DEFINITION OF COMPONENT AND STRUCTURAL FRAGILITY FOR USE IN THE SEISMIC SAFETY MARGINS RESEARCH PROGRAM

R. G. DONG

Lawrence Livermore Laboratory, University of California,
P.O. Box 808, Livermore, California 94550, U.S.A.

SUMMARY

The Seismic Safety Margins Research Program (SSMRP) is to estimate the conservatism in the Standard Review Plan seismic safety requirements and to develop improved seismic requirements. The approach to achieve these objectives is to develop probability methodology that more realistically estimates the behavior of nuclear power plants during an earthquake. The development of fragility descriptions for components, systems, and structures is a necessary part of this approach, and the Components and Structural Fragilities Project of the SSMRP is responsible for developing these descriptions. The SSMRP will comprise several phases. Phase 1 is addressed at this time, and will focus specifically on the Zion 1 plant and site.

A fragility description of a component, system, or structure characterizes the probability of failure as a function of a load parameter such as stress, strain, and acceleration. Failure for our purposes is defined as the inability to serve an intended function; e.g., a valve is considered failed if it is unable to open or close due to perhaps body distortion when it is called upon to do so.

An execution plan for the project has been established. The critical components, systems, and structures will be identified. Information pertaining to design, qualifications, installation, and in-service performance will be gathered. Test data will be collected from nonnuclear as well as nuclear industries and foreign as well as domestic sources. Relevant failure modes will be determined following the gathering of information and data. Fragility descriptions to be developed will then be selected. Finally, the fragility descriptions will be developed. For Phase 1 the project execution will be based on existing information.

The fragilities area is quite developmental. Regular exchange of information with knowledgeable people in the area is, therefore, important. Consequently, a panel of six such persons was formed for this purpose. The first meeting of the SSMRP Fragilities Panel was held December 13, 1979.

This paper summarizes the execution plan for the project and the observations of the December 13 meeting of the panel.

This work was supported by the U.S. Nuclear Regulatory Commission under Interagency Agreement DOE 40-550-75 with the U. S. Department of Energy.

1. Introduction

The Components and Structural Fragilities Project is Project VI of the Seismic Safety Margins Research Program (SSMRP) [1 and 2]. The objectives of the SSMRP are to estimate the conservatism in the Standard Review Plan seismic safety requirements [3] and to develop improved seismic requirements. The approach to achieve these objectives is to develop probabilistic methodology that more realistically estimates the behavior of nuclear power plants during an earthquake. A necessary part of this approach is the development of fragility descriptions for components, systems, and structures. The objective of Project VI is to develop the necessary descriptions.

The SSMRP will consist of several phases. Phase 1 is being addressed at this time, and will focus on the Zion 1 plant and site. Zion 1 was shown to be representative of a typical PWR nuclear power plant in a comparison study with other plants [4]. The emphasis of Phase 1 will be on the construction of the systems model for the seismic design methodology chain, an assessment of the feasibility of such a model, and sensitivity studies to identify the weak links in the methodology chain.

The program comprises six major projects, as shown in Figure 1, each dealing with a certain facet of the overall seismic design methodology chain. Project VI, Components and Structural Fragilities, is one of the six. Presentations on the other five projects are also given at this SMIRT conference [5 through 9]. Nine tasks are planned for Project VI for Phase 1. A flow chart of the tasks and the necessary interactions with other projects are shown in Figure 2. A general description of each task is given in this paper.

2. Background Information

A fragility curve describes the probability of failure of a component, system, or structure as a function of a load parameter such as stress, strain, and acceleration which induces the failure. A representation of a typical fragility curve is shown in Figure 3. For the SSMRP, failure is defined as the inability to serve an intended function. Examples include a valve sticking open or closed due to distortion of its body, a pump seizing upon failure of its support, and a building collapsing due to failure of structural elements.

A simplified representation of the SSMRP systems model is depicted in Figure 4. Fragility descriptions enter into the model in the determination of initiating events and the fault tree analyses. For Phase 1 the execution of Project VI will be based on existing test and/or analytical information.

Fragilities of components, systems, and structures are not normally assessed during the course of design. Qualification testing and analyses are to assure in-service reliability rather than to determine fragilities. Consequently, usable data for fragilities description are sparce, and standardized analyses for fragilities characterization do not exist. The subject of fragilities is quite developmental. Consequently, it will be highly advantageous to periodically exchange thoughts and information with researchers in this and related areas. A SSMRP Fragilities Panel was formed for this purpose. The members are Dr. Spencer H. Bush, Battelle; Dr. Robert P. Kennedy, Engineering Decision Analysis Corporation; Mr. George Shipway, Wyle Laboratories; Dr. John D. Stevenson, Arthur G. McKee and Company; Dr. Jerrell M. Thomas, Failure Analysis Associates; and Dr. Peter P. Zemanick, Westinghouse Electric Corporation. We plan to meet approximately four times a year as the need arises. The first meeting has been held on December 13, 1978 at the Lawrence Livermore Laboratory.

3. The First Meeting of the SSMRP Fragilities Panel

Some key points of the December 13 meeting of the SSMRP Fragilities Panel included the following:

- Testing done by Wyle Laboratories was qualitatively described. Most tests were for qualification, and a majority were on electrical components. Very few failures were observed. At times the support fails before the component. Much of the data is proprietary, and the availability for SSMRP use will need to be investigated.
- A procedure was presented for analytically developing fragility descriptions using a combination of factors of safety embodied in the design calculation, design code, and material inelastic behavior. The procedure was based on the work of Newman and Ang [10].
- One-dimensional or multi-dimensional fragility descriptions are possible. For Phase 1, the panel generally recommended using only one-dimensional descriptions.
- The fragilities of elbows and pipe connections might overshadow the fragilities of the piping. Welds, however, are more susceptible to defects; therefore, their fragilities may be more important than elbows and pipe connections. There were differing opinions on the topic of welds.
- The tails of the fragility curves are generally felt to be not as important as some other considerations. For Phase 1 the panel generally recommended ignoring the tails.
- The fragility of buildings is a complex topic which will require further thought and discussion. Not all structural elements of a given building are important for sustaining systems operability. Therefore, the difficulty is determining the relevant failure modes.
- The panel generally believes off-site power will be lost before the diesel generators.
- The panel generally agreed with the approach being taken by the Lawrence Livermore Laboratory for Project VI.

4. Development of Fragility Descriptions

The Component and Structural Fragilities Project will consist of nine tasks in Phase 1. The progression of the tasks is indicated in Figure 2 along with the necessary interactions with other SSMRP projects. The tasks will be carried out with a combination of in-house and contracted efforts. A general description of each task is as follows:

Task 1: Zion 1 Systems and Structures Identification

The identification of systems and structures of the Zion 1 plant critical to preventing radioactive release is being carried out. A preliminary identification was made based on past experience with nuclear power plants, and the results are given in Table 1. A more precise identification is underway.

Task 2: Architectural and Engineering Information Gathering

Information pertaining to the design and performance of the Zion 1 plant are being obtained from the architectural and engineering firm, Sargent and Lundy. For components, pipings, and their supports this includes design calculations, qualification procedure, installation, location, and in-service performance. For buildings this includes design calculations and specifications.

Task 3: Information Gathering on the Nuclear Steam Supply System Piping and the Reactor Pressure Vessel

The nuclear steam supply system and the reactor pressure vessel were designed and built by Westinghouse. The information being gathered is of the same nature as described for Task 2.

Task 4: Test Data Gathering

Test data gathering will be as broad as possible to maximize the chances of finding usable data. Accordingly, nonnuclear as well as nuclear, and foreign as well as domestic, sources will be covered. Any data which can shed light on fragilities will be of interest. For example, qualification tests can indicate a lower bound for a fragility description, accident data can provide information concerning fragility, and tests carried out to failure can provide a direct measurement of fragility. Included in the search will be not only components, pipings, systems, and structures the same as those of concern but also ones similar to those of concern. Sources of test data include firms doing testing, organizations maintaining data banks, vendors of components, piping and equipment, the military, and various government and industrial agencies.

Task 5: Determination of Failure Modes of Components and Systems, and Categorization of Components

An important part of developing fragility descriptions is the determination of failure modes. The information gathered in Tasks 2, 3, and 4 should provide valuable insight for identifying the relevant failure modes of components and pipings. Vendors and knowledgeable persons are also important sources of information, and these will be surveyed as necessary. Multiple failure modes will apply in many cases. The parameter controlling each failure mode will be identified. Since these parameters must be the output quantities of transfer functions to be developed by Project V, "Structural Subsystems Response", close interaction with Project V will be necessary to establish the parameters which are acceptable for both fragility description and transfer function development.

The components of concern are expected to number in the thousands. It will be impossible to develop fragility descriptions for each individually within Phase 1. Consequently, categorization of the components will be necessary, and the fragilities will be addressed by categories. A suitable categorization procedure will be developed and the components will be categorized accordingly.

Task 6: Determination of Failure Modes of Structures

As in the case of components and systems, the determination of failure mode is an important part of developing fragility descriptions for structures. The information gathered in Tasks 2, 3, and 4 should provide insight on the relevant failure modes. Each structure will most likely have multiple failure modes. Expert opinions may provide additional insight, and will be surveyed as necessary. The parameter controlling each failure mode must be established. Since the parameters are to be output quantities of transfer functions to be developed by Project III, "Soil Structure Interactions", and Project IV, "Structural Building Response", close interaction with Projects III and IV is important to establish workable parameters.

Task 7: Selection of Fragility Descriptions for Components, Systems, and Structures

A wide range of fragility descriptions is possible. For example, we have the choice of developing fragility descriptions for: (1) individual components and pipe sections; (2) a subassembly of components and pipe sections; or (3) an entire safety system. Another example, in the cases of multiple failure modes we have the choice of developing multi-dimensional descriptions or multiple one-dimensional descriptions. The fragility descriptions to be developed will be selected jointly by Projects IV, V, VI, and VII. Considerations important for making the selection include: (1) what is required for event trees and fault trees of the systems analysis model; (2) what is possible to develop from the information and data gathered and with the techniques available; and (3) what are the transfer functions which can be developed by Projects III, VI, and V.

Task 8: Fragilities Description Development for Components and Systems

All fragility descriptions selected for development in Task 7 for components, pipings, and systems will be developed in Task 8. At the present, we are aware of four approaches to developing fragility descriptions:

- Test Data
- Analysis
- Delphi procedure
- Expert opinion

We prefer to base the development on test data when possible. However, test data generally will be insufficient to do the job alone. Therefore, the other three approaches are expected to play a major role in the Task 8 effort. The second approach is inclusive of all kinds of analyses ranging from estimation procedures to sophisticated finite element analysis. The choice of analytical procedure in each case should be commensuable with the level of importance of the fragility description and with the available information and resources. The Delphi procedure iterates on the subjective opinions of knowledgeable persons. The individual opinions are solicited, combined, and fed back to the persons, and revised opinions are then solicited. This process is repeated until convergence is reached. The fourth approach is a subset of the third; i.e., the opinion of an extremely knowledgeable person is accepted. We will not necessarily be limited to the approaches described. Due to the highly developmental nature of the fragilities area we plan to pursue more than one approach in the development of the fragility descriptions.

Task 9: Fragilities Description Development for Structures

All fragility descriptions selected for development in Task 7 for structures will be developed in Task 9. Comments made for Task 8 apply also to Task 9.

5. Conclusions and Comments

Phase 1 of the SSMRP has proceeded five months out of the scheduled 20 months as of this writing. A reasonable approach for carrying out Project VI in Phase 1 has been established. The SSMRP Fragilities Panel has been formed, and based on the results of the first meeting, the panel should proved to be a valuable source of information and relevant experience. Most test results to our knowledge are proprietary; therefore, an effort to make the data available for our use must be undertaken immediately and be given a high priority.

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TABLE 1

CRITICAL SYSTEMS & STRUCTURES IDENTIFIED IN A PRELIMINARY REVIEW OF ZION 1

Systems	Structures
Reactor Coolant System	Auxiliary Building
Emergency Core Cooling System	Crib Housing Forebay
Containment Fan Cooler System	Containment Building
Containment Spray System	Turbine Building
Auxiliary Feedwater System	
Engineered Safety Auxiliary Power System	
Diesel Auxiliary Power and Support System	
Residual Heat Removal System	
Footings and Support Structures for Various Systems and Components	
Instrumentations and Power Sources for Various Systems and Components	
Ceramic Insulators in the Switch Yard	
Component Cooling Water System	
Service Water System	
Pumps and Motors for Lake Intake Water	
Reactor Protection System	

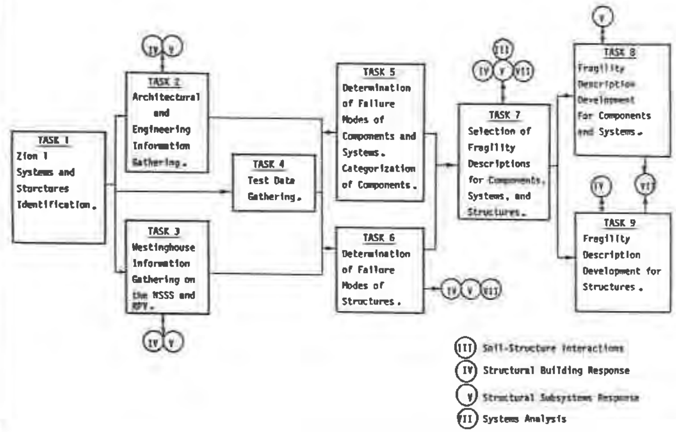
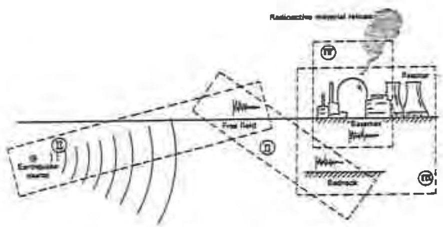


FIGURE 2: COMPONENTS AND STRUCTURAL FRAGILITIES PROJECT TASKS AND INTERACTIONS WITH OTHER SSMRP PROJECTS



(I) Seismic Input
(II) Soil Structure Interaction
(IV) Structural Building Response
(V) Structural Subsystem Response
(VI) Components and Structural Fragilities
(II) Systems Analysis

FIGURE 1: THE SIX MAJOR PROJECTS OF THE SEISMIC SAFETY MARGINS RESEARCH PROGRAM

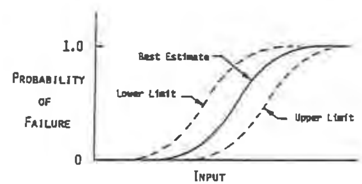


Figure 3. Representation of a Typical One-Dimensional Fragility Curve

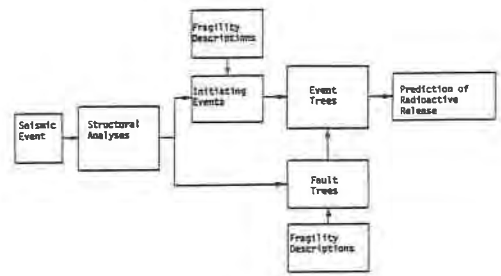


FIGURE 4: FRAGILITY DESCRIPTIONS ENTER INTO THE SYSTEMS MODEL IN THE DETERMINATION OF INITIATING EVENTS AND THE FAULT TREE ANALYSES