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An expert system for the earthquake-resistant design of buildings

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ABSTRACT: The paper presents ERDES, an Earthquake-Resistant Design Expert System. The main goal of ERDES is to determine the required improvements to the configuration and size of the structural system of the building towards increased safety and economy. ERDES has two main functions: synthesis/solution generation and analysis/evaluation. Both functions are based on a diagrammatic knowledge representation that contains several rule-bases and individual knowledge frames. The inference engine calls the appropriate diagram for the problem at hand and generates or evaluates a solution. The above knowledge is based on the Greek and European Aseismic codes (EC8), and on design rules from engineering practice. The paper shows that the ERDES expert system offers the engineer a new tool for an improved and cost-effective aseismic design of buildings.

1 INTRODUCTION

It is well known that a better configuration of the elements of the structural system leads to an improved behaviour of a building during a strong earthquake, much more than a detailed dynamic analysis of its abstract mathematical model, and more so, if this model is not based on such a good configuration. Recently, the rational earthquake-resistant design of buildings is moving systematically towards this direction of selecting the right and most suitable structural system of a building with the aim of optimizing the seismic load resisting system.

This paper presents the research work of the authors in the NTUA on the development of an expert system that will assist engineers in the design of earthquake-resistant structures. The Earthquake Resistant Design Expert System, ERDES, determines the structural system of a reinforced concrete building that is most suitable for the aseismic behaviour of the building and which satisfies architectural, economical, and other constraints imposed by the designer. It is developed based on the requirements of the Greek and the new European Codes (EC8) in order to be usable in the long term by Greek and European engineers alike. ERDES is developed as a practical tool which supports the design of buildings based on the fundamental principles that control the seismic behaviour of structures. It aids the designer in selecting and optimizing the structural system of a building for an improved aseismic response of the building.

ERDES is a real design program and not just a consultative system. It runs on high-end personal computers because it is made with the purpose to work in everyday design practice and to help the engineer in the reality of earthquake resistant building design. Its main goal is to determine the required improvements to the configuration and size of the structural system of the building towards increased safety and economy. ERDES communicates with the engineer graphically, making design choices and showing alternative solutions in the form of graphical displays.

In the following, the paper starts with an overview of ERDES and its system architecture. It then proceeds to explain the main program components and its functions of synthesis and analysis. Finally, the paper describes the expert system's operation and its typical results.

2 OVERVIEW OF ERDES

The main objective of ERDES is the development of a program-expert consultant to the designer, civil engineer or architect, in the areas of aseismic design of structures. In the long run, the program can be used in every phase of the life cycle of a structure: preliminary design-conception, final design, construction, and operation. This aim is assisted with other smaller size modular expert systems which later on will be built-in or will cooperate with ERDES, as shown in Fig. 1. Such systems include MASCON (masonry aseismic design module) and DASCON (preliminary design module using architectural constraints) which are described elsewhere [1].

These other systems will be combined with ERDES using a model of cooperating expert systems, known as the MDS (Multi-Domain System) model, that has been developed by one of the authors [2]. The main features of MDS (Fig. 2) include:

- VI - a virtual user-system and system-system interface that provides for Inter-Process Communication.
- KR - several knowledge representation languages and techniques.
- IE - several inference engines that can be combined with the various KR techniques.
- DBM - a database manager that provides access to various databases.
- AM - an analytical/algorithmic model library that allows execution of different algorithmic programs.
- G/CAD - Graphics and Computer-Aided Design packages.
- R/C - Real-Time access of instruments, sensors, and control systems.

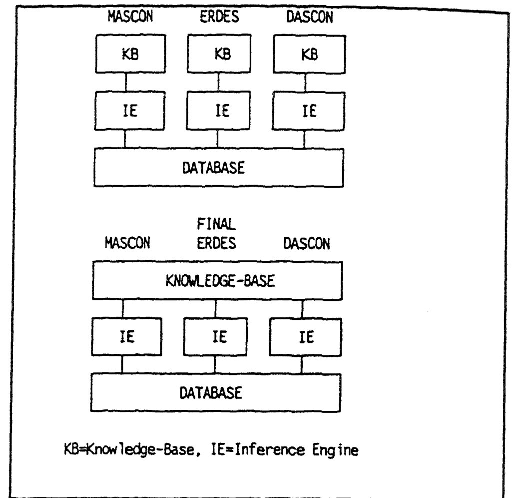

Fig. 1: Cooperation of ERDES with other expert systems

This general system architecture is based on a system communication protocol that has been successfully tried in other civil engineering applications and is now used for combining MASCON, DASCON, and other programs with ERDES, at a later stage. MDS allows for the different systems to be developed separately (even in different programming languages), tested independently, and later on combined together in a generic manner.

The main body of the ERDES program has already been developed by the authors [1,3,4], and concerns mainly the determination of the structural system of

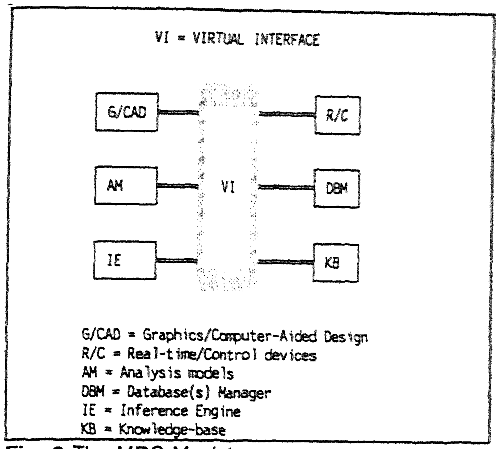

Fig. 2 The MDS Model

the building according to the principles of aseismic design.

Following the general expert system development method, a prototype-skeletal program was developed first, which includes the basic functions of ERDES, and a portion of its final knowledge-base. This allows testing of the system operation and of its assumptions. This ERDES prototype is developed in PROLOG, although it is envisioned that other modules could be developed in other languages.

3 SYSTEM FUNCTIONS

ERDES has two main functions: synthesis / solution generation and analysis / evaluation. The function of synthesis is the basic design function of the program and is applied during various stages of the building design to generate/propose solutions. The function of analysis comes in after the generation of a basic solution through synthesis. It evaluates the solution at hand which was derived by synthesis or proposed by the designer and gives several indicative measures of the aseismic behaviour as well as estimates of cost. In this way, the designer can assess the advantages of each solution and select the one which offers the best combination of cost and resistance to earthquake.

Each function can be executed independently of one another, during different stages of the building design. In this manner, when ERDES is being used in the preliminary design stage, synthesis proposes solutions and analysis evaluates them, whereas in the final design stage, or in the stage of checking an existing structure, synthesis is inactivated and only analysis/evaluation is used.

Both functions of the system, analysis and synthesis are based on a diagrammatic knowledge representation. The knowledge-base contains several rule-bases and individual knowledge frames, which correspond to various stages/levels of detail in the design process. Every level of detail is considered as a diagram of interrelated rule units each one of which solves a specific problem of design. Their interrelationships are expressed through a knowledge diagram (a frame). The inference engine calls the appropriate diagram for the problem at hand and generates or evaluates a solution. For the implementation of the above, ERDES is based on the Greek as well as the European Aseismic codes (EC8), but also on practical design rules from the experience of engineers in earthquake resistant design.

4 ERDES OPERATION

The operation of the system follows the sequence: (1) Data entry, (2) Solution, and (3) Evaluation. The user selects the corresponding functions with the help of menus, cycling through (1), (2), and (3) during the design of a given building. This is done by selecting from the menu options: "DATA", "SOLUTION", "ASSESSMENT", and "RESULTS".

The required data for the program are given by the

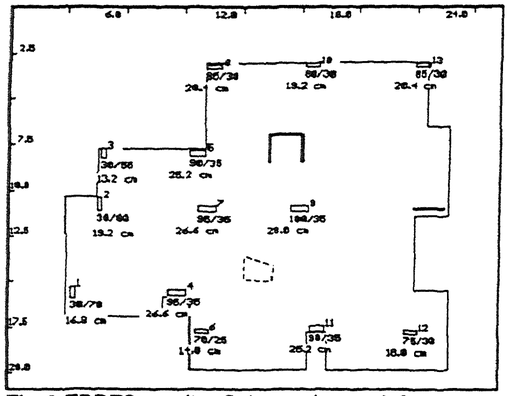

Fig.3 ERDES results: Column sizes, reinforcement (3rd floor of 8-story building)

option "DATA" and include general design information regarding number of stories, seismic coefficient, heights and types of stories, concrete strength, and story loads. Also, at this stage of development of the ERDES prototype, other data given to the system are the possible locations of columns by floor, the location of specified walls (e.g. elevator core), the plan outline, the outline of openings in the plan (e.g. stairways). All these data are given presently in the form of PROLOG facts using the program's editor from the system menu.

In addition, if the designer wishes so, ERDES can generate a basic structural system configuration by determining on its own the possible location of columns in the building plans based on architectural constraints. These constraints are the shape and size of the plan, the location of holes, of cores, and (if provided) the location and sizes of nonstructural walls in the building plan. Alternatively, the designer may change this basic choice of the system, or propose a configuration of his own. Presently, this capability is being developed separately as part of the DASCON expert system, which however can be called from ERDES to propose such an architectural solution. This paper presents the structural aspects of ERDES, and thus, the details of DASCON are left to another presentation.

The user specifies the desired type of solution (by the menu option "SOLUTION") and the given structure is solved instantaneously. With the given possible locations (centre of gravity) of columns, the distribution of loads to the columns is determined. A virtual grid is created, with at most four sides to a column (three for the perimeter and two for the corner columns), and the corresponding influence areas of the grid adjacent to a column are taken into account. Then the preliminary sizing of the columns is done with main criteria the uniform distribution of stresses in all the columns and the coincidence of the centre of gravity (C.G.) with the centre of rotation (C.R.) of the building plan. For reasons of executional speed, in this ERDES prototype, the structural analysis solution of the building is done using the approximate method of aseismic analysis of one-story structures by Roussopoulos [5]. *In the final* ERDES the possibility of selecting a more accurate method of analysis is anticipated. Finally, the initial column sizes are corrected, after checking stresses due to normal load and bending in both earthquake directions. If the user wishes so, two shear walls are placed in suitable column locations in order to achieve the coincidence of C.G.-C.R.

The synthesis stage concludes by proposing, according to the user choice, one or a combination of four possible solutions:

(1) square columns only
(2) rectangular columns only
(3) square columns and two perimeter shear walls
(4) rectangular columns and two perimeter shear walls

The corresponding columns to each solution are immediately displayed to the user. The first two cases provide the minimum cost solution, whereas the other two provide a solution with minimum rotation and displacements. The idea is to give to the designer two limits (lower and upper) of column sizes. The lower limit gives the sizes that will pass the detailed structural analysis of the building and will minimize cost. The upper limit gives sizes that will minimize building displacements during the earthquake.

The user has the capability of mixing the basic solutions (1) and (2) or (3) and (4) by specifying a desired ratio of column sides for either the inside, or the perimeter, or the corner columns of the building. Using these ratios ERDES can produce, for example, a solution with rectangular perimeter columns, L-shaped corner columns and square inside columns.

When the designer selects the "ASSESSMENT" option ERDES goes into the analysis stage of a given solution. It scores the corresponding solution with respect to the overall safety of the building, the anticipated response of the structure in earthquake, the regularity of the configuration of the structural system, and the building cost. For the cost comparison, it calculates the volume of concrete the total weight of reinforcement, the total area of scaffolding, etc., for the requested solutions. For the expected earthquake response of the building, it compares the maximum displacements and the rotation of the building, the total stiffness of the building in each direction, the uniformity of the distribution of earthquake induced stresses of the columns, and the average distance between centre of gravity and centre of rotation of the building stories (as calculated from the above approximate method of analysis). Lastly, for the assessment of the regularity of the structural system, ERDES performs several checks of building dimensions, plan ratios, story heights, and building shape and evaluates a scoring function which takes into account several other factor such as the number of discontinued columns, the presence of openings in the plan, the continuity of column lines, etc.

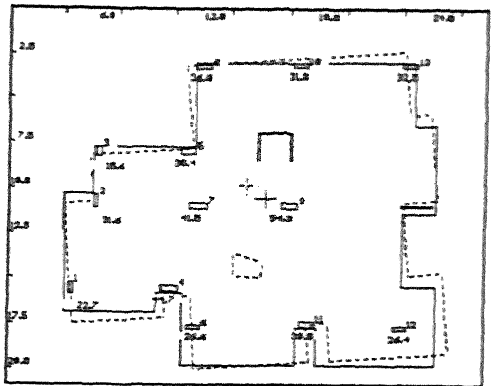

Fig.4 ERDES results: Displacements, column stresses (3rd floor of 8-story building)

Finally, by choosing the option "RESULTS" the designer can see graphically on the screen the story displacements, the column loads, the column stresses and the column reinforcement (Figs. 3, 4). The practical usefulness of ERDES as a design tool starts from this point on, since the designer has now the capability to examine instantaneously alternative solutions and/or scenarios. This is a luxury to the engineer when using one of the standard structural analysis packages, because of the great quantities of data required to produce a solution, and especially because of the prohibitive computer times in order to obtain many solutions. Using ERDES however, the engineer can immediately examine the results of his design choices (e.g. adding a column, deleting another, choosing a denser grid, etc.), graphically on the screen, and to visualize their impacts to the entire building structure with respect to criteria of cost, earthquake response, and regularity/simplicity of solution. This exercise allows the civil engineer or the architect to investigate several alternative configurations of the structural system and to choose the "optimum" solution.

5 CONCLUSION

ERDES is a new aseismic design expert system that offers real-life solutions to engineers and architects alike in designing cost-effective buildings with improved performance when subjected to earthquakes.

The ERDES expert system offers to the engineer not only the capability of an improved earthquake-resistant design, but also alternative solutions with criteria the improved seismic response of the structure and the greater economy in the building cost. It is anticipated that, in the long run, utilization of ERDES like the similar expert systems in everyday practice by the designers will lead to a more reliable earthquake-resistant design and to improved safety of structures in general.

REFERENCES

1. C.A. Syrmakezis, G.K.Mikroudis, "*Application of Expert Systems in the Aseismic Design of Structures*", Technika, February 1992 (Greek).
2. Fang H.Y, and Mikroudis G.K., "*Role of Modular Expert Systems in the Design and Analysis of Tall Buildings*", Conference on High-Rise Buildings, Hong-Kong, November 1990.
3. C.A. Syrmakezis, G.K.Mikroudis, "*Application of Expert Systems in Structures*" Technical Chamber of Greece, 1992 (Greek).
4. C.A. Syrmakezis, G.K.Mikroudis "*Expert System for the Selection of an Aseismic Structural System of Buildings*" 10th Greek Concrete Conference, Rhodes, October 1991, p.219-227 (Greek).
5. A. Roussopoulos "*Aseismic Structures*", Athens, 1956 (Greek).