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EARTHQUAKE PROBABLE LOSS EVALUATION OF BUILDINGS

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SUMMARY

Many sophisticated techniques for probabilistic risk assessment have been developed over the last decade. These techniques are not, however, being used by practicing engineers. This paper reports on a study to compare these techniques with currently used simplified methods, to determine why these techniques have not been implemented and to determine the feasibility of developing an easy to use, computer program to help achieve implementation. Results to date indicate that losses estimated from the detailed analysis are significantly different from currently used simplified methods, and that personal computer implementation of the detailed analysis is possible, making use of these sophisticated techniques economic. Also, a new approach for estimating damage repair costs based on actual building rehabilitation cost data is presented. Finally, a prototype expert system for aiding structural engineers with little or no background in probabilistic methods, that is being developed, is described.

INTRODUCTION

Many sophisticated, powerful techniques for seismic probabilistic risk assessment have been developed by university researchers over the last decade. These techniques are not, however, being used by practicing engineers in the design/analysis process. Also, many of the sophisticated analysis techniques that have been developed are not used in the risk assessments made by engineers for insurance companies and owners of major commercial buildings. Currently used methods are comparatively simplistic and approximate and tend to give overly conservative results, leading to uneconomical decision making. A study, supported by a National Science Foundation Small Business Research Grant, is being conducted to determine why the techniques developed over the last decade have not been implemented by practicing engineers and to determine the feasibility of developing an easy to use, practical to apply, computer program to help achieve implementation. This paper describes the specific objectives of the study, the technical approach, and the results obtained to date.

OBJECTIVES AND SCOPE

The study is focused on two key areas in seismic risk assessment: (1) nonlinear random vibration analysis techniques, and (2) damage and economic loss assessment. The scope is limited to assessing problems associated with practical implementation of random vibration based loss assessment techniques in the design office and to assessing the feasibility of developing a computer program that is practical to apply and easy to use, for evaluation of probable structural and non-structural damage costs, building interruption cost, and life-safety hazard of buildings located in seismically active areas. The program should be simple to use, not require detailed knowledge of probabilistic methods, yet would use state-of-the-art probabilistic structural analysis methods.

The specific objectives of the study are:

1. Develop an outline of the input data generation rules and guidelines that are required to aid structural engineers with limited background in probabilistic methods.

2. Identify the specific areas of the random vibration analysis method that most require simplification and have prevented the methodology from being widely used in practice. Identify approaches that will help to achieve implementation.

3. Develop a framework for evaluating economic losses (due to structural damage, non-structural damage, and building use interruption) and structural safety from analytical structural response results. Estimate the levels of uncertainty that will be inherent in these evaluations.

TECHNICAL APPROACH

Due to space limitations, the technical approach is only briefly summarized here. The approach is based on earlier research in probabilistic response analysis of structures subjected to earthquake loadings (Sues, Wen, and Ang, 1985; Park, Ang, and Wen, 1985; and Lai, 1983), and research in the area of estimating damage and economic loss of structures due to earthquake ground motions (ATC-13, 1986; Sabol and Hart, 1986; Zorapapel, 1981; Steinbrugge, et al, 1980; Blume, et al, 1977; Whitman, 1973). This research has made great theoretical strides in methodological development. The intent here is to make these methods practical to apply and give results in a usable format, that is in terms of real dollar losses. The approach consists of 7 steps: (1) Site hazard analysis, (2) Modeling the ground motion as a random process, (3) Formulation of the structure equations of motion and the hysteretic restoring force relations, and assessment of the model error and parameter uncertainties, (4) Random vibration analysis of the structure and analytic evaluation of response sensitivity coefficients, (5) Evaluation of response statistics accounting for ground motion, modeling, and parameter uncertainties, (6) Evaluation of probabilities of damage and damage costs based on structural response statistics, and (7) Evaluation of the lifetime loss probabilities by convolving the site hazard curves and the loss probabilities associated with the range of levels of ground motion.

RESULTS

Efforts to date have been focused in several areas: (1) adaptation of existing computer programs to personal computers, (2) a review of currently used approaches for earthquake loss assessment, (3) comparison of results from currently used approaches with the random vibration based approach, (4) development of a new approach for estimating damage repair costs, and (5) development of an integrated, expert system based computing environment. The results are presented below.

Preliminary efforts were concerned with adapting existing computer programs to personal computers. PC implementation is critical if the risk assessment methods are to gain wide use. An IBM PC-AT compatible machine with a numeric coprocessor was used to carry out an example stationary analysis of a four story steel frame building. The complete probabilistic risk assessment took less than 20 minutes of computation time demonstrating the practicality of the approach. Of course, for larger buildings and for nonstationary analysis, capabilities of current personal computers may be taxed. Estimates of the feasibility of PC implementation for these cases is still under investigation.

Currently there are two basic approaches used for predicting expected economic losses due to earthquakes, those based on ATC-13 (ATC, 1986), and those based on the California Earthquake Zoning and Probable Maximum Loss Evaluation Program (California Department of Insurance, 1986). The ATC-13 approach gives the probability of experiencing various levels of damage as a function of Modified Mercalli Intensity (MMI) in the form of damage probability matrices (Whitman, 1973). The matrices are given for 78 different building facility classes and are based on expert opinion. The California insurance department approach gives probable maximum losses for 19 different construction classes for an earthquake of magnitude 8.25 on the Richter scale.

Figure 1 shows a comparison of these approaches with the random vibration based approach for a seven story reinforced concrete frame structure. For this comparison, the California Department of Insurance's probable maximum loss is taken to be a 90% nonexceedance probability loss. Note the marked difference in the results obtained with the three approaches. The random vibration approach has a steep slope initially and then becomes very flat. This is because a nonlinear degrading model is used for the structural behavior. For small earthquakes (large exceedance probabilities) the structure is essentially linear; whereas, for large earthquakes (low exceedance proabilities), the nonlinear degrading behavior causes losses to increase rapidly for only small increases in earthquake size. This behavior is not reflected in the ATC-13 expert opinion approach wherein very large earthquakes are required to achieve significant losses and a reverse shape is obtained for the curve.

From the studies thus far it has been determined that the one of the most significant problems to achieving practical implementation of risk assessment is the uncertainty associated with predicting economic loss from structural response statistics. Reducing this uncertainty would allow for easier interpretation of results, more economic decision making, and increase the confidence of the industry users in these methods. Toward this end, a new approach for estimating the cost to repair structural damage is being developed. In this approach, costs to repair a damaged structure are estimated from actual cost data for rehabilitating existing structures to meet current standards. The rehabilitation costs are plotted as a function of ductility demand and ductility capacity for the structure. These curves can then be used to estimate repair costs using ductility demand computed in the probabilistic response evaluation. Rehabilitation cost data have been compiled for 50 reinforced concrete buildings in Los Angeles, along with the corresponding ductility demands and capacities. Figure 2 shows an example of these data for concrete shear walls buildings at the University of California at Los Angeles. Current efforts are concerned with further development of this approach, quantification of uncertainties, and identifying the steps that are necessary to help reduce the uncertainties in all phases of economic loss evlauation.

The final stage of this Phase I research effort is the development of a prototype integrated computing environment for the seismic risk and loss assessment. Figure 3 shows this environment schematically. At the heart of the system is an expert system coded in the OPS 5 production system language. It is important to note that the expert system does not perform any response or damage estimation; rather it serves to aid structural engineers that have limited background in probabilistic analysis. The expert system performs necessary interface functions with several modules for data input and also is directly linked with the FORTRAN application program that performs the random vibration analysis. The modules inside the dashed box have been developed in the Phase I effort and the remaining modules will be developed in the Phase II research effort. Note that a dashed line is shown from the expert system out to the structural model module. This indicates that future developments in expert system research in structural engineering may allow for the development of a system that would actually build the mathematical structure model. With the aid of this system, it is estimated that an entire analysis could be completed with a 2 man-day effort. This level of effort is economically practical for many mid to high-rise structures.

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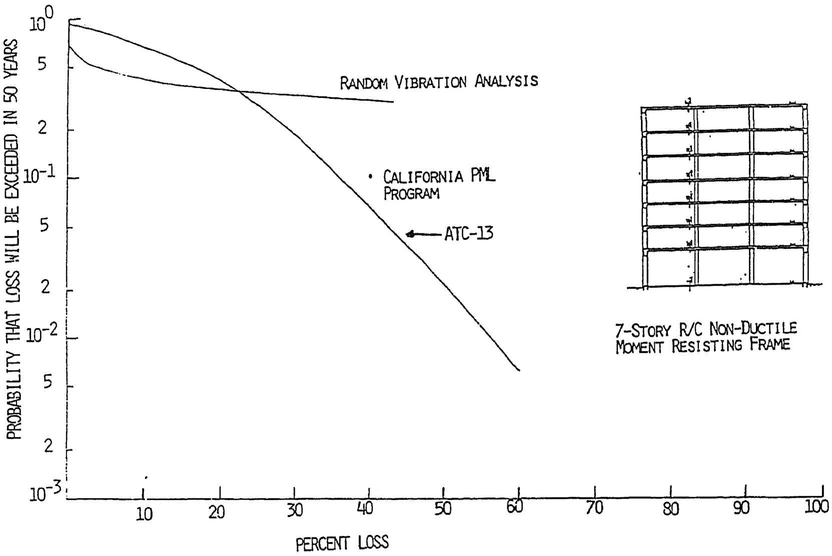

FIGURE 1: METHODS COMPARISON

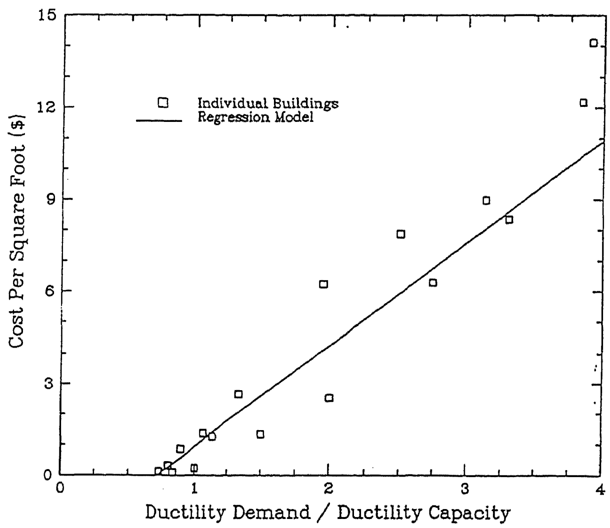

FIGURE 2: DAMAGE ASSESSMENT

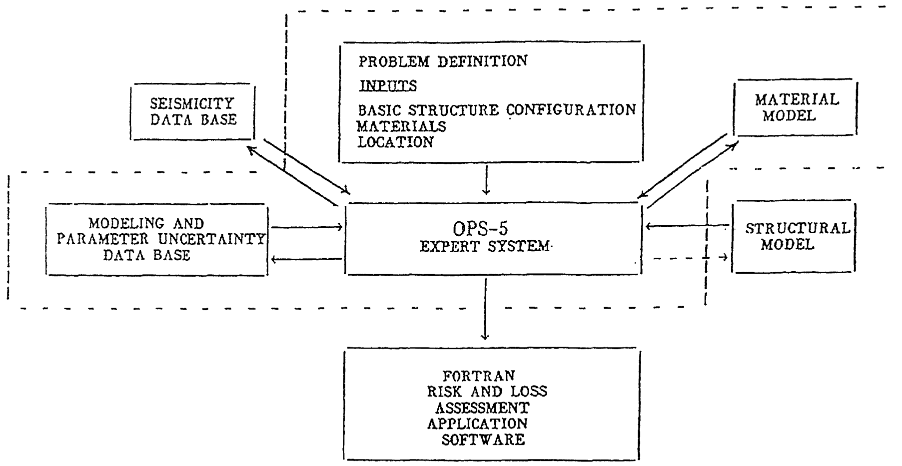

FIGURE 3: INTEGRATED ENVIRONMENT FOR BUILDING SEISMIC RISK AND LOSS ASSESSMENT