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Methods for Developing Seismic and Extreme Wind-Hazard Models for Evaluating Critical Structures and Equipment at U.S. Department of Energy Facilities and Commercial Plutonium Facilities in the United States

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Summary

Lawrence Livermore National Laboratory (LLNL) is developing seismic and wind hazard models for the U.S. Department of Energy (DOE). The work is part of a three-phase effort to establish building design criteria developed with a uniform methodology for seismic and wind hazards at the various DOE sites throughout the United States. In Phase 1, LLNL gathered information on the sites and their critical facilities, including nuclear reactors, fuel-reprocessing plants, high-level waste storage and treatment facilities, and special nuclear material facilities. Phase 2--development of seismic and wind hazard models--is discussed in this paper, which summarizes the methodologies used by seismic and extreme-wind experts and gives sample hazard curves for the first sites to be modeled. These hazard models express the annual probability that the site will experience an earthquake (or windspeed) greater than some specified magnitude. In the final phase, the DOE will use the hazards models and LLNL-recommended uniform design criteria to evaluate critical facilities.

The methodology presented in this paper also was used for a related LLNL study—involving the seismic assessment of six commercial plutonium fabrication plants licensed by the U.S. Nuclear Regulatory Commission (NRC). Details and results of this reassessment are documented in reference [1].

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1. Introduction

The Division of Operational and Environmental Safety of the Department of Energy (DOE) asked Lawrence Livermore National Laboratory (LLNL) for technical assistance in evaluating and developing building design criteria for critical facilities at DOE sites throughout the United States. The criteria in question are those relating to a structure's ability to withstand earthquakes and strong winds, from both tornadoes and other severe storms.

Building design criteria, developed by a uniform methodology, currently, does not exist for seismic, tornado, and high wind hazards at the various sites in the United States under the management of the Department of Energy (DOE). In 1975, the Division of Operational Safety of the DOE asked Lawrence Livermore National Laboratory (LLNL) for technical assistance in developing uniform building design criteria. A three-phase project was begun. The first phase, which was completed in 1978, involved information gathering, including:

- Selection of the DOE sites to be included in the project.
- Identification of critical facilities at each site and determination of the criteria for their selection.
- Review of the current seismic and high-wind design criteria in use at each site.

During this phase, critical facilities were defined, and information about such facilities at each site selected for the study was gathered and summarized.

Figure 1 shows the DOE sites considered in this study. In general, the critical facilities at each site fell into one of the following categories:

- Nuclear reactors;
- Special nuclear materials facilities;
- Fuel-reprocessing facilities;
- High-level waste storage and treatment facilities;
- Hazardous chemicals storage facilities.

In the second phase, experts in seismic and extreme wind hazards were asked to develop models for each site. The methodology used is discussed in detail in reference [2]. TERA Corporation, Berkeley, Calif., was selected to develop the seismic hazard models. McDonald, Mehta, and Minor, Consulting Engineers, Lubbock, Texas, and T. T. Fujita of the University of Chicago were both contracted to independently develop hazard models for tornado and high winds. McDonald, Mehta, and Minor were selected to provide the engineering expertise in extreme wind hazard modeling while Fujita provided input from the meteorology point of view. LLNL will take input from both national experts and construct a combined extreme hazard model for DOE. These models and the methodology used by the consultants in developing them are summarized in this report.

2. Seismic Hazard Analysis

Seismic hazard analysis is the process of developing seismic input, peak ground acceleration and response spectra, for an area or region of interest. The are two distinctly different approaches to seismic hazard characterization--deterministic and probabilistic. In the deterministic approach, the analyst must do the following:

- Decide that an earthquake of a given magnitude or intensity occurs at a certain location.

- Attenuate the ground motion from the earthquake source to the site.
- Determine the effects of that earthquake.

The problem with this approach is that it is difficult to define the margin of safety in the resulting design parameters. As a result, the analyst generally uses upper-bound estimates of ground motion, which are typically overly conservative.

In a probabilistic approach, on the other hand, the analyst quantifies the uncertainty in the number, size, and location of possible future earthquakes and can thus present a trade-off between more costly designs or retrofits and the economic or social impact of a failure.

Although the probabilistic approach requires significantly more effort than does the deterministic approach, we used it to develop seismic hazard characterizations in order to:

- Quantify the hazard in terms of return period.
- Rigorously incorporate the complete historical seismic record.
- Incorporate the judgment and experience of seismic experts.
- Account for incomplete knowledge about the locations of faults.
- Assess the hazard at the site in terms of spectral acceleration, velocity, displacement, or earthquake intensity.

The method is particularly appropriate for eastern facilities where the seismicity is very diffuse and cannot be correlated with surface faulting as it can be in the western United States. The location of the design earthquakes in the eastern United States is therefore particularly uncertain. The strength of the probabilistic approach is its ability to quantify these uncertainties. Its major weakness is the lack of plentiful statistical data from which to characterize the various input parameters in probabilistic terms. Nevertheless, the credibility of the probabilistic approach has been established through detailed technical review of its application to several important projects and areas. Recent applications include assessments of the seismic hazard in Boston described in reference [3], in the San Francisco Bay Area [4], in the Puget Sound Area [5], and the continental United States [6]. Results of these studies have been applied to, among other areas:

- Development of long-range earthquake engineering research goals.
- Planning decisions for urban development.
- Environmental hazards associated with the milling of uranium.
- Design considerations for radioactive waste repositories.

This diversity of application demonstrates the inherent flexibility of the probabilistic hazard assessment approach.

2.1 Input

The probabilistic approach was used to characterize the seismic hazard for each site in this study. The input to a probabilistic hazard assessment comprises earthquake frequency relations, attenuation functions, and a specification of local source regions. Because hazard assessment calculations are very sensitive to the particular composition of the input, we consulted with experts in local and regional seismology during the preparation of input for each facility.

2.2 Methodology

The product of a probabilistic approach is a measure of the seismic hazard expressed in terms of return period, or reciprocal annual probability. The methodology to determine seismic hazard at a site is usually divided into the following steps, which are discussed below:

- Specify the geometry of local seismic regions.

  Based on the geology and historic seismicity of the region, sources are identified as line sources (faults) or area sources. The largest earthquake (in terms of magnitude or intensity) associated with each source is established as shown in Fig. 2a.
- Describe past seismicity in terms of earthquake occurrence.

  The recurrence of earthquakes of various magnitudes is based primarily on historical seismicity. A straight line or a set of straight lines is fitted on the data using regression analysis to develop these relationships as shown in Fig. 2b.
- Choose a transfer function to mathematically transmit information from the epicenter to the site under consideration in terms of parameters that a structural engineer can use. See Fig. 2c.
- Using a combination of theory and data, derive the peak accelerations at a given site that result from earthquakes of various sizes at different source locations. Different approaches are needed for sites in the western vs the eastern United States. Then, combining the potential activity of all sources, the probability that a certain acceleration will not be exceeded within a given time period t is determined. This is the seismic hazard model. See Fig. 2d.

3. Tornado Hazard Modeling

A methodology for assessing tornado hazards was also developed. Hazard is defined here as the annual probability of any point within a geographic region experiencing windspeeds in excess of some threshold value. As defined, this is a point probability that is independent of a structure's size and location within the geographic region.

The methodology uses available tornado records for the geographic region. Distribution functions that relate area to intensity and occurrence to intensity are empirically derived from the data for use in the probability calculations. The geographic region must be carefully defined so that tornado characteristics are reasonably homogenous in the region. The effect of low population density on the number of tornadoes that may go unreported is taken into account.

The tornado hazard model is determined from statistical analyses of records of tornadoes that have occurred in the region surrounding the site of interest. A consistent data set is first obtained. Then, the hazard model is developed by sequentially determining the following relationships and probabilities:

(1) An area-intensity relationship in a global region surrounding the site.

(2) An occurrence-intensity relationship in a local region surrounding the site.

(3) The probability that a point in the local region experiences windspeeds in some windspeed interval.

(4) The probability that windspeeds in the local region exceed the interval values. A plot of this probability vs windspeed is the hazard model.

4. McDonald's Straight-Windspeed Methodology

In the United States, the work of Thom in reference [7] has been used to evaluate the annual probability of straight winds exceeding some threshold value. Thom selected the Type II extreme value distribution (Fisher-Tippett Type II) to represent the annual extreme fastest-mile windspeeds. In all the cases compared by McDonald, the Type II distribution predicts higher windspeeds for a given mean recurrence interval than does the Type I distribution. At recurrence intervals of less than 100 yr, the differences are small. The windspeeds predicted by the Type I distribution for large recurrence intervals (500- to 10,000 yr) appear to give more reasonable values of windspeed. The values are not significantly larger than upper-bound windspeeds expected in extratropical storms.

McDonald used Type II distribution in his first studies then switched to the Type I distribution for estimating straight-wind hazards at the other sites because of the more reasonable windspeeds at large mean recurrence intervals. McDonald's methodology is arrived at by using statistical methods beyond the scope of this report. Reference [2] discusses his method in detail.

Figure 3 shows a typical combined extreme wind hazard model from McDonald and Fujita inputs. Notice the high windspeed regions are controlled by tornadoes, while straight winds control the low windspeed region.

5. Conclusions

Once all the hazard models are developed, LLNL will recommend uniform hazard criteria for the DOE to use in the third phase of the project--evaluating the existing design criteria at the various sites and upgrading or modifying those critical facilities that do not meet the new uniform criteria.

The hazard model for a given site is a tool that enables one to establish an acceptable level of hazard for that facility and thus deduce criteria for the design of new structures and the evaluation of existing ones. When the methodology is applied to several sites in different regions, design criteria at a consistent level of hazard can be established. A major advantage of this approach is that the hazard models are applicable to all types of facilities. The user evaluates the facility and its intended use and assesses the consequences of an accident. This allows a selection of a return period and thus definition of extreme wind and seismic design values. We are in the process of preparing guidelines for use of these models [8].

References

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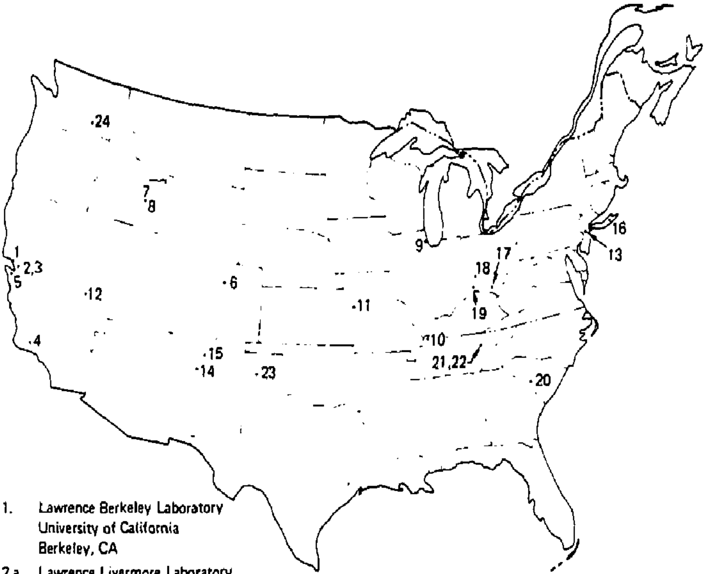
Figure Captions

Fig 1. DOE sites included in project

Fig. 2. For a probabilistic hazard assessment, an analyst generally (a) specifies the geometry of important seismic regions, (b) characterizes the relative frequency of earthquakes of various sizes, develops an earthquake recurrence model (usually a Poisson distribution in time, not shown), and (c) selects a transfer function that transforms information about the earthquake at the epicenter into information at the site, such as ground acceleration. The result of such an assessment is a plot of return period vs peak horizontal ground acceleration (d).

Fig. 3. A typical combined extreme wind hazard model from McDonald and Fujita inputs.



1. Lawrence Berkeley Laboratory
University of California
Berkeley, CA

2.a. Lawrence Livermore Laboratory
University of California
Livermore, CA

b. Lawrence Livermore Laboratory
Site 300
Livermore, CA

3. Sandia Laboratories
Western Electric Co.
Livermore, CA

4. Liquid Metal Engineering Center
Atomics International
Canoga Park, CA

5. Stanford Linear Accelerator Center
Stanford University
Stanford, CA

6. Rocky Flats Plant
Rockwell International
Golden, CO

7. Idaho National Engineering Laboratory
EG&G, Inc.
Idaho Falls, ID

8. Argonne National Laboratory-West
University of Chicago
Idaho Falls, ID

9. Argonne National Laboratory-East
University of Chicago
Argonne, IL

10. Paddah Gaseous
Union Carbide Corporation
Paducah, KY

11. Kansas City Plant
Bendix Corporation
Kansas City, MO

12. Nevada Test Site
REECo
Mercury, NV

13. Princeton Plasma Physics Laboratory
Princeton University
Princeton, NJ

14. Sandia Laboratories
Western Electric Co.
Albuquerque, NM

15. Los Alamos Scientific Laboratory
University of California
Los Alamos, NM

16. Brookhaven National Laboratory
Associated Universities, Inc.
Upton, NY

17. Portsmouth Gaseous Diffusion Plant
Goodyear Atomic Corporation
Piketon, OH

18. Mound Laboratory
Monsanto Research Corporation
Miamisburg, OH

19. Feed Materials Production Center
National Lead Company of Ohio
Cincinnati, OH

20. Savannah River Plant
E.I. du Pont De Nemours and Company
Aiken, SC

21. Oak Ridge National Laboratory (X-10)
Union Carbide Corporation
Oak Ridge, TN

22. Y-12 Plant/K-25 Plant
Union Carbide Corporation
Oak Ridge, TN

23. Pantex Plant
Mason & Hanger – Silas Mason Co., Inc.
Amarillo, TX

24. Hanford Project Site
Rockwell Hanford Operations
Richland, WA

Fig. 1

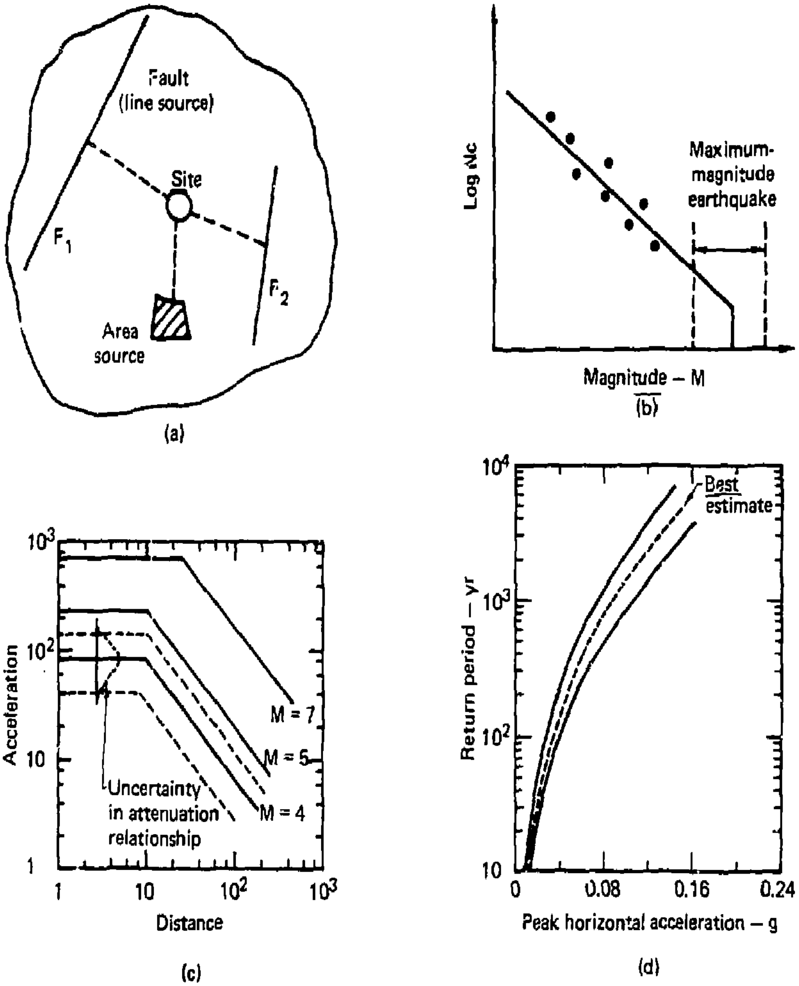

Fault
(line source)
Site
F1
F2
Area
source
(a)
Log Nc
Maximum-
magnitude
earthquake
Magnitude – M
(b)
10³
10²
10
1
Acceleration
M = 7
M = 5
M = 4
Uncertainty
in attenuation
relationship
1
10
10²
10³
Distance
(c)
10⁴
10³
10²
10
Return period – yr
Best
estimate
0
0.08
0.16
0.24
Peak horizontal acceleration – g
(d)

Fig. 2

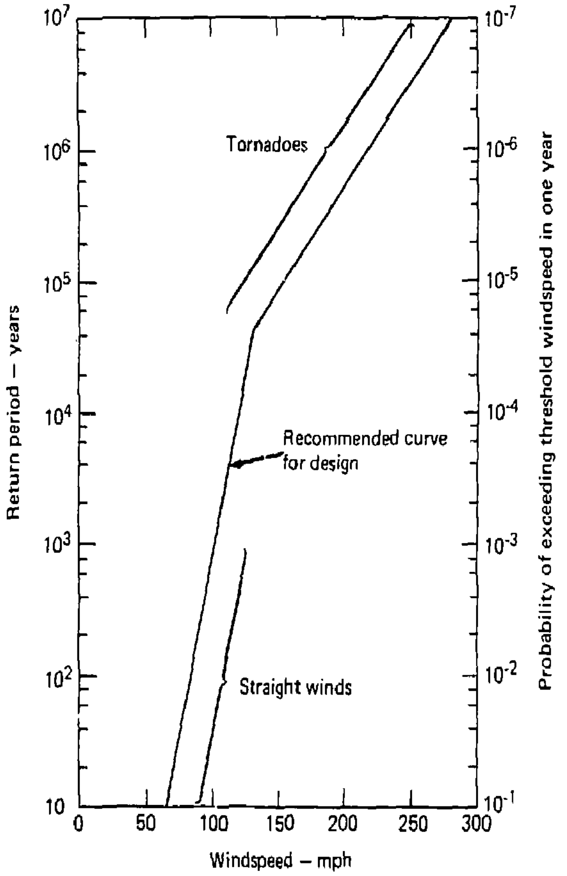

Return period — years
10
10^2
10^3
10^4
10^5
10^6
10^7
Probability of exceeding threshold windspeed in one year
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
Windspeed – mph
0
50
100
150
200
250
300
Tornadoes
Recommended curve for design
Straight winds

Fig. 3