds of risk evaluation with the purpose of developing our methodology (figure 3). These applications aim also to give the readers some sense of the overall risk in Belgium.



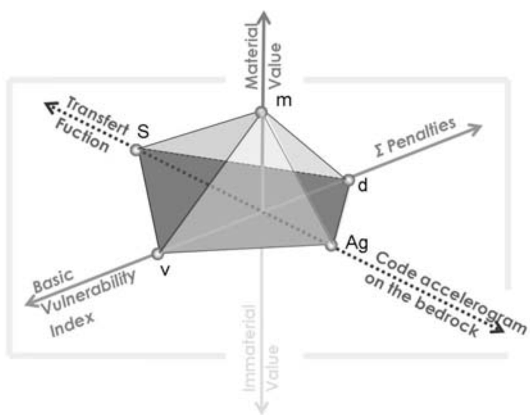


Figure 3 - Representation of the seismic risk following methods used in Belgium. On the left (a), a method for a large study scale. On the right (b), a scale for a limited study scale.

In the first method (figure 3(a)), the Housner index is considered predictive of the local intensity. To account for local site effects, an amplification factor depending on the lithology class of the soil is then applied. Four different vulnerability classes are considered: one for reinforced concrete type, three for masonry buildings with varying vulnerability to an earthquake event. The fraction of buildings that fall into 6 different damage classes (ranging from no damage to total collapse) depends on the local intensity, statistical distribution of buildings over the vulnerability classes (based on Italian data) and the associated vulnerability curves. More details about this method can be found in the references [5] [7] [8] [10] [11].

Extended results of a study on the whole Belgian territory shows that the regions most at risk are around the Rhine valley and in the Mons Basin, as would be expected. The method also showed that the total expected annual earthquake loss would be higher than the total expected annual flood loss in Belgium, even if these are more frequent. This conclusion should be considered however tentative since both estimates are uncertain. Nevertheless it indicates that earthquake loss in Belgium is perhaps infrequent but, considering the size of the losses that might occur, is certainly not negligible.

In the second method (figure 3(b)), hazard on the bedrock is considered through two modeled accelerograms, corresponding to different possible earthquakes of magnitude M=5.0 under the city of Liège and M=6.0 at a distance of 40 km. Soil Transfer functions have been calculated each 20 meters to consider the influence of the local geology. The method used to qualify exposure stems partly from the Italian expertise [12] [13]. It was adapted to the ordinary Belgian built environment. Vulnerability of buildings is assessed by means of a rapid screening method, materialized in a vulnerability index. 4 typologies with specific basic vulnerability indexes were differentiated ('v' on figure 3(b)). For instance, a masonry house with wooden floors (not considered as efficient diaphragms), attached on both sides, has a basic index 42. Parameters that could modify this index are mainly a high percentage of openings, a soft storey, a heavy balcony and horizontal or vertical irregularity ('d' on figure 3(b)). Then a potential damage factor, representative of seismic risk, can be calculated using vulnerability curves. These are relationships between the vulnerability index, acceleration of the ground motion and damages. They are built on basis of post-seismic observations in Italy and have been fitted to Belgian ordinary buildings. The damage factor is the ratio between repair cost and reconstruction cost.

Damage factor has been evaluated for all ordinary buildings of the studied area and points an important risk: for more than 60% of buildings, repair costs worth up to 60% of reconstruction costs. The used method [9] still needs to be validated and the seismic scenarios should also be defined more properly, nevertheless the study confirmed the high vulnerability against earthquakes of ordinary buildings in many old industrial cities of northwest Europe.

Applying the same method as these used in Liège, a potential damage level in a part of the historical centre of Mons has been evaluated [14]. We focus here on damage assessment for two different houses in order to give more details about the method. We consider the horizontal plan of the risk representation of figure 3(b) (figure 4).

Hazard on the bedrock and site effects are taken as constant because the houses are very close. The PGA is a little more precise than the one recommended in the code Typologies have been adapted to the context. Determination of vulnerability indexes is synthesized. Vulnerable elements of the first building are mainly slender walls, a high and old chimney and an extended glass roof. For the second building, more vulnerable, there is a gable on façade, an opened ground floor (in one adjacent building too) and façade, some weak points like cracks and humidity traces, and also a chimney problem.

Linear relationships have been used to assess a damage rate (see (1)) [9], basing on hazard and vulnerability. Under an acceleration of 0.14g, the first building is presumed to suffer a damage of 39% against 56% for the second. That means that repair costs are supposed to be 39 or 56% of the reconstruction costs, if immaterial value is neglected.

$$d[\%] = \frac{PGA - a_{min}}{a_{max} - a_{min}} \quad \text{with} \quad a_{min} = 0.155 \times e^{-0.0207 \times (I_v + 25)}$$

$$a_{max} = \frac{1}{0.625 + 0.00029 \times (I_v + 25)^{2.145}} \qquad (1)$$

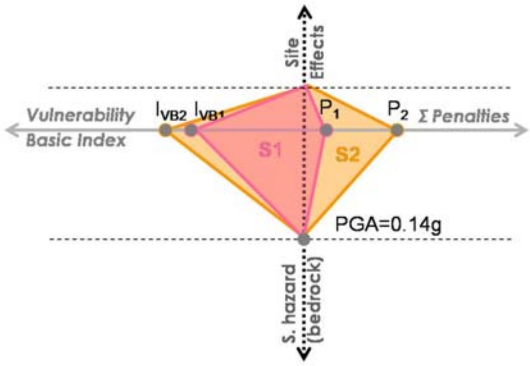


Figure 4 - The horizontal plane of the risk representation according to the method used in Liège for the two houses of our example. There is a relation between the surface of the quadrilateral, defined by hazard and vulnerability, and the damage rate. This rate is calculated following linear relationship (1) that often leads to overestimation.

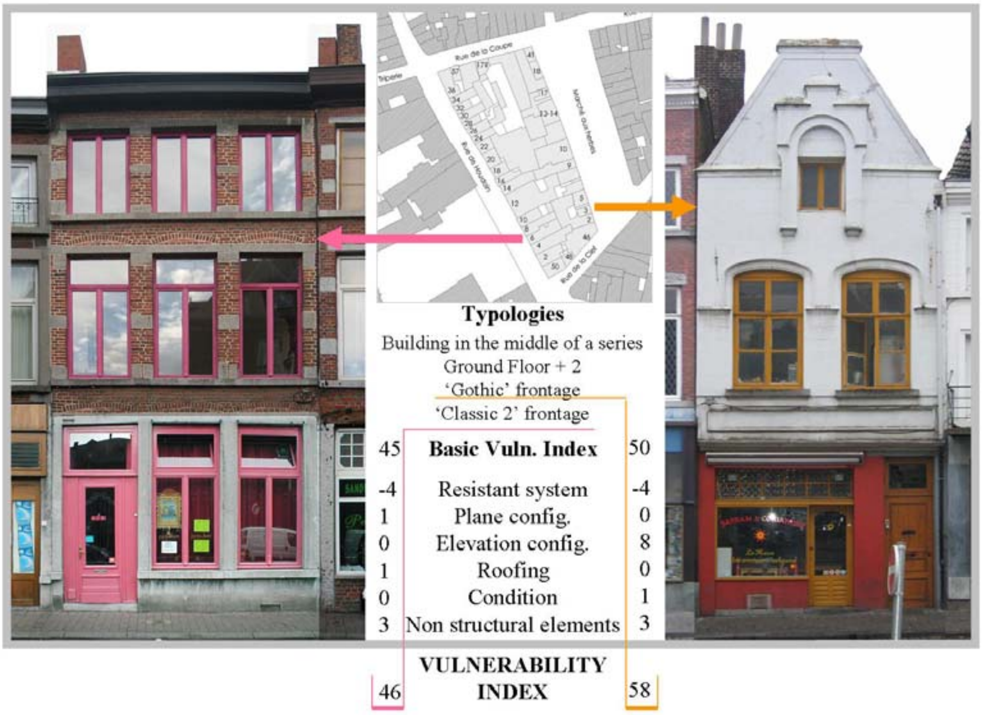


Figure 5 - Presumed vulnerability index for two buildings of the historical centre of Mons.

Conclusions

In this paper, we introduce a tool to represent seismic risks. It should allow methodological developments to better define the different risks caused by earthquakes and to define the relative importance of the parameters that control the risks.
The proposed tool has been used to compare two methodologies adapted and already applied in Belgium to assess seismic risk. They differ by the spatial scale of the studied area. The first one is a large scale method while the second targets part of cities. Study cases in Belgium, in the Liège and Mons cities have been mentioned. For the two last applications for instance, uncertainties on estimations comes as well from the ground motion as from vulnerability curves. These relationships are notably linear and have been calibrated from Italian ones. These last have already been re-examined in Italy [15]. In any case, vulnerability curves, accurate enough for a first rapid comparative screening but calibrated for the Belgian built context need to be defined. The proper assessment of the Belgian buildings vulnerability is the main part of the methodology that we are currently developing. Results of a systematic application of our methodology to a survey of buildings could then be used to improve the assumption on vulnerability distributions in global loss models, like the one presented in the first application.

Even if results of study the cases have to be improved, case studies of seismic risk assessment have shown that seismic risk is a reality in Belgium. Particularly, seismic vulnerability in town centres is very high. So it is important to go on in getting an interest in that problematic.

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