UCRL--86239

DE83 012037

UCRL- 86239
PREPRINT
Conf-830805--39

THE EFFECT OF LOCAL SOIL CONDITIONS ON SITE AMPLIFICATION

J. C. Chen
D. L. Bernreuter
J. J. Johnson

7th SMiRT Conference
Chicago, Illinois
August 22-26, 1983

February 18, 1983

Lawrence Livermore National Laboratory

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

SUMMARY

The Seismic Safety Margins Research Program (SSMRP) is an U.S. NRC-funded multiyear program conducted by Lawrence Livermore National Laboratory (LLNL). Its goal is to develop a complete fully coupled analysis procedure (including methods and computer codes) for estimating the risk of an earthquake-induced radioactive release from a commercial nuclear power plant. The analysis procedure is based upon a state-of-the-art evaluation of the current seismic analysis and design process and explicitly accounts for uncertainties inherent in such a process. In Phase I, completed in January, 1981, the seismic input, the soil-structure interaction, dynamic response of structures and subsystems, and fragility were developed and combined using a probabilistic computational procedure. Demonstration calculations were completed for the Zion nuclear power plant. In Phase II, presently ongoing, additional models, improvements to existing models, and improvements to the probabilistic computational assessment of Zion have been developed.

One area requiring considerable additional study was the area of local site amplification. Local site amplification has significant effect on structural response and is a major source of uncertainty. Phase I of the SSMRP did not include the effect of local site conditions on the seismic hazard curve or on the free-field acceleration time histories used in the structural analysis. As part of the final Zion analysis in Phase II, an assessment of the local site effect at the Zion site was made using new time histories modified for the Zion soil conditions.

In this paper, we briefly describe the approach used to correct the seismic hazard curve and time histories developed in Phase I for local site effects and discuss in some detail the results of our efforts to validate the approach. The principle step in the approach was the use of an equivalent linear iterative technique assuming vertically incident waves to correct a set of time histories appropriate for a rock outcrop for the local soil column. For the Zion soil column this led to large correction factors.

To validate our approach we compared the amplification factors computed to those observed at several sites somewhat similar to the Zion site. In particular, we used data from soil/rock station pairs recorded from Friuli, and Oroville earthquakes. The mean site amplifications are expressed in terms of spectral ratio between the soil/rock station pair. The results show that the mean site amplifications estimated at the Zion site are comparable to those derived from real data.

*This work was supported by the United States Nuclear Regulatory Commission under a Memorandum of Understanding with the United States Department of Energy.

NOTICE
PORTIONS OF THIS REPORT ARE ILLEGIBLE.
It has been reproduced from the best available copy to permit the broadest possible availability.

1. Introduction

The ground motion model used in seismic hazard assessment (seismic hazard curve and frequency characteristics of the motion) of Phase I of the SSMRP was based on the ground motion data of Western United States. The effect of local site amplification at Zion was not explicitly taken into account. The ideal way to develop the seismic hazard at the Zion site would be to use a ground motion model based on regression analysis of data from sites similar to the Zion site. However, this was not possible because there was so little data from sites like Zion. An alternate approach would be to use the current site response procedure, such as equivalent linear techniques, assuming a vertically incident wave to correct a set of time histories appropriate for a rock outcrop for the local soil column at Zion. The site amplficiation factors at the Zion site were computed using equivalent linear techniques accounting for the uncertainty in dynamic soil properties with a numerical experimental design scheme.

One important step of this approach was to validate the computed amplification factors for the Zion site to assure that they are reasonable and consistent with recorded data. To show this, we examined some recently available data recorded at both soil sites and nearby rock outcrops from a number of earthquakes. Site amplifications were developed based on these real records. These results, along with the previously available results from underground nuclear explosions, provide an empirical database which is used to judge results of our Zion analysis. We also modeled one of the sites, Forgaria-Cornino, and employed the SHAKE [1] code to calculate the response to see how well such analysis can predict the recorded results. These comparisons served as an additional validation of the procedure used.

2. Development of Site Amplification for the Zion Site

The Zion site is composed of 110 feet of soil overlaying a bedrock of Niagara dolomite. This layer is further subdivided into three distinct sub-layers and our site response analysis explicitly represent these three layers and the bedrock. Modeling the soil properties at Zion entailed estimating the nominal shear modulus and material damping to be expected for each discretization of the seismic hazard curve. Also, assigning variability to soil shear modulus and material damping representing our lack of knowledge as to their values.

The characteristics of the Zion site, i.e., a relatively flat shallow soil over a very stiff bedrock, lead to the expectation of amplified motion in a narrow frequency range associated with the soil properties and layering structure of the Zion site. In our SSMRP response calculations, we explicitly account for this phenomenon. The seismic hazard curve and the ensembles of acceleration time histories are defined on the rock outcrop. The free-field surface motion could then be estimated or calculated by at least two alternative methods:

- o If site response data exists for Zion itself or a site similar to Zion, transfer functions could be developed between rock and soil surface motions. Data of this type is presented here; however, none of the sites presented correspond directly to Zion.
- o Generate a theoretical model of the expected behavior of the Zion site, validate the model to the extent possible, and calculate free-field surface motions from

rock outcrop motions.

The latter approach was taken in the SSMRP. The soil column was modeled as a system of horizontal layers of infinite extent. Viscoelastic material models for each layer were assumed--shear modulus, density, Poisson's ratio, and material damping. One dimensional wave propagation was also assumed--vertically propagating shear waves producing horizontal motion and dilatational waves producing vertical motion.

For the Zion analysis, local site amplification was modeled explicitly in the seismic response calculations and in generation of the seismic hazard curve. The procedure was to define the free-field ground motion and associated seismic hazard curve on a hypothetical rock outcrop [2]. This seismic hazard curve was developed from a ground motion model with uncertainty removed which was thought to be due to differences in site conditions at which ground motion data was recorded. The time histories were then propagated through a linear viscoelastic soil model with properties of the experimental design used in the SMACS [3] analysis. Figures 1a and 1b show spectral ratios for horizontal and vertical free-field ground motion. The mean and mean +/- one standard deviation are shown. Note the uncertainty in these ratios is due to uncertainty in the rock outcrop time histories and in the soil properties. For this case, only sources of random uncertainty in the soil were treated [4]. Thirty earthquake simulations were analyzed with soil properties selected according to a Latin hypercube experimental design used in the SMACS analysis. The results show mean amplification of the PGA of about 2 which corresponds well with recorded data. Mean amplification in the amplified frequency range are 3 to 4 which is slightly less than exhibited by the data. This model appears to be reasonable considering most sources of uncertainty.

3. Site Amplification Based on Real Records

Recorded motions at several sites from a number of earthquakes were used for this study. A summary of site conditions, earthquake location parameters and average peak acceleration data of outcrops are shown in Table 1. The response spectra of recorded motions between soil/rock station pairs for the same component were computed to develop the spectral ratio of the site. For engineering purposes, the site amplification is defined as the mean spectral ratio computed from the same component of soil/rock station pair for a set of selected earthquakes. The mean spectral ratio in two horizontal directions are frequently different due to the complicated nature of geologic properties and wave characteristics. This is an aspect of the phenomenon which the one dimensional model and assumed material behavior cannot represent. For the purpose of validation of our representation, we combined results for the two horizontal components into one data set. Results shown below do not include very low frequencies since the data was not baseline corrected and large ratios could results. This is not critical because it is out of our frequency range of interest.

3.1 Forgaria-Cornino Station from the 1976 Friuli Earthquake

Five records at this station were compared with the corresponding records at S. Rocco rock outcrop stations. The S. Rocco station is located on the hillside about 200 meters higher than the Cornino station. The two stations are only about 650 meters apart, as shown in Figure 2. The shear wave velocities at both sites were measured by in-situ cross-hole seismic velocity surveys, Fontanive and Gorelli [5]. As shown in Figure 3, the shear wave velocity at Cornino varies from 600 fps near the ground surface to about 1900 fps at 49 feet in depth where a moderate rock layer about 12 feet thick is encountered. Below this layer the shear wave velocity decreases to about 1400 fps around the depth of 80 feet and increases again to about 2500 fps between 90 feet and 112 feet which my be considered as another rock layer. The shear wave velocity below 116 feet varies less which enables us to define the rock half space with an average shear wave velocity of 2855 fps. An average amplification of 2.3 on PGA and 4.2 on peak spectral acceleration at a dominant frequency of approximately 3 Hz are shown in Figures 4a and 4b. The average vertical amplification is of the same order on PGA and peak spectral acceleration around 5.5 Hz.

3.2 Buia Station from the 1976 Friuli Earthquake

Data from the Friuli 1976 earthquake recorded on the rock outcrop at S. Rocco and the soil station at the Buia site were compared. The Buia site is located on a soil deposit consisting of recent and quite deep alluvium overlying rock formation of limestone and sandstone. The S. Rocco station is situated on limestone with average shear wave velocity of 2000 fps. Four earthquakes ($M_L = 4.4 \sim 6.1$) with epicenters varying from 10 km to 20 km were used for this pair station. The average peak ground acceleration is 0.11g at S. Rocco outcrop. The average site spectral ratio for both horizontal and vertical components are shown in Figures 5a and 5b. It is noted that for this deep soft soil site, the PGA has not been amplified but appreciable amplification is observed in the low frequency range. In this case it is about 0.75 seconds which is likely the fundamental period of the site.

3.3 D. Johnson Ranch Station (DJR) from the 1975 Oroville Earthquake

This site consists of about 35 feet of pleistocene gravel and alluvium, having an average shear wave velocity of 1100 fps, overlying the bedrock with an average shear wave velocity of 5000 fps. Two rock stations, Station 6 and 8, were used as station pairs to DJR. Four earthquakes with magnitudes ranging from 4.0 to 4.9 were used for the evaluation of site amplification at DJR. The mean and the mean +/- standard deviation of the spectral ratio of soil to rock for both horizontal components and vertical components are shown on Figures 6a and 6b. The first peak frequency shown between 6 and 7 Hz agrees quite well with the frequency obtained form the simple 1-D shear wave model of the site. Assuming the Poisson's ratio of the soil is 0.3, the first peak frequency of P-wave model also agree reasonably well with recorded data shown in Figure 6b.

In spite of the complicated 3-D nature of the real situtation, the results found in these sites did show reasonances occuring at certain frequency ranges similar to the phenomenon of site response predicted by a simple vertically propagating body wave. In summary, Table 2 shows the numerical values of site amplifications derived on the basis of recorded data for these sites. In addition, the amplification at the Tonopah site shaken by a nuclear underground explosion are also included, Hayes [6].

4. SHAKE Procedures Applied to Forgaria-Cornino

To help validate our modeling procedure, models of the Forgaria-Cornino site were constructed, analyses performed, and the results compared to the recorded motions. Neglecting the topography effect, each horizontal component of recorded motion at S. Rocco was specified as rock outcrop motion and input to the soil model of the Cornino site. Surface motions were calculated using the compter code SHAKE. These calculated motions were compared to the corresponding recorded motions. At this site, good agreement between calculated motion and recorded motion was found in the E-W components. Figure 7 shows the comparison of response spectra between the recorded motion and one of the calculated motions. *In the N-S direction, our analysis gives the right peak frequency but* underpredicts the response amplitudes for most of the frequencies. This fact may be due to the profound topography effect in the N-S direction while shaking in E-W direction is closer to the horizontal layer assumption made in the SHAKE procedure.

Site response calculations must consider the uncertainty contributed by the variation of the depth of soil model, dynamic soil properties and impedence ratio between soil and bedrock. All of these factors could contribute significant uncertainty to calculated responses. As the complex soil profile found at Cornino, three models having the bedrock assumed at the depths of 49, 90 and 116 feet were considered in the analysis. The variation of soil properties were only performed on the 116 foot model. Multiple analyses including various sets of soil properties were conducted. We considered ± 50% of nominal shear modulus and of nominal damping ratio as the upper and lower bound limits. Four possible combinations of shear modulus and damping ratio in soil properties plus the case of nominal soil properties lead to a total of five sets of different properties for analysis. Two additional cases considering the variation of bedrock shear wave velocity were also included. The lower bound limit of bedrock shear wave velocity was taken as 2020 fps (71% of nominal) and upper bound limit of 3500 fps (122% of nominal). Only nominal soil properties were used for the 49 feet and 90 feet models. The mean, minimum and maximum response spectrum for all the cases considered, are shown in Figure 8 together with the recorded soil/rock motion. With the complicated real situation in contrast with the simple assumption made in the SHAKE procedure, one can imagine that it is almost impossible to match the predicted motion to the recorded motion for the entire frequency range. However, the overall predicted response by SHAKE are comparable to the recorded data.

5. Conclusions

The analysis of real data recorded on several sites show that shallow soil sites strongly amplify earthquake motions from bedrock to the ground surface. The order of amplification is consistant with results reported by other investigators for underground explosion data and some earthquake data, Hayes [6].

The site amplifications at Zion were computed by equivalent linear techniques. The shape and the magnitude of mean site amplification predicted by this technique are similar to those obtained from recorded data of similar sites. However, the coefficients of variation (COV) of mean site amplification from the recorded data show much higher than those of calculated ones. The higher COV could possibly be due to the effect of complicated irregular topography, soil-rock interface and the contribution of the inclined body wave as well as horizontal surface wave propagation.

A first step in the validation of the SHAKE code was first taken by comparing the response spectra between the calculated and recorded motion at Forgoria-Cornino site. In the E-W direction the response spectra of calculated motions are comparable to those of recorded motion for engineering design purpose. In the N-S direction SHAKE code underestimates the response which may be due to the effect of topography and heterogenicty of the soil/rock formation.

References

1. Schnable, P. B., Lysmer, J. and Seed, H. B., "SHAKE a Computer Program for Earthquake Response Analysis of Horizontally Layered Sites," EERC 72-12, U.C. Berekely, December 1972.

2. Seismic Safety Margins Research Program; Final Report on the Completion of Zion Analysis - Report in progress.

3. Johnson, J. J., Goudreau, G. L., Bumpus, S. E., Maslenikov, O. R., "SSMRP Phase I Final Report - SMACS - Seismic Methodology Analysis Chain with Statistics (Project VIII)," Lawrence Livermore National Laboratory, Livermore, California, UCRL-53021, Vol. 9, September 1981. (Also published as *U.S. NRC NUREG/CR-2015, Vol. 9.*)

4. Fontanive, A. and Gorelli, V., Indagini Geofisiche Sui Terreni Sottostanti Gli Accelerografi Di Forgaris-S. Rocco E Forgaria-Cornino (Udine), CNEN-Laboratorio Ingegneria Sito RAD/RSI-CSN Casaccia

5. Hayes, W., Procedure for Estimating Earthquake Ground Motions, USGS Prof. Paper 1114, (1980).

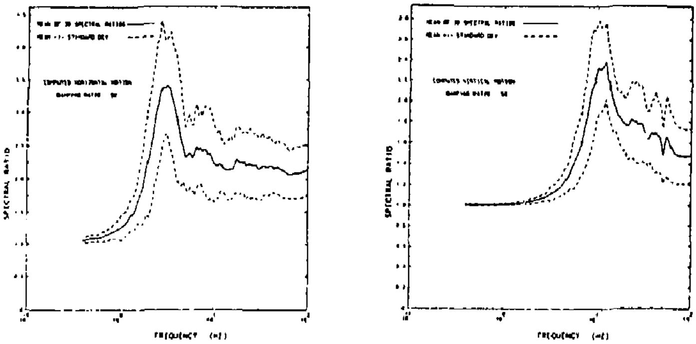
6. Johnson, J. J., Maslenikov, O. R., Chen, J. C., Chun, R. C., "SSMRP Phase I Final Report - Soil-Structure Interaction (Project III)," Lawrence Livermore National Laboratory, Livermore, California, UCRL-53021, Vol. 4, February 1982. (Also published as U.S. Nuclear Regulatory Commission NUREG/CR-2015, Vol. 4.)

Table 1. Summary of site conditions, earthquake location parameters and the average horizontal peak ground accelerations at rock outcrops.

	Site Conditions		Earthquakes				
Sites	Soil Layer (ft)	Soil/Rock	Names	No. of Records	M_L Range	Epicenter Distance (km)	Rock Outcrop Average PGA(s)
Forgaria	116	Partiallly overconsolidated alluvium/limestone and sandstone.	Friuli (1976)	5	4.4-6.1	5-20	0.095
Buia	Deep Soil	Recent alluvium/limestone and sandstone.	Friuli (1976)	6	4.4-6.1	10-20	0.137
DJR	33	Pleistocene gravel and alluvium/mesozoic greenstone.	Oroville (1975)	5	4.0-4.9	6-20	0.082

Table 2. Average site amplifications obtained from motions recorded at different sites.

	Average in Two Horizontal Directions			Average in Vertical Direction		
Sites	PGA	Peak	Frequency (Hz)	PGA	Peak	Frequency (Hz)
Forgaria	2.3	4.2	2.8	2.2	4.1	5.5
Buia	1.2	3.8	1.4	1.4	2.2	2.1
DJR	2.8	5.2	6.1	2.4	2.9	12.0
Tonopah	2.6	4.9	7.0			



Figs. 1a & 1b The Mean and the Mean +/- Standard Deviation of the Spectral Ratios of Soil to Rock for (a) Horizontal Motion and (b) Vertical Motion; Computed by Analytical Procedure Involving Numerical Experimental Design for ZION Site

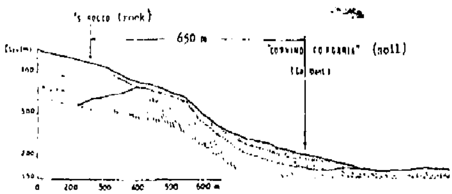


Fig. 2 Site Profile Passing through the Accelergraphic Stations of S. Rocco and Cornino Forgaria -- Nearly Along the North-South Direction

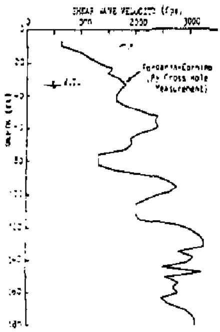
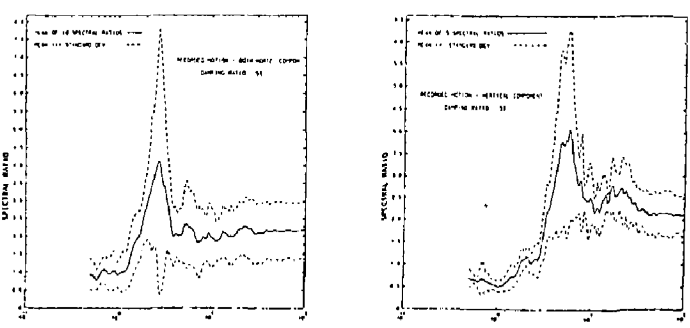
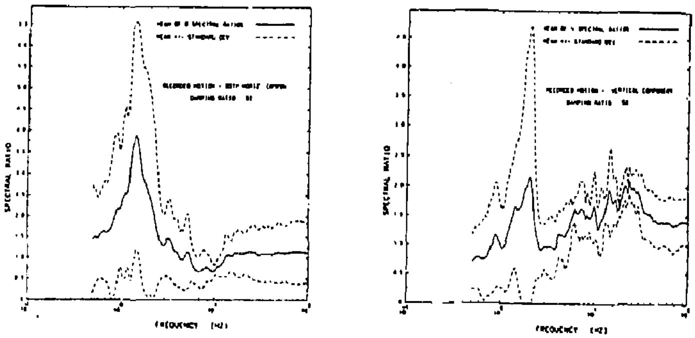


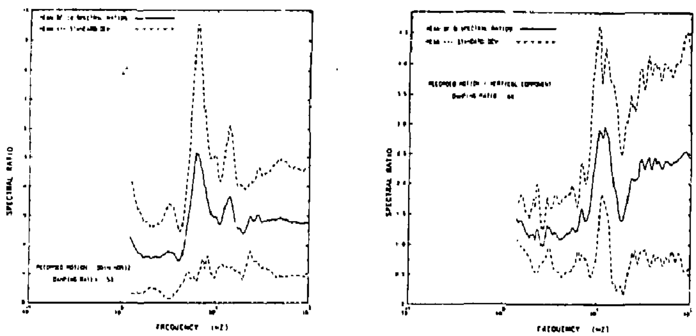
Fig. 3 Shear Wave Velocity Profile at the Forgaria-Cornino Site



Figs. 4a & 4b The Mean and the Mean +/- Standard Deviation of the Spectral Ratios of Soil to Rock for (a) Both Horizontal Components and (b) The Vertical Component; Recorded at Forgaria-Cornino Soil Site and S. Rocco Rock Site, from Friuli Eqks.



Figs. 5a & 5b The Mean and the Mean +/- Standard Deviation of the Spectral Ratios of Soil to Rock for (a) Both Horizontal Components and (b) The Vertical Component; Recorded at Buia Soil Site and S. Rocco Rock Site, from the 1976 Friuli Eqks.



Figs. 6a & 6b The Mean and the Mean +/- Standard Deviation of the Spectral Ratios of Soil to Rock for (a) Both Horizontal Components and (b) The Vertical Component; Recorded at Johnson Ranch Soil Site and CDMG#6 and CDMG#8 Rock Site, from the August and September 1975 Oroville Earthquakes

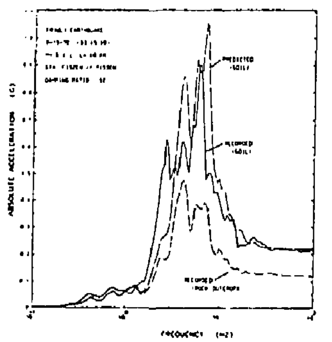


Fig. 7 Comparison of Response Spectra between the Calculated Motion and the Recorded Motion at Forgaria-Cornino of the 1976 Friuli Eqk.

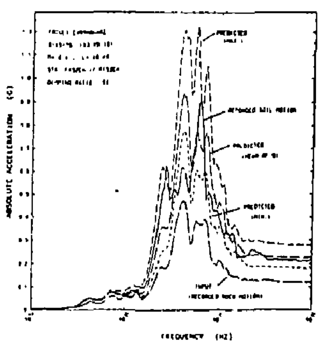


Fig. 8 Comparison of Response Spectra between the Recorded Motion and the Calculated Motions Including Modeling Uncertainty