SOFTWARE PLATFORM FOR THE ASSESSMENT OF SEISMIC RISK IN ROMANIA BASED ON THE USE OF GIS TECHNOLOGIES

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ABSTRACT :

The structure of the ROSERIS software platform consists of a core GIS application and of two “satellite” applications dedicated to building stock data collection and management and to seismic risk analysis. Data is stored in a geodatabase containing building stock data, geospatial references and seismic hazard information. Building stock is classified according to a building typology matrix, assembled based on structure type, structure height and seismic design code level. Seismic hazard is defined by a simplified approach, compatible with the new Romanian seismic design code, entirely harmonized with Eurocode 8. The risk assessment methodology built in the platform uses fragility curves for different structure typologies in Romania, derived from previous studies carried out by some of the university members of the team. Typical output values consist of probabilities corresponding to damage states, as well as of mean damage ratios. Both input and output data are mapped or presented by means of several types of reports, by using the graphical user interface of the core GIS application.

KEYWORDS: seismic risk, GIS, seismic hazard, fragility curves, damage states, Romania seismicity

1. INTRODUCTION

The development of methodologies and software applications for seismic risk assessment of building stock is currently a major challenge for both professionals and decision-makers in countries affected by earthquakes. Several applications have been created during recent years, most being designed according to the specific requirements of a specific country. Among these, the HAZUS Multi-Hazard methodology and software (FEMA, 2003) is today a landmark in the field, by its complexity and multitude of features.

During the last three years, a research project has been conducted in Romania, aiming to develop a software platform for seismic risk assessment of the general building stock in the country. The project has benefited of the experience and results from several studies performed during the last two decades by the participants, in the framework of national and international research programs.

2. STRUCTURE OF THE ROSERIS PLATFORM

A simple scheme of the structure of the ROSERIS platform in shown in Fig. 1.

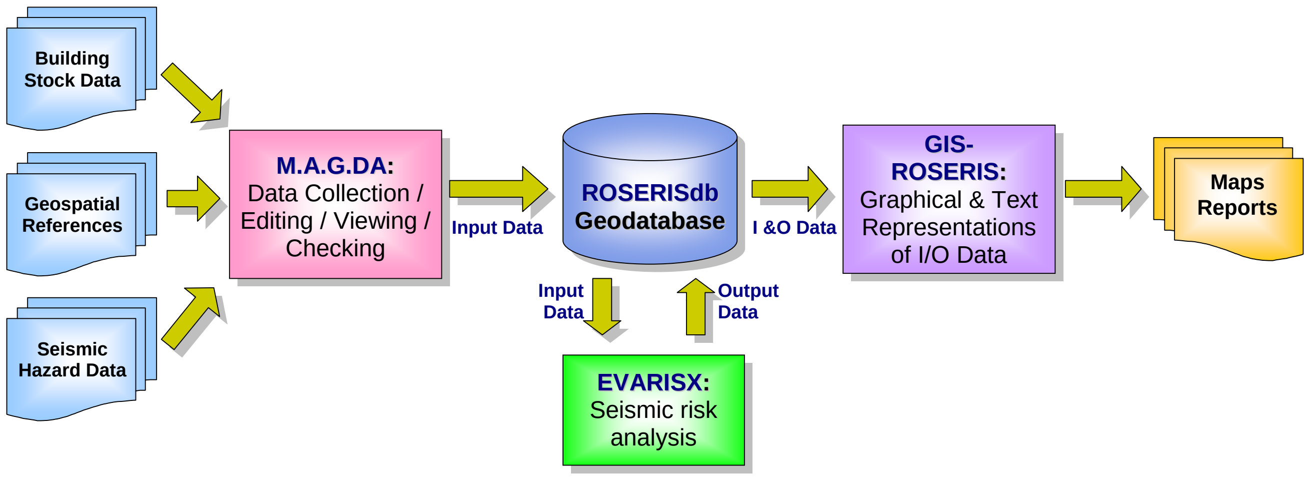

Figure 1. Structure of the ROSERIS platform

Input data used by the platform is stored in the ROSERISdb geodatabase. Data is structured in three major categories: data on building stock, geospatial references and seismic hazard data.

To facilitate data collection, editing, viewing and checking, a specialized software application, named MAGDA, was developed.

The seismic risk analysis is performed by another specialized software application, EVARISX. This uses the ROSERISdb geodatabase to get input data and to store output data.

Finally, both input and output data are represented, as maps and reports, by the GIS-ROSERIS software, using the customized graphical user interface of the application.

3. SEISMIC RISK ASSESSMENT METHODOLOGY

3.1. General

A detailed flowchart of the seismic risk assessment methodology implemented in the ROSERIS platform is presented in Fig. 2.

3.2. Basic

Data on building stock includes basic attributes to be used as an input for the seismic risk assessment methodology, as well as auxiliary attributes, as building occupancy or area, which are used for a better definition of building stock properties.

Basic attributes of building stock are: year of construction, structure type and number of stories. Key attributes (structural typology and spectral displacement) are determined by intermediate data processing operations performed by MAGDA upon basic attributes.

Structure type is specified according to 23 categories, defined according to the features of the building stock in Romania. To each structure type is assigned a unique code.

Also, to each building is assigned a unique identifier, which serves for creating relationships to geospatial references and to other data.

Seismic hazard is defined in a simplified manner, according to the prescriptions of the new Romanian seismic design code, P100-1/2006 (MTCT, 2006). The new code is harmonized with Eurocode 8 (CEN, 2004). Seismic hazard data is specified, for a mean recurrence interval of 100 years, by the values of peak ground acceleration, a_g, and of control periods, T_B, T_C, T_D. The functions which define the shape of the design spectrum are built in the software application. Alternatively, the spectrum function can be specified by the user.

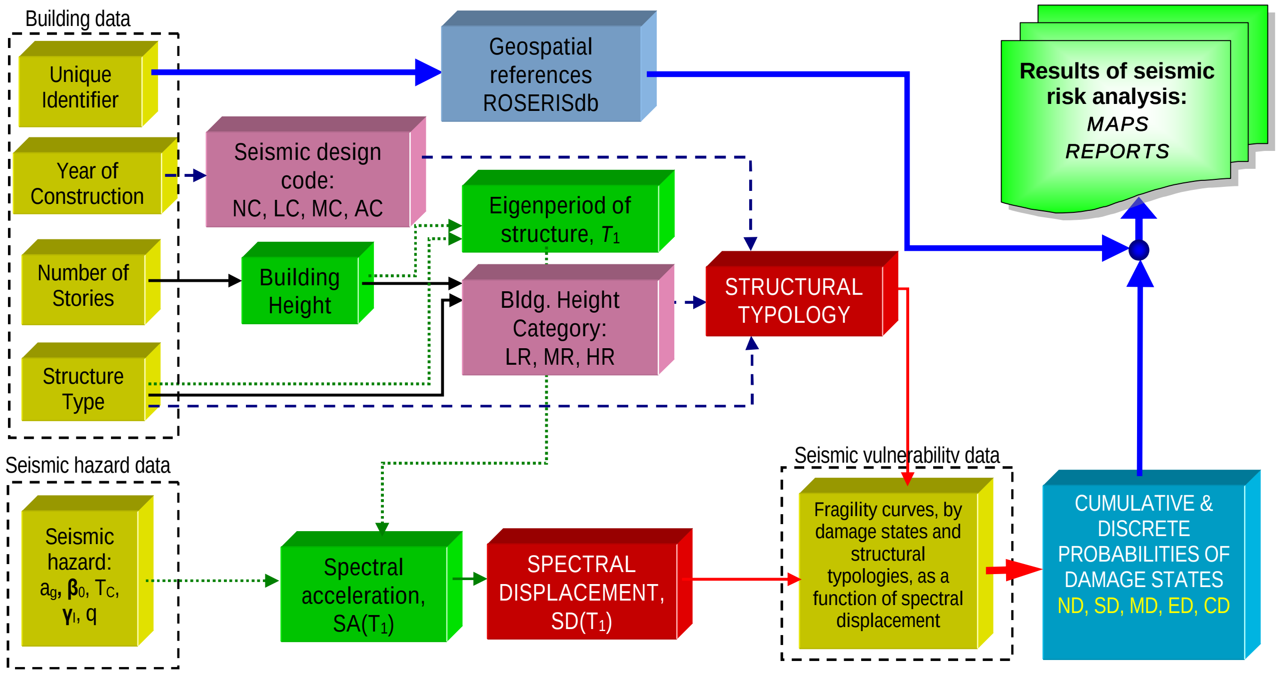

Figure 2. Flowchart of the seismic risk assessment methodology implemented in the ROSERIS platform

3.3. Intermediate Processing. Determination of Key Attributes of Buildings

In the phase of intermediate processing, the two key attributes of buildings, structural typology and spectral displacement, are determined.

The structural typology categories are established according to the proposal in the RISK-UE project (RISK-UE, 2001-2004). For the determination of structural typology, the seismic code used for the design of the building is first determined, based on the year of construction, according to Table 1. The years in the table are specified according to the timeline of seismic design code development in Romania.

Table 1. Classification according to year of construction

Year of construction	Seismic code category	Description
<= 1963	NC	No Code
1964…1977	LC	Low Code
1978…1991	MC	Moderate Code
>= 1991	AC	High Code

The building height category (low-rise, LR, medium-rise, MR, and high-rise, HR) is then determined based on the number of stories, correlated with structure type.

Finally, the structural typology is determined based on structure type, building height category and code level category. The construction of the structural typology code, based on the codes of the basic attributes is exemplified in Table 2.

Table 2. Construction of the structural typology code

Structure type	*Building height*	*Seismic code level*	*Typology*
M1.1	LR	NC	**M1.1-LR-NC**
M3.1	LR	LC	**M3.1-LR-LC**
S2	MR	MC	**S2-MR-MC**
RC3.1	HR	AC	**RC3.1-LR-AC**

The second key attribute is spectral displacement. In order to calculate it, the fundamental period of the building, T_1, is first computed, by using the approximate formula provided by the P100-1/2006 code:

$$T_1 = C_t \cdot H_C^{3/4}, \tag{3.1}$$

where H_C is the building height and C_t is a coefficient depending on structure type.

Then, by using formula (3.2), the spectral displacement, in centimetres, is obtained.

$$SD(T_1) = c(T_1) \cdot q \cdot \left(\frac{T_1}{2\pi}\right)^2 \cdot SA(T_1) \cdot 100\,. \tag{3.2}$$

In the above formula, q is the behaviour factor, $SA(T_1)$ is the design acceleration spectrum, and $c(T_1)$ is a coefficient, determined according to the prescriptions of the P100 code, as a function of T_1 and T_C.

$$1 \le c(T_1) = 3 - 2{,}5\frac{T_1}{T_C} \le 2\,. \tag{3.3}$$

3.4. Assessment of Seismic Structural Vulnerability

The building vulnerability functions describe the conditional probability of being in, or exceeding, a particular damage state, *ds*, given the spectral displacement, S_d, and are defined, according to (FEMA, 1999a), as:

$$P\left[ds \middle| SD(T)\right] = \Phi\left[\frac{1}{\beta_{ds}} \ln\left(\frac{SD(T)}{\bar{S}_{d,ds}}\right)\right] \tag{3.4}$$

where

$\bar{S}_{d,ds}$ is the median value of spectral displacement at which the building reaches the threshold of the damage state, *ds*,

β_{ds} is the standard deviation of the natural logarithm of spectral displacement for damage state *ds*, and

Φ is the standard normal cumulative distribution function.

Building vulnerability functions are provided, for different building typologies, based on previous studies of the university members of the project team (Lungu et al., 2002, Vacareanu et al., 2002a and 2002b) and on the specifications of the HAZUS methodology. The values of the parameters of the building vulnerability functions are implemented in the software module dedicated to seismic risk assessment, EVARISX.

Figure 2 shows an example of building vulnerability function used in the methodology, for reinforced concrete structures.

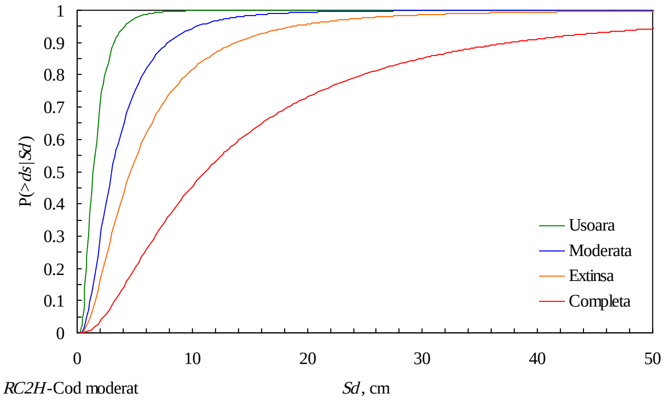

Figure 3. Example of a building vulnerability function determined for reinforced concrete structures

3.5. Risk Analysis

The structural typology and the spectral displacement are used as input parameters with the building vulnerability functions, in order to determine the probabilities of the buildings of being in one of the following damage states: ND (no damage), SD (slight damage), MD (moderate damage), ED (extended damage) and CD (complete damage).

Based on the above probabilities, *P*, a mean damage ratio is computed as:

$$GMA = 0\times(1-P_{SD})+1\times(P_{SD}-P_{MD})+2\times(P_{MD}-P_{ED})+3\times(P_{ED}-P_{CD})+4\times P_{CD} \tag{3.5}$$

The significance of the values of GMA, along with the corresponding color coding used on the maps, are shown in Table 3.

Table 3. Significance and color coding of GMA values

GMA	State of the structure	Colour
0…0.5	No Damage	White
0.5…1.5	Slight Damage	Green
1.5…2.5	Moderate Damage	Yellow
2.5…3.5	Extended Damage	Orange
3.5…4.0	Complete Damage	Red

Output data is written in the ROSERISdb geodatabase. Using the GIS-ROSERIS application, both input and output data can be visualized as maps and reports.

4. SOFTWARE IMPLEMENTATION

The structure of the platform consists of a core GIS application (GIS-ROSERIS), which is able to perform both the management of own built-in modules and the launching of two “satellite” applications, MAGDA and EVARISX. These applications can either be launched by the core GIS application or they can be run independently on any computer, without requiring the installation of other platform components. The feature is aimed to ensure maximum flexibility in performing various operations on different computers, in order to allow contributions from multiple operators.

The application for building stock data collection and management, MAGDA, was developed for creating and editing records in the ROSERISdb database. In the first phase of data collection, MAGDA can be used by different operators, which are not necessarily instructed in the use of the entire ROSERIS platform. Only basic computer knowledge is required for these operators, whose role is to collect and transmit data to the central operator. Figure 4 shows one of the screenshots of the MAGDA application.

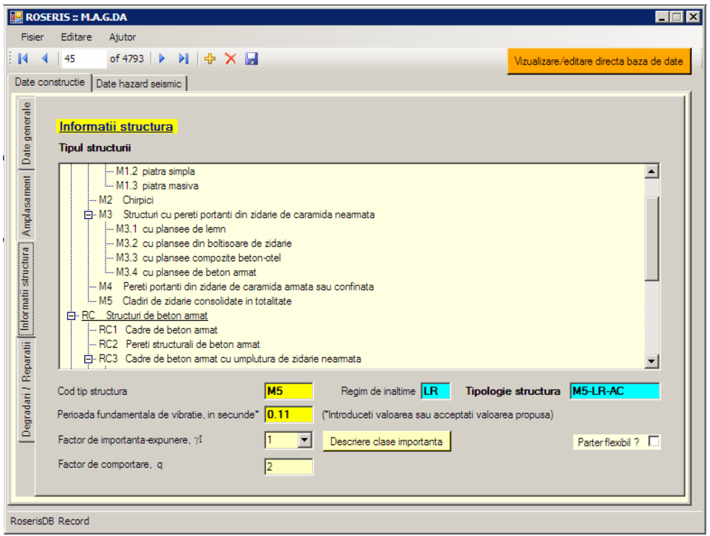

Figure 4. Screenshot of graphical user interface of MAGDA application

As mentioned before, besides data collection and editing, MAGDA also performs some preliminary data processing, in order to determine the building typology and the fundamental period, T_1. Obtained values are stored in the ROSERISdb database.

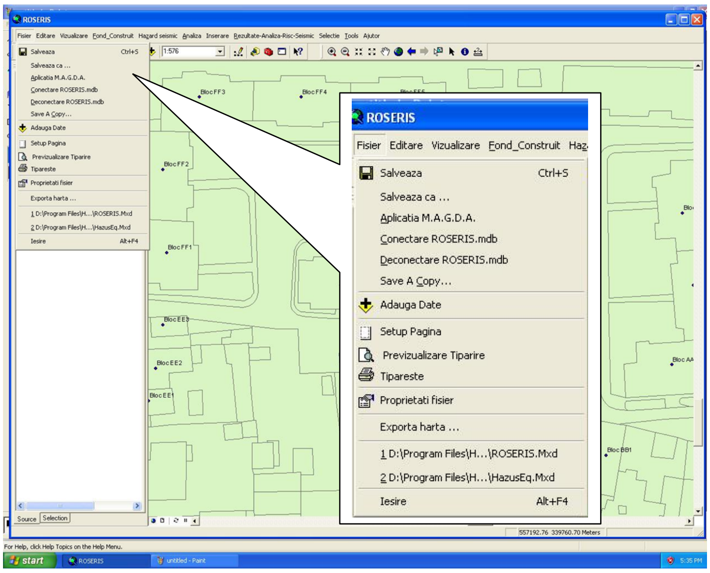

Figure 5. Screenshot of the GIS-ROSERIS core application

The EVARISX application performs the final calculations of the seismic risk analysis, obtaining the probabilities for damage states and the mean damage ratio. Resulted values are stored in the ROSERISdb database. EVARISX provides also the capability of viewing and editing the records in the database.

The GIS-ROSERIS application, based on the use of the ESRI ArcView software, allows the generation of maps and reports for all significant input and output data of the analysis, allowing a thorough and accurate understanding of the results. This capability is probably one of the most important component of the interaction and communication between scientists and decision makers. The graphical user interface of the GIS-ROSERIS application is shown in Fig. 5.

5. PLATFORM TESTING

The ROSERIS platform was tested on a study zone in Bucharest, chosen for the diversity of the building stock and also for being considered as representative for the building stock in Romania. Data for a number of 80 buildings was collected and introduced in the ROSERISdb geodatabase by using the MAGDA application. The seismic risk analysis was performed with EVARISX, and results were displayed by using the GIS-ROSERIS application. The testing of the platform provided essential information for improving its functionality. Some maps generated for the study zone by using the ROSERIS platforms are shown in Fig. 7.

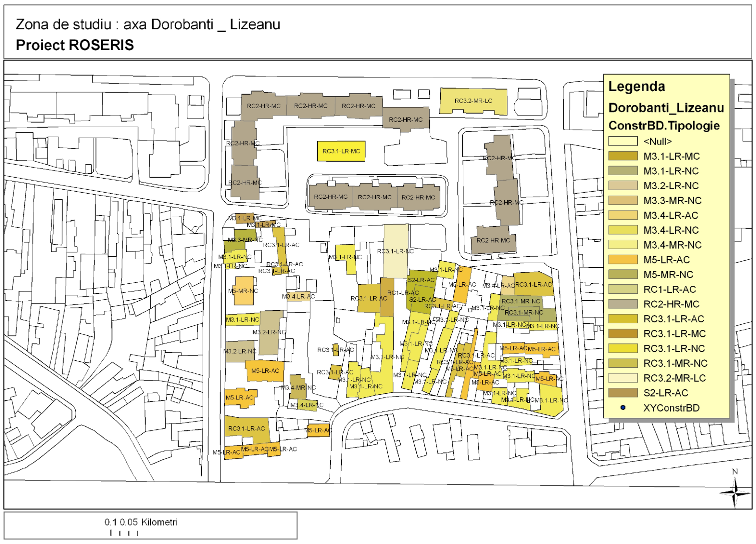

Figure 6. Map of structure typology in the study zone, generated using the ROSERIS platform

Figure 7. Map of mean damage ratio in the study zone, generated using the ROSERIS platform

6. CONCLUDING REMARKS

The ROSERIS software platform provides a basic tool for the assessment of seismic risk. In the present phase of development, the methodology uses a simple approach, being focused on general building stock and on damage directly caused by earthquake. Also, seismic hazard is defined in a simplified manner. The structure of the methodology is adapted to the seismicity of the country, building stock characteristics and national and European regulatory context. The functionality of the platform allows an efficient work procedure, by de-coupling the operations of data collection, analysis and presentation.

The main advantages of the ROSERIS platform reside in the simple and robust seismic risk assessment methodology, compatible with European standards, and in the capacity of providing intuitive representations of the spatial distribution of significant input and output characteristics.

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