Expert system for seismic vulnerability assessment of masonry structures

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ABSTRACT: Possible method for seismic vulnerability assessment of masonry structures with special attention to low-rise residential structures in Macedonia is proposed in this paper. For this purpose, special calculation tool which contains specific knowledge for masonry structures derived by numerical calculations and analyses is developed. The aim of this assessment tool is to be simple for application even for personnel with slight or no experience in behaviour of masonry structures under seismic action, so it could be developed as a serious system for fast and precise assessment of the condition of many structures in a wide region. In this paper, a numerical model for calculation of the bearing capacity of the structure based on the discrete element method is suggested, so that it is first application of this relatively new numerical technique for calculation of masonry in Macedonia. A method for creation of the knowledge base for an Expert System suggested by the given methodology is presented. Also, results from the application of this methodology are applied on a real structure.

1 INTRODUCTION

The aim of this paper is development of a Expert System which will enable fast and precise seismic vulnerability assessment of existing masonry structures and will provide data for predicting the damage of masonry structures under influence of earthquakes with given intensity. The Expert System is a tool for accurate seismic vulnerability assessment of masonry structures based on a numerical analysis model which includes nonlinear behaviour of masonry and takes into account nonlinear bearing reserves of masonry. Due to the complexity and the different geometric and material parameters, the Expert System contains several databases that include capacity and seismic demands for the most common layouts of low-rise residential masonry buildings, typical for Macedonia and Balkan region. For the purpose of development of an Expert System, Exsys CORVID shell was used. (Exsys CORVID 2004).

2 THE BASICS OF EXPERT SYSTEMS

Expert System is a computer program which emulates mutual conversation of one human to another, expert in specific domain, who asks for advice or recommendation from the human expert in order to solve particular problems. This new approach is promising, especially in structural analysis of masonry structures, where often one can make a decision which is not based on analytical models, but only on experience and intuition of the engineer involved. Many expert systems are not complex or difficult to build. In a very simple case, consider a tree diagram on paper describing how to solve a problem. By making a selection at each branch point, the tree diagram can help someone make a decision. In a sense, it is a very simple expert system. This type of tree structured logic can easily be converted to a computerized system that is easier to use, faster and automated. More elaborate systems may include confidence factors allowing several possible solutions to be selected with different degrees of confidence.

Expert systems can explain why data is needed and how conclusions were reached. A system may be highly interactive (directly asking the user questions) or embedded where all input comes from another program. The range of problems that can be handled by expert systems is vast.

Expert systems can be developed with Expert System Shells. An expert system shell is a software programming environment which enables the construction of expert or knowledge based systems. Expert systems software can be developed for any problem that involves a selection from among a definable group of choices where the decision is based on logical steps. Any area where a person or group has special expertise needed by others is a possible area for an expert system. Expert systems can help automate anything from complex regulations to aiding customers in selecting from among a group of products, or diagnosing equipment problems.

Traditionally expert system development has been a major expense both in time and money. Getting even a single system built was a big project. The cost of system development prohibited building expert systems on more than a few projects. The key to implementing expert systems widely, effectively and at low cost is to have easy-to-use expert system development tools readily available to the experts. As more power is needed for certain applications, higher level tools...
can be used with advanced features to give you complete control over the inference engine, modularization of the knowledge base, flow of execution, the user interface and integration with other programs.

Expert systems have several advantages and disadvantages. Among the advantages, the following are most important:

- **Permanence** – Expert systems do not forget, but human experts may.
- **Reproducibility** – Many copies of an expert system can be made, but training new human experts is time-consuming and expensive.
- **Efficiency** – Can increase throughput and decrease personnel costs. Although expert systems are expensive to build and maintain, they are inexpensive to operate. Development and maintenance costs can be spread over many users. The overall cost can be quite reasonable when compared to expensive and scarce human experts.

- **Consistency** – With expert systems similar transactions handled in the same way. The system will make comparable recommendations for like situations.

- **Humans** are influenced by recency effects (most recent information having a disproportionate impact on judgment) primacy effects (early information dominates the judgment).

- **Documentation** – An expert system can provide permanent documentation of the decision process.

- **Completeness** – An expert system can review all the transactions, a human expert can only review a sample.

The most important disadvantages of expert systems are:

- **Common sense** – In addition to a great deal of technical knowledge, human experts have common sense. It is not yet known how to give expert systems common sense.

- **Creativity** – Human experts can respond creatively to unusual situations, expert systems cannot.

- **Learning** – Human experts automatically adapt to changing environments; expert systems must be explicitly updated. Case-based reasoning and neural networks are methods that can incorporate learning.

- **Sensory Experience** – Human experts have available to them a wide range of sensory experience; expert systems are currently dependent on symbolic input.

- **Degradation** – Expert systems are not good at recognizing when no answer exists or when the problem is outside their area of expertise.

When the rule set for an expert system is written, the knowledge of humans is observed. Video tapes, interviews, protocol, and other techniques are used to try to capture the thought process of experts. A problem with expert systems is writing the rules themselves. Thought processes that are highly rule-oriented are easier to write than ones that rely more on creativity or intuition. Another problem is that often experts themselves disagree. Different experts might take different courses of action or go through different thought processes when given the same problem to solve. Thus there is disagreement in the professional community about the validity of expert systems.

Expert systems are improving as technology advances. In the past, expert systems have received criticism and some negative publicity because of the failures that were highly publicized. Unfortunately, the successes are less publicized, because companies want to maintain their competitive edge. It is important for companies to remember, however, that humans should make the final decision, and not the computer. Humans still have the insight and intuition that computers are unable to possess—now anyway.

### 3 METHODOLOGY FOR DEVELOPMENT OF EXPERT SYSTEM KNOWLEDGE BASE

Figure 1 presents the suggested methodology for development of Expert system knowledge base for seismic vulnerability assessment of masonry structures that corresponds to the core of the system and without it the expert system would not operate. It contains three major branches which determine Capacity, Demand and Damage of the building.

Seismic vulnerability assessment of a structure is determined by a seismic capacity coefficient, defined as a ratio of Capacity to Demand. The limit value of seismic capacity coefficient is 1.0 and the values greater than the limit value define a vulnerable structure which cannot withstand and transfer the seismic loads.

All needed data is stored in databases and communication between the expert system and the databases is obtained by using the expert system shell options for connecting the rules with the data.

#### 3.1 Capacity of the building

In order to determine the capacity of a building to resist seismic action, in earthquake engineering it is presented by a capacity curve. To express the capacity of any structure, several assumptions should be made:

- **Regular layout in ground and elevation plan.** It supposes continuous shear walls over the height of the building, so one can assume failure mechanism in the ground floor.

- **Floor slabs are assumed as rigid horizontal diaphragms,** while masses are concentrated at the floor slab levels.

- **Stiffness of out-of-plane walls is not taken into consideration,** it is assumed that they transfer the loads in their own plane only.

- **Torsion effects are not included into calculations.**

According to the previous assumptions, one can make a conclusion that it is necessary to determine the Capacity Curve of the ground floor only, since the
rest of the floors behave in linear elastic manner. The Failure mechanism of the ground floor is presented in Figure 2.

In order to calculate the capacity curve of the ground floor it is assumed that floor slabs act as rigid horizontal diaphragms which transfer the horizontal loads caused by earthquake actions onto the walls.

This methodology suggests numerical calculation of capacity curves by discrete element method and application of the software UDEC (UDEC, 2005). Hence, to obtain the capacity curves database which is a component of the Expert system, it is necessary to take into consideration different wall geometries, materials and different vertical loads. According to this, it is required to perform numerical analysis for all possible combinations of wall data and loads and to create the knowledge database.

3.2 Seismic demand of the building

For the purpose of seismic vulnerability assessment of a masonry building, one should determine the second key element, namely seismic demand. This methodology proposes calculation of the seismic demand by 3 different techniques that prescribe the maximal horizontal force which should be resisted by the masonry structure:

- Seismic design force according to Macedonian regulations for Seismic design of structures;
- Dynamic analysis (seismic force calculated by time-history analysis); and
- Capacity spectrum method.

The knowledge base of the Expert system allocates tabular data for equivalent horizontal seismic forces in
dependence on soil conditions and earthquake intensity according to MCS. Also, it is supposed to generate seismic demand database which will contain the total seismic force calculated as base shear reactions for specific earthquake records and the adopted ground plans. As typical earthquake records El Centro (1940), Petrovac (1979) and Bitola (1994) earthquake records are used.

Numerical calculations are performed by the program Robot Millennium (Robot Millennium User’s Manual, 2007) by applying linear dynamic time-history analysis. On the other hand, the Capacity spectrum method as a technique for seismic evaluation is not included in the expert system, but some other calculation tools like M-DESIGN use it. In this paper, a comparison of the results obtained by the suggested methodology and the program M-DESIGN is presented.

4 APPLICATION OF THE SUGGESTED METHODOLOGY TO A TYPICAL BUILDING IN MACEDONIA

The suggested methodology for development of the Expert system knowledge base and the suggested methods to obtain the capacity of the building and the seismic demand are applied to a masonry structure characteristic for the period from the beginning of 20th century in urban areas in Macedonia with an assumed earthquake scenario, i.e. seismic action.

The building under investigation is a typical structure for the wider surrounding of the city of Gevgelija, built in 1928. The structure has basement, ground floor and one floor, so it is classified as low-rise building. Total building area is 240 m², while available net area is 183.65 m². The building has suffered moderate damage after Gevgelija earthquake on December 21, 1990 with magnitude of 5.6 and intensity according to MCS VII-VIII. This earthquake has caused damage on the structural systems of approximately 1,120 buildings in the surrounding area.

Figure 3 presents the layout and geometry data of the ground floor of the building under consideration. The footings and the basement walls are made form limestone and lime mortar. The walls on the first floor are constructed from solid clay bricks and lime mortar. Two partition walls on the first floor are made from adobe bricks in wooden “bondruk” system. The floor slabs are made from timber beams simply supported on the masonry walls. The floors in the ground floor are concrete with timber flooring and on the first floor with parquet.

4.1 Capacity curve and seismic demand of the building

After performing numerical calculations by the discrete element method and the software UDEC, the capacity curves for all individual ground floor walls are obtained. Since the walls which spread with their planes in X direction define the weaker direction of the building, only ground floor walls in direction X are taken into account. Figure 4 shows the capacity curves of the individual ground floor walls and the total capacity curve of the ground floor which is derived by simple superposition of the capacities of individual walls.

In order to obtain the ultimate values for the total seismic force calculated from real earthquake records, a linear dynamic time-history analysis by finite element method is performed. The calculated period of free un-damped vibrations is $T_1 = 0.103$ sec. The maximal accelerations of the used earthquake records are scaled from 0.1g to 1.0g.

Figure 5 presents a comparison diagram of the building capacity and seismic demand for the seismic force obtained by different analysis techniques and earthquake records. From the obtained results it is obvious that the building has sufficient capacity compared to the total seismic force calculated by Macedonian regulations, as well as by time-history analysis with un-scaled earthquake accelerations of El Centro (0.3 g), Petrovac (0.4 g) and Bitola (0.23 g).

If the capacity of the building is expressed by the value of the force that determines the beginning of the
nonlinear range (C), for X-direction $\sim 800$ kN, and the seismic demand (D), one can obtain the value for the seismic capacity coefficient ($r_c$). The following table summarizes the values for the seismic capacity coefficient obtained by calculations of the ratio of Capacity over Demand.

Until the value for the seismic capacity coefficient is greater than 1.0, the structure is assessed as with sufficient vulnerability and has strength to withstand the seismic forces. According to this, the limit values for different earthquake intensities are denoted in bold.

From the aforementioned, one can make a conclusion that the building will suffer some structural damage under El Centro 0.3g, but it will survive total collapse of the structure. The same result applies for the other two earthquakes Petrovac (0.4 g) and Bitola (0.23 g).

For validation of the suggested methodology for seismic vulnerability assessment of masonry structures used in the presented Expert system, a Capacity spectrum method was used. Therefore, program M-DESIGN was used to calculate the structure behavior according to capacity spectrum method. As input data the program uses the same capacity curves for the individual walls. In order to calculate the seismic load, elastic spectra definition as proposed in Eurocode 8 was applied. The calculation of the Performance point for the example building as defined in the capacity spectrum method is presented in Figure 6.

Table 2 summarizes the position of the Performance point and calculated period of free un-damped vibrations of the building. The conclusions obtained with M-DESIGN and Capacity spectrum method are listed as follows:

Ultimate limit state results:
- Bearing capacity of the building is satisfied
- Seismic actions do not cause structural damage on the building
- Expected Damage grade according to EMS98 is I
- Ultimate limit state is proved

Ultimate serviceability state results:
- Maximal displacement on wall 5 is 0.039 cm
- Calculated floor displacement is $0.039 \text{ cm} \times 0.4 = 0.016 \text{ cm}$
- Allowable floor displacement is $0.0075 \text{ cm} \times 245 \text{ cm} = 1.838 \text{ cm}$
- $0.016 \text{ cm} < 1.838 \text{ cm}$

The results obtained by using the Capacity spectrum method are close to the results obtained by the suggested methodology in the Expert system. The stability of the structure is proved and according to the suggested concept it has sufficient stability with occurrence of no structural damage. This is also proved by M-DESIGN where the structure is classified with I damage grade according to EMS 98.
4.2 Screen shots of the developed Expert system

REFERENCES


