A PERSONAL COMPUTER CODE FOR SEISMIC EVALUATIONS OF NUCLEAR POWER PLANT FACILITIES

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1. INTRODUCTION

In the process of review and evaluation of licensing issues related to nuclear power plants, it is essential to understand the behavior of seismic loading, foundation and structural properties and their impact on the overall structural response. In most cases, such knowledge could be obtained by using simplified engineering models which, when properly implemented, can capture the essential parameters describing the physics of the problem. Such models do not require execution on large computer systems and could be implemented through a personal computer (PC) based capability. Recognizing the need for a PC software package that can perform structural response computations required for typical licensing reviews, the U.S. Nuclear Regulatory Commission sponsored the development of a PC operated computer software package---CARES (Computer Analysis for Rapid Evaluation of Structures) system. This development was undertaken by Brookhaven National Laboratory (BNL) during FY's 1988 and 1989.

A wide range of computer programs and modeling approaches are often used to justify the safety of nuclear power plants. It is often difficult to assess the validity and accuracy of the results submitted by various utilities without developing comparable computer solutions. Taken this into consideration, CARES is designed as an integrated computational system which can perform rapid evaluations of structural behavior and examine capability of nuclear power plant facilities, thus CARES may be used by the NRC to determine the validity and accuracy of analysis methodologies employed for structural safety evaluations of nuclear power plants. CARES has been designed to:

a) operate on a PC,
b) have user friendly input/output interface, and
c) have quick turnaround.
CARES program is structured in a modular format. Each module performs a specific type of analysis. The basic modules of the system are associated with capabilities for static, seismic and nonlinear analyses. This paper describes the various features which have been implemented into the Seismic Module of CARES version 1.0. In Section 2 a description of the Seismic Module is provided. The methodologies and computational procedures thus far implemented into the Seismic Module are described in Section 3. Finally, a complete demonstration of the computational capability of CARES in a typical soil-structure interaction analysis is given in Section 4. and conclusions are presented in Section 5.

2. DESCRIPTION OF SEISMIC MODULE

The development of the Seismic Module is based on an approach which incorporate all major aspects of seismic analysis currently employed by industry into an integrated system that allows for carrying out interactively the computations of structural response to seismic motions. The process of seismic analysis of nuclear power plant structures and components generally involves the following steps:

- Definition of the design criteria at a given site.
- Evaluation of the free-field motion.
- Evaluation of the structural response and floor response spectra including soil-structure interaction effects.

The capabilities required to accomplish the above steps have been implemented into the Seismic Module with special emphasis on the areas of regulatory requirements pertaining to structural safety of nuclear plants.

A flowchart describing the overall structure of CARES and the detailed structure of the Seismic Module is illustrated in Figure 1. As seen from this figure, various capabilities to account for all aspects of the seismic analysis have been incorporated into the system. The computational aspects of the Seismic Module are organized to

a) perform analysis associated with the definition of the the seismic input motion and the generation of Power Spectral Density functions, b) provide the user with a capability to perform convolution/deconvolution analysis for a given uniform or layered site and to compute strain compatible soil properties, and c) evaluate structural response to seismic motions by taking into account the soil-structure interaction effects.

Using the Seismic Module, one can start with a design seismic input e. g., Reg. Guide 1.60 design spectra and develop a synthetic acceleration time history compatible with the design spectra, then perform deconvolution analysis and finally generate floor response spectra at various locations of a nuclear facility. All steps can be done interactively with minimum input data requirements and at reasonable cost of computing time. Since the system has friendly input-output interfacing characteristics, a seismic analysis can be performed conveniently. This allows for efficient parametric variation studies which are typically required in dealing with licensing issue reviews. It should be pointed out that the theoretical basis of the
Seismic Module consists of known standard methods and techniques which are commonly employed in structural and foundation mechanics and dynamics. Therefore, the advantage of the Seismic Module is associated with its ability to integrate various modeling and computational aspects of the seismic response analysis process into an autonomous user-friendly system.

3. METHODOLOGIES/COMPUTATIONAL PROCEDURES

The development of Seismic Module is based on methodologies and computer codes which have been used for structural and seismic analyses of nuclear power plants over the last decade. Specific details pertaining to the methodologies and computational procedures of all options in the Seismic Module are described below:

Option 1: General Manager

This option deals with main computational aspects associated with various input/output interfacing, time/frequency domain transformations and development of response spectra required by other components of the Seismic Module. Specifically,

- Generates Fourier components of time history,
- Combines Fourier components into time history,
- Generates Response Spectra of time history,
- Generates Power Spectra of time history,
- Generates Power Spectra consistent with Response Spectra and vice-versa,
- Develops plot files for each of the above.

Option 2: Convolution Analysis

This option performs deconvolution analysis and computes a set of time histories throughout a given horizontally layered soil profile, given seismic motion at one location and pertinent soil properties. It also generates strain-compatible soil properties. The main features of this option are:

- Assuming vertically propagating shear waves through horizontally layered site,
- Developing frequency dependent transfer function between all interfaces in soil column,
- Computing Fourier components of specified pulse,
- Solving a set of simultaneous algebraic equations to obtain Fourier Components of motion at all interfaces,
- Recombining time histories and computing soil strains,
- Modifying soil properties based on strain level,
- Iterating through above steps until soil strain data converges.
**Option 3: SSI Structural Data Preparation**

This option prepares input data for superstructures and the SSI models. The superstructures are modeled with 3-D beams, springs and lumped masses, while the SSI effects representing dynamic stiffnesses of the foundation are simulated with a number of closed form solutions which are built in the Seismic Module.

**Option 4: SSI Input Motion Preparation**

Fourier components of a given free field motion are generated for SSI analysis.

**Option 5: SSI Analysis**

This option uses inputs generated by Option 3 and 4, and calculates structural responses to the given earthquake motion through soil-structure interaction analysis. The output from these calculations include response time histories at specified locations within a given structure. These data are subsequently used to compute floor response spectra and structural inertial loads. It also computes transfer functions which can be subsequently used to develop PSD’s at various floor locations. The basic steps involved in this option are:

- Reading in the structural data from the input generated by option 3,
- Assembling stiffness, mass, and damping matrices,
- Calculating frequency dependent SSI parameters including base and sidewall effects,
- Reading in free field motion input generated by option 4,
- For specified set of frequencies solving sets of algebraic equations for Fourier components of structural motion,
- For specified duration combining Fourier components of structural motion into time histories of response motion at selected points.

**Option 6: Earthquake Simulations**

This option generates artificial time histories compatible to given design target response spectra. It also performs computation of power spectral density functions for given time histories and generates response spectra from a target PSD function via direct generation method. Specifically:

- Breaks standard time history into Fourier components,
- Computes response spectra of a given time history,
- Modifies Fourier coefficients based on comparison between computed and criteria spectra,
- Iterates through the above steps until fit is adequate,
- Combines Fourier components into time history.
Option 7: PSD-related Acceleration/Spectra Analysis

Recent revision (rev.2) to the Standard Review Plan (SRP) has added new requirements on free field motions. One of them is that a single earthquake time history must meet not only the enveloping requirement in terms of design spectra but also a set of minimum PSD requirements. In order to satisfy the PSD requirement, the Seismic Module has included a new capability which is based on a recent study on this subject conducted jointly with Princeton University. At this stage, the capability includes algorithms associated with the development of a response spectrum given a PSD function as well as the development of a PSD consistent with a response spectrum. These features are carried out in option 7.

Option 8: Plot Utility

Plot utility provides various plot options for graphical presentations of outputs produced by the Seismic Module. Specifically, it plots time histories, response spectra, amplification functions and PSD spectra, as well as general x-y graphs.

4. DEMONSTRATION EXAMPLES

In order to demonstrate the calculational capability of the Seismic Module, a typical reactor building is selected and an evaluation of its seismic response is performed. The reactor building is represented by the beam-type, lumped mass stick model (see in Figure 2) which is attached to the free field through interaction springs and dashpots. The seismic design response spectrum applied at the ground surface in the free field is the Reg. Guide 1.60 horizontal spectrum for 5% damping anchored at 0.2g. The Seismic Module first generates a time history compatible with the design spectrum. The compatibility of the design spectrum and the spectrum produced by the design time histories is shown in Figure 3. The generated free field time history is then applied at the surface of the soil profile shown in Figure 4 and a deconvolution analysis performed to obtain the input motion at the foundation of the reactor building. The response spectrum of the deconvoluted motion at the foundation level is shown in Figure 5. From Figure 5, it can been seen that the soil column frequency is approximately equal to 3 cps where a dip in the spectrum is observed. The Seismic Module applies the latter motion as input to the base of the SSI model and performs structural response computations. A typical floor response spectrum which is generated at the top of the reactor building is shown in Figure 6.

The chain of computations described above are performed with consistency and in a timely fashion. It should be pointed out that, although different phases of the seismic analysis can also be performed separately by other existing codes, the uniqueness of CARES, however, lies in its ability to perform all required steps of the seismic analysis in an integrated manner. It also has input-output interfacing compatibility which often poses difficulties in conversions between input and output data when different codes are employed to perform different phases of
seismic analysis. To this end, CARES becomes more reliable in terms of avoiding errors within the process of a complete seismic analysis. Finally, CARES is a completely interactive system with minimum input data, is user friendly features, has quick turn-around and provides comprehensive post-processing capability to display results graphically or in tabular form so that direct comparison can be easily made.

5. Conclusions and Future Enhancements

This paper has presented the features which have been implemented into the Seismic Module of the CARES system version 1.0. Especially emphasized are the capabilities of the Seismic Module which include the latest changes to the Standard Review Plan (SRP, rev.2). The advantages of the CARES system are summarized below:

a) Capability to perform all phases of seismic analysis in an integrated manner.

b) Input-output interfacing compatibility which often poses difficulties in conversions between input and output data when different codes are employed to perform different phases of seismic analysis.

c) Complete interactive capability with minimum number of input data, user friendly features and quick turnaround.

d) Comprehensive post-processing capability to display results graphically or in tabular form.

The revised SRP (rev.2) contains changes in the seismic and soil-structure interaction area. For example the reduction of input motion with depth is now permitted for embedded structures (up to 60%). However, when credit is taken from the reduction in translational input, it is required that the corresponding rotational component due to kinematic interaction be included in the analysis. Such requirements can be easily implemented into the existing version of the Seismic Module of CARES so that checks can be made to verify compliance with SRP acceptance criteria. In addition, future enhancements will be lift-off, time domain SSI option and a more comprehensive library of impedance functions for a variety of foundation configurations will be implemented into the Seismic Module of CARES.

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6. References


Figure 1. CARES System
Figure 2 Stick Model

Figure 3 Free Field Simulation
Figure 4  Typical Soil Profile
Figure 5  Convoluted to Foundation Level

Figure 6  Floor Response Spectrum at Top
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