A large-scale soil-structure interaction experiment: Part II EPRI/NRC research program on method validation

Y.K.Tang, R.P.Kassawara & H.T.Tang
Electric Power Research Institute, Palo Alto, Calif., USA
M.G.Srinivasan & C.A.Kot
Argonne National Laboratory, Ill., USA

1 INTRODUCTION

Various seismic soil-structure interaction (SSI) analysis techniques have been developed and used for nuclear power plant design and licensing. The methods vary from those using simple spring and dash-port representations (Richart, 1967) to more complexed finite element and substructure impedance methods (Lysmer, 1975; Wong & Luco, 1980; Lysmer, 1981). However, to date, relatively little effort has been devoted to validating the assumptions and approximations of the analysis techniques against structural and site response data recorded during actual earthquake events. In view of this, the Electric Power Research Institute (EPRI), with cooperation from the Taiwan Power Company (Taipower) has undertaken a large-scale seismic experiment in Lotung, Taiwan to collect earthquake response data for SSI method validation and evaluation. Since the completion of the construction of the facility in October 1985, eighteen earthquakes have been recorded at the site. With this data base, a cooperative SSI method validation program was initiated in 1986 by EPRI, U.S. Nuclear Regulatory Commission (NRC) and Taipower.

Details of the large-scale experiment, including models and instrumentation, are presented in a separate paper (Tang, 1987). This paper describes the approach and scope and also the data base of recorded earthquakes and the forced vibration tests to be used in the validation program.

2 EARTHQUAKE DATA

The Institute of Earth Sciences of Academia Sinica in Taiwan is responsible for maintaining, collecting, and reducing the data base for Taipower and EPRI. The reduced earthquake data are stored in a digitized time history form for analysts to use. Eighteen earthquakes with Richter magnitudes from 4.5 to 7.0 have been recorded since the seismic instrumentation was in place. The sensors are activated by a common seismic trigger with threshold acceleration level set at 0.01 g. The earthquakes recorded to date consist of both near-field and far-field events with epicentral distances varied from 4.7 Km to 78 Km. The data base also contains both shallow and deep earthquakes having depth from 1 Km to 79 Km. Table 1 summarizes the eighteen events.

Among the earthquakes, events 4, 7, 12, and 16, which occurred on January 16, May 20, July 30, and November 14 of 1986, respectively, are the most significant. The peak accelerations recorded at the free-field ground surface are 0.25 g, 0.20 g, 0.18 g and 0.2 g, respectively.

In the current scope of the cooperative program, one earthquake event is to be selected for SSI method validation. Additional events may be selected for further assessment of the analysis techniques. For the selected event, the earthquake records are provided to the analysts in two stages. First, the triaxial accelerations recorded at free-field ground surface are used as input control motions to predict the SSI responses. Second, after this "blind" prediction is completed, the entire set of recorded responses (building, downholes, and free field) for the event is released for correlations of result and method evaluation.

3 FORCED VIBRATION TESTS

The objective of the low-level forced vibration tests is to define basic dynamic characteristics of the soil-structure system in an as-built condition before the system underwent strong earthquake shaking. The results of the tests are to be included as part of the data base for the SSI method validation. They are to be first predicted by the analysis and subsequently to be used for refining the predictive models.

The testing program, partly sponsored by NRC and partly by EPRI, was conducted in two stages. In the first stage, the tests were performed on the 1/4-scale containment model with only its basemat completed. In the second stage, the tests were executed when containment models were completed and foundation soils were backfilled. A single eccentric-mass shaker was used to generate steadstate vibrating motions. For the basemat test, the shaker was placed on top of the mat, while for the complete model test, the shaker was placed on top of the building roof slab. For each directional excitation, the eccentricity of the shaker rotating masses varied from test run to test run to generate a sufficient wide frequency range of excitation (1 Hz to 30 Hz). The measurement locations were selected so that essential response modes of the system can be determined from the test data. Figure 1 shows the shaker location and the placement of the 20 accelerameters on the 1/4-scale containment structure during the second stage test. Additional sensors were also placed on the internal piping-steam generator model during the test.

4 SSI METHOD VALIDATION

The scope of the current EPRI/NRC cooperative program focuses on validating U.S. industry practice of SSI analysis using existing methodologies. The methods selected for evaluation include the lumped-parameter spring-dashpot approach, direct method using the finite element code FLUSH, and substructuring impedance techniques by the CLASSI and SASSI codes. Each method will be used to make blind predictions (recorded responses not available to predictor) of the site, building, and equipment response to the given input. The program utilizes a round-robin approach so that independent assessment on various methods can be provided by more than one analyst. In the program, EPRI is sponsoring four industry practitioners, and NRC, through Argonne National Laboratory (ANL), is sponsoring three university groups involving original method developers.

The validation program involves simultaneous independent effort by each analyst to devise models, perform blind predictive calculations, compare predictions with measurements, and finally to evaluate and assess the methodology. The essentials of the programs consist of the following four major elements:

- Given soil, structural, and geological information typically available to a nuclear plant design, construct a best estimate analytical model and perform blind prediction of response to forced vibration tests (in the NRC program, two models were developed using different levels of available soil information).

- Compare the predictive calculations with the forced vibration measurements and develop an improved soil-structure model by correlating dynamic response characteristics between test and analysis.

- Given earthquake control motion at free field ground surface, perform blind prediction of site and structural responses by using common industry SSI practice, which considers soil parameter variations and vertically propagated shear waves. At least two models are to be used in these predictive calculations. One is the original best-estimate model, and the other is the forced-vibration correlated model.

- Compare prediction results with recorded earthquake response data for both original and modified models. Conduct an engineering assessment of modeling technique and analysis method used.

Details of the EPRI and NRC/ANL programs are shown in Figures 2 and 3, respectively. Although there are some differences between the workscopes of the two programs, the approaches undertaking to validate the existing SSI methods are consistent.

5 CONCLUDING REMARKS

The round-robin SSI method validation program provides a unique opportunity for the industry practitioners as well as method developers to evaluate and assess various SSI methodologies in a systematic and independent fashion. Since blind predictions are essential to this effort and are currently being performed by the program participants, no measured data and analysis results are reported in this paper. A workshop is planned in which all the results and findings will be presented and discussed. The results of the program are expected to form the basis for evaluating various SSI methods as to their conservatism and sensitivity to various assumptions and procedures. Ultimately the conclusions of these assessments will form the basis for modification to the USNRC Standard Review Plan and hence a more realistic SSI practice and improved plant licensing procedures.

6 REFERENCES

Whitman, R.V. and Richart, F.E., "Design Procedure for Dynamically Loaded Foundations," Journal of the Soil Mechanics and Foundations Division, Proceedings of the ASCE, 1967.

Lysmer, J., Udaka, T., Tsai, C.F., and Seed, H.B., "FLUSH - A Computer Program for Approximate 3-D Analysis of Soil-Structure Interaction Problems", Report No. EERC 75-30, Earthquake Engineering Research Center, University of California, Berkeley, November 1975.

Wong, H.L., and Luco, J.E., "Soil-Structure Interaction: A Linear Continuum Mechanics Approach (CLASSI)", Report CE79-03, Department of Civil Engineering, University of Southern California, 1980.

Lysmer, J., Tabatabaie-Raissi, M., Tajirian, F., Vahdani, S., and Ostadan, F., "SASSI - A System for Analysis of Soil-Structure Interaction", Report No. UCB/GT/81-02, Geotechnical Engineering, University of California, April 1981.

Tang, H.T., Tang, Y.K., Wall, I.B., and Lin, E., "A Large-Scale Soil-Structure Interaction Experiment: Part I - Design and Construction", Paper K4/1, Proceedings of 9th SMiRT, Switzerland, August 1987.

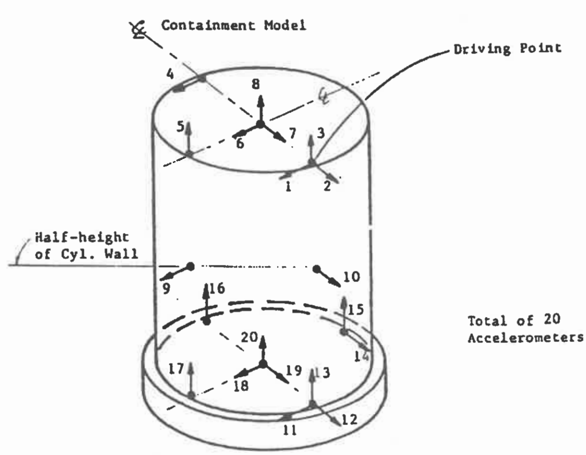

Figure 1: Vibration Test Instrumentation of Structure

TABLE 1: EARTHQUAKES RECORDED BY LARGE-SCALE SEISMIC EXPERIMENT AT LOTUNG, TAIWAN

EVENT #	ORIGIN TIME	DEPTH (km)	MAG (M)	AZIM. (deg)	DELTA (km)
1	1985.09.20 15:01:24.01	3.99	6.3	106.97	45.7
2	1985.10.26 03:30:39.04	1.15	5.3	164.90	29.1
3	1985.11.07 05:25:17.31	79.00	5.5	30.46	16.9
4	1986.01.16 13:04:31.97	10.22	6.5	61.31	23.7
5	1986.03.29 07:17:14.66	10.32	4.7	159.43	8.5
6	1986.04.08 02:14:58.51	10.89	5.4	174.17	31.4
7	1986.05.20 05:25:49.58	15.82	6.5	194.53	66.2
8	1986.05.20 05:37:31.69	21.84	6.2	191.66	69.2
9	1986.07.11 18:25:26.27	1.14	4.5	146.21	5.0
10	1986.07.16 23:50:31.84	0.88	4.5	162.41	6.1
11	1986.07.17 00:03:33.51	2.01	5.0	90.10	6.0
12	1986.07.30 11:31:47.53	1.55	6.2	131.05	5.2
13	1986.07.30 11:32:	N/A	N/A	N/A	N/A
14	1986.07.30 11:38:31.70	2.28	4.9	118.75	4.7
15	1986.08.05 00:56:	N/A	N/A	N/A	N/A
16	1986.11.14 21:20:01.15	6.94	7.0	173.93	77.9
17	1986.11.14 23:04:	N/A	N/A	N/A	N/A
18	1986.11.15 00:18:	N/A	N/A	N/A	N/A

AZIM: Azimuth from 1/4-scale model center to epicenter.
DELTA: Epicenter distance from 1/4-scale model center.

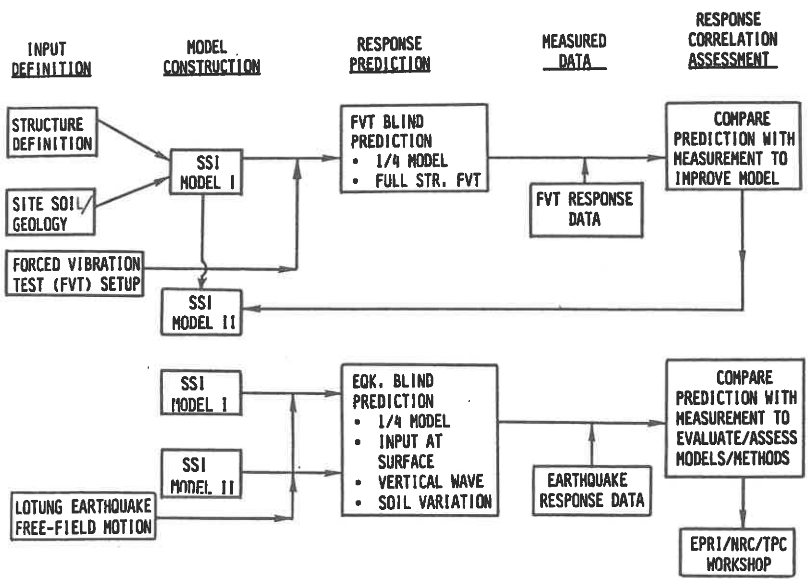

Figure 2: SSI Analysis for Lotung Seismic Experiment (EPRI Program)

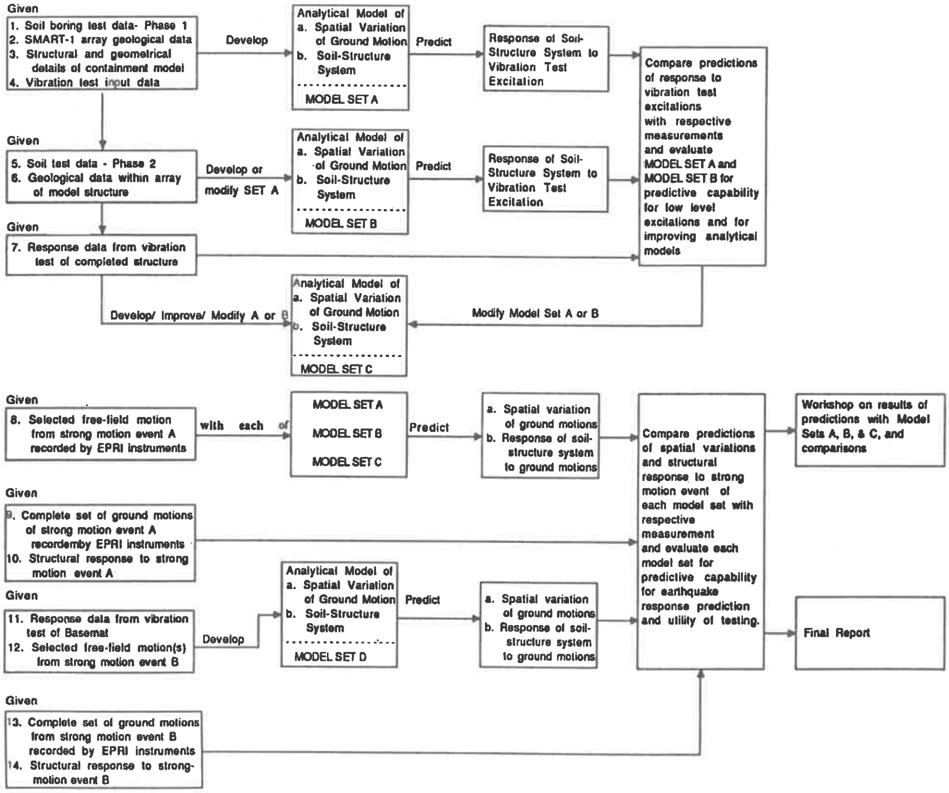

Figure 3: NRC/ANL Plan for Validation Program