A large-scale soil-structure interaction experiment: Part I Design and construction

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1 INTRODUCTION

In the simulated earthquake experiments (SIMQUAKE) sponsored by EPRI, Higgins et al (1981,1983) and Howard et al (1985), the detonation of vertical arrays of explosives propagated wave motions through the ground to the model structures. Although such a simulation can provide information about dynamic soil-structure interaction (SSI) characteristics in a strong motion environment, it lacks seismic wave scattering characteristics for studying seismic input to the soil-structure system and the effect of different kinds of wave composition to the soil-structure response. To supplement the inadequacy of the simulated earthquake SSI experiment, the Electric Power Research Institute (EPRI) and the Taiwan Power Company (Taipower) jointly sponsored a large scale SSI experiment in the field. The objectives of the experiment are: (1) to obtain actual strong motion earthquakes induced database in a soft-soil environment which will substantiate predictive and design SSI models; and (2) to assess nuclear power plant reactor containment internal components dynamic response and margins relating to actual earthquake-induced excitation. These objectives are accomplished by recording and analyzing data from two instrumented, scaled down, (1/4- and 1/12-scale) reinforced concrete containments sited in a high seismic region in Taiwan where a strong-motion seismic array network is located, Bolt et al (1982). Figure 1 shows the test site location.

2 MODEL DESIGN CRITERIA

To obtain best practical results, the following design criteria for the 1/4-scale model were established, Penzien (1983) and Stephens and Cloud (1984a):

- The dominant free-field earthquake ground motion frequencies should be comparable to the significant interaction frequencies of the model test structure as they are comparable to the significant interaction frequencies of the prototype structure,
- The test structure, to be constructed of the same materials as the prototype structure, should not experience significant inelastic deformations under maximum expected seismic inputs. However, under these same seismic conditions, it would be desirable to develop stresses in the model structure similar to

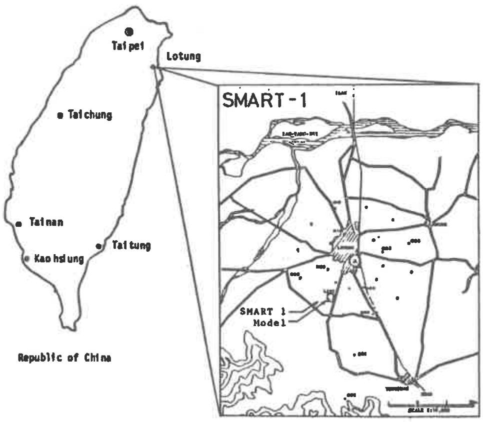

Figure 1. Test site location.

those developed in the prototype structure under expected earthquake conditions, i.e., similar to working stress levels,

- The configuration of the model structure should easily permit implementation of forced vibration tests,
- The basemat of the model structure should be designed so that it acts essentially as a rigid body under seismic conditions,
- The start of lift-off and sliding of the model structure should occur at earthquake ground motion intensities similar to the corresponding intensities for the prototype structure,
- The ratio of dead load stress on the soil to its allowable stress should be similar to the corresponding ratio for the prototype,
- Equipment masses relative to the model structure should be comparable to the corresponding mass ratio in the prototype. Further, their stiffnesses should be set so that fundamental frequencies of the modeled internal systems equipment items on their supports are the same as the corresponding frequencies for prototype equipment.

Since the dominant frequencies of earthquakes in Lotung are in the range of 3 to 8 Hz, the 1/4-scale model was designed to have a rocking frequency in the same range. For internal component response monitoring, a mocked-up steam generator and a pipe run were included within the model. The 1/4-scale size of the containment was judged to be the minimum scale which could be used successfully to reproduce as much as possible the prototypical containment behavior during an earthquake, as guided by the design criteria and scaling considerations. The possibility of increased complexity in design and construction with small size was also considered in the decision process. It should be noted that the scaling considerations were used only as guidelines. The final design was constrained by additional practicality considerations, such as soil bearing capacity and others, Stephens and Cloud (1984a, 1984b). The most important governing consideration was to insure that data with significant SSI would be obtained. Since exact scaling is difficult for SSI experiments, one should be careful about extrapolating the model results to full scale cases directly. Rather, one should use analytical methods qualified against model test data for full-scale SSI predictions.

The 1/4-scale model as constructed has the following dimensions:

- Elevated slab (roof) thickness 3.5 ft (1.07 m)
- Basemat thickness 3 ft (.91 m)
- Total model height (including roof and basemat) 50 ft (15.34 m)
- Cylinder outer diameter 34.5 ft (10.52 m)
- Cylinder wall thickness 1 ft (.30 m)
- Embedment (including basemat) 15 ft (4.58 m)

An illustration of the model is given in figure 2.

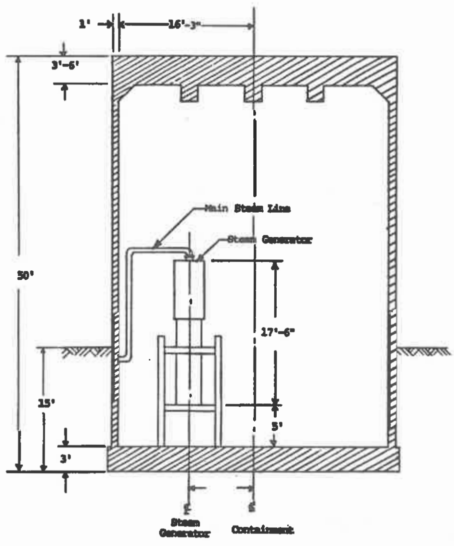

Figure 2. The 1/4-scale containment model, cross-section view.

The 1/12-scale model does not have roof and internal components. It has the following dimensions:

- Basemat thickness 1.5 ft (.46 m)
- Total cylinder height (including basemat) 15 ft (4.5 m)
- Cylinder outer diameter 10 ft (3.0 m)
- Cylinder wall thickness 1 ft (.30 m)
- Embedment 3.75 ft (1.14 m)

3 INSTRUMENTATION

The containment models have been provided with instruments, Liu and Yeh (1985), that record the desired free field, soil-structure interaction region, and structural response parameters. The free field has been instrumented to collect data which will enable a detailed

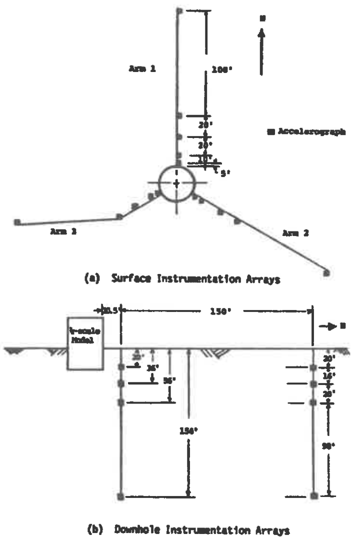

Figure 3. Location of free-field instrumentation around the 1/4-scale model.

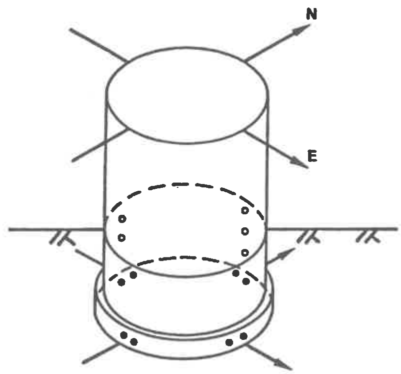

Figure 4. Location of soil-structure interface instrumentation on the 1/4-scale model.

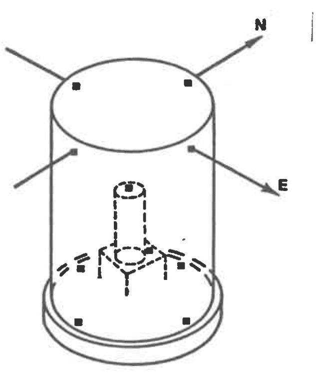

Figure 5. Location of structural response instrumentation on the 1/4-scale model.

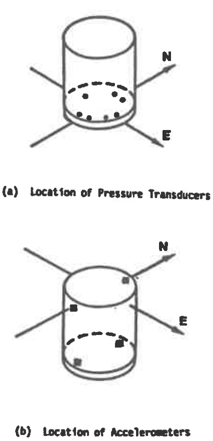

Figure 6. The 1/12-scale model instrumentation.

description of the ground motion both in the close vicinity and away from the model structure. Triaxial accelerographs have been deployed in an array of three arms, equally spaced at 120 degrees, which extend radially from the structure for a distance of approximately 4-1/2 diameters. Additionally, two downhole arrays have been deployed to provide data on vertical spacial distribution of ground motion. Triaxial accelerographs were used, as all horizontal and vertical accelerations are of interest. Accelerographs have also been installed on the model structure and internal subsystem components to provide data on their response to a seismic event. In addition, pressure transducers have been installed under the foundation and on the shell outside surface below ground level to help describe behavior at the soil-structure interface. The instrumentation has been equipped with a timing capability to allow for correlation between data received at various stations. A central data collection, recording, and processing system has been installed to facilitate data transcription.

Final instrumentation installation layout is shown in figures 3 to 6.

4 CONCLUSION

The experiment was designed to furnish the following:

- Free-field accelerations.
- Downhole accelerations.
- Containment accelerations.
- Containment-soil contact pressures.
- Internal component accelerations.
- Site soil properties.
- Forced vibration test response.

Construction was completed and data collection started in September 1985. To July 1986, twelve major earthquakes ranging from Richter magnitude 5.3 to 6.5 were recorded. The maximum peak ground acceleration recorded was about 0.3 g. Data will be continuously recorded for a period of no less than five years with the option to extend if such a need is deemed appropriate.

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