THE PREDICTION OF ACCIDENT PROBABILITIES IN A NUCLEAR POWER PLANT DUE TO EARTHQUAKE EVENTS

by

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SUMMARY

A methodology is presented to predict accident probabilities in nuclear power plants due to earthquakes. The procedure includes:

1) a Seismic Hazard Module to generate earthquake parameters and establish the site free-field ground motion environment;

2) a Structural Response Module to compute local responses in the reactor structure as a function of free-field seismic ground motion;

3) a Failure Module which computes component failure as a function of local stress or dynamic environment created by structural responses to the earthquake;

4) an Accident Sequence Module which computes failure probabilities of initiating events and safety systems and then calculates accident sequence probabilities.

INTRODUCTION

The computational procedure outlined herein has resulted in the design of computer codes which, at the time of writing, are at the programming and debugging stage of development. An overview of the procedure is presented graphically in Fig. 1 and as a flow diagram in Fig. 2.

The general concept is of cascading runs from one module to another. The first module will generate a suitable number of earthquake ground motion records covering the entire range of events that could lead to damage at the site, or sets of earthquake ground motion parameters describing the variability of the earthquake environment at the site. The information from this module will be stored on disk, awaiting application by the structural response module. The second module will address the stored sets of earthquake parameters, using them to develop sets of structural and system component responses for each earthquake.

The third module will access the response data from module two to compute failures using fragility functions (univariate or multivariate probability distributions of component failure as a function of local stress or other response characteristics). The output will be a collection of component failure probabilities for each of the earthquakes generated out of module one.

The fourth module accepts as input failure logic descriptions which, coupled with component failure probabilities, enable synthesis of initiating

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event and safety system failure probabilities. Accident sequence logic is incorporated into this module from which the output will be distributions of sequence probabilities as a result of the initial set of generated earthquakes.

The following sections give more details of each module. The seismic hazard and structural response descriptions are from one of several methodologies considered and are outlined here as representative.

SEISMIC HAZARD MODULE

An overview of the Seismic Hazard Model is presented in Fig. 3. The activities of this module are summarized as follows: regional seismicity characteristics are prepared which describe source zones and recurrence characteristics of earthquakes for an area. Also input are the characterizations of the earthquake sources, the regional attenuation laws for the transmittal of energy from the hypocenter of the earthquake to the plant site. The activities shown in Fig. 3 trace the development of information beginning with various possible earthquake sources through the source to site modifications and finally to ground motion characteristics at the site. One of the principal concerns is the statistical representation of the frequency of events of various magnitudes and adequate simulation of the full range of response at the site. Since large earthquakes occur with less frequency than smaller ones, it is important to establish sampling procedures that place enough emphasis on the large events without requiring an overwhelming number of cycles because of the many more small events.

The randomness inherent in the earthquake process is incorporated within a set of geo-seismic models and associated statistical distributions. Model uncertainty is treated by shifting the means of the model distributions.

STRUCTURAL RESPONSE MODULE

Fig. 4 is an overview of the Structural Response Module of which there are two parts. One is an on-line portion operating in series with the rest of the program and the other, an off-line model providing basic inputs resulting from studies of structural dynamics and soil-structure interaction.

The approach taken attempts to minimize the complexity of the on-line computation in order to reduce the cost of repeated computational cycles. Consequently, the bulk of the complex dynamic analysis is performed off-line. To do this, certain assumptions are made: (1) only a limited number of soil models are considered, (2) simplified soil-structure modification factors are adequate. As a result, all finite element analysis of the reactor structure and its internals, along with the finite element/continuum analyses of the soil-structure interaction problem, can be handled off-line.

COMPONENT/STRUCTURAL FAILURE

Fig. 5 outlines the approach to computing failures of system components and structural elements. The input to this module is the output from the Structural Response Module which contains descriptions of the local stresses and response environments at critical system components. Output from this module is the probability of failure of these various elements. The primary activity is to compare the response levels (e.g., stress, acceleration, etc.)

in these local environs with appropriate fragility functions to determine a probability of failure. The term "generate fragility functions" is shown as the first activity in the flow diagram, acknowledging that there can be modeling uncertainty in the fragility function. By sampling from a distribution for modeling error, a particular fragility function can be defined. This modeling uncertainty will represent primarily a shift in the mean capability of the component to resist the specified local load.

There are three types of loads which must be combined when computing component responses to an earthquake. The first is created by the operation of the plant and the resulting thermal environment. The second is the loading imposed upon the plant by the earthquake forcing function. The third results from a failure, such as a pipe break, where large dynamic and pressure loads occur because of the high pressure in the line. The model will accommodate the computation of failure probabilities in this complex loading environment.

ACCIDENT SEQUENCE PROBABILITY COMPUTATION

There are three basic steps to the accident sequence computation as outlined in Fig. 6. The first is the computation of the probability of various initiating events. These initiating events are caused by failure at points in the structure or systems due to the seismically induced environment. As mentioned in the previous section, new loads may be induced upon the structure by a failure (initiating event). This possibility must be factored into the computation of failure probabilities of certain safety systems. The second step is computation of the probability of failure of components of the engineered safety features. With these probabilities established, the final step computes probabilities of the accident sequences defined by the event trees and categorizes them. A unique feature of the methodology outlined is the ability to calculate top event probabilities based on correlated failures.

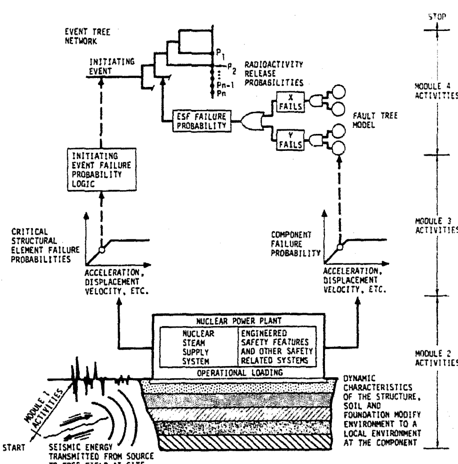

Fig. 1. Graphical Description of Computational Procedure.

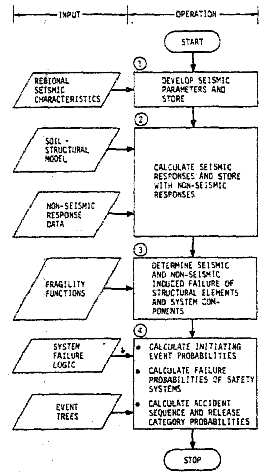

Fig. 2. Computational Procedure Overview.

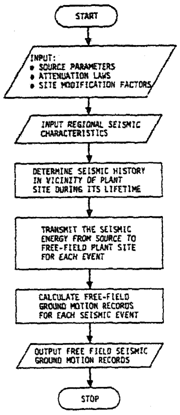

Fig. 3. Seismic Hazard Module Overview.

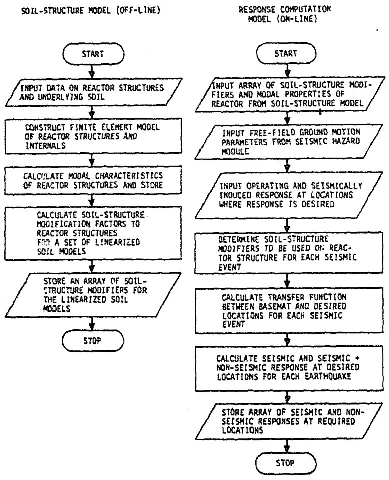

Fig. 4. Structural Response Module Overview.

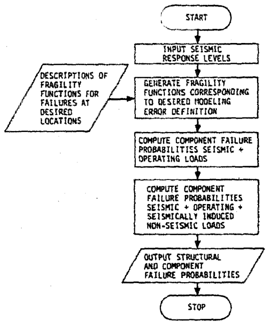

Fig. 5. Component/Structural Failure Computational Overview.

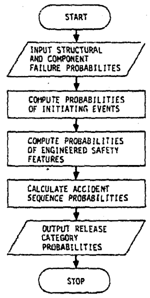

Fig. 6. Accident Sequence Computational Overview.

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