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8 December 1980

Mr. William T. Russell, Chief
Systematic Evaluation Program Branch
Division of Licensing
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555 (Mail Stop 516)

Re: SSRT Guidelines for SEP Soil-Structure Interaction Review
Contract NRC-03-78-150

Dear Mr. Russell:

The Guidelines for SEP Soil-Structure Interaction Review, as prepared by the Senior Seismic Review Team, are transmitted herewith with signature approval.

We are appreciative of the help of the many individuals who contributed to the preparation of these guidelines.

Sincerely yours,

N. M. Newmark

N. M. Newmark
Chairman, SSRT

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Enclosure

Distribution:

W. T. Russell - 2
T. Cheng - 1
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SSRT GUIDELINES FOR SEP SOIL-STRUCTURE INTERACTION REVIEW

Background

When a structure is founded within or on a base of soil, it interacts with its foundation. The forces and displacements transmitted to the structure and the feedback to the foundation regions are complex in nature; the interactions that take place modify the free-field motions. Many methods for dealing with soil-structure interaction have been proposed by a number of writers. These methods can be classified in various ways and involve generally: (1) procedures similar to those applicable to a rigid block on an elastic half-space; (2) finite element or finite difference procedures corresponding to various forcing functions acting on the combined structure-soil complex; and (3) substructure modeling techniques that may or may not include use of the direct finite element method. Another, and perhaps more convenient, classification of soil-structure interaction analysis procedures is that of (a) direct solution techniques and (b) substructure solution techniques as described in the report entitled "Recommended Revisions to Nuclear Regulatory Commission Seismic Design Criteria", Report NUREG/CR-1161, May 1980.

The elastic half-space theory considers a foundation plate resting on an elastic medium with harmonic oscillation applied to the plate; the few test results available to date in general have been obtained for this type of model in this excitation condition. This concept is the basis for the first of the three procedures described above, although for seismic excitation the problem is the inverse of the original problem formulation

in that the excitation originates in the earth. The other two methods noted also involve modeling of the structure-soil system; as such the system has intrinsic properties reflecting the make-up of the modeled system, physical properties, and especially the boundaries (for example, as they affect motion input, and reflection).

These analysis methods represent major advances in computational ability, but unfortunately all the techniques have limitations, and in many cases are not well understood. At present their use involves a great deal of interpretive judgment.

One principal difficulty with all of the techniques is associated with the handling of the ground input. Except for special long period waves, in most cases the ground motion is noncoherent and nonuniform. Thus far it appears that the analysis models may not be able to handle a broad spectrum of complex wave motions. None of the techniques adequately handle nonlinear effects, which are known to be of importance. As yet no good confirmatory comparison basis exists between field observations and computations made prior to an earthquake.

This entire topic is one that requires the most careful consideration. Exercise of judgment as to the meaning of the results, in the light of the comments given above, is required. Reliance on any sole approach is to be avoided.

<u>SEP Review Guideline Recommendations</u>

In keeping with the SEP approach to review existing facilities, and as reflected in the philosophy and criteria developed to date, it appears

desirable to outline briefly one technical procedure for estimating soil-structure interaction effects. As a result of extensive discussions between members of the SSRT and the NRC/LLL staff, and with recognition of the many uncertainties and complexities of the topic under consideration, the general approach presented below is recommended at this time as a guideline. It will be appreciated that many decisions will have to be made as a part of the calculational procedures described below and the exercise of judgment obviously will be required. Justification and documentation are necessary parts of the final analysis product.

At the outset it should be noted that the simplified approach described below is not intended to preclude the use of any other procedures. The structural input motions (at the foundation level), however developed and justified, under no conditions shall correspond to less than 75 percent of the defined control motions (normally taken as the free-field surface motions); if a reduction in translational input motion is employed, then the rotational components of motion also should be included. If other procedures are employed they should be reviewed on a case-by-case basis.

For purposes of SEP review, one simplified approach for evaluating the effects of soil-structure interaction, involving a lumped parameter model, is deemed to be acceptable when employed under the following conditions.

1. The control motions are defined as the free-field surface motions and are input at the structure foundation level.

2. The soil stiffness, as represented by springs anchored at the

foundation level, shall be modeled as follows.

i) To account for uncertainty in soil properties, the soil stiffnesses (horizontal, vertical, rocking and torsional) employed in analysis shall include a range of soil shear moduli bounded by (a) 50 percent of the modulus corresponding to the best estimate of the large strain condition, and (b) 90 percent of the modulus corresponding to the best estimate of the low strain condition. For purposes of structural analysis three soil modulus conditions generally will suffice corresponding to (a) and (b) above, and (c), a best estimated shear modulus.

For structural capacity review the analyst generally should employ the worst case condition. For equipment review the in-structure response spectra shall be taken as a smoothed envelope of the resulting spectra from these three analyses.

ii) When embedment is to be considered it is recommended that the soil resistances (stiffnesses as noted above) shall correspond to 50 percent of the theoretical embedment effects. This reduction is intended to account for changes in soil properties arising from backfilling, and any gap effects.

iii) Where it is judged necessary to model the supporting soil media as layered media, the stiffnesses are to be estimated through use of acceptable procedures.

3. The radiation and material energy dissipation (i.e., the damping values) are considered to be additive for computation convenience. Normally the material damping can be expected to be about 5 to 8 percent.

The geometric damping (radiation energy dissipation) is recognized to be frequency-dependent. However, in order to reduce the calculational

effort (at least initially), and to be sure that excessive damping is not employed, it is recommended that values of damping be estimated theoretically (on a frequency-independent basis) as follows.

i) Horizontal to be taken as 75 percent of the theoretical value.*

ii) Vertical to be taken as 75 percent of the theoretical value.*

iii) Rotation (rocking and torsional) to be taken at 100 percent of the theoretical value.*

In the case of layered systems the approach employed in establishing these values needs to be justified.

4. The following analysis approaches are considered to be acceptable.

i) When all composite modal damping ratios** are less than 20 percent, modal superposition approaches can be used without any validation check.

ii) If in investigating the use of modal superposition approaches it is ascertained that a composite modal damping ratio** exceeds 20 percent, one must perform a validation analysis. To perform this validation, it is generally acceptable to use a time-history analysis in which the energy dissipation associated with the structure is included with the structural elements, and that associated with the soil is included with the soil elements.

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*As calculated by generally accepted methods, as for example given in the book Vibrations of Soils and Foundations, by F. E. Richart, Jr., J. R. Hall, Jr., and R. D. Woods, Prentice-Hall Inc., 1970.

**As defined by generally accepted methods.

In-structure response spectra obtained from a modal superposition analysis employing composite modal damping throughout the frequency range of interest must be similar to or more conservative than those obtained from the validation analyses.

It is emphasized that the aforementioned procedures are intended to be guidelines and may be subject to revision as experience is gained under the SEP Program in attempting to arrive at relatively economical and simplified techniques for estimating the possible effects of soil-structure interaction.

Respectfully submitted by the Senior Seismic Review Team:

N. M. Newmark

N. M. Newmark, Chairman

W. J. Hall

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Robert P. Kennedy

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