

# The Proposed Soil-Structure Interaction Licensing Criteria Resolution of USI A-40, "Seismic Design Criteria"

Nilesh C. Chokshi, Syed K. Shaukat  
*U.S. Nuclear Regulatory Commission, Washington, DC USA*

Newton R. Anderson  
*EG&G Idaho, Inc., Rockville, MD USA*

## **INTRODUCTION**

In June 1988, the U.S. Nuclear Regulatory Commission (NRC) issued the proposed resolution of Unresolved Safety Issue (USI) A-40, "Seismic Design Criteria," for public comment (Federal Register, June 1, 1988). This resolution included proposed Revision 2 for Sections 2.5.2, 3.7.1, 3.7.2, and 3.7.3 of the Standard Review Plan (SRP), NUREG-0800 (NRC, 1981).

Section 3.7.2 of the revised SRP contained proposed review procedures and acceptance criteria for soil-structure interaction (SSI) analyses, and public comments were solicited regarding four, specific SSI questions. These questions were based on the results of the SSI Lotung experiment conducted in Taiwan (Tang, 1987; EPRI [Electric Power Research Institute], 1989). The experiment was conducted by EPRI, the NRC, and Taiwan Power Company (TPC), and the results were not yet available when the proposed resolution was drafted.

This paper presents a brief description of the proposed SSI criteria. The paper also discusses the public comments related to the revised SRP sections, including those comments specifically related to the four questions on the Lotung experiment. In addition, the paper discusses the NRC's proposal for final resolution of USI A-40.

## **PROPOSED REVISION FOR PUBLIC COMMENTS**

In June of 1986, the NRC and Brookhaven National Laboratory (BNL) sponsored an SSI-related workshop (Graves, 1987). The objectives of this workshop were as follows:

- o Examine SSI-related licensing concerns and various procedures and alternatives based on recent analytical and experimental developments.
- o Examine areas of greater uncertainties, and identify methods of addressing them.
- o Review NRC licensing criteria in the SSI area, and discuss improvements in the licensing process.

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- o Present the results of recent NRC research.

The revised SSI criteria that were included in the proposed resolution for public comment were based, in part, on the NRC/BNL workshop. The following alternative acceptance criteria for SSI analyses were proposed (Chokshi et al, 1988).

#### Alternative 1

This alternative, which was similar to the staff acceptance criteria published in the current version of the SRP (1981), contained some modifications and presented a simplified approach that required less effort than Alternative 2, discussed below. Use of Alternative 1 was more appropriate if the input ground motion had broad-band response spectra (e.g., Regulatory Guide 1.60 spectra) and was not based on detailed, site-specific considerations.

In the past, the two most commonly used methods of analysis had been broadly identified as the half-space (lumped-parameter, substructure solution technique), and the finite boundary (direct-solution technique, discrete modeling) methods. Alternative 1 proposed that modeling methods for implementing the soil-structure interaction analysis should include both the half-space and finite boundary approaches. The alternative also proposed that Category I structures, systems, and components should be designed to accommodate responses obtained by enveloping results from both methods.

In both Alternative 1 and Alternative 2, control motion was specified to be at ground surface in the free field -- either at the surface of a rock outcrop (real or hypothetical) in the vicinity of the site or at the ground surface (finished grade). Both alternatives also postulated that appropriate variation in soil properties must be considered to smooth out the effects of the resulting dips in the response spectra (at the natural frequencies of soil columns) at the foundation level of an embedded structure. In addition, the magnitude and the form of the reduction in the spectra at the foundation level should be supported by the study of data applicable to the site.

It was noted that for embedded structures a translational motion specified on the surface of the soil produces translation and rotation of the massless foundation. The SSI method should account for this rotational effect. The input motion at the base of the discrete soil model or soil column should produce the specified design spectra at the free surface of the soil profile in the free field (finished grade).

#### Alternative 2

This alternative provided the option of using a suitable state-of-the-art approach to perform the SSI analysis for sites with detailed site-specific investigations, without resorting to the enveloping requirements discussed in Alternative 1. However, Alternative 2 requires greater effort when addressing uncertainties and performing sensitivity studies.

The proposed revision for public comment included specific guidelines to account for items such as nonlinearity, variation of soil properties, layering effects, strain-dependence of material properties, modeling of soil-structure systems (using various approaches), and spatial variation of ground motion.

In December 1987, a second SSI workshop (sponsored by EPRI, NRC, and TPC) was held at Palo Alto, CA. The purpose of this workshop was to discuss the analytical predictions of actual, recorded seismic response data provided by a 1/4-scale model of a containment structure with a simulated steam generator loop inside. This scale model had been used in the SSI experiments at the Lotung facility in Taiwan (EPRI, 1989). Blind predictions using several analytical techniques had revealed some limitations in the various approaches. However, in light of the new information from the Lotung experiment, reviewers of the proposed USI A-40 resolution were asked to comment on the following questions during the public comment period.

1. Lotung data indicate[s] that, for that site, the deconvolution procedure did not predict consistent results to reflect observed variation of motion with depth. Therefore, for proposed acceptance criteria in SRP Section 3.7.2.II, (primarily, for Alternate 1), should a limitation be included, such as no more than 40% reduction be allowed from the surface motion (e.g., ASCE [American Society of Civil Engineers], 1986 contains such a limitation) on the deconvolved motion at the foundation level in the free field for certain site conditions?
2. A number of post test correlation studies of the Lotung facility found that the calculated soil damping values had to be reduced to match the observed results. Therefore, should a limitation be placed on the soil damping values used in the SSI analysis, particularly when a simplified half-space approach is used?
3. Similarly, should a limitation be placed on low-strain values of soil used to determine the soil properties (e.g., shear modulus and damping) used in the SSI analysis?
4. Should the requirement of enveloping results of the two methods of SSI be retained in the proposed Alternate 1 of the acceptance criteria in SRP Section 3.7.2.II, in light of the limitation which may be placed on the ground motion reduction and soil material properties?

#### **PUBLIC COMMENTS ON PROPOSED REVISION**

Comments on the proposed revision to the SRP sections and Lotung questions were received from five organizations. Comments were also received from EPRI. Resolution of all of these comments is discussed in Philippacopoulos (1989). Specific SSI comments of major importance are summarized below in terms of responses to the four, Lotung-related questions.

Three specific comments, expressing differing opinions regarding the limit on reduction of ground motion with embedment, were received on Question 1. A brief description of these comments follows:

- One organization suggested that arbitrary limits on the reduction of ground motion should not be imposed.
- One organization agreed with provision 3.3.1.2(b) of American Society of Civil Engineers (ASCE) Standard 4-86 (ASCE, 1986) which states:

"Variations of amplitude and frequency content with depth may be considered for partially embedded structures. The spectral amplitude of the acceleration response spectra in the free-field at the foundation depth shall be not less than 60% of the corresponding design response spectra at the finish grade in the free field."

- One organization suggested that a realistic limit on the allowable reduction should be established by looking into more data.

In addition, EPRI commented that the limit of 40% reduction of the translational ground motion is not clear. EPRI is currently investigating this issue using the Lotung data and expects to provide final recommendations when work is completed on this issue.

In response to Question 2 ("Should a limitation be placed on soil damping values used in SSI analysis?"), one commentor indicated that placing an arbitrary limit on total damping would not be consistent with the actual phenomenon. Two other commentors pointed out that it is possible to overestimate the radiation damping effect when a simple half-space, frequency-independent approach is used, particularly if this approach is used to represent a layered soil profile. For such situations, some limitations may be in order. However, when layering effects are properly considered, there is no need to place a limitation on the soil radiation damping values. A commentor also suggested that the composite modal damping in the SSI analysis should be limited to 20 percent if the modal superposition approach is used.

The EPRI comments in response to Question 2 discussed observations at the Lotung site. EPRI indicated that additional research is being conducted in order to understand more about soil characterization based on additional test data and evaluations of earthquake response. EPRI is also conducting additional field exploration and laboratory testing to bridge the field and laboratory results.

In response to Question 3 ("Should a limitation be placed on low-strain values of soil used to determine the soil properties for the SSI analysis?"), one commentor suggested that the soil strain values used should be consistent with strain generally observed during earthquakes and that shear modulus and damping values should be limited to the corresponding strain value. Other commentors on the issue agreed with recommendations made in NUREG/CR-1161 (Coats, 1980) that the strain-dependent value of shear modulus should be no less than 40% of the low-strain values. All the commentors indicated that the internal hysteretic soil damping values should be allowed to a maximum of 15% rather than the 5% suggested in the proposed SRP revision.

The commentors responded unanimously that the proposed requirement in Alternate 1 regarding enveloping the results of two SSI methods (Question 4) should be deleted.

The NRC, in conjunction with BNL, organized a consulting panel to help resolve these public comments. The members of the consulting panel were:

- Prof. C. J. Costantino, City University of New York
- Dr. R. P. Kennedy, Structural Mechanics Consulting, Inc.
- Prof. M. Shinozuka, Princeton University
- Dr. J. D. Stevenson, Stevenson and Associates
- Prof. A. S. Veletsos, Rice University