Evaluation of Control Motion Input Location

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INTRODUCTION

The Electric Power Research Institute (EPRI) and the U.S. Nuclear Regulatory Commission (NRC) supported a research program where a quarter scale model reactor containment structure was constructed in Lotung, Taiwan. This is a seismically active region and the same local as the strong motion array (SMART) supported by the National Science Foundation. Two types of experiments have been conducted by NRC/EPRI at the site. First, shaker tests were conducted on the model. Second, instrumentation placed on the structure and in the free field was set to be triggered by seismic motions occurring at the site. Data was collected from many earthquakes which have occurred at the site. The input free field motions were made available. Predictions were then made for the structural response, and compared with the measured in-structure motion.

This paper is based on work performed (Ref. 1)at the City College of New York (CCNY) in making the blind predictions. The work presented in this paper focuses on the comparisons made between the predicted and measured results as influenced by the location of the control point motion used as input to the structural response calculation.

DESCRIPTION OF EXPERIMENT AND MODEL

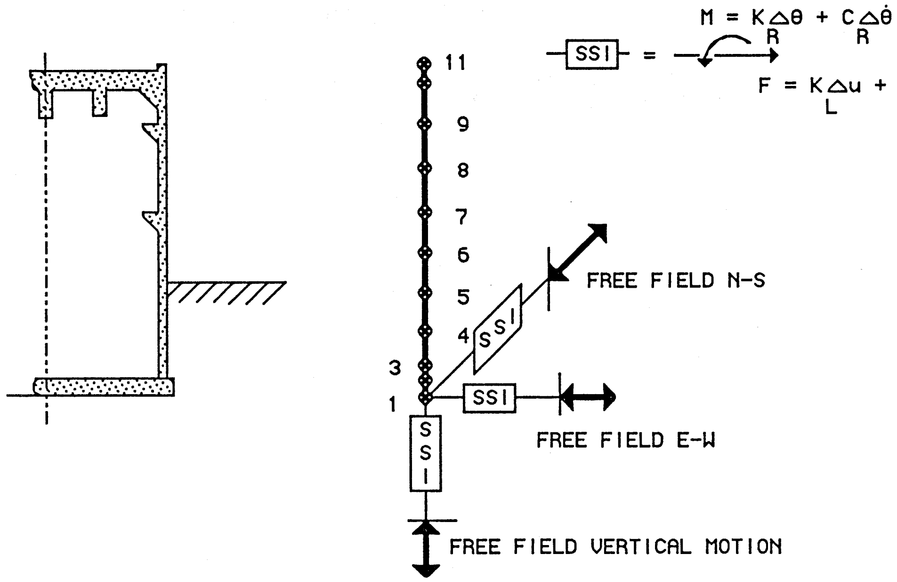
The structural model, the free field characteristics, and the soil structure interaction parameters are described in this section of the paper.

The quarter scale model containment (see Fig. 1a) consists of an 11.81 inch thick reinforced concrete cylinder having an outer radius of 206.69 inches. The overall height of the containment is about 600 inches. The basemat is 36 inches thick and has a radius of 212.6 inches. The structure is embedded about 15 feet.

The roof and basemat are rigid and were modeled as lumped masses. The cylindrical shell was modeled as a shear beam. A sketch of the structural model is shown on Fig. 1b. Each node in the model was assigned six degrees of freedom although some of the degrees of freedom were restrained for a particular solution. Four accelerometer stations are located at the elevations of nodes 3 and 9, with the stations separated by 90 degrees in azimuth at each elevation. Three components of acceleration are recorded at each station.

The SIM Code was used to perform all of the structural response calculations. This is a code which was first developed for the US Air Force (Ref. 2) to treat the response of buried cylindrical structures to air-blast induced ground shock loadings. The code was modified (Ref. 3) so that it would be applicable to seismic problems. Additional modifications to the code are described in (Ref. 4). The code operates in either the time or frequency domains. The computations performed in this study were all performed in the frequency domain.

Structural damping was taken as four percent for the seismic loading. The first two flexural frequencies for the model were found to be 13.2 cps and 51.0 cps.



(a) Test Model (b) SIM Code Model

Fig.1 MODEL OF SCALE STRUCTURE

EPRI/NRC provided three sets of data describing the soil properties at the site. The first set was based on soil boring data and static soil property tests. The second included additional seismic site exploration data and cyclic soil property tests. The third utilized the soil/structure response data from the shaker tests to evaluate soil properties. These three sets of data span the type that could be used as input to the design process for nuclear power plants. The older plants relied on the first set, the second set of data reflects current practice, and the third represents something that could be done for future plants. Models based on the three sets of soil data are labeled "A", "B", or "C" respectively in the CCNY study.

The free field for the "A" models was obtained from a review of the blow count numbers for the site. As a result the free field was divided into two layers having the following properties:

LAYER 1	LAYER 2
Depth : 0 - 69 ft	Depth : > 69 ft
Shear Modulus : 1,732 ksf	Shear Modulus : 5,138 ksf
Poisson's Ratio : 0.35	Poisson's Ratio : 0.25
Dry Density : 110 pcf	Dry Density : 120 pcf
Saturated Density : 135 pcf	Saturated Density : 145 pcf

The free field for the "B" models was developed from the downhole seismic measurements. The free field was divided into three layers having the following properties :

LAYER 1	LAYER 2	LAYER 3
Depth : 0-16 feet	Depth : 16-41 feet	Depth : >41 feet
Shear Modulus : 590 ksf	Shear Modulus : 980 ksf	Shear Modulus: 2,670 ksf
Poisson's Ratio : 0.45	Poisson's Ratio : 0.49	Poisson's Ratio : 0.48

The dry density for the three layers was taken as 110 pcf and the saturated density as 135 pcf.

Free field instrumentation was placed along three lines radiating from the structure. Five surface accelerometer stations (each measuring three components) were located along each line at radii varying between 10 and 160 feet. At two stations (10 feet radius and 160 feet radius) four stations were placed at depths down to 160 feet.

Lumped parameter SSI models were used. A set of springs and dampers were used to connect node 1 of the model shown in Fig. 1b to the free field. The seismic motion was input directly to these elements.

Three sets of interaction springs and dampers were specified for each of the "A" and "B" models. The first set of elements were frequency independent parameters (labeled _ .1)and typical of those used for the design of most of the existing nuclear power plants. The base component of the SSI parameters were determined from Ref. 5 and the sidewall contribution was determined from Ref. 2. The second set were frequency dependent and accounted for layering effects (labeled _ .2). The basemat interaction coefficients were taken from Ref. 6. Sidewall interaction coefficients were taken from Ref. 7. The third set were also frequency dependent, accounted for layering, and considered the effects of ground water on the interaction process (labeled _ .3). These parameters were developed based on data contained in Ref. 8.

COMPARISONS OF PREDICTIONS WITH MEASURED EARTHQUAKE DATA

On May 20, 1986 a magnitude 6.5 earthquake occurred at the site resulting in a peak surface horizontal acceleration of about 0.2 G's. The measured data and the comparisons of the predicted and measured in-structure responses are discussed in this section.

Spectra of the N-S free field measured motions are shown on Fig. 2. The recorded data at the surface, 6 m, 17 m, and 47 m depths are shown at the DHA location (10 feet from the quarter scale model), and at the DHB location (about 160 ft north of the structure). The measured motions indicate little attenuation from the surface down to the 6 m depth at the close-in station (DHA), and significant attenuation of the components having frequencies lower than 2 cps from the upper elevations down to the 17 m and 47 m depths. Note that there is a large attenuation between the surface and 6 m motions at the DHB station.

The control point free field motion was given as the surface motion at the DHB station, and all predictions were based on this free field data. The remainder of the free field data were not made available prior to making the structural response predictions. The three components of the surface free field motions were then used as input to the seven SSI models (A.1-3, B.1-3, and C). The E-W, N-S, and vertical free field motions were then input simultaneously to the SSI model shown on Fig. 1b. The torsional degrees of freedom of all nodes were restrained. The complete 9 second pulse resulted in solutions out to about 26 cps. Since all of the significant motion occurred well before 15 cps, the SIM Code solutions were limited to the first 200 Fourier components.

The spectra (5%) of the calculated N-S motions of gage F4US (at the upper node 9 and at the south azimuth of the structure) are shown on Figs. 3. Three sets of spectra are shown, one for each of the model sets (A, B, and C). In each case spectra of the measured motion are shown with crosses. A comparison of the measured and calculated motions show reasonably good agreement except for the frequency range of about 1.7 cps-5 cps. This is the same frequency range where the measured 6 m depth spectral values were found to be lower than those used as input to SIM Code. An overview of the computed and measured spectra on Fig. 3 indicate that the calculated spectra are conservative (except for a small area around 1.2 cps) and that the Models C and B.2 results are the best representation of the measured data.

The spectra of the N-S motion of the control point has a large spike at 2.6 cps. This spike is not found in the other free field records. This excursion is carried over into the structural response predictions and results in poor comparisons between the measured and predicted structural spectra around 2.6 cps. A second set of comparisons were made using the measured free field motion at a depth of 6 M (basemat elevation) as the control motion. The comparisons for gage F4US, using the B.2 SSI model are shown on Fig. 4. It may be seen that the anomalous peak at 2.6 cps for the N-S motion has disappeared, and the agreement at that frequency is good. In general, the comparisons between the predicted and measured structural motions using the 6 M depth control point are unconservative however.

CONCLUSIONS

1. There appears to be an anomaly in the measured free field data at 3 cps for the N-S motion at FA1-5. This peak is not as severe at the other surface locations or at the 6 M depth gages.
2. The calculated horizontal in-structure spectra correlate reasonably well with the spectra of the measured motion except for the frequency range where the input foundation level free field motion differs from the actual free field motion. It is concluded that the SSI models are reasonably good .
3. The Model B.2 and C predictions compare best with the measured data.
4. The use of a 6 M deep control point motion resulted in the elimination of the large spectral peak at 2.6

cps but gives unconservative results at other frequencies. It would therefore be concluded that the surface control point motion is more desirable.

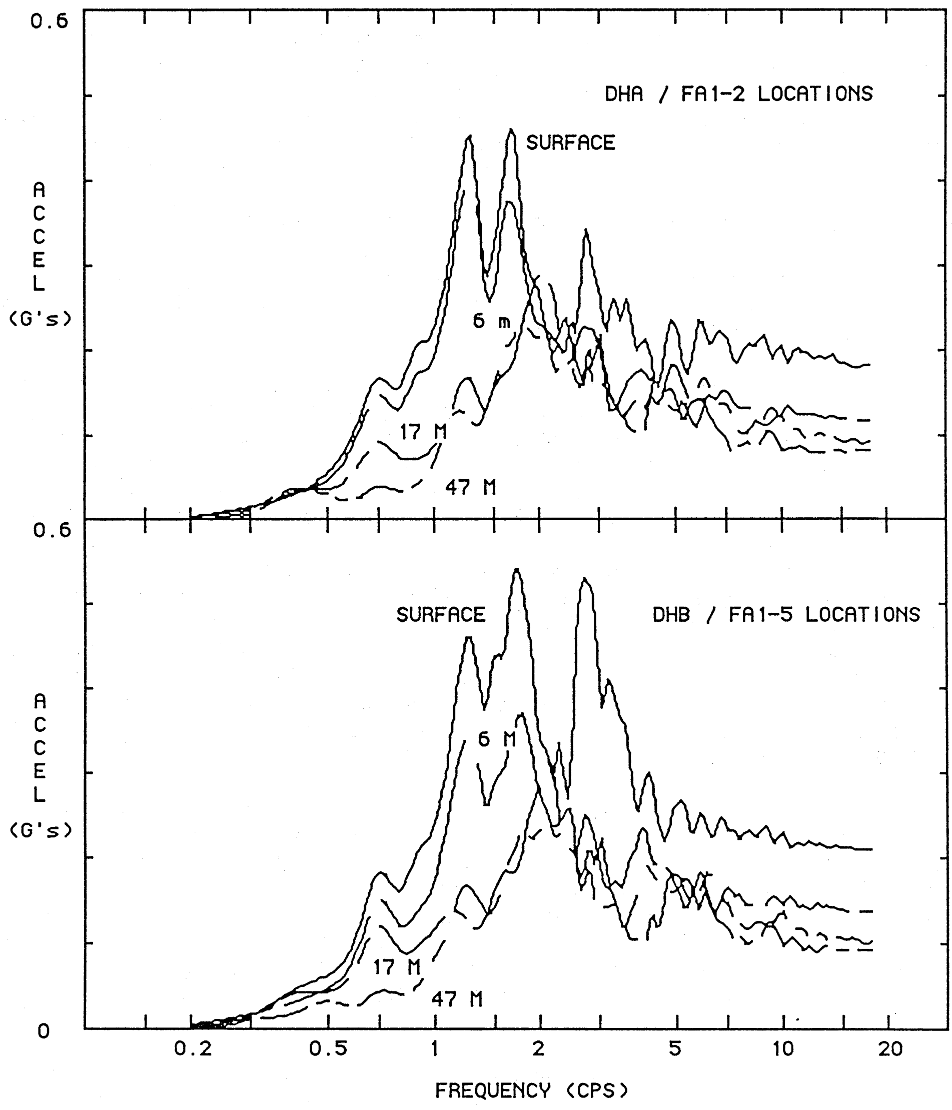


Fig. 2 MEASURED N-S FREE FIELD SPECTRA (2%)

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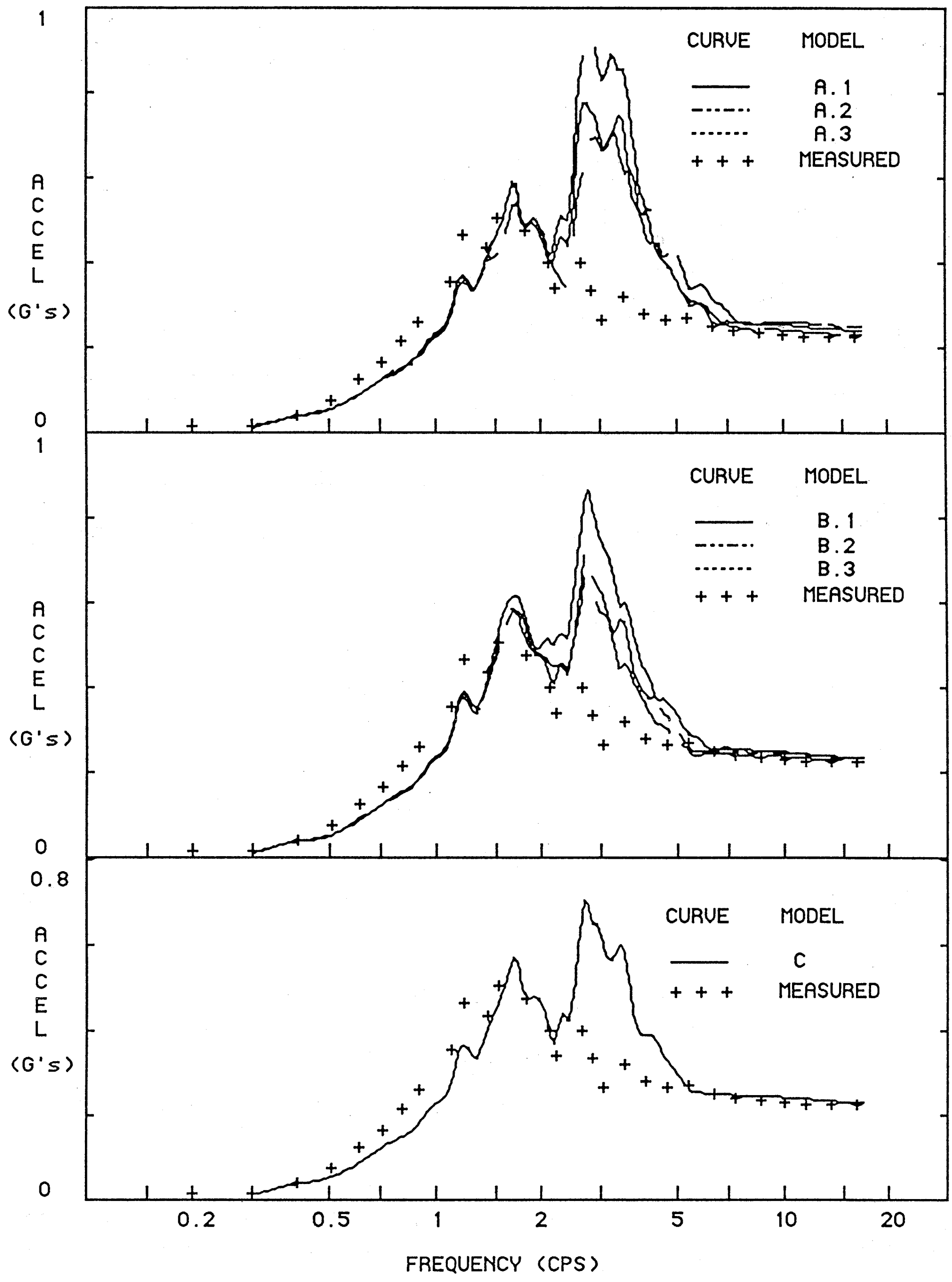

Fig. 3 PREDICTED AND MEASURED N-S RESPONSE OF F4US

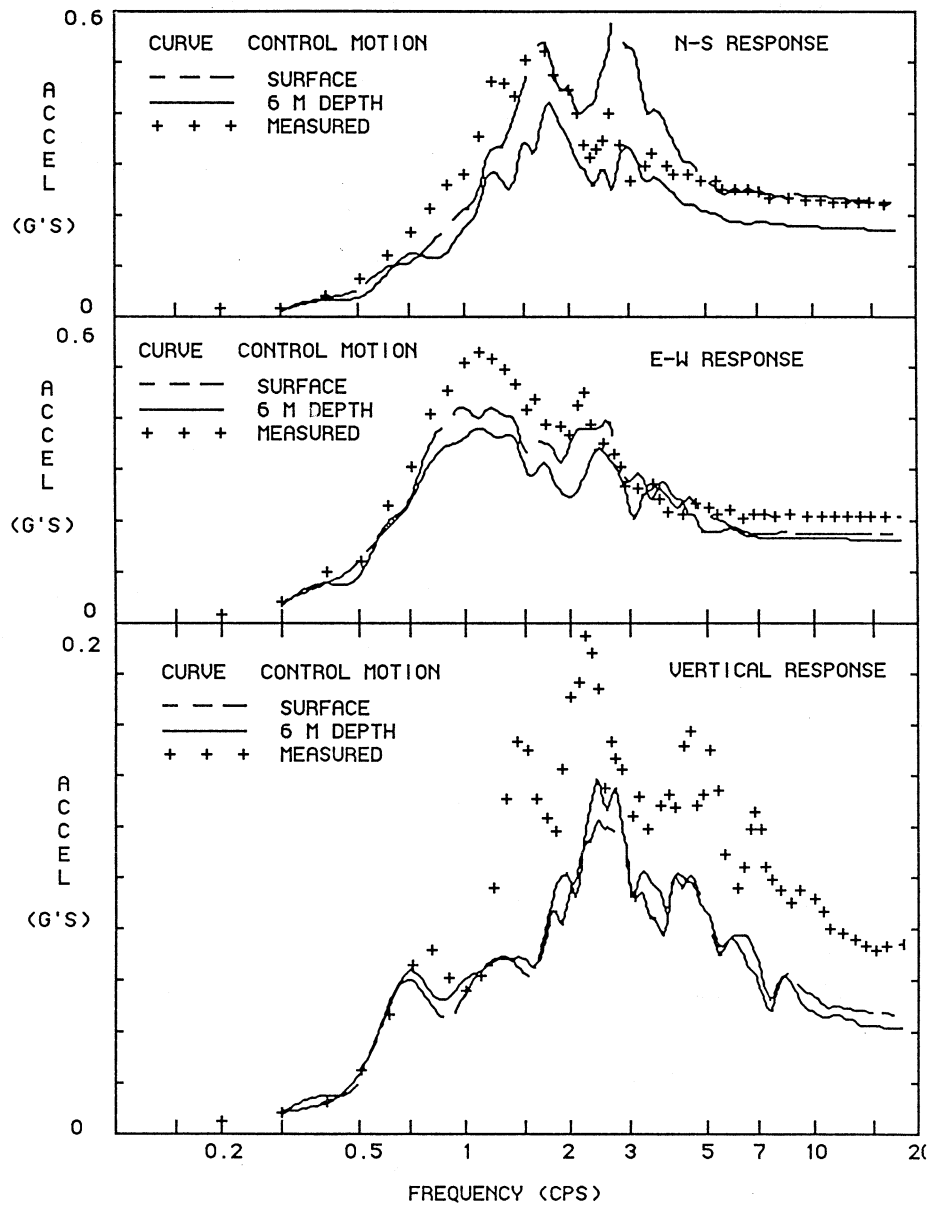

Fig. 4 EFFECT OF CONTROL POINT ON RESPONSE FOR F4US

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