



Knowledge base for evaluation of seismic vulnerability of unreinforced masonry buildings - UMDAS

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ABSTRACT

An application of expert systems in earthquake engineering, is proposed in this work. The designed knowledge base UMDAS[1] (acronym of Unreinforced Masonry Damage Analysis System) enables evaluation of damage of existing unreinforced masonry buildings due to the given earthquake. VP-Expert[2] shell was used as software base for designing of the expert system. Procedure offered in FEMA-178[3] was used to define particular building's quality and relations, Damage Factor - Earthquake Intensity, defined by Stojanovski et al.[4] make possible evaluation of physical damage due to the given earthquake.

INTRODUCTION

Countries and regions with a high seismic risk devote substantial resources to mitigate the seismic risk posed by existing buildings. Meeting this goal requires existence of relatively quick, formalized consistent and reliable procedure for seismic vulnerability evaluation of existing structures. It is obvious that the opinion of an expert in the field of earthquake engineering is desirable during such evaluation. Consideration of the great number of structures which need such evaluation in a particular region, reveal how inappropriate that would be. An expert system, artificial intelligence tool, which is a knowledge-based program that provides "expert quality" solution to problems in a specific domain, could be a successful solution to this problem.

There are significant number of masonry structures in almost every country and great deal of them were built before the existence of the seismic regulations. That makes them especially sensitive to the ground motions and their strengthening absolutely necessary for seismic risk mitigation. Before defining the strengthening measures, their seismic vulnerability evaluation



is desirable. That is the purpose of a knowledge base for damage evaluation of existing unreinforced masonry buildings proposed in this paper.

METHOD FOR DAMAGE EVALUATION

In principle, physical damage is evaluated by two different types of methods: mechanistic (building specific or micro scale) methods and statistical or empirical (macro scale) methods. The former are still in a phase of rapid development, they require detailed knowledge of building specific information (material, mechanical, and physical properties, structural configuration, structural detailing etc.) and site specific information (knowledge of the potential earthquake sources, site to source distance, maximum expected magnitude, recorded or synthetic accelerograms etc.). Latter are generally based on actual post event or empirical damage statistics, they operate with relatively little specific information about the building under consideration. Often, development of these methods has been based on expert's knowledge and/or statistics of expert's assessment and classification of damage, recorded after a given size earthquake. This paper proposes method which synthesize the two methods mentioned above. It is an attempt to use expert's knowledge and/or statistics considering some of the building's characteristics which define it's response to the ground motion.

Damage is measured by means of a damage factor (DF) which relates the physical damage with the replacement value of the building, equation (1).

$$\text{Damage Factor (DF)} = \frac{\text{Physical Damage}}{\text{Replacement Value}} \quad (1)$$

In the project ATC-13[5] Damage Probability Matrices (DPM) for 78 structural types have been determined. In the DPM format, damage to facilities for a given shaking intensity is described by a series of damage states. Each number in the matrix represents the probability that a particular damage state will occur for a given shaking intensity, the Modified Mercalli Intensity scale was chosen as the indicator of earthquake shaking intensity.

As an attempt to consider specific characteristics of the buildings Stojanovski P. et al.[4] have proposed further classification of the buildings of every structural type in three subclasses considering their design and construction quality *less-than-average*, *average* and *better-than-average*. In their study damage factors were assumed to be discrete random variables with probabilities as given in the DPM mentioned above. The first two statistical moments of the DF were used in order to separate DF values for the three subclasses. The DF values for the three grades were computed by the h-sigma bounds of the DF. These bounds are defined as a range between the mean plus-and-minus "h" standard deviations of the DF (Figure 1).

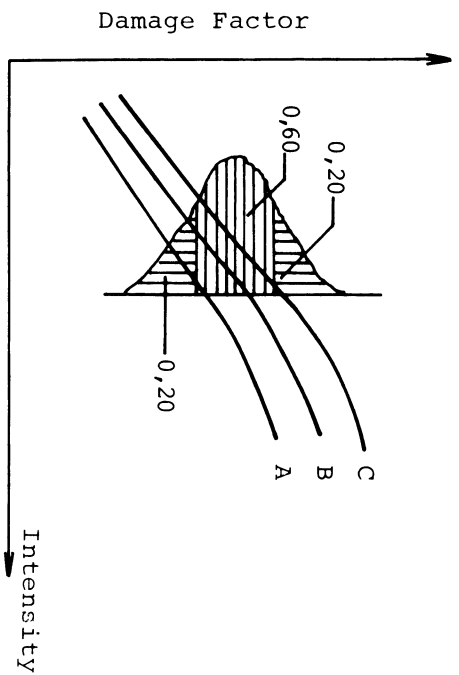


Figure 1: h-Sigma Bounds for the Damage Factor

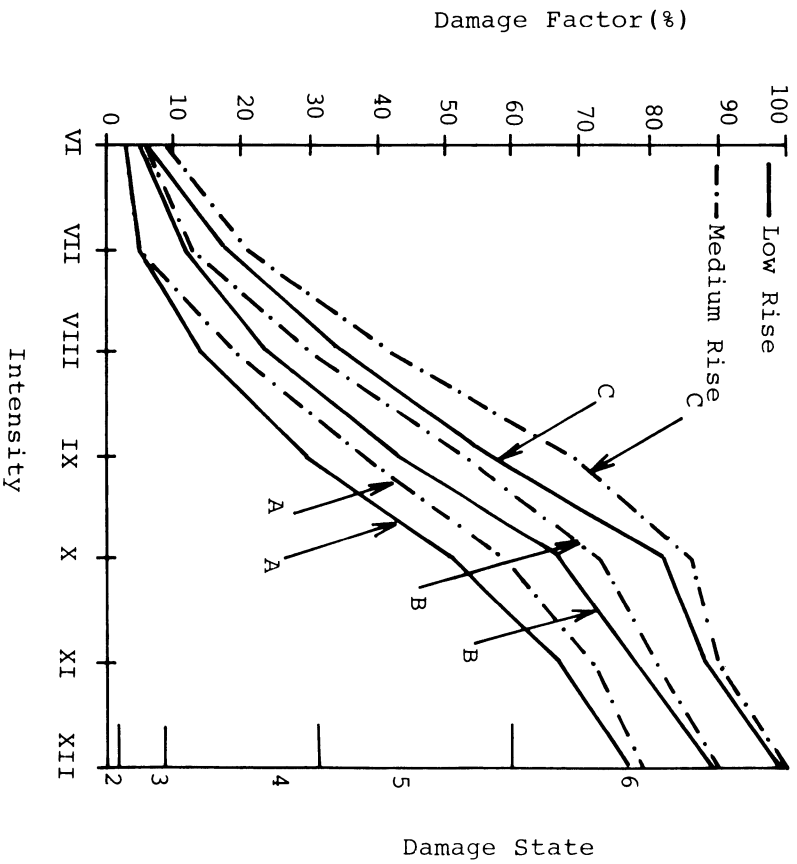


Figure 2: Damage Factor - Intensity Relations for URM Buildings



They defined such relations for 78 structural types, two of them are included in the knowledge base UMDAS - unreinforced masonry (URM) low and medium rise buildings (Figure 2).

Classification of individual URM buildings

The above relations can be used on particular URM building if it's design and construction quality is already known. Procedure offered in FEMA-178[3] was used to define the design and construction quality of particular URM building. The methodology proposed in this reference suggests checking building's characteristics which define it's response to the ground motions. These characteristics are selected in four groups; Building Systems, Masonry Walls, Diaphragms and Connections.

In the first group, checking existence of weak story, soft story, significant geometrical irregularities, significant mass irregularities, vertical discontinuities, torsion, adjacent buildings, masonry units deterioration and masonry joints is suggested. In the second group shearing stress and height-thickness ratio of the infill wall panels are checked. In the third group plan irregularities, reinforcing at openings, span-depth ratio and sheathing are controlled. And in fourth group masonry wall anchors and anchor spacing are controlled.

For carrying out the shearing stress check, ultimate shear capacity of bearing walls is determined according to Toma-zevic[6]:

$$V_u = 0.9 A \frac{f_{wt}}{\xi} \sqrt{\frac{\sigma_o}{f_{wt}} + 1} \quad (2)$$

V_u - ultimate shear capacity of the wall

σ_o - average compressive stress due to vertical load

f_{wt} - tensile strength of the masonry wall

A - horizontal cross-sectional area of the wall

ξ - shear stress distribution factor which depends on the height/length ratio of the wall and eccentricity of vertical load

So determined capacity is related to the demand, defined by actual provisions for seismic design, and earthquake capacity ratio is calculated:

$$r_c = \frac{C}{D} \quad (3)$$

where C is capacity and D demand. Considering the fact that most of those buildings were build before the existence of such provisions it si unrealistic to expect that this ratio could be greater then 1.0 . This is discussed in ATC-3-06[7] report, and the following values for " r_c " are suggested, Figure 3.

According to all mentioned above the following procedure for classification of individual URM buildings is proposed:

1. Checking building's characteristics which define it's response to the ground motions.
2. Defining earthquake capacity ratio " r_{cw} " for each bearing wall, on every floor.
3. Defining floor's earthquake capacity ratio " r_{cf} " for every floor, as relation of capacity of all bearing walls on the floor and floor's demand.
4. Defining structure's earthquake capacity ratio " r_c " as the smallest floor's earthquake capacity ratio " r_{min} ".
5. The structure has *less-than-average* design and construction quality (C), if some shortages have been detected and/or structure's earthquake capacity ratio $r_c < 0.5$.
6. The structure has *average* design and construction quality (A) if no shortages have been detected and structure's earthquake capacity ratio is $0.5 < r_c < 0.75$.
7. The structure has *better-than-average* design and construction quality (A) if no shortages have been detected and structure's earthquake capacity ratio is $r_c > 0.75$.

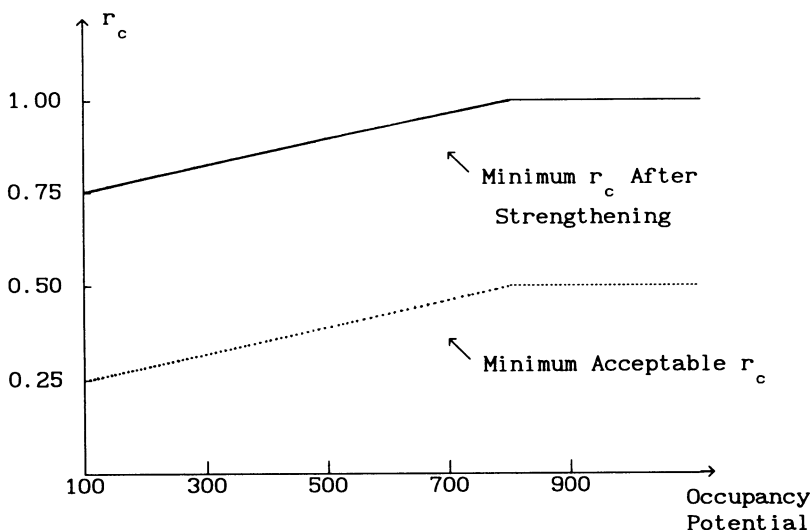


Figure 3: Strengthening requirements for buildings



KNOWLEDGE BASE STRUCTURE

VP-Expert[2] shell has been used as software base for designing of the knowledge base. VP-Expert is a rule-based expert system shell and rules, stated as *if....then....* propositions, contain the actual "knowledge" of the knowledge base. The expert system efficiency depend on the configuration and systematization of the knowledge in the knowledge base. Structure of the UMDAS knowledge base is branchy. The final goal and the main path to it is the trunk of the base, variables on the main trunk are determinated on their own paths which are the branches of the structural tree, variables on this branches have their own branches and so on. Such configuration of the knowledge base enables replacement of one part of the file without making any changes in the other parts. This capability make the process of innovating and extending the knowledge base with the state of the art information simple and efficient.

Characteristics of the VP-Expert shell

A knowledge base file contains three basic elements; the "actions" block, rules and statements. The "action block tells the inference engine what it needs to find out, and in what order. Rules consist of rule premise and rule conclusion. The rule premise is where one or more (up to 20) conditions are stated, conditions can be combined with logical operators "and" and "or". Whereas rules contain the "expertise" of the knowledge base, statements generally contain information pertinent to the consultation itself.

The problem-solving method used by the VP-Expert inference engine is called "backward chaining". The inference engine starts by identifying the goal variable and then moves through a sequence of rules until it finds a value that can be used to assign a value to the goal variable. Whenever the inference engine can't find the conclusion of a rule, it looks for the variable in an "ask" statement. "Ask" statements are used to prompt the user for information not contained in the knowledge base. Once a value is known, the inference engine can retrace its steps and test the rules that provided its original path.

One of the VP-Expert advantages is it's ability to ask why some question is being asked, and how a value was assigned to a given variable. This enables the user to follow the solving path and to be certain about the validity of the solution. It's another outstanding feature is the ability to call external programs. This capability allows VP-Expert to perform the functions and operations of other software. This opportunity was used and knowledge base UMDAS during the consultation call an external program, WALL, which enables running all necessary calculations. WALL is a program in FORTRAN, originally written for this purpose. The number of rules in one file of the knowledge base is limited, but the possibility to chain several fi-

les in one totality enables create a knowledge base with a significant number of rules. Knowledge base UMDAS consists of three files.

CONSULTATION PROCESS

The process of consultation consists of asking and answering questions. The user must answer a particular number of questions, giving necessary information about the building under consideration. There are two types of questions; one type are the question which are accompanied by two or three offered answers, so the user could chose one of them, another type, without offered answers so the user must type the answer. During the consultation user can ask why some information is requested, this enables following the reasoning logic (see Figure 4).

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[ KBS: UUMDAS1 ]
Is any of the shear walls discontinuous from the
foundation to the roof ?

Yes                               No

[ WHY ]
The question is being asked because:

if a discontinuous shear wall exists , the shear at the
level of discontinuity should be transferred  to another
shear resisting element that does extend to a lower level .

(Press Any Key To Continue)

1Help      2How?      3Why?      4Slow      5Fast      6Quit
Ask why a question was asked

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Figure 4: Illustration of the consultation process

All this information are checked according to the rules in the knowledge base and as a result of this consultation the user receive messages about the detected shortages, concerning seismic resistance of the building. All those return information could be helpful in the process of determining the strengthening measures.

In the end of the consultation, building design and construction quality and corresponding probable damage due to the given earthquake are presented. The value of the probable damage compared with the cost of the strengthening measures could be an indicator of economical justification of this measures.



CONCLUSIONS

Using expert system as a artificial intelligence tool, relatively quick, formalized, consistent and reliable procedure for damage evaluation of existing unreinforced masonry buildings due to given earthquake is proposed in this paper. This tool could be especially effective if it is used during evaluation of seismic vulnerability of existing buildings in a wide region as a part of a general program for seismic risk mitigation.

It must be mentioned that the Damage Factor - Earthquake Intensity relations for the certain region have to be developed and included in the knowledge base. UMDAS-knowledge base structure make the process of its own extension simple and efficient.

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