Expert System for Earthquake–Resistant Design of Structures and Components

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INTRODUCTION

The earthquake-resistant design of structures and components of nuclear power plants is a specialized field requiring expertise and inputs from a variety of experts in various inter-related disciplines, e.g., seismology, geology and tectonics; local geotechnical analysis and soil mechanics; linear and nonlinear, static and dynamic analyses; seismic behavior of different types of structural systems and components constructed of different materials; soil-structural interaction analyses; structural design and detailing; understanding of codes and regulatory and licensing requirements; as well as specialized knowledge of financial, legal and public-safety related issues. An engineer, designing and analyzing structures and components on a routine basis, does not have the knowledge in all these facets of the earthquake-resistant design process. The Expert System, described in this paper, will be able to mimic the reasoning process and the decision-making actions of a variety of Experts needed to provide consultation and inputs to the engineers on the various different phases of the earthquake-resistant design process, which include the following:

- Seismic Criteria Development
- Seismic Input Development
- Analysis for Seismic Response
- Structural Design, Modification or Qualification
- Licensing Activities

An Expert System which can consult with and assist Engineers with the above phases of the earthquake-resistant design process can help the engineers in making better decisions during the design process, improving their productivity, providing significant savings in man-hours and costs, and helping produce reliable and safer designs.

Significant progress has been made in the last decade in the development of sophisticated tools for structural analysis and design. However, most of the software packages used in the earthquake-resistant design process are cumbersome to use without significant expert training and judgment, and are subject to unknown accuracy limitations. They are usually rigid in structure and flow, making it difficult to change them, and are not geared to answering the "what if" questions that an engineer would like to ask.

Thus a major need exists for an Expert System for Earthquake-resistant design of structures. The research work described in this paper presents the results of the initial phase of this on-going research project.

The following are the two major tasks of the study described herein:
- Development of the Basic Characteristics, Architecture and Primary Building Blocks of the Expert System
- Development of Prototype Modules of the Expert System

These two tasks are presented below, followed by Summary and Conclusions.

DEVELOPMENT OF THE BASIC CHARACTERISTICS, ARCHITECTURE AND PRIMARY BUILDING BLOCKS OF THE EXPERT SYSTEM

Basic Characteristics and Architecture

The following are the basic characteristics of the Expert System:

- Modular Design —As better algorithms or more refined data/knowledge sources become available, they can be easily incorporated into the existing architecture.

- Loosely-linked Integration Scheme—The knowledge modules/data bases are designed to be potentially distributed, perhaps over different hardware/software systems at diverse locations.

- Multi-level Knowledge Representation and Inferencing—This allows meta-knowledge (abstractions or generalizations) to be incorporated to enhance abstract reasoning.

- "Blackboard" System—A "blackboard" system is utilized for global project data, and user interaction with the Expert System.

- Ability to Use Existing Software—The Expert Software is able to efficiently utilize existing software and other procedures and technology, for example structural analysis software, graphics software, etc.

The architecture of the Expert Software, based on the above characteristics is shown in Figure 1. A conceptual view of a component Expert System is shown in Figure 2, Basic Building Blocks of the Expert Software.

Building Blocks of the Expert Software

Area-Specific Expert System Modules

The component blocks of the overall software package are full-fledged Expert Systems. The design of these blocks is intended to capture the domain-specific knowledge, data, reasoning processes and experiential heuristics for the technology or area in which they act as expert consultants. In addition, these components are designed to use currently existing domain software—analysis, drafting, graphics and design programs—from diverse sources.

The conceptual design of the individual Expert System building block is shown in Figure 2.

"Blackboard" or Global Data Base

The "Blackboard" design concept for the linked package of Expert Systems allows transfer of information across the individual Knowledge Based Expert System (KBES) modules and permits modularity as well as interactive decision making.

The "Blackboard" component of the Expert package is simply a globally accessible data base that contains key project information essential to the operation of all the KBES's.

The "Blackboard" global data base is the primary link between the Expert System modules. However, it provides sufficient information so that there is total integration of the modules. For example, if certain external files are needed by different modules, the file names might be part of the global data base.

The information in the global data base or "Blackboard" is interactively accessible to the Expert System user. He can also modify or update the data as necessary.

External Programs and Data Bases

Within each area of expertise represented by a KBES in the Expert software package, there are already in existence many different computer programs and data bases performing specific design, analysis or other computational, display or information tasks. These programs and data bases are available to the KBES as tools and will be controlled and used by the KBES to perform specific tasks or enquires on its way to making expert building design decisions.

The interface between the KBES's and the external programs is shown in Figure 2. The external programs do not have to be rewritten or extensively modified to be integrated with a KBES. Instead, input/output links are build from the relevant KBES.

Internal Programs and Data Bases

As shown in Figure 2, the KBES also consists of internal programs and data bases. These programs and data bases are distinguished by the fact that they are completely within the control of the Expert System and perform functions for the sole use of the KBES. These data bases/programs are generally not publicly available and would be meaningless outside the context of the KBES.

As the KBES becomes more sophisticated (e.g., fuzzy logic, semantic networks or object-oriented designs are included), the internal programs and data bases along with their links with the other KBES components become more complex and important.

User Interface and Display/Reporting Facilities

The User Interface allows the user to communicate with the problems with English-like commands and user prompts, help menus and graphics, whenever possible.

DEVELOPMENT OF PROTOTYPE MODULES OF THE EXPERT SOFTWARE

The overall design of the Expert software package consists of several linked Knowledge-Based Expert Systems (KBES's). These KBES's are full-fledged Expert Systems with their attendant Knowledge Bases, Inference Machines, Internal Data Bases, etc. In addition, each KBES is linked to existing analysis/design procedural computer programs and outside data bases. The external software runs under the control and direction of the KBES with interactive user interface allowing the user to make the ultimate decisions. These decisions are made in an environment where the KBES provides relevant decision support in terms of advice, data/knowledge display, and analysis.

A block diagram showing the components of the software package is provided in Figure 3. One KBES is provided for each independent reasoning or consultative module of the overall earthquake design process.

As part of this research effort, two KBES modules: "Seismic Analysis Criteria Development Advisor," and "Seismic Hazard Analysis and Seismic Input Development Advisor," were prototyped.

The design of the "Blackboard" (or Global Data Base), adequate to support these two modules, but sufficiently general to incorporate the needs of the other KBES modules, was also developed.

KBES Module: "Seismic Analysis Criteria Development Advisor"

This module helps the designer with the development of the seismic analysis criteria, i.e., deciding what types of analyses will be required for an adequate earthquake-resistant design and what type of seismic input will be required to support the recommended analyses.

Specifically, this module will provide advice on:

- Type of Building Analyses Recommended
- Type of Site/Foundation Analyses Recommended
- Type of Seismic Input required to perform seismic analyses in accordance with the criteria recommended in above steps.

The advice in each of these categories is generated using the Inference Mechanism and applying it to the relevant Knowledge Base. The most likely course of action is then displayed on the "Blackboard" for the user's review and evaluation. It is also saved in the Global Data Base for use by the other modules in the Expert Software.

The user can take one of several actions when the recommended analysis criteria are displayed:

- Accept the recommended analysis criteria

- Ask about the reasoning behind the selection of those particular criteria
- Change the criteria using a list of alternatives or lower order suggestions
- Rerun the KBES with a different set of data or modified instructions

The Knowledge Base for this KBES module must contain all the data, processes, rules, etc., that are required to make decisions relative to the seismic analysis criteria development. Typically, the nature and extent of the seismic analysis required is not a well defined procedure—it is an inexact, judgmental process and depends on numerous factors and data.

Thus, the Knowledge Base of this KBES will contain data that has bearing on all major aspects of the structure and the project. With time, this Knowledge Base will be expanded as more and more past experience with this kind of decision-making becomes available

The Knowledge Base will also contain rules to manipulate the above mentioned data. These rules are derived from experience, expert judgment and regulations or practice in the given area.

The Knowledge Base contains several data bases—many of them external and diverse, with large amounts of information. Information condensed out of this Knowledge Base that is relevant to the Inference Mechanism, of this KBES, as well as to the functioning of other (linked) KBES's is written in the special global data base called the "Blackboard," which is accessible to all the KBES's in the software package and is also available for interactive manipulation by the user.

Inference Mechanism for KBES Module: "Seismic Analysis Criteria Development Advisor"

Many different types of Inference Mechanisms are available for performing the deductive and control functions using the data in the Knowledge Base. Even if the actual inferencing required for a particular class of problems is relatively straight forward, the separation of the control logic and the Knowledge Base aspects of the process provides important modularity to the software.

The Inference Mechanism provided for the "Seismic Analysis Criteria Development Advisor" KBES is a Forward Chaining process that fires the rules in sequence and tests the control or decision choices until a desirable decision or a control action is indicated. This Inference Mechanism was developed in-house in 'C' language.

KBES Module: "Seismic Hazard Analysis and Seismic Input Development Advisor"

This module helps develop the relevant seismic input for the seismic analysis of the building, foundation and other elements in accordance with the analysis criteria established by the "Seismic Analysis Criteria Development Advisor" KBES described in the previous section.

Specifically, this module assists in making the decisions and performs the procedural analysis associated with the following steps in the seismic hazard analysis and seismic input development:

- Select the seismic sources in a region in the neighborhood of the site
- Select the historical earthquakes in the vicinity of the site
- Perform a site-specific seismic hazard analysis

The main components, e.g., the Knowledge Base and the Inference Engine, of the "Seismic Hazard Analysis and Seismic Input Development Advisor" KBES are similar to the "Seismic Analysis Criteria Development Advisor" KBES, described previously.

SUMMARY AND CONCLUSIONS

This paper presented the results of a study on the development of the architecture and prototype modules for two major steps of the earthquake-resistant design process for structures and components of nuclear power plants.

The Artificial Intelligence/Expert Systems Technology is ideally suited for application to the earthquake-resistant design of structures and components of nuclear power plants. A significant amount of Knowledge/Data has been accumulated over years related to all the different aspects of earthquake-resistant design, including modeling techniques, analytical procedures, design approaches, relationships between input parameters for site/structures/components and structural response for a variety of loadings, safety and licensing issues, etc. A lot of this accumulated Knowledge/Data can be efficiently and cost-effectively used on current and future projects utilizing the Expert Systems technology. This can help develop safer and better designs at significantly lower costs. Licensing questions can also be readily answered, and safety and licensing issues can be easily resolved, reducing time for plant start-ups. Furthermore, older plants can be readily upgraded to meet new requirements.

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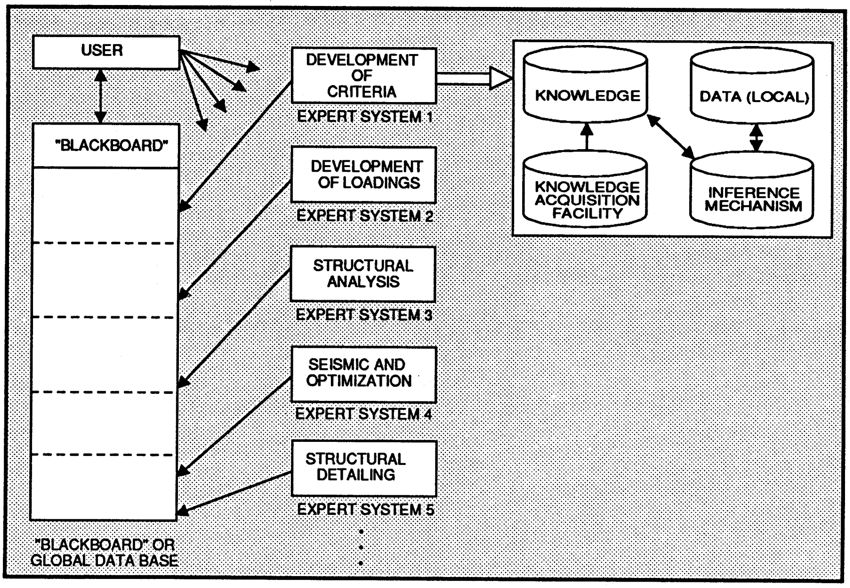

FIGURE 1: DESIGN OF A LOOSELY-LINKED SET OF EXPERT SYSTEMS FOR EARTHQUAKE-RESISTANT DESIGN OF STRUCTURES

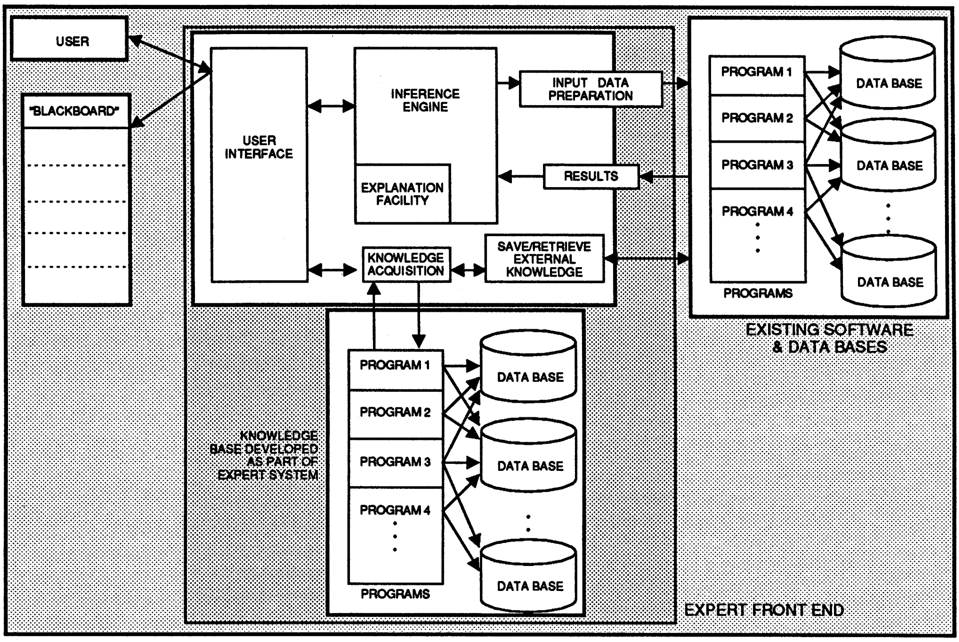

FIGURE 2: CONCEPTUAL VIEW OF A COMPONENT EXPERT SYSTEM

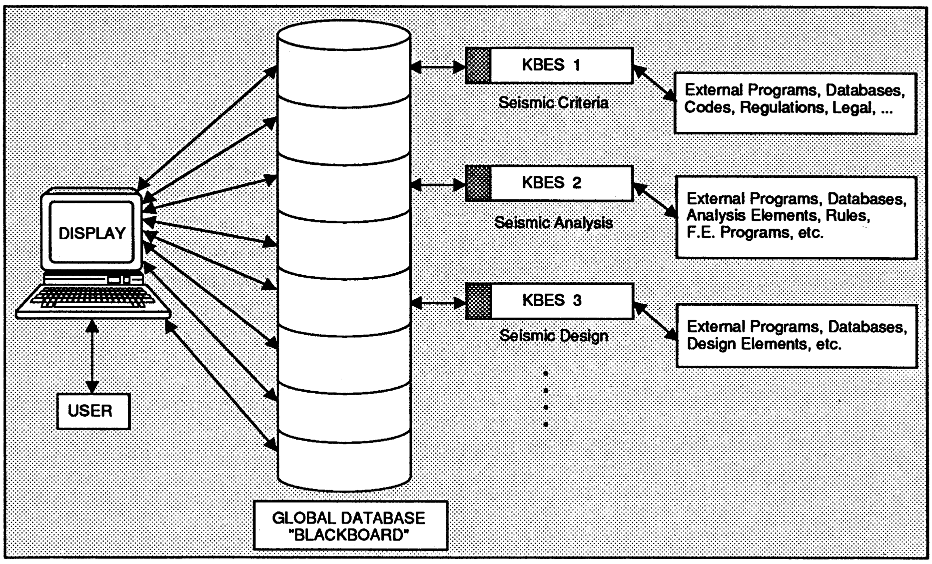

FIGURE 3: BLOCK DIAGRAM ILLUSTRATING COMPONENTS OF THE SOFTWARE PACKAGE