Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.V)

8-2-4

A DECISION SUPPORT SYSTEM FOR SEISMIC RISK EVALUATION

Glenn H. Miyasato[1] *and Haresh C. Shah*[2]

1. Research Assistant, Dept. of Civil Engineering, Stanford University

2. Chairman, Dept. of Civil Engineering, Stanford University

SUMMARY

This article reports on the development of a microcomputer-based model to perform a screening level seismic risk evaluation. Since many factors that determine a building's risk are in the form of judgmental rules, an expert system shell employing fuzzy logic is used to capture this knowledge. The user is queried for information on building and site characteristics which the model combines with various knowledge bases, databases and programs to decide the risk level of an individual building or to rank several buildings. An internal validation performed over several buildings showed that the model evaluation favorably corresponded with the expert's opinion.

INTRODUCTION

In recent years considerable effort in the field of Earthquake Engineering has been expended to investigate the problem of seismic risk evaluation of existing buildings. This is because many existing structures are known to pose a great hazard to human life. However the uniqueness of every building makes it difficult for a simple, overall evaluation procedure. Instead, evaluation relies on the experience of a skilled structural engineer to evaluate the many types of structures currently in existence.

The number of these experts qualified to do evaluations are few. In fact many inexperienced engineers lack the expertise gathered through observations of actual buildings after earthquake occurrences. A decision support system to assist the inexperienced evaluator in screening buildings for seismic risk would be of great value. The evolution of computers has made possible the development of such a tool. Development of this tool involved the creation of an overall methodology as well as the investigation of fuzzy representations of knowledge in the decision making process.

Determining the level of seismic risk of a building depends on such factors as its design, construction, configuration, use and age, as well as the seismic hazard at the site. Many of these factors are not easily defined or quantified. However, seismic risk experts do have heuristics based upon their broad experience to supplement traditional analytical models. This research develops a general seismic risk evaluation methodology (SRE) that includes this heuristic knowledge to screen suspect buildings. The evaluation involves an assessment of the potential death and injury losses that may be sustained by earthquake related building damage or collapse.

The objective of the SRE model is to perform a general evaluation at the screening process level. The user is queried for information on building and site characteristics which SRE combines with various knowledge bases, databases and programs in order to make a decision on the risk level. The model should be able to evaluate an individual building at a site, rank several buildings at a site or determine which site is more suitable to build on. Another peripheral sub-objective is to evaluate the seismic risk for a region.

Expert system techniques were used to develop a system that applied the methodology and knowledge representation schemes due to their ability to model the heuristic knowledge inherent in the methodology. Since the research emphasized the knowledge acquisition and methodology development rather than software development, an expert system shell was used to implement the system. The tool chosen for this purpose was the personal computer-based INSIGHT 2+ shell which contains a backward-chaining inference engine to flexibly connect facts provided by the expert (ref.[1]). INSIGHT 2+ also allows access to external knowledge bases, databases and programs. The use of this shell makes the system easy to access and economical to develop and maintain.

KNOWLEDGE REPRESENTATION

The SRE system was developed using knowledge supplied by experts at the John A. Blume Earthquake Engineering Center and supplemented with information from various technical reports (ref. [2,3,4]). The methodology integrates analytical, empirical and heuristic methods to perform evaluations at various levels of complexity. These levels vary from surface knowledge evaluations that capture the expert's "feel" for the building to deep knowledge evaluations that identify possible weak links in the building.

Expert system modules were developed for each type of knowledge. These modules contained individual knowledge bases, databases or programs needed to appropriately represent the knowledge. These included modules in construction quality, architectural configuration, general damage and risk evaluation, and structural analysis. Other previously developed systems such as those in seismic hazard analysis or fire hazard analysis are also incorporated where applicable.

The modules were also grouped into five levels of increasing complexity and detail with respect to the evaluation process, as well as other criteria such as by structural system type and material type. This partitioning of types of knowledge and level of complexity was done so that only appropriate levels and types of knowledge could be accessed according to the user's needs, wants and the available information supplied by the user.

The system queries the user for information on building and site characteristics by using rules built in to ascertain the appropriate evaluation level. The modules and rules matching these levels were then accessed and a system was built to link the various software representations together and a control structure was devised to make the appropriate connections between the modules. As only those modules involved in that level of evaluation were needed, unnecessary modules were temporarily deleted from the system. The modules can also adapt to incomplete or limited information about the building by supplying prior or default building knowledge in the form of fuzzy values.

MODEL STRUCTURE

The SRE model determines the level of risk a building will face due to seismic hazard and concludes with a numeric value which is mapped to linguistic risk ratings. Similar to the SRA system (ref. [5,6]), the methodology uses an inference net formulation, where ideas are organized in a hierarchical network from the general to the specific. This can be seen in figure 1. The hierarchy starts with the main idea at the top and progresses to the supporting levels below. The main idea appears as: "Seismic Risk". At the next level, four attributes, "Seismic Hazard", "Vulnerability", "Importance" and "Occupancy", support the main idea. These attributes have additional sub-levels of increasingly specific support. The form of the attributes may vary from a single rule to an entire expert system module.

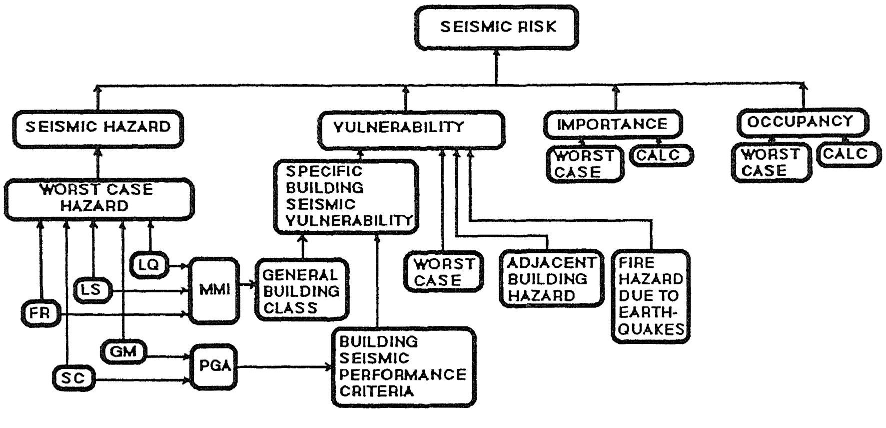

Figure 1: SRE overall network model

The Seismic Hazard attribute includes the primary hazard of Ground Motion (gm) as influenced by the Soil Condition (sc). This characterization of the ground shaking level is needed to make an assessment of the structural system. STASHA, a seismic hazard analysis program developed at Stanford University is used to estimate a ground motion response parameter for input into the structural systems analysis program (ref. [7]). Information about the remaining life of the structure and the probability of exceeding the unknown ground shaking level during this period is queried for by the system. This is used to calculate a return period value representing the time between occurrences of ground motion with specific characteristics. This value along with information about the specific site location of the structure as well as the soil class value are used by the system to estimate a peak ground acceleration (PGA) value.

Relationships between the PGA and modified mercalli intensity (MMI) are used to get a MMI value for the site. The secondary hazards of Liquefaction (lq), Landslide (ls), and Fault Rupture (fr) influence this value. The MMI values and PGA values are both sent to the Vulnerability attribute for use in determining the building vulnerability. Values representing the primary and secondary hazards are sent for possible use in the worst case Seismic Hazard attribute.

The Vulnerability attribute takes into account the sensitivity of a particular structure to the seismic hazard. Supporting attributes below Vulnerability include Adjacent Building Hazard, Fire Hazard Due to Earthquakes, and Specific Building Seismic Vulnerability. This last attribute represents the evaluation specific to the building seismic characteristics. Included in this attribute are General Building Class and Building Seismic Performance Criteria attributes.

Figure 2 shows a flowchart for vulnerability evaluation including a more detailed breakdown of the seismic performance criteria idea. Selected modules (general building class, base shear comparison, weak link) are described in the following paragraphs.

The general building class evaluation procedure accesses the appropriate database depending on building class (ref.[8]). The classification is based on structural system type and material type (17 classes) and building heights (3 heights). The system gives a measure of damage factor vs. MMI for each building type. All buildings go through this evaluation. This accomplishes two tasks. First of all, the evaluation establishes a common baseline for comparison of the evaluated buildings with other evaluated buildings. Secondly, the evaluation relates the final vulnerability value to a parameter with physical meaning. Other attributes modify this value, usually by the addition and subtraction of modifying factors.

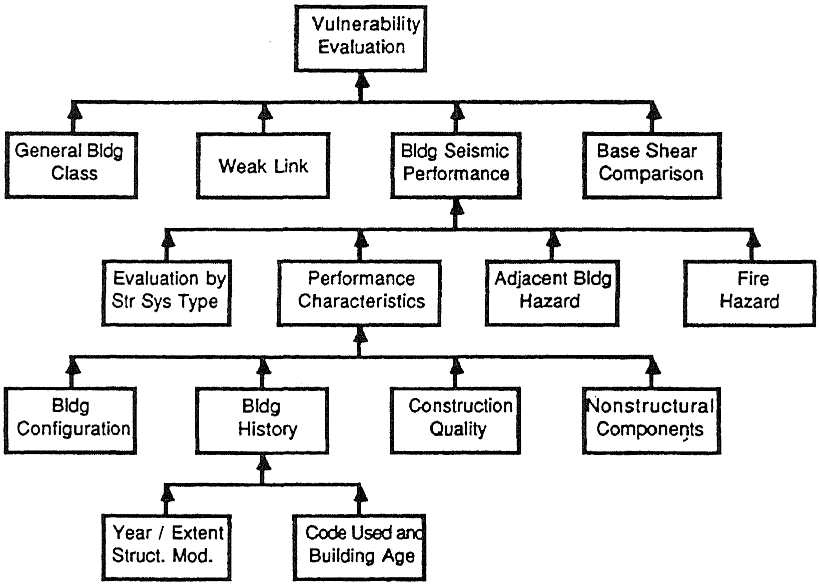

Figure 2: Vulnerability Evaluation Inference Network

Once this general building type evaluation is completed, a more specific evaluation is performed. This evaluation involves theoretical evaluation of the structural response, combined with heuristics and numerical or linguistic evaluations specific to the building being evaluated.

As a quick way to include analytical information in the evaluation process, a base shear comparison is performed. The latest available base shear calculation procedure is used to estimate the current demand on the structure. This demand base shear is compared to the capacity base shear of the structure as represented by the base shear calculated in the actual design.

The weak link system acts as a general guide to identify weak links known to represent life-safety hazards. The system attempts to determine if there are any weak links in the structure that can cause a "hazardous building" situation during an earthquake. If a weak link is identified the system automatically defaults the results to a high risk value.

"Importance" reflects the utility value that is placed on the structure; where utility is measured in terms of public safety. High importance suggests that damage or destruction of the building due to an earthquake would be detrimental to public safety. The Occupancy attribute also measures the potential occupancy of the building and its effect on the possible loss of human life during and after an earthquake.

Both the Importance and Occupancy attributes have a worst case system similar to the weak link system described above as well as a module that calculates a rating for importance and occupancy.

LOGICAL RELATIONSHIPS

Various relationships linking a group of ideas at each level were investigated. These logical relationships combine the ideas to reach a conclusion about the above idea that they support. Several relationships were developed for use in the methodology and the most appropriate relationship was selected and tailored to each situation. Efforts were made to compare and contrast results for different relationships in order to represent the knowledge as accurately as possible.

The most common approach used different types of mapping functions to calculate the overall value of the attribute. Weights are assigned to act on the value of each attribute through various logical relationships (e.g. maximum, minimum, sum, product). These weight/attribute values are also combined through logical relationships to get a value of the higher level attribute.

Frequently, the knowledge was approximate or was represented by linguistic terms. Fuzzy set theory was used to map this uncertain knowledge into numeric values (ref. [9]). The fuzzy set value was chosen because it represented the vagueness in the linguistic value and measured the reliability of the answer. The triangular fuzzy set was the specific type of set chosen because it not only supplies an answer with a range, it also gives a sense of sensitivity towards one side or the other of the range. This adequately characterizes the expert's knowledge in the vulnerability evaluation.

The triangular fuzzy set value has the added advantage of being easily explained to the expert. Due to the ease of addition of triangular values the expert can easily see how values are combined. The expert can also more easily assign the value as only the end values which can be thought of as upper and lower bounds or a range on the value and the apex value which can be thought of as a best estimate or most likely value need be assigned.

If the attribute quality was unknown, the system defaulted to a prior value assigned by an expert. Approximate reasoning techniques were also used to characterize the uncertainty associated with the use of a default value. Triangular fuzzy sets were used to capture both the value for an average structure in place of more specific information about the structure as well as the bounds due to the uncertainty. It was felt that the representation was accurate enough for the level of evaluation as the information was very qualitative. The fuzzy values were combined with the crisp values and the results were carried upwards in the analysis to give a fuzzy rating characterizing both the value of the attribute and its reliability.

VALIDATION

Validation was performed using nine San Francisco Bay Area buildings of various ages, uses, structural system types and construction materials. A seismic risk evaluation using the SRE model was run on the first six buildings. An external expert from the John A. Blume Earthquake Engineering Center also evaluated the buildings by giving an range or interval estimate of the risk level. The model gave a triangular fuzzy set estimate where the apex value lies at an $\alpha=1.0$ cut and the end values lie at an $\alpha=0.0$ cut. The model answer, besides giving a range also gave a sensitivity towards one side of the range over the other through the apex value.

A comparison of these results with those of the external expert can be seen in figure 3. The vertical scale of the graph measures the seismic risk level of the building as evaluated by the expert. The horizontal scale measures the risk level as evaluated by the system. Both scales are the same, varying from 1 (very high risk) to 0 (very low risk). In order to make this comparison a mean of the expert's interval result was plotted against a three point average or centroid of the model's triangular fuzzy set result for each building. A three point average was used over the middle value because the fuzzy triangular values were asymmetric. As the diagonal line represents an exact match between expert and model, it can be seen that the model and expert answers corresponded well.

A vulnerability evaluation using the vulnerability option in the SRE model was run on the last three buildings. These results were compared to an external expert's results in the same manner as the seismic risk evaluation results. The model and expert answers also compared favorably.

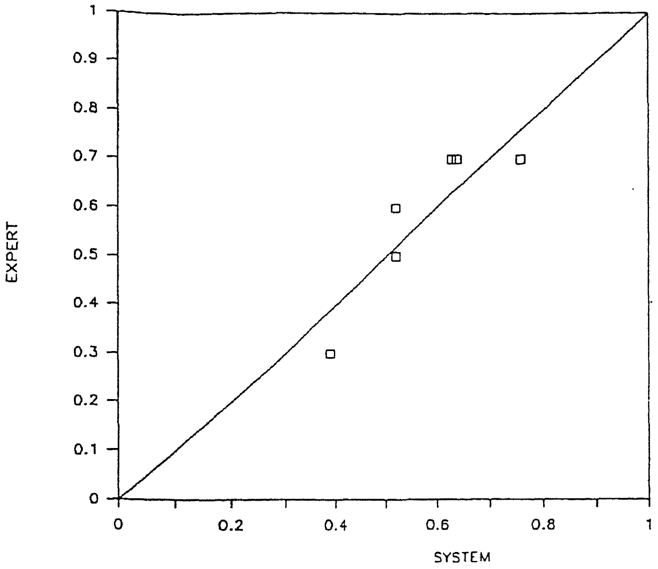

Figure 3: Seismic Risk Evaluation Results

CONCLUSION

The system is designed to perform a risk evaluation of large groups of buildings where there is a lack of time, resources or information to do a detailed analysis of each building. Possible applications include inspections for the seismic safety of existing buildings, assessments for seismic upgrading of buildings, and earthquake insurance feasibility studies (ref. [10]). If the number of buildings are many, a computerized system may be of great benefit over the use of a human expert as inexperienced personnel can be trained to efficiently perform the evaluations.

The general methodology integrates analytical and heuristic methods together in one system. Thus, the system is an improvement over an expert system consisting of only expert opinion based rules as it also employs theoretical and empirical techniques and accesses appropriate data bases. These techniques along with qualitative rules are incorporated together to calculate and quantify ground motion hazard and building response. Thus, the system methodology assists in bridging the gap between analytical and heuristic methods for seismic risk evaluation.

This risk model is by no means complete. Due to the great amount of knowledge available in the field of seismic risk evaluation, every factor affecting risk could not be investigated in great detail. Although an effort was made to include the important factors in seismic risk evaluation, opinions may vary as to the choice of factors considered. Future knowledge to be gained in this rapidly expanding field will also warrant inclusion. However, the very nature of the expert system format allows for the addition of factors if it is deemed necessary.

REFERENCES

[1] Level Five Research Inc. *INSIGHT 2+ Reference Manual, Version 1.0.* Level Five Research, Inc., 503 Fifth Avenue, Indialantic, Florida, 32903, 1986.

[2] ATC. *Evaluating the Seismic Resistance of Existing Buildings.* Technical Report 14, Applied Technology Council, October 1987.

[3] C. Arnold and R. Reitherman. *Building Configuration and Seismic Design.* John Wiley and Sons, Inc., New York, 1982.

[4] J.H. Wiggins. *Seismic Performance of Low-Rise Buildings-Risk Assessment.* Technical Report, J.H. Wiggins Co., Redondo Beach, California, 1981.

[5] G.H. Miyasato, W. Dong, R.E. Levitt, and A.C. Boissonnade. Implementation of a knowledge based seismic risk evaluation system on microcomputers. *The International Journal for Artificial Intelligence in Engineering*, 1(1), July 1986. Computational Mechanics Inc., UK.

[6] G.H. Miyasato, W. Dong, R.E. Levitt, and A.C. Boissonnade, and H.C. Shah. Seismic risk analysis system. In Celal N. Kostem and Mary Lou Maher, editors, *Expert Systems in Civil Engineering*, pages 121-132, Technical Council on Computer Practices, American Society of Civil Engineers, New York, New York 10017-2398, April 1986.

[7] M. Lamarre. *Development of an Expert System for Seismic Hazard Evaluation of Sites in California.* Ph.D. thesis, Stanford University, 1988.

[8] ATC. *Earthquake Damage Evaluation Data for California.* Technical Report 13, Applied Technology Council, 1985.

[9] W. Dong. *Application of Fuzzy Set Theory in Structural and Earthquake Engineering.* Ph.D. thesis, Stanford University, 1986.

[10] H.C. Shah, F.S. Wong, W. Dong, M. Lamarre, and G.H. Miyasato. An expert system for earthquake insurance and risk assessment. In *US-Asia Conference on Engineering for Mitigating Natural Hazards Damage*, Bangkok, Thailand, December 1987.