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ILLUSTRATIVE METHODS FOR DERIVING EARTHQUAKE LOSSES EXPECTED TO A WATER SYSTEM

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SUMMARY

The Technical Council on Lifeline Earthquake Engineering (TCLEE) of the American Society of Civil Engineers (ASCE) has performed an illustrative analysis of how to estimate direct dollar losses to a culinary water system as a result of earthquakes potentially affecting it. This paper provides an overview of the project process. Included is a synopsis of the methodology and of project assignments. Participation by committee members extremely knowledgeable about specific topics (i.e., booster stations, liquefaction susceptibility) has assured attention to detail and also statement of issues not yet resolved within the state-of-the-art.

INTRODUCTION

In early 1986, TCLEE of ASCE embarked on a project to provide an illustrative analysis on how to estimate direct dollar losses to a culinary water system from potential earthquakes affecting it. Two TCLEE committees have participated in this project: seismic risk and also water and sewerage. This paper provides an overview of the project process, emphasizing how the methodology was implemented through task assignments and special problems that have arisen. A detailed account of project methods and findings is scheduled for publication in 1989.

This project began for several reasons. First, because the reinsurance capacity market was in a downswing, earthquake insurance rates rose dramatically. Owing in large part to their dependence on the reinsurance market, these rates have typically reflected neither actual earthquake loss experience nor the results of seismic risk studies. This has been especially true for utility system facilities. Even in the technical literature, estimation of direct losses to utility facilities has received scanty attention (notable exceptions include Refs. 1 and 2). Hence, estimation of direct earthquake losses to utility components has received little attention either theoretically or practically. Second, as a result of the completion of its Advisory Notes on Lifeline Earthquake Engineering (Ref. 3), TCLEE decided to turn to another topic that potentially includes all committees: seismic risk. Since scientific and engineering data pertinent to potential water system damage from earthquakes has matured, water systems became the focus of this project.

METHODOLOGY AND TASK ASSIGNMENTS

The overall methodology employed in this project is shown in Fig. 1. Major technical steps have consisted of exposure definition, loss algorithm development, hazard identification, and loss calculation.

To accomplish these steps, task assignments have been made within the committees. Table 1 lists these task assignments and shows that on particular topics chosen, experts in the field were drawn upon. The degree of specialization on this project is far greater, in our opinion, than typical seismic risk projects. This specialization therefore provided careful attention to details but required considerable coordination so that the overall direction of the project remained clear to project participants.

The first task was to define a model system for study purposes. The system employed is shown in Fig. 2. The model system contains major water system components of interest: filtration plants, booster stations, distribution reservoirs, wells, and pipelines, including aqueducts. A variety of these types of components were further defined to ensure coverage of numerous seismic vulnerability issues. As examples, both prestressed concrete rectangular and steel cylindrical flat-bottomed distribution reservoirs were included as were a variety of types of pipe materials, joints, and sizes. Dams, however, were excluded owing to their special analysis needs.

As a result of the emphasis on loss estimates as opposed to reliability statistics, one key difference between this and previous seismic risk projects has been the effort to streamline procedures to derive replacement cost estimates. For filtration plants, for instance, development of replacement cost estimates required a cost sheet for eighteen subsystems (i.e., alum feed system and sodium hydroxide feed system) and eight categories of materials and labor (i.e., steel, excavation and sitework, and labor).

Loss algorithms were defined as mathematically continuous functions relating loss, as a percent of replacement cost, to some measure of earthquake intensity (peak ground acceleration (PGA), Modified Mercalli Intensity (MMI), peak ground velocity (PGV), or permanent ground displacement). The algorithms are distinguishable from seismic fragility analyses (probability of component failure or dysfunctionality versus some measure of earthquake intensity), required for seismic fragility analyses and frequently produced for the nuclear power industry. Whereas direct dollar damage to a facility may be slight (repair costs for a pipe leak, a ruptured outlet connection, or a piece of fallen equipment may be small), system implications of even short-duration dysfunctionality may be large . Conversely, even though very costly damage may occur to a facility (such as extensive damage to a chemical administration building or buckling near the top of a tank), the system or facility may remain operational.

Several difficulties were encountered during loss algorithm development. Since many project participants were more familiar with PGA than MMI or PGV, it was decided to allow participants to use whatever measure they were most familiar with. Nonetheless, numerous questions arose pertaining to the relations among these intensity descriptors as well as which intensity descriptor was most suitable for loss algorithm development. As a further complication, participants proposed cases in which repair of damage may cost more than the replacement cost of the existing facility, such as when special sitework is needed, overtime and other special costs are needed for rapid restoration of operations, or seismic upgrades are required for damaged facilities.

To provide a basis for loss algorithms developed, past earthquake damage data were collected. Data sets are becoming more complete for various types of pipelines and distribution storage reservoirs. However, data are scarce for filtration plants and extensive data that have been gathered for electrical equipment remain proprietary. Various methods were proposed to develop these loss algorithms. These include various types of categorization techniques, which distinguish facilities by various structural categories and apply earthquake statistical techniques or expert judgment to derive loss algorithms. These further include visual inspection and rating techniques, semi-analytical and analytical techniques, and experimental techniques (for a more extended discussion, see Ref. 4). Combined analytical and empirical techniques were applied to develop algorithms for pipelines and selected filtration plant facilities. However, owing to the complexity of the task of developing loss algorithms for many components and subcomponents, versions of categorization techniques were understandably resorted to for other components and subcomponents.

Local geology was delineated in terms of high liquefaction susceptible zones, potential landslide zones, and a fault zone of deformation. A second pertinent fault system was postulated in the far field. Return intervals for various magnitude events and locations (rupture center and rupture length) were postulated for these two fault systems. Attenuation functions were developed for PGA and PGV. Conversion relationships between PGA and MMI and PGV and MMI were used for estimation of MMI. A shallow-soil zone was placed at the base of the mapped landslide which corresponds to the base of inferred hills. PGA was estimated to be higher in this shallow-soil zone. Moreover, since PGV estimates depended on depth to crystalline basement rock, depth to basement rock contours were provided. Rapid procedures were developed for assessing liquefaction and landslide probabilities.

One distinctive feature of the overall loss methodology used is that numerous potential earthquakes may be evaluated of diverse sizes and rupture center locations (Refs. 2, 5). Given assignments of return intervals for each earthquake postulated, probabilities of various exceedance loss levels can be derived either for the system as a whole or for any selected component. These probability estimates are driven by the return intervals associated with each earthquake scenario used. Owing to the complexity of providing a probabilistic analysis for each term used in this analysis, and the slim basis for developing distributions for some terms, a more complex probabilistic analysis was not undertaken. The methodology selected, though, provides an account of how one may incorporate areal seismicity to derive estimates of aggregate system losses. For some purposes, only the highest possible losses may be of interest. However, for many other purposes, including those used to guide insurance underwriting and those used to assess which facilities to upgrade seismically, less conservative estimates of losses are typically desirable.

CONCLUSION

This paper examines some of the main features of the process whereby two TCLEE committees joined to provide an illustrative method for assessing direct losses to culinary water systems. Specialists on a number of study topics volunteered their time so that adequate attention to detail was assured. The project also involved overall coordination so that products produced on one topic could be used within the overall methodology. This attention to detail and interdisciplinary interaction has led to the formulation of many issues, some of which are unresolved within the state-of-the-art. The overall methodology produced is distinctive in its contributions from various experts on special topics. The methodology is also capable of assessing losses within a probabilistic framework while at the same time providing loss estimates that may be reached for less probable larger magnitude more damaging earthquakes.

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TABLE 1 PROJECT TASK ASSIGNMENTS

MODEL SYSTEM DEFINITION	Isenberg, Taylor, Elloit
Replacement Cost and Loss	
• Algorithm Development Methodology	Taylor, Werner, Kiremidjian
• Past Earthquake Damage Data Collection	Water and Sewerage Committee Lead
• Distribution Reservoirs	Lund, (lead), Cheyhey, Kuebler, Elliot
• Boosters Stations	Elliot (lead), Anton, Blair, Jorgensen Gupta, Cheyhey
• Well (s)	Ballantyne (lead), Anton, Gupta, Legatos, Elliot
• Filtration Plants	Cornell (lead), Ballantyne, Daily, Laverty, McCarty, Singly
• Pipelines (including aqueducts)	Wang (lead), Ford, O'Rouke, Kennedy, Keyser, Swanson, Eguchi, Isenberg
Hazard Identification	
• Seismic Source Zone Definition	McGuire (lead), Seismic Risk Committe
• Surface Fault, Liquefaction, and Landslide Hazards	Crouse, Hawkins
• Attenuation Functions and Soil Factors	Campbell (lead), Seismic Risk Committe
Loss Calculation Methodology	Ostrom (lead), Moghtaderizadeh, Taylor, Eguchi, Kiremidjian, Isenberg

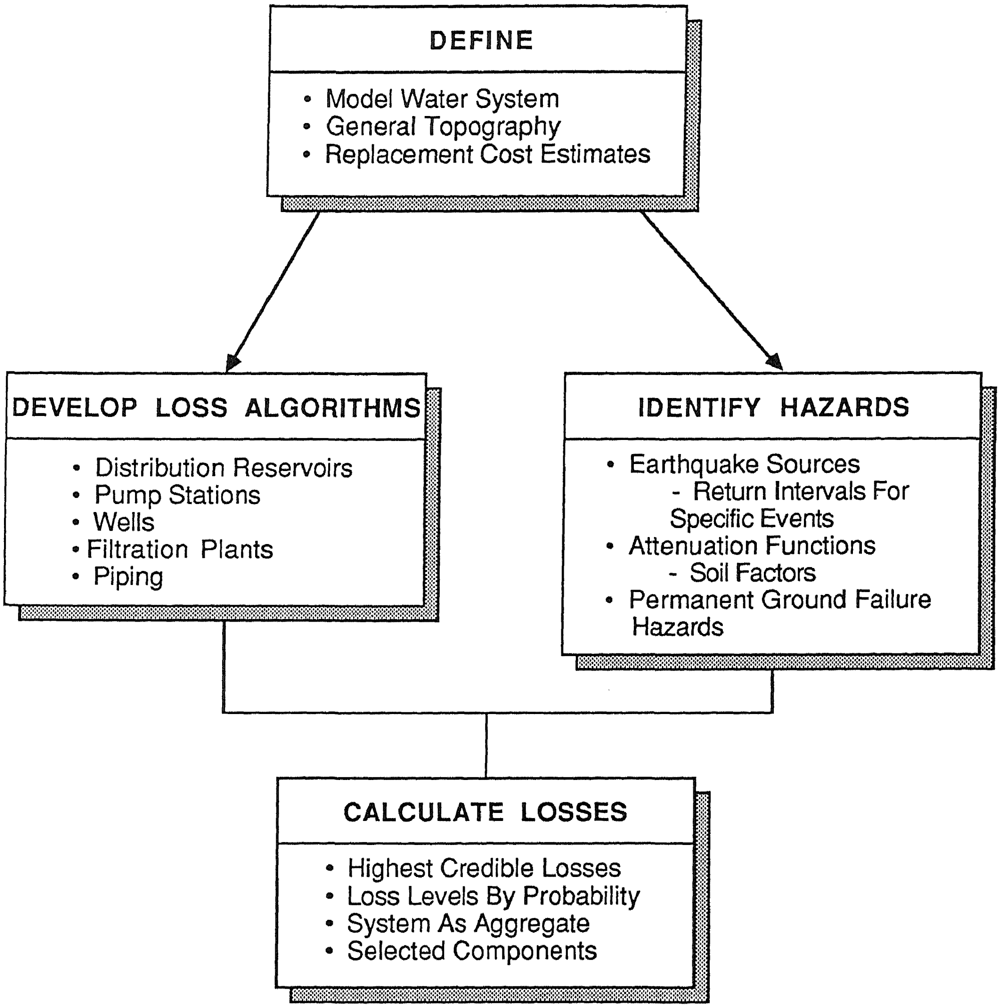

FIGURE 1
OVERALL PROJECT METHODOLOGY

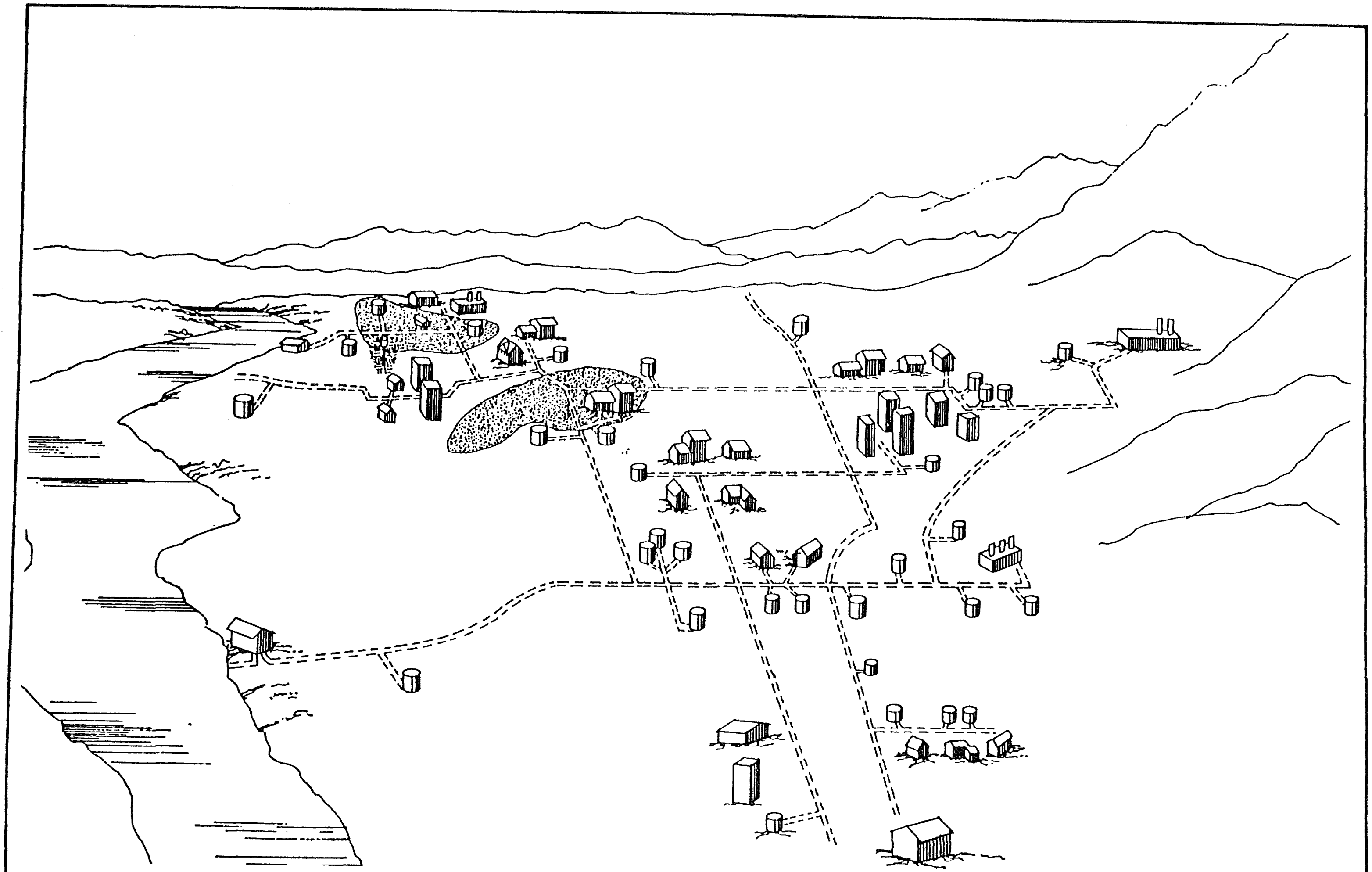

FIGURE 2 SEISMIC CITY