EVALUATING THE VULNERABILITY OF EXISTING INFRASTRUCTURE EXPOSED TO DYNAMIC/SEISMIC LOADING

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Представлена методология мониторинга сейсмических подвижек, основанная на ГИС-технологиях, учитывающая повреждения, обнаруженные при прогоне ГИС-сценариев, и нацеленная на идентификацию сейсмической стойкости структуры. Применяя географическую информационную систему (ГИС), содержащую географические данные, можно разработать подходящие сценарии для совершенствования знаний об уязвимости городской инфраструктуры. На основе наших исследований мы предлагаем способ применения дерева решений для анализа рисков возможных землетрясений в районах с высокой сейсмической активностью. Описываются сценарии моделирования, расчета и нелинейного сейсмического анализа, и они применяются к классу поврежденных моделей для некоторых RC структур, типичных для существующей городской инфраструктуры города Ияси, Румыния. Управление основанной на ГИС сейсмической уязвимостью существующих железобетонных конструкций представлено как средство для осведомления и снижения возможных будущих сейсмических воздействий в городских условиях.

Introduction

Earthquake Engineering Research Institute (US) reports the possibility of an escalation of the financial loss not seen in earthquakes before. Based on this report estimations, in 2022 buildings should be *risk certified* which will involve in fact a process of probable annualized loss of life per occupant day, damage repair cost per square foot and loss of service hours due to various hazards. A business willing to locate in a new community should be able to review risk certification in services in the community, including roads, power, water, telecommunications, health care and education to determine the disaster-resiliency. Once an individual real estate is selected, the cost of potential losses from a natural hazard, as resulting from risk certification should be possible to be compared with lease costs, insurance costs and other business costs associated with each propriety. It follows that investing in real estate is like to become more and more dependent of risk certified evaluations so that the building up of a new project should include methods of planning and mitigation of the natural hazard risk for investments. However, a well established plan is not set up yet for estimating the risk of natural hazards.

The literature dealing with natural hazards risk assessment typically can be organized in three mainstreams: a scientific technological approach (natural hazards are the cause of vulnerabilities and cannot be prevented), an economic approach (trying to develop economically rational criteria to reduce vulnerabilities — Andersen [1]) and social (recognizing the central role of humans in creating vulnerabilities — starting with White [2]). Consequently the learning process to assess and mitigate natural hazards effects is likely to be complex to incorporate all directions of potential impact.

1. Knowledge in Disaster Risk Planning

For an earthquake risk estimation learning process we use a general risk assessment philosophy adopted by the Cities Project Perth (Australia) and presented conceptually as follows:

$$\textit{Risk} = \textit{Hazard} \times \textit{Elements at Risk} \times \textit{Vulnerability of the Elements at risk}. \qquad (1)$$

Based on the risk elements definitions, the central role of knowledge follows as Input as well as Output in managing the risk. To obtain the following conclusion we use Gherardi [3] definition of disaster and learning and Wiedeman [4] definition of project risk. The definitions broadly capture the Project Management during disaster and the resulting inference can be seen in fig. 1.

Typically, Knowledge Management (KM) is considered as involving four key steps: creating/generating knowledge, representing/storing knowledge, accessing/using/reusing knowledge and disseminating/transferring knowledge. Knowledge creation seems to be generally accepted as the first step for any knowledge management initiative. This is a pertinent approach if we consider the knowledge resulting from the business process. However for the Project Risk Management, using knowledge learned based on past events might be more appropriate for the first step in a knowledge management initiative. Using and transferring knowledge should be perceived as an iterative process of knowledge creation for risk reduction within the Project Management.

Then how do we get the knowledge to be used within the Project Management? A particular approach is induced by the nature of the knowledge in itself. Stolle et al. [5] and Polyani [6] address knowledge as an object that can exist in essentially two forms: explicit or factual knowledge and tacit or "know how". In the organizational framework, knowledge frames can be expressed as in fig. 2, *a*.

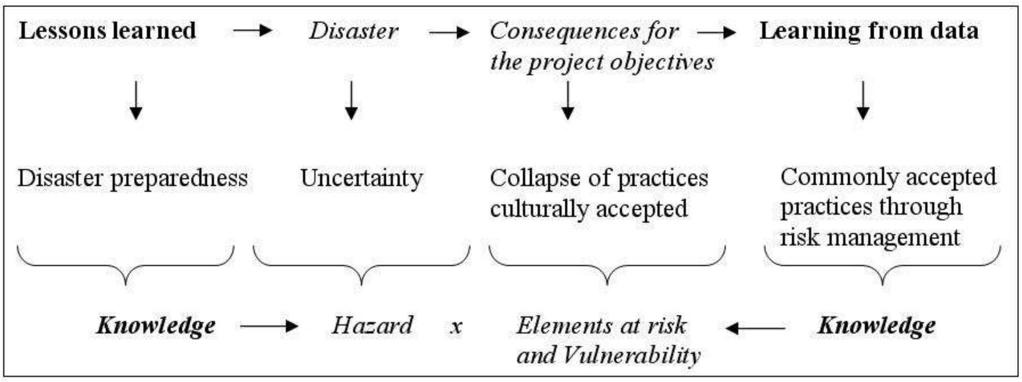

Fig. 1. Project management during disasters.

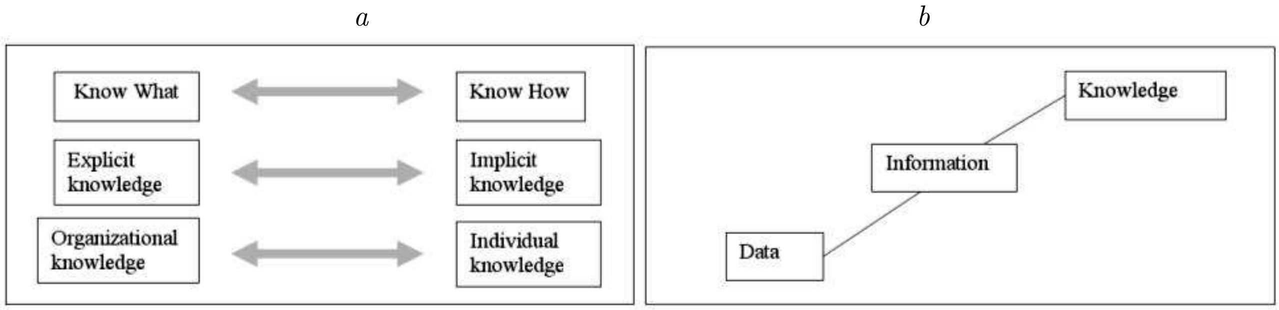

Fig. 2. Knowledge frames (*a*); increasing abstraction and usefulness of knowledge (*b*).

For a successful integration of KM in Project Risk Management the organization should seek ways to integrate knowledge in every form. Explicit knowledge is declarative and based on actual documented data. Normally is easier to track for Project Management purposes. It encompasses data offering information on the activities to be performed and the mean of accomplishment (*procedural knowledge*) or information about the types of activities ant their motivation setting up the ground for a *strategic knowledge* management (fig. 2, *b*).

However, the real challenge in Project Risk Management is implicit knowledge embedment. Therefore, to know the main forms of implicit knowledge is a first step towards knowledge retrieval. Generally implicit knowledge is considered to be *technical* (involving skills through practice and understanding), *cognitive* (referring to mental models, beliefs and perceptions in the environment), *functional* (based on inference rules in decision making), *phenomenal* (including organizational response to environmental changes), and *semantic* (interpreting patterns and their effect on organization).

Once with a growing awareness of natural hazards risk for business, community and natural habitats, reflected in the work of prominent international (e.g. World Bank, FEMA) there is an increasing availability of data for knowledge retrieval used in natural hazards risk preparedness. Despite data availability, there is a limited concerned for natural hazards risks preparedness from businesses which are most likely to be affected in terms of continuity. An overview of the existing information about natural hazards allows for an immediate conclusion. Data learned from past disasters is centered on offering information about global effects on business environment. A code of conduct for corporate management to mitigate risk in planning it is not set yet. The explanation could be obvious. The economic and financial effects of disasters are particular cases of particular businesses. Mitigating risks within projects is mainly based on implicit knowledge generated by Project Risk Management in itself. Next we have to explore a pattern of knowledge management within the Project Risk Management where risk is generated by the natural hazards occurrence.

Risk management within the project is a complex task, within which the risk may show up at different stages of the project including business environment. Barkley [7] suggests to exceed the traditional approach of identifying risk task by task and to prepare organization by identifying overall project risk in the business environment. This should be seen as the first stage of knowledge use for Project Risk Management. Barkley places the business environment risk identification as starting point of managing risk in projects. The information from the lessons learned from past disasters is built up in business planning of threats and weaknesses generated by natural hazards. The central role of knowledge shows up in developing an organizational culture of Project Risk Management.

Procedural knowledge about key activities which needs to be accomplished to prepare the organization for natural hazards risks it is easily perceivable from data available about past disasters consequences. Information about how business environment was affected in the past and possible governmental actions must be accounting for in planning overall organizational risk and contingencies.

In order to create an organizational culture for risk, implicit knowledge as integral part of people thinking is the key. Cognitive knowledge about "something I want my people to do in the normal course of work" is the main assumption behind risk management. Not for the last phenomenal knowledge about the organizational response to environmental changes had a special role in planning risk generated by natural hazards occurrence.

Sustaining the culture of risk management is considered as a major function in corporate leadership, in the risk-planning phase. This is not typically a mysterious, mathematical process, but an open communicative process in which key stakeholders, team members, and customers talk about uncertainty. The challenge for the organization is teaching and training project leaders and team members to think in terms of risk and to internalize the risk management process in daily work.

2. Data Mining Methods for Seismic Analysis

The Vrancea region in Romania, situated at the sharp bend of the South-East Carpathians, is one of the well-defined seismically active areas of Europe. A narrow, near-vertical focal volume sub-ducted at intermediate depths (60. . . 220 km), supposed to be in a relic stage at present, is the site of an unusually intense seismic activity — an average frequency of 3 shocks with magnitude greater than 7 per century [8]. Figure 3 [9] shows the epicenters of around six thousand shallow depth and intermediate depth earthquakes that took place in this region throughout the 20th century.

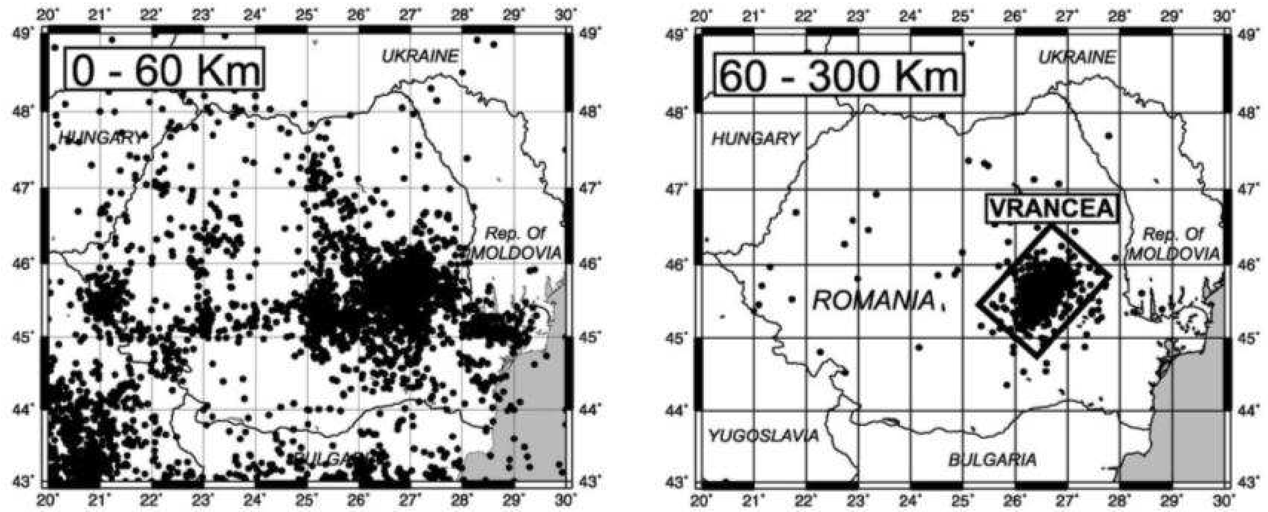

Fig. 3. Epicenters of around 6000 shallow depth ($h < 60$ km) and intermediate depth (60. . . 300 km) earthquakes in Romania.

a

```
long < 26.64
|   long < 26.13 : medium
|   long >= 26.13
|   |   h < 145 : very-dangerous
|   |   h >= 145 : medium
long >= 26.64 : medium
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b

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long < 26.64
|   lat < 45.22 : medium
|   lat >= 45.22
|   |   h < 141
|   |   |   long < 26.29 : very-dangerous
|   |   |   long >= 26.29
|   |   |   |   lat < 45.54 : medium
|   |   |   |   lat >= 45.54 : very-dangerous
|   |   h >= 141 : medium
long >= 26.64
|   h < 81.5 : very-dangerous
|   h >= 81.5
|   |   h < 95 : dangerous
|   |   h >= 95 : medium
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Fig. 4. REP tree categorization (*a*); random tree categorization (*b*).

The prediction of earthquakes is a very difficult and challenging task where one cannot operate on only one level of resolution. One cannot neglect the spatial localization of earthquakes, since there may be subtle correlation between different seismic events. After the initiative sponsored in 1995 by Directorate XII for Science, Research and Development of the European Commission sponsored since research aimed at the retrieval, processing analysis and dissemination of strong motion data generated by earthquake and collected from strong motions networks and individual station in Europe a growing database in terms of digital records is now available for research and information. The Romanian Institute of Soil Physics is also posted for public use sets of earthquakes occurred in Romania in a Seismic National Catalogue, published in the Official Monitor of Romania.

A *geographical information system* (GIS) is a software capable to assemble, keep, process, and display specific information, identified by geographical location. It combines layers of information about a location to give the user a better understanding of that location. Nowadays, when the volume of data has greatly increased, data mining procedures become increasingly important in order to give the user knowledge about facts at a higher level of understanding. By using an intelligent geographical information system containing geospatial data, one can develop useful scenarios to reduce natural disaster risk and structural seismic vulnerability.

The data mining techniques we considered in this paper are the *decision trees* referring to categorization. Other methods concerning traditional and spatial data bases, such as clustering or association can also be applied to seismic analysis. One of the strategies used to reduce the number and diversity of objects is categorization, i. e. establishing classes that include a group of objects or stimuli that have some common traits. For most practical uses, a supervised approach is applied in order to find the rules that describe a certain category or class.

In order to perform our analyses, we selected only the geographical coordinates of an event: latitude, longitude, and epicenter depth [10]. We also discretized the magnitude attribute, and we only took into account earthquakes with magnitude greater than 5, since earthquakes with lesser strength do not pose serious threats, except for wearing the built infrastructure. We thus divided the range of values into 3 classes: *medium*, with $M \in [5, 6)$, *dangerous*, with $M \in [6, 7)$, and *very dangerous*, with $M \geq 7$.

The popular method of categorization by decision trees classifies an instance by repeated hierarchical tests on its attributes. In fig. 4, *a* and *b* respectively we can see the decision trees generated by the *REPTree* algorithm and *random tree* [11]. In this way we can describe the classes of magnitude by the location of the earthquake epicenters.

3. Methodology of Digital Management of Seismic Urban Risk

The whole process of digital management for the vulnerability of constructions in built urban environment is an integrated activity with multidisciplinary features, involving civil engineers as well as architects, IT administrators, and the public administration sector. The strategic objectives of this process address the following purposes:

• P_1 — vulnerability assessment of existing infrastructure for planning the preventive measures of human safety against earthquake, as it has been proposed in the application of GIS to urban Northern Caucasian regions [12];

• P_2 — creating instruments for the emergency management of situations based on a possible seismic scenario;

• P_3 — education goals for enhancing the social culture in crises management during and post catastrophic events;

• P_4 — building of safety patterns to seismic hazard in various urban samples, which will lead to a Digit City Map for evaluation of seismic vulnerability.

This complex program needed a strategic planning for the methodology of GIS-based management of seismic urban risk. Such a planning has been initially set up by Atanasiu and Gâlea [13]. The research presently goes on in a Postdoctoral Program supported by Ministry of Education and Research of Romania within the Excellence Program CEEX developed between 2005 and 2007 [14].

Research has begun so far on an urban sample of Iaşi municipality, a city with about 360 000 inhabitants with a complex urban structure of constructions, from historical monuments as churches and castles from the 15th — 20th centuries to residential multi-floor buildings over 40 years of functionality, critical facilities, one-storey residential old houses over one hundred years, etc. This urban area experienced only in the last century, sometimes almost without any repairs, two strong ground motions over 7 in magnitude on the Richter scale and an important number of moderate earthquakes under 6 in magnitude due to still ongoing tectonic activities in the Vrancea area of the Romanian Carpathians.

Following our objective of preventing the effects of the disasters on people's safety from a dense populated urban area, we chose a generic sample from the digital map of the city, which includes a significant number of different classes of constructions and critical facilities. Fig. 5, *a*

a *b*

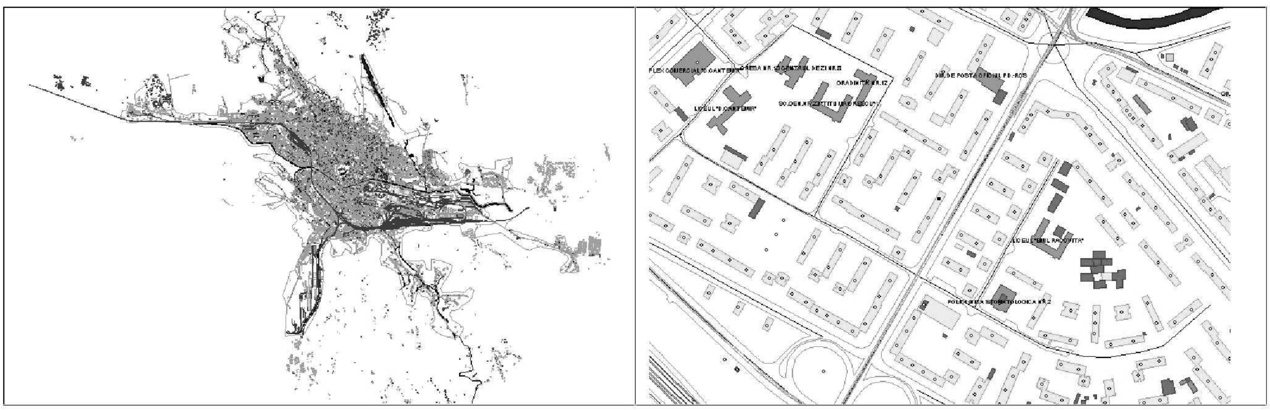

Fig. 5. A digital map of Iaşi City (*a*); a specific urban sample of the analyzed buildings (*b*).

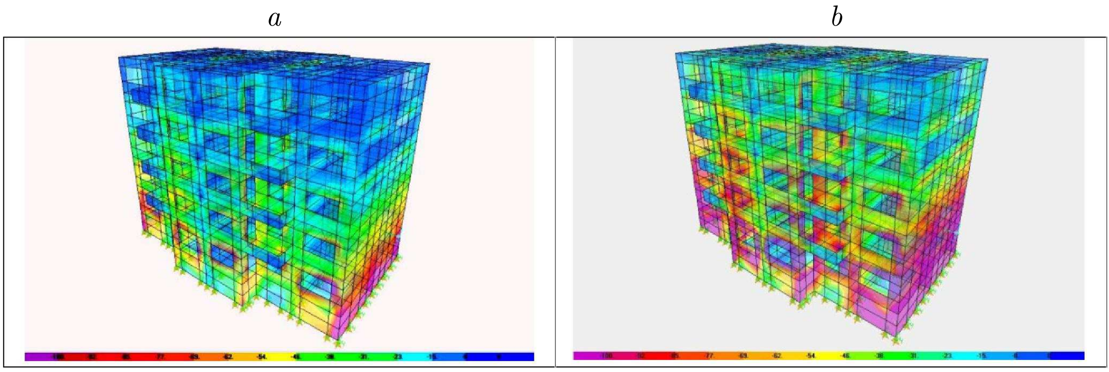

Fig. 6. Initial model of the building (*a*); damaged structure response — S22 stress state for seismic analysis (*b*).

is a digital map of Iaşi, the second largest city of Romania, located in the North-Eastern part of the country. A brief inventory of the modern residential part of Iaşi coupled with information from technical expert reports shows that in the Central and South-Eastern part of the city a set of different classes of structures, having mostly residential destinations are considered in the first, second and respectively third stage of emergency state on the latest list of existing damaged buildings. Analyzing the structural characteristics and material type of construction, these buildings are grouped in the following main categories: shear wall buildings, reinforced concrete frame structures, and masonry structures.

This selected urban sample is shown in fig. 5, *b*. One of the most vulnerable classes of structure is the class of prefabricated shear wall with a typical topology of ground floor and fourth level, build after 1965. The shear wall has usually a height of 2.8 m, a span between 3 m and 5.40 m, a thickness range between 0.12 m and 0.25 m. The corresponding concrete resistance class is C16/20, according to Romanian Code [15]. One of the typical structures existing in the analyzed urban sample is shown in fig. 6, *a*. The methodology we used to describe vulnerability assessment consists of Finite Element modeling and Spectral Response analysis of the building, taking into account two cases of Peak Ground Acceleration (PGA) of 0.5 g and 1 g respectively [16]. The results of stress analysis given in the Spectrum Response method are illustrated in fig. 6, *b*. The fundamental periods for the two analysed models are displayed in table.

Using the global damage index recommended by DiPasquale and Cakmak [17], we can assess the damageability index of the structure, DI, which is in our case:

$$DI = 1 - \frac{(T_0)_{\text{initial}}}{(T_0)_{\text{equivalent}}} = 1 - \frac{0.23}{0.41} = 0.439. \tag{2}$$

T a b l e 1. Fundamental periods for the two considered models

Mode of vibration	Fundamental period T [sec]	
	Initial structural model	Damaged structural model
1	0.231688	0.410182
2	0.215277	0.381126
3	0.164714	0.291611
4	0.087354	0.154651
5	0.076916	0.136173

Fig. 7. Spatial clusters of vulnerability classes on a GIS map.

Taking into account the scale of damageability presented in *IDARC* [18], one can assess that this structure belongs to the class of "Severe Degree of Damage", with *DI* between 0.4 and 1.0.

By applying GIS technology, the results of the diagnosis presented are visualized on the digital map of seismic vulnerability for the analyzed urban sample, and the methodology can be extended for the whole class of buildings belonging to the same feature cluster (fig. 7) [19].

Conclusions

Our analysis methods presented here can emphasize the levels of risk vulnerability for each earthquake class. In order to understand more clearly the behavior of the Vrancea seismic region, data mining techniques must be applied to large databases containing information about events for an extended period of time. Using the GIS technology, the results of the diagnosis presented are visualized on the digital map of seismic vulnerability for the analyzed urban sample. By generalization, the digital map of seismic vulnerability can be built, which is useful for the risk management of cities requested by various stakeholders at local and national level.

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