EARTHQUAKE RISK MANAGEMENT SYSTEMS

FOR

DEVELOPING COUNTRIES

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THE WORLD BANK

I. INTRODUCTION

On October 17, 1989, an earthquake of magnitude 7.1 shook the San Francisco Bay area. With an epicenter in the Santa Cruz mountains, the earthquake killed 67 people, injured 2435, and caused damage of about $6 billion. Earthquakes of this size and greater occur in California at a rate of approximately twelve per century. However, worldwide about 15 such events occur per year.Even though the event in San Francisco Bay Area resulted in relatively small number of deaths, such an event in a developing country could kill thousands (or even tens of thousands) of people and can cause economic disruption on a scale that could effect the political and socual stability of the nation. There are various countries where the main political and economic centers are highly vulnerable to seismic events. Examples are:

Central America (Managua in Nicaragua, Guatemala City in Guatemala, San Jose in Costa Rica, etc.)
North Africa (Algiers in Algeria, Rabat in Morocco, etc)
Middle East (Damascus in Syria, Baghadad in Iraq, Tehran in Iran, Tel Aviv in Isreal, etc.)
Asia (Manila in Phillipines, Jakarta in Indonesia, etc.)

Many such examples can be given around the world. It is important that these developing countries have an access to the state-of-the-art technologies for managing their risks. This paper discusses the main architecture of a computer software system and then suggests that a pilot program be initiated to implement such a system in developing nation and one newly developed nation of the world.

Earthquakes can cause damage in a number of ways. Damage to buildings occur through *primary* , *secondary* , and tertiary hazards. Primary hazards are those which can be directly related to the earthquake. They include such phenomenon as ground vibration and fault rupture. Secondary hazards are those potentially dangerous situation triggered by the primary hazards. These include foundation settlement, landslides, soil liquefaction , or tsunamis Tertiary hazards result from structural damage caused by the primary and secondary hazards and are often the most serious. These include such events as flooding due to dam failure or fire following an earthquake. In fact, most of the property damage in the 1906 SF earthquake was due to the great fire, not the ground shaking itself. Losses resulting from these seismic hazards are numerous. They can be categorized as follows:

- *Life and injury*
- *Property damage*
- *Business Interruption*
- *Lost opportunities*
- *Building contents damage*
- *Long term economic and political implications*
- *Other loses*

Even though the fundamental goal of good earthquake engineering is to minimize life loss and injury, in this paper we will concentrate on issues related to economic risk. It is tacitly understood that by minizing property damage (buildings, lifelines, infrastructure, etc.), we also minimize casualties and socio/economic impact.

In light of such earthquake induced hazards and the enormity of the potential losses, there is an increasing concern on how to manage earthquake risk. Walter Hays of the United States Geological Survey reinforces such concerns:

> *An urgent need exists for earthquake risk management on all scales...it is clear that the economic value of the dwellings, buildings, public and private facilities, and lifeline systems that are at risk from earthquakes is not only very large (trillions of dollars on the global scale), but also that it is growing with time. This situation calls for action now!*

Many organizations have failed to recognize the full extent of their potential earthquake exposure. This has occurred due to several factors:

- *The seeming remoteness of a major seismic event,*
- *The lack of appreciation of the damage potential,*
- *The lack of tools to cost-effectively quantify the risk.*

It all seems so overwhelming; Earthquakes appear to occur at random intervals in random locations in random sizes and cause seemingly random amounts of damage.

Fortunately, earthquake risk can be managed just like other economic uncertainties by knowing as much as possible about the risk, narrowing down the uncertainty, and planning a strategy or trade-off accordingly. While engineers and geologists cannot predict with reliability the occurrence of earthquakes, recent developments in earthquake and geotechnical engineering permit experts to rationally estimate earthquake hazard, vulnerability, and risk. A great deal of research has been performed over the past 50 years throughout the world in order to systematically address these concerns. At Stanford University's John A. Blume Earthquake Engineering Center alone, the list of earthquake research projects is long. It includes hazard studies for Central America and North Africa, the cataloging of earthquakes, the development of computer codes such as STASHA, joint projects with China, Japan and Turkey, studies for the insurance industry and National Science Foundation sponsored studies on unreinforced masonry, tilt-up structures, and expert systems for site hazard, building vulnerability, city planning and risk assessment. As a result, by considering the factors that contribute to the extent of earthquake damage, such as the magnitude of the quake, the location of the epicenter, local soil conditions, and architectural and construction characteristics, the approximate seismic risk for a given structure at a given site can be estimated.

II . THE EARTHQUAKE RISK MANAGEMENT PROCESS

Let's take a look at how an expert in the field of earthquake engineering would, in generally go about evaluating a given building.

Damage assessment and loss reduction planning are complex issues that require the analysis of large amounts of data and the consideration of many alternative situations. Given a particular building at a particular location, the first step is to define the seismic hazard. Seismic hazard is defined as the combination of physical phenomenon (i.e. ground shaking, ground failure..) associated with an earthquake which may produce adverse effects on human activities. The seismic hazard at a particular site or region depends on the geographic distribution of potential earthquake sources,the geologic conditions which "fingerprint" each fault, the recurrence rate of earthquakes from each source, the propagation and attenuation of ground motion from the source to the site, and a forecasting model of future earthquakes.

The next step is to define the exposure of the site(s) to the regional seismic hazard. The engineer must identify the number of buildings of interest and classify them according to location, building class, number of floors per building, footprint area of each building, the year of the applicable uniform building code, the local geology of each site, and the replacement value.

In order to determine the vulnerability of the building or portfolio of buildings the engineer would combine the exposure data with the hazard data. Drawing upon his knowledge the engineer will be able to estimate damage ratios for the general classes of buildings present. The expert would then use his best judgement to modify these results to account for any building or site specific factors or peculiarities. From such a vulnerability analysis, the seismic risk can be determined. Given various relevant earthquake sources, each with a probability of generating a wide range of earthquakes, the probable loss over a given time window and the maximum potential loss can be approximated.

However while earthquake risk can be managed, the necessary expertise is not readily available to the end user. Earthquake risk assessment expertise is largely confined to a few research institutions and engineering consulting firms and is not readily available to decision makers and planners in government, financial institutions and insurance industry. It is difficult for non-engineers to define and obtain the relevant data for earthquake risk evaluation and use the analytical tools necessary to apply this data for decision making. Further confusing the situation is the fragmented nature of the earthquake research and consulting community. The requisite expertise is scattered over several disciplines such as seismology, geology, geotechnology, and structural and earthquake engineering; all play a role in the research process. Advances made in one field are often overlooked by the other disciplines. Furthermore, research on earthquakes is largely based on empirical data and hence conclusions are modified with every new earthquake. As a result, it is very difficult to keep up with the dynamics of the profession.

Edwin Simner of Lloyds of London sums up the insurance industry's frustration with the current state of earthquake knowledge dissemination in general:

> *...(we) are asked to write earthquake insurance with only the most trivial of information. For example, I have all too frequently refused to provide reinsurance because the broker presenting the request could not give me fundamental information...the scientists have it, and we should have it, too.*

Similar frustrations have been expressed by bankers, government planners and other knowledge users.

III. AN EARTHQUAKE RISK ASSESSMENT SYSTEM (ERAS)

In light of the demanding nature of the expertise, it is not surprising that specialist consultation is time consuming and very costly. An evaluation to determine the potential loss at a given site for a given earthquake can run into the thousands of dollars. While such detailed examinations by an expert are prudent for certain facilities or for certain major buildings of special interest, it is simply just not cost effective to attempt such an evaluation for an entire portfolio of risk.

To summarize the major issues raised so far:

- *The exposure to earthquake risk in seismic regions is tremendous*
- *Despite the uncertainties, this risk can be managed.*
- *Unfortunately, the expertise necessary for effective seismic risk management is not being properly transferred from research producers to research users.*

The knowledge necessary for effective earthquake risk management exists. The missing link is a cost-effective mechanism to transfer the existing state of the art knowledge in a usable form.

The Earthquake Risk Assessment System (ERAS), developed at Stanford University, serves as this link between the technical and the user community by providing sophisticated, flexible, and user friendly decision making support to those concerned about the economic impact of earthquake events. ERAS represents the culmination of over twenty years of collaborative research between Stanford University, the United States Geological Survey, the engineering community, other universities, government agencies and research institutions throughout the world.

Development of the software itself began in 1985 at the John A. Blume Earthquake Engineering Center. Supported by grants from private and governmental agencies, the ERAS development team, after four years of intensive work, has engineered a software which can transfer the state of the art in earthquake engineering directly to the non-technical user in a flexible, easy to use format.

While representing the state of the art in earthquake engineering, ERAS is designed for maximum flexibility and ease of use. The software is an expert system (based on artificial intelligence technology) and is developed to run in a minimum computer environment; all it requires in an IBM (XT/AT, PS/2) compatible microcomputer with a 20 MB hard disk, a CGA/EGA graphics card, and a 8087 math coprocessor.

By simply providing the system with a building's structural type, location and value, the user can determine the probable damage the building will suffer in a given earthquake. ERAS can evaluate the seismicity of a region, model earthquakes of varying magnitudes, and project damage estimations for a single building or portfolio of buildings. In addition to providing its conclusions in an easy to interpret "summary screen" form, complete with the reliability of the estimates, the conclusions can be manipulated through a number of graphical views. Not only do the full color, high resolution graphics highlight ERAS'S conclusions, but they can serve as stunning visual aids for presentations.

Simulations can be based on historical earthquakes, earthquakes which are probabilistically most likely to occur within a certain time frame, or those events which will cause the worst damage to the building or portfolio of interest. Any other imaginable earthquake scenario can also be simulated.

With the aid of ERAS, it is possible to routinely perform otherwise impractical analyses quickly, easily, and accurately. Question such as the following can be rationally addressed:

- *What kind of earthquake shaking will a region or a given site experience over a given future time window?*
- *What will the performance of a specific type or class of building be due to the above earthquake loading?*

- *How will a specific building at a given site behave in a given earthquake. What will the probable damage to this building be?*
- *What are the risks involved in a given property mix for a given region?*
- *Given a portfolio of risk, what will be the most damaging earthquake? What will be the most likely earthquake?*
- *How cost effective are the engineering options, including retrofitting and strengthening, to minimize risk?*
- *What will be the regional impact of a given earthquake or the maximum earthquake?*

With the ERAS feedback, it is possible to make informed judgements to minimize exposure to earthquake events.

ERAS is a sophisticated knowledge based expert system that recognizes the fact that seismic risk evaluation needs both judgmental expertise and well-established mathematical procedures. It integrates four major objective databases and state of the art hazard and risk estimation models with a powerful inference engine. The following section provides an overview of the technical base of ERAS.

IV. TECHNICAL BASIS OF ERAS

There are three specific expert systems in the software. The first system evaluates seismic hazard for a given site. It integrates an existing data base of past geological and seismological information, which includes location of seismic sources, recurrence relationships for all these sources, and any secondary hazard information that is available in the literature (see figure 1). A computer program called STASHA (Stanford Seismic Hazard Analysis) provides the base for this first system. The second system evaluates the seismic vulnerability of a group or a class of buildings in a given region whose seismic hazard has been evaluated by the first expert system. This system can also be used for rapid identification of high risk buildings in a region. It relies only on readily available information about the buildings under investigation; no detailed engineering drawings or other input is needed(see figure 2). The third system evaluates detailed vulnerability and risk for a specific building which either has been identified as a high risk building by the previous expert system or is of particular interest to the analyst (see figure 3).

ERAS has several special features. First, it adopts the commercial software I/O PRO as main Input-Output facilitator. The screen development system facilitates creation of text and graphic screens used as the input and output media for interactive programs. The slides displayed on screen are used to communicate with the user for input and output and explanations. Input formats can be numerical, linguistic, or graphical, based upon the context. Second, the control strategy for the inference mechanism in ERAS is a combination of backward chaining (goal-driven and forward chaining (data-driven). The system uses backward chaining to satisfy diverse goals (inquiries). However, if the goal is specified, the system uses forward chaining to collect the relevant data. Since goal specification significantly reduces the search space, only minimum search effort is required. Third, unlike the conventional rule-based systems, ERAS recognizes the fact that seismic risk evaluation needs both judgmental expertise and well established mathematical procedures. Hence, ERAS incorporates both rule-based systems

Figure 1.

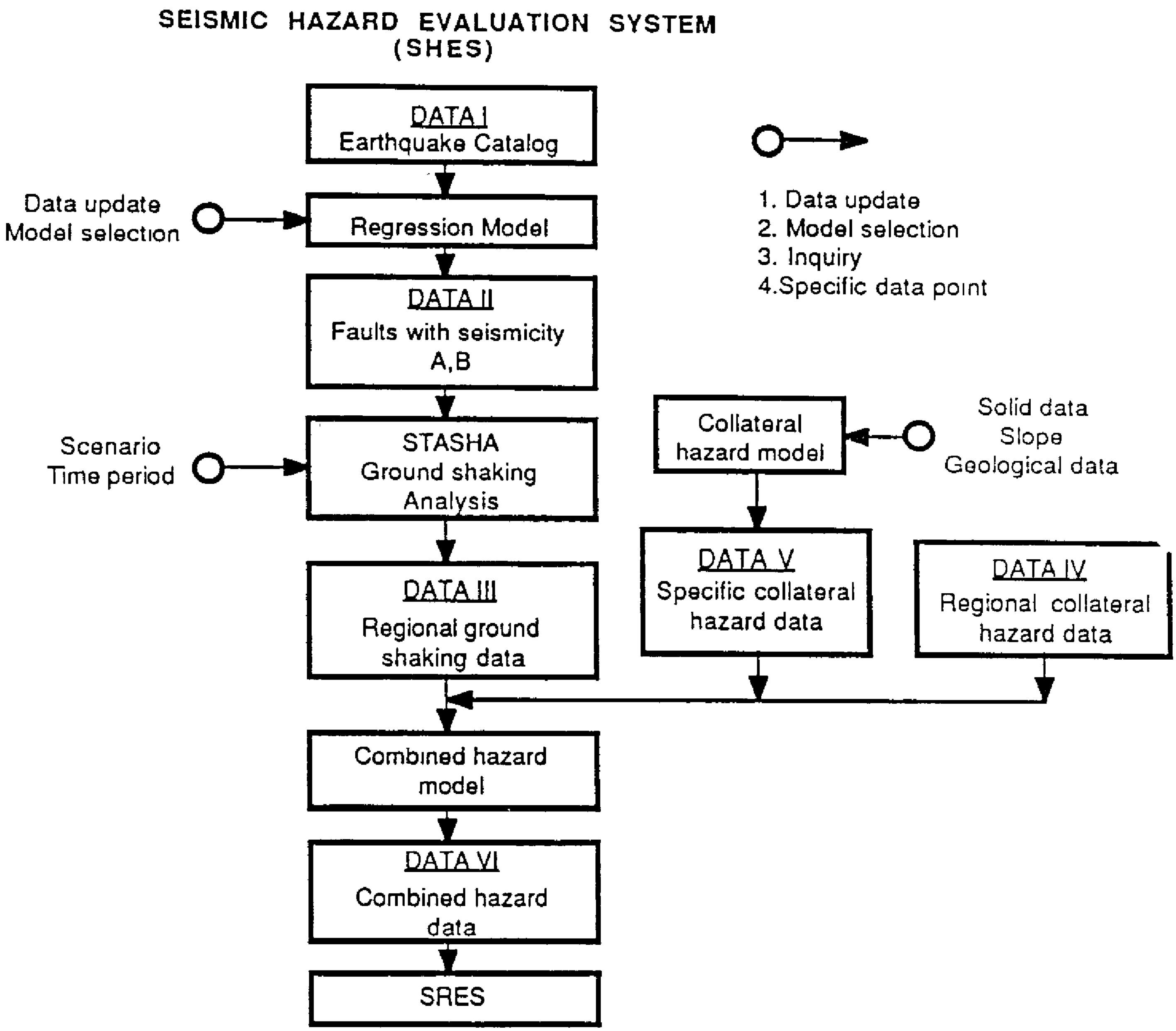

SEISMIC HAZARD EVALUATION SYSTEM
(SHES)
DATA I
Earthquake Catalog
Data update
Model selection
Regression Model
DATA II
Faults with seismicity
A,B
Scenario
Time period
STASHA
Ground shaking
Analysis
DATA III
Regional ground
shaking data
1. Data update
2. Model selection
3. Inquiry
4.Specific data point
Collateral
hazard model
Solid data
Slope
Geological data
DATA V
Specific collateral
hazard data
DATA IV
Regional collateral
hazard data
Combined hazard
model
DATA VI
Combined hazard
data
SRES

Figure 2.

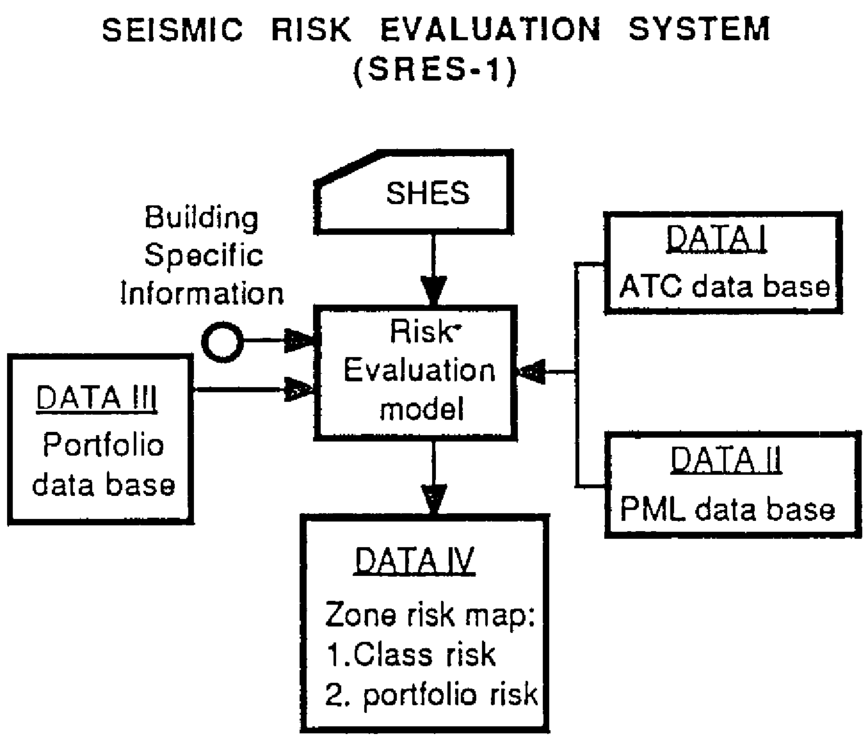
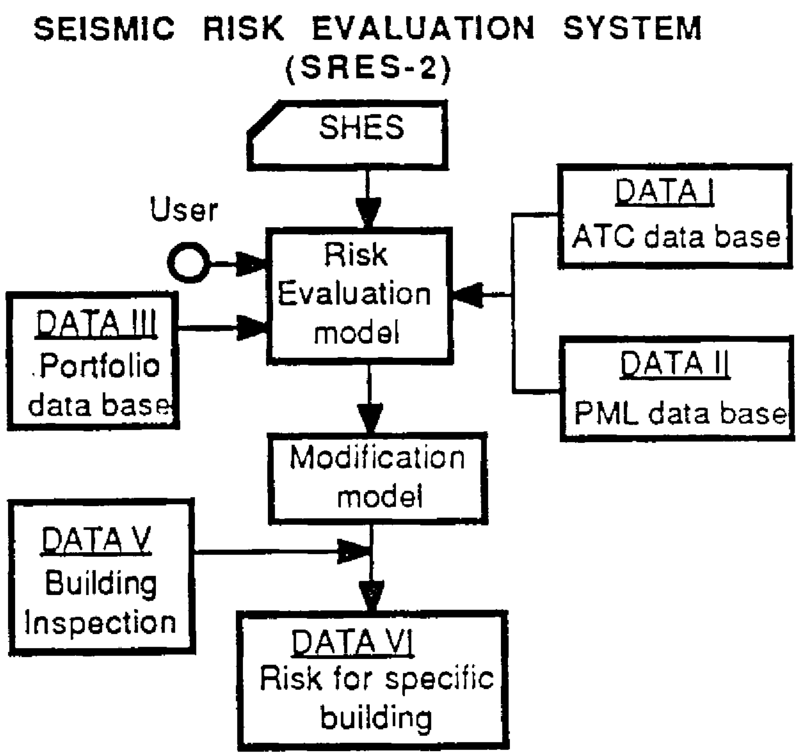

SEISMIC RISK EVALUATION SYSTEM
(SRES-1)
SHES
Building
Specific
Information
DATA I
ATC data base
Risk
Evaluation
model
DATA III
Portfolio
data base
DATA II
PML data base
DATA IV
Zone risk map:
1.Class risk
2. portfolio risk

Figure 3.


SEISMIC RISK EVALUATION SYSTEM
(SRES-2)
SHES
User
Risk
Evaluation
model
DATA I
ATC data base
DATA II
PML data base
DATA III
Portfolio
data base
Modification
model
DATA V
Building
Inspection
DATA VI
Risk for specific
building

and algorithmic programs which saves a great deal of computation. Fourth, to increase the ease of upgrading of ERAS and to ease the restriction of internal memory, the submodules of ERAS are written as independent program The programs are compiled independently and are then called into memory when needed by the driver Fifth, ERAS adopts the current probabilistic approach for hazard analysis to handle uncertainties in the prediction of ground shaking for the site. However, in evaluating the vulnerability of a building, design detail, construction quality and other factors will affect the performance of a building during earthquakes and must be identified in order to get a reasonable. evaluation. To reflect the judgmental knowledge of the effect of different factors on building damage, the system uses an uncertainty model based on fuzzy set theory.

ERAS is designed in such a way that the knowledge bases can be updated as new information is made available. Furthermore, the systems are user friendly, and hence their repeated usage can make them a standard for evaluating seismic hazard and risk for the banking and insurance industries. Figure 4 shows how ERAS can assist different users with varying "end use" interests.

DOMAIN KNOWLEDGE

Seismic risk is defined as the likelihood of loss due to earthquakes and involves four basic components: hazards. exposure. vulnerability. and location. These factors are further defined below (Miyasato et al, 1986):

- *The hazards or dangerous situations may be classified as follows:*
  - *Primary hazards (fault break, ground vibrations).*
  - *Secondary hazards which are potentially dangerous situations triggered by the primary hazards. For example, a fault break can cause a tsunami or ground shaking can result in foundation settlement, foundation failure, liquefaction, landslides, etc..*
  - *Tertiary hazards produced by flooding by dam break, fire following an earthquake and the like.*

All these hazards lead to damage and losses. They may be expressed in terms of severity, frequency, and location.

- *The exposure is defined as the value of the structures and contents, business interruption, lives, etc.*
- *The vulnerability is defined as the sensitivity of the exposure to the hazard(s) and the location relative to the hazards(s).*
- *The location is defined as the position of the exposure relative to the hazard.*

A seismic risk analysis requires the identification of the losses to be studied as well as the identification of the hazard exposures and their locations and vulnerability.

As mentioned above ERAS is divided into three subsystems which corresponds to the major components of seismic risk: SHES, SRES 1 and SRES2. The seismic hazard evaluation system (SHES) combines hazard and location components to obtain the seismic hazard estimation. SRES 1, the seismic risk evaluation system, is used to screen the property loss from exposure and vulnerability of the building. In this level, only building type (classification) is required. SRES2, performs the second level of seismic risk evaluation taking into consideration specific information of the buildings. Data management and the inference mechanism of these subsystems will be described in the following subsections.

INFERENCE MECHANISM (INFERENCE ENGINE)

An inference engine incorporates reasoning methods which act upon input data and knowledge from the knowledge base to solve the desired problem and produce an explanation when requested (See Figure 4). Control strategy for the inference engine could be forward chaining, backward-chaining or a mixture of both.

In the ERAS application, the system should be able to satisfy diverse goals (inquiries). The goal specifies the reasoning path that should be pursued. Hence, it is natural that backward chaining (goal-driven) should be used.

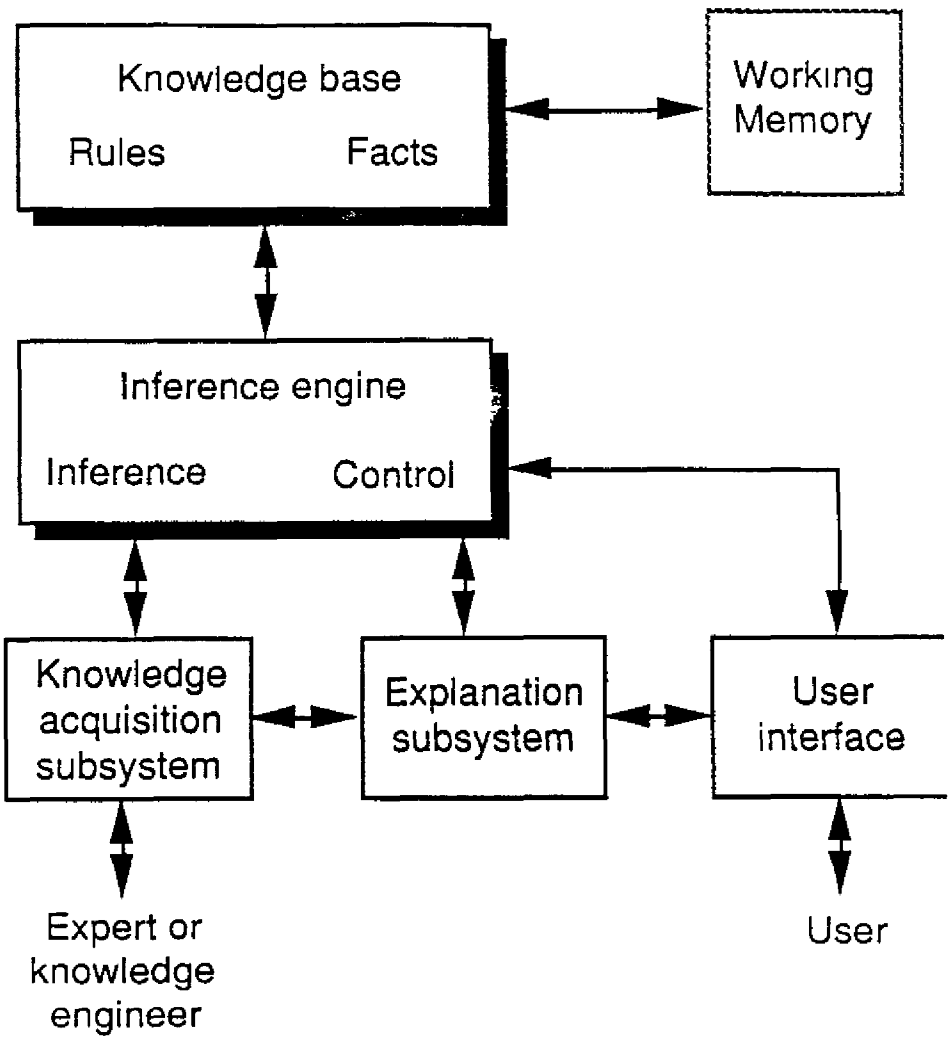
However, when the goal is specified and the reasoning path to achieve this goal is identified, the systems will use forward chaining (data-driven) to collect the relevant data either by querying the user or searching and retrieving it from the knowledge base. Thus, the control mechanism is a combination of backward chaining and forward-chaining. Since goal specification significantly reduces the search space, only a minimum search effort is required.

KNOWLEDGE (DATA) BASE

The knowledge (data) base for the ERAS systems consists of raw data, production rules, engineering and analysis programs and approximate reasoning schemes. Unlike conventional rule based systems which use "If-Then" rules only, ERAS recognizes the fact that seismic risk evaluation needs both judgmental expertise and well-established mathematical procedures. Hence, ERAS incorporates both "If-Then" production rules and algorithmic programs. For instance, model selection depends heavily on the expert's subjective judgement, and "If-Then" rules are suitable to guide the user to select the appropriate model. After the model is selected, the relevant procedures are executed using algorithmic programs.
Combining inference rules with algorithmic programs is also necessary for the following reason. In most cases during inference, when the facts match the antecedents of a particular rule, the rule is triggered and the consequent can be retrieved directly from the knowledge base without further computing. When the conditions do not match the antecedents of any rule in the knowledge base, the systems will refer to the relevant programs to calculate the consequents (results). This approach saves a great deal of computation, a consideration especially important for microcomputer implementation. Obviously, it is applicable only for problems where the inference mechanism is well-defined (as regular computational programs). For loosely structured inference mechanism, the partial matching problem is resolved through default (applying prior information). In this case, the reliability of the consequent is reduced. The process of uncertainty propagation will be described presently.

Figure 4.

ERAS **USES KNOWLEDGE-BASED EXPERT SYSTEM TECHNOLOG**



INTEGRATING INDEPENDENT PROGRAMS

A common practice in programming is to have a main driver and many subroutines. The driver and subroutines are compiled into a global executable program. However, when the problem to be solved is complex, many subroutines and submodules are needed. The size of the program increases rapidly and soon the capacity of the internal memory of a microcomputer is exceeded. It is then necessary to rely on fancy input/output manipulation and peripheral storage to fit the program into the computer memory. Furthermore, when any submodule of the program needs to be changed due to technological or engineering advances, the relevant routines must be changed and recompiled. The fitting must be reconstructed.
To facilitate upgrading of ERAS and to ease the restriction of internal memory on the IBM AT, the submodules of the systems are written as independent programs. Most of these programs have already been developed during the past ten years by staff and students at the John A. Blume Earthquake Engineering Center of Stanford University, and they are simply ported to the microcomputer. The programs are compiled independently and individually, and are then called into memory when needed by the driver, much like a subroutine is used. The retrieval, execution and then return of the external programs is easily achieved on the IBM AT using the interrupt feature of DOS. Each external program can be as large as the total internal memory of the AT (currently at 640K).

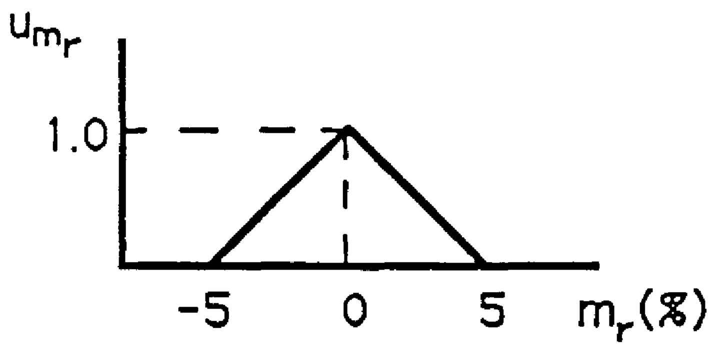
UNCERTAINTY TREATMENT

As mentioned in the previous sections, there are uncertainties involved at each stage of the evaluation process. Earthquake occurrence is random in nature; so is its size. For this type of uncertainty, the probabilistic approach has been well established and the data in California is reasonably good to support estimation using this approach. Hence, ERAS adopts the current probabilistic approach for hazard analysis to handle uncertainties in prediction of ground shaking for the site. The program STASHA, developed at Stanford University for hazard analysis, was incorporated into IRAS using the approach described in the previous section.

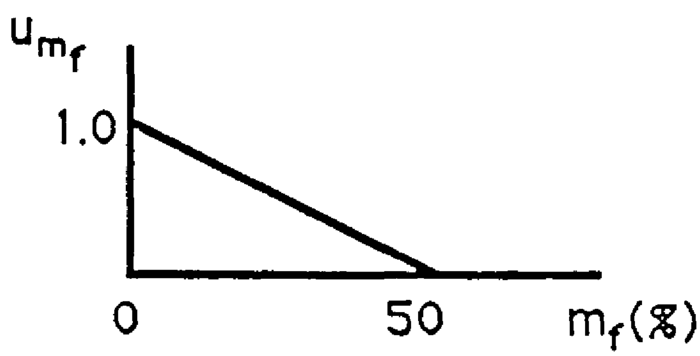
There is yet another type of uncertainty in the evaluation which cannot be handled using probabilistic methods. In evaluating the vulnerability of a building, design detail and construction quality will affect the performance of the building. The damage degree will vary in a wide range from bad engineering design to good engineering design. All these factors will significantly influence the building performance during earthquakes and must be identified in order to get a reasonable evaluation. When the user fails to answer the inquiry on these factors from the systems, it is then expected that the system will give an answer with a wider spread due to the larger uncertainty. Because data regarding damage from diverse building types is scarce and is not sufficient to support a probability distribution, ERAS uses an uncertainty model based on fuzzy set theory to reflect the judgmental knowledge of the effect of different factors on building damage.

Fuzzy sets with different membership functions are used to represent the prior information on these effects. Some examples are given in Figure 7. Whenever the response to a query for data is unknown, the system will use the fuzzy set instead of a crisp number to count its effect. The Vertex method (Dong and Wong, 1987, Dong and Shah, 1987) is used to combine all these effects and to calculate the total effect, resulting in a certainty factor which reflects the degree of uncertainty. When the system gives the evaluation result, it also indicates the reliability of the result (certainty factor) and how the reliability can be improved.

Figure 5.



Modification for roof system



Modification for fault rupture

INPUT/OUTPUT FACILITIES

IRAS adopts as the main I/O facility the commercial software I/O PRO, developed by MEF Environmental (MEF, 1985). I/O PRO is a modular set of software development tools and utilities which together create a high productivity environment for FORTRAN, C and Pascal programmers. The screen development system facilitates creation of text and graphic screens used as the input and output media for interactive programs. The slides displayed on screen are used to communicate with the user for input and output and explanations if requested. Input data formats can be numerical, linguistic or graphical, based upon the context.

Besides the interactive mode, the user can also choose the batch mode in which all data are read in together using a format such as the Lotus 1-2-3 spreadsheet or Dbase III.

In order to display the regional risk, ERAS also incorporates another commercial software, ATLAS (Strategic Locations Planning, 1985), to show the thematic map of regional risk All I/O options are built into the master program and can be exercised according to the user's goal and decision needs.

V. CONCLUSION

The greatest challenge in seismic risk analysis procedures is to make them less "mysterious" and more usable. Whether we are trying to identify high risk structures or developing strengthening strategies for such high risk structures to minimize risk, we must find vehicles by which knowledge generators and knowledge users are communicating. Earthquakes can affect large urban areas in developed or developing countries. Some of the largest urban regions of the world are in such countries with relatively high seismic risk. Government planners, economic decision makers do not have appropriate tools to help them understand the extent and relevance of seismic risk. There are ways in which they could manage that risk if they were properly informed. The knowledge base on which they currently make their decisions is not consistent with the state of knowledge currently existing in research (and to a lesser degree in practicing engineering) community. This lack of integration must change.

Another problem that exists is the problem of technology transfer between the developed and the developing regions of the world. Massive reliable data bases about earthquake occurrences, source modeling, source mechanism, instrumental recordings, and attenuation, exists in few central locations around the world. A global and regional network of such centers could help many developing countries who can not afford to maintain their own data bases. The challenge is not only to develop new models for source mechanism or new attenuation or new occurrence model; the most pressing challenge is to assist the world in utilizing the current know how. The challenge is to develop ERAS type systems that any informed user can utilize for improving the quality of seismic know how. Such an effort would provide opportunities to assess earthquake risks in regions of the world where historically many have died in past earthquakes. Such an awareness and technology would help in identifying factors that increase or decrease seismic vulnerability of communities or regions.

The International Decade for Natural Hazard Reduction (IDNHR) could be an excellent vehicle to achieve the above stated objectives. Amongst the ten most important programs that the EERI Committee on IDNHR has identified as candidate projects for the decade, at least four projects address the issues of international co-operation, technology transfer and reduction of seismic risk through intelligent development of mitigation strategies. With the rapid development of global Geographic Information Systems (GIS), it is not too futuristic to assume that future ERAS type systems will be able to assess site specific seismic risk and possible mitigation strategies to minimize such a risk. The AI based software architecture introduced in this paper provides a first step towards that goal.

VI. REFERENCES

1 *Applied Technology Council, Earthquake Damage Evaluation Data(ATC- 13), (Redwood City, CA, 1986).*

2. *Chiang, W.L. et al, Computer Programs for Seismic Hazard Analysis, Report No. 62, The John A. Blume Earthquake Engineering Center, Stanford University (1984).*

3. *Dong, W. and Shah, H., Vertex Method for Computing the Function of Fuzzy Variables Fuzzy Sets and Systems (1987), Vol. 24, No. 1, pp. 65-78.*

4. *Dong, W. and Wong, S., Fuzzy Weighted Averages and Implementation of the Extension Principle, Fuzzy Sets and Systems (1987), Vol. 21, No. 2, pp. 183-199.*

5 . *MEF Environmental Inc., IO PRO -Screen Development System and Utilities, Version 1 . 1 (1985), Austin, TX.*

6. *Miyasato, G., Dong, W., Levitt, R., Boissonnade, A., Implementation of a Knowledge Based Seismic Risk Evaluation System on Microcomputers, Artificial Intelligence in Engineering, (1986) Vol. 1, No. 1, pp.29-35.*

7. *Steinbrugge, Karl V., Earthquakes, Volcanoes, and Tsunamis - An Anatomy of Hazards (Skandia America Group, New York, 1982).*

8. *Strategic Locations Planning, ATLAS-AMP-EGA (1985), San Jose, CA.*