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# INTEGRATED SYSTEM FOR SEISMIC EVALUATIONS

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## INTRODUCTION

This paper describes the various features of the Seismic Module of the CARES system (Computer Analysis for Rapid Evaluation of Structures). This system was developed by Brookhaven National Laboratory (BNL) for the U.S. Nuclear Regulatory Commission to perform rapid evaluations of structural behavior and capability of nuclear power plant facilities. The CARES is structured in a modular format. Each module performs a specific type of analysis i.e., static or dynamic, linear or nonlinear, etc. This paper describes the features of the Seismic Module in particular. The development of the Seismic Module of the CARES system is based on an approach which incorporates all major aspects of seismic analysis currently employed by the industry into an integrated system that allows for carrying out interactively computations of structural response to seismic motions. The code operates on a PC computer system and has multi-graphics capabilities. It has been designed with user friendly features and it allows for interactive manipulation of various analysis phases during the seismic design process. The capabilities of the seismic module include a) generation of artificial time histories compatible with given design ground response spectra b) development of Power Spectral Density (PSD) functions associated with the seismic input c) deconvolution analysis using vertically propagating shear waves through a given soil profile and d) development of in-structure response spectra or corresponding PSD's. It should be pointed out that these types of analyses can be also performed individually by using available computer codes such as FLUSH, SAP, etc. The uniqueness of the CARES, however, lies on its ability to perform all required phases of the seismic analysis in an integrated manner.

## DESCRIPTION OF SEISMIC MODULE

A diagram describing the main options of the Seismic Module of CARES is illustrated in Figure 1. As can be seen from this figure various capabilities have been incorporated into the system to account for all aspects of the seismic analysis. One can start with a design input, then go through a free-field and soil-structure interaction analyses and the final product be expressed in terms of floor response spectra or PSD functions.

The front part of the Seismic Module deals with the free-field input. The latter can be specified by means of earthquake records or by design smooth spectra from which synthetic acceleration time histories can be generated. Furthermore, PSD functions can be developed for evaluating the adequacy of the synthesized time history at the frequency range of interest. The capability of generating response spectra compatible to given PSD's has also been implemented so that further checks for compliance with recently revised SRP requirements (A-40) can be easily made.

Another capability available in the CARES system is the deconvolution analysis from which the free-field motions at various depths of soil profile can be obtained. The final phase of the Seismic Module involves computation of structural response and in-structure spectra. The system also computes transfer functions which can be subsequently used to develop PSD's at various floor locations. The latter can be further used in conjunction with probabilistic evaluations. Finally, a comprehensive post-processing capability is available to display results graphically or in tabular form so that direct comparisons can be easily made.

METHODOLOGIES/COMPUTATIONAL PROCEDURES

The Seismic Module of CARES is based on methodologies and computer codes which have been developed over the last ten years. Specifically, the basis of this module is the SIM and SLAVE computer codes. The SIM code calculates the response of a structure to a given earthquake input while the SLAVE code computes a consistent set of time histories throughout a soil when the motion is given at one location (deconvolution). In addition, the seismic module of the CARES has the capability to generate spectrum-consistent acceleration time histories as well as the capability to perform Power Spectral Density (PSD) computations. All these features have been put together in an integrated form so that complete seismic evaluations of a given nuclear structure can be performed very conveniently. Specific details pertaining to the calculational procedures of CARES follow:

<u>TRANSPEC</u>

This is a pre- and post-processing unit of the system which performs various operations needed by the 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 Density functions.
- Generates Power Spectra Consistent with Response Spectra and vice-versa.
- Develops plots for each of the above.

<u>SIME</u>

Computes acceleration time histories which are consistent with given response spectra. Specifically:

- Breaks standard pulse into Fourier components
- Computes spectra of pulse
- Modifies Fourier coefficients based on comparison between computed and criteria spectra
- Iterates through above steps until fit is adequate
- Combines Fourier components into time history

<u>SLAVE</u>

Performs deconvolution analysis and computes a consistent set of time histories throughout a given soil profile. The main features of SLAVE are:

- Assumes vertically propagating shear waves through horizontally bedded site.
- Develops frequency dependent transfer function between all interfaces in soil column.
- Computes Fourier components of specified pulse.

- Solves a set of simultaneous algebraic equations to obtain Fourier components of motion at all interfaces.
- Recombines time histories and computes soil strains.
- Modifies soil properties based on strain level.
- Iterates through above analysis until soil strain data converge.

SIMF

Calculates structural response for a given earthquake through soil-structure interaction analysis. The output from SIMF includes time histories at specified locations within the structure. These data are subsequently used to compute floor response spectra and structure inertial loads. SIMF operates in either the time or the frequency domain. The latter mode has been selected for implementation into the CARES system. The basic steps of the frequency-domain SIMF are:

- Calculate structural stiffness, mass and damping matrices.
- Calculate frequency dependent SSI parameters including base and sidewall effects.
- Expand free field time history into its Fourier components.
- For specified set of frequencies solves a set of algebraic equations to compute Fourier components of structural motion.
- At specified max time combines Fourier components of structural motion into time histories at selected points.

DEMONSTRATION EXAMPLES

In order to demonstrate the calculational capability of the CARES a typical reactor building was selected and its seismic response was evaluated. The reactor building is represented by the beam-type 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 surface in the free-field is the Reg. Guide 1.60 horizontal spectra for 5% damping anchored at 0.2g. CARES then computed a time history compatible with the design spectrum. The compatibility of the design spectra and the spectra produced by the design time history is demonstrated in Figure 3. The free-field design time history was applied at the surface of the soil profile shown in Figure 4 and a deconvolution analysis was performed to obtain the input motion at the foundation of the reactor building. The deconvoluted response spectrum at the foundation level is shown in Figure 5. From the latter figure it can be seen that the soil column frequency is approximately equal to 3 cps where a dip in the spectrum occurs. CARES applied the latter motion as input to the base of the SSI model and performed structural response computations. A typical floor response spectrum which was computed at the top of the reactor building is shown in Figure 6.

The above chain of computations were performed with consistency and time efficiency. As mentioned previously, although different phases of the seismic analysis can be also performed separately by other existing codes, the main advantage of CARES is that it performs all phases together.

CONCLUSIONS

This paper presented the current features of the CARES system and its Seismic Module in particular. The advantages of this system (developed at BNL) can be summarized as follows:

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 used 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.

c) Complete interactive capability with minimum number of input data, user friendly features as well as quick turn-around. In addition, comprehensive post-processing capability to display results graphically or in tabular form so that direct comparisons can be easily made.

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## NOTICE


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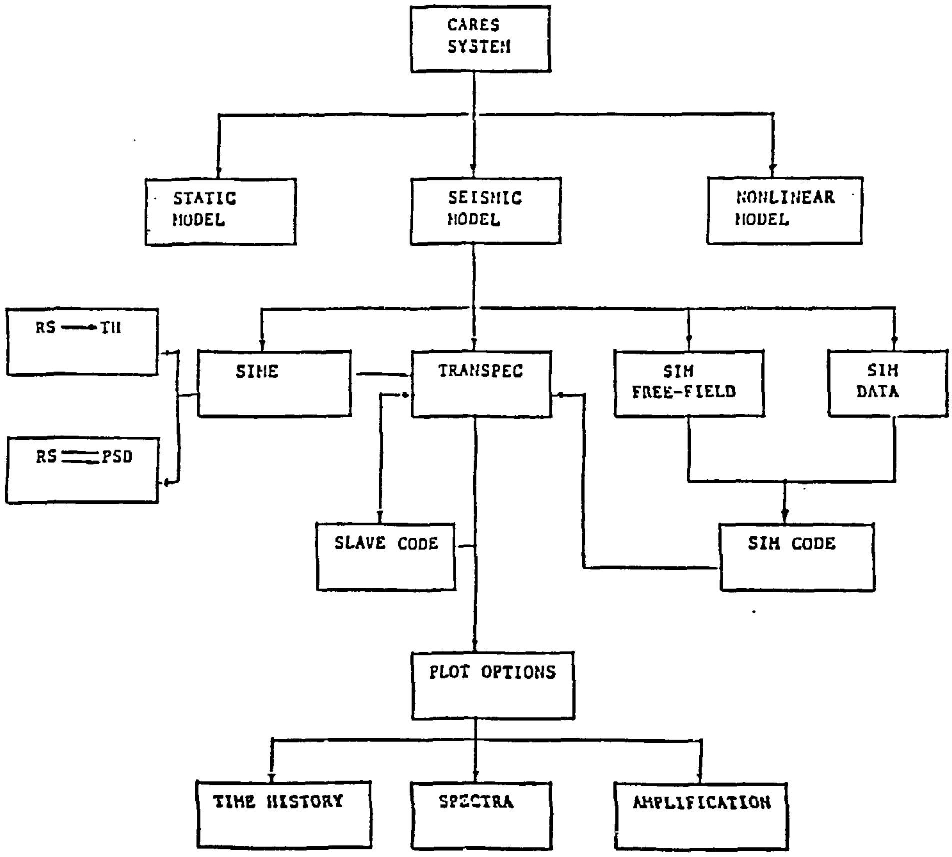


Figure 1 Flow Chart of Cares System

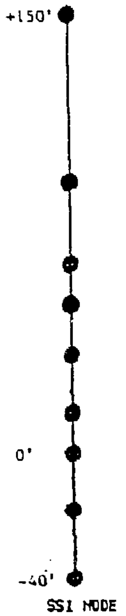


Figure 2 Stick Model

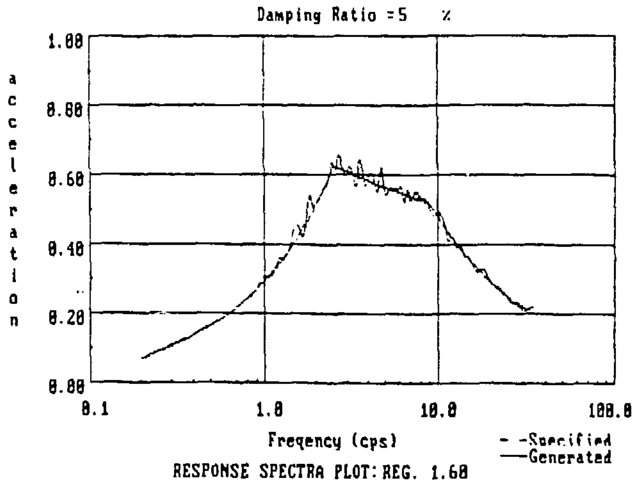


Figure 3 Free Field Simulation

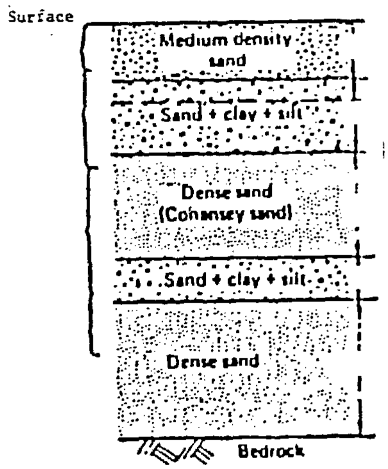


Figure 4 Typical Soil Profile

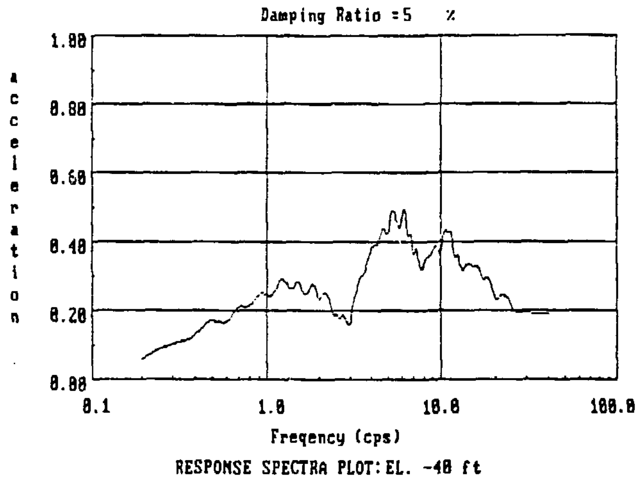


Figure 5 Convoluted to Foundation Level

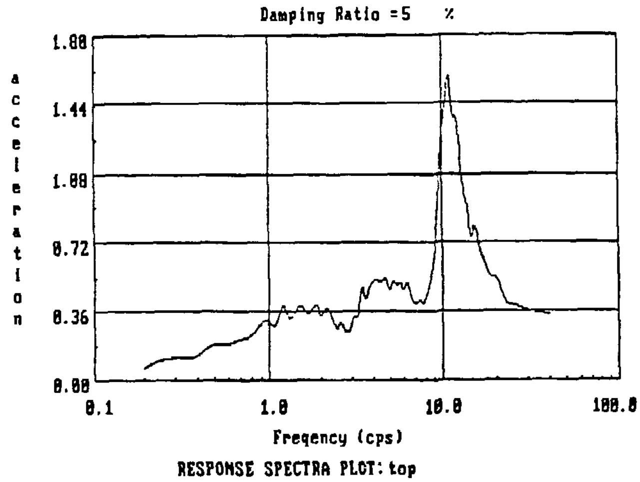


Figure 6 Floor Response Spectrum at Top