Applying Earthquake Risk Analysis Methods to a Town in Hungary

L'application des méthodes d'analyse du risque sismique dans le cas d'une ville de Hongrie

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ABSTRACT: Determining the earthquake risk of buildings in a town or settlement has lately become a more prominent issue. The process can provide important data for governments, authorities, disaster management and insurance companies to better understand risks to many buildings and engineering systems rather than a single building. This paper addresses the rapid evaluation of a large number of similar buildings in one area using a forecasting approach. Back-casting mainly considers the effect of previous earthquakes by listing and categorizing the damaged buildings and casualties. Forecasting offers a method to evaluate the possible damages in advance, however many uncertainties need to be taken into consideration. A fast and simple method should be developed to avoid the time and expertise required from research-based approaches. The steps involve determination of the hazard, assessing building stock, and computing vulnerability. The method for determination of vulnerability functions is a non-linear static analysis using a bilinear approximation of the capacity curve, assuming first mode force distribution and mode shape thus linear strength distribution. From the curve of the seismic demand and the shear capacity of the building, the vulnerability function of the building can be obtained. These vulnerability functions should be derived for typical layouts; offering a family of curves allowing the experts to decide the vulnerability category of a specific building on-site based on visual screening. With the given value of possible PGA (peak ground acceleration), expected damages can then be estimated.

RÉSUMÉ : La détermination du risque sismique des zones et des villes en considérant leur parcs immobiliers existants est devenu récemment un problème saillant. Ce processus peut fournir des données importantes pour les gouvernements, les autorités, la gestion des catastrophes et les compagnies d'assurance afin de mieux comprendre les risques liées á un ensemble d'édifices plutôt qu' á un bâtiment unique. Ce document porte sur l'évaluation rapide d'un grand nombre de bâtiments similaires situés dans le même terrain en utilisant une approche de prévision. L'approche rétrospective évalue les effets des tremblements de terre antérieurs par l'énumération et la catégorisation des bâtiments endommagés et celles des blessés. La prévision offre une méthode par laquelle les dommages possibles sont évalués á l'avance bien que nombreuses incertitudes doivent être prises en considération. Une méthode rapide et simple devrait être élaborée au lieu des approches basées sur la recherche qui exigent beaucoup de temps et de l'expertise. Les étapes de ce processus impliquent la détermination du risque sismique, l'évaluation du parc immobilier et un calcul de vulnérabilité. Les fonctions de vulnérabilité sont déterminées á l'aide d'une méthode d'analyse statique non linéaire qui utilise l'approximation bilinéaire de la courbe de capacité en supposant la distribution des forces selon le premier mode, ainsi la distribution uniforme de tensions. La fonction de vulnérabilité peut être obtenu á partir de la courbe de la demande sismique et de la capacité de cisaillement du bâtiment. Dans le cas des plans de bâtiment typiques, la détermination des fonctions de vulnérabilité nous offre de courbes et l'expert ne pourra décider que sur place á la base d'une inspection visuelle. Avec la valeur donnée de l'accélération maximale du sol possible, les dommages attendus peuvent être estimés.

KEYWORDS: earthquake risk analysis, seismic vulnerability assessment

1 INTRODUCTION

Recent earthquakes with high number of casualties and enormous devastation proved that the hazard of natural disasters should not be neglected (even in 2012 there were major events around the world). Preventive approaches have received greater attention recently. Research in earthquake hazard mitigation has focused on evaluating possible damage scenarios for different magnitude events.

Two widely different approaches exist; one considers the effect of previous earthquakes; listing the damaged buildings and casualties. The other offers a method to evaluate possible damage prior to an event. The latter method facilitates prevention by gathering information about the state of the building stock and the expected damages, so the authorities can strengthen the most vulnerable buildings in order to mitigate risk. The challenge with this method is that many uncertainties must be taken into consideration.

In order to determine earthquake risk within towns, a fast and simple method should be developed. Otherwise, it would be very time-consuming and it would require too much expert participation.

This concept should be considered also in Hungary. Here, there are about 100-120 smaller earthquakes per year, which are below the perceptible level, and 4-5 perceptible earthquakes per year (Földrengés Információs Rendszer / Earthquake Information System / www.foldrenges.hu).

Earthquakes with a greater effect, causing structural damages, can be expected every 15-20 years, and in 40-50 years major earthquakes with high economic and social effects. With this earthquake hazard level, Hungary ranks with the medium-hazardous countries.

In Hungary, the goal should be the reduction of the expected damage during an earthquake. This provides an economic motivation for funding and executing seismic engineering research.

2 EARTHQUAKE RISK ANALYSIS

2.1 *Proposed process to derive earthquake risk*

Calculating earthquake risk requires the cooperation of several disciplines. To derive earthquake risk, the following steps should be performed:

- First, develop a hazard map of the investigated area; taking into account local site effects, liquefaction potential, soil type, etc. The target PGA would correspond to 10% PE in 50 yrs (design value), this will be the input parameter for vulnerability analysis.
- Second, identify the building classes based on construction methods. The vulnerability functions of each building class can be derived from the baseline structure.
- Third, generate a building inventory based on the vulnerability functions and the mean damage level. This can be calculated for every building class.
- Finally, assess damage based on all building classes, and determine earthquake risk.

Some of the factors involved that affect hazard and vulnerability are shown in Table 1 (EMS 1998).

Table 1. Factors affecting hazard and vulnerability

Factors affecting the earthquake hazard:	Factors affecting building vulnerability:
type of soil	construction system and period
thickness of layers	quality of materials
lateral variation of layers	workmanship
the potential of liquefaction	regularity in plan and elevation
master faults	position of the building
	changes in function
	state of the building, damages
	dynamic characteristics

Data obtained from paleoseismic studies and seismic engineering research will further enhance regional hazard assessment and development of microzonation maps. Such efforts would consider local site effects and examine a significant database of buildings with computed vulnerability so that earthquake risk can be assessed as:

$$\text{RISK} = \text{HAZARD} \times \text{VULNERABILITY} \times \text{EXPOSURE} \quad (1)$$

2.2 *Defining vulnerability*

One of the basic tasks in determining vulnerability of buildings is the classification of buildings from the point of view of earthquake risk. The classification worked out by researchers and agencies (EMS 1998, Vaseva 2002) is largely based on inspections of structural systems, possibly the time of construction and the proximity to earthquakes. The aim of this study is to work out a more precise method, which takes more factors into consideration such as the regularity in the layout, the direction of earthquake wave propagation to the building, etc.

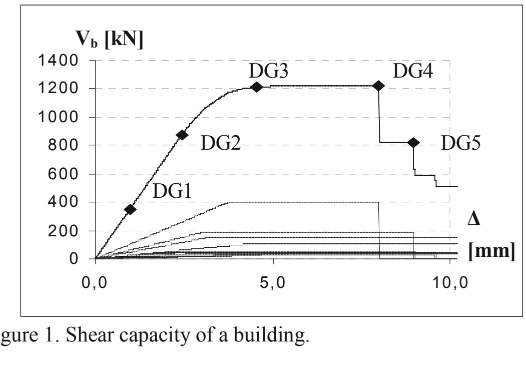

Figure 1. Shear capacity of a building.

Vulnerability is the possibility of damage or loss of buildings due to a seismic event; it is the characteristic of the building and it can be expressed in probabilistic or statistical terms. A vulnerability function is typically expressed as a function of displacements caused by different ground motion intensity.

The vulnerability function of each building class can be derived from the shear capacity of the buildings and the seismic demand expressed by the spectral acceleration. The extent of damage can be represented by damage grades related to the onset of cracking, the yield point and to the destruction. This is shown in Figure 1, where base shear is plotted against overall building drift. Damage grades 1 and 2 are within the elastic range of the structure, while grade 3 is beyond the onset of yield. Grade 4 represents an ultimate condition while 5 indicates partial collapse.

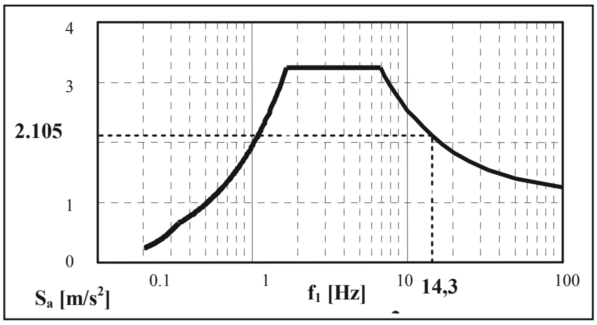

Figure 2. Elastic acceleration response spectrum medium stiff soil, 5% damping, a_g=1,1 m/s^2.

Vulnerability as an input parameter to earthquake scenarios requires evaluation of a large building population in a rather short period of time using a simple method, which describes the seismic performance of the buildings adequately.

There are different methods to analyze the vulnerability of the buildings: methods used during the post-earthquake study as well as analytical or numerical methods. Vulnerability can be determined by observation or based on expert opinions; usually based on post-earthquake studies. Other methods offer a possibility to estimate the possible damages before an earthquake occurs.

In the case of observed vulnerability, (Haddar 1994, Castano 1994, Porro et al. 1989) the damage is defined with the repair cost as a ratio of the replacement cost or the amount of loss of all affected buildings considering the number of casualties as a ratio of their value. The relation between damage and earthquake intensity is valid only for the region where it was developed. Another method is to ask experts to estimate the expected percentage of damage caused by a given intensity, which are implied in macroseismic scales. These scales are used to evaluate the possible damages after an earthquake (Fäh et al. 2001).

The analytical approaches are based on identification of collapse mechanisms yielding the equivalent shear capacity (Benedetti et al. 1996). The vulnerability is expressed as the critical acceleration causing the mechanism to take place. In the case of score assignment, the structural deficiencies are identified and scores for different deficiencies are calibrated by experts (Calvi 1999).

Detailed analyses are the most time-consuming evaluation of vulnerability. These analyses correspond to the methods of design: linear static analysis (lateral force method); modal-response spectrum analysis which is a linear dynamic analysis; pushover analysis (Lang et al. 2000); an increasingly popular non-linear static analysis; and a fully non-linear time-history dynamic analysis. These analyses above are listed in increasing order of complexity, work demand, cost, and difficulty of interpretation. For regional applications, finding a balance between available resources and level of sophistication is a major challenge.

3 STUDY AREA

3.1 *City of Győr*

Győr is the most important city of northwest Hungary often referred to as the City of Associations or Meetings. The city is the sixth largest in Hungary, and it is the capital of Győr-Moson-Sopron county and Western Transdanubia region, an important economic, industrial, ecclesiastic, educational, cultural and sports centre. The dynamically developing city lies halfway between Budapest and Vienna, on one of the important roads of Central Europe with an excellent accessibility.

Figure 3. City of Győr, main roads and rivers crossing (Google map).

Győr is also referred to as the City of Waters as it lies at the bank of river Rába, at the confluence of the Moson-Danube, the Rába and the Rábca not far away from the main channel of the Danube and it is rich in thermal water as well. Győr is Hungary's second richest town in historic buildings outside Budapest. Characteristic corner-balconies and narrow lanes, churches, museums are all reminders of a historic past, mainly situated in the centre of the town.

From a geological point of view Győr lies in the eastern part of Little Hungarian Plain. The Little Hungarian Plain is a deflational lowland of ca. 7700 km^2 on the western part of the Carpathian Basin System. Its medium altitude is 125 m a.s.l., a little higher than that of the Great Hungarian Plain. The river Danube divides into a southern and a northern part.

The southern marginal hills consist of gently undulating hilly country, dissected by a deep valley. They are composed of sandstones, gravel and clay. The present morphology was formed during the Quaternary period by fluvial erosion, tectonic movements and deflation processes. The northern margin of the Little Plain consists of similarly hilly country dominated by thick loess cover. The rivers entering the Little Plain flow eastward.

The Little Hungarian Plain is a structural basin, subsided along step faults and the basement can be found beneath thick basin sediments. Two large tectonic lineaments in the basement determine the geological structure.

3.2 *Seismicity of Győr*

The tectonics of the Carpathian basin is determined by the counterclockwise rotation of the Adria microplate and the north-northeast directed movement originating from the rotation. The seismicity of the area is moderate. Earthquakes causing light damages occur every 15–20 years, while stronger, more damaging 5.5–6 magnitude quakes happen about every 40–50 years.

The distribution of earthquakes is diffuse; however, there are certain areas where the occurrence is higher. For example at the surroundings of Komárom-Mór-Berhida, known as Móri-trench, where the largest earthquake of Hungary occurred in the city of Komárom in 1763 with an estimated magnitude of 6.1. This is shown also in the seismic hazard map of Hungary computed for 475 years return period. PGA values were computed for bedrock and are expressed in m/s^2.

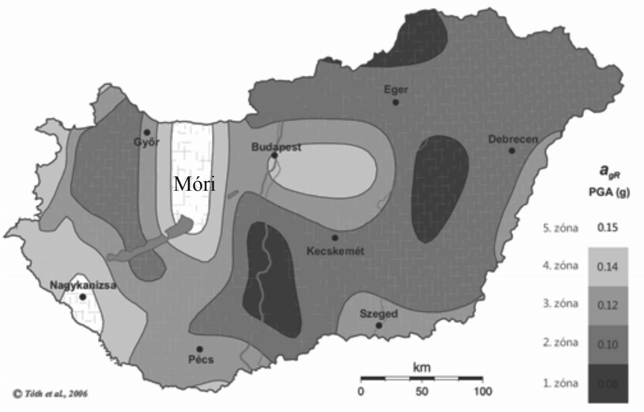

Figure 4. Seismic hazard map of Hungary indicated Móri-trench and Győr (Georisk).

Aerial distance between Győr and Móri-trench is 60 km. Historic data show that major earthquakes of this area had significant effect on buildings in Győr. The importance of the city as a regional centre, the number of inhabitants and the closeness to the above-mentioned fault emphasizes the necessity of earthquake risk analysis of this town.

The other significant fault lies beneath the river Rába and meets the fault beneath river Mosoni-Duna at Győr. Recorded earthquakes with epicenter at Győr mainly occur due to these faults.

Table 2. Historical earthquakes with epicenter at Győr and approximately 8 km depth

Date	Magnitude	Maximum intensity
1700.02.11	3.5	5.0
1754.10.21	3.5	5.0
1758.08.07	3.2	4.5
1763.08.04	2.2	3.0
1763.08.09	3.2	4.5
1765.02.05	2.9	4.0
1765.02.21	2.9	4.0
1768.01.05	3.9	5.5
1768.09.20	2.2	3.0
1768.10.29	2.2	3.0
1779.04.02	2.9	4.0
1779.04.02	2.9	4.0
1781.10.07	2.9	4.0
1786.02.29	2.9	4.0
1850.10.07	**4.9**	**7.0**
1850.10.29	3.5	5.0
1860.04.13	2.2	3.0
1914.02.04	2.9	4.0
1921.05.04	3.5	5.0
1990.08.22	2.9	4.0
1993.07.12	2.8	3.5

3.3 *Examined zones and buildings*

Twenty six selected zones were examined more closely. The zones differ from each other not only in location, but also in types and ages of buildings. Building data were gathered with the help of a questionnaire and the screening evaluation of trained staff. Data concerning the soil types and layers were collected in parallel.

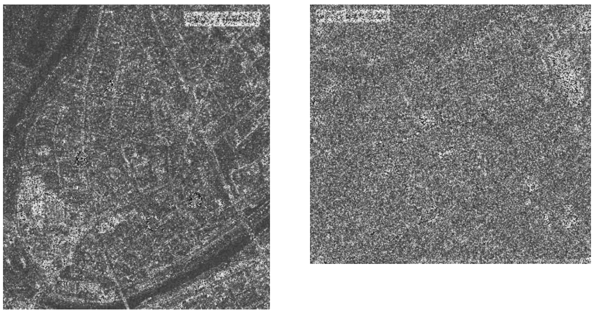

Figure 5. Zones from the town part called Révfalu and the inner city.

The checklist consisted of questions about:

- General data of each building (age and function of the buildings, regularity in plan and elevation, position of the building, changes in function, previous damages, state of the building, etc.)
- Structural data of each building (dimensions, construction system, quality of materials, workmanship)

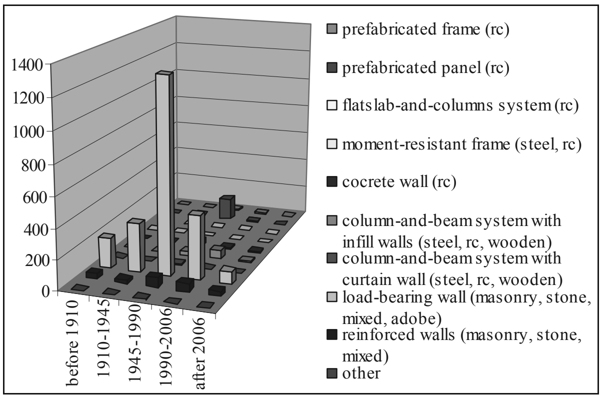

Figure 9. Building heights of the analyzed town parts.

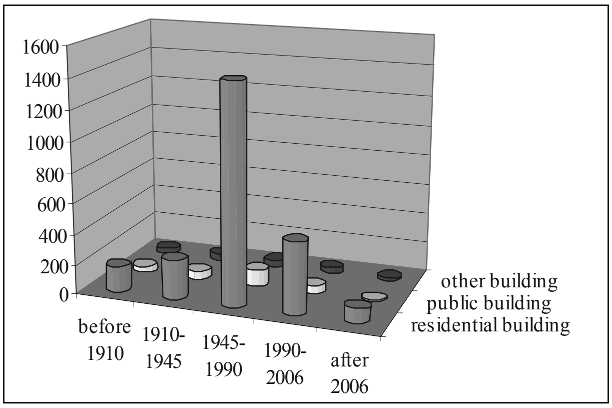

Figure 10. Building functions and construction period.

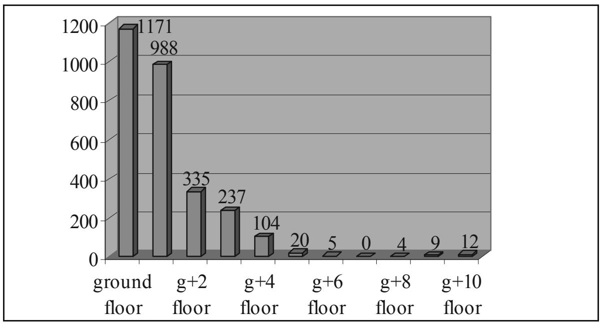

Figure 11. Structure of the buildings and construction period.

Data from 2885 building were analysed, and buildings are classified based on these results. For each building class, a vulnerability function is assigned. The figures above give an overview about the analysed building-stock.

4 CONCLUSION

First, it should be emphasized that a large percentage of building stock was built without consideration of earthquake loads and these buildings are very vulnerable to a moderately strong seismic event. Focus of efforts should be directed toward prevention: a relatively large building stock needs remediation, highlighting the importance of this research.

The vulnerability functions are being derived for typical layouts, this way offering many curves. With these, experts could decide on-site to which group the building belongs just based on visual screening.

Further research focuses on the determination of the expected damage for different values of PGA.

This way the method would offer a fast evaluation and allow the evaluation of many earthquake scenarios to a given town. It is very important to provide useful information for governments, authorities and insurance companies for setting up a priority order, so that remediation and intervention can be prioritized.

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