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ESEE – EMBAYMENT SEISMIC EXCITATION EXPERIMENT: COLLABORATIVE RESEARCH WITH CERI AND THE U.S. GEOLOGICAL SURVEY

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TECHNICAL ABSTRACT

We have estimated P-wave and S-wave anelastic attenuation coefficients for the thick, unconsolidated sediments of the Mississippi embayment, central U.S., using the spectral distance decay of explosion P and Rayleigh waves. The sediment-trapped P-wave, P_{sed}, is observed to ranges of 80 km at 10 Hz and 1 Hz Rayleigh waves are observed out to 130 km from a 5000 lb borehole explosion in the northern part of the embayment. Four Hz Rayleigh waves are seen to distances of 3 km from a smaller 50 lb explosion. Analysis of the group velocity and amplitude-distance decay of both waves yields an average Q_s of 100 and Q_p of 200 for embayment sediments that are independent of frequency. Scatter in the Q estimates comes from interference of multiple P wave reverberations and Rayleigh wave modes. The attenuation model is self-consistent in that it is the same as obtained by the analysis of synthetic seismograms using the inferred Q values. Inferred Q_p and Q_s values are more than three times higher than previous estimates and imply that unconsolidated sediments of the embayment do not significantly attenuate small-strain earthquake ground motions. These estimates represent a lower bound to Q of the sediments since significant scattering is observed in the waveform data that contributes to the distance decay of wave amplitude. Higher Q values also imply that the unconsolidated sediments of the embayment will form an efficient wave guide for surface waves radiated from shallow earthquakes or large earthquakes that rupture into the sediments, producing high-amplitude, long-duration wave trains that should be considered in earthquake hazard assessments.

Two strong motion arrays were deployed for the October 2002 Embayment Seismic Excitation Experiment to study the spatial variation of strong ground motions in the deep, unconsolidated sediments of the Mississippi embayment because there are no comparable strong motion data from natural earthquakes in the area. Each linear array consisted of 8 3-component K2 accelerographs spaced

15 m apart situated 1.2 and 2.5 km from 2268 Kg and 1134 Kg borehole explosion sources, respectively. The array data show distinct body wave and surface wave arrivals that propagate within the thick, unconsolidated sedimentary column, the high velocity basement rocks, and small-scale structure near the surface. Time domain coherency of body wave and surface wave arrivals is computed for acceleration, velocity and displacement time windows. Coherency is seen to be high for relatively low frequency vertical component Rayleigh waves and high frequency P waves propagating across the array. Prominent high frequency PS conversions seen on radial components, a proxy for the direct S wave from earthquake sources, lose coherency quickly over the 105 m length of the array. Transverse component signals are least coherent for any ground motion and appear to be highly scattered. Horizontal phase velocity is computed using the ratio of particle velocity to estimates of the strain based on a plane wave propagation model. The resulting time-dependent phase velocity map is a useful way to infer the propagation mechanisms of individual seismic phases and time windows of three component waveforms. Displacement gradient analysis is a complimentary technique for processing general spatial array data to obtain horizontal slowness information.

NON-TECHNICAL ABSTRACT

A large geographical area around the New Madrid Seismic Zone is covered by thick unconsolidated sands and silts of the Mississippi embayment, a part of the coastal plain of south eastern United States. There are good reasons to believe that these thick sediments could significantly enhance strong ground motions from large earthquakes within the New Madrid Seismic Zone, like those in 1811-1812, and cause widespread damage in urban areas surrounding the seismic zone. Although thick sediments are known to increase ground motions from well-known wave propagation theory, they may also absorb seismic wave energy by deforming under the same high levels of ground motions. The absorption of seismic wave energy is quantified by a measurement called "Q" which represents the efficiency of seismic wave energy propagation in earth materials. High values of Q, such as 500 or greater, represent materials that do not absorb seismic wave energy. Low values of Q, such as 30 or lower, represent material that readily absorbs seismic wave energy. Past studies of Q in sediments over the New Madrid Seismic Zone have suggested that Q for shear waves, a major earthquake wave responsible for damage, is quite low with values of 30 or less. Our collaborative research involved testing this assertion by creating small "earthquakes" within the embayment sediments. These earthquakes were made by detonating explosives within 160 foot deep wells and had equivalent earthquake magnitudes of 2.8 and 3.1. The seismic waves generated by the explosions traveled almost exclusively within the sediments and were very effective probes of how much the sediments can absorb seismic wave energy. Seismic stations of the New Madrid Cooperative Network and 9 other temporary seismic stations recorded these waves to surprisingly large distances. By measuring how fast the various seismic waves lost energy as they propagated away from the explosions, we estimated that Q for the embayment sediments was at least 3 times larger than previously believed. Our results indicate that high frequency waves from large earthquakes in the seismic zone will probably be made larger as they pass up through the sediments to the surface, rather than being attenuated as previously believed. We also suggest that the embayment is a very unusual large-scale geological structure that is not found in other seismically active areas of the world. This structure will have a dangerously unique attribute in the event of a large earthquake that can rupture into the sediments. If such a rupture occurs, it is very likely that very large, high-amplitude surface waves can be produced by this kind of earthquake that will cause damage throughout the region.