# Annual Project Summary Report

*Earthquake Hazard from Focusing of Seismic Waves by Basin Structures*

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## INTRODUCTION

The Los Angeles Basin was formed by extension in the mid Miocene and is now contracting by compression due to the formation of the big bend in the San Andreas fault. The process has created extreme variation in the basement morphology over small wavelengths (~ 5 km). Deep basin structures and local site effects combine to cause extreme variation in the amplitudes of seismic waves passing through the structures. Recent studies by Gao et al. (1996) and Baher et al. (2001) presented evidence of deep basin structures affecting the seismic waveforms from aftershocks from the Northridge earthquake measured in Santa Monica. Baher et al. (2001) used tomography to show that the 2 to 3-km deep structure beneath the Santa Monica Mountains acts like a lens, focusing energy from earthquakes. This mechanism was thought to have been a major contributor to the localized damage at the time of the Northridge earthquake.

The 1987 Whittier earthquake provides another example where the effects of substructure may have affected the amplification of seismic waves. Damage from the earthquake was more extreme in a small section of downtown Whittier than in surrounding areas (Kawase and Aki 1990). Most damage occurred in a region that lies on the south side of the Puente Hills relative to the location of the earthquake which was to the north. Kawase and Aki (1990) proposed that the damage was due to magnification of the energy in that region from SV waves at critical incidence along the Puente Hills. An alternative hypothesis, that a substructure focused seismic waves, has not been investigated for Whittier.

The Los Angeles Basin Passive Seismic Experiment (LABPSE) involved the installation of a dense linear seismic array across the LA basin. Amplitude data from local earthquakes measured on the array can be used to determine the effects on seismic amplification of some of the short wavelength features of the basin. The array crossed the Puente Hills in the vicinity of Wittier and offers the opportunity to test the focusing hypothesis in this area.

## EXPERIMENT

LABPSE ran from March to November of 1997. The stations were installed along the LA basin part of the profile of the Los Angeles Region Seismic Experiment (LARSE I). The array was comprised of 18 stations which recorded local and regional earthquakes and teleseisms. The seismographs consisted of Reftek recorders coupled to 3 component 1Hz Mark Products geophones. The array stretched north to south across the LA Basin, with seismic stations spaced approximately 5 km apart, running from the southern edge of the San Gabriel Mountains to Seal Beach (Fig. 1). The total length of the array was 60 km. More than 2000 events were recorded and cataloged during the experiment; 78 of those events were strong enough to provide seismograms with good signal-to-noise ratios (SNR). These events range in magnitude from 2.1 to 5.1. The 78 events and 18 LABPSE stations are shown in Fig. 1.

## LABPSE Array and Local Events Used in Study

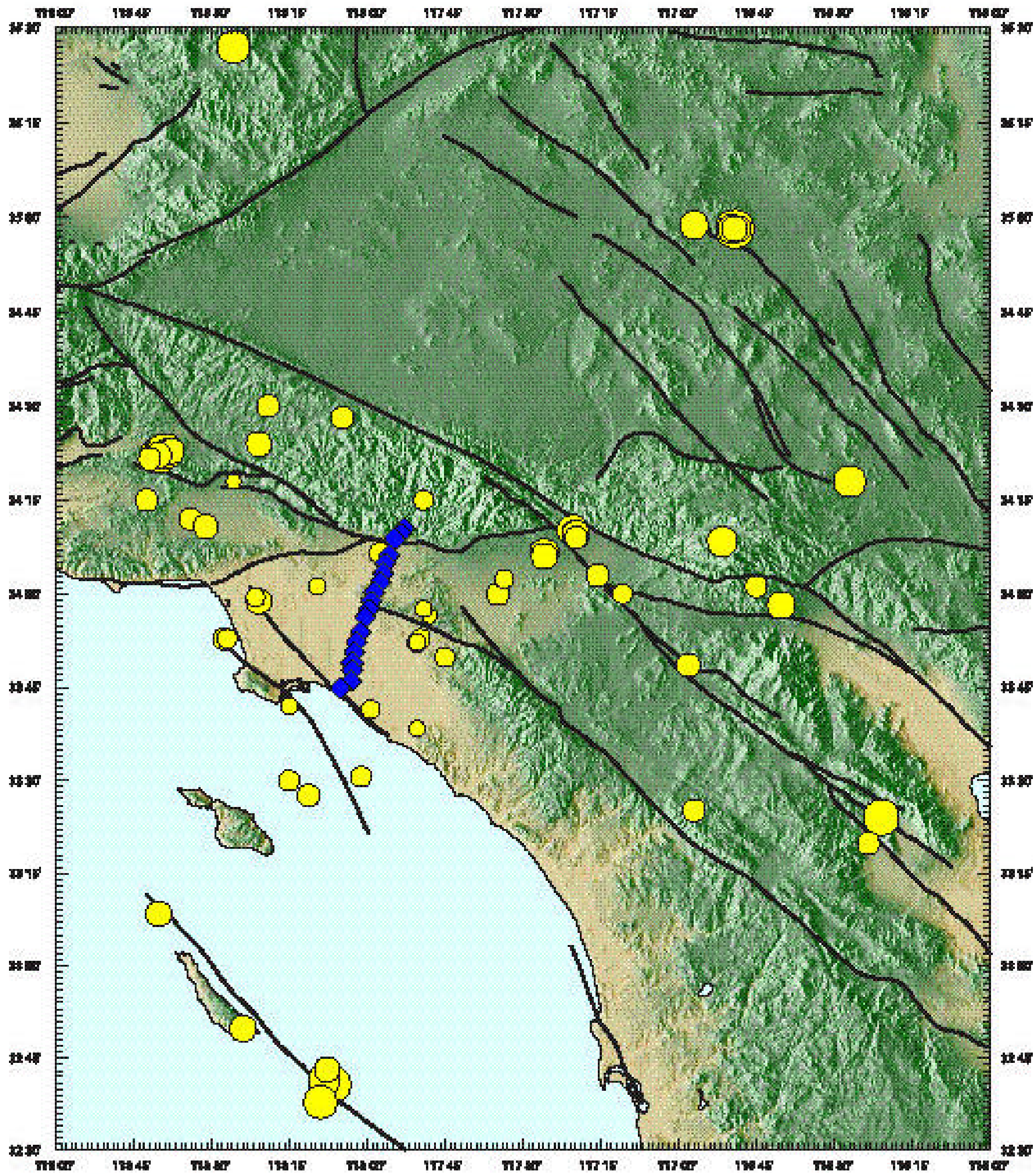


**Figure 1:** Yellow circles represent events. Blue diamonds represent stations. Sation #1 is the most northern station and #18 the most southern.

DATA ANALYSIS

Events were analyzed if they had at least half of the stations showing a clear first arrival resulting in the 78 events. However, only 57 of those had fault plane solutions (Hauksson, 2000). The primary features to be analyzed are maximum amplitudes for each seismogram. They were chosen as the maximum value from within a +/-2 second window from the first arrival P waves and a +/-3 second window from the first arrival S waves.

After picking the amplitudes we fit the amplitude data to a simple model of geometric attenuation. We used a non-linear least squares inversion to solve for the parameters of the function

$$f_{ij} = F_j(z,q) A_j S_i / r^a \qquad (1)$$

where $f_{ij}$ is the model value for the amplification at the ith station for the jth earthquake, $A_j$ is the event amplitude, $S_i$ is the station amplification term, α the exponent for geometrical spreading, $F_j(z,q)$ is the radiation pattern (Aki and Richards, 1980), and *r* is the radial distance expressed in km. The least squares inversion minimizes the difference between the data, $y_{ij,}$ and model values, $f_{ij}$. We determined relative site factors by setting the site factor at station 1 in the San Gabriel Mountains bedrock to unity, i.e., $S_1$ =1. Thus we obtain 17 relative site factors for stations 2-18, 57 event amplitudes, and the attenuation factor α for both the S-wave and P-wave data. This yielded a total of 75 parameters. The data consisted of 876 P-wave amplitudes and 836 S-wave amplitudes.

Average values of the amplitudes of the events were used to determine the input parameters for the non-linear inversion. We used α = 0.8 as a starting parameter. Different starting values of α do not greatly affect the outcome as long as α is close to 1. For the radiation pattern $F_j(z,q)$, the incidence angle $q$ was found by ray tracing through the SCEC Reference 3D Seismic Velocity Model (Magistrale et al., 2000) from the hypocenter of each event to each station.

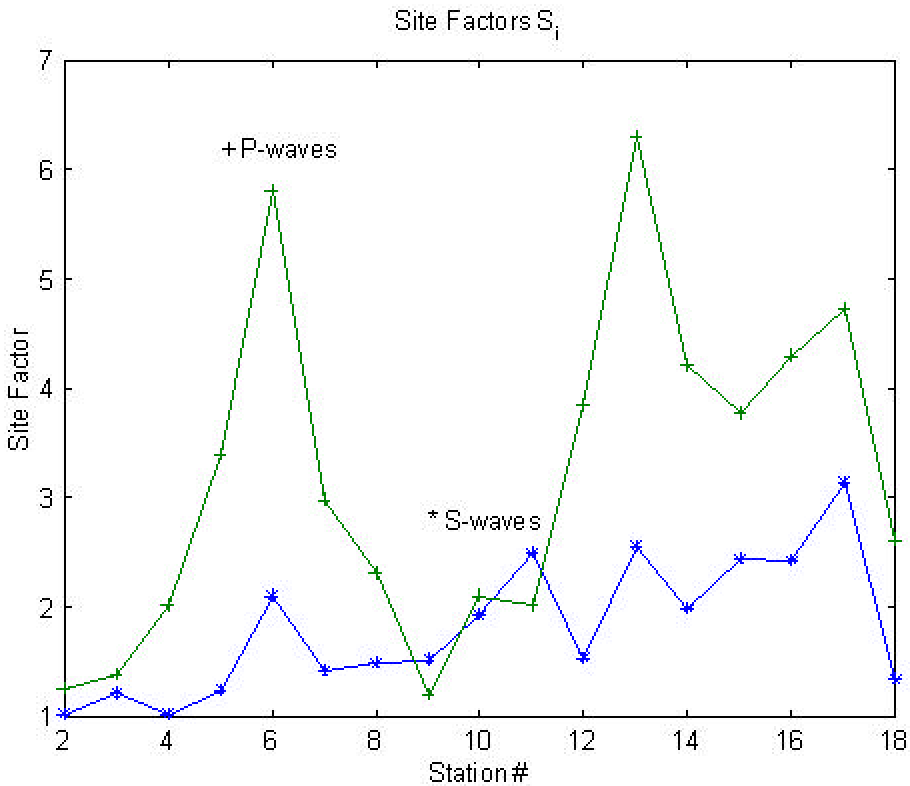


Figure 2. Site factors at LABPSE stations

RESULTS

Values for $\alpha$ from equation (1) were $\alpha$=1.42±0.17 for S waves and $\alpha$=1.12±0.25 for P waves. P-wave and S-wave site factors are plotted in Fig. 2. Sites are numbered 1 to 18, where 1 is located in the San Gabriel foothills to the north, and 18 is on the coast at Seal Beach. While the site factors are roughly proportional to each other, the P wave factors are much larger than those for S. However this relies on normalization to the factor at station 1 which, if abnormally low for P, could bias the remaining stations high. The station terms increase towards the coast (2-18) which is expected because the basin deepens in this direction.

In Figs. 3 and 4 we plot the P and S residuals ($y_{ij}$-$f_{ij}$), respectively, normalized by respective site factors and by the amplitude at station 1, as a function of incidence angle and azimuth. The P-wave residuals are very noisy and it is not possible to observe any systematic pattern of azimuth-dependent amplification. The S residuals are more promising. Stations 1-3 have similar amplifications, whereas the basin stations show azimuthal dependence. We observe large amplification anomalies for arrivals from the west for a number of stations.

At this stage of the processing we need to check that we have taken into account the radiation pattern and site effects properly. We are extracting data from the Southern California Seismic Network to confirm that the radiation pattern and attenuation law are applicable to a wider distribution of stations. We are also investigating other ways to normalize the data including using averages of the bedrock stations 1,2 and 3 rather than just station 1.

Figure 3: Relative normalized P wave amplitudes as a function of incidence and azimuth angles.

Figure 4: Relative normalized S-wave amplitudes as a function of incidence and azimuth angles.

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