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# Analysis/test correlation of a model containment structure subjected to seismic excitation

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ABSTRACT: The results of the analytical investigation of the Lotung Large-Scale Experiment are presented. A one-quarter scale concrete containment structure was constructed and instrumented in the seismically active region of Lotung, Taiwan. The containment structure was subjected to forced vibration tests and actual earthquakes. "Blind-prediction" and "refined" analysis/test correlation studies were performed as part of a research investigation to assess the accuracy of current methods used in seismic soil-structure interaction analysis.

## 1. INTRODUCTION

This paper presents the results of the analytical investigation of the Lotung Large-Scale Experiment. A one-quarter scale concrete containment model was constructed in the seismically active region of Lotung, Taiwan by the Electric Power Research Institute (EPRI) and the Taiwan Power Company. Extensive instrumentation was installed in the containment structure and on the field, which monitored the response of the soil and the containment to actual local earthquakes (Figure 1).

The subject of the work described herein was to correlate recorded data from forced vibration tests and actual earthquakes with results obtained from analytical investigations using state-of-the-art procedures for soil-structure interaction (SSI). In particular, SSI analyses of the soil-containment system are presented for two different input excitations to the containment: (1) forced vibrations produced by rotating-mass vibration generators installed at the containment roof, and, (2) the May 20, 1986 Taiwan earthquake.

The main objective of this investigation was to assess current industry practice in SSI analysis, to identify important SSI parameters and quantify conservatisms included in industry-type SSI analyses. To obtain the maximum benefit out of this investigation, a two-phase approach was used in each analysis/test correlation. First, a "blind prediction" of the response of the containment was performed using as input structural design information and geotechnical data from site investigations. In the blind-prediction phase, the recorded response of the containment and the soil was not known. Following the submittal of the "blind prediction" results to EPRI, response records were obtained and correlated to the blind prediction results. Based on the comparison between the recorded responses and the analytical predictions, the analytical models of the soil/containment system were "refined" and final analyses were performed in order to better match the experimental results.

## 2. METHODOLOGY

The methodology of the computer program SASSI (References 1 and 2) was used in the SSI analyses. SASSI uses a general substructuring technique which employs the finite element method and solves the equations of motion in the frequency domain using the method of complex response. The complete soil-structure system is divided in two substructures: the "foundation" and the "structure". The impedance problem is solved using the "foundation" model. The model of the soil site consists of semi-infinite viscoelastic horizontal layers on a semi-infinite viscoelastic halfspace. The structure is idealized by an assembly of standard, three-dimensional finite elements. Earthquake excitation is provided in the form of time histories of accelerations assigned to any soil layer interface.

## 3. CONTAINMENT STRUCTURE

The 1/4-scale containment structure is a cylindrical reinforced concrete structure 15 m high by 10.5 m in diameter (Figure 2). The bottom 4.5 m are embedded in the soil. The containment rests on a 0.91 m thick basemat. The top of the cintainment is covered by a 1.07 m slab which is further stiffened by three concrte beams running across the full span of the slab.

## 4. LOTUNG SITE CHARACTERISTICS

The geotechnical investigations from Reference 3 showed that the Lotung site was a "soft" soil site with layering that was not perfectly horizontal. However, there were several soil strata that were encountered in all the boreholes and constituted the general composition of the subsurface area of the site. The site consisted of silty sands near the surface with gravely and clay layers at bigger depths. In-situ downhole and crosshole measurements provided low-strain shear wave velocities between 100 to 150 m/sec at the top 10 m of the site, and 150 to 300 m/sec for the deeper layers.

## 5. FORCED VIBRATION ANALYSIS

Prior to any earthquake-induced response monitoring, the concrete containment model was subjected to forced vibrations produced by rotating-mass shakers installed at the roof of the containment. Separate tests were performed with the load applied in each of two different directions: radial and tangential (Figure 3).

The blind prediction analyses of the forced vibrations were performed using the finite element model shown in Figure 4. The foundation basemat and the roof were modeled with eight node solid finite elements and the cylindrical wall was modeled with shell elements. Two soil profiles were developed to be used in separate analyses with the structural model of the containment. The first soil profile was based on the geotechnical borehole data (standard penetration tests) and analytical procedures to calculate shear moduli and shear wave velocities (Reference 4). The second profile was based on the in-situ measured shear wave velocities derived from the geophysical investigations.

Representative results of the SASSI analyses are shown in Figures 5 and 6. The amplitude of the response at the containment is plotted as a function of forcing frequency. The analytical model with shear wave velocities which were based on the geophysical test results provided excellent correlation with the measured response of the containment. The analytical model with the computed shear wave velocities had approximately 20% shift in the fundamental frequency of the combined soil/structure system because of overestimation of the computed shear wave velocities.

## 6. SEISMIC ANALYSIS

Seismic analysis/test correlations were performed for the May 20, 1986 Taiwan earthquake (Magnitude 6.5). This earthquake produced maximum horizontal accelerations of 0.2g at the Lotung ground surface.

The modeling assumptions used in the blind-prediction forced vibration analyses were also used in the seismic studies so that truly blind predictions of the seismic response be obtained. However, since the earthquake motion induced large strains in the soil, new shear moduli and damping ratios were developed with the computer program SHAKE (Reference 5) to be compatible with the level of excitation.

The seismic wave composition was assumed to consist of vertically propagating S-waves for the horizontal excitation and vertically propagating P-waves for the vertical excitation. The control motion corresponded to the free-field surface acceleration time history recorded at the site and consequently was applied at the free-field ground surface of the analytical model.

The results of the seismic analysis showed very good correlation with the measured response. Figures 7, 8 and 9 show correlations of 5% damped response spectra corresponding to the basemat and the top of the containment. In addition, Figure 10 shows the analysis/test correlation for the free-field soil response at a depth of 6 m. It is observed that the attenuation of motion with depth was accurately predicted by the SSI model.

## 7. CONCLUSIONS

The Lotung Large-Scale Experiment has been a very successful research program to assess current analytical methods to predict

SSI response. The recorded data at Lotung constitute a valuable experimental database for seismic response of structures on soft soil sites.

In the analysis presented herein, it was shown that SASSI's methodology provided powerful means for proper modeling of soil, foundation and structure and accurately predicting structural response. The capabilities of the SASSI program to model flexible foundations with three-dimensional embedment of arbitrary spatial geometry are unique. The Lotung correlation studies have shown that proper modeling of the embedded part of the structure is very important in calculating realistic impedances and radiation damping, and consequently, obtaining accurate structural responses.

Geophysical site investigations provided a shear wave velocity profile which was most representative of the Lotung site for the low-strain forced vibration analysis. The use of field and laboratory geotechnical data was essential for the determination of high-strain soil properties. However, careful review and judgement were required in the determination of the dynamic soil properties.

Finally, based on the foundation and free-field subsurface recordings measured in the Lotung experiment, it is concluded that current analytical methods realistically predict attenuation of motion below the ground surface at free-field and foundation locations.

## 8. REFERENCES

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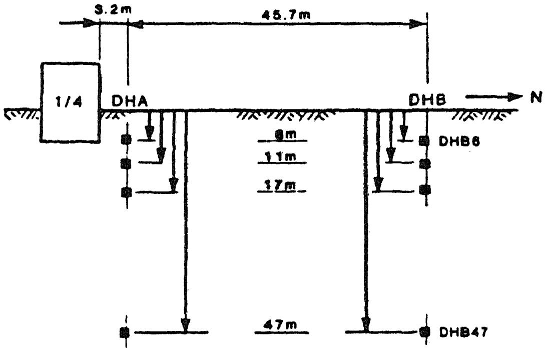

Figure 1 Location of Accelerometers at Containment and Free-Field

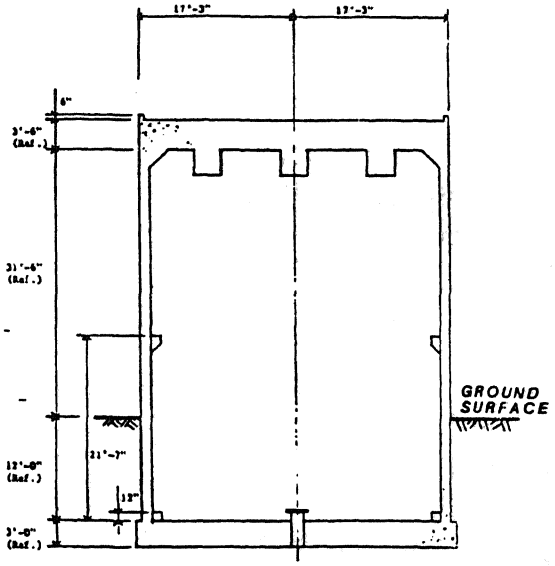

Figure 2 Lotung 1/4-Scale Concrete Containment

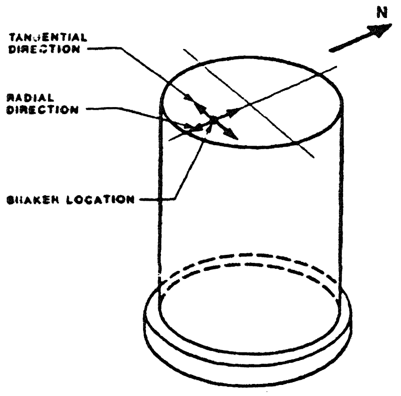

Figure 3 Shaker locations for Forced Vibration Tests

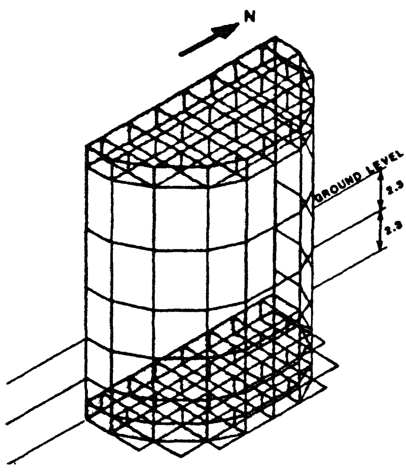

Figure 4 Structural Model of Containment (Half model)

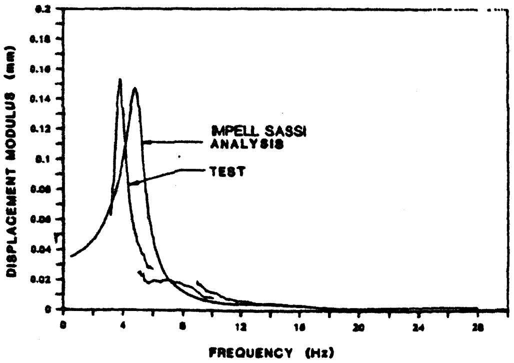

Figure 5 Forced Vibration Response at Basemat Using Calculated Shear Wave Velocities

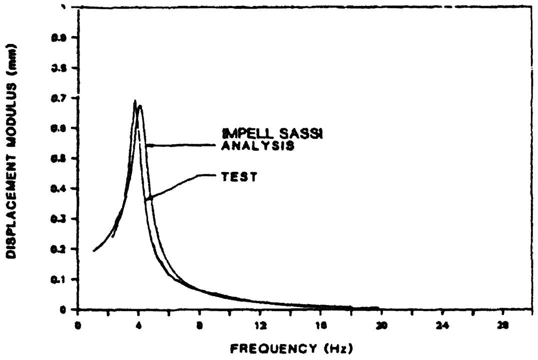

Figure 6 Forced Vibration Response at Midheight Using Measured Shear Wave Velocities

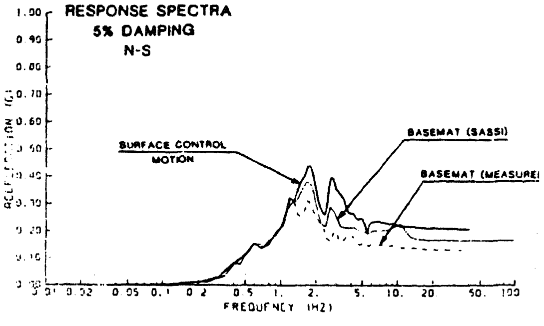

Figure 7 Blind Prediction Seismic Response at Basemat

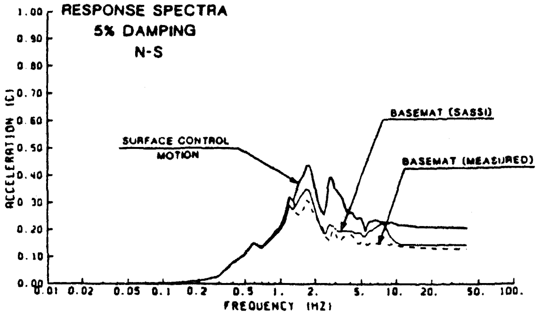

Figure 8 Refined Seismic Response at Basemat

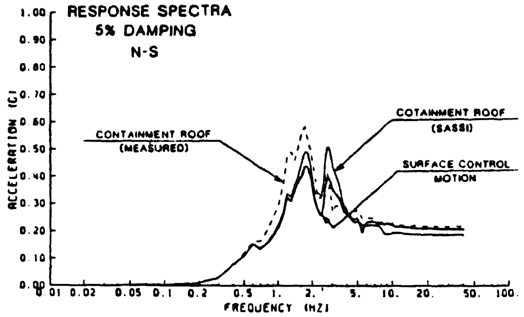

Figure 9 Refined Seismic Response at Top of Containment

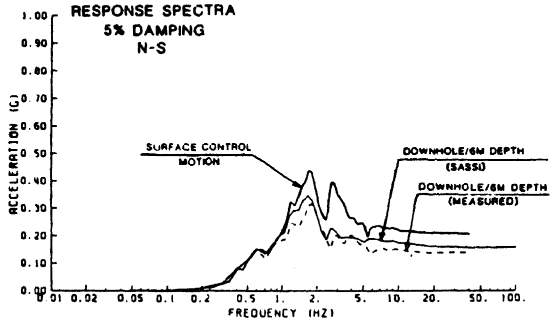

Figure 10 Blind Prediction Seismic Response at Free-Field Depth of 6m