Downhole Recordings at McGee Creek, California: Numerical Simulation of Source and Path Effects

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INTRODUCTION

The seismic records obtained at different depths at McGee Creek in the Mammoth Lakes region of California provide a remarkable set of data to study the response of a shallow soil column to seismic excitation. To fully understand these records we need to relate the characteristics of the seismic motion at depth below the site to the dynamic parameters of the rupture at the earthquake source. We present here such a study and we also investigate the effects of surface and sub-surface topography at the site.

NUMERICAL SIMULATION OF THE SEISMIC MOTION AT DEPTH

The characteristics of the incident seismic excitation below the McGee Creek site may be calculated by using physical models of the earthquake source and by solving mathematically and numerically the equations of propagation of the rupture on the fault plane and the wave equations in the medium. For this simulation we have chosen the largest event recorded at McGee Creek, the November 23, 1984 Round Valley earthquake.

This event of magnitude M_L=5.7 was localized at 53°27.48'N and 118°35.32'W, a little over 20km from the recording site, and at a depth of 12km. The focal mechanism inferred is a left-lateral strike-slip occurring on a vertical fault striking in the N38°E direction (Barker and Wallace, 1985). The size of the fault may be estimated from the spatial distribution of the aftershocks which defines a 6km-wide square extending between depths of 6 and 12 km (Corbett et al., 1985). The rupture initiated near the northeastern edge of the fault and propagated towards the southwest.

We represent the earthquake source by a network of circular cracks located on the fault plane. This model is based on the work of Das and Aki (1977) and Papageorgiou and Aki (1983). In the simulation presented here, the source is made up of 4 identical cracks having a radius of 1.5km (Figure 1). The rupture is initiated at the center of the lower northeastern crack and propagates radially to the other cracks at a velocity of 2.8km/s. The slip time-history at each point of the fault is determined using the circular crack model of Madariaga (1976). The crustal structure is represented as a homogeneous half-space with velocities $V_P=6km/s$ and $V_S=3.55km/s$ inferred from seismic profiles along the Long Valley caldera (Hill et al., 1985).

The comparison between the observed ground velocities at 166m depth and the ones calculated is displayed in Figure 2. The amplitude matching leads to a maximum fault slip, at the center of the cracks, of 39cm. The corresponding seismic moment is M_0=2.8 x 10^{24}*dyne.cm*, a value smaller than the one inferred from long period teleseismic records (M_0=4.8 x 10^{24}*dyne.cm*; Barker and Wallace, 1985). The good agreement between data and synthetics, except at high frequencies which are not included in the calculation and toward the end of the signal, shows that present-day earthquake models may be used successfully to simulate the seismic ground motion. In turn, the characteristics of the seismic excitation at a site can be related to the time-history of rupture on the earthquake fault.

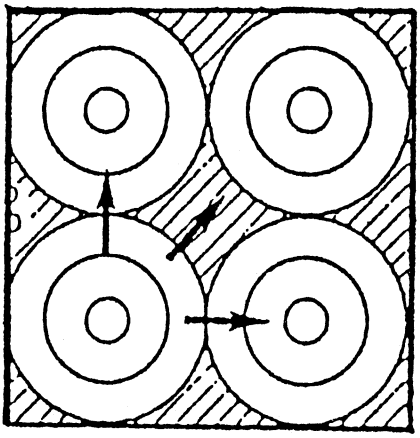

Figure 1. Source model used in the calculation.

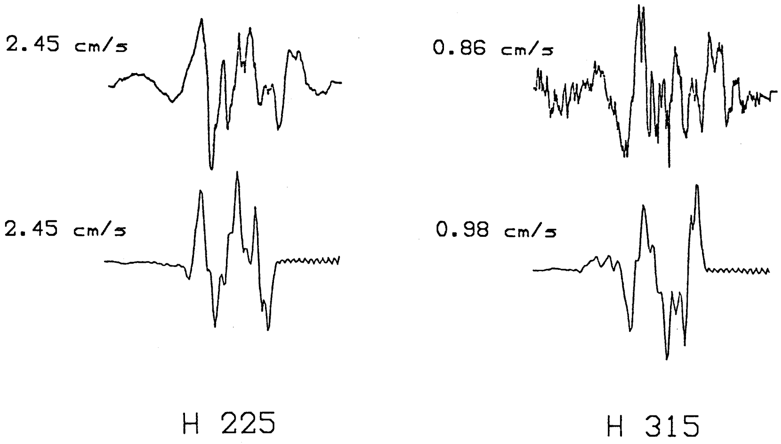

Figure 2. Comparison between the once-integrated recorded horizontal accelerograms (top) and the calculated velocities (bottom). The values indicated are the peak velocities of each trace.

TWO-DIMENSIONAL SITE EFFECT AT McGEE CREEK

The presence of an irregular topography in the vicinity of the site of McGee Creek and the lateral variation of thickness of the moraine cover are going to diffract and scatter the incoming seismic waves and may affect the recorded motion at the McGee Creek site. The importance of such a diffraction mechanism is suggested in Figure 3 where the radial and vertical components of acceleration produced at the surface site during one of the aftershocks of the November 1984 Round Valley earthquake are combined to show the motion of a particle in the plane of propagation. The first four frames display a rectilinear motion while at later times, the motion becomes circular or elliptic. This indicates at these times the predominance of surface waves, which likely have been generated by the diffraction of the incident body waves by the irregular bedrock-moraine interface and by the topography around the recording site.

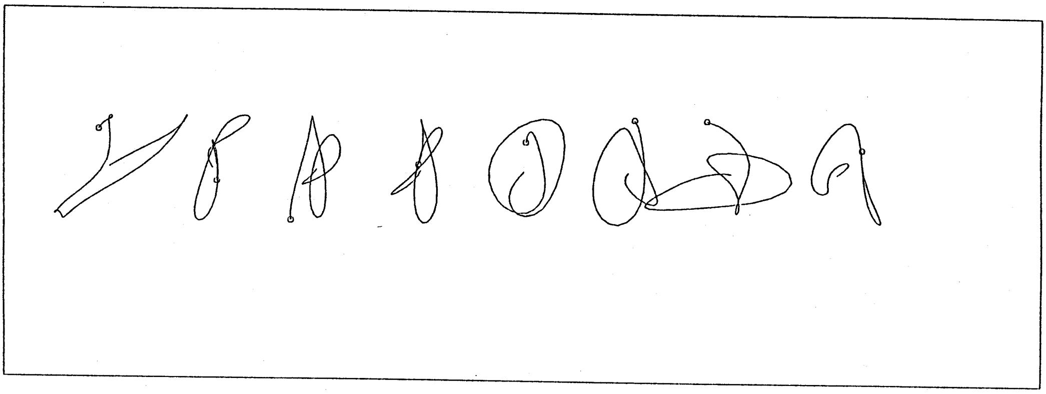

Figure 3. Particle motion diagram in the plane of propagation at the surface site. The time increases from left to right.

A topographic map of the area is presented in Figure 4. The directions of the incoming seismic waves generated by the main shock and by the aftershock are indicated on the figure. The orientation of the horizontal components of the accelerometers at the surface, at 35*m* depth and at 166*m* depth is also shown. We have digitized the topography along a profile running across the McGee Creek valley and passing through the recording site. This profile corresponds roughly to the direction of the incoming waves. From the corresponding geological map, we have estimated the lateral depth variation of the moraine-bedrock interface.

We have calculated the response to seismic wave excitations of the resulting two-dimensional model of the topography and sub-surface geology. The results are presented in Figure 5. They show the amplification of the acceleration spectrum relatively to the case where the topography is flat and no sediments are present. Several locations surrounding the recording surface site are considered. The results show that the amplification is small at the edge of the valley and reaches a maximum of about 6 at the recording site.

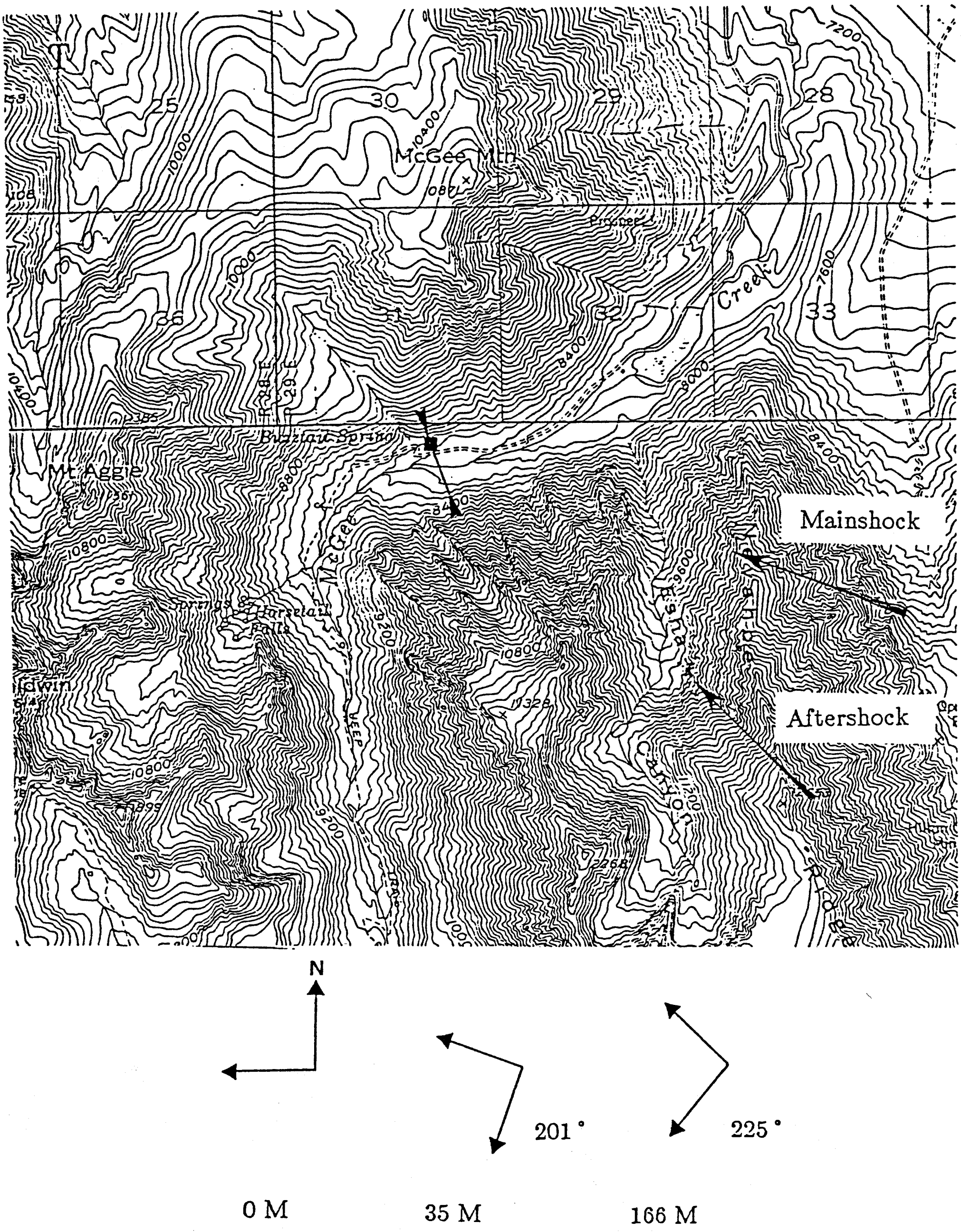

Figure 4. Topographic map of the McGee Creek region. The recording site is indicated by the black square.

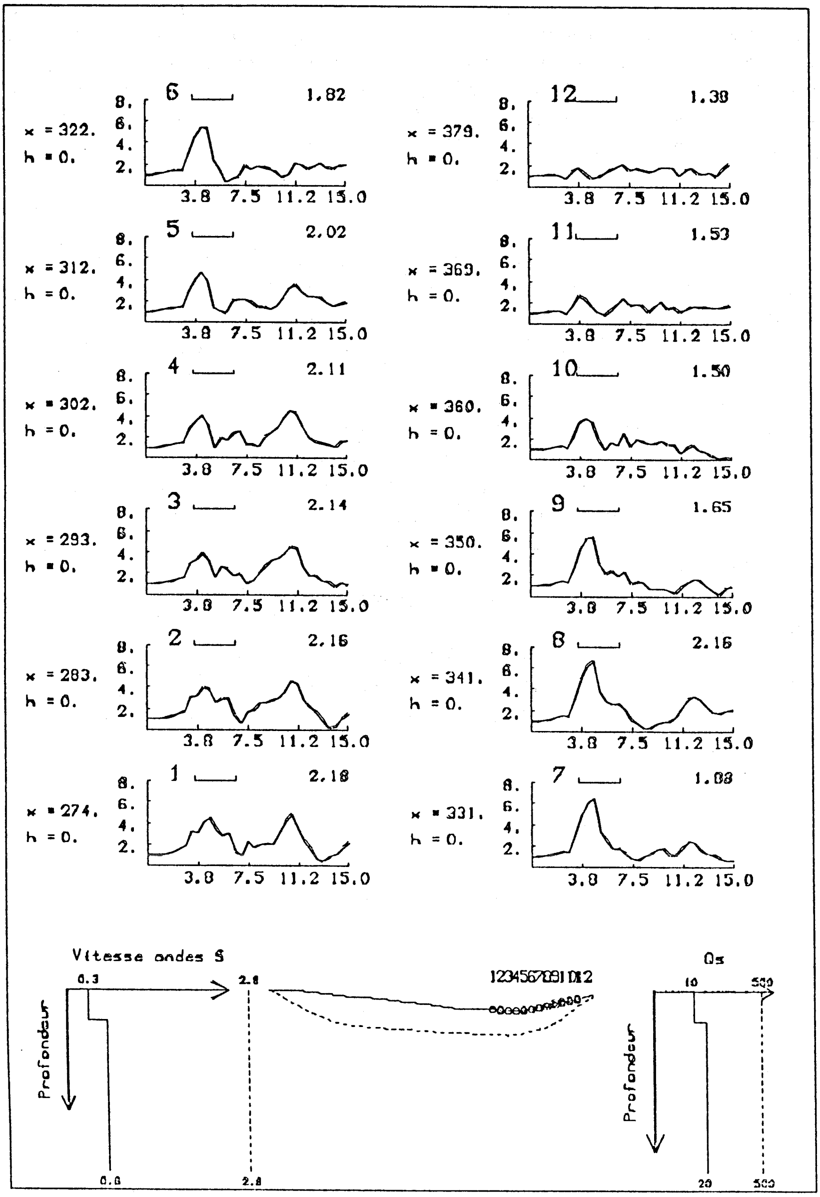

Figure 5. Plots of spectral amplitude obtained at the sites of the McGee Creek valley model shown at the bottom of the figure. The seismic excitation consists of SH waves incident on the structure at an angle of 56° corresponding to the direction of energy arrival from the November 1984 earthquakes.

CONCLUSION

We have shown that the velocity records obtained at depth below the McGee Creek site during the largest event recorded can be successfully modelled knowing the geometry of the fault and using a composite-crack model to represent the rupture. We are thus able to relate the seismic excitation at depth to the static and dynamic parameters of the rupture. We have also tried to quantify the effect of irregular surface and sub-surface topography on the surface recordings at McGee Creek.

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