SITE-STRUCTURE INTERACTION FOR A

FLOATING NUCLEAR PLANT UNDER SEISMIC LOADING

Paul D. Smith[I], Ashok K. Vaish[II], and Frank L. Porter[III]

SYNOPSIS

This paper describes the application of the finite element method for a floating nuclear generating facility where dynamic interaction between the floating nuclear plant (FNP), its mooring system, other site-related structures, the sea water and the foundation soils must be included in the determination of the seismic response. Standard finite element techniques have been augmented by the development of a fluid finite element for sea water modeling and by the formulation of a "split-modeling" procedure in which the analyses of a particular cross section are performed using two site models; one a large coarse model to obtain low frequency site response, the other a smaller more refined model to obtain high frequency response. The results from the two models are combined to obtain the site response over the full frequency range of interest. The advantage of this procedure is the substantial reduction of computational effort over that otherwise required.

INTRODUCTION

The procedures discussed in this paper were developed for the seismic analysis of the Atlantic Generating Station (AGS), a nuclear power generating facility, to be built and operated by Public Service Electric and Gas Company of New Jersey, USA. The facility will be located approximately three miles off the New Jersey coast and features two 1,150 megawatt nuclear plants to be constructed on floating barges which will be moored to caissons in a basin which is surrounded by a protective breakwater (Figure 1).

Plane strain soil-structure interaction analyses were performed on different cross sections through the AGS site to obtain the interactive seismic response of the different site-related structures. These results were used to provide input for further, more detailed analyses of the structures and to evaluate the adequacy of the foundation soils.

Because of the unique features of the AGS design, new techniques were required to include the hydrodynamic effects of the ocean water and to obtain the seismic response of the site over a relatively wide range of frequencies. These requirements were met by the development of a fluid finite element and by the formulation of a "split-modeling" technique in which separate analyses are performed over different frequency ranges and the results combined.

I Engineer, Nuclear Test Engineering Division, Mechanical Engineering Department, Lawrence Livermore Laboratory, Livermore, California, USA Formerly of EDS Nuclear Inc.

II Manager, Advanced Analysis Division, EDS Nuclear Inc., San Francisco, California, USA

III Group Manager, Engineering, EDS Nuclear Inc., San Francisco, California USA

FLUID FINITE ELEMENT

The fluid finite element developed for use in the AGS analyses is a two-dimensional plane strain isoparametric quadrilateral element having bulk modulus as its only elastic property. Thus, the fluid has no resistance to shearing deformation, resisting only volume change with a change in pressure. The element stiffness matrix is formed using standard finite element techniques, assuming small displacement theory. No damping matrix is explicitly defined for the element; any energy dissipation due to the fluid is included in the equations of motion as equivalent viscous damping. The element mass is lumped.

Model construction using the fluid element is similar to that for plane strain solid elements. Sliding at fluid/solid interfaces is modeled with thin fluid boundary elements. Bouyancy and fluid gravity wave forces are simulated with vertical springs attached to the floating bodies and the water surface nodes.

SPLIT-MODELING TECHNIQUE

For seismic soil-structure analysis the lowest frequency of interest generally controls the depth and extent of the soil medium that must be modeled to eliminate boundary effects, while element refinement is controlled primarily by the highest frequency which must be transmitted by the model. Frequently, the two requirements - model depth and element refinement - necessitate large finite element models which can require out-of-core computer solutions and are very expensive. This problem is avoided by the development of a split modeling procedure described below. In this procedure, the site-structure system is represented by two finite element models. The first one is deep and has sufficient extent to eliminate boundary effects for the lowest frequency of interest. The refinement in this model is limited and allows adequate transmission of frequencies up to about 5 Hz - adequate for the modelling of soil shear stresses which are predominantly low frequency induced. In addition to providing low frequency response, this model is therefore used to iteratively determine the strain-compatible soil properties.

The second finite element model used to represent the site-structure system is a model of relatively shallow depth and limited lateral extent, but which has a high degree of mesh refinement so that high frequencies (greater than 5 Hz) can be accurately reproduced. The mesh generally consists of subdivisions of the mesh used for the primary model so that results may be obtained at common data points. The soil properties used for the high frequency model are obtained from the iterative analysis of the primary model.

Separate low and high frequency analyses are performed using the two models. Both analyses consist of deconvolution of the free-field motion to the model base level followed by an interaction time history analysis to develop the soil properties appropriate for the established equivalent linear procedure. For the high frequency analysis, iteration is not used as the soil properties are obtained from the low frequency converged results. The low and high frequency results are combined to obtain complete results over the full frequency range of interest.

APPLICATION TO AGS SEISMIC ANALYSES

The techniques described above were used for the soil-structure interaction analysis for the Atlantic Generating Station (AGS). One of the AGS site cross-sections which was investigated is shown as Section A-A in Figure 1. Two finite element models were developed for this cross-section; the low frequency model, whose base is at 300 ft. below mean low water (MLW) is shown in Figure 2A, and the high frequency one, with base at 120 ft. below MLW in Figure 2B. The mesh refinement allows adequate transmission of frequencies up to 5 Hz and 16 Hz in the low and high frequency models, respectively. Both models contain all the significant dynamic components in the cross section including the FNP, mooring struts, caissons, breakwater, foundation soils and sea water.

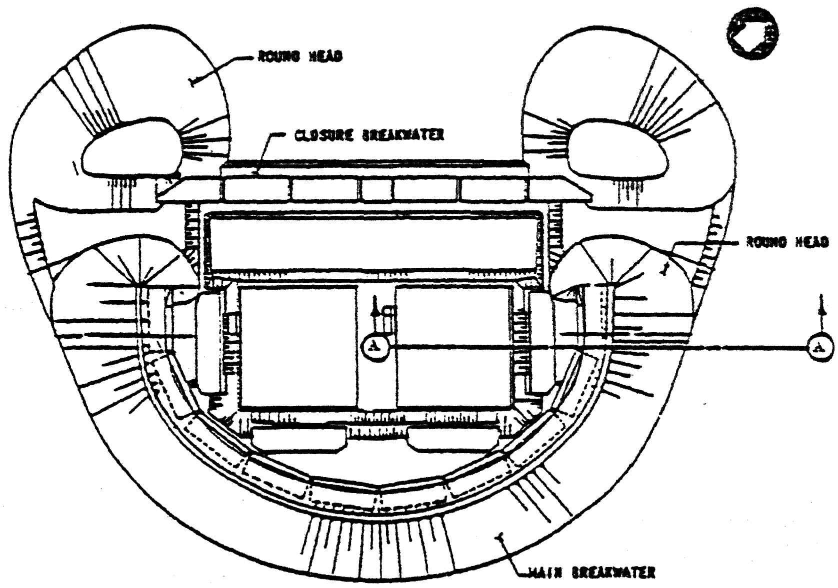
Time history analyses were performed, as described above, using numerical integration. Rayleigh damping, shown in Figure 3, was used to approximate the average damping in the soil over the frequency ranges appropriate to each analysis. The results of analyses on the two models were combined using Fourier Transform techniques. An example of combined response is presented in Figure 4 which shows response spectra at the mooring strut attachment point from both low and high frequency analyses. Similar results were obtained at the other locations. This "splicing" technique provides results which are adequate over a large frequency range and can then be used for further detailed analyses.

CONCLUSION

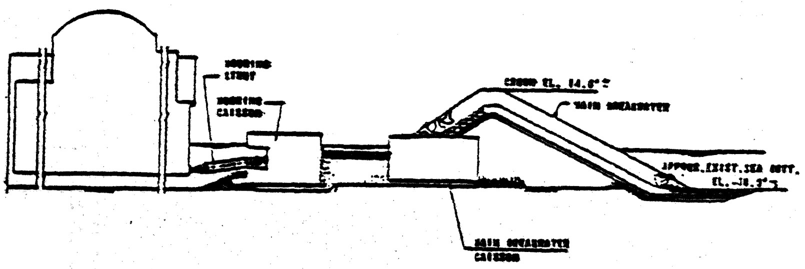
This paper has briefly described the application of two useful techniques to the seismic design of the first floating nuclear power plant. The first of these two techniques, the fluid finite element, is relatively well-known, and the second, the split modeling technique, apparently is not. These two techniques have proved to be quite useful in the seismic design/analysis at Atlantic Generating Station. The results described herein provided reasonable input for more detailed design/analyses for frequencies up to 16 Hz.

BIBLIOGRAPHY

1. Reimer, R. B., "Deconvolution of Seismic Response for Linear Systems", Earthquake Engineering Research Center, Report No. 73-10, University of California, Berkeley, 1973.
2. Constantopoulos, I. V., Roesset, J. M., Christian, J. T., "A Comparison of Linear and Exact Nonlinear Analysis of Soil Amplification", Fifth World Conference on Earthquake Engineering, Rome, 1973.
3. Seed, H. B., Idriss, I. M., "Soil Moduli and Damping Factors for Dynamic Response Analysis", Earthquake Engineering Research Center, Report No. 70-10, University of California, Berkeley, 1970.
4. Whitman, R. V., Roesset, J. M., Dobry, R., Ayestaran, L., "Accuracy of Modal Superposition for One-Dimensional Soil Amplification Analysis", Proceedings of the International Conference on Mocrozonation for Safer Construction Research and Application, Seattle, Washington, 1972.



PLAN VIEW



PROFILE OF SECTION A-A

FIGURE 1: LAYOUT OF AGS SITE

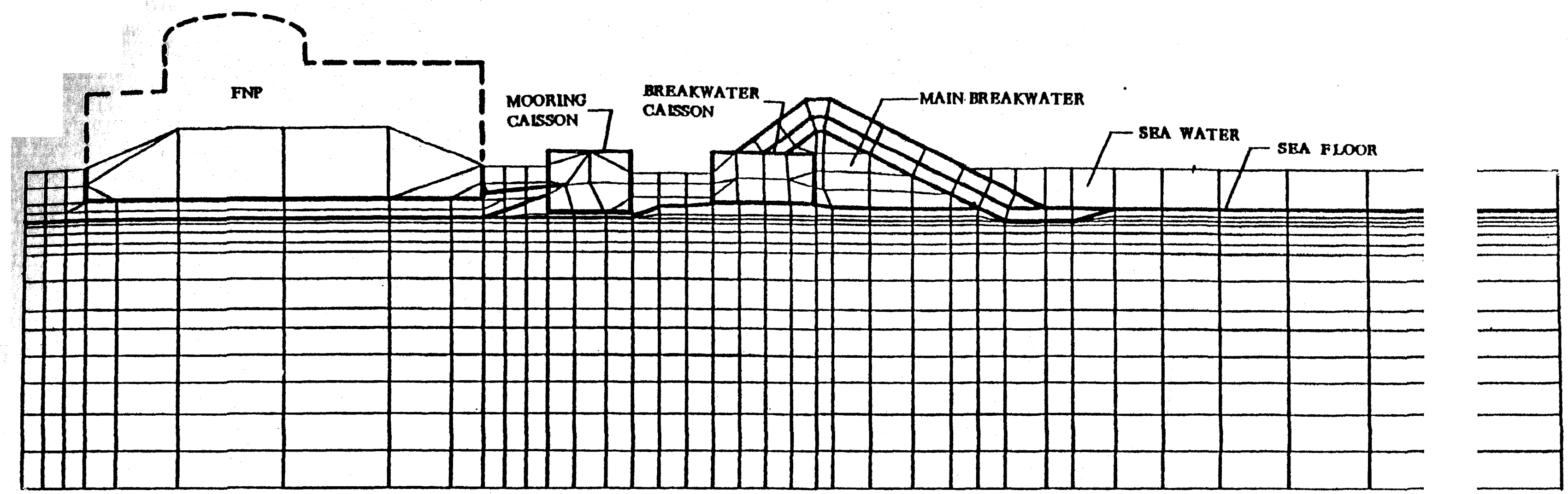


FIGURE 2A LOW FREQUENCY INTERACTION MODEL, SECTION A-A

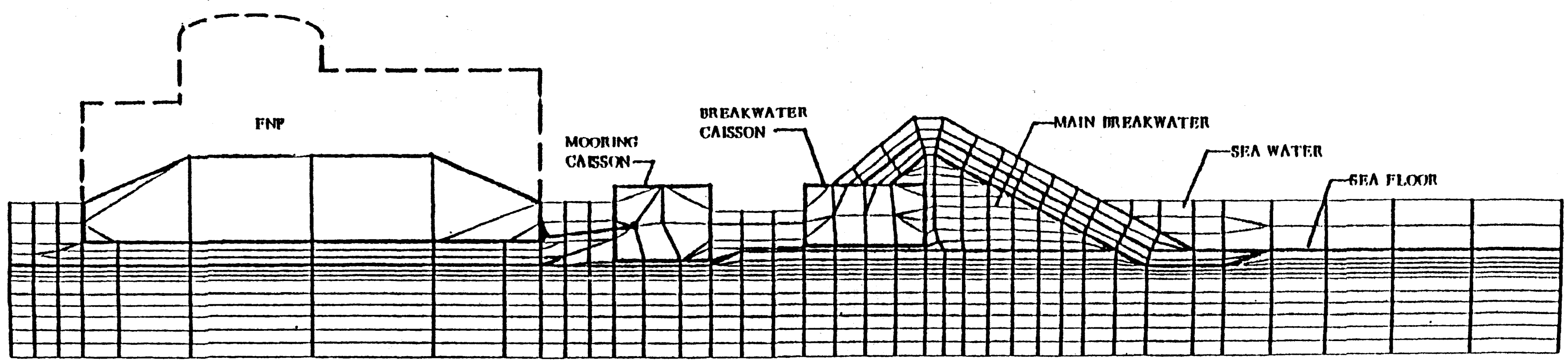


FIGURE 2B HIGH FREQUENCY INTERACTION MODEL, SECTION A-A

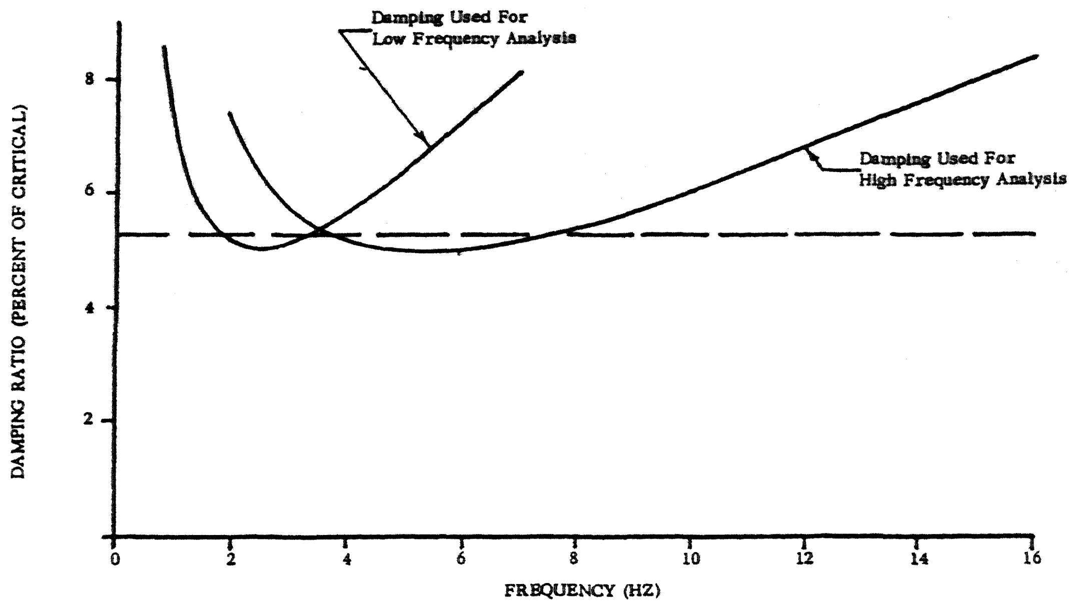


FIGURE 3 RAYLEIGH DAMPING CURVES: DAMPING RATIO VS. FREQUENCY

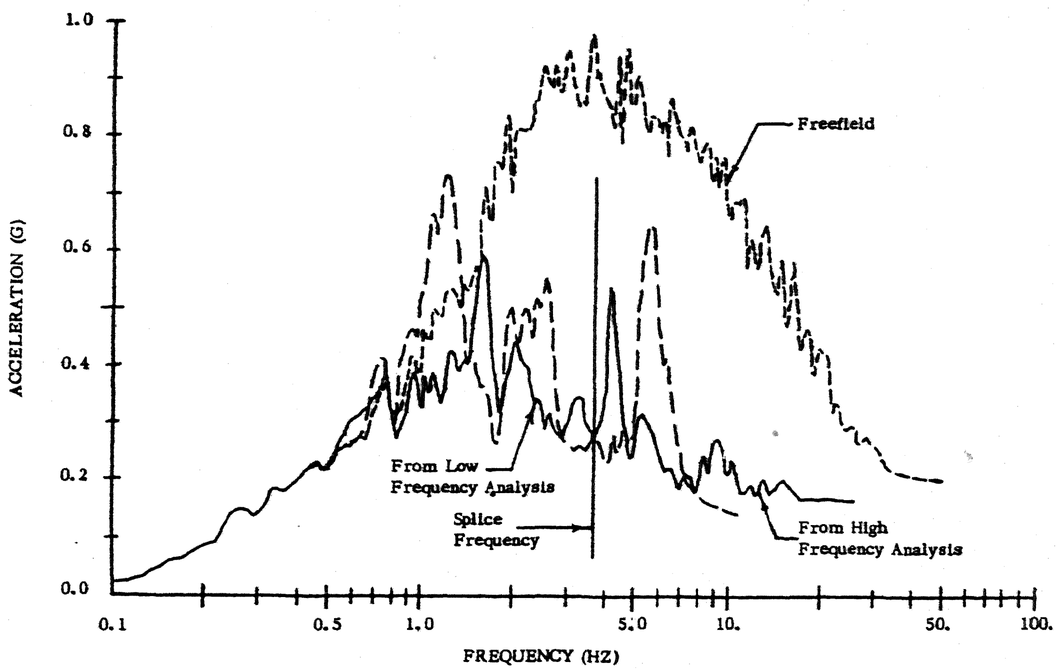


FIGURE 4 COMBINATION OF LOW AND HIGH FREQUENCY SITE RESPONSE AT MOORING CAISSON STRUT ATTACH POINT

DISCUSSION

A.R. Chandrasekaran (India)

Important equipments in nuclear power plants have a very low tolerance for absolute and relative displacements due to vibration. The discussor expects in the case of floating power plants, due to wave action of wind and Tsunamis during earthquakes, the displacements would be much larger than plants located on land. Are any special isolation devices used for equipments in floating power plants?

P.S. Singh (India)

1. Are the components/structural systems of the floating nuclear power plant designed to resist the motion induced due to the P-wave (compression waves) ?

2. Is it possible to dissipate the energy of P-waves also by introducing some sort of isolation ?

3. Have the economics of siting a nuclear power plant on sea and on land been compared ?

4. How are the pitching, yawing and other wave effects that the barrage of the nuclear power plants is subjected to, accounted for ?

Author's Closure

With regard to the question of Mr. Chandrasekaran, we wish to state that the most of the work we did on Atlantic Generating Station was related to the site structures as the FNP is being designed by the plant manufacturer. I do understand, though, that the turbines are being placed on a flexible foundation. Since the FNPs at the AGS site are so well-protected from waves, and because the design tsunami for the Atlantic is so small, I think in this case the tornado or earthquake would be the more likely source of the effects you describe.

With regard to the question of Mr. Singh, we wish to state the answers as follows:

1. Yes they are, and this is being done by the plant manufacturer.

2. Air-bags in cells under the keel have been proposed by some.

3. No doubt the plant manufacturer has done so.

4. The main topic of this paper was soil structure interaction. Many other types of analysis were performed also, and these are described in the PSAR for Atlantic Generating Station. In particular, analyses were carried out for storm wind and wave, tornado, and earthquake effects on the floating plants and the mooring system.