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Probabilistic analysis for Hualien seismic test model considering uncertainties in free-field control motion

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ABSTRACT

This paper presents results of the probabilistic analysis for the Hualien Large Scale Seismic Test. Considering uncertainty of free field control motion, which is one of the major parameters in SSI analysis, repeated earthquake simulations on the Hualien 1/4 scale containment model was performed. It has been found that the variability of the response provides a measure of the uncertainty in the median response within a certain confidence bound.

1. INTRODUCTION

Many investigators independently performed SSI analyses of the one-quarter scale containment model. The analyses employed round robin blind predictions. The results are reported at the EOC/TMC meeting of the Hualien project.[4] In general the SSI analyses were generally deterministic. Uncertainties in SSI parameters such as soil and structural properties were not explicitly incorporated. Instead, they were treated in a manner consistent with industry practice; i.e. the "best-estimate" set of properties was selected which generally reflected the average of the scattered data and dependent on the engineering judgment of each investigator. In one instance, upper and lower bound properties, approximately plus and minus a standard deviation, were also used for response prediction, in the U.S. NRC Standard Review Plan requirement for design. The deterministic approach was considered appropriate for the evaluation of analytical methods against the experimental data. The correlation studies made as part of the research program demonstrated that, in general, the various analytical methods are capable of modeling the SSI phenomenon to a sufficient degree of accuracy for most engineering purposes. The studies emphasized the fact that, regardless of the methods used, the results rely largely upon the input parameters. For the soil-structure configuration and seismic environment at Hualien, the predicted responses were very sensitive to assumed soil properties. Thus, given the scatter in the soil data and its interpretation, a single deterministic prediction could become a hit-or-miss proposition. On the other hand, a probabilistic approach offers the capability to include and propagate uncertainties in the input parameters throughout the response calculation. The end product would be probability distributions on response instead of point estimates. Furthermore, the mean of the response distribution would be a true representation of the average tendencies as opposed to a point estimate using average input parameters. [1] The 84th percentile non-exceedance probability (84% NEP) would be analogous to an acceptance criterion typically used in the design. The comparison of these two bounds from a probabilistic response analysis to the recorded data is therefore of interest. The objective of this study is to perform a probabilistic response analysis of the one-quarter scale containment model at the Hualien site for one of the events previously studied and to compare the analytical results with the recorded data. Significant uncertainties exist in the SSI analysis, including uncertainties in the definition of the free-field ground motion, the idealization of the soil- structure system, the estimation of in situ soil behavior, and the details of the solution process. Definition of the free-field ground motion (specifying the location of the control point, the amplitude and frequency content of the control motion, and the spatial variation of the control motion) is generally recognized as the single most significant source of variability in SSI calculations. [2] So parameter for which uncertainties were considered in this study, as the first step of the probabilistic SSI analysis, is the variations in the free-field ground surface motions.

2. DISCUSSION OF ANALYSES

To isolate the effects of uncertainties in free field control motions, repeated simulations of earthquake were performed to obtain probabilistic response of the one-quarter scale model structure by SASSI code. [5] The simulations used free-field motions recorded from the Jan. 20, 1994, event, each being free- field motions from a different station. No variation of soil or structural properties was made for this case.

2.1 Soil and Structural Model

The analysis model used in this study is the modified model of unified soil model according to additional geotechnical investigation by CRIEPI, Japan. Fig. 1 shows the modified soil model used as input to SASSI. Table 1(a) and (b) lists the soil and structural properties .The structure and soil around the structure are modeled by finite elements. A quarter model for soil around the structure is used utilizing the symmetry and anti-symmetry for 2 planes of the structure. For the structure, 8-node solid element for the basemat slab and 3-D beam element for superstructure are used. Additional rigid link element are used to rigidly connect the superstructure to basemat slab. As shown in Fig. 1, soil is assumed as horizontal layers on half-infinite region and the half-infinite region is modeled as 10 sub-layers and dashpots in horizontal and vertical directions.

2.2 Free Field Motion

Recorded free-field ground surface motions from the Jan. 20, 1994 earthquake were used as the free-field motion for the analyses. [3] The locations of the recording stations are shown in Fig. 2. For this study, only the three stations on each arm of the array farthest from the 1/4 scale structure (A13 to A15, A23 to A25 and A33 to A35) were included so as to avoid possible feedback effects from the structure itself. The variability in the free-field motions is shown in Fig. 3(a) and Fig. 4(a), where the mean and mean-plus-one-standard-deviation of the spectra for the nine free-field locations are plotted against the spectra of the records at station A15. As can be seen from the overplots, the coefficients of variance(COV's) of the spectra are generally about 0.1.

3. DISCUSSION OF RESULTS

Response spectra of the motions on the basemat and the roof were calculated at 5% spectral damping for the case described above. Plots of these spectra, shown in Fig. 3(b),(c) and Fig. 4(b),(c), show comparisons of the median and 84% NEP spectra with the recorded motions. An evaluation of the comparisons from the analyses led to the following observation: 1) The medians of the response distributions from the analysis, for which there was no variation of soil and structural properties-only free-field motions, were largely close to the deterministic response obtained using the median input properties; in general, with some exceptions, they were in good agreement with the recorded motion. The response distributions had small variabilities (COV's) which were of the same magnitude as those of the input motions. 2) Mostly, the variations between the median and 84% NEP spectra were less than 15% and in many cases they were less than 10%. The recorded motions were generally less than the 84% NEP spectra.

4. CONCLUSIONS

Probabilistic analyses, which incorporated estimates of uncertainties in the free-field input motion, were performed for the 1/4 scale containment model at Hualien for the Jan. 20, 1994, earthquake. Median and 84% NEP spectra were calculated for two locations in the structure and were compared with the recorded motions from that earthquake. From the observations it was concluded that: 1) the variability of the response from a probabilistic analysis is useful in that it provides a measure of the uncertainty in the median response within a certain confidence bound. 2) The 84% NEP spectra resulting from a probabilistic analysis can be expected to produce conservative results, and would therefore be suitable for design. 3) There was little spatial variation of ground surface motion in the free-field for the earthquake used for these studies. The consequence of this little spatial variation was to produce little variation in response in the structure due to the variation of input motion records. If the probabilistic response to multiple earthquakes were to be obtained, we would expect that the effect of the variation of the input motion on response would be much larger and probably would dominate. With variations in soil and structural properties, a more meaningful evaluation of the conservatism in the 84% NEP spectra could then be made.

References

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Table 1 (a) Soil Properties of Analysis Model

Layers	Density (g/cm^3)	S-Wave Velocity	D-Wave Velocity	S-Wave Damping	P-Wave Damping
A	1.69	125	284.1	0.02	0.02
B	1.93	220	500.1	0.02	0.02
C	2.42	330	750.1	0.057	0.057
D	2.42	450	1022.9	0.026	0.026

Table 1 (b) Soil Properties of Analysis Model

NO	ELASTIC MODULUS ($tonf/m^2$)	POISSON RATIO	P-WAVE VELOCITY (m/sec)	S-WAVE VELOCITY (m/sec)	UNIT WEIGHT (g/cm^3)	P-WAVE DAMPING	S-WAVE DAMPING
1	N/A	N/A	613.7	270.0	2.33	0.02	0.02
2	N/A	N/A	659.2	290	2.33	0.02	0.02
3	2.88×10^6	0.16	N/A	N/A	2.582	0.01	0.01
4	N/A	N/A	795.6	350	2.39	0.02	0.02
5	N/A	N/A	500.1	220.0	1.93	0.02	0.02
6	N/A	N/A	565	280	2.42	0.01	0.01
7	N/A	N/A	773	383	2.42	0.01	0.01
8	N/A	N/A	672	333	2.42	0.01	0.01

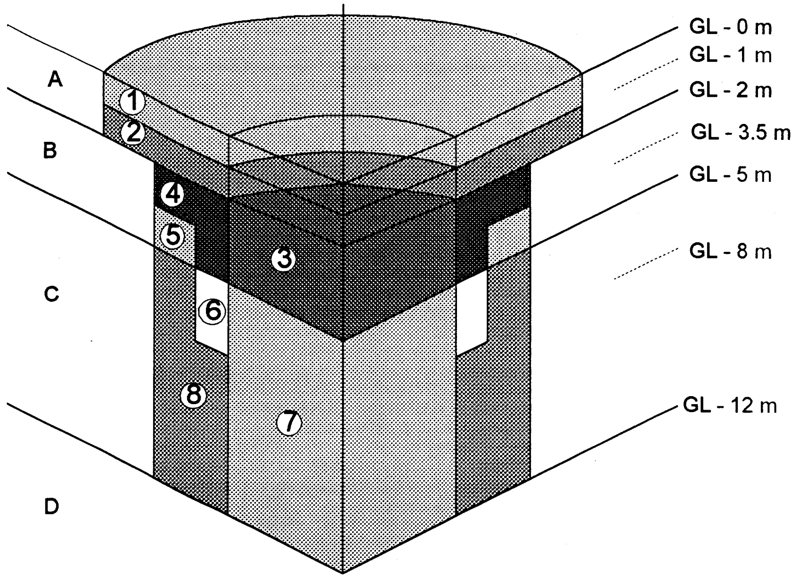

Figure 1. Soil model

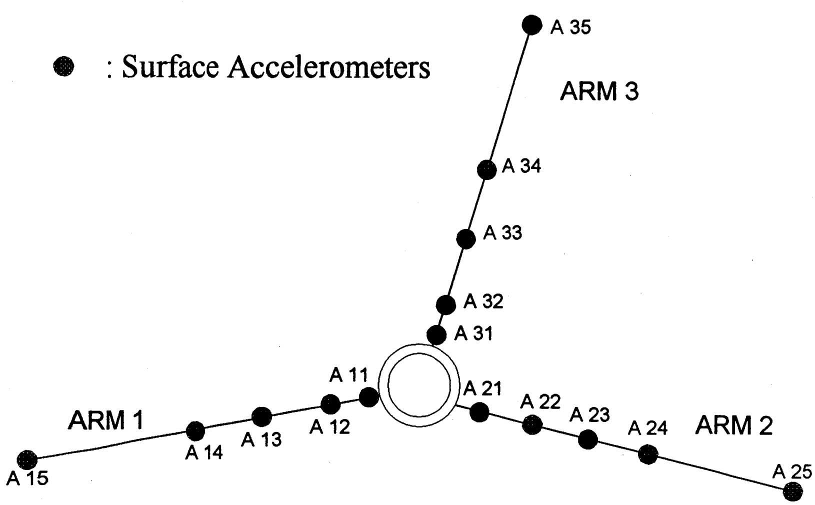

Figure 2. The location and station name of surface station at ARM1, ARM2 and ARM3.

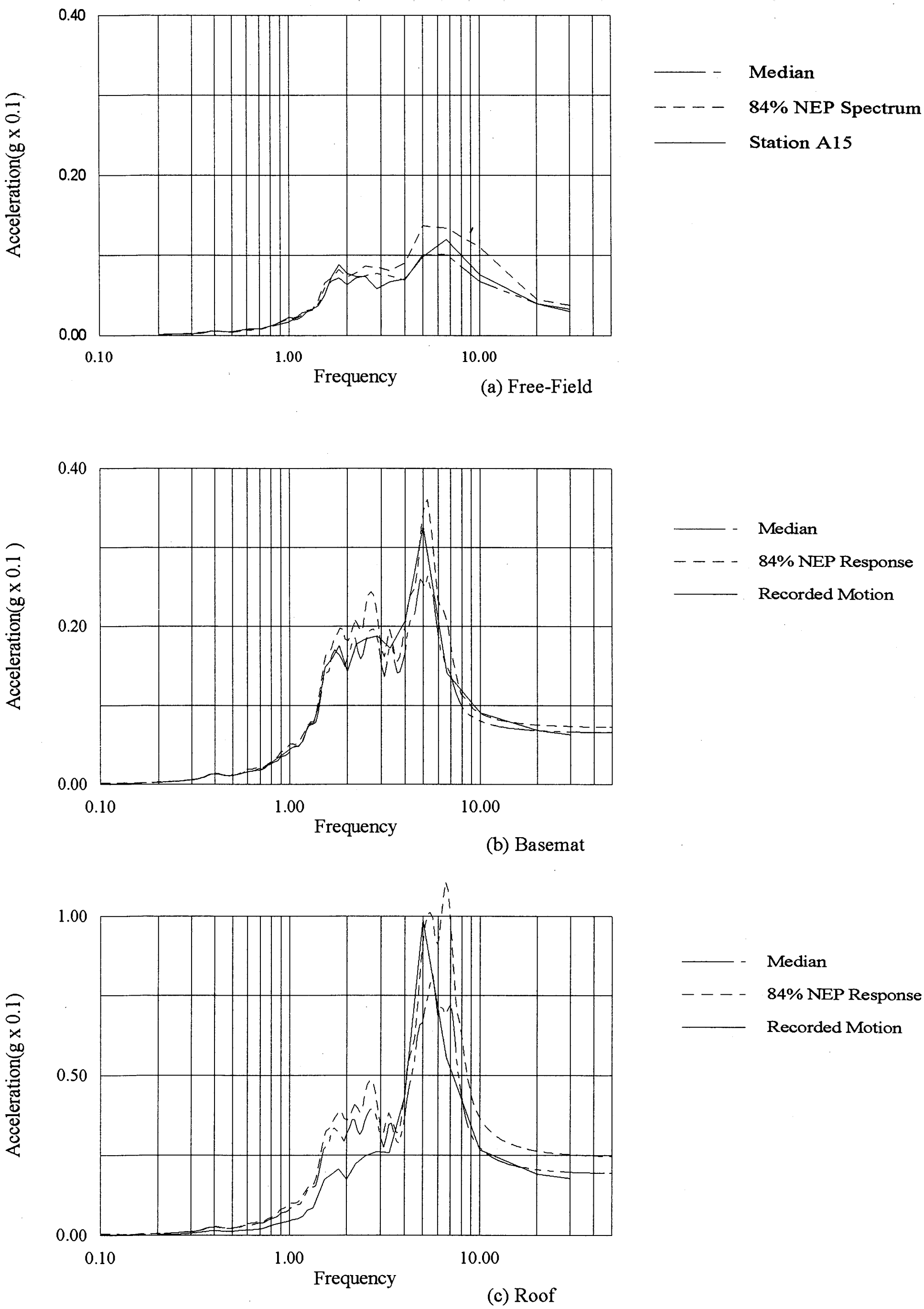

Figure 3. Response Spectra for Free-field Stations and Structure
(Longitudinal, 5% Damping)

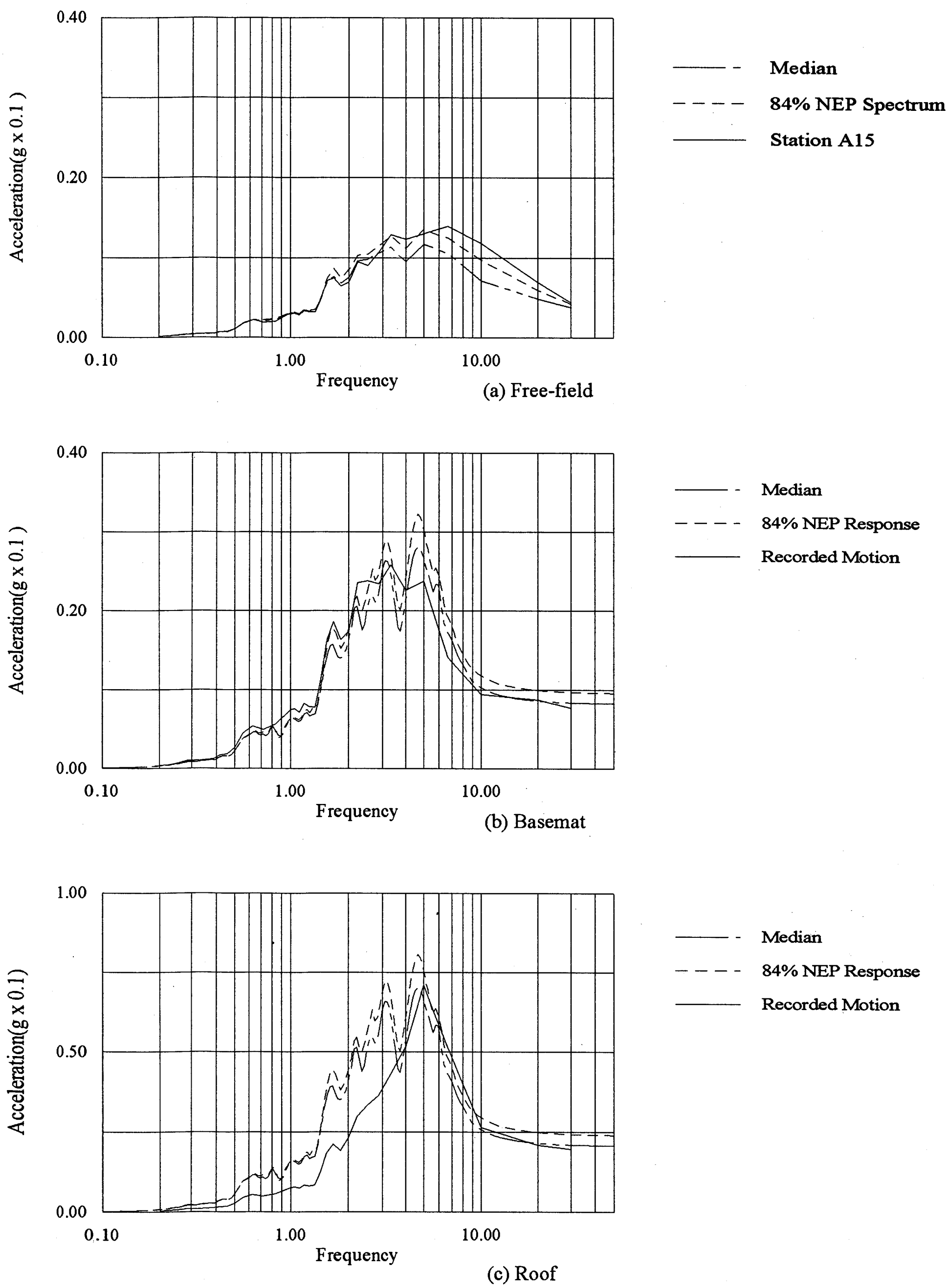

Figure 4. Response Spectra for Free-field Stations and Structure
(Transversal, 5% Damping)