COMPUTER-AIDED EARTHQUAKE ANALYSIS AND PLANNING FOR BUSINESSES AND ORGANIZATIONS

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SUMMARY

This National Science Foundation-funded project dealt with the problems of businesses and organizations in assessing earthquake vulnerabilities and identifying promising earthquake countermeasures. The project reviewed 25 existing damage estimation methods and a like number of government and business earthquake emergency plans. A microcomputer program, COUNTERQUAKE, was produced which rapidly provides an estimate of the damage that would occur at a given facility in an earthquake, and which generates reports that tabulate life safety, property loss, and outage risks. COUNTERQUAKE analyzes individual nonstructural components, rather than dealing with the nonstructure of a building as a single entity. An approach to emergency plan formulation was also produced.

INTRODUCTION

An analogy may be drawn between medicine and earthquake engineering: Brief physical exams are used to screen people for health problems, and earthquake engineering can be used to rapidly check the "seismic health" of a facility and estimate the effects of earthquakes. (The word "facility" is used, rather than "building," since the contents, hazard exposure of occupants, vulnerability of processes, and other factors that transcend the building itself are involved; the word "estimate" rather than "predict" is used, since it was concluded in this study that even with more expensive, detailed methods, the precision of the results is implicitly overstated by the connotation of "predict," whereas "estimate" connotes less exactitude.)

While sophisticated medical diagnostic technology can be useful in the case of a human patient, just as sophisticated structural analyses have their place in the earthquake field, the use of these detailed, expensive, and specialized techniques is most efficient and reliable when preceded by a briefer analysis on the level of the typical physical exam. COUNTERQUAKE, the earthquake damage estimation computer program produced in this project, is a diagnostic method analogous to the initial physical exam.

To meet real needs, a damage estimation method must be based on an idea of what the client or end user requires. Generally, a business or organization first needs an approximate view of its earthquake vulnerability, as well as an estimate of what would be required to reduce the risk. This initial step need only be approximate, because the first

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business decision to be made is whether to bother about the problem at all, rather than to decide what to do about it. Companies and government agencies that eventually institute earthquake risk reduction or safety programs have generally started this process with only a small amount of information, not in-depth data. Detailed analyses, when used as an initial step in assessing the "seismic health" of a facility, are sometimes counterproductive since they can obscure the most essential and basic points.

COUNTERQUAKE

COUNTERQUAKE is an easy-to-use microcomputer program that presumes pre-existing earthquake engineering expertise on the part of the user. Just as the judgment of a doctor cannot be eliminated by the use of a technician operating a sophisticated piece of medical equipment, so it was found that there was no substitute for earthquake engineering expertise in the process of estimating earthquake vulnerability. The following description summarizes the major modular components of COUNTERQUAKE.

Damageability

Damageability values, on a one to five scale, were devised for 20 different classes of structures, to account for differences in classes of construction, with each class containing three subclasses to account for variations in quality of construction. Using classes of construction as an inference of damageability draws heavily on the work of Steinbrugge and others (Ref. 1). Past earthquake performance is the primary basis for establishing damageability ratings, although numerous interpolation and extrapolation judgments must be made because of the lack of historical data on the performance of all of the currently available types of construction when they are subjected to different levels of ground motion.

Period

The period spectrum for buildings was bracketed into three ranges. This long, intermediate, or short period factor is combined with ground motion parameters to estimate the intensity of shaking imparted to the structure.

Intensity of Ground Shaking

In a modification of Blume's Engineering Intensity Scale (Ref. 2), three different intensity values are calculated, for the high, moderate, and low frequency ranges. The ground motion maps of the Applied Technology Council Tentative Provisions for the Development of Seismic Regulations for Buildings, or ATC-3 (Ref. 3), were used, and a relationship between the velocity and acceleration maps (A_v and A_a values) was devised. For example, for sites where the seismic zone as determined by the velocity map was greater than the acceleration zone, less high frequency content was inferred. Soft soil was assumed to bias the spectrum toward low frequency motion, as compared to hard soil material, in an adaptation of the three-level division of soils in ATC-3. The result of this step is three different estimated intensities of ground motion, in the high, moderate, and low frequency bands.

Response-Modified Intensity

In this step, the program compares the three intensities with the building's period to produce three values for the intensity of shaking within the structure. The highest value is then used to combine with the damageability value to estimate a level of structural damage.

Casualties

Two matrices of estimated casualty percentages (no injuries, minor injuries, major injuries, and fatalities) are used: one for buildings in which pancaking is possible (such as a multistory concrete frame), and one for buildings in which "collapse" is not really synonymous with pancaking or complete reduction of the hollow space within the building (as in the case of most wood frame structures).

Property Loss

Loss ratios are associated with each damage level similarly to the linking up of casualty ratios with damage.

Interruption of Function

A description of the time of outage and the estimated percentage of floor area usable after the earthquake are associated with each damage level.

Structural Countermeasures

Separate from COUNTERQUAKE, but cross-referenced, are lists of possible structural countermeasures, usually five to ten for each construction class. For some of these measures, one-page summary sheets were developed which include a description of the vulnerability the measure is intended to correct, a sketch of the upgrading feature, an estimate of the effect on performance if that one measure is implemented (which indicates quickly which measures are valuable only if combined with others), an estimated cost, and references.

Nonstructural Component Classification

Treating nonstructural components individually is a rational means of accounting for the great difference in damageability as well as the consequences of damage among nonstructural items. This is a distinctive feature of COUNTERQUAKE, since other damage estimation methods usually neglect the nonstructural topic, or treat the nonstructure as an undifferentiated whole. Approximately 50 typical nonstructural components were pretabulated in COUNTERQUAKE. (It even does windows.) Additional components can be easily added. For each nonstructural component, five values are assigned: deformation-dependent nonstructural damageability value (on a one to five scale) rates the component's susceptibility to damage caused by drift; shaking-dependent damageability value rates the component's inertial vulnerability (a tall, freestanding piece of equipment would typically have a high shaking-dependent value); the hazard rating accounts for the fact that at the same level of damage, one nonstructural component may be more likely to cause casualties (failure of a glass window creates a greater hazard than failure of a lightweight drywall partition, for example); an outage rating accounts for the different repair or replacement times involved (replacement of industrial production equipment may require several months, while replacement of broken windows may take only days); an importance rating is assigned to each component on the basis of its importance to the overall functioning of the building (elevators in a tall building are more essential than partitions, for example, and disabling damage to the elevators interrupts the functioning of the building much more than damage to partitions).

The location of the component (ground or ground floor mounted versus upper level) is specified, and if desired, multiple entries for equipment located at different levels in the building may be made to account logically for the expected differences in shaking severity. It is also possible to easily use multiple entries to separately account for identical nonstructural items used by different functional portions of the organization.

The previously calculated structural damage level is compared with nonstructural damage, since structural collapse will cause nonstructural damage no matter how damage resistant the nonstructural component.

The program then separately calculates deformation-dependent damage and shaking-dependent damage. The mechanisms of damage for these two cases are quite distinct, though they may both be present, and the measures taken to reduce these two causes of damage are usually different as well.

Nonstructural Casualties

A high, moderate, or low category of life safety hazard is determined. To directly relate nonstructural damage to life safety in more quantitative and precise terms would require data on the number of people adjacent to each type of component, which is too burdensome an information collection requirement. Relationships between nonstructural damage and casualties are also less well documented than with the case of structural damage.

Nonstructural Property Loss

This is similar to the structural property loss step, in which percentage losses are associated with damage levels, except that replacement cost values for each different nonstructural component may be entered.

Interruption of Essential Functions Caused by Nonstructural Damage

A statement ("severe," "intermediate," or "minor") is displayed or printed out, based on a calculation that combines nonstructural damage level with the importance rating for each component.

Nonstructural Countermeasures

As with the structural countermeasures, this is not a part of the computer program itself, but is cross-referenced to it. For each nonstructural component, a description of its general vulnerability, type of restraint retrofit, probable effect of using the countermeasure, the cost of this measure, and references can be listed.

Hazardous Materials and Fire

A simple high-intermediate-low hazard is entered with comments on probable problem areas. As with the geologic hazards, this is not a part of the computer program itself, but is integrated into the format of the report that the program generates. Previous work by the author (Ref. 4) was relied upon to devise these risk judgments.

EMERGENCY PLANNING

Review of Existing Earthquake Emergency Plans

Approximately two dozen earthquake plans of government agencies in California, and a like number of plans of California corporations, were reviewed in this study and as a task for the Engineering Committee of the Governor's Earthquake Task Force (Ref. 5). Several typical strengths and weaknesses were noted. Government plans devote a large part of the volume to what might be called the preamble: Authority, objectives, assumptions underlying the type of disaster expected, etc. Common to both public and private plans is a lack of operational detail. For example, government plans may include damage reconnaissance as a task for which a certain department is responsible, but how this process will occur is never spelled out. Including the phrase "Save lives and protect property" and similar generalities in these plans may make them appear more official, but does nothing to make them help in the process of actually saving lives and protecting property.

Government plans often use a variety of military-derived jargon, such as "concept of operations," "annexes," "mission assignments," "support functions." Close scrutiny of the plans, observance of several large scale earthquake exercises, and observations made after three recent damaging California earthquakes have led the author to conclude that the actual level of planning and coordination is less than what the written plan indicates and the assumption that the emergency planning is such a sophisticated undertaking that it requires its own vocabulary only increases the illusion. Corporate plans are less likely to indulge in jargon, but rarely contain much detailed planning that would enable the company to respond to an earthquake more effectively than if there were no plan at all. It should be noted that the plans of a few corporations and agencies, about 5% of the total reviewed, did not have the weaknesses mentioned above, but none of the plans appeared to have had any major input from a person with earthquake engineering expertise.

Improvements in Emergency Planning Methods

Based on this critique, an attempt was made at improving the process of formulating earthquake preparedness and emergency planning. Two different approaches were followed: a brief sample plan for a small company and a more elaborate format for a large company or organization. For the large organization, a series of functionally-related categories were devised, such as Facilities, Personnel, Management, Safety, Security. Most local governments have an organizational structure that can be summarized under typical departmental headings such as Public Works, Fire, Police. For each functional area or department, typical earthquake-related responsibilities were organized in terms of pre-event, during and post-event headings. Then alternative means of meeting each task were commented upon in a brief narrative section, followed by a sample of one or more ways in which the written plan might actually word the planning. Rather than offer the user a "fill in the blanks," unthinking approach, the goal was to offer intelligent commentary and a sample, from which an individually tailored plan would be prepared. Ironically, many emergency plans are prepared without any real planning, but rather by copying other written plans.

One of the innovative ideas developed included printing of alternative instruction sheets in advance, so that once an earthquake occurred and a given level of damage or disruptiveness had occurred, the decision could be rapidly made to follow one of several previously outlined courses of action, such as: close down, stay open, send employees home, suggest that employees stay at the site because of transportation problems, or request only designated essential employees to remain. Once this decision is made, the appropriate instruction sheet would be distributed. In addition to reducing the momentary decisionmaking chaos that can occur in a disaster, preprinted instruction sheets allow for legal review of the directions to prevent liability problems. Different categories of employees can be identified in advance, and different instructions devised for each group.

Emergency Planning Countermeasures

Parallel with the tabulation of structural and nonstructural countermeasures, there is a listing of emergency planning options. A menu list of numerous potential countermeasures were ordered in the categories of training and exercises, emergency operations center or emergency management, mutual aid and liaison, information gathering and organization, medical, shelter, facilities and engineering, rescue, fire and hazardous materials, security, communications, and transportation. An example of a specific countermeasure under the heading of training and exercises is the take-cover drill, in which employees are briefly drilled on getting under desks or tables, and with discussion afterward by supervisors to review the other actions that are to take place after an earthquake (utility shutoffs or equipment shutdowns by certain designated employees, exiting and re-assembly outside, etc.) An estimated effect is described for the implementation of the countermeasure. If take-cover drills are instituted, "Injuries due to nonstructural causes reduced significantly: no fatalities, no serious injuries, and minor injuries reduced by half" is the comment listed. A cost in terms of labor hours is also estimated.

CONCLUSIONS

During the study, the prototype method was applied on a trial basis on a large Bay Area electronics firm. The results of the COUNTERQUAKE-generated results were compared with earthquake damage estimations produced by three engineers. On the most essential points, there was usually agreement. The validity of using rough categories (one to three or one to five scales, for example, or ranges of values in terms of high-moderate-low) seemed corroborated by the comments of the engineers.

Another application was the use of the COUNTERQUAKE method to analyze typical nonstructural vulnerabilities and countermeasures in the preparation of Reducing The Risks Of Nonstructural Earthquake Damage: A Practical Guide, prepared for the Southern California Earthquake Preparedness Project of the California Seismic Safety Commission (Ref. 6). The booklet is intended to be used by corporations and government agencies with office or commercial buildings in the development of earthquake protection programs.

A graphic format was used to itemize the typical vulnerabilities and protective measures associated with about 25 typical nonstructural items. In addition to this reference section, preceding material provides background material on earthquakes and nonstructural damage, and following chapters provide guidance on emergency planning related to nonstructural damage and the administration of construction projects to insure appropriate nonstructural protective features. Along with the worksheets and guidance provided in the booklet, this information offers a complete package approach to the reader and user of the booklet. No technical background is presumed, since the most important phase in any earthquake protection program is the very first step of explaining to non-engineer decisionmakers in government or corporate management the general nature of the problem and how to proceed to begin to deal with it. Reference material for architects and engineers is also included, however, since many design professionals are unaccustomed to the seismic aspects of nonstructural design.

The primary conclusion of the study and subsequent experience with applications is that the creation of more knowledge, such as more precise analytical methods, is not the major solution to our numerous practical earthquake problems: initiating and implementing earthquake protection programs using the technical knowledge we already have is a more effectual as well as more difficult task.

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