A Cooperative NRC/CEA Research Project on Earthquake Ground Motion on Soil Sites: Overview

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ABSTRACT

This paper provides an overview of a multi–phase experiment being conducted jointly by the U.S. Nuclear Regulatory Commission and the French Commissariat a l'Energie Atomique. The objective of the experiment is to collect a comprehensive set of data on the propagation of earthquake ground motions vertically through a shallow soil column(on the order of several tens of meters). The data will be used to validate several of the available engineering computer codes for modeling earthquake ground motion. The data set will also be used to delevop an improved understanding of the earthquake source function and the potential for non–linear effects controlling the propagation through the shallow soil column.

The desired data are being recorded or will be recorded by vertical arrays of accelerometers. The first phase of the experiment consisted of installation of instruments at three levels(two subsurface and one surface) in a seismically active area of northeastern California. Several years of recording at this glacial till site proved the validity of the experimental plan and produced a valuable data set. Thus, the second phase was undertaken at a site more representative of nuclear power plant sites in the eastern U.S. and France. A sedimentary site in southern California will be fully instrumented in the Spring of 1989. Both experimental sites are very close (15–20 km) to active seismic areas.

This paper is also an introduction to three other papers being presented at this conference. These papers will present the details of the research analyses that have been conducted to date. Briefly, these analyses include:
1) a linear wave model used to predict the ground motion at the surface based upon ground motion actually recorded in the borehole, 2) computation of response spectra at 5% damping, transfer functions, and wave propagation analyses through the surface layer using standard engineering computer codes, and 3) a study of source and path effects using propagating crack or dislocation models.

INTRODUCTION

The anti–seismic design of critical structures, such as nuclear power plants, presupposes a precise and/or consrvative determination of the vibratory ground motion which these facilities may be subjected to during a strong earthquake. Seismic monitoring in highly active zones has produced a number of strong–motion records from epicentral areas and has aided in defining certain source and propagation parameters, but records from the immediate vicinity of faults (R < 10 km) continue to be rare. The prediction of ground motion parameters (most frequently peak ground acceleration) at these distances for anti–seismic design purposes relies on extrapolations of attenuation laws derived from the far field. The weaknesses of the method are highlighted by recordings of recent significant earthquakes such as Mexico and Chile in 1985 and Whittier Narrows in 1987, which, at short distances, show a high degree of scattering where these parameters are concerned.

Recourse may be had to theoretical developments. Recent headway in the area of the theoretical simulation of earthquake sources and wave propagation has, in many instances, been made possible on the strength of the aforementioned strong ground motion records. Usually these data, however, likewise bear the imprint of the surficial soil layers at the recording site. Thus, when attempting to solve the inverse problem of reconstituting the source function on the basis of the end–product record, not only large–scale (tens of kilometers) corrections are required, but also quite small–scale corrections (tens of meters) should be made whenever soil dynamics problems are addressed. These two scale ranges also correspond to contrasting ranges in frequency: while basic seismology is mainly preoccupied with frequencies under 1 Hz.(large–scale features), engineering seismology must operate in the often delicate realm of high frequencies, from 1 up to 30 Hz.(small–scale features).

In the field of engineering seismology, the behavior of surficial soil and rock layers of poor mechanical resistance is of particular concern because it is responsible for a preponderant proportion of the damage incurred during major earthquakes (we may cite, in particular, the Alaska and Niigata, Japan, events of 1964, Irpinia in 1980, and Mexico in 1985). A great many nuclear facilities are located near rivers, and accordingly on alluvial deposits. The ability to predict soil behavior accurately is therefore extremely important to safety authorities. Computer codes developed on this topic invariably call upon simplifying hypotheses such a one–dimensional propagation models and linear or equivalent linear behavior, and most have yet to be validated by a detailed analysis of appropriate earthquake records.

The contribution of the experiment to the topic of soil dynamics is basically to test computer code validity. Although linear behavior in propagating media may reasonably be expected where consolidated rock is concerned, other types of media are likely to display strain–dependent behavior(Mohammadioun and Pecker, 1984; Mohammadioun,1986). By giving access to seismic sources capable of generating ground motion both strong and weak, over an extensive range of frequencies and due to a wide variety in focal distances, both the threshold of non–linear behavior and the nature of its influence on the seismic signal should be able to be determined. It is also hoped that information on the role of the incident angle may be gained because of the presence of different focal depths.

With the second phase of the experiment, where earthquake motion is to be recorded simultaneously within each geological formation present at the site, including the bedrock, by means of a vertical array composed of accelerometers installed in downholes, several objectives may in fact be sought. In basic seismology, the records can be used to test methods that simulate source and propagation, throwing light upon specific areas such as the self–similarity of earthquake source spectra and establishing whether f_{max} (an empirically observed high frequency cutoff, the origin of which is the subject of debate) is a consequence of the source itself or rather of the media through which the wave is propagated. As an added benefit, these records should help to complete the set of available near–field data.

McGEE CREEK: FIRST PHASE OF THE EXPERIMENT

The McGee Creek phase of the experiment was conducted near the seismically active Long Valley Caldera of northeastern California. The site was instrumented with both three–component acceleration and velocity transducers at subsurface depths of 166 m and 35 m as well as at the surface. Recording was started in November, 1984 and continues to the present although there have been component failures. The recording site consists of approximately 30m of glacial till over bedrock of hornfels. Thus, one instrument package was placed just below the soil–bedrock interface and one significantly below it.

The analysis of data from the first phase indicates that the glacial till generally increases the amplitude and duration of the signal recorded at depth. However, the corner frequency of the S–waves(a measure of the energy distribution with frequency) measured at depth and at the surface are nearly identical. Based on this data, Archuleta(1986) was able to infer that the local site effect due to the glacial–till is not the cause of the nearly constant source radius observed for earthquakes in the region. Seale and Archuleta(1988) analyzed the accelograms from two earthquakes: M_L = 6.4 Chalfont Valley, distance 32 km. and M_L = 5.8 Round Valley, distance 22 km. Both earthquakes produced peak accelerations of about 120 cm/s^2 at the surface and about 15 cm/s^2 at 166 m depth in bedrock. Using the transverse component of acceleration recorded at 166 m and the elastic and linear damping properties of the bedrock and glacial till, Seale and Archuleta computed a synthetic surface accelerogram that closely matched the amplitude and phase of the actual accelerogram for each earthquake. Thus for these soil conditions and acceleration levels, it is not necessary to invoke non–linear theory or models to explain the observations.

Pecker and Mohammadioun(this volume) discuss the results of computing 5% damped response spectra and transfer functions for the 30.5 m surface layer which is a glacial till. They cited as a typical result that for a magnitude 6.2 earthquake the average vertical amplification between about 7 and 10 Hz is a factor of 5. They also carried out one–dimensional propagation analyses that predicted surface ground response spectra from subsurface spectra. The calculated spectra compared favorably with those from the recorded data provided site specific parameters were taken into account. They conclude that "due to the nature of the sediments at McGee Creek(glacial tills) non–linearities are not very pronounced and can be reflected by an equivalent linear model with sufficient accuracy for engineering purposes."

Bouchon and Gariel(this volume) studied the source and path effects for several earthquakes that have been recorded at McGee Creek. Their objective, as well as that of Archuleta and Seale, is to investigate the relative importance of source effects and path effects. Bouchon and Gariel modeled the source as a propagating crack embedded in the crustal structure and compute the expected velocities and accelerations which they compare with the recorded data.
While the McGee Creek experiment did not fully resolve the technical issues presented in the Introduction, as the first phase of the project it did establish that the experimental setup was viable and that with a number of experimental changes it could provide the type of data that was necessary to resolve the issues.

GARNER VALLEY: SECOND PHASE OF THE EXPERIMENT

The second phase of the project was initiated to collect data from a more comprehensive experiment at a site more representative of nuclear power plant sites in France and the eastern United States. The site sought was to have a

shallow soil column for bedrock in a seismically active area already monitored by a seismographic network. After some initial difficulties finding such a site with the needed amount of soil cover, a site was found in Garner Valley, California, which is adjacent to the Anza seismic gap.
A through geophysical and geotechnical survey of the site has been carried in cooperation with the U.S. Army Corps of Engineers and the U.S. Geological Survey to fully characterize the site. The site's location and preliminary soil column are shown in Figures 1a and 1b.

The site will be instrumented with four subsurface instrument packages and one surface package. Each package will consist of a three component(three orthogonal sensors) feedback accelerometer with electronic integration to provide a velocity output in addition to the acceteration signal. The packages(Figure 1b) are being deployed for specific purposes. Beginning with the deep package, it is providing the initial input unperturbed by the soil column. Two packages are being placed adjacent to the soil–rock interface, one above it and one below, to record the effect of the interface. A package is being paced in the soil column at approximately the typical depth of embedment for a nuclear power plant. The signals from the five instrument packages will be recorded on site by a 16–bit digital recorder. The full sensor and recording system will be fully operational in the Spring of 1989.

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