DEVELOPMENT OF A WEB-BASED INFORMATION SYSTEM FOR URBAN SEISMIC RISK MANAGEMENT

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ABSTRACT

Urban earthquake risk derives from local seismic hazards combined with a large number of exposed infrastructures (buildings, bridges, roads, etc.) and population. Aging of the infrastructure, growing population and socio-economic pressure are all factors that significantly contribute to increase the seismic risk in large urban areas. The complexity of modern urban systems (infrastructures, lifeline systems, etc.) requires a multi-disciplinary approach to risk management that involves geologists, geotechnical and structural engineers and decision makers. The diversity of the data makes information management a corner stone in risk evaluation. The development of an information system for urban risk management must be upgradable, open and multi-users. Theses characteristics will allow maximum transparency at the level of methods and computing code.

More specifically, the Quebec City Office of emergency preparedness and engineering department identified the need to develop a rational method for better managing the seismic risk. A new framework for better managing information required for risk management has been developed by researchers at Laval University and ÉTS, with the support of the Joint Emergency Preparedness Program of Canada and the City of Quebec. A web-based information system, based on a three-tier software architecture, using open source components and combined with a geographical information system, has been developed to integrate and manage geotechnical and structural information and support the decision making process in seismic hazard identification and risk management. The information system, by providing an accurate knowledge base as well as a tool for visual display of layers of complex geological, geotechnical or structural information, is aiming at becoming an essential tool for planning and managing seismic emergency capabilities.

KEY WORDS: Seismic Risk, Seismic hazard, Web-Based Information System, Relational Database Management System, GIS.

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1. INTRODUCTION

Technological and natural hazards, ranging from toxic spills to floods, earthquakes or tornados affect millions of people every year throughout the world. Risk and emergency management are now becoming significant issues in our modern industrialized societies. As a result, the legal environment is being continuously adapted and emergency preparedness programs are being produced at the national, state/province and city levels to help face the possibility of natural disasters, technological accidents, terrorism and even biological or chemical attacks. The complexity of urban systems, which encompass both the socio-economic and the physical environments, requires a multi-disciplinary approach to risk management that involves natural scientists, engineers and decision makers. So, new theoretical, information and engineering frameworks are required and being developed to better address this series of whole new complex problems.

Urban systems vulnerability to natural or technological hazards is being compounded by several aggravating factors. In the case of seismic hazards, for example, the aging of the existing infrastructures (buildings, roads, bridges) have contributed to gradually increase their vulnerability: the American Federal Highway Administration (FHWA) actually evaluates that 70% of U.S. road infrastructures are vulnerable to earthquakes. FEMA (Federal Emergency Management Agency) note that the damages costs related to natural disasters have constantly increased in the last decades. Actually, it is considered that most cities in North America, outside California, remain unprepared to face a major earthquake, which is an extreme event that can affect all the elements of an urban system. It is therefore important to identify and prioritize the elements of this system which require preventive actions and to prepare and develop emergency management capabilities. A rational seismic risk management approach for modern cities must rely on a rigorous characterisation of the seismic hazard and a quantification of the vulnerability of the structures. Several issues need to be addressed at both the theoretical and practical levels if one wants to know what our risks are from seismic hazards and take judicious mitigation measures to protect our cities and our lifeline networks.

The purpose of this paper is to describe some applied research work being currently carried out in Quebec City to develop a rational method for better managing the seismic risk at a local scale. Earthquakes are extreme events that can affect all the elements of the urban system. It is therefore important to identify and prioritize the sectors of the city requiring preventive and mitigation actions. The main objective of the project is, in a first step, to characterize, assess and quantify the seismic hazard at a local scale and, at a second step, to assess the seismic vulnerability of city-owned buildings by acquiring, analyzing and modeling geological, geotechnical and structural data. This project extends the original work carried out by Michaud (2004) on the seismic microzonation of Quebec City. In this paper, the focus is on presenting a new decision and information framework developed for better managing the information required for seismic risk assessment and civil protection planning. The implementation of this system will allow Quebec City decision makers to have an updated quantitative and visual display of the geographical areas or buildings presenting a potentially high seismic hazard, a crucial information in the planning of an earthquake protection program and the development of mitigation strategies.

The paper is organized as follows: a brief overview of seismic risk in Eastern Canada is presented in section 2; the third section presents the methodology used for seismic microzonation and structural vulnerability evaluation; the fourth section presents an overview of a new GIS and web-based geotechnical information system develop to compile, store, manage, process and assist in the analysis and visualization of structural and 3D geotechnical information. Typical applications of the combined GIS/Web-based information system, related to microzonation and rapid seismic assessment of the structural vulnerability of buildings, are presented and discussed in the last section.

2. BACKGROUND INFORMATION: SEISMIC RISK IN EASTERN CANADA

It is now widely accepted that seismic hazard is one of the most significant natural hazards in Eastern Canada. Although this area is characterized by a low to moderate rate of seismicity, several significant earthquakes of magnitudes up to 7 have occurred in the past and triggered significant ground and structural failures. At a world-wide scale, recent earthquakes have shown the high vulnerabilities of older structures as well as the crucial importance of site effects on ground motions and related earthquakes damages. In Eastern Canada, the M_N6,5 1988 Saguenay earthquake was the strongest event in eastern North America within the last 50 years. The total felt area was over 3.5 million km^2 (Cajka and Drysdale, 1996) and geotechnical and structural damage outside the epicentral area was strongly correlated with underlying soil deposits.

More recently, Quebec City has suffered itself a M_N5.1 earthquake in 1997, although with limited observed damages. It is now clear that similar or stronger earthquakes can occur again and cause significant losses. In this perspective, the development of site-specific ground motions taking into account the local site effects becomes an important engineering task in the seismic design of critical facilities or in the development of seismic microzonation maps. New regional seismic zonation maps have been produced by Adams and Halchuk (2003) for inclusion in the forecoming new edition (2005) of the National Building Code of Canada (NBCC). This new 2005 NBCC (IRC-CNRC, 2005) will include a new seismic geotechnical site classification system, adapted from NEHRP (FEMA, 1994). This classification system uses six site classes (A,B,C,D,E,F). These classes are used to produce site amplification factors that reflect local soil conditions; they are defined by standard geotechnical parameters (shear wave velocity, undrained shear strength or SPT blow-count). However, to date, very few detailed regional seismic risk evaluation projects, taking account these new seismic models and geotechnical criteria, have been conducted and published for large urban areas in Eastern North America (ENA). Consequently, only relatively limited experience is still available for developing ground motions for microzonation or site-specific design and to help understand and predict local site effects in the geotechnical context of ENA.

Seismic microzonation, according to Finn (1991), is a "p*rocedure for improving estimates of seismic hazard for design by taking the effects of local site conditions into account*". It is often viewed as a rational approach to better predict seismic hazard at a local scale.

3. METHODOLOGY FOR SEISMIC MICROZONATION AND STRUCTURAL VULNERABILITY EVALUATION

GLOBAL DECISION MAKING PROCESS

Seismic microzonation and structural vulnerability evaluation are parts of larger decision making process that addresses the analysis, assessment and management of seismic risk for an urban system (Figure 1). This six-step risk-based approach to urban seismic risk assessment is adapted from a methodology put forward by Wu, Tang and Einstein (1996) for landslide risk evaluation. At this stage, the Quebec City project is actually concerned with steps 1 and 2, namely: 1) site characterization/building inventory and 2) geotechnical seismic hazards identification and structural vulnerability evaluation of targeted buildings for emergency use.

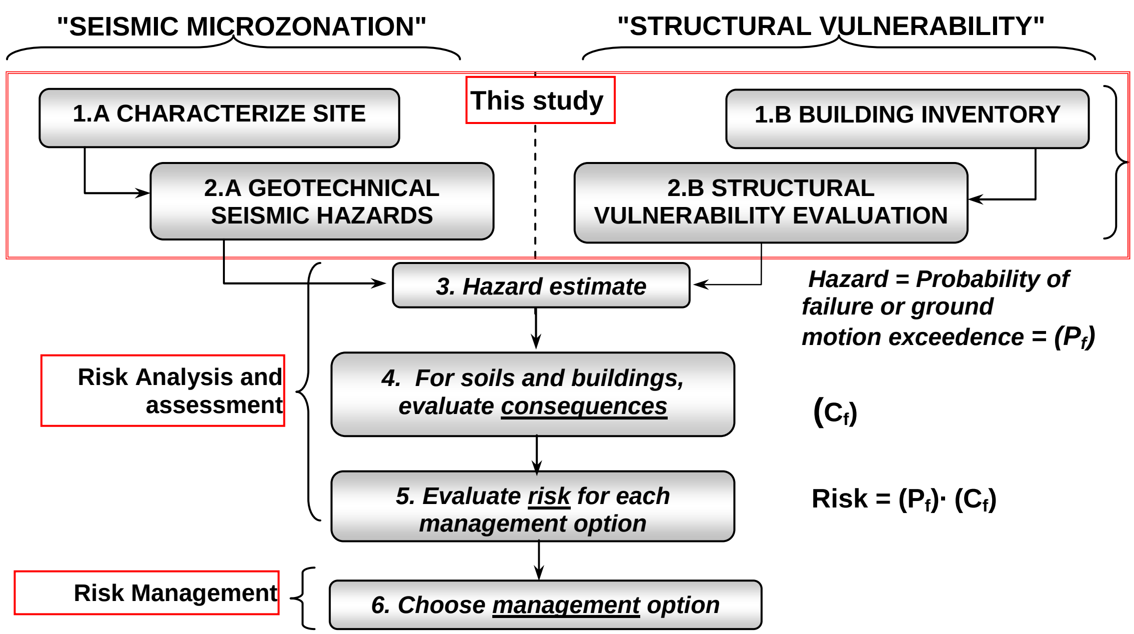


Figure 1: Risk-based approach for seismic risk analysis and management (modified from Wu, Tang and Einstein, 1996)

SEISMIC MICROZONATION METHODOLOGY

Seismic microzonation is a mapping technique that aims at providing a graphical view, at the local scale, of geotechnical seismic site hazards (which may either be: amplification, liquefaction, slope stability and soil deformation effects). These geo-data can subsequently be combined with an evaluation of the seismic vulnerability of the structures and infrastructures to form the basis of a hazard estimate, consequences evaluation and seismic risk evaluation. Figure 2 shows the detailed steps of the seismic microzonation methodology.

In this project, the approach developed for the seismic microzonation is based on historical seismic data and the most recent regional seismic hazard maps developed by

Geological Survey of Canada and recent seismic design criteria of the NBCC 2005. The methodology takes into consideration the nature, thickness and mechanical properties of the local soil deposits, water table location and the bedrock characteristics.

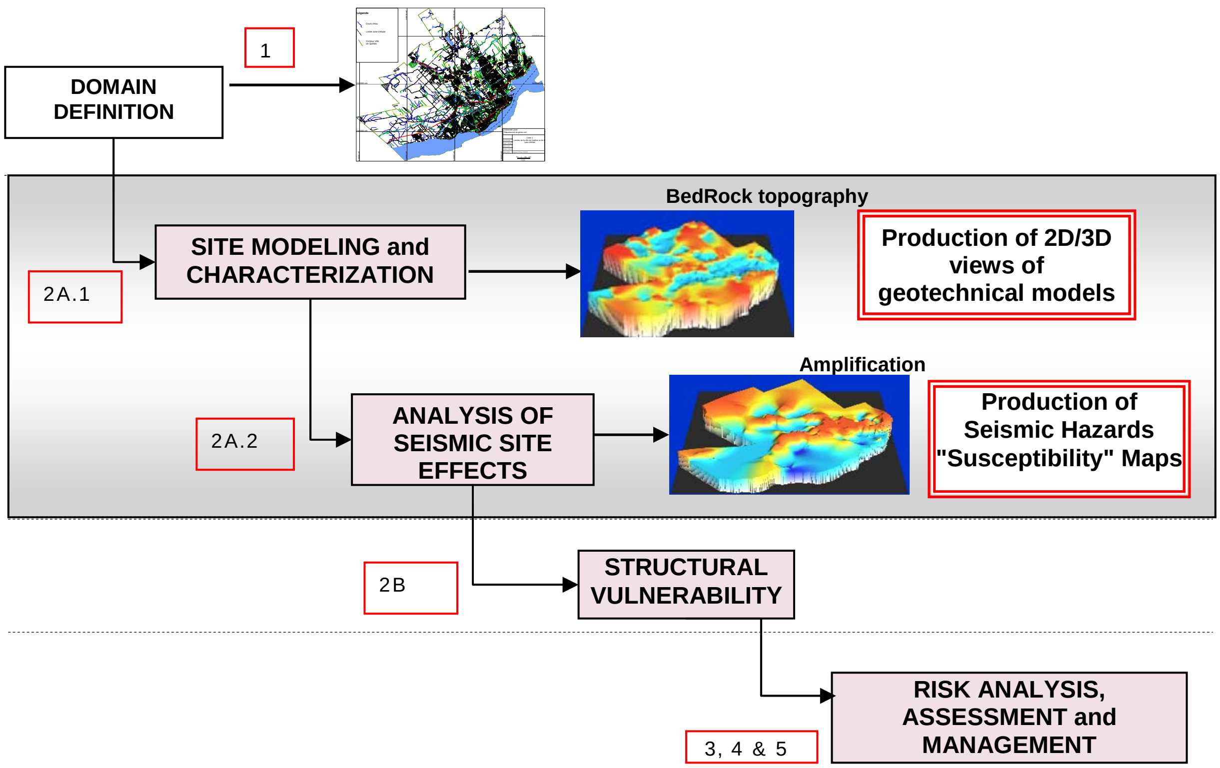


Figure 2: Microzonation methodology for geotechnical seismic hazards identification (Steps 2A.1 and 2A.2)

The site modeling and characterization process (step 2A.1) uses basic environmental data (regional seismic hazard, seismic sources location, topographic data, hydrological data and roads and infrastructures data) as well as data from drill holes and in-situ geotechnical tests. The geotechnical models produced from those data are surface topography, rock topography, overburden thickness and superficial deposits maps.

Analysis of the seismic site effects is carried out in step 2.A.2 to better take into account the influence of local soil conditions on ground motions parameters, such as the spectral amplification ratio. This is accomplished by carrying out a detailed analysis of 2 300 boreholes logs. This has the advantage to rely upon high quality real geotechnical soil deposit information. Some of the collected parameters are: soils layers information (thickness, geological name, nature, etc.) mechanical properties (such as undrained shear strength form, SPT blow counts, piezocone and soil grain size analysis). This information is then used to categorize the site according to the new seismic site classification proposed by the forecoming new edition NBCC 2005 and to predict local site amplification.

STRUCTURAL VULNERABILITY EVALUATION

The structural vulnerability (step 2.B in Figure 2) of 104 buildings was evaluated with two score assignment procedures, the CNRC-1992 (IRC-NRC, 1992) and FEMA-154 (BSSC, 2002). Theses procedures are ranking systems which aim at recognizing high-hazard buildings by identifying their structural deficiencies. These two techniques are relatively simple procedures and allow a rapid visual screening of buildings for potential seismic hazards. In the Quebec City project, the CNRC-1992 procedure and a "modified" FEMA-154 procedure adapted to the NBCC 2005 and the City of Quebec local seismicity, were implemented in the structural database discussed below. Both methods enable the users to quickly rank buildings according to their ability to withstand an earthquake. They include a seismic screening procedure (based on visual survey and technical drawings data, among others) that examines regional seismicity, local soil conditions, structure type, structure irregularities, the presence of non-structural hazards, and the use and occupancy of the building. Surveyed buildings are classified among 15 building types identified by the construction materials and the seismic resistance system (braced steel frames, unreinforced masonry wall, etc.). This information is used to assign scores leading to a seismic priority index (IPS) for the CRNC1992 procedure and a final score (S) for the FEMA-154 procedure. The priority index or final score are used to classify the building into a minimum of two categories: (1) those having an acceptable level of performance due to the risk to life safety, and (2) the buildings that are seismically hazardous and should be evaluated in more detail.

4. WEB-BASED INFORMATION SYSTEM

SOFTWARE ARCHITECTURE

The diversity of the data makes information management a corner stone in seismic risk evaluation. The following factors make it a unique and difficult challenge: (1) risk evaluation has to deal with huge amount of geographical, geotechnical and structural data; (2) the data must be easily updated on a regular basis; (3) models and methods of evaluation are constantly being revised and updated (codes, standards, computation methods, etc.); (4) data validation, which is an essential step in the risk evaluation process, must be easily provided. Furthermore, system management tools must be easily upgradable, low-cost, open and multi-users.

The web-based information system developed specifically for the Quebec City project integrates both the geotechnical and the structural information and is based on a three-tier software architecture using only open source components. Level 1 is the user interface (client) and manages data display and local processing (input control, data formatting, etc.). Level 2 provides web server resources (Apache web server), manages process logic and is the level where applications are executed. Level 3 is the data management level and is based on a relational database management system (MySQL) managing access to both geotechnical and structural databases (DbGEO and DbBAT). This type of architecture provides excellent performance and maximum flexibility and scalability with a user interface, the web browser, which hides the actual complexity of distributed processing. Figure 3 illustrates the structure of the three-tier system, and Figure 4 shows some examples of the geotechnical and structural web access forms. The applications are all written in *PhP*, a free open-source computer language.

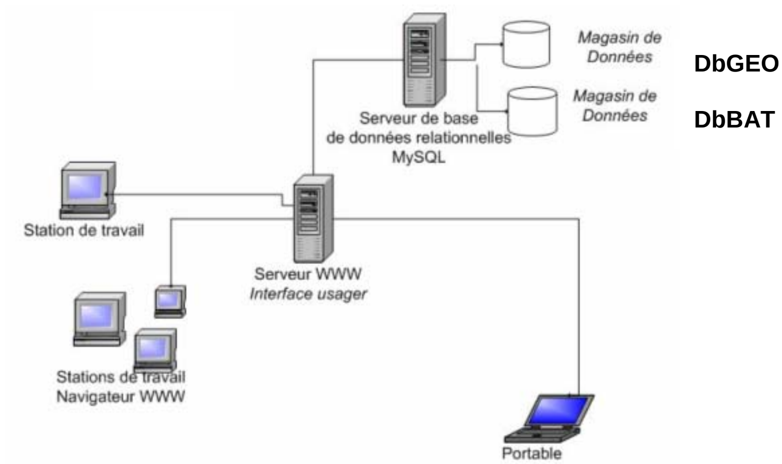
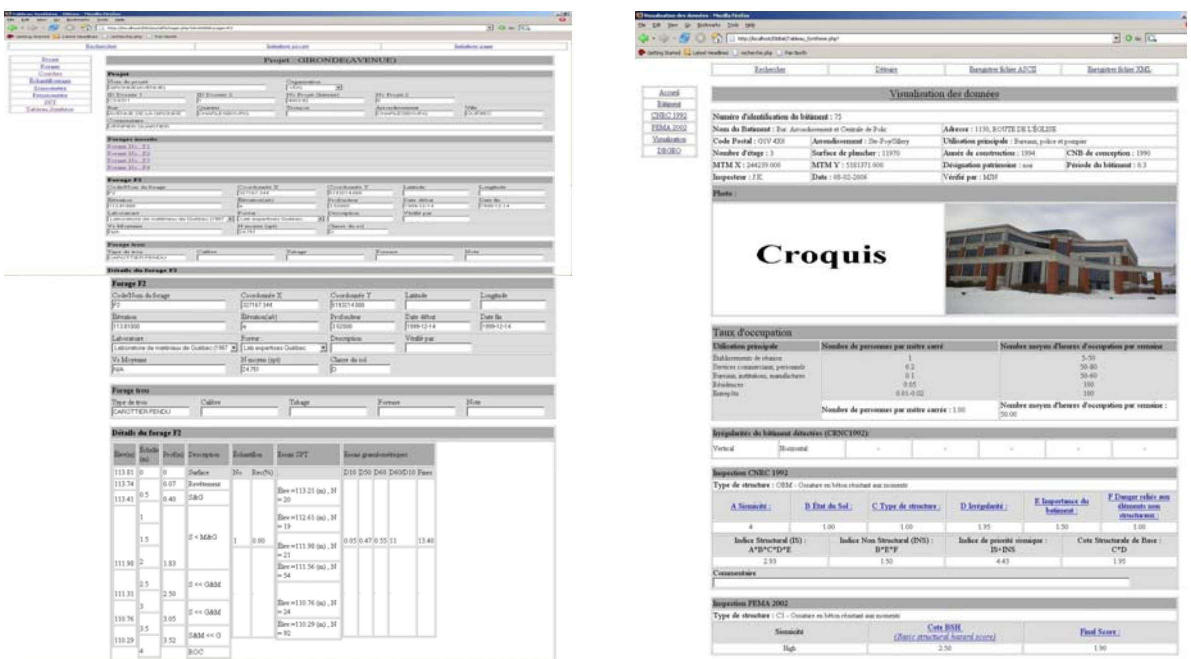


Figure 3: Three-tier web-based information system



(a) (b)

Figure 4: Geotechnical (a) and structural (b) databases typical web access forms

5. APPLICATIONS OF THE GIS/WEB-BASED INFORMATION SYSTEM

One of the most significant feature of this project is the development of tools enabling the combined use of geotechnical and structural information in view of producing seismic hazard maps. Different levels of geotechnical and geological information, stored and processed in DbGEO, can also be used to analyze data and produce several images or maps of parameters of geotechnical interest, namely a geotechnical map of superficial soil deposits, an overburden thickness map, ground motion and spectral amplification maps developed according to various seismo-tectonic models, site classification maps and spectral amplification maps. A typical map, showing here the spectral amplification ratios (defined as the ratio between surface spectral acceleration $S_a(T)$ and bedrock $S_a(T)$) for period T = 0,2 s (and for the regional seismic model (model R, Adams and Halchuk,2003)), is presented in Figure 5.

Figure 6, showing the City's buildings with the superficial soil deposit map, is a good example of how GIS can easily integrate and display layers of information of different nature, which is of great help in urban emergency planning.

CONCLUSION

This paper describes how Internet, database and GIS technologies can be used to develop more efficient methodologies for microzonation and seismic hazard assessment of urban systems. The information system presented here was developed with the objective to give Quebec City decision makers and engineers a very flexible and powerful tool for urban seismic hazard assessment and management. Its web-based structure and the easy access to its open source computer code make it scalable and easy to upgrade. A graphical analysis of the local geotechnical seismic hazards combined with structural vulnerability information thus become possible. These new tools will be use for planning an earthquake protection program and developing mitigation strategies.

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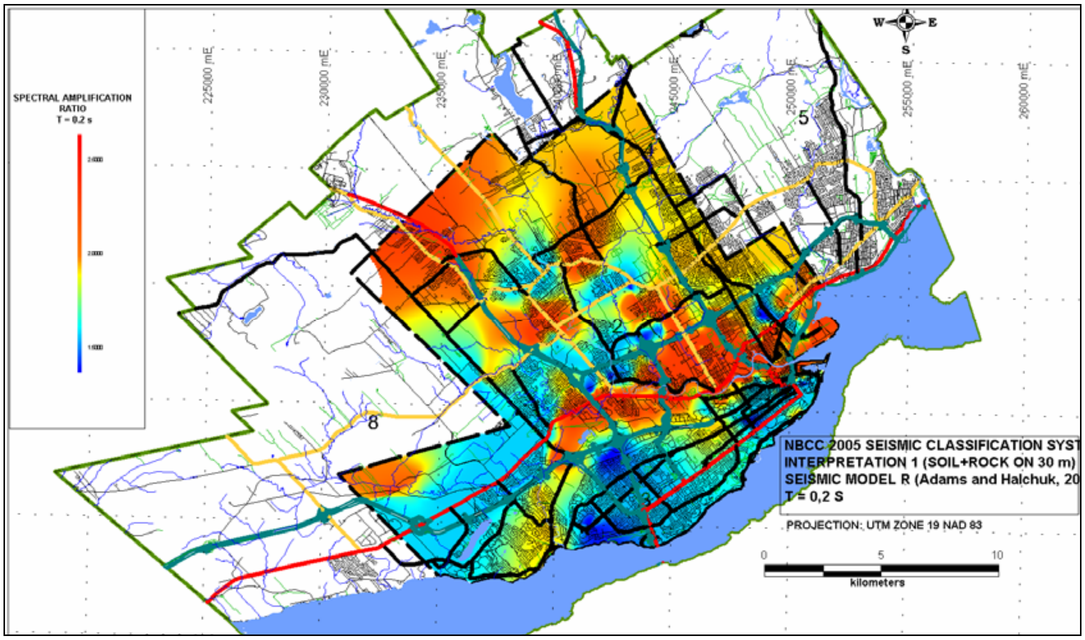

Figure 5: Seismic microzonation: spectral amplification ratio mapping for Quebec City (seismic model: Regional; seismic interpretation for site classification : soil + rock on the upper 30 m)

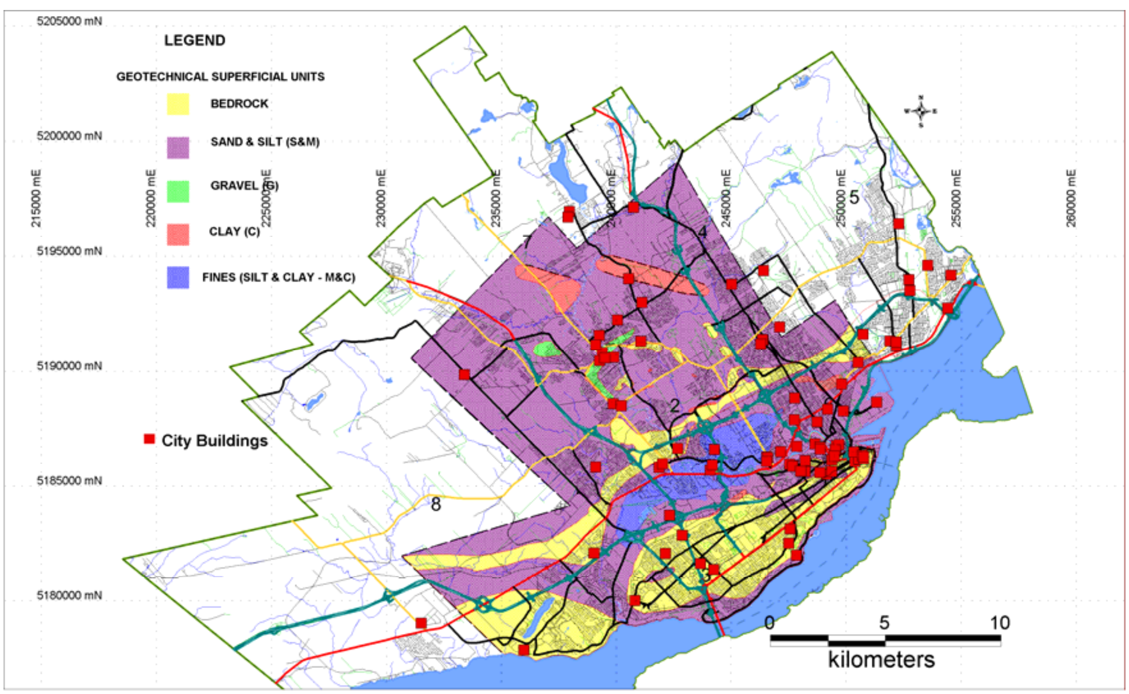

Figure 6 : Geotechnical map (superficial geotechnical layers) and buildings layer overlay

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