

A SYSTEM FOR EVALUATION AND MITIGATION OF REGIONAL EARTHQUAKE DAMAGE

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SUMMARY

REDEEM (Regional Earthquake Damage: Economic Evaluation and Mitigation) is a prototype computer system which can be used by regional public and private officials to: (a) estimate, monitor and document monetary losses due to actual or predicted earthquakes and (b) evaluate the impact of alternative mitigation plans. The system procedures include modules, which are based on recent developments in the technologies of earthquake predictions, structural engineering, microzonation, damage assessment, disaster socio-economics and finance. Through the use and maintenance of the system, research results and sophisticated seismic technologies are directly utilized by the public. REDEEM is currently under development at Merritt CASES, Inc., with the cooperation of San Bernardino County, California.

INTRODUCTION

The needs for an integrated, estimating mechanism (which realistically must be a computerized system) based on the state-of-the-art of earthquake engineering and on a prototype economic and financial model, are numerous and well documented (Ref..1). The technology of earthquake prediction is in a stage of vigorous development. Other pre- and post-earthquake actions and mitigation plans have been developed and several methods of estimating damage have been suggested. (References on these topics are too numerous to list in this paper due to space limitation.) It is imperative that this wealth of technological information be integrated and interpreted for the public and interested organizations in tangible, financial terms, which are essential for many subsequent social, legal and political decisions.

Existing methodologies of damage estimation were applied to obtain gross estimates of earthquake effects for the entire United States based on macrozonation; or on entire city blocks based on a single type of structural model. While very useful for making gross assessments and general policies, these methodologies do not address the problems of detailed planning, including adoption of potential mitigation plans. Counties and urban centers in earthquake-prone states require systems based on microzonation, local soil conditions, detailed classification of structures, structural and non-structural damage evaluation and more accurate cost-benefit analysis of different optional mitigation plans for the public and the individual. Unless based on such detailed information, and on socio-economic data, any effort, predicting or planning individual or community behavior, will be futile. Insurance and loans for structure/content rehabilitation and/or replacement are examples of issues that must be handled on a case-by-case basis, rather than by statistics.

Works addressing the problem of detailed planning are few. Anderson (2) discussed aspects of detailed "regional community planning" and reported measures taken by JPL to mitigate potential seismic damage to its building complex in Southern California. Kudder, et al (3), discussed a methodology and a computer program for evaluating building safety within GSA's Safety and

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Hazard Abatement Program. A significant step in assessing the economic impact of disaster was made by the University of Pennsylvania Group, by developing a system, WHIMS (Ref. 4) to estimate and predict flood damage. Many of the principles used in the economic model can be utilized for earthquake damage.

This paper is essentially a report on a prototype computer system which is currently being developed at Merritt CASES, Inc. with the cooperation of San Bernardino County, California, as an answer to the needs specified above. The system is named REDEEM, which stands for Regional Earthquake Damage: Economic Evaluation and Mitigation.

REDEEM is to be used by regional public and private officials to: (a) estimate, monitor and document economic losses due to actual or predicted earthquakes and, (b) evaluate the impact of alternative mitigation plans. The system procedures are developed in modules, based on recent developments in the technologies of earthquake predictions, structural engineering, microzonation, damage assessment, disaster socio-economics and finance. Through the use and maintenance of the system, research results and sophisticated technologies can be directly utilized by the public.

GENERAL APPROACH

The three basic elements of the process of estimating the monetary losses resulting from natural hazards are: Hazard, Exposure and Vulnerability. HAZARD includes the characterization of ground motion or other indirect effects. It could be based on existing records of past earthquakes or on predictions of earthquake effects. EXPOSURE includes the characterization of the subjects being analyzed, which could be people or structures. From engineering and economic standpoints, structures (including buildings and lifelines) are the exposure of concern in this paper. Various degrees of interaction between HAZARD and EXPOSURE, based on the principles of earthquake engineering, result in different levels of expected damage or VULNERABILITY, which can be transformed into dollar figures through an economic model.

Generally, therefore, it is required to characterize the exposed structure and the ground motion, perform the necessary analysis and interpret the response. Assessing the potential benefits of a mitigation plan, which requires structural upgrading, follows essentially the same approach with modified structural models. The integration of the results for all structures in the region can be further processed and used as input for decision-theory-based techniques to arrive at optimal financial policies.

IMPLEMENTATION

The approach outlined above may be implemented through the following objectives (underlined) and activities (numbered):

Structure Characterization

1. Define the region to be studied.
2. Acquire data from existing records or surveys on buildings and lifelines in the selected region. These data include structural, socio-economic and occupancy data. The data should be similar to or compatible with those usually collected in the field after earthquakes.
3. Structure, digitize and store the data in the system database.
4. Construct models of typical structures, according to a building code

such as Ref. 5.

5. Select suitable existing methods for static and dynamic analysis, which may vary depending on the structure type. The methods may be as simple as multi-connected shear beams for framed elements or as complex as finite-element programs for more complex continuous structures.

Ground Motion Characterization

1. Study data pertinent to macrozonation for the purpose of defining parameters and ranges or parameters typical to the region. The parameters must be compatible with typical ground motion predictions. Existing seismicity, geology and risk maps will be examined as sources for the data.
2. Construct a matrix of earthquake-parameter combinations, representing potential different levels of shaking. The combinations should be sufficient to define equivalent response spectra for analysis purposes. Based on this matrix, define response spectra of different levels of selected past earthquakes typical to the region; e.g., full, half and quarter of El Centro 1940 Earthquake level. Modify generated spectra for typical damping and ductility factors.

Microzonation

1. Define specific soil or rock types and other local conditions in the region.
2. Adopt methods for microzonation according to the local conditions and modify response spectra according to microzonation.
3. Incorporate microzonation data in the system database.

Structural Analysis

1. Perform structural (static or dynamic) analysis using the procedures, models and earthquake spectra indicated above.
2. Develop and program procedures for classifying seismic response of the structural models into different levels of shaking. The classification is to be added to the database and subsequently used as input for the financial damage model.

Damage Quantification

1. Study and select existing methods of damage prediction including methods of relating intensity to magnitude. Define scenarios or a matrix of shaking levels to be applied to the structural models.
2. Establish criteria for defining response levels as a basis for damage evaluation.
3. Define criteria for generating structural and non-structural damage factors to be stored in the database for subsequent damage assessment

Safety Criteria

1. Define criteria for structural safety levels based on damage prediction and occupancy.
2. Program the monitoring of unsafe cases.

Economic and Financial Models

1. Study existing economic models and methods for computing economic losses and select or develop methodologies for costing structural and non-structural damage.
2. Develop an estimating model based on damage factors and costs.

3. Modify the basic model to include land value and financial impact on factors such as mortgage lending and insurance.
4. Incorporate procedures for long term evaluation factors, such as inflation and other economic forecasts.

SYSTEM MODES OF OPERATION

Damage Estimating

Damage estimating is one basic mode in which the REDEEM system operates. Typically, this mode will be used prior to a disaster, immediately after it and during the recovery period.

Mitigation Evaluation

The following are specific objectives set for evaluating the financial impact of alternative mitigation plans, as a second mode for system operation:

1. Select existing, common and well defined methods of earthquake hazard mitigation. Rehabilitation and upgrading of structures should be emphasized. Formulation of other methods, such as land-use and regulatory codes, is to be considered for subsequent applications.
2. Collect data on costs of mitigation plans.
3. Define parameters corresponding to several alternative mitigation measures as input for modifying existing structural models and local conditions.
4. Develop a procedure for cost-benefit analysis of mitigation plans. This procedure involves the repeated operation of the system in its basic mode, recording the differences between the resulting damage values and benefits, and comparing benefits with costs.

Sensitivity Analysis

The repeated use of the system in its basic modes, considering excursions in the ground motion parameters, will give results which are useful for sensitivity and decision analysis. Furthermore, using alternative routines for damage evaluation can be effective in comparing the underlying models.

Decision Analysis

1. The operation in the three modes described above are based on deterministic principles. The assignment of probabilities to the input in general, and to the predicted ground motion data and resulting damage, in particular, provides the necessary ingredients for developing Bayesian decision models. Probability matrices should be constructed based on risk maps, prediction confidence levels, frequencies of past earthquakes and
2. Different decision models to be developed are: (a) recommendations of viable mitigation plans (such as land-use, structure upgrading, insurance and research) by region officials or private groups; (b) choice among mitigation options by individuals, based on their social, economic and behavioral profile, and (c) analysis of alternative insurance and loan plans by local, state and federal agencies.

TECHNIQUE

Considerable effort is required for analysis and coordination before a system of such complexity can be programmed. Nevertheless, the objective

of this paper is to outline basic specifications for general system developments. The next paragraphs describe some of these requirements qualitatively.

Basic Modules

The system consists of six major modules: (1) Database (DB); (2) Data Manager (DM); (3) Control Program (CP); (4) Algorithms; (5) a Problem Oriented Language (POL) and (6) an Interface with an existing regional system and data source (INTF).

In general, selective regional data are transferred from the regional system and database through the INTF module and stored in the DB. The DB is subsequently augmented by system-generated data, part of which is transferred back to the regional database in response to calls by the CP. The CP also handles the input and output for the many algorithms which are based on the procedures and models described earlier. The whole system is driven interactively by a POL which triggers the CP. Similar systems dealing with other disasters (such as flood, landslide and wind storms) can share the same database. The CP of every system may then gain access of the DB through the DM.

Programming Guidelines

It is intended that REDEEM be a prototype, modular system to be used for regional planning. For such systems, provisions must be made for maximum flexibility.

1. The Database must efficiently accommodate different types of data: (a) small and large subregions; (b) transferred, surveyed and generated data; (c) active data used in this program and other data which may be used by other programs. For example, data on occupancy can be acquired quite easily and may later be used by a program concerned with loss of lives.
2. The algorithms or systems, subroutines, for the various analytical and computational models should be: (a) readily replaceable in response to changes in the state-of-the-art, and (b) readily interchangeable for comparative studies and applications.
3. The language should be designed to facilitate the use of the system by engineers and planners who may not be familiar with all the technical details involved. Hence, the following features of the interactive system are desirable: (a) commands in language used by the user; (b) a prompting and query system; and (c) format-free input.
4. The system as a whole, should be programmed and structured such as to facilitate the use of commercial database management systems.

DATA PROCESSING

Generating Damage Factors

It is assumed that the inventory of structures can be sorted and structured according to AGE, OCCUPANCY, STRUCTURAL FRAMING, etc. This will lead to definition of prototypes and structural models $S_1, S_2, S_3...$ Similarly, by structuring predicted or actual past earthquake records according to MAGNITUDE, INTENSITY, PEAK ACCELERATION, PEAK VELOCITY, etc., it is possible to construct a matrix of response spectra (or time histories) and level of shaking. The data for the spectra will be stored in a "library" of earthquake records and modified before use (and stored) according to a matrix of percentage of critical DAMPING, DUCTILITY and the local type of SOIL. Letting the typical modified earthquake Response Spectra be $R_1, R_2, R_3...$

Conceptually, it is required to calculate the structural response V_{ij} resulting from the action of the level of shaking R_i on the structural model S_j . The response will be used as a measure of vulnerability, in the damage model, to derive structural damage and non-structural damage factors (SD and ND, respectively). These factors are stored in the structure record and documented in the regional database. It should be remarked that SD and ND could each represent a series of factors rather than a single one.

Economic Loss Estimation

The economic model to be developed will be used to generate damage loss factors (DL) based on the damage factors SD and ND. DL will also be stored in the DB and documented for individual properties corresponding to different levels of shaking.

Applying the DL factor to the economic data of individual properties will result in a loss estimate. These values can be summed up to obtain regional losses related, for example, to prediction parameters.

Cost Benefit of Mitigation Plans

Consider various options of mitigation such as LAND USE, STRUCTURE UP-GRADING, (razing and rebuilding, strengthening,...etc.). It is possible to define a matrix of mitigation plans $P_1, P_2, P_3...$ which will be used to generate modified models M_{kj} representing the influence of plan P_k on structural model S_j . The process of damage estimation can then be repeated with modified structures and the reduced loss from each plan can be defined as the benefit of that plan. Comparing the benefits with cost data on each plan will allow its evaluation.

Probabilistic Approach

1. Seismic Risk maps can be used to associate expected return periods to various levels of shaking.
2. The damage resulting from a given level of shaking can also be associated with a matrix of probabilities. The reaction of individuals can also be treated as a stochastic variable depending on their socio-economic data. These principles were successfully used in WHIMS (Ref. 4).
3. Probabilities and frequencies can be used in a Bayesian decision approach for a more systematic comparison of different economic decisions and mitigation plans.

UTILIZATION

Research of earthquake effects and mitigation in general, and engineering, economic, financial, social, legal and political studies in particular, can all benefit from a system that gives immediate and accurate dollar estimates of damage resulting from expected earthquakes. No attempt will be made here to list all of the many ways in which the completed system can be utilized. A few points, however, will be emphasized:

1. The operation of the system by regional officials will provide them with many products which are essential for proper planning. Some of these are:
 - a. Documentation of the regional inventory by means of the constructed database, which can be updated whenever damage resulting from earthquakes or other disasters or rehabilitation of properties are reported. The pre- and post-earthquake values of this option are obvious.

- b. The incorporation of socio-economic data in the database can be used to predict effects of decision options and action patterns by individuals and can also be used for individual and regional financial planning.
 - c. Current condition of buildings can be documented and hazardous situations monitored.
 - d. Different strategies of mitigation can be compared and evaluated before releasing them with recommendations to individuals.
 - e. Areas of needed research or priorities of research will be indicated.
2. The output of the proposed system can provide every individual property owner with an estimate of potential risk to his property in dollar figures. Optional mitigation plans, relevant to his own property with costs and benefits, may be indicated. Aside from the actual occurrence of the disaster and the tragic loss of life, this is probably the only tangible way of making the public aware of the potential risks and spurring individuals into action resulting from their own decisions.
 3. The level of detail (down to the individual), provided by the system, bases ensuing decisions on actual, rather than on average and statistical numbers, thus adding credibility, which, for low-frequency disasters, is a dominant reason for the failures of many insurance plans.
 4. The analysis of the detailed cost estimates and socio-economic data may be used for insurance planning, loans or other forms of financial assistance prior and following earthquakes.
 5. The impact of code modifications and validity of research results to be implemented can be examined and compared using the mode of sensitivity analysis,
 6. The system and models may be adjusted based on past earthquake records and data on corresponding actual damage.

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