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The report presents Phase I SBIR study on the development of a conceptual architecture and a basic framework for expert software capable of providing consultation and decision support for earthquake-resistant design of buildings. The feasibility of the architecture and framework so developed was demonstrated by building two prototype modules of such an expert system, representing two major steps in the process of earthquake-resistant design of buildings. The proposed integrated expert system, EXPERTISE, to be developed at the end of this research and development effort (Phases I and II), will be able to mimic the reasoning process and the decision-making actions of a variety of experts in the field of earthquake engineering, e.g., seismologists, geologists, geotechnical engineers, structural analysts, structural designers, structural detailers, statistical/probability engineers, as well as experts from legal, financial, regulatory, and public safety related fields.

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DEVELOPMENT OF AN EXPERT SYSTEM FOR EARTHQUAKE-RESISTANT DESIGN OF STRUCTURES

SBIR—Phase I Final Report

Prepared for

National Science Foundation

Washington, DC 22055

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APPENDICES

1. INTRODUCTION AND SCOPE OF WORK

This report presents a research and development study on the application of the latest Artificial Intelligence (AI) techniques to earthquake-resistant design of buildings. The main objective of this Phase I SBIR effort was to develop a conceptual architecture and a basic framework for expert software capable of providing consultation and decision support for all phases of the earthquake-resistant design process for buildings.

The feasibility of the architecture and framework so developed was demonstrated by building two prototype modules of such an expert system, representing two major steps in the process of earthquake-resistant design of buildings.

The architecture and framework, so developed, provides an excellent foundation on which a complete, integrated software package can be built in Phase II which will cover all major aspects of the earthquake-resistant building design process. This software package will be able to mimic the reasoning process and the decision-making actions of a variety of experts in the field of earthquake engineering. Such reasoning and decision-making currently require expert knowledge in several 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 (e.g., frames, shear walls, etc.), constructed of different types of materials (steel, reinforced concrete, timber, etc.); soil-structure interaction effects; elastic, plastic, working stress and ultimate strength designs of structures of different types; structural detailing; damage estimation procedures; and understanding of the bases of earthquake requirements of the Uniform Building and other codes. In addition, many times, specialized knowledge in legal, financial and regulatory aspects of the earthquake-resistant design is required.

A design engineer, designing buildings on a routine basis, does not have knowledge in all these facets of the earthquake-resistant building design process. Different experts are needed to provide consultation and inputs to the design engineer on all these different aspects of earthquake-resistant design of buildings, e.g., Geologist, Seismologist, Geotechnical Engineer, Structural Analyst, Structural Designer, Structural Detailer, Statistician/Probability Engineer, as well as experts from legal, financial, regulatory and public safety related fields. The proposed integrated expert system, "EXPERTISE," to be developed at the end of this research and development effort (Phases I and II), will duplicate these diverse inputs and expertise.

The functions of the proposed Expert System package would be the following:

— assistance with establishing seismic design criteria

— decision support and assistance with analyses for the development of seismic input for the project

— advice for, and assistance with, seismic response analysis

— consultation support for seismic design or re-design efforts

— assistance with the design detailing

The intent of this effort is not to produce a general purpose building design package which would also include the task of conceptual building design and the development of a building design from scratch to meet owner/functional requirements. It is assumed that a conceptual building design has already been developed before the proposed Expert System is used. The primary purpose of the expert system would be to provide consultation only on the earthquake-resistant aspects of the design/analysis process, not usually available at a design office.

The scope of work for the Phase I effort, presented herein, consisted of the following major tasks:

— Detailed Survey of the tools and concepts in Artificial Intelligence and Expert System Technology, available architectures for Knowledge Based Systems and Data Base Systems, and applications to structural engineering

— Detailed review of process of the earthquake-resistant design of buildings and its incorporation into an easy-to-use format for development of an Integrated Expert System

— Development of a feasible architecture and basic framework for expert software for integrated earthquake-resistant design/analysis of buildings

— Definition of the building blocks of the software package, "EXPERTISE," a Knowledge-Based Expert System (KBES) for integrated earthquake-resistant design/analysis of buildings

— Development of prototype KBES module: "Seismic Analysis Criteria Development Advisor," of "EXPERTISE" , with user interface

— Development of prototype KBES module: "Seismic Hazard Analysis and Seismic Input Development Advisor" of "EXPERTISE," with user interface

- — Use of 13 sample examples of selected earthquake-resistant building designs for verification of the two prototype demonstration KBES modules of "EXPERTISE"
- — Development of recommendations for future work (Phase II).

Chapter 2 of this report presents a review of the state-of-the-art in engineering expert systems, followed by a review of the earthquake-resistant design process for buildings in Chapter 3. Chapter 4 presents the proposed architecture of the expert software for earthquake-resistant design/analysis of buildings, followed by a description of the building blocks and two prototype KBES modules of "EXPERTISE" (the final end-product of the Phases I and II) in Chapter 5. Recommendations for future work (Phase II) are presented in Chapter 6. References are then listed. Appendix A includes sample examples of selected earthquake-resistant building designs for verification of the two demonstration modules of "EXPERTISE." Appendix B presents sample screens of "EXPERTISE" for a selected sample example.

2. REVIEW OF THE STATE-OF-THE-ART IN ENGINEERING EXPERT SYSTEMS

The engineering design process involves a number of tasks requiring different types of technologies, expertise and processing. Since the advent of the computer, continuous attempts have been made to automate these tasks and develop computer-aided tools to assist with their performance.

A very significant level of progress has occurred in the last two decades in developing computer-aided design tools. In the field of structural engineering, the principal area of progress has been the development of finite element programs, such as, ANSYS, NASTRAN, SAP, MARC, ADINA and STARDYN, etc., that permit the stress analysis of a very large number of very complex structures, subject to a variety of static and dynamic loadings, in linear and nonlinear (e.g., ANSYS, MARC, ADINA) regimes. Other computer-aided design tools have also been developed in areas that are generally prone to the development of algorithms or procedures, which can be mechanically performed using the computer, e.g., graphics, seismic hazard analysis, data querying and support.

The process of engineering design involves a number of steps that can not be easily broken down into algorithms or procedures. Many researchers have studied the non-algorithmic nature of the design process [Ref. 1,2,3,4]. In these studies, researchers have focussed on issues such as: the process of design; how designers think; whether design can be fully automated; etc. It is clear that engineering design is an ill-structured problem, requiring judgment, creativity, cultural conditioning, heuristic reasoning and the manipulation of large amounts of relevant and partially-relevant data from which complex inferences must be derived.

With the growth of concepts and techniques in Artificial Intelligence (AI) and significant improvements in hardware architecture and speed, the development of intelligent software for engineering design is receiving increasing attention. As of now, sufficient work has been undertaken in the area of Knowledge-Based Expert Systems (KBES) and the architecture of integrated expert software to allow a meaningful synthesis of existing AI elements in developing a functioning integrated earthquake-resistant design package. Such a package would perform at the level of expert consultants integrating the many different fields of expertise required for the earthquake-resistant design of buildings.

This chapter provides a review of the concepts and tools (relevant to this effort) that exist in the engineering design field; and, in particular, in the structural design field. In Chapter 4, the concepts and architectural elements of engineering KBES's are synthesized into a proposed architecture for the integrated software package for earthquake-resistant design of buildings.

Table 2-1 provides a list of the major seismic analysis/design tools and concepts that exist currently. These have been divided into two categories:

1. Conventional (Procedural) Engineering Tools, i.e., algorithmic software packages that perform a given, repetitive engineering function.
2. Knowledge-Based or"Intelligence"-Oriented Tools and Concepts that perform judgmental tasks (inferencing in complex environments), synthesize expertise, and test hypotheses, etc.

The integrated expert software package for earthquake-resistant design of buildings will use components and concepts from both categories in order to develop a system of functional, user-friendly, continuously upgradable AI software. The items in Table 2-1 and their research and development status is discussed in the following sections.

2.1 Conventional Engineering Tools

The conventional, procedural, engineering tools used in the structural design process are very briefly outlined in this section. Since much is known about this kind of software, and since conventional software programs are not the primary focus of this effort (except as building blocks for the integrated system), the level of detail for the description of these tools is minimal.

A. Structural Analysis Programs

As mentioned in the previous section, a considerable amount of progress has been made in the development of structural analysis programs and techniques. Finite element packages, such as SAP, NASTRAN, ANSYS, MARC, ADINA and STARDYN, etc, can perform structural (stress) analysis for:

— Two-dimensional and three-dimensional arbitrary shapes and structural elements

— A large range of loadings, including thermal, pressure, shock, earthquake response spectrum and time history, support movements, etc.

— A variety of material types, including anisotropic materials, composites, plastics, materials with a variety of nonlinear constitutive relations

For building analysis, computer programs that can analyze almost any two or three-dimensional building types, with extremely efficient interfaces, are now available on microcomputers.

B. **Building Component Design Programs**

There are many small programs available for design of building components, such as beams, columns, walls, slabs, footings, etc., especially on microcomputers. They include, for example, BEAM-1, RCOLUMN, TILTWALL, FOOTING, RETWALL, among numerous others.

C. **CAD Packages**

Many excellent programs are now available on minicomputers and microcomputers for assisting with the design-drafting and graphical two and three-dimensional modelling of buildings. Programs such as AUTOCAD and PATRAN produce an important productivity link in the building design process — by allowing the designer to view the geometry and shape of the building, as well as in facilitating the finite element model development of strucutres for analysis.

D. **Seismic Hazard Analysis Programs**

Existing packages include:

— Data bases of worldwide seismic sources (faults, tectonic regions, etc.)

— Regional geotechnical and geologic information

— Historic earthquake data

— Computer programs, e.g., STASHA, developed at Stanford University, to interpret historic data and to perform probabilistic seismic hazard analyses.

E. **General Tools**

General purpose analysis and computational tools, relevant to the seismic design process, include the following:

— Engineering Data Bases (e.g., standard components, materials, codes and standards)

— Code checking programs

— Probabilistic/Stochastic analysis tools

— Time History/Response Spectra development, tools, etc.

2.2 Knowledge-Based or "Intelligence"-Oriented Tools and Concepts

In the previous section, several computer programs, available for different steps of the structural design process, were described. These programs provide tools for solving a wide range of structural engineering problems. However, these tools are algorithmic in nature, and are not able to solve, efficiently, many problems that require engineering judgment. Furthermore, many of these programs were developed by different organizations, and no consistent format is available for exchange of information between these programs. The emerging technology of knowledge-based expert systems (KBES), along with traditional CAD programs, offers a methodology to overcome some of the above barriers. The example of SACON [Ref. 5] and the successful development of HI-RISE [Ref. 6] and ALLRISE [Ref. 7] have paved the way for more research on the use of KBES for structural engineering applications. A number of other KBES applications to structural engineering are described in References 8 and 9.

The technology of the KBES is extensively utilized in the design of the proposed integrated seismic design package. A review of this technology and the components of modern day designs of KBES's are described below.

A Knowledge-Based Expert System (KBES) is an interactive computer program package that incorporates judgment, experiences, rules of thumb, and intuition acting upon a potentially large amount of domain data or knowledge to solve ill-defined, non-procedural problems. In this way, it mimics the actions and reasoning processes of an expert in its domain.

A schematic view of a typical Knowledge-Based Expert System is illustrated in Fig. 2-1, and consists of the following components.

A. Knowledge Base

The Knowledge Base consists of domain-specific data, general facts and heuristics (rules of thumb) that are pertinent to the expert reasoning and problem solving performed by the KBES.

The design and implementation of the Knowledge Base is a key parameter that controls the efficiency of a KBES. A great deal of research has been performed and is continuing in the development of effective Knowledge Representation schemes [Ref. 10,11,12,13].

A number of formalisms, such as production rules, frames (concepts) and semantic nets are available for representing knowledge. The production rule representation has been extensively used in current KBES designs. In this approach, knowledge is represented as "IF—THEN" rules or "premise—action" pairs: the action is taken if the "premise" evaluates to be true. Uncertainty in the knowledge can also be represented by means of confidence factors [Ref. 14]. Other forms of representations commonly used are logic and frame-based schemes.

In their most general level of complexity, the production rules can handle the following:

— Fuzzy or imprecise knowledge, using probabilistic constructs

— Redundant or contradictory rules

— Lack of knowledge base in certain areas of the inferencing

— Meta rules—or rules governing the generation and firing of other rules. Meta rules are essential in the design of "Self Learning" Systems, i.e., Systems that can modify their own rules as more knowledge usage comes into being.

The knowledge base may also be partitioned into knowledge levels in order to help organize the problem solving activities. Examples of commercial products that provide efficient Knowledge Representation are KEE (Tecknowledge), KL-ONE [Ref. 10], KRL [Ref. 11], and KRYPTON. For structural design applications, DESTINY [Ref. 14], a conceptual design package, uses a "Blackboard" architecture and a multilevel Knowledge Base design, as shown in Figure 2-2.

B. Knowledge Acquisition Facility

Attached to the Knowledge Base is the Knowledge Acquisition Facility. This facility permits the continual generation of new or modified knowledge that is pertinent to the expertise of the KBES. Thus the Expert System, like an expert in the field, is able to remain current, reflecting the latest body of knowledge, consensus opinions, related projects, data bases, etc.

C. Context

The context is a collection of symbols or facts that reflects the current state of the problem at hand. It consists of all the information generated during a particular program execution.

The "awareness" of the context by the Expert System allows it to ask only pertinent questions and seek relevant data. The User Interface can also be made greatly user friendly by utilizing context-specific querying and user responses.

D. Inference Machine

The Inference Machine (inference engine and inference mechanism are other terms commonly used, instead of Inference Machine) monitors the execution and performs the reasoning to arrive at decisions and other control actions. Various strategies for inferencing to arrive at valid conclusions or decisions exist—e.g., forward/backward chaining, unification, means end analysis, least commitment principle, reasonings by analogy, etc. A detailed description of these strategies can be found in References 15, 16 and 17.

Different Inferencing strategies are suitable for different expert domains. Most KBES designs, proposed for limited domain applications, provide a common Inference Mechanism for the entire software package.

However, for the seismic design Expert Package architecture proposed in this effort (Chapter 4), an independent Inference Mechanism is proposed for each module—making each module a stand-alone KBES, linked to the other KBES's via the "Blackboard." The advantages of this approach are described in Chapter 4.

E. Explanation Facility

An important aspect of an Expert System is the ability to explain how it arrived at certain decisions or conclusions. In this way, the non-expert user can gain insight into the logical process utilized by a domain expert in performing project tasks. In due time, the user can be trained using an Expert System with an Explanation Facility and can also modify the decision process if he has more specific or detailed knowledge than the Expert System.

F. User Interface

The User Interface is an important aspect of an efficient, interactive, Expert System. The function of a User Interface is to shield the user from having to interact with the software at an internal computer hardware/software design level. Instead, the user interacts with the software, using the following facilities:

— Windows & Pop-up menus

— Graphics devices wherever feasible

— English-like constructs

The user need not know the names of the data bases, program modules, file names, etc, that the software uses. An efficient User Interface also provides "Help" levels and diagnostics that make the program easy to learn and use. Although a significant amount of work is in progress in developing natural language interfaces [Ref. 18,19], the problem is complex and much remains to be done. The development of a natural language interface is not an objective of this effort.

G. "Blackboard" Architecture

A general framework—the "Blackboard" Architecture—for integrating knowledge from several sources—has been successfully designed and implemented [Ref. 20,21].

A "Blackboard" system consists of a number of knowledge sources that communicate through a "Blackboard" of a global data base. These knowledge sources are controlled by an Inference Mechanism, as shown in Figure 2-3.

The data that goes onto a "Blackboard" can be divided up using many different types of schemas—the most commonly proposed schema for engineering design being a multi-level data organization where each level contains a higher level of abstraction (or the next level of completed decision) based on the previous level.

The KBES components described above represent very powerful knowledge-oriented tools. These tools with modifications and additions are the basic building blocks of the proposed integrated expert software for seismic design. The architecture of the proposed AI package is described in detail in Chapter 4.

References 22 and 51 provide additional technical background into the work that has been done or is in progress in the development and refinement of knowledge-oriented tools.

TABLE 2-1
LIST OF SOFTWARE TOOLS FOR EARTHQUAKE-RESISTANT DESIGN OF BUILDINGS

A. Conventional (Procedural) Engineering Tools

1. Structural Analysis Programs

   SAP, ANSYS, NASTRAN, MARC, ADINA, STARDYN, ...

2. Building Component Design Programs

   BEAM-1, RCOLUMN, TILTWALL, FOOTING, RETWALL, ...

3. CAD Packages, Graphics Input/Output Programs

   PATRAN, AUTOCAD, ...

4. Seismic Hazard Analysis

   STASHA, ...

5. General Probabilistic/Stochastic Tools

   Numerous

6. Code Checkers

   Numerous

7. Engineering Data Bases, Material/Standard Component Libraries, Historic Earthquake Data Bases, Seismic Sources Data Bases

B. Knowledge-Based or "Intelligence"-Oriented Tools and Concepts

1. Knowledge-Based Expert Systems

   SACON, DESTINY, None available yet (to best of our knowledge) for earthquake-resistant design of buildings

2. Knowledge Representation

   KL-ONE, KRL, KRYPTON (KEE, GURU), ...

3. Data Base Management Programs

   — Object Oriented Database programs (NIAL), Semantic Nets,

MDBS (MIDAS, MDBS III), ...

— Linked Systems (KADBASE), ...

4. Inferencing Programs

   — Production Rule Based Shells- EXSYS, PERSONAL CONSULTANT,GURU, VPEXPERT, GOLDWORKS, ...

   — Top-down Refinement; Constraint Handling (HI-RISE, PRIDE, AIR-CYL), ...

   — Analog Reasoning

   — Probabilistic or Fuzzy Reasoning Tools (GURU, ...)

5. "Blackboard" Architectural Designs

   DESTINY

6. Intelligent User Interfaces & Natural Languages

7. Context Management

8. Knowledge Acquisition Software

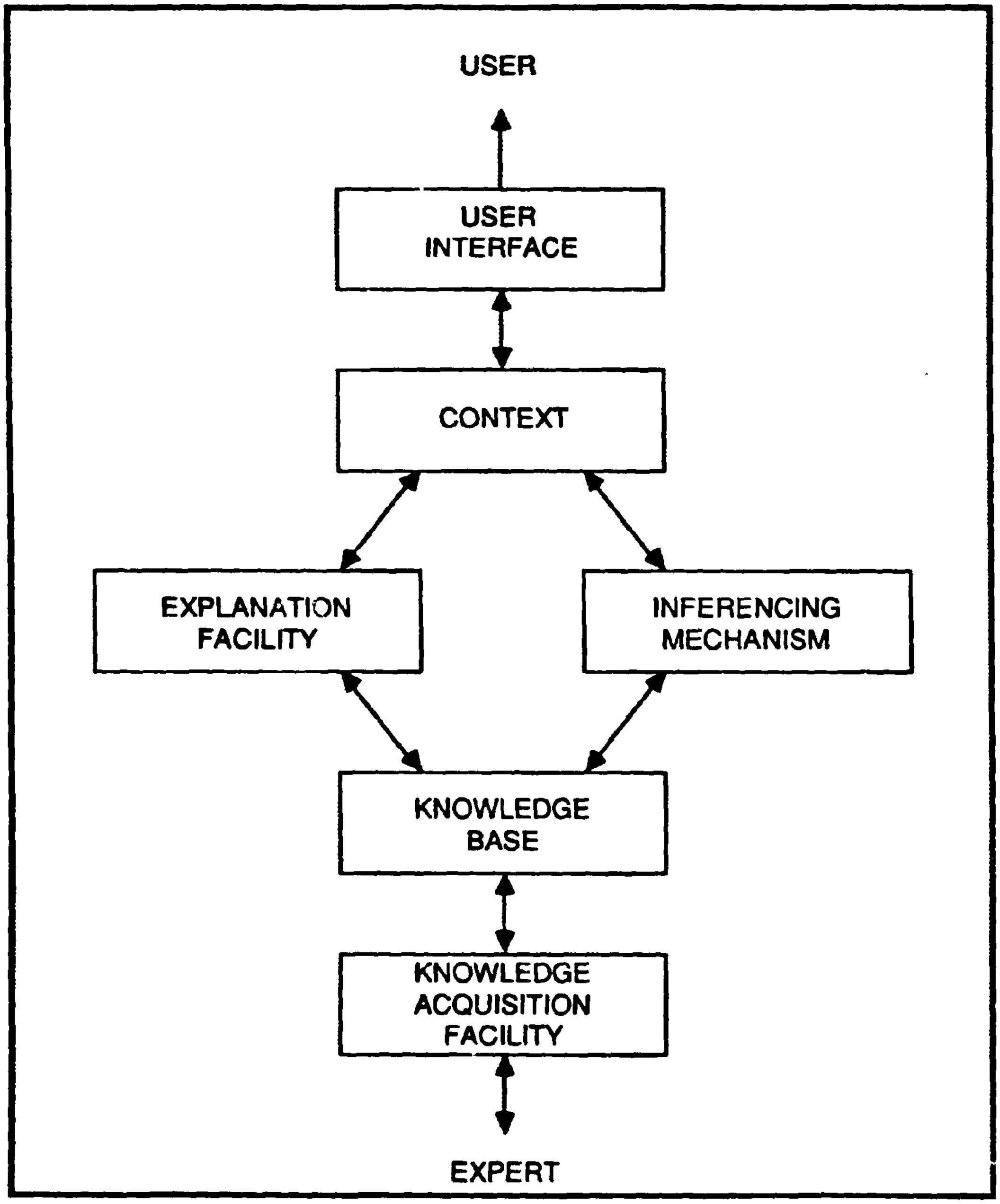

FIGURE 2-1: SCHEMATIC VIEW OF A TYPICAL KNOWLEDGE-BASED EXPERT SYSTEM

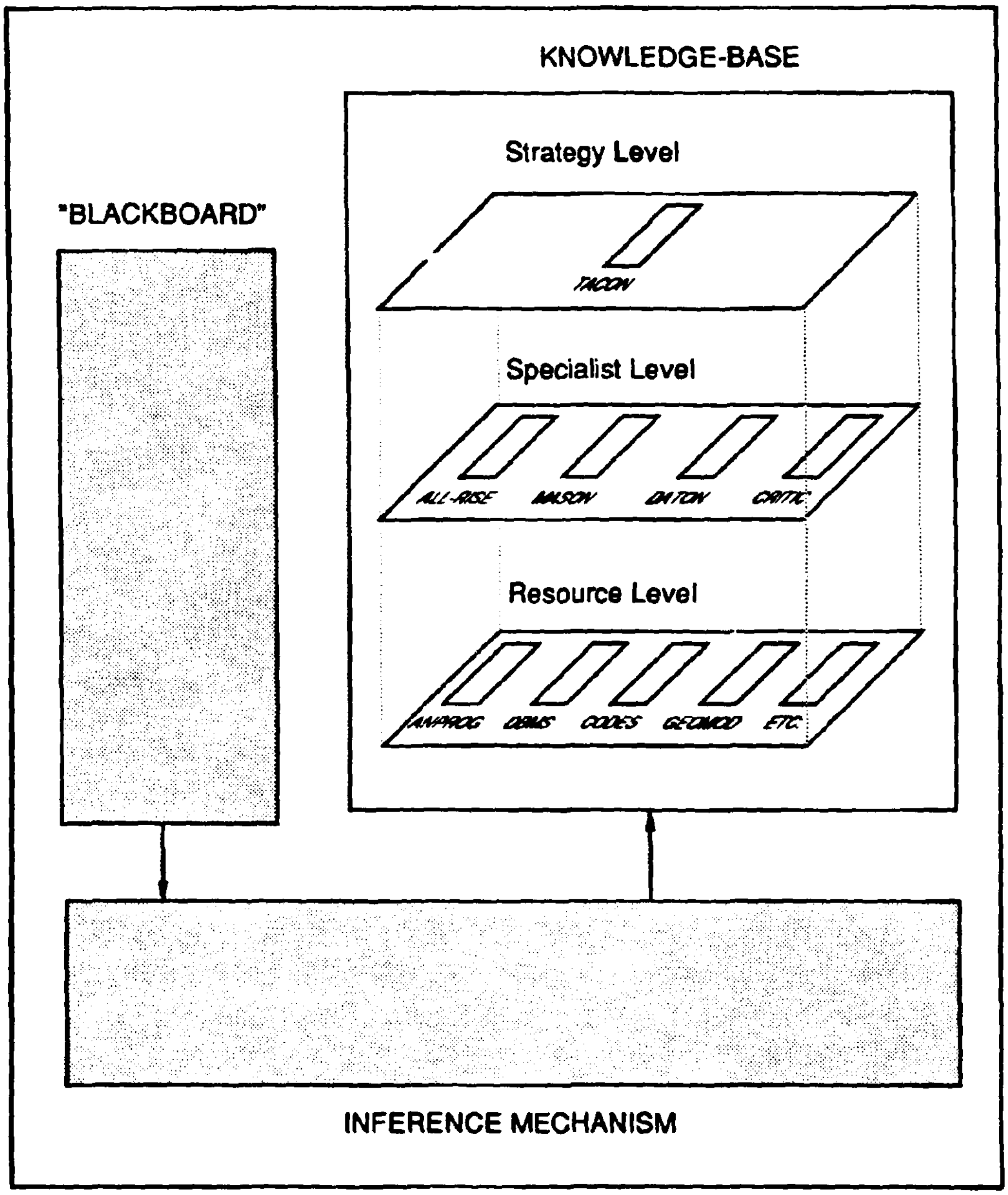

FIGURE 2-2: A CONCEPTUAL VIEW OF AN INTEGRATED STRUCTURAL ANALYSIS AND DESIGN SYSTEM USED IN DESTINY (ADAPATED FROM REFERENCE 14)

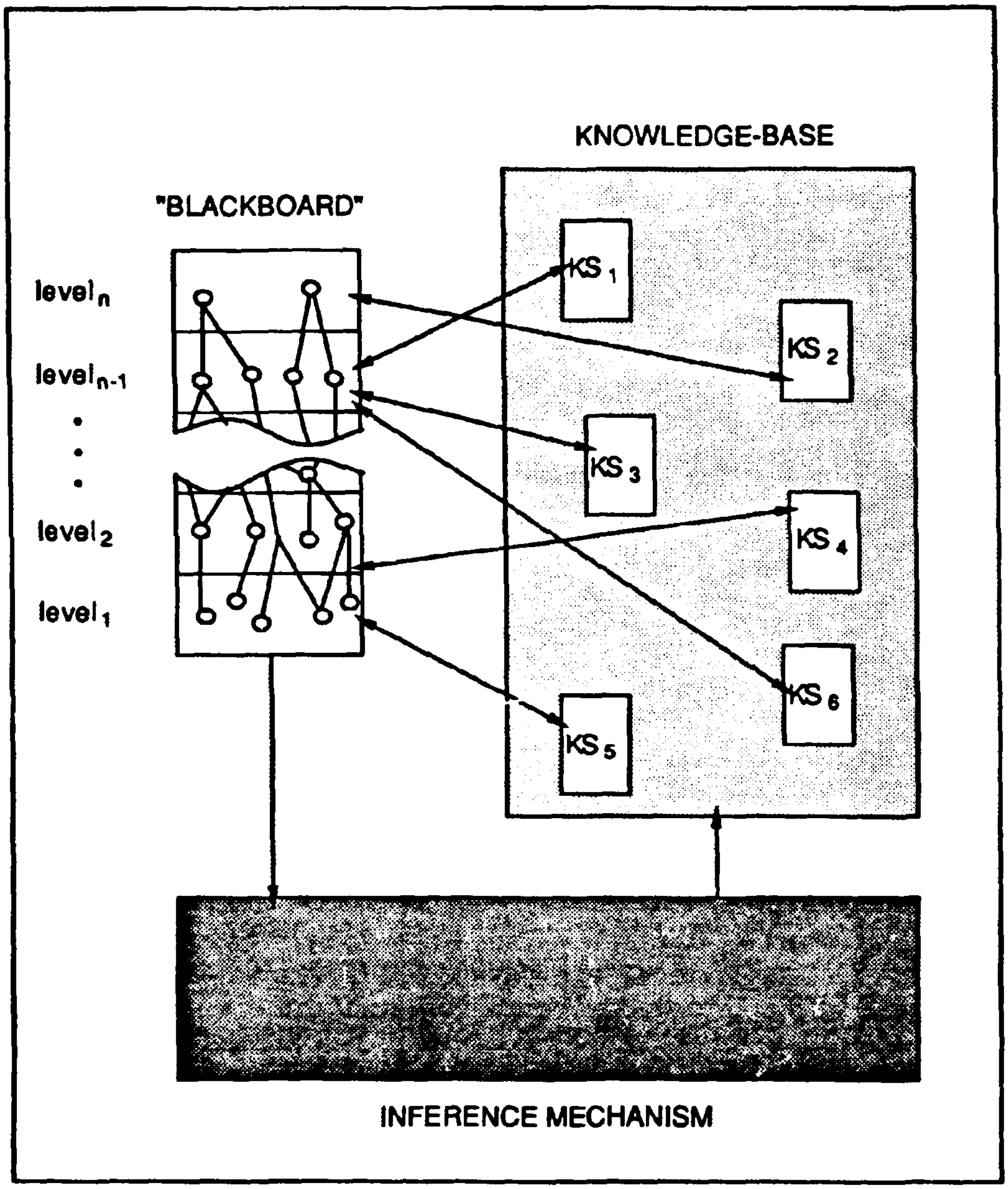

FIGURE 2-3: THE "BLACKBOARD" ARCHITECTURE (ADAPTED FROM REFERENCE 21)

3. THE EARTHQUAKE-RESISTANT DESIGN PROCESS FOR BUILDINGS

3.1 Introduction

The end product of this research and development effort (Phases I and II) will be a consultative expert system for the earthquake-resistant design of structures, specifically buildings. The computer program, so produced, will be able to mimic the decision-making actions of a variety of experts in this specialized area. The decisions currently require significant specialization and experience covering the many different aspects and tasks involved in the earthquake-resistant design of buildings—viz., establishing seismic criteria, developing appropriate seismic input motions, performing the structural (stress) analysis for the seismic and other loads, designing, detailing, and ensuring code compliance, etc. Each of these areas may require different types of expertise. In addition, decisions and design actions in these areas will require access to different types of diverse knowledge and data bases. A typical project in which an earthquake-resistant design of a significantly important building is undertaken will involve inputs from: Architects/Planners, Geologists, Seismologists, Geotechnical Engineers, Structural Analysts, Structural Designers and Detailers, as well as from legal, financial and public safety related experts and agencies.

In order to design the components of an expert system that will duplicate these diverse inputs and expertise, the first step is to outline the building design process for earthquake-resistant design and identify the nature and extent of the knowledge/data and decision-making inferences needed in the process. This is presented in this chapter. In the next Chapter, the architecture of an Expert System is discussed, and a suitable architecture that can satisfy the requirements of Earthquake-Resistant Design is developed.

3.2 Major Phases in Earthquake-Resistant Building Design

The engineering activities associated with the earthquake-resistant design of structures, particularly buildings, after the preliminary design has been completed, can be divided into the following phases:

Phase 1. Seismic Criteria Development

Phase 2. Seismic Input Development

Phase 3 Analysis for Seismic Response

Phase 4. Structural Design or Re-Design

Phase 5 Structural Detailing

These phases are described below in more detail.

Phase 1. Seismic Criteria Development

During this stage, the criteria governing all aspects of the seismic design are established. Sample examples of criteria and criteria-related decisions that must be made as part of this activity include the following:

— Establish applicable codes/standards/regulations that will govern the seismic design of the structure. In particular, determine the Federal, State and Local codes and ordinances that apply, as well as requirements for satisfying the Environmental & Regulatory Agencies that have oversight jurisdiction on the project.

— Establish the seismic level(s) and the types of seismic input(s) for the project—e.g., UBC Zone '4' or site-specific spectra, etc. If it is decided to use two levels of earthquakes, then, in addition to a "design level" earthquake, a "service level" earthquake should also be established.

— Select Site/Foundation and Building Analysis and Design Procedures. For example, it needs to be decided whether it is sufficient to perform equivalent static analysis based on UBC type (or other) loads, or dynamic response spectrum and/or time history analyses are required for the building. Similarly, it needs to be decided if any site soil amplification, soil-structure interaction, or liquefaction analyses are required. The design procedure, e.g., elastic or plastic design procedure (for steel), working stress or ultimate strength design procedure (for reinforced concrete), also needs to be decided.

— Establish the acceptable risk and the level of safety that will determine the seismic criteria at the site—e.g., service life of the building, return period of the earthquake hazard for which the building will be designed. This should also take into consideration the importance of the building based on occupancy type.

— Establish load combinations.

— Establish the Acceptance Criteria for the building and other structural components. Acceptance criteria may need to be established for the following, depending upon the importance of the structure, based on its occupancy and potential seismic performance:

- Site/soil stability
- Acceptance criteria for members (e.g., Allowable stresses in beams, columns, etc.)
- Acceptable deformations/displacements
- Substructures and their seismic performance
- Treatment of umbilicals, appendages, embedments, etc.
- Acceptance criteria for critical equipment, and mechanical & electrical and architectural components and systems.

Each of the above decisions require engineering input, data and expertise—e.g., soil data, understanding of potential building behavior, historical earthquake data, etc., and other non-engineering input—e.g., legal expertise, owner's criteria and preferences, economic data, environmental & safety data, applicable regulatory data, etc.

Phase 2. Seismic Input Development

This step in the earthquake-resistant design process involves the development of the appropriate seismic input for site/foundation stability evaluation, building analysis and design, and component and equipment design evaluation. This may be done for "design level" earthquake, as well as "service level" earthquake (if applicable).

The seismic input reflects the expected level of earthquake shaking at the site with a defined risk (or return period) as defined in the criteria established as part of the previous step. The level of shaking is usually expressed in terms of: a peak ground acceleration ('g') or "equivalent" static loads for analysis of response of the building based on static analysis; response spectra, anchored to a peak ground acceleration or an "effective" peak ground acceleration, for a linear dynamic analysis; or/and time histories for special analyses for those cases where displacements, nonlinearities or subcomponent design may be critical. (In such cases, artificial time histories may be developed, consistent with the response spectrum).

Steps that may be considered in developing the seismic input at the building site are:

A. In Conjunction with "Equivalent" Static Analysis:

— Establish the seismic zone in the applicable code (e.g., UBC) and/or the level of design earthquake for this zone in terms of peak ground acceleration, g, or "effective" peak ground acceleration.

B. In Conjunction with Response Spectrum Analysis:

— Establish the level of acceptable risk and desired safety (e.g., Acceptable probability of exceedance of the seismic input).

— Define the regional seismic sources that will control the design level of shaking at the site.

— Consider historical seismicity of these sources to establish their potential for generating earthquakes.

— Evaluate the regional terrain attenuation characteristics to determine how the motions are affected in reaching the site from the sources.

— Perform a regional seismic hazard analysis and obtain a probability distribution of the level of expected earthquake shaking (e.g., in terms of peak ground accelerations).

— Determine the potential for local amplification of the motions at the site.

— Develop appropriate response spectra for the site (site-specific) considering local site amplifications. Alternately, a standard "shape" of a response spectrum, e.g., Housner spectrum or NRC spectrum, may be used. The response spectrum, so selected or developed, can then be anchored to the peak ground acceleration, g, selected in conjunction with the acceptable probability of exceedance.

C. In conjunction with the Time History Analysis:

— Select a duration of shaking and develop time histories consistent with the spectra developed or selected for the site.

Each of these steps require decision making using a variety of expertise and inputs, e.g., earthquake engineering, seismological/geological, geotechnical, and structural engineering expertise and inputs. Examples of major decisions that need to be made during this phase of the project (especially if site-specific seismic input is desired) are:

— What seismic sources near the site are significant?

— Is the available historical seismicity data sufficient or should it be supplemented with other evidence or reasoning?

— What parameters and cutoffs are required for the regression analysis?

— Should site-specific spectra be developed or can a "standard" shape be applied ? (anchored to the peak ground acceleration)

Phase 3. Analysis for Seismic Response

The analysis is needed to determine the response of the building (and foundation), as well as components (architectural, mechanical and electrical), to the postulated earthquake input. The analysis can be based on UBC code type procedures utilizing "equivalent" static load distributed over the building height, or may require detailed, computer modeling and dynamic (linear or nonlinear) analysis based on a finite element approach.

Examples of the decisions required for this step of the earthquake-resistant design process are presented below:

— What kind of analysis is required to design or seismically qualify the building, the foundation, substructures, and components (architectural, mechanical and electrical) for the postulated earthquake input? This may include the following choices:

- UBC Code type (or other codes, e.g., local city code, ATC, SEAOC, etc.) "equivalent" static procedure
- UBC Code "equivalent" static procedure, with special additional calculations
- Finite Element Computer Analysis, e.g.:
  - Static
  - Dynamic Response Spectrum (Modal Superposition)
  - Dynamic Time History

- Linear (Modal Superposition or Direct Integration)
- Nonlinear (Direct Integration)
- Dynamic Frequency-Domain
- Probabilistic/Stochastic (e.g., Random Vibrations)

— What load combinations and service states should be used in conjunction with the various analyses?

— How should the structure, substructures and components be modeled? The modeling decisions may include the following:

- Should a 3-D model be developed, or several 2-D models (several cross-sections in longitudinal and transverse directions) be used? Alternately, the structure can be "collapsed" in the longitudinal and transverse directions to develop two 2-D models.
- What type of finite elements should be used, e.g., beam, truss, plane stress, plane strain, plate, shell, brick, etc.?
- Should a lumped-mass "stick" type of dynamic model be used, or a detailed finite element model be used?
- What refinement of the finite element mesh should be used for different portions of the structure and substructures (coarse, fine, very fine, etc.)?
- What boundary conditions, and initial conditions (for dynamic time history analysis) should be used? Should structural symmetry be utilized?
- Is it desirable to utilize substructuring? If so, how the structure should be substructured? How many substructures should be used?
- What material properties should be used? This is especially important if nonlinear analyses are performed since material constitutive (stress-strain), yield surface and failure criteria models would be required.
- In case of dynamic analysis, how many masses should be used and how they should be lumped? (or, should a "consistent" mass matrix be used rather than a "lumped" mass matrix?)

- Should soil-structure interaction effects be included? If so, how should they be modeled? (For example, frequency-independent soil springs and dash pots, or frequency-dependent impedance functions could be used to model the soil. Alternately, the soil can be modeled using finite elements, and a complete soil-structure finite element model can be used. If soil-structure interaction effects are to be included, there are many other associated decisions, e.g., the boundary cutoffs for soil mesh, use of energy absorbing boundaries, etc., and many others, which would need to be considered).
- Should building slabs be assumed to be rigid or flexible?
- Should appendages, and non-structural components be modeled? If so, how? (For example, they can be modeled as "lumped" mass cantilevers, or their masses and stiffnesses can be included with the supporting primary structure)

— What analysis parameters should be used? The decisions regarding analysis parameters may include the following:

- For a UBC type analysis, how should the factors, C,K, and S, be calculated or selected, for the calculation of total base shear, V, for unusual (nonstandard) cases, not covered by the code?
- How should the total base shear be distributed over the height of building (vertically), especially for unusual buildings (e.g., with nonuniform distribution of stiffnesses over the height)?
- How should the seismic lateral shear be distributed horizontally to different shear walls and frames (and how should the torsion be considered?), especially for unusual (nonstandard) cases?
- How should vertical forces, resulting from overturning moments, be distributed?
- How should the story drifts be calculated? Should P-Delta effects be included?
- In dynamic modal superposition analysis (for response spectrum or time history analyses), how many modes should be included, and how should modal responses be combined? How should the response in the three orthogonal directions (x,y,z) be combined?

- In dynamic time history analysis (direct integration), what time step size should be used?

- In dynamic time history analysis (direct integration), how should the damping be treated? (For example, the standard Rayleigh damping, mass and stiffness dependent, may be used. But use of such damping is based on two modes only, and it is possible to damp out some important modes. Should an alternate way of treatment of damping be considered?)

- If nonlinear analysis is performed, what parameters should be used in conjunction with material and geometric nonlinearities and yield criterion? (For example, what rate of strain hardening should be used?)

- How should the ductility be treated and calculated in any of the different types of analyses (spectral, time history-linear, time history-nonlinear, etc.)

- If soil-structure interaction analyses are performed, many major decisions are required about various different parameters, e.g., shear modulus, shear wave velocity, damping (especially radiation or geometric damping), frequency cut-off, embedments, etc.

- How the earthquake loading should be applied? (The loading can be applied at the foundation level or the ground surface; single input or multiple inputs may be used, depending on the foundation configurations)

— How should the post-processing and interpretation of the analysis results be performed? The decisions regarding post-processing may include the following:

- What response quantities should be output, displayed and reviewed? (For example, displacements, accelerations, forces and stresses, etc.)

- How should the response quantities be presented? (For example, tables, graphs, contours, vector diagrams, etc.)

- Are there any combinations of the different response quantities required? (For example, for the various load cases, etc.)

- Is there a need to perform any re-analyses? (For example, some modifications to certain parameters may be required based on review of results, or certain additional response quantities may be needed, at additional nodes or for additional members, etc.)

- Is there any need to transform or reinterpret the results into different forms for easy use by the designers? (For example, should the maximas of moments with corresponding shears, and maximas of shears with corresponding moments, resultant forces, story-to-story relative displacements, relative accelerations, etc., be calculated?)

Phase 4. Structural Design or Re-Design

After the response of the structure (and foundation, and/or any components thereof) has been determined, structural design or re-design (for seismic forces) is performed using the forces calculated by analysis. This primarily includes use of UBC and other codes (e.g., AISC, ACI, etc.) for the design (sizing) of members (beams, columns, shear walls, etc), the design of joints, design of foundations, ensuring that the different framing systems and foundations are properly connected and that the lateral load can be adequately transmitted, through the diaphragms, to the different frames and shear walls and ultimately to the foundation system and the supporting soil, check for drift, and check for building stability.

Example of major decisions required for this step of the earthquake-resistant design process are presented below:

— What type of design concept would be used, e.g., elastic design, or plastic design (for steel structures), working stress, or ultimate strength design (for reinforced concrete structures), strong column-week girder design, etc.?

— How much safety margin and energy absorption capacity (available ductility) should be distributed throughout the structure? (There shouldn't be any abrupt changes, e.g., shear walls in the building should be continued through the height down to the foundation and not abruptly stopped at the top of the first story)

— How should the lateral load be properly transmitted between different frames and shear walls through diaphragms? (the diaphragms must be designed for such transfer)

— How should the structure be properly tied together and to the foundation for appropriate transfer of lateral load to the foundation and the underlying soil?

— How should the connections be designed to adequately transmit load from one member to the other, especially at shear wall-frame connections, and at connections between pre-cast slabs and steel framing?

— How should the interactions between structural and non-structural components be properly taken into consideration?

— How should the "drift" be controlled adequately in design to restrict damage to partitions, shafts and stair enclosures, glass and other fragile nonstructural elements?

— How should the foundations be adequately designed for combined lateral, overturning and vertical seismic effects? Have the individual footings been tied together using tie beams?

— How should the building be properly designed for torsional effects?

— How should the openings in slabs and shear walls be properly reinforced by using chords?

— How should the overall stability of the building be checked to ensure no overturning (and no potential uplift), for lateral plus P-Delta effects (if not already considered in analysis)?

Phase 5. Structural Detailing

In the previous step, the members and connections of the structure, as well as foundations were supposed to be designed and their sizes were obtained; for reinforced concrete members, reinforcement was also supposed to be calculated. It was ensured that all the frames, shear walls, diaphrams, and structural elements, could resist postulated seismic loads and could transmit them so that no failure of members and connections, as well as overall stability failures of the building, would occur.

In this step, the details of the design, obtained in the previous step, are developed, in accordance with the applicable codes. It is ensured that the details are adequate for seismic loads and resulting behavior of members and connections, etc. This is a very critical step in the earthquake-resistant design. Many failures in the past earthquakes have occurred because of inadequate attention to design details. Such detailing also requires extensive "hands on" experience.

The detailing includes the exact details of different type of welds, their sizes, locations, distributions; bolts and rivets, their numbers and exact locations, pitch, edge distance, etc; anchor bolts, their lengths, numbers, locations; details of reinforcement bars including exact overlaps, splices, length of anchorages, sizes and diameter of hooks, sizes and number of ties, hoops, their spacings; web stiffeners, their sizes, lengths, locations, etc. These details may vary for flexural, compression, tension, combined flexural and compression, and other members and their connections, especially for composite construction.

Example of decisions required for this step of the earthquake-resistant design process are presented below:

— What details should be provided for connections between precast slabs and steel framing?

— How much embedments should be provided for anchor bolts in the concrete footings at the bases of steel columns?

— What details of "collector bars" should be used with diaphragms for appropriate transfer of lateral force through the diaphragm?

— What details of the special transverse reinforcement be used at the locations of columns supporting discontinued walls?

— What details of reinforcement should be used to "confine" concrete to ensure "ductile" behavior?

— What details of reinforcement should be used around openings in shear walls?

— What details of stiffeners and welds should be used to restrict excessive distortions and local buckling in panel regions of a frame joint under cyclic earthquake loading?

— What details of ties should be used to prevent local buckling of reinforcing bars in columns? How should they be hooked to prevent opening after outer cover of concrete has spalled?

— What details of dowels should be used for column footings to columns, wall footings to walls, columns at floor levels where vertical reinforcement can not be offset, bent and extended?

— What details of reinforcement should be used at offsets between columns (where a column is smaller than the one below)?

— What details of reinforcement should be used for beams, framing into both sides of a column or one side of a column?

— How should it be ensured that congestion at beam-column joints of beam reinforcing bars, column reinforcing bars, and joint hoops is avoided to ensure that a design can be assembled and concrete can be placed?

The proposed Expert System will consist of a linked system of Expert System Modules that will help make the decisions of the type mentioned above, and will provide the analyses/evaluations in each of the above steps of the earthquake-resistant building design process.

It should be noted that the Expert Software proposed is not meant to cover the process of conceptual design of the building, i.e., configuring the building components satisfying the usage and other design constrains. The primary scope of this package would be to:

— assess the seismic capability of a given design

— flag if any of the acceptance requirements are not met , and

— provide retrofitting (or re-design) to correct seismic design deficiencies.

4. ARCHITECTURE OF EXPERT SOFTWARE FOR EARTHQUAKE-RESISTANT DESIGN/ANALYSIS OF BUILDINGS

4.1 Introduction

The Expert Software that provides the consultative and computational support for the earthquake-resistant design of buildings must mimic the project activities described in Chapter 3. Since these activities involve a number of different types of decision areas and technologies, each with its own Knowledge and Data Bases, and its own experience base, the desired Expert Software would need to consist of a number of almost independent Expert Systems, each performing within its own area of specialty.

The architecture for such a system will consist of a number of "Loosely-Linked" Knowledge-Based Expert Systems (KBES) with each KBES having its own Knowledge and Data Bases, its own Inference Engine, and Data Acquisition Facility, etc., as described in Chapter 2. However, essential project information, parameters and decisions that must be shared across the boundaries of the individual Expert Systems will be available through the Global Database link or "Blackboard." See References 20, 21, and 37 for a discussion of the "Blackboard" architecture.

For this application, a special "Blackboard" architecture is proposed in which the "Blackboard" integrates a number of KBES's together. Thus the overall design of the Loosely-Linked Expert Systems is as shown in Figure 4-1.

This figure shows the essential building blocks of the overall software package. In the actual software design, these building blocks are enhanced by display facilities, graphics, report generation, error checking and a user-interface.

Since the essential building blocks, including the user interfaces, databases and data acquisition facilities, are almost independent of each other, the program design is highly modular. As new knowledge becomes available, or radical changes occur in the design paradigm, the individual building blocks can be modified or replaced without affecting the other pieces of the software significantly.

The loosely-linked approach also allows the individual data bases for each Expert System building block to be independently designed and located. Thus, data that is scattered over many different locations, or has different designs developed by researchers in different fields, can be accessed and integrated into the concept.

The Expert Software for earthquake-resistant design of buildings will use pre-existing computer programs for many of its analytical and procedural aspects. These programs have been developed over the years by experts in the field of earthquake engineering. They are written in different languages (mostly FORTRAN) for main-frame type batch environments. The loosely-linked design permits the use of this pre-existing software on an independent stand-alone basis.

Finally, the loosely-linked design supports the use of multiple frames in the implementation of the Knowledge Base and the inferencing. Current capabilities in inferencing from a large set of rules, particularly if probabilistic or fuzzy logic concepts are employed, are very limited. Systems tend to become very slow and error-prone when the number of rules in one frame exceeds about 200.

4.2 Component Blocks of the Linked System

A. Area-Specific Expert System Modules

As described in the previous section, 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 4-2.

B. "Blackboard" or Global Data Base

The "BLACKBOARD" design concept for the linked package of Expert Systems allows transfer of information across the individual KBES modules and permits modularity as well as interactive decision making [Ref. 21].

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. Specifically, the information that is contained in the "Blackboard" data base includes the following:

— Project Parameters: Project ID, Title, Client, Project Manager, etc.

— Building Parameters: Type, Usage, Occupancy, Size, Configuration, Cost, Structural Description, etc.

— Site Parameters: Location, Latitude, Longitude

— Seismic Parameters: Seismic Zone, Seismic Sources, etc.

— Owners Preferences: Owners Constraints, Objectives, and Requirements

— Applicable Regulations/Codes

— Results of Decision or Choices Made by the Expert System Modules or Interactively by the User.

The "Blackboard" global data base is very often the only 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.

For reasoning about rules or abstractions from other data, the "Blackboard" can be subdivided into levels—each level representing knowledge that is abstracted or processed from lower level knowledge.

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

Almost all key decisions are made by the user and the Expert System in an interactive manner—the Expert System suggests decisions, choices, or recommended actions; but the final selection is up to the user.

C. 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 and the external programs is shown in Figure 4-2. The external programs do not have to be rewritten or extensively modified to be integrated with the KBES. Instead, input/output links are built from the relevant KBES.

As more and more external data and programs become available, additional links may have to be developed.

Also, as existing programs become obsolete, they may need to be replaced. This can be readily done in a loosely-linked system.

Examples of external programs and data bases for some of the KBES modules in the Earthquake-Resistant design package are:

KBES Module	External Programs and Data Bases
1. Development of Seismic Criteria	Past Projects, Codes—UBC, ATC, etc., Regulatory data bases.
2. Development of Seismic Input	Seismic faults and other seismic sources data bases, Historical seismicity data base, Attenuation curves, Programs for seismic regression analysis, Seismic hazard analysis software, Programs for development and display of response spectra and time histories, etc.
3. Building Response Analysis	Finite Element programs, model and mechanical generation programs, post processors.

D. Internal Programs and Data Bases

As shown in Figure 4-2, 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. Examples of such programs and data bases are:

— Data acquisition and maintenance utilities

— Context/Environment definition utilities and data bases

— KBES analytical tools

— Meta rule development and learning tools

— Pointers to data bases accessed; syntax, semantics and other information on data bases.

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.

E. 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.

The proposed architecture of the Expert Software Package is extremely flexible and modular. For example, if some segment design is altered (e.g., a data base is redesigned to be object oriented), the new elements can be incorporated with the overall architecture with the minimum of reprogramming.

As part of this Phase I project, initial development of two KBES modules utilizing the above architecture was completed. The overall design of the expert software package, called "EXPERTISE," and the specific descriptions of two KBES modules are provided in the next chapter.

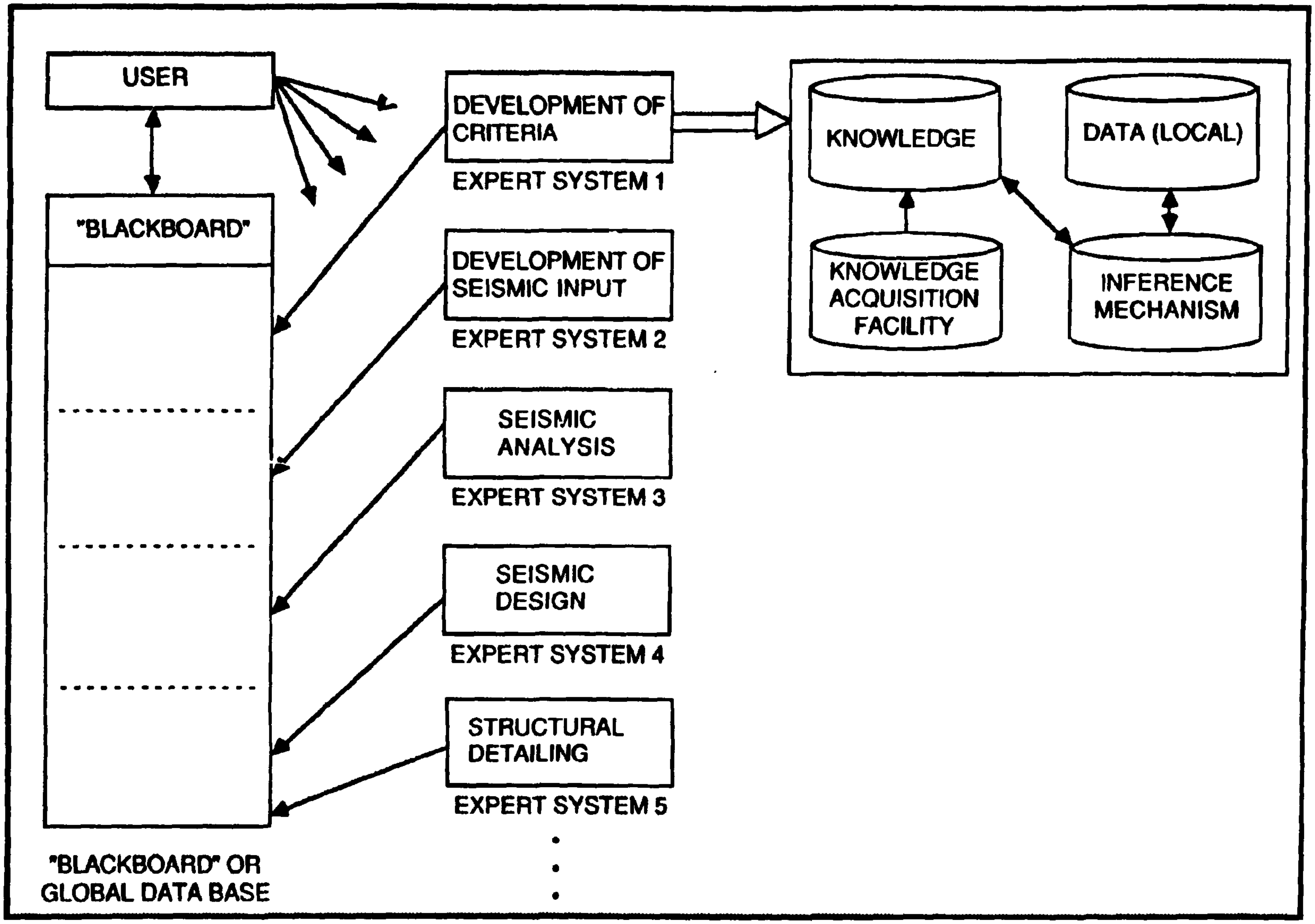

FIGURE 4-1: DESIGN OF A LOOSELY-LINKED SET OF EXPERT SYSTEMS FOR EARTHQUAKE-RESISTANT DESIGN OF STRUCTURES

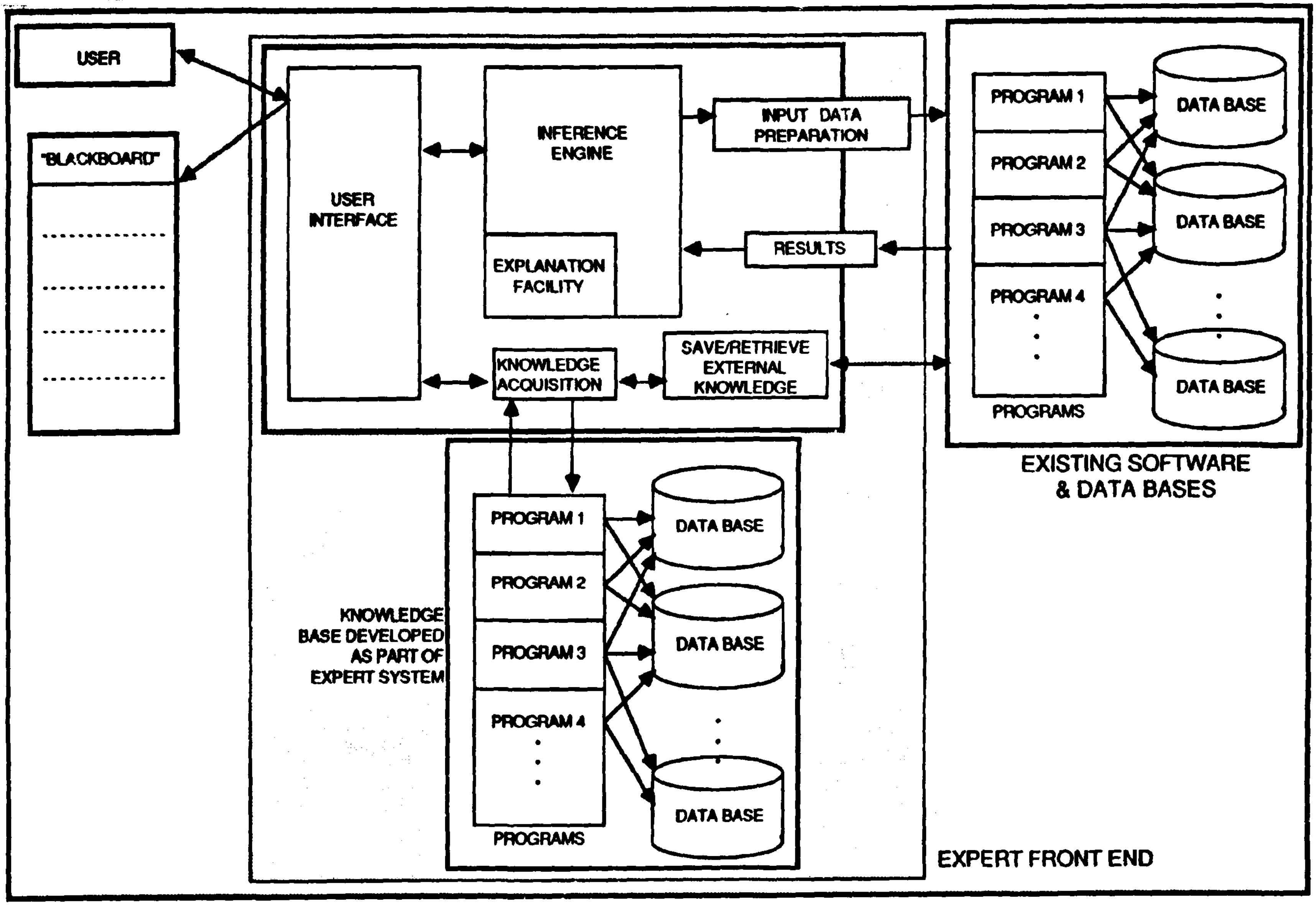

FIGURE 4-2: CONCEPTUAL VIEW OF A COMPONENT EXPERT SYSTEM

5. COMPUTER PROGRAM "EXPERTISE"-DESIGN AND IMPLEMENTATION

The architecture of a proposed expert system software package that would provide consultative support for the earthquake-resistant design of buildings was described in the previous chapter. The main feature of this architecture was a system of loosely-linked KBES's (Knowledge Based Expert Systems), each a modular, self-standing program sharing essential project information, decisions and user input through an interactive global data base called the "Blackboard."

As part of this Phase I effort, two demonstration prototypes of the above-mentioned architecture were developed. These prototypes consist of two of the modules (or KBES components) of the overall software package.

The design and capabilities of this software package, called "EXPERTISE" or "Expert Integrated Software for Earthquake Engineering," is described in this chapter.

In a continuation of this research and development effort in Phase II, we propose to build the complete, comprehensive software package started in this phase of the project. Such a package would contain all the KBES's related to earthquake analysis and design, including extensive, multilevel Knowledge Bases, with expert production rules for the different phases of the project, data base designs, Knowledge Acquisition Facilities, a powerful engineering problem-solving oriented Inference Engine, and friendly, interactive User Interfaces. An outline of this very essential and highly useful continuing effort (in Phase II) on the development of this Expert Software is provided in the next chapter.

5.1 "EXPERTISE" — Building Blocks

The overall design of the software package, "EXPERTISE," consists of several linked 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 5-1.

One KBES is provided for each independent reasoning or consultative module of the overall earthquake design process. Table 5-1 presents a list of the KBES modules that are proposed for the Integrated Expert System Package.

As part of this Phase I effort, KBES modules A.1: "Seismic Analysis Criteria Development Advisor," and B.1: "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.

Each of the KBES modules, developed as part of Phase I, is described in the following sections.

5.2 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:

A. Type of Building Analyses Recommended, e.g.:

— UBC calculations using zonal peak 'g'

— UBC calculations using site-specific peak 'g'

— Computer-aided (or Finite Element Type) Analyses

- Static
- Response Spectrum (Dynamic)
- Time History (Dynamic Linear or Nonlinear)
- Two-Dimensional or Three-Dimensional
- Load combinations recommended in the analyses

B. Type of Site/Foundation Analyses Recommended, e.g.:

— UBC site amplification factor evaluation

— Analysis type required, if any, for seismic site stability evaluation

— Special analyses for local amplification, liquefaction, etc., if UBC is not adequate

— Special Foundation Analysis concerns, e.g., separation, embedment, etc.

C. Type of Seismic Input required to perform seismic analyses in accordance with the criteria recommended in Steps A and B, e.g.:

— Use UBC Zonal 'Z' factor

— Develop site-specific 'g' values

— Develop site-specific 'g' value, and use standard spectral shape

— Develop site-specific 'g' value and corresponding site-specific spectra

— Develop site-specific 'g' and corresponding set of time-histories

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 on 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 "Seismic Analysis Criteria Development Advisor" KBES, similar to all other generic KBES designs, consists of the following modules (See Figure 5-2).

Knowledge Base: Contains all data, processes, rules and intermediate results that are used to make decisions

Knowledge Acquisition Facility: Continually updates the data and incorporates new expert opinions and methodologies into the Knowledge Base

Inference Mechanism: Acts as formal mechanism for manipulating data to test hypothesis and make decisions

User Interface: Acts as user communication mechanism with the KBES

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 the following types of factors and data:

Non-engineering Factors

— Codes/Regulations governing buildings

— Legal aspects, legal precedence

— Safety ordinances

— Risk tolerance (Acceptable risk) of the project/owners

— Other projects, structures in the same area

— Past practice

— Owner preferences

Engineering Factors

— Project ID and project related data

— Seismicity level

— Site/Foundation type

— Soil characteristics

— Building usage, importance, and occupancy

— Building size and cost

— Building structural type (structural system, material, etc.)

— Building Configuration

— Unusual aspects, if any, of the structure, etc.

Thus, the Knowledge Base of this KBES will contain data that has bearing on all of the above 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. Appendix 'A' provides documentation on a review of building designs for significant buildings in earthquake-prone zones. The rules for the functioning of this expert module were generated from such a review, coupled with judgment.

The Knowledge Base will contain 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. The contents of the Knowledge Base and the portion of the "Blackboard" facility used by this KBES module are listed below.

5.2.1 Knowledge Base for KBES Module: "Seismic Analysis Criteria Development Advisor"

5.2.1.1 Static Data

Non-engineering Data

— Building Design Codes - UBC, ATC, SEAOC, etc.

— State and Federal Regulations pertaining to buildings

— Local ordinances and conventions regarding buildings

— Safety related requirements

— Environmental data

— Data base of past projects in region

— Risk profiles

— Insurance requirements

Engineering Data

— Local seismic sources

— Historical seismicity

— Geologic and tectonics data

— Regional soil characteristics

— Site soils report

— Soils reports on associate projects

— Building - structural data

— Building analysis programs, e.g., finite element programs with library of finite element types

— Soils analysis programs

Rules/Judgments/Heuristics Data

— Assessments based on legal precepts

— Risk assessments

— Assessment, valuation of different analyses vs. benefits, (e.g., when to use what type of analyses)

— Seismic hazard assessments/rules

— Rules regarding analysis decisions, etc.

5.2.1.2 "Blackboard" Data

Project Data

— Project I.D.

— Project Manager

— Client/Owner

— Applicable code(s)

— Location

— Site I.D.

Site/Foundation Data

Building Data

Conclusions/Choices

5.2.2 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 in "EXPERTISE" 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.

More complex Inferencing Mechanisms do exist and as the "EXPERTISE" software incorporates increasingly advanced consultative features in Phase II, the Inferencing Mechanisms will be modified.

5.2.3 Phase I Demonstration Version of the KBES Module: "Seismic Analysis Criteria Development Advisor"

The Phase I demonstration prototype of the "Seismic Analysis Criteria Development Advisor" KBES in "EXPERTISE" contains only a portion of the Engineering Knowledge Base. Much of the data that it uses in its inferencing, as well as the conclusions developed, are saved on the "Blackboard" (Global data base). Appendix B provides a screen-by-screen walk through this module of "EXPERTISE."

An interactive, menu-driven User Interface was developed for the prototype "EXPERTISE." This is also demonstrated in the screen-by-screen example session documented in Appendix B.

Even though this prototype module currently represents only some of the engineering aspects of the reasoning that go into the establishment of the seismic analysis criteria for a building design project, its implementation, power and modularity are very clearly demonstrated.

5.3 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:

A. Select the seismic sources in a region in the neighborhood of the site

This module helps decide on the extent of the region based on building and geologic characteristics, and helps pick the seismic sources based on a catalog data base of the faults and other sources in the vicinity. It provides judgment regarding the capabilities of the sources in regard to producing motions at the site for which the seismic response would be important.

B. Select the historical earthquakes in the vicinity of the site

This module uses a data base of historical earthquakes to select the ones that are significant, assigns a magnitude or intensity to the historical earthquake if none exists, using damage descriptions and other data, and assigns the earthquake to the appropriate seismic source. All these steps require considerable judgment and reasoning regarding the historical seismicity data.

C. Perform a site-specific seismic hazard analysis

This module integrates the above data into a seismic hazard model using estimated attenuation relationships from seismic sources to the site and a regression analysis to determine the fault earthquake probabilities. The use of the module results in a Probability of Exceedance Curve for a given level of shaking ('g'), as shown in Figure 5-3. From this, the program selects a recommended 'g' for the project.

The components of the "Seismic Hazard Analysis and Seismic Input Development Advisor" KBES are the same as for the "Seismic Analysis Criteria Development Advisor" KBES described in the previous section.

5.3.1 Knowledge Base for KBES Module: "Seismic Hazard Analysis and Seismic Input Development Advisor."

The Knowledge Base for this KBES requires the following data elements:

Static Data

- Seismological procedures and practices
- Geologic and tectonic data
- Historical seismicity by region
- Regional seismic sources
- Attenuation relationships
- Geotechnical engineering procedures for determining local amplifications, etc.
- Project risk profile
- Past projects data

Rules/Judgments/Heuristics

- Evaluation of regional seismicity
- Rules for selecting region of influence for seismic sources
- Rules for adjusting incomplete or fuzzy historic earthquake data
- Rules for selecting attenuation relationships
- Rules for long period motions vs. short period motions, etc.

TABLE 5-1: PROPOSED KBES MODULES

KBES MODULE	DESCRIPTION
A. Seismic Criteria Development	
A.1 Building/Foundation Analysis Advisor	Provides decision support for the type of building & site seismic analysis required, e.g., UBC, spectral analysis, etc., and the type of seismic input required to conduct the analysis recommended.
A.2 Acceptance Criteria Development	Assistance with the development of seismic acceptance criteria and qualification standards for the building components, subcomponents and equipment.
B. Seismic Input Development	
B.1 Regional Seismic Hazard Analysis	Consultative support in selecting regional seismic sources, defining historical regional seismicity and performing a probabilistic, sit-specific seismic hazard evaluation.
B.2 Development of Site-specific Seismic Inputs	Develop site-specific 'g' level, and if required, spectra and time histories to be used for building analysis/design.
C. Seismic Analysis	
C.1 UBC Analysis Advisor	Support with a UBC type seismic qualification, e.g., establish UBC factors, types, perform checks and advise on design changes to qualify for UBC.
C.2 Analysis Parameters Development	Nature, extent and objective of the seismic analysis—e.g., loadings/load combinations, service states, failure modes, boundary conditions, linear vs nonlinear, 2D or 3D, etc.
C.3 Model Development Advisor	Assistance with finite element model development—e.g., substructuring of the building, essential elements, model type, extent and requirement of finite element mesh.
C.4 Analysis Execution	Analysis execution support—e.g., monitoring convergence, nonlinear regions, error estimation, solution schemes, interactive advice on adjusting analysis parameters such as time step, frequency range/step, etc.
C.5 Post Processing Expert System	Post processing support: display of relevant results, contours, vector diagrams, load combinations, mode shapes, displacement checks, flagging members/joints for redesign, code checking.
D. Design	
D.1 Building Design/Redesign Advisor	Provides recommendations on design modifications required for the building to seismically qualify.
D.2 Member/Joint Detailing	Support with member and joint detailing

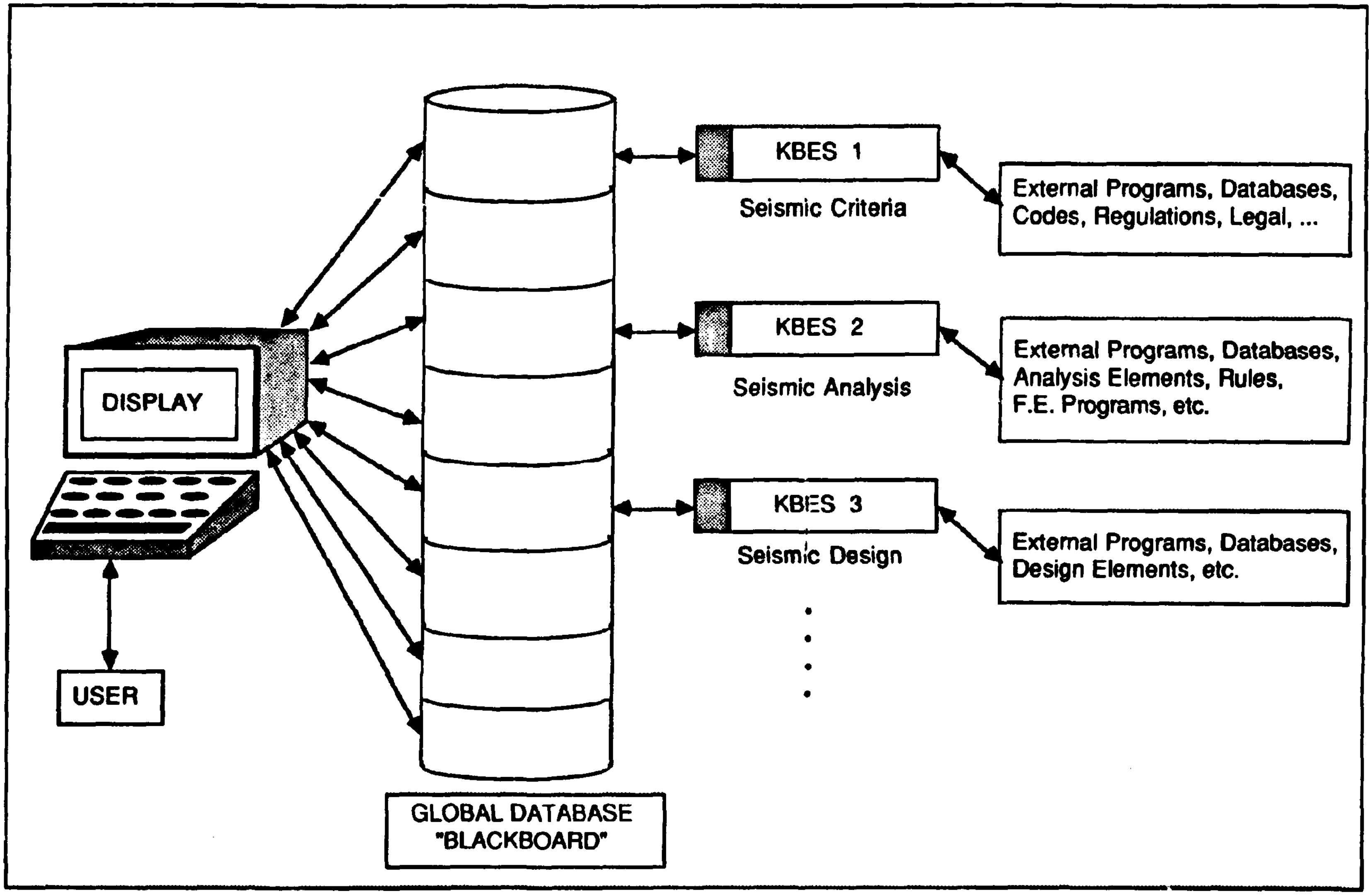

FIGURE 5-1: BLOCK DIAGRAM ILLUSTRATING COMPONENTS OF SOFTWARE PACKAGE, "EXPERTISE"

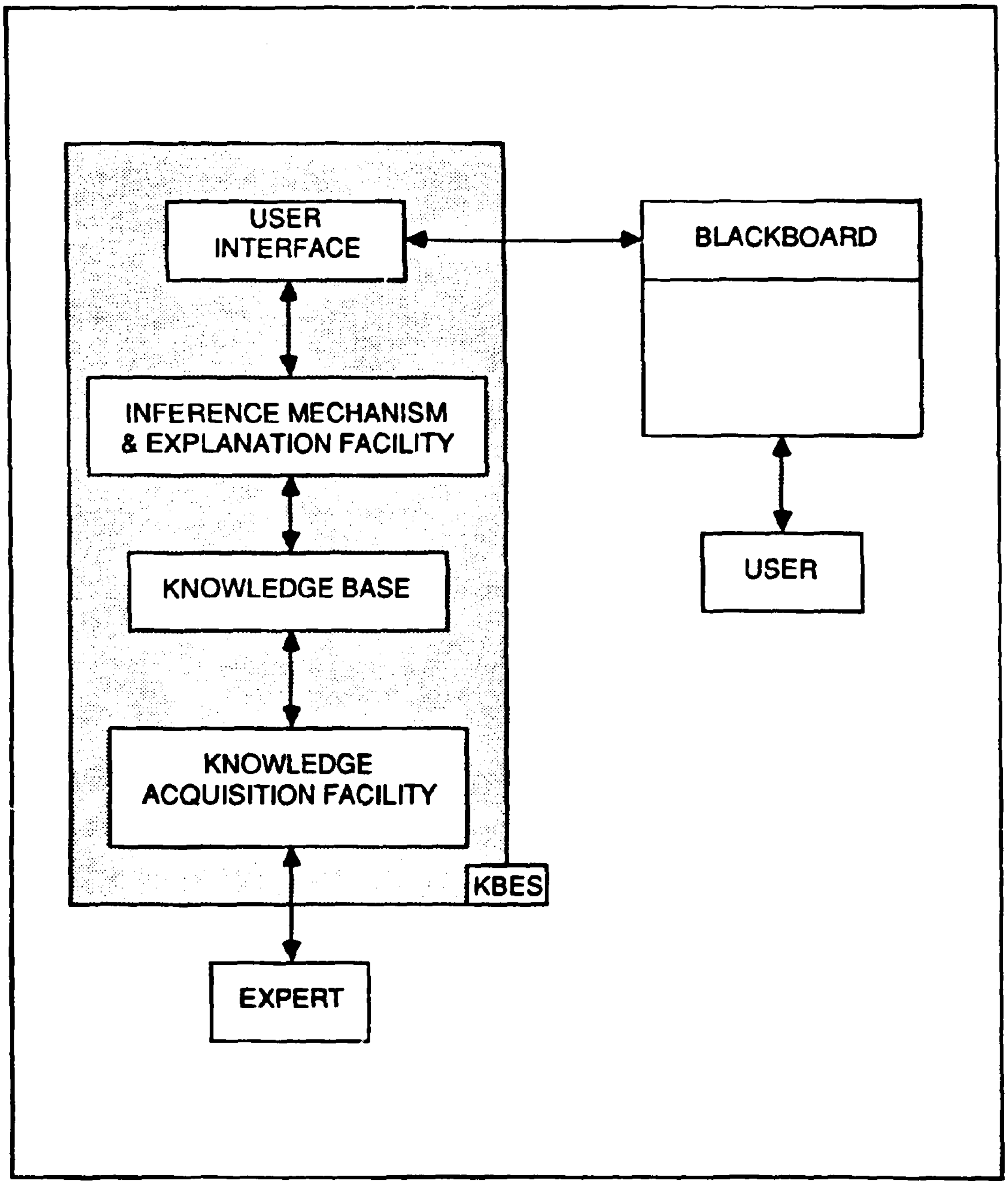

FIGURE 5-2: COMPONENTS OF KBES MODULE- "SEISMIC ANALYSIS CRITERIA DEVELOPMENT ADVISOR"

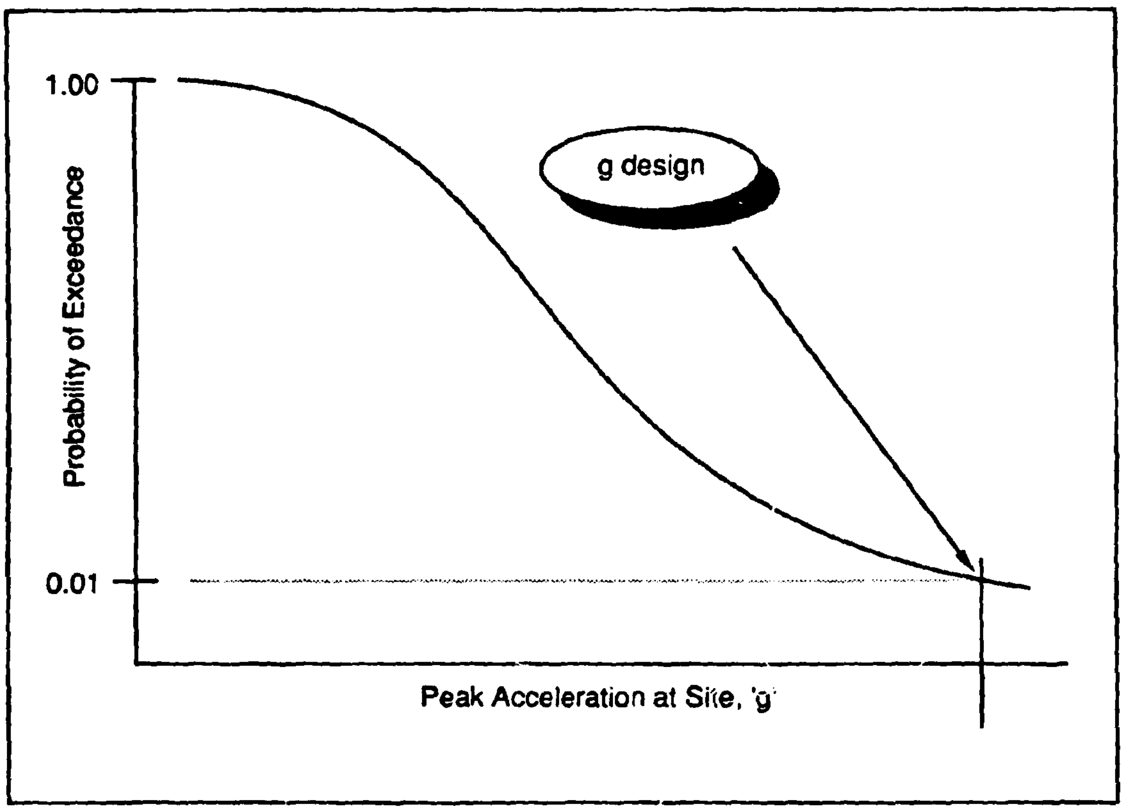

FIGURE 5-3: RESULTS FROM THE KBES MODULE- "SEISMIC HAZARD ANALYSIS AND SEISMIC INPUT DEVELOPMENT ADVISOR," A PROBABILITY OF EXCEEDANCE CURVE FOR AN EXPECTED LEVEL OF SHAKING 'g' AT THE SITE

6. RECOMMENDATIONS FOR FUTURE WORK (PHASE II)

In Phase I research and development work, presented in the previous chapters, an important conceptual framework for the application of AI technology to the domain of Earthquake-Resistant Design of Buildings has been developed and its feasibility has been demonstrated by building functioning software modules. We believe that this framework provides an excellent foundation on which to build a complete, integrated software package that will cover all major aspects of the seismic design process.

In order to complete the development of such a package, significant research and development efforts are still required. A major portion of this work involves research in the integration of knowledge, procedures, and judgments/heuristics associated with the various steps of the earthquake-resistant design process into functional KBES (Knowledge Based Expert System) modules. The other aspects of the remaining work are the design and development of the supporting modules and facilities, e.g., an interactive user interface, data base design and implementation, and a flexible "black-board" support facility, etc.

This chapter describes the research and development effort that, the authors recommend, should be undertaken in Phase II of this project to produce an integrated expert software package covering the major aspects of earthquake-resistant design of buildings.

Specifically, the next stage of development needs to complete the KBES modules for "EXPERTISE" that have been identified in this phase. These modules are listed in Table 5-1.

The following is a list of investigations and development tasks that must be performed as part of the recommended Phase II scope of work:

1. Complete the Knowledge Bases associated with the KBES modules of the Integrated Expert Software Package.

2. Investigate the applicability of alternate inferencing and control mechanisms that are appropriate to the decision/control support required in this Expert software. Implement the selected Inference Mechanisms.

3. Develop the data base design for the knowledge and other data bases that most efficiently fulfills the Expert Package's data storage, retrieval, analysis, integration, reliability, maintenance and upgradability requirements. Implement the optimum data base design that is developed.

4. Finalize the contents and the facilities provided with the "Blackboard." Implement the final "Blackboard" design that serves all the KBES modules in the package.

5. Develop the Interface software elements required for the efficient functioning of the Integrated Software Package. The most important software module in this category is the User Interface. Other elements that need design and implementation are:

   — Context Module

   — Report Generation Module

   — Knowledge Acquisition Module

Each of the above five categories of tasks is described in following sections.

6.1 Completion of the Knowledge Bases associated with the Expert Software Package, "EXPERTISE"

The development and programming associated with the Knowledge Bases of the KBES modules of "EXPERTISE" is a major outstanding effort and a key to the efficient and effective functioning of the software package.

For each KBES, which represents an independent frame of knowledge or technology associated with the seismic design process, there is a vast range of data, knowledge and expert experience that will need to be identified and cataloged. Much of the knowledge which is in the form of expert opinions, judgments or heuristics, will have to be developed via interviews with experts, review of past practices on earthquake engineering projects and integration of regulation and regional design "culture."

The nature of the contents of the Knowledge Base varies from one KBES to another. Typically, the types of information that is required in the Seismic Analysis/Design Expert System are:

— Data Elements, e.g., data base of structural members (e.g., standard AISC sizes), materials and their properties, past project data, soil and seismicity data, finite element libraries, code contents (e.g., UBC, SEAOC, ATC, ACI), etc.

— Procedural Elements, e.g., computer programs that retrieve and process data, statistical and regression analysis programs, finite element programs, optimization routines, etc.

— Knowledge Elements, e.g., rules regarding the control of analysis and design actions, decision making principles, judgments, heuristics, problem specific constraints, or cost functions that must be optimized, etc.

— Meta rules - or rules about the Knowledge Elements. These allow the KBES to possess learning-type characteristics by automatically modifying the rules and heuristics as more data and experience becomes available to the software package

An efficient way to store the data and the knowledge base for easy retrieval and upgradability will be a part of each KBES design. This task is described in more detail in section 6.3.

6.2 Design and Implementation of Inferencing and Control Mechanism

The Inferencing and Control Mechanism is the brains of the Knowledge-Based Expert System. The functions of this module are:

A. Monitor the execution of the program by using the Knowledge Base and selectively modifying the context.

B. Control the execution of the program by firing the Knowledge Base rules and invoking the appropriate software resource.

C. Solve subproblems and make decisions from the Knowledge Base by using "Problem Solving" or "Inferencing" Strategies.

Many different types of capabilities can be provided in an Inference Engine for solving different types of problems and performing control functions.

Some of the inferencing and problem solving strategies commonly used have been mentioned in Chapter 2 of this report; namely:

— Forward Chaining

— Backward Chaining/Backtracking

— Heuristic Operations

— Hierarchical Planning and Least Commitment

— Constraint Handling

— Reasoning by Analogy

— Fuzzy Reasoning

The prototype Expert Systems developed in Phase I of this effort use a strategy based on sequential firing of rules with Forward or Backward Chaining.

Future work will refine the types of Inferencing and Control Mechanisms available in "EXPERTISE." This will allow more general manipulation of the information in the Knowledge Base and sophisticated control, reasoning and "rules-about-rules" or "meta rules" manipulation. It will also allow "EXPERTISE" to handle uncertainties.

6.3 Design and Implementation of the Knowledge Base Architecture

As mentioned in Section 6.1, the KBES Knowledge Bases contain a potentially large amount of data. In addition, the Knowledge Bases cover many different types of information, procedures and other items.

The design of a data base that can store the Knowledge Base of the different KBES modules is a formidable and challenging task. An ideal Knowledge Base must possess the following characteristics:

— Ability to store different types of objects. In addition to static data elements—numbers, strings,etc., the data base must be able to store functions, abstractions, rules, etc.

— Ability for fast retrieval, efficient storage

— Easy upgradability and maintainability of the data base

— Ability to work in an integrated fashion with other data bases and with the Inference Mechanism, Flexible querying and data processing

— The data base should not require duplication in storing similar concepts or objects

Many different designs have been explored and implemented for Civil Engineering data bases. [Ref. 50, 34, 18, 38, 27, 10, 11]

For the Phase I effort, "EXPERTISE" was provided with a simple, hierarchichal data base design, which is adequate to demonstrate the working of the prototype KBES modules.

In Phase II, it is proposed that a Knowledge Base design that uses the latest concepts in data base architecture be used. In particular, the design and implementation of an object-oriented data structure, with a network relationship between the objects, will be studied and refined for the final Integrated Expert System for Earthquake-Resistant design of buildings.

6.4 Finalization of the "Blackboard" Design & Implementation into "EXPERTISE"

As mentioned in Chapter 2 of this report, the "Blackboard" architecture facilitates the following functions in an Integrated Expert Software Package:

— Providing a Global Data Base link between all the KBES modules

— Providing a convenient mechanism for display and interactive decision making

— Displaying intermediate results from the inferencing, hypotheses, control decisions, etc., for analysis and user action

— Retaining decisions made by the different segments of the software for input or analysis by other segments

— Controlling the level of abstraction of the Inferencing Process

In the Phase I development of "EXPERTISE", the "Blackboard" consists of an interactive, global data base, which retains information pertinent to all the significant problem solving aspects and facilitates the linking together of the KBES modules.

In Phase II, this concept needs to be further refined to cover the many sophisticated needs of the final "EXPERTISE" design and implementation.

6.5 Development of Interface Software for the Efficient Functioning of "EXPERTISE"

Many support facilities are required to make a software package, such as "EXPERTISE," truly integrated. It is recommended that some of these facilities be developed as part of the Phase II effort.

Support facilities that must eventually be added to "EXPERTISE" are:

— User Interface

This will be an interactive user language that will provide the communication link between the user and the software. By designing a user interface that is easy to use and learn, the program's internal details will be shielded from a user, and training time with the program will be substantially reduced.

The User Interface module will have several input/output/display subprograms to draw upon; namely:

- Graphics packages
- Menu driven input/output screens
- Finite element pre- and post-processors

— Knowledge Acquisition Facility

This subprogram will assist in keeping the Knowledge Bases current by continually adding and updating information.

— Report Generation Module

This module will provide final documentation for the seismic design project. It will describes the design steps, the criteria, the decisions made along the way (and the reasons behind them), the analyses performed, the design and details developed, and the qualification/critique of the design.

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APPENDIX A

SAMPLE EXAMPLES OF SELECTED EARTHQUAKE-RESISTANT BUILDING DESIGNS FOR VERIFICATION OF TWO DEMONSTRATION MODULES OF "EXPERTISE"

APPENDIX A

SAMPLE EXAMPLES OF SELECTED EARTHQUAKE-RESISTANT BUILDING DESIGNS FOR VERIFICATION OF TWO DEMONSTRATION MODULES OF "EXPERTISE"

For the design of the architecture of the proposed expert system, and especially for the development and verification of the rules for the prototypes of the two KBES modules of the expert system, "EXPERTISE", viz., the "seismic analysis criteria development advisor" module and the "seismic hazard analysis and seismic input development advisor" module, a range of existing earthquake-resistant building designs, including their seismic design criteria and seismic inputs, as well as other relevant data, were reviewed. A total of thirteen sample examples of buildings, all located in California, were used for this purpose. They consisted of a wide range of building types, structural systems, material types, number of stories, foundation/soil types, with a variety of seismic design criteria, seismic input, and the analysis and design procedures. The objective was to review the reasoning process in reaching the conclusions for the analysis criteria and the seismic input, given the information for each building. Furthermore, the two KBES modules were used for each building to ensure that the same conclusions were reached by the modules as by the real designers (with experience and expertise). It was found that, in general, the two KBES modules provided decisions and conclusions consistent with the real ones made during the actual design process. Thus, the reasoning of the rules used in the two KBES modules of EXPERTISE were validated.

Following is a brief discussion of the reasoning associated with the selection of the seismic design criteria, seismic input and analysis procedure for each building, based on the information about the building, soil and the seismicity available to the designer at the beginning of the design process. This available information usually includes the following:

— Type of Building, its occupancy and its Importance

— Location of the building

— UBC Seismic Zone where the building is located

— Type of Material and Structural System]

— Size of building, e.g., number of stories

— Underlying Soil type and Water Table Location

— Type of Foundation

— Other Relevant Information

The use of the above information to reach the appropriate conclusions regarding seismic design criteria, seismic input and the analysis procedure is discussed below, for each sample building. All relevant information for each building is summarized in Table A-1.

1. **Terman Engineering Center, Stanford Universivty Campus, California**

   The Terman Engineering Center, located at Stanford University Campus, California, is within UBC Seismic Zone 4. The structural system consists of concrete shear walls, in conjunction with timber frames, the shear walls constituting the primary lateral load resisting system. The building has five stories above ground and two stories underground. The underlying soil is clay. The soil report also indicates that there are no landslide or liquefaction potentials.

   Since the building is meant for normal office and classroom use; it has a good lateral load resisting system; it is constructed of good material, it is not too tall; has spread footings supported on very competent soil (with no liquefaction potential); has no unusual characteristics or considerations; thus, in spite of the fact that it is located in UBC Zone 4, it can be concluded that it is sufficient to use UBC Code for its design and that it is not necessary to perform any special analyses (e.g., response spectrum or time history analyses).

2. **Medical Center (Expansion), Stanford University Campus, California**

   The medical center (expansion) building, located at Stanford University Campus, California, is within UBC Seismic Zone 4. The building contains very expensive equipment on different floors. The structural system consists of a moment-resisting steel frame. The building has four stories above ground, and a basement. The underlying soil is clay. The soil report also indicates that there are no landslide or liquefaction potentials.

   Since the building has a good structural system; it is constructed of good material; it is not too tall; has spread footings supported on very competent soil (with no liquefaction potential); it can be concluded that UBC code should be used for its design. However, since it is an emergency building with very expensive equipment on different floors, it is also concluded that, in addition, a site-specific response spectrum, and a matching time history be developed, and a time history analysis be performed. This is essential for the development of floor spectra at various floor levels of the building which could be used for the design of the very expensive equipment located at those floors.

3. **Parking Structure, Stanford University Campus, California**

   The parking structure, located at Stanford University Campus, California, is within UBC Seismic Zone 4. The structural system consists of a ductile moment resisting frame, in conjunction with post-tensioned concrete beams and slabs. The structure has six stories. The underlying soil is clay. The soil report also indicates that there are no landslide or liquefaction potentials.

   Since the structure is meant for normal parking use; it has a good lateral load resting system; it is constructed of good material; it is not too tall; it is supported on very competent soil (with no liquefaction potential); has no unusual characteristics or considerations; thus, in spite of the fact that it is located in UBC Zone 4, it can be concluded that it is sufficient to use UBC code for its design and that it is not necessary to perform any special analyses (e.g., response spectrum or time history analyses).

4. **Graduate School of Business (Expansion), Stanford University Campus, California.**

   The Graduate School of Business (expansion) building, located at Stanford University campus, California, is within UBC Seismic Zone 4. The structural system consists of a combined concrete shear wall/moment resisting steel frame system. The building has three stories above ground and a partial basement. The underlying soil is clay. The soil report indicates that there are no slide or liquefaction potentials.

   Since the building is meant for normal office and classroom use; it has a good lateral load resisting system; it is constructed of good material; it is short; has spread footings supported on very competent soil (with no liquefaction potential); has no unusual characteristic or considerations; thus, in spite of the fact that it is located in UBC Zone 4, it can be concluded that it is sufficient to use UBC Code for its design and that it is not necessary to perform any special analyses (e.g., response spectrum or time history analyses).

5. **Law School, Stanford University Campus, California**

The Law School building, located at Stanford University Campus, California, is within UBC Seismic Zone 4. The structural system consists of concrete shear walls/moment resisting steel frame. The building has three stories. The underlying soil is heavy clay. The soil report indicates that there are no slide or liquefaction potentials.

Since the building is meant for normal office and classroom use; it has a good lateral load resisting system; it is constructed of good material; it is short; has spread footings supported on very competent soil (with no liquefaction potential); has no unusual characteristics or considerations; thus, in spite of the fact that it is located in UBC Zone 4, it can be concluded that it is sufficient to use UBC Code for its design and that it is not necessary to perform any special analyses (e.g., response spectrum or time history analyses).

6. **Sweet Hall (Computer Center), Stanford University Campus, California**

The Sweet Hall (Computer Center), located at Stanford University Campus, California, is within UBC Seismic Zone 4. The structural system consists of a moment resisting steel frame. The building has four stories, plus an attic. The underlying soil is heavy clay.

Since the building is meant for normal office and classroom use; it has a good lateral load resisting system; it is constructed of good material; it is not too tall; has spread footings supported on very competent soil; has no unusual characteristics or considerations; thus, in spite of the fact that it is located in UBC Seismic Zone 4, it can be concluded that it is sufficient to use UBC Code for its design and that it is not necessary to perform any special analysis (e.g., response spectrum or time history analyses).

7. **Union Bank Building, Los Angeles, California**

The Union Bank Building, located in the city of Los Angeles, California, is within UBC Seismic Zone 4. The structural system consists of ductile moment resisting frame. The building has 42 stories. The underlying soil is silty, with fractioned shales.

Although the building is meant for normal banking use; it has good lateral load resisting system; however, the building is very tall, is located in UBC Seismic Zone 4 and is supported on low to medium quality soil; thus, it is not sufficient to use UBC Code. A time history (linear elastic dynamic) analysis, therefore, needs to be performed, especially since story-to-story drift is also an important consideration for the design. Furthermore, the analysis is performed for seismic loads higher than the UBC/LA City code. (In this case, two times the seismic requirement for the LA City code is used for the peak ground acceleration).

8. **Municipal Court, Van Nuys, California**

The Municipal Court, located in Van Nuys, California, is within UBC Seismic Zone 4. The structural system consists of a moment resisting steel frame. The underlying soil is silty clay.

Since the building is meant for important use and is an emergency building, and it is supported on soft to medium soil; in spite of the fact that it is a short building with a good lateral resisting system, it is concluded that a site-specific response spectrum be used for its design.

9. **Certified Life Building, Los Angeles, California**

The Certified Life Building, located in Los Angeles, California, is within UBC Seismic Zone 4. The structural system consists of concrete shear walls, distributed nonuniformly in plan. The building has fourteen stories above ground. The underlying soil is clay and silty sand. The water level is 26 to 32 feet below grade. The building is founded on cast-in-place piles and grade beams.

Since the building is meant for normal office use; and although it has poor underlying soil and high water table, but since it is supported on piles, it is concluded that it is sufficient to use UBC Code for its design. However, since the shear walls are nonuniformly distributed in plan, a special torsional analysis needs to be performed.

10. **State of Alaska Court House, Anchorage, Alaska**

The State of Alaska Court House, located in Anchorage, Alaska, is within UBC Seismic Zone 4. The structural system has a structural steel dual system (moment resisting and braced frames) for superstructure, where the eccentrically braced frames resist the entire lateral load, the moment resisting frames are capable of resisting 25% of the shear — thus providing redundancy. The substructure is made of reinforced concrete and steel. The number of stories are 5 in one wing and 4 in the other wing. The soil type is cove clay wh.ch could become unstable under seismic loads. There is potential for both, liquefaction and landslide.

Since the building is an emergency building and has poor underlying soil conditions; in spite of the fact that it is not very tall and has a good lateral load resisting system, it is concluded that site-specific response spectrum analysis be used. Furthermore, special liquefaction analysis is to be performed, and displacement criterion is to be set, in addition to acceleration criterion, for design.

11. **KB Valley Center, Lost Angeles, California**

The KB Valley Center, a shopping center, located in Los Angeles, California, is within UBC Seismic Zone 4. The structural system is a ductile moment resisting steel frame. The building has 16 stories above ground. The underlying soil is medium to stiff silty sand, with ground water level at 30 ft. below surface.

Since the structure is meant for normal shopping center use; it has an excellent structural system; it is supported on piles (so that there is no need for concern about poor soil condition and high water table); it is concluded that it is sufficient to use UBC code for its design.

12. **Muir Medical Center, Hollywood, California**

The Muir Medical Center, located in Hollywood, California, is within UBC Seismic Zone 4. The structural system consists of concrete shear walls, in conjunction with moment resisting steel frame. The building has eleven stories, and a basement. The underlying soil is silty sand up to 21 ft. below grade and then firm silty clay. The foundation consists of caissons and cast-in-place piles.

Since the structure is meant for important use (it is a medical center); it is supported on caissons and piles (therefore, poor soil conditions should not be of concern); although it has an excellent structural system, it is concluded that the building be designed for base shear and torsion higher than the code, although no special analysis (such as response spectrum or time-history analysis) is recommended.

13. **Kagima International Building, Los Angeles, California**

The Kagima International building, located in Los Angeles, California, is within UBC Seismic Zone 4. The structural system consists of three-dimensional ductile moment resisting steel frames. The building has 15 stories, and is supported on fine sand up to 28 ft. below grade, and then siltstone. The water table is low.

Although the building is meant for normal office use only and the structural system is adequate; but, since the soil is poor quality, it is concluded that UBC code be used, but a detailed soil-structure interaction study and a ductility study be performed.

A-8

TABLE A-1
SAMPLE EXAMPLES OF BULDING DESIGNS AND RELATED INFORMATION

Sample No.	Building Name	Location	Seismic Zone	Type
1	Terman Engg. Center	Stanford University	4	Mixed System: Timber frame/ concrete shear wall. Assumption is that SW will take all the lateral load (K=1.33)
2	Medical Center Expansion	Stanford University	4	Moment resisting steel frame
3	Parking Structure	Stanford University	4	Beam and slab (post tensioned concrete) - Ductile moment resisting frame.
4	Graduate School of Business (Expansion)	Stanford University	4	Shear wall Moment resisting steel frame. Masonary verneir.
5	Law School	Stanford University	4	Steel frame/Reinforced concrete shear walls (2,3 story)
6	Sweet Hall (Computer Center)	Stanford University	4	Moment resisting steel frame
7	Union Bank Building	Los Angeles	4	Moment resisting steel frame
8	Van Nuys Municipal Court	Van Nuys	4	Moment resisting steel frame
9	Certified Life Building	Los Angeles	4	Concrete shear wall
10	State of Alaska Courthouse	Anchorage	4	Superstructure: Structural Steel du system; eccentrically braced frames resist entire base shear and moment resisting frames resis 25% base shear (redundant). Sub-structure: Reinforced concrete an composite steel construction
11	KB Valley Center (shopping center)	Los Angeles	4	Ductile moment resisting steel frame
12	Muir Medical Center	Hollywood	4	Concrete shear wall Moment resisting steel frame
13	Kagima Int.	Los Angeles	4	3-D ductile moment resisting steel frame.

No. of Stories	Soil Information	Seismic Design Criteria	Remarks
5 above ground 2 below ground	Extensive soil study conducted Results: clayey soil; no liquefaction potential; no landslide potential	UBC 1972: no special analysis conducted	Spread Footings
4 + Basement	Alluvial deposits (Clay); no liquefaction potential; no landslide potential.	UBC 1985; however, in addition, site specific and time history analyses were performed	Spread Footings
6	Site soil study conducted. Results: clayey soil; no liquefaction potential; no landslide potential.	UBC 1985: no special analysis conducted.	Shallow spread footing
3 + partial basement	Detailed geotechnical report available. Clayey soil; no liquefaction potential; no landslide potential.	UBC 1982: no special analysis conducted.	Spread Footings
3	Heavy clay; no liquefaction potential; no landslide potential.	UBC 1970: no special analysis conducted.	Spread Footings
4 + attic	Detailed soil study available. Results: heavy clay	UBC 1982: no special analysis conducted.	Spread Footings
42	Silty, fractionated shales	UBC/LA 1964: Time History study conducted	Elastic/dynamic analysis; drift design; designed for seismic loads higher than code; 2 x LA code; Spread Footings.
	Detailed soil investigation. Silty clay	Site specific seismic analysis conducted	Detailed soil investigation provided site-specific response spectra.
14	Clay and silty sand. Water level 26 to 32 feet below grade.	UBC/L.A. 1974: Torsional analysis performed	Founded on cast-in-place piles and grade beams.
5 in one wing 4 in 2nd wing	Detailed soil analysis of site conducted (static and dynamic analysis).	Site specific response spectra and special criteria for ground shaking and displacement were developed.	Soil-structure interaction was studied
16	Medium to stiff silty sand, ground water level 30' subsurface	UBC 1970: no special analysis conducted	founded on 54' driven concrete piles
11 + basement	silty sand up to 21' below grade, then firm silty clay	UBC 1964: Designed for higher shear and torsional capacity than code.	Founded on drilled and belled caissons and drilled and cast-in-place piles
15	Fine sand up to 28 feet below grade, then siltstone. Low water table	UBC 1970: Soil-structure Interaction and Ductility studies conducted.	Founded on spread footings

APPENDIX B

SAMPLE SCREENS OF "EXPERTISE"

APPENDIX B
SAMPLE SCREENS OF "EXPERTISE"

This appendix presents a walk-through the "Seismic Criteria Development Advisor" KBES module of "EXPERTISE," screen by screen for a sample example of a building. The first few screens for the "Seismic Hazard Analysis and Seismic Input Development Advisor" KBES module are also shown. The Medical Center (Expansion) building, located at Stanford University Campus, California, has been selected for this purpose. The screens of "EXPERTISE" for this sample example are presented in Figures B-1 through B-20.

Figure B-1 shows the Title/Logo screen for "EXPERTISE."

Figures B-2 and B-3 show the main menu without and with one of the HELP menus, respectively. This menu is for the full-fledged final software package. Item 1 (File Operations) and Items 2 and 3 (KBES Modules, "Seismic Criteria Development" and a major part of "Seismic Input Development") have been developed in Phase I, and are currently available.

Figures B-4 and B-5 shows the menu for "Seismic Criteria Development" KBES module, without and with the HELP menu, respectively.

Figures B-6 and B-7 show the input screens for site location information, without and with one of the HELP menus, respectively, where the location, seismic zone, seismicity, latitude and longitude of the site are input. The sample example Medical Center (Expansion) building is located in California, UBC Zone 4, and is very close to known faults nearby, as shown on this screen. The default option is California.

Figures B-8 and B-9 show the input screens for site-soil and terrain, without and with the HELP menu, respectively. In addition to the general terrain information, site characterization and soil information, the ground water level information is also included. The HELP menu in Figure B-9 shows the different options available for site characterization.

Figure B-10 shows the input screen, with one of the HELP menus, for additional information on the soil type, such as whether it it fine grained or coarse grained, saturated or unsaturated, as well as the blow count. The HELP menu shows all the different options available.

Figure B-11 shows the input screen for the building without any HELP menus, querying whether it is a new or old building.

Figures B-12 and B-13 show the input screens for more detailed information about the building, without and with one of the HELP menus. The user is asked to provide information about the building usage, structural type, height, cost and foundation type. The HELP menu in Figure B-13 lists all the options available to the user for the building structure type.

Figures B-14 and B-15 show the input screens, without and with one of the HELP menus, for additional information required about the building. The user is queried about safety requirements, unusual characteristics about the building and materials, unusual joints, and the importance of the equipment in the building.

Based on all the above information provided by the user, shown in the previous figures, the KBES module on "Seismic Criteria Development" provides its recommendations to the designer. These recommendations are presented in Figures B-16 and B-17, without and with one of the HELP menus. The HELP menu shown in Figure B-17 provides all the options available for the type of building analysis.

For the sample example under consideration, namely, Medical Center (Expansion) building, located at Stanford University, California, the following final recommendations are provided by the KBES module on "Seismic Criteria Development" of "EXPERTISE."

— Time History Analysis Recommended

— Evaluate Site - Amplification, Hand Calculations OK

— No Evaluation Necessary

— Site-specific Spectra and Corresponding Time Histories Required

These recommendations match with the actual actions taken during the earthquake-resistant design of this building by experienced designers.

Figure B-18 shows the main menu, set for the KBES module for "Seismic Input Development," with the HELP menu. Figure B-19 shows the different steps involved in the development of the seismic input, and Figure B-20 shows a plot of the sources that the KBES module has selected for the site from the data base.

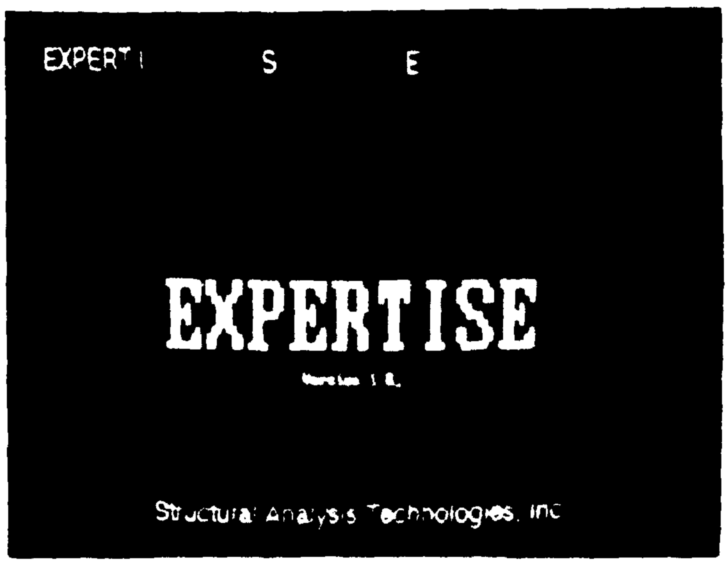

FIGURE B-1: EXPERTISE LOGO SCREEN

FIGURE B-2: **EXPERTISE MAIN MENU**

FIGURE B-3: **EXPERTISE MAIN MENU**
WITH DEVELOPMENT SEISMIC CRITERIA HELP MENU ACTIVATED

FIGURE B-4: SEISMIC CRITERIA DEVELOPMENT MENU

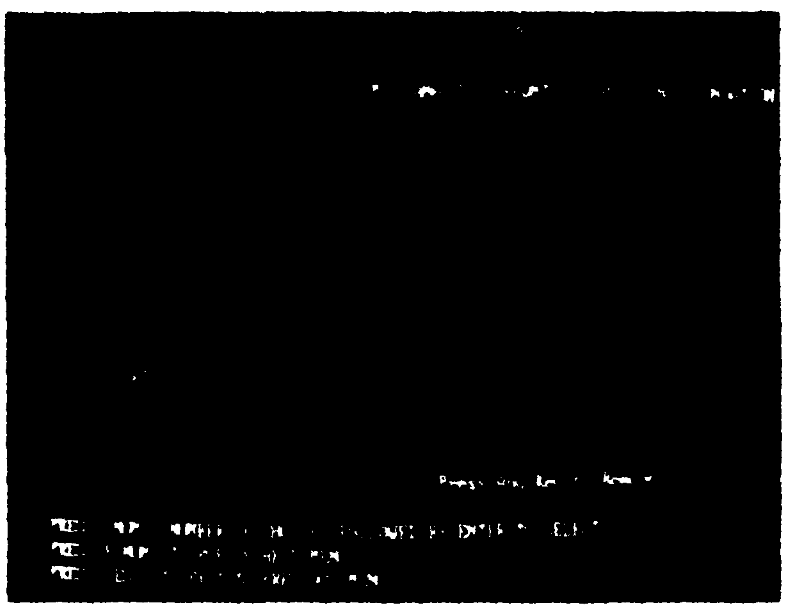

FIGURE B-5: SEISMIC CRITERIA DEVELOPMENT MENU
WITH SEISMIC ANALYSIS REQUIREMENTS HELP MENU ACTIVATED

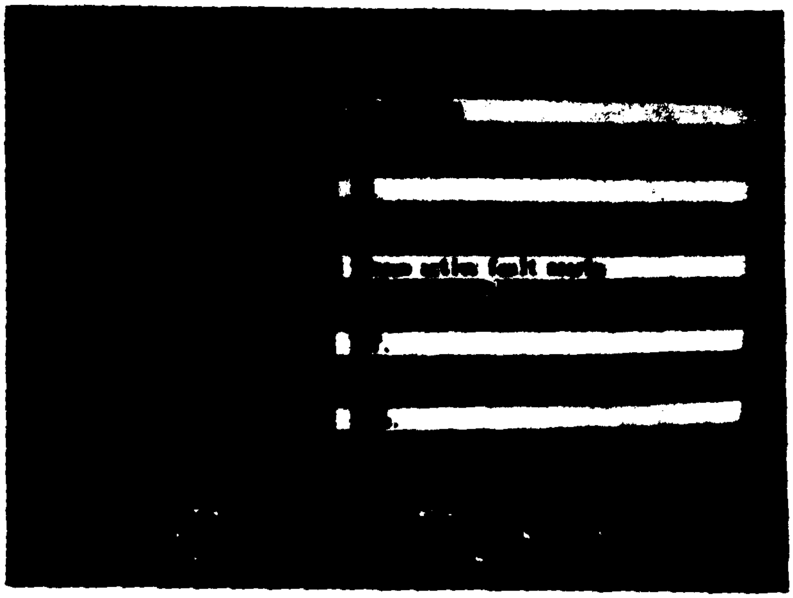

FIGURE B-6: INPUT SCREEN FOR SITE LOCATION

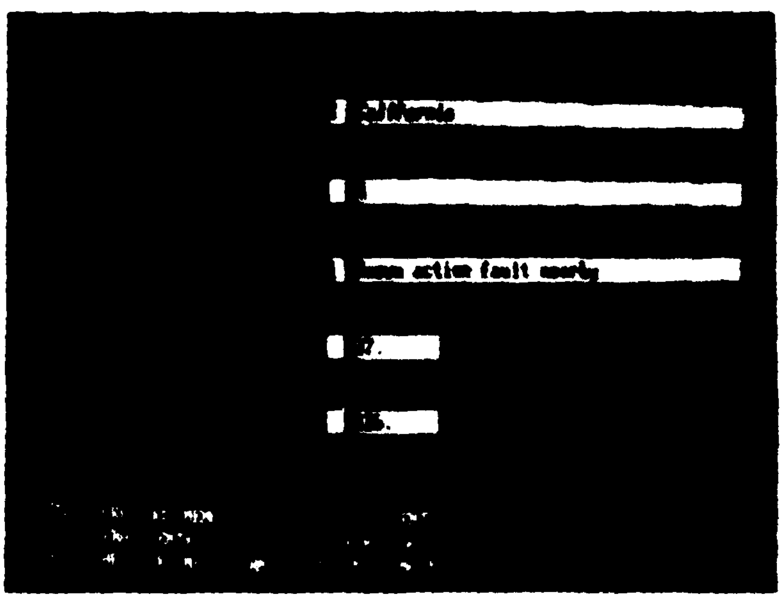

FIGURE B-7: INPUT SCREEN FOR SITE LOCATION
WITH SEISMICITY HELP WINDOW ACTIVATED

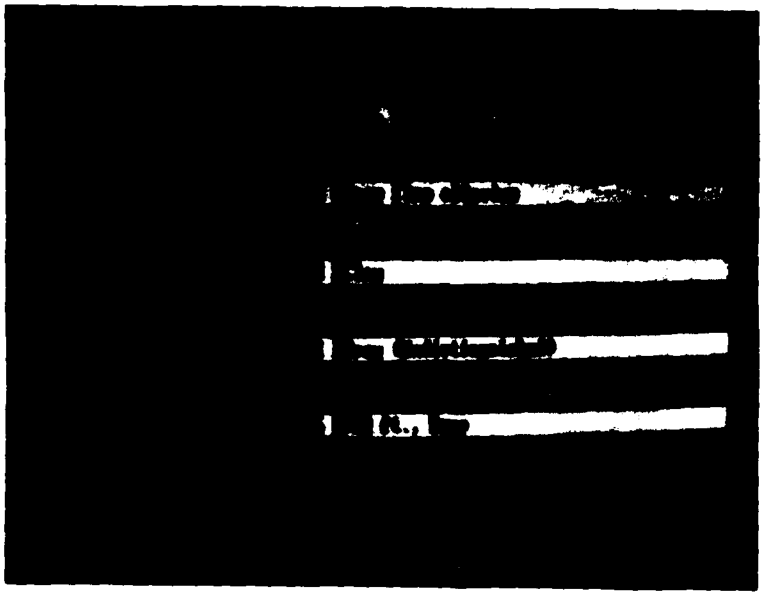

FIGURE B-8: INPUT SCREEN FOR SITE SOIL AND TERRAIN

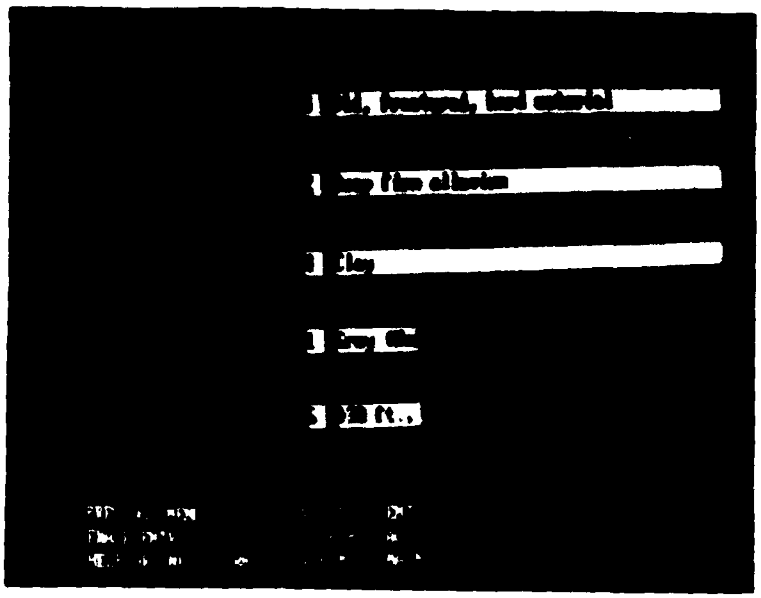

FIGURE B-9: INPUT SCREEN FOR SITE SOIL AND TERRAIN WITH SITE CHARACTERIZATION HELP WINDOW ACTIVATED

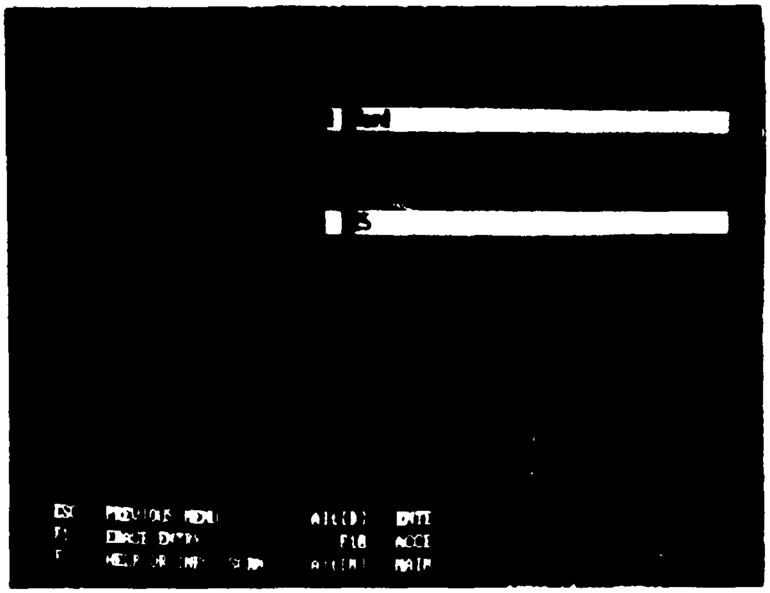

FIGURE B-10: INPUT SCREEN FOR ADDITIONAL SOIL INFORMATION (IN THIS CASE CLAY), WITH CLAY CHARACTERIZATION HELP MENU ACTIVATED

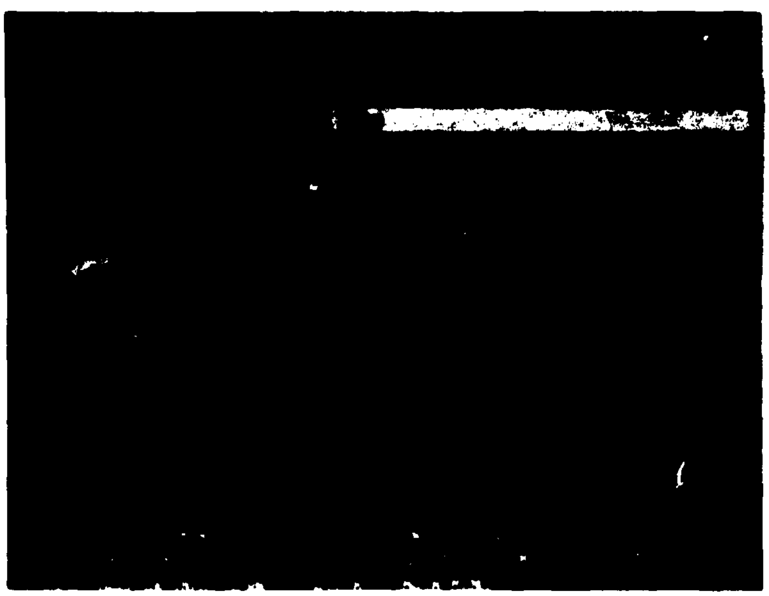

FIGURE B-11: INPUT SCREEN FOR NEW OR EXISTING BUILDING

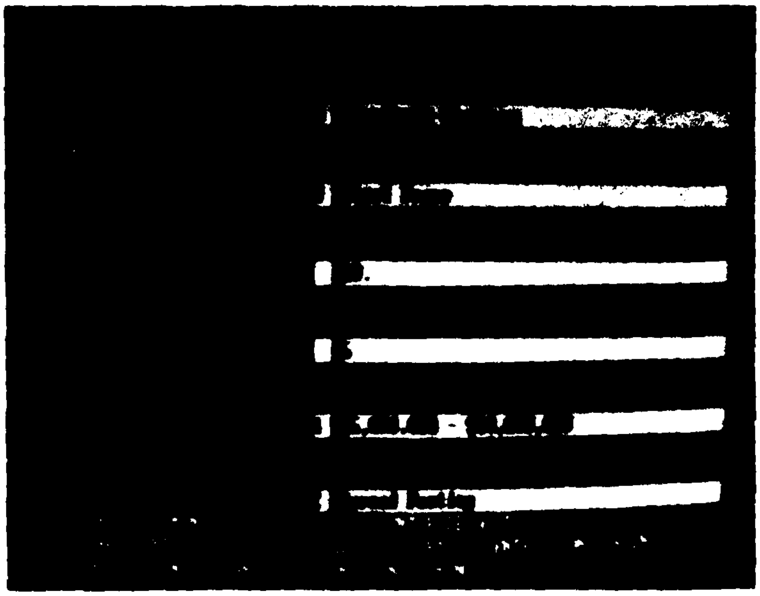

FIGURE B-12: INPUT SCREEN FOR BUILDING INFORMATION

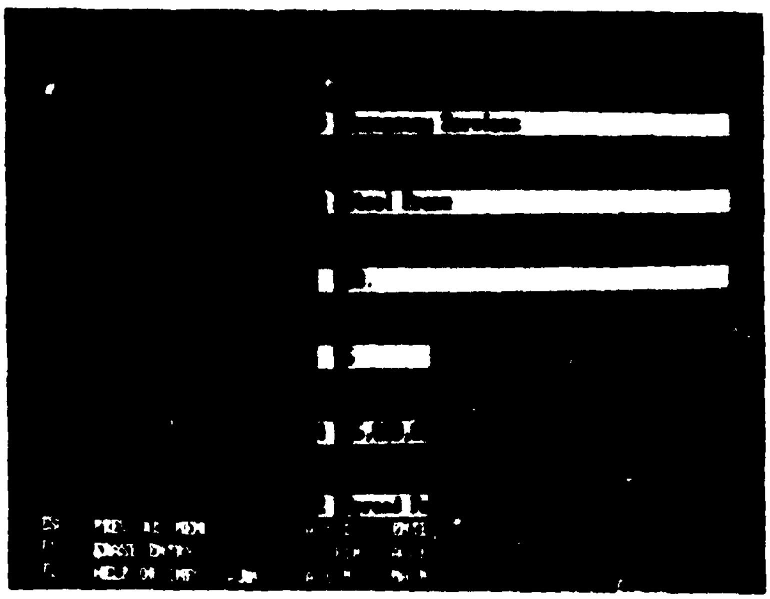

FIGURE B-13: INPUT SCREEN FOR BUILDING INFORMATION WITH BUILDING STRUCTURE TYPE HELP MENU ACTIVATED

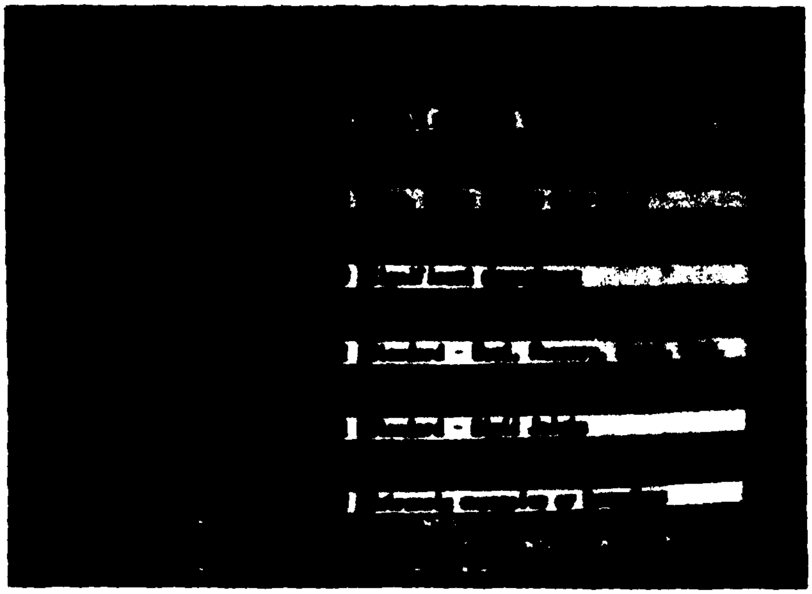

FIGURE B-14: INPUT SCREEN FOR ADDITIONAL BUILDING INFORMATION

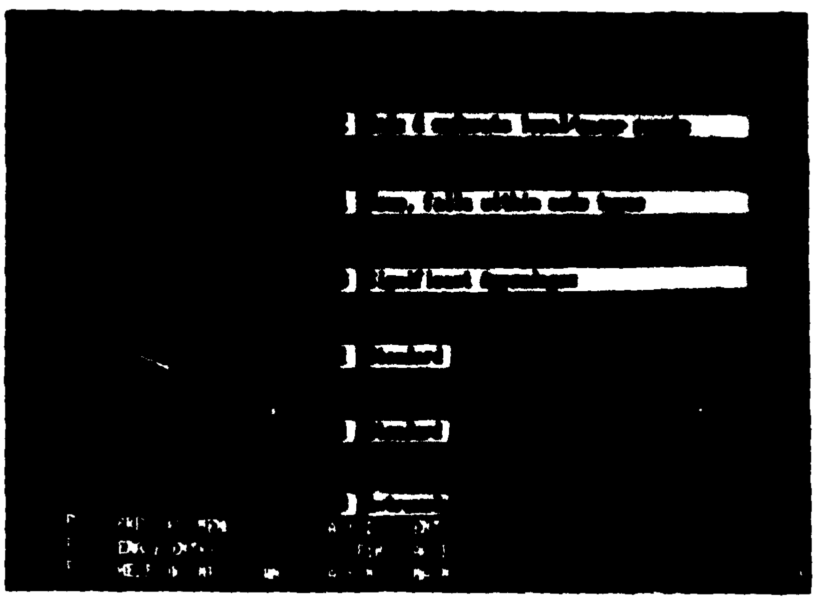

FIGURE B-15: INPUT SCREEN FOR ADDITIONAL BUILDING INFORMATION WITH UNUSUAL SYSTEM CHARACTERIZATIONS HELP MENU ACTIVATED

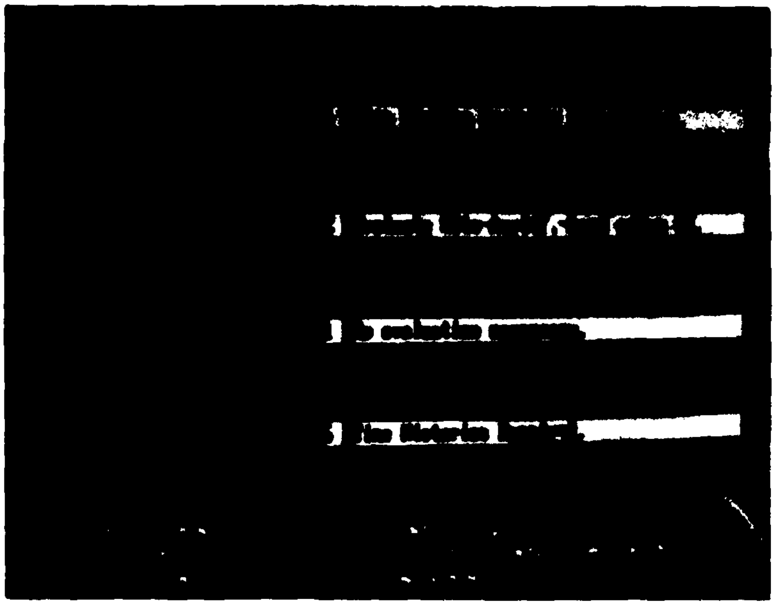

FIGURE B-16: EXPERTISE RECOMMENDATIONS

FIGURE B-17: EXPERTISE RECOMMENDATIONS
WITH TYPE OF BUILDING ANALYSIS HELP WINDOW ACTIVATED

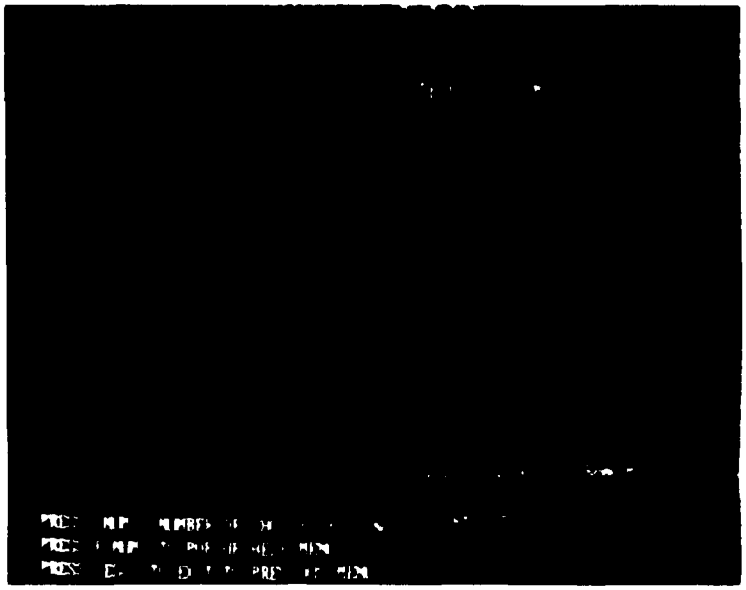

**FIGURE B-18: EXPERTISE MAIN MENU
WITH DEVELOP SEISMIC INPUT HELP WINDOW ACTIVATED**

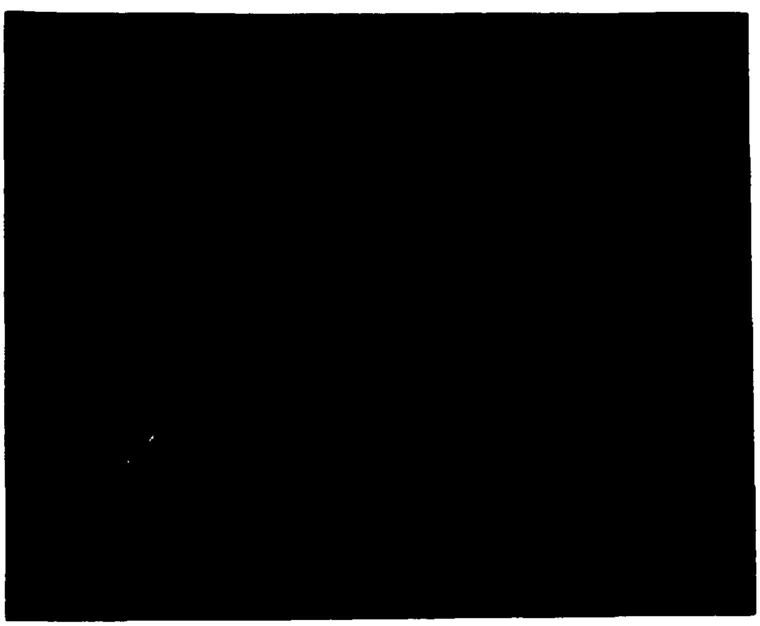

FIGURE B-19: SEISMIC INPUT DEVELOPMENT MENU

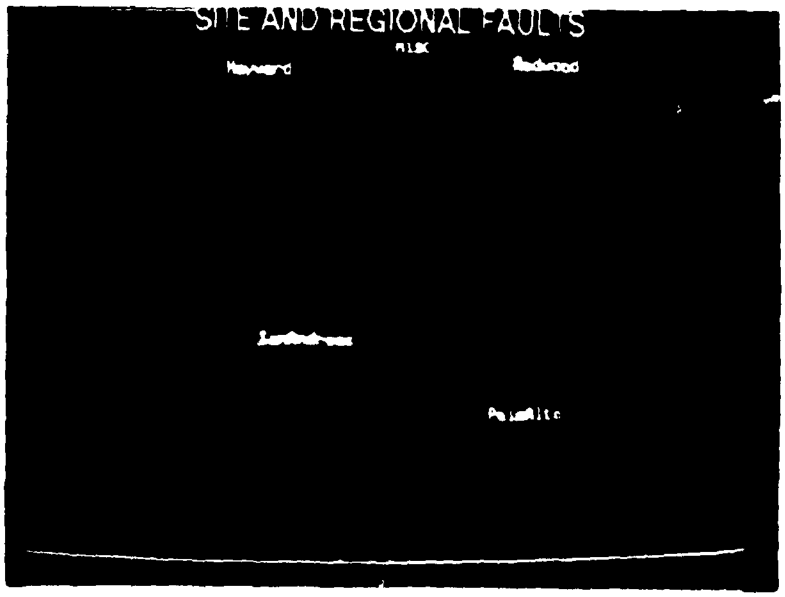

FIGURE B-20: PLOT OF SITE, AND REGIONAL FAULTS