DEVELOPMENT OF A SEISMIC MICRO-ZONATION MAP FOR THE SAGUENAY TERRITORY, QUEBEC

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Abstract- In order to realize a seismic risk analysis in the Saguenay territory, a seismic micro-zonation was developed to determine the potential of seismic site effects. The methodology used in this study is composed of three important steps. Firstly, a 3D geological model of the soft deposits was developed. Then representative average shear wave velocity values were assigned to the clay layer, to the granular deposits layer, to the till layer and to the bedrock. Finally, the average shear wave velocity of the first 30 meters was calculated over a regular grid for the study area. The results include a spatial distribution map of the average shear wave velocity in the first 30 meters and the spatial distribution map of the seismic soil classes from the National Building Code of Canada.

Keywords- Seismic risk analysis ; seismic site effects ; V\(_\text{s,30}\)

I. INTRODUCTION

Local geological site conditions have a major influence on the intensity of seismic ground shaking and on the negative effects associated with an earthquake [1]. The National Building Code of Canada [2] includes a seismic soil classification that considers the sensitivity of a soil to seismic site effects. This seismic soil class is determined by the average shear wave velocity in the first 30 meters (V\(_\text{s,30}\)). Thick soft soils, characterized by a low V\(_\text{s,30}\) value, are more susceptible to amplify and to extend the duration of the seismic wave.

Commonly, urban scale studies of the spatial distribution of V\(_\text{s,30}\) [3]–[6] use an approach that generally relies on a dense coverage of geological, geotechnical and geophysical data. However, for regions where data are clustered or insufficient, such approach is unusable. In this latter case, supplementary geological and geomorphological information are used [7], [8].

The Charlevoix region (Québec, Canada) is the most active intraplate seismic zone in north-eastern America. The Saguenay territory is located 130 km to the north-east of this zone. Moreover, the Saguenay region has experienced in 1988 a 5.9 magnitude earthquake with the epicenter located within its own limits. For these reasons and because of the new regulations in regards to the risk prevention imposed to municipalities, a seismic risk analysis is currently conducted over the city of Saguenay. This study includes the determination of the potential seismic site effects. The objective of this paper is to present the development of a spatial distribution map of V\(_\text{s,30}\), known as seismic micro-zonation, over the territory of the city of Saguenay.

The spatial distribution of V\(_\text{s,30}\) was realised using a combination of a 3D geological model of soft deposits and of representative average values of shear wave velocity.

II. METHODOLOGY

The methodology used to realize the spatial distribution map of V\(_\text{s,30}\) is composed of three main steps. First, a simplified 3D geological model of the soft deposits is developed to define the spatial distribution of the type and the thickness of deposits. Then representative average values of shear wave velocity are assigned for each soil unit. Finally, V\(_\text{s,30}\) values are estimated over a regular grid in the study area to determine its spatial distribution over the Saguenay territory.

A. 3D geological model of the soft deposits

The 3D geological model of the soft deposits represents the most crucial part of this study. A special care has been taken in the selection of the considered stratigraphic units and in the development of the model in order to represent the regional and local geological heterogeneities, as explained in Foulon et al. [9].

The input data for this model are extracts from the geological database developed as a result of a groundwater knowledge acquisition project over the Saguenay–Lac-Saint-Jean region [10], [11]. The model covers the territory of the city of Saguenay. The stratigraphic units represented in this model are, from top to bottom: layers of sand, gravel, clay, fluvio-glacial deposits, and till, over the bedrock unit considered as the basement of this model.

B. Assignment of representative average shear waves velocity values to the geological units

Data of geotechnical penetration test have been gathered to determine the average shear wave velocity of the clay and of the granular deposit layers. The granular deposits layer includes the sand, the gravel and the fluvio-glacial deposits layers defined in the 3D geological model. This database is composed of 122 cone penetration test (CPT) and 12 standard penetration test (SPT) profiles (Figures 4 and 5).
The shear wave velocity of the clay layer was estimated from the CPT data using the empirical relationship of Mayne and Rix [12], whereas for the granular layer, it was estimated from the SPT index using the Ohta and Goto [13] empirical relationship. Then, representative interval shear wave velocity vs depth relationships were assigned to the clay layer and to the granular deposits layer according to Nastev et al. [8].

For the till layer and the bedrock, the representative average shear wave velocity values were extracted from the literature.

C. Seismic micro-zonation
The type and thickness data of the soft deposits have been extracted from the model in the form of raster values that represent the thickness of a sedimentary layer, using a 250 by 250 meters cell size. The spatial distribution of $V_{s,30}$ was obtained by calculating a $V_{s,30}$ value for each raster cell using Equation 1:

$$V_{s,30} = 30 / \left( \sum \left( \frac{d_n}{V_{s,n}} \right) \right)$$

where $d_n$ is the thickness of the layer $n$ in the first 30 meters and $V_{s,n}$ is the average shear wave velocity of the layer $n$ determined from the representative average shear wave velocity values.

III. RESULTS

D. 3D geological model of the deposits
A top view of the 3D geological model (Figure 1), a raster value that represents the interpreted thickness of deposits (Figure 2) and two cross-sections are presented (Figure 3).
E. Representative average values of shear wave velocity

Figures 4 and 5 present the values of shear wave velocities interpreted from the penetration data for clay and granular deposits. The interval shear wave velocity vs depth relationship, determined from these values is indicated below the Figures.

The shear wave velocity profile of clay (Figure 4) shows a decrease in the first 5 meters, before increasing with the depth. The decrease of shear wave velocity in the first 5 meters is probably due to the freeze-thaw or the artificial consolidation along the roads [4]. The shear wave velocity profile of the granular deposits (Figure 5) increases from 80 m/s to 260 m/s in the first 20 meters.

For the till layer and the bedrock, representative values of respectively 385 m/s and 2500 m/s were chosen according to Nastev et al. [8].

\[ V_{s30} \]

Figure 6. Spatial distribution map of \( V_{s30} \)

Figure 7. Spatial distribution map of seismic soil classes

F. Seismic micro-zonation

The distribution of \( V_{s30} \) (Figure 6) is widely influenced by the partitioning of the soft soils and their thickness. The lowest velocity sites are typically present in the thickest deposits at the south and the north part of the lowlands, and locally at the center of the study area. The highest velocity sites are visible in the thin till layer or rock outcrops, mainly present in the highlands. Figure 7 presents the spatial distribution of seismic soil classes from the National Building Code of Canada [2].

CONCLUSION

A seismic micro-zonation was developed for the territory of the city of Saguenay. It is based on the development of a 3D geological model of the soft deposits over the territory, combined with representative average values of shear wave velocity assigned to each unit considered.

The spatial distribution of \( V_{s30} \) developed in this study constitute the first characterization of the potential seismic site effects in the study area. It also represents a good basis for the development of ground motion maps. These ground motion maps will be realised to conduct a seismic risk analysis of selected public buildings in the city of Saguenay.

The 3D geological model developed in this study could have others applications, notably for the characterization of areas with high potential of landslide or soil liquefaction.

REFERENCES


