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COST-BENEFIT ASSESSMENT METHODOLOGY FOR SEISMIC DESIGN OF HIGH-LEVEL WASTE REPOSITORY FACILITIES *

by

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OBJECTIVE

This paper summarizes a methodology for performing a cost-benefit assessment of the seismic design of the surface facilities associated with the prospective high-level waste repository at Yucca Mountain, NV. The methodology described will develop the costs and benefits of varying design levels for vibratory ground motion and surface fault displacements for structures, components, and equipment in the repository facilities.

INTRODUCTION

A cost-benefit study implies the determination of the optimum solution for the problem under consideration. When all costs and benefits are expressed in dollars, the selection of the optimum solution is relatively straightforward. The independent variable in a cost-benefit analysis could be a continuous function, such as ground motion acceleration or a set of discrete alternatives such as specific fault rupture displacements.

The value-impact analysis used by the Nuclear Regulatory Commission (NRC) (Heaberlin, et al., 1983) selects the most cost-effective regulatory action from among several proposed actions, relative to existing regulations, rather than developing the most cost-effective design for a given type of loading. Nonetheless, Heaberlin et al. (1983) provide a detailed discussion of the attributes to be considered in any cost-benefit analysis. The study reported herein, while not a strict value-impact analysis, uses selected attributes of a value-impact analysis, as discussed in Heaberlin et al. (1983).

FUNDAMENTALS OF THE COST-BENEFIT ANALYSIS

To determine the optimum seismic design level (with associated fault displacement) for a given structure, the optimum design acceleration can be obtained simply by setting the first derivative of the total cost objective function, C_T, with respect to the design acceleration, a, to zero:

$$\frac{dC_T}{da} = 0 \quad (1)$$

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In this particular case, the objective function is the total cost of the initial investments and consequences, expressed in terms of the design level acceleration. Obviously, other cost parameters could be used: e.g., total cost per health effect (deaths) or the incremental cost per reduction in health effect could be optimized. These concepts are in common use and could be employed to arrive at a decision regarding the design level. In this study, total costs are used.

The total cost can be divided into two major elements: accident-related costs and nonaccident-related costs. An estimate of accident-related costs is associated with the probabilities of both earthquake occurrences and system, structure, and component failures; thus this estimate requires the calculation of expected rather than direct costs. An estimate of nonaccident-related costs is direct and relatively straightforward.

A common cost basis must be established for combining cost elements. For example, accident-related costs may be given as annualized costs and may be based on the annual probabilities associated with the seismic hazard curve. Nonaccident-related costs are generally total costs rather than annualized costs. To combine these two different types of costs, the costs must be normalized by:

- calculating the present worth of the annual accident-related costs or
- annualizing the nonaccident costs.

For either alternative, the discount rate of money and the life of the facility in years are required. The discount rate of money is the net cost of money. It is conservative to use zero discount. Given the annual uniform costs (R), the present worth (P) is given by

$$P = \frac{R[(1 + i)^n - 1]}{i(1 + i)^n} \quad \text{for } i > 0 \quad , \tag{2}$$

where i is the discount rate and n is the life of the facility in years.

For $i = 0$, $P = \underset{i \to 0}{\mathrm{Lt}} \dfrac{R[(1 + i)^n - 1]}{i(1 + i)^n}$ in accordance with L'Hopital's rule.

ACCIDENT-RELATED COSTS

Accident-related costs due to a seismic event are difficult to quantify in dollars. However, such a quantification must be attempted with uncertainties in estimates considered. The more important effects of an event could include one or more of the following costs:

- off-site public exposures,
- short-term occupational exposure,
- off-site property damage/cleanup,

- on-site damage/repairs/decontamination, and
- mission delays.

NONACCIDENT-RELATED COSTS

Nonaccident-related costs considered include

- engineering and construction: structures and equipment (related to the seismic design aspects of the facility),
- licensing,
- site characterization,
- nonregulatory delays, and
- maintenance.

COST-BENEFIT METHODOLOGY

The steps required to obtain the optimum design level, assuming that cost details can be reliably obtained are shown in Figure 1. Figure 1 is a flowchart showing the steps required to calculate the total cost objective function, C_T. Solving Equation 1 would then produce the optimum design level. In the subsequent paragraphs, this methodology is explained. The numbers enclosed in brackets ([ ]) refer to the respective numbered boxes in Figure 1.

ACCIDENT-RELATED COSTS

[1] An earthquake could cause a spectrum of different damage states. However, different events would cause different damage states on a given structure. Each damage state could result in different offsite and onsite consequences. Therefore, the damage state of the structure should be determined for the "beyond design basis" conditions for each of the specific design levels.

For critical facilities designed for realistic ground motions and expected to withstand any ground motion without collapsing, four damage states are deemed sufficient and meaningful. Thus, for this study, the following four damage states should be defined in terms of the complete structural response:

- Light (L),
- Moderate (M),
- Heavy (H), and
- Total (T).

Events that are within the design basis are assumed to cause no damage. The damage state L is associated with an earthquake occurrence of slightly beyond the design basis earthquake. The other states correspond to increasing levels of beyond-design-basis events. For each specific design level, the levels of the beyond-design-basis events that would cause the given damage states to occur must be determined. For each damage state, a list of structure failures, such as potential falling concrete and concrete crack widths and lengths, must also be identified.

[2] Given the falling concrete, concrete crack widths and lengths, and associated radioactive material inventories, the off-site radioactive release and associated dose for each of the damage states is calculated (Box [2]).

[3] Due to uncertainties in modeling parameter values, the damage states are represented as a conditional probability of the event level. Box [3] shows this schematically for each damage state, both as a probability density function and a cumulative probability function. The graphical representations of the latter are often referred to as fragility curves. Fragility is defined as the useful limit of the prescribed damage state. A set of fragility curves for each design level is developed so that all damage state fragilities are known.

[4] The seismic hazard curve for the site is determined by plotting the annual probability of exceedance vs. the peak ground acceleration (Box [4]).

[5] Given the seismic hazard curve for the site, the damage state probabilities are calculated by convolving the seismic hazard curve with the fragility curves. Because each damage level is related to a radioactive release, computation results can be summarized for each design level.

[6] The accident-related costs are quantified in dollars for each damage state. Resulting cost curves are displayed schematically.

[7] For each damage state, the total cost is summed and presented as a function of the associated radioactive release. This summary curve applies to all designs at any design level.

[8] Given the annual probability of the release (Step [5]) and the cost of the release (Step [7]), the expected cost, E(c), can be computed using Equation 3 as

$$E(c) = \int_{-\infty}^{\infty} c(x)f(x)dx \quad , \tag{3}$$

where c(x) and f(x) are functions of cost and release.

The above integration can be algebraically approximated by

$$E(c) = \sum_i \frac{c(x_i) + c(x_{i+1})}{2} P\ (x_i < \hat{x} \leq x_{i+1}) \quad , \tag{4}$$

The terms of Equation (4) are shown for a release resulting in $\hat{x}$ rems between x_i and x_{i+1}. The summation of incremental expected costs for each accident-related attribute will produce the annual expected cost of the accident-related effects.

This cost is the annual cost for the life of the facility. Multiplying by the life of the facility in years and adjusting for the discount rate of money determines the present worth of the expected uniform annual costs.

[9] The previous steps are repeated for each design level and the results are plotted.

<u>NONACCIDENT-RELATED COSTS</u>

[10] The calculation of nonaccident-related costs does not involve the probability of the release of radioactive material. These costs are incurred regardless of whether an accident occurs. These are directly calculated costs.

[11] The individual cost elements are summed to give the total nonaccident-related cost.

[12] The accident-related and nonaccident-related costs are summed to obtain total present cost, C_T. The graphical equivalence of Equation 1 is the bottom of the trough (where the tangent is horizontal). This point defines the optimum design level.

This methodology has been applied to evaluate the waste handling facilities for the proposed Yucca Mountain repository and is described in Reference 2.

<u>TREATMENT OF FAULT DISPLACEMENT</u>

A similar methodology was developed examining hypothetical fault displacements beneath structures.

<u>Reference</u>:

1. Heaberlin, S. W., J. B. Burnham, R. H. V. Gallucci, M. F. Mullen, R. J. Nesse, L. A. Neives, J.J. Tawil, M. B. Triplett, S. A. Weakley, and A. R. Wusterbarth, "A Handbook for Value-Impact Assessment," NUREG/CR-3568, Pacific Northwest Laboratory, Richland, WA, December 1983.

2. Subramanian, C. V., A. H. Hadjian, L. J. Jardine, J. W. Kemp, O. Kiciman, C. W. Ma, J. King, W. Andrews, and R. P. Kennedy, "Preliminary Seismic Design Cost-Benefit Assessment of the Tuff Repository Waste-Handling Facilities," Sandia National Laboratories, Albuquerque, NM (under publication).

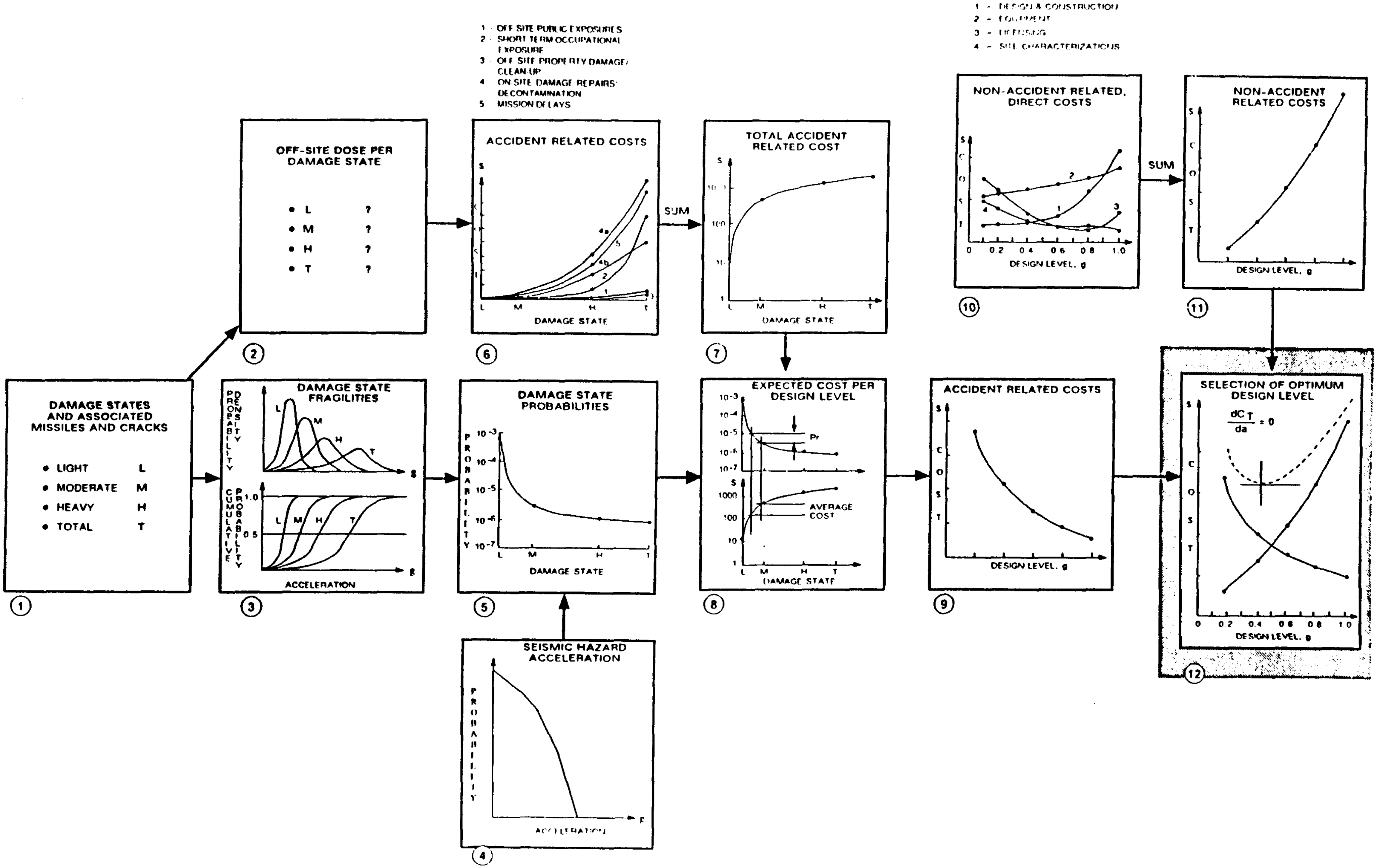

Figure 1. Steps to Obtaining the Optimum Design Level

APPENDIX

Information from the Reference Information Base Used in this Report

This report contains no information from the Reference Information Base.

Candidate Information for the Reference Information Base

This report contains no candidate information for the Reference Information Base.

Candidate Information for the Site & Engineering Properties Data Base

This report contains no candidate information for the Site and Engineering Properties Data Base.