The Hualien Large-Scale Seismic Test for Soil-Structure Interaction Research

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ABSTRACT

A Large-Scale Seismic Test (LSST) Program at Hualien, Taiwan, has been initiated with the primary objective of obtaining earthquake-induced SSI data at a stiff soil site having similar prototypical nuclear power plant soil conditions.

Preliminary soil boring, geophysical testing and ambient and earthquake-induced ground motion monitoring have been conducted to understand the experiment site conditions. More refined field and laboratory tests will be conducted such as the state-of-the-art freezing sampling technique and the large penetration test (LPT) method to characterize the soil constitutive behavior. The test model to be constructed will be similar to the Lotung model. The instrumentation layout will be designed to provide data for studies of SSI, spatial incoherence, soil stability, foundation uplifting, ground motion wave field and structural response.

A consortium consisting of EPRI, Taipower, CRIEPI, TEPCO, CEA, EdF and Framatome has been established to carry out the project. It is envisaged that the Hualien SSI array will be ready to record earthquakes by the middle of 1992. The duration of the recording is scheduled for five years.

INTRODUCTION AND BACKGROUND

EPRI, in 1985, with the cooperation of the Taiwan Power Company (Taipower), designed and constructed 1/4-scale and 1/12-scale reinforced cylindrical concrete containment models in the field for studying SSI under strong ground motion earthquakes (Tang, 1987). The model structures are located in an active seismic region, Lotung, Taiwan, where a two-dimensional strong motion array (SMART-1) (Bolt et al., 1982) has been operating. The soft soil site conditions at Lotung were viewed as ideal for invoking significant SSI, particularly for reduced scale models. The Lotung experiment was well instrumented to record free field, SSI and structural response data. Before the deployment of instruments, the U.S. Nuclear Regulatory Commission (NRC) also co-sponsored low-level forced vibration tests (FVT) for the purpose of defining basic dynamic characteristics of the soil-structure system.

To date, more than thirty earthquakes with Richter magnitudes larger than 4.0 have been recorded at Lotung. Some have peak accelerations greater than 0.2g, furnishing significant strong motion records. Using the earthquake data and the forced vibration test data as a basis, EPRI, NRC and Taipower initiated a cooperative analytical program in January 1986 aimed at assessing the validity of various SSI analysis methodologies and quantifying uncertainties associated with SSI parameters (Tang et al. 1987). A round-robin approach was adopted to assure independent evaluations (EPRI, 1989).

The analytical program has yielded the following major observations and findings (Tang et al. 1990):

- Overall, the analytical results are reasonable and generally conservative for all models tested. The differences between measured and predicted responses are mainly attributed to: (a) uncertainties of site geometric and material parameters; and (b) modeling assumptions and limitations of various SSI methods.
- One major uncertainty is the site soil properties. Although quantitative field geotechnical and geophysical explorations and laboratory soil testing were performed, uncertainties remain in areas such as: (a) location of soil layer boundaries; (b) backfill material property; (c) water saturation effect; and (d) strain-compatible modulus and damping. Interpretation of data based on judgment and experience seem to have played a major role in modeling the soil behavior.
- In general, predictions based on more advanced capabilities considering soil layering, wave scattering, and embedment effect agree better with measurements. Simplified approaches, such as the soil-spring model, tend to produce overly conservative results. However, if those advanced capabilities are considered in an approximate manner in simplified models, more realistic predictions can be realized.
- The measured shear wave velocities for the upper 200 ft of soil layers range from 300 ft/sec to 1000 ft/sec. Because of such softness, the containment model response was dominated by rigid-body rocking mode during both FVT and earthquake excitation. Analysis generally underpredicted the amplitude of the rocking motion. This suggests that soil stiffness degradation during the strong ground motion earthquake might be more profound than assumed. Other possible reasons could be: (a) strong soil nonlinearity in the upper layers; (b) partial separation of foundation and soil media; or (c) pore water pressure buildup.
- Deconvolution solutions using SHAKE are in generally good agreement with the measured response at shallow depth, but not for the deeper downholes. It appears that the SHAKE deconvolution reached its limit in computing deep layer responses for such soft soil media. However, the difficulty in deconvolving to depth (greater than 50 ft) did not seem to impact the response prediction of the 1/4-scale containment structure, whose embedment depth is 15 ft.
FVT proved to be useful in calibrating and confirming analytical models. However, caution is required when applying FVT results at low strain levels to actual strong motion earthquakes at higher strain levels.

NEED FOR A STIFF SOIL SITE SSI EXPERIMENT

Because of its extreme soft soil conditions and the small size of test models, the Lotung experiment is limited in addressing certain SSI issues, such as effects of structural deformation, foundation uplifting, seismic wave spatial incoherency and particularly, the stiff soil conditions. To confirm and expand the findings and analytical validations achieved in the Lotung program for more prototypical stiffer soil site applications, a stiff soil site experiment is needed. One needs to address the following specific questions:

- Have Lotung results captured all key critical SSI behaviors directly applicable to prototypical nuclear power plant?
- Are conservatisms identified based on soft soil site data equally valid for stiff soil sites based on extrapolation using qualified analytical methods but lacking actual stiff soil data confirmation?

Additionally, associated with the U. S. Standard Review Plan revision, resolution of Unresolved Safety Issue (USI) A-40, NRC raised several questions specifically pertaining to the Lotung results. Stiff site data and analysis can certainly substantiate answers to these questions.

OPPORTUNITY

With the cooperation of the Taiwan Power Company (Taipower) and the Institute of Earth Sciences (IES) of Academia Sinica, a site meeting the desired stiff soil conditions has been identified in Hualien, Taiwan. As shown in Figure 1, Hualien is situated along the east coast of Taiwan, south of Lotung. The general geology in Hualien consists of massive unconsolidated, poorly bedded conglomerative composed of pebbles varying in diameters from 10 to 20 centimeters. Scoping geophysical and boring tests conducted in 1989 by Taipower show that the shear wave velocity for the top layer of 100 meter depth is around 400 m/sec and for the layer below (up to about 7 km depth) is 1500 m to 1850 m/sec. The 50 m boring revealed that the top 5 m is of silty sand and the layer below consists of gravels varying from 3 cm to 7 cm.

From Figure 2, one can observe that Lotung and Hualien are two high seismicity regions. Based on Figure 3, which depicts the distribution of the historically destructive earthquakes from 1898 to 1988, one may infer that Hualien has had slightly more destructive earthquakes than Lotung in the past.

The second strong motion network (SMART-2), conducted by the Institute of Earth Sciences in Taiwan, in cooperation with U.C. Berkeley, will be deployed in Hualien which will monitor earthquakes in Hualien for seismological studies.
Based on the above, EPRI and Taipower took the lead and initiated the planning of the Hualien Large Scale Seismic Test project (LSST) as an extended phase of the Lotung project. Participation of other parties, including U.S., Japan and France, were also solicited to share project cost and research efforts.

OBJECTIVES

The objectives of the Hualien project can be summarized as follows:

- To obtain earthquake induced SSI data at a stiff soil site having similar prototypical nuclear power plant soil conditions.
- To confirm the findings and methodologies previously qualified against the Lotung soft soil SSI data for prototypical plant site applications.
- To quantify results which were not available or lacked resolution in the Lotung study, such as structural deformation, torsional response, spatial incoherency effects and others.
- To further validate the technical basis for realistic SSI analysis approaches.
- To further support the resolution of USI A-40 issue, and provide a basis for improved and rational seismic design.

PROGRAM TASKS

To accomplish the project objectives, the following tasks, similar to the ones in Lotung are planned:

- Field test model design and construction
- Instrumentation layout
- Instrumentation deployment
- In-situ and laboratory soil testing
- Forced vibration testing
- Analytical evaluation
- Synthesis of results and findings
- Technical basis and guidelines for realistic SSI analysis approaches

For a more direct comparison and correlation with the Lotung results, the test model will be designed similar to the Lotung one although it will be heavier for achieving frequency requirements (within the earthquake energy band) and maximum possible soil bearing conditions. Soil testing and in-situ geophysical characterization will be extensively conducted. Because of the gravelly nature of the soil in Hualien, boring tests and soil sample preparation will be more difficult. The parameter that was of large uncertainty in the Lotung project is the backfill property. Special attention will thus be paid to testing and characterization of backfill in the Hualien experiment. The Central Research Institute of Electric Power Industry (CRIEPI) in Japan, a partner of the Hualien LSST project, has developed an extensive experimental program plan on soil property and site characteristics determination covering in-situ sampling via ground freezing techniques, large penetration testing, seismic refraction survey, P-S logging, laboratory soil testing and others. TEPCO, another partner, will perform forced vibration tests to characterize the soil-structure system dynamic behavior.
Surface instrumentation and downhole gages will be deployed with sufficient numbers and appropriate layout for capturing horizontal and vertical spatial variations of seismic waves relevant to SSI analysis. Accelerometers, soil-structure interfacial pressure cells, settlement gages and pore pressure gages will be deployed on the test model and in the field to obtain data for interpreting structural and soil response under earthquakes and serve as a basis for analytical methods validation.

PROGRAM COORDINATION AND COFUNDING

A consortium, consisting of the Electric Power Research Institute (EPRI), the Taiwan Power Company (Taipower), the U.S. Nuclear Regulatory Commission (NRC), the Tokyo Electric Power Company (TEPCO), the Central Research Institute of Electric Power Industry (CRIEPI), and the French Group (Commissariat A L'Energie Atomique (CEA), Electricité de France (EdF), and Framatome) has been established to carry out the experimental phase of the Hualien LSST project. The consortium members either provide direct funding contribution to the project or commit to perform certain tasks based on a consortium charter signed by each member. The project remains open to accept new members. Current project schedule calls for completing test model construction by the end of 1991 with the full instrumentation array operational by May 1992.

REFERENCES


Figure 1: Location Map of Lotung Site and Hualien Stiff Site

Figure 2: Earthquake Events From 1973 to 1988

Figure 3: Destructive Earthquakes From 1985 to 1988