UCRL- 91241
PREPRINT
CONF- 850809--14

UCRL--91241
TI85 007521

EVOLUTION OF A SEISMIC RISK ASSESSMENT TECHNIQUE

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This paper was prepared for submittal to
8th International Conference on
Structural Mechanics in Reactor Technology
Brussels, Belgium

August 19-23, 1985

MASTER

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Abstract

To assist the NRC in its licensing evaluation role the Seismic Safety Margins Research Program (SSMRP) was started at LLNL in 1978. Its goal was to develop tools and data bases to evaluate the probability of earthquake caused radioactive releases from commercial nuclear power plants. The methodology was finalized in 1982 and a seismic risk assessment of the Zion Nuclear Power Plant was finished in 1983. Work continues on the study of the LaSalle Boiling Water Reactor. This paper will discuss some of the effects of the assumptions made during development of the systems analysis techniques used in SSMRP in light of the results obtained on studies to date.

1. Introduction

To assist the NRC in its licensing evaluation role the Seismic Safety Margins Research Program (SSMRP) was started at LLNL in 1978. Its goal was to develop tools and data bases to evaluate the probability of earthquake caused radioactive releases from commercial nuclear power plants. The methodology was finalized in 1982 and a seismic risk assessment of the Zion Nuclear Power Plant was finished in 1983. Work continues on the study of the LaSalle Boiling Water Reactor. This paper will discuss some of the effects of the assumptions made during development of the systems analysis techniques used in SSMRP in light of the results obtained on studies to date.

There are five steps in the SSMRP methodology for calculating the seismic risk in a nuclear power plant. These five steps are illustrated in Fig. 1. In this paper the emphasis will be on the affect of the assumptions made in Steps 4 and 5.

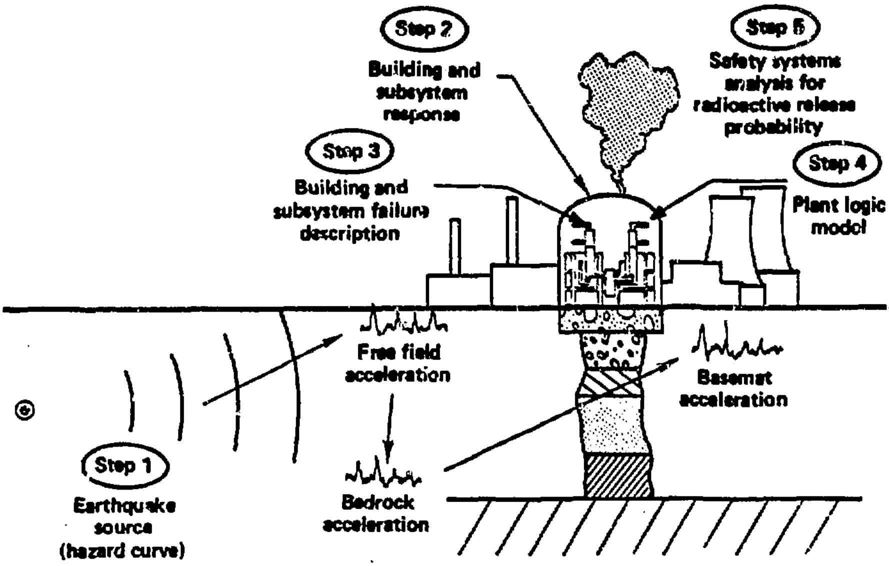
2. Seismic Risk Issues

The SSMRP was recognized at its inception as a comprehensive effort requiring risk based procedures to provide focus even though the bulk of the effort (approximately 75%) was expended on the seismic/structural and fragility tasks. To guide these latter efforts an early decision was made to use event/fault tree methodology for the risk assessment part of the program since these methods had been established at that time by the Reactor Safety Study [3]. Once the methodology was defined specific issues needed to be addressed and compromises or assumptions made to apply these methods to the seismic

This work was supported by the United States Nuclear Regulatory Commission under a Memorandum of Understanding with the United States Department of Energy.

problem. We will discuss some of these issues and describe how they were treated in the SSMRP.

Fig. 1. SSMRP Seismic Risk Methodology [1]



Probabilistic Culling

Because of the size of the system fault trees used in the Zion seismic risk assessment a method was needed to reduce the resultant expressions. Probabilistic culling was selected. Probabilistic culling disgards cut sets that do not contribute significantly to the top event. Because basic events in a cut set are dependent, it is not efficient to compute cut set probabilities in order to cull them. We can, however, compute an approximation to cut set probabilities and cull using them if the bounds or approximations satisfy conditions.

We require that two conditions be satisfied before disregarding a cut set. If the minimum of the basic event probabilities in a cut set are sufficiently small and if the product of the basic event probabilities in a cut set is sufficiently small, we disgard the cut set. The first criteria, culling on the minimum probability basic events, is needed because of the common-cause aspect of the problem. If all basic events are fully correlated then the upper bound to the cut set probability is the probability of the minimum probability basic event. The second criteria, culling on the product of the basic event probabilities in a cut set, is based on the assumption that all basic events in a cut set are independent.

Using this culling technique we were able to reduce the number of cut sets to less than 5000 per accident sequence. A considerable amount of computer time was saved while still retaining the important aspects of the analysis.

Uncertainty

There are two basic types of uncertainty that must be considered in a seismic risk analysis. One is random uncertainty and the other modeling uncertainty. The two types of uncertainties can be handled in a two loop process; the outer loop treats modeling uncertainty and the inner loop treats the random uncertainty. The parameters varied on the outer loop are generally data representing the seismic hazard, the medium of the seismic responses, the medium of the fragilities, and the probability of failure of any unmodeled systems. Because the analysis using the outer loop involves a large number of iterations, an alternative method was selected in SSMRP.

An appropriate method to do the uncertainty analysis is to choose values for each of the inputs such that the entire range of values for the input is represented in the sample of inputs used. In the SSMRP, a Latin hypercube sampling procedure was used to select the primary values for inputs into the Zion risk analysis. The Latin hypercube is then repeated for each of the earthquake levels that one would like to consider in the analysis. As a result of the experimental design, the probabilities can then be combined to 1) evaluate a point estimate median of each probability and 2) estimate the cummulative distribution function which represents the uncertainty. From that distribution a median and other percentiles, such as 10th and 90th percentiles, can be determined. Further study is needed to see whether the fourteen (14) data points calculated in SSMRP are sufficient to adequately estimate these quantities.

Sensitivity Studies

Importance, sensitivity, and marginal analyses were used to identify systems, components, and parameters having important effects on seismic risk. They were also used to estimate the effects and rank the changes. The measures used in the importance analysis are an approximation to the Vesely-

Fussell importance measure for components and systems, and probabilities for higher order events such as terminal event sequences. Sensitivity analyses are based on construction of partial derivatives of seismic risk and probability with respect to important fragilities and responses.

The most important considerations in terms of seismic risk found in Zion were the following:

1. Local site effects - This refers to the shallow soil sites which give rise to accelerations at certain frequencies several times higher than would be estimated if these effects were not considered.
2. Piping between buildings - These were identified as important because of the high relative motion between buildings at high earthquake levels. The piping in the case under study (Zion) was fixed at either end where it exited the buildings so that relative displacement could not be accommodated.
3. Piping fragility - This is important because it effects all the piping in the plant simultaneously. This means that piping fragility is an important input. The Zion piping was not necessarily a key contributors to risk except between buildings.
4. Crib house pump enclosure roof - This fragility ranks high because of the low capacity of the roof and the assumption that roof failure causes the loss of function of all six service water pumps. Recent reviews tend not to substantiate this assumption. If true, then the roof fragility would not be so important.
5. Base slab uplift - This refers to failure of the soil beneath the foundation of the reactor building.

The important measures used proved useful in identifying these key contributors to risk. However, they are only indicators and the results generated should be interpreted accordingly. We used the results to identify areas for further study and have done so on Items 4 & 5. Item 1 is being studied as part of another project and Items 2 & 3 have been identified as areas requiring further investigation.

Modeling of Structural Failures

Structural failures can be modeled in one of several ways. In the SSMRP we modeled structural failures in the accident sequences. For example, if the failure of a structure causes failure of certain specified systems then those accidents sequences that contain failure of those specified systems (and no success of any of those systems) are subjected to that structural failure. For those accidents sequences that contain success of one of those systems then the structural failure is assumed not to occur. Another way to handle the structural failure problem is at the basic event level in the fault trees. This is the approach that we are taking for the LaSalle BWR analysis. In this way you put as one mode of failure for a basic event the failure of a component due to a structural failure. This structural failure could be the roof failing, a shear wall failing, or any other appropriate structural failure. The event would then be "anded" to that component failure. The disadvantage of this technique is that it increases the size of your fault trees considerably and makes the data handling problem more severe.

Relay Chatter

In the SSMRP relay chatter and breaker trip was assumed not to lead to loss of function because it was assumed the components would revert to their normal position following the strong motion. Recent studies [4] have shown that inadvertent operations of anti-pumping relays may lock out the circuit breakers or failure of the manual or test switches might cause problems. The importance of this consideration depends on the number of circuits in the nuclear power plants susceptible to these effects and the degree of susceptability. Inclusion of these failures could lead to an order of magnitude increase in the annual probability of core melt. Further study is needed.

Correlation

The significance of the effects of correlation was determined by the dependency between components or structures in a plant. Based on the Zion seismic risk study, we feel that correlation is important and that these dependencies need to be taken into account when performing a seismic risk assessment. Results show that correlation has little effect if total risk is due primarily to single failures, while in contrast, correlation can change the final risk result by an order of magnitude if the risk is dominated by pairs of failures. Furthermore, the difference between including correlation in responses only and including correlation in both responses and fragilities, resulted in a factor of five difference in the total core melt frequency. Thus it can be concluded that the effects of correlation are significant and that it would be worthwhile to perform some experimental determination of the type of fragility correlation most appropriate for typical components in nuclear reactors. Results computed for Zion tend to indicate that electrical gear should be examined for correlation.

Systems Modeling

When modeling the systems we noted that several changes were necessary to make an internal event fault tree appropriate for addressing seismic concerns. For a seismic event analyses a single passive, double active criteria should not be used when developing the fault trees. That criteria is a potential concern in a seismic risk analysis since passive components which are close together may fail together due to correlation effects with a measurable contribution to risk. When the single passive criteria is used, doubles and higher order events are not modeled. Therefore, dominant doubles which may become important in a seismic analysis may never show up in the analysis. The same is true for active components, particularly when discussing electrical active components such as circuit breakers. The chance of a circuit breaker tripping or a relay chattering during an earthquake is high. Doubles and triples of electrical components could put the plant in a non-desirable status and may not be modeled in an internal event analysis. Results from the Zion analysis showed that double passives can have a significant effect on release probability. However, triple passives were not found to have a significant effect.

Another item to be considered is an accurate location analysis to determine where components are located within the plant. This is necessary before any response/fragility calculations can take place. In many internal event analyses, locations are not specified unless common-cause concerns have been brought up and specifically examined.

Simplified Methods

Simplifications in the SSMRP methodology were made to save time and money while adequately estimating seismic risk [5]. Several assumptions were made to make possible the simplification. They were the following.

1. Systems information about the plant is available and identification of unique features relating the the seismic risk has been made. Plant information also includes fault tree analysis that is assumed to have been done.
2. The seismic hazards models (sites specific hazard functions and response spectra) for the site are available.
3. Seismic design data is available for all structures, systems, component, and equipment.

The primary focus of the simplification efforts is in simplifying computation of the seismic response structures, piping systems, components, and equipment. This is done by use of calibration factors which relate responses calculated in the design process to the best estimate response as required for risk calculations. The calibration factor is defined as:

$$f_c = r_d/r_{be}$$

with r_d the seismic response used in the plant design and r_{be} a best estimate response. The value r_d is developed for the design earthquake and thus keys the responses to the free field acceleration at that level. The many detailed response calculations performed in the SSMRP made possible the development of these calibration factors.

3. Conclusions

Seismic risk studies up to this point have been successful in identifying many areas of concern. While many of these areas have been addressed adequately we feel there is further work which should be done. Some candidate areas for further work are as follows.

1. Enhancement of fragility data.
2. Improvement in modeling and analysis of structural failure.
3. Improvement in treatment of human error.
4. Investigation of the effect of relay chatter and locking circuits.
5. Improvement in the method of handling uncertainty.
6. Improvements in calculation of initiating event probabilities.
7. Assessment of the effects of design and construction errors.
8. Investigation of the effects of non-linear analysis on seismic risk assessment.
9. Investigation of calculational modeling assumptions.
10. Investigation of piping failure assumptions.

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