PRELIMINARY RESULTS ON TOPOGRAPHIC SEISMIC AMPLIFICATION EFFECT ON A FOAM RUBBER MODEL OF THE TOPOGRAPHY NEAR PACOIMA DAM

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SUMMARY

Photographic recording of particle motion in foam rubber models provides a simple non-electronic method of measuring amplification effects in complex three-dimensional models.

A special study was made using a three-dimensional model of the actual topography around the Pacoima Dam Accelerograph site which recorded a peak horizontal ground acceleration of about 1.25g in the 1971 San Fernando earthquake. Preliminary results from the three-dimensional model indicate that for many angles of incidence the motion at the accelerograph site is reduced due to the site's location in a canyon. The conclusion that the Pacoima Dam record was anomalously high because of topographic amplification appears unwarranted.

CONSTRUCTING THE MODEL

A transparency contour map of the area is projected onto the flat surface of a large block of foam rubber, and an ink tracing is made of the contours. The block (6'x8'x3') is stripped down with a sharp razor or scalpel until the contour levels have been cut. The model thus consists of a familiar step three-dimensional model. Lastly, the surface is smoothed between each step to obtain the final topographic model. The contour steps can be taken at smaller intervals in critical areas to make the representation more exact. Figure 1 shows our most recent model in the process of being contoured to the topography in the neighborhood of Pacoima Dam, the site at which the famous Pacoima Dam accelerogram (with the highest yet-recorded horizontal acceleration, ~1.25 g) was obtained. This figure illustrates the intermediate stage of modeling and shows gross contours (200 ft. equivalent) for regions more distant from the accelerograph site, and finer contours (40 ft. equivalent) in the neighborhood of the site. The photograph also illustrates the method of measuring the elevation of the contours relative to the base level marked by the taut string.

MODEL EXCITATION

The model can be excited either in the steady state or by impulse. For steady state excitation we have used a carpenter's router with an eccentric arm and two bearings to provide a linear sinusoidal motion of about 1/16" amplitude (Figure 2). The model is excited from the flat, uncut side and the resulting particle motion, which is general elliptic, is observed on the side with the topographic surface. The frequencies of the router vibration are controlled by a rheostat and can be varied from about 100 RPM to 20,000 RPM (1.7 Hz to 330 Hz). The equivalent frequency in the earth depends on the

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scale of the model according to the formula f(earth) = f(model) x scale x β(model)/β(earth). Thus corresponding earth frequencies can be varied up to about 20 Hz for our most recent model, which has a scale of 1/1200.

For impulsive excitation we use a spring which is flexed and then released to impact a lightweight rigid coupler attached to the surface. The frequency band of the pulse extends to about 300 Hz. Just as for the steady state experiment, the model is excited from the flat, uncut side and the resulting particle motion pulse is observed on the side with topography.

RECORDING OF PARTICLE MOTION

We have used three different techniques to record particle motion: photographic, field effect sensors (photofets) and, most recently, photosensitive quadrature position detectors.

The photographic technique is used only for the steady state experiment. The particle motion ellipse is determined by photographing points of light on the surface with a shutter speed slow enough that the exposure includes several cycles of the particle motion ellipse. The photograph is then projected on a screen or wall and x and y amplitudes (or maximum amplitude) of the ellipse is measured. The points of light are created by reflecting light obliquely off ρf small droplets of aluminum paint. Figure 3 shows an example of ellipses recorded on the surface of the model.

The fotofet measuring device consists of a photo sensor which measures the amount of light received from a black and white target. It only measured one component of motion at a site and is somewhat cumbersome to accurately calibrate. Recently we have been using a quadrature position detector. This sensor measures two horizontal components of motion at the same time and is simple to calibrate.

PRELIMINARY RESULTS FOR TOPOGRAPHIC AMPLIFICATION

Numerous numerical and theoretical studies in two dimensions have shown that ground motion is amplified on ridges (e.g. Refs. 1,2,3,4). Observations of ground disturbances during the 1971 San Fernando, California earthquake also indicated intense shaking on ridges (Refs. 5,6). To illustrate this in the foam rubber model, we have constructed a simple dipping ridge with an apex angle of 45° (Figure 4). The structure was excited by steady state oscillations on the opposite side of the block and photographs were taken of the particle motion ellipses at various points along the surface of the block away from the ridge and up the side of the ridge to the peak (ink marks shown in Figure 4). Measurements of the amplitude of the ellipses for transverse oscillation of the ridge are plotted in Figure 5 for various frequencies. At a frequency of 3,000 RPM, corresponding to a wavelength to base ratio of about a factor of 5, there is very little amplification. However, at frequencies over 5,000 RPM, corresponding to wavelengths to base ratios less than about 3, amplification of the peak relative to the flat block away from the ridge can be more than a factor of 3. This result for the foam rubber model clearly confirms that for nearly vertical angle of incidence, ridges will have high amplification, as indicated previously in two-dimensional theoretical and numerical studies.

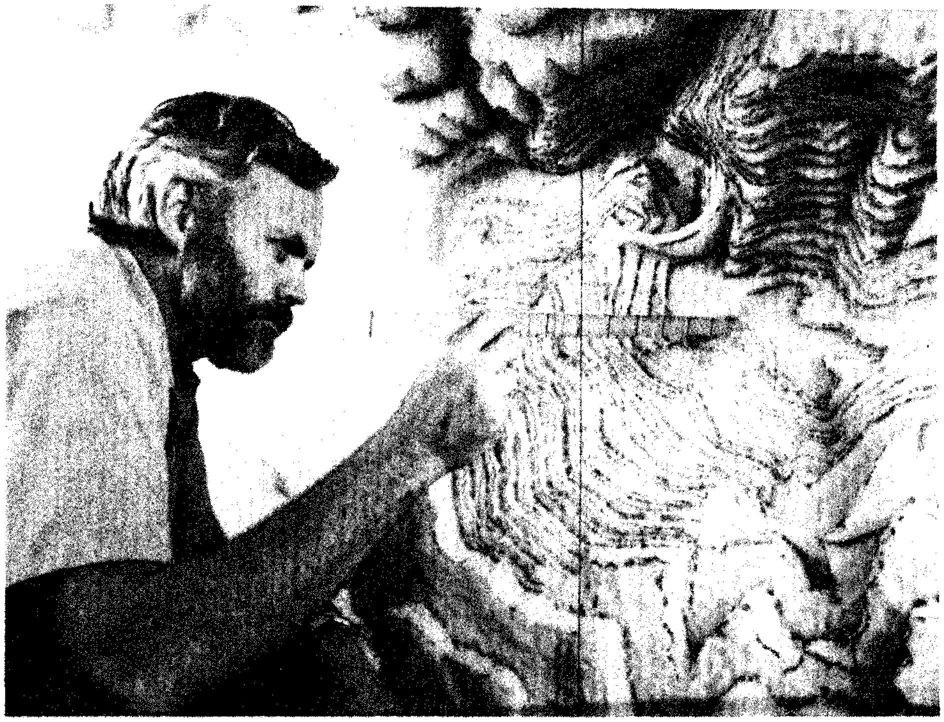

Figure 1. The method of checking contour levels in the process of constructing a three-dimensional model (of the area around Pacoima Dam) is illustrated.

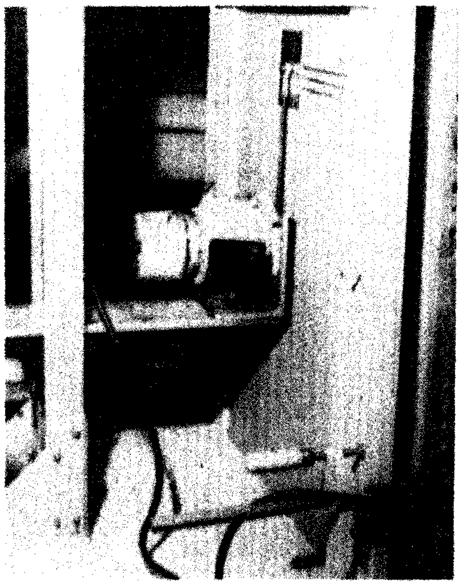

Figure 2. Photograph of a carpenter's router with an eccentric arm used for exciting vibrations in the foam rubber model. This is an earlier photograph; in recent experiments we used a shorter eccentric arm.

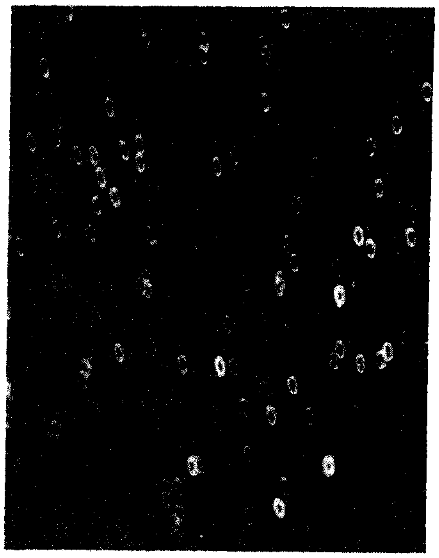

Figure 3. Particle motion ellipses from the vibrating surface of a foam rubber model.

TOPOGRAPHIC AMPLIFICATION FOR THE REGION AROUND PACOIMA DAM

We have constructed a three-dimensional topographic model of the region around the Pacoima Dam using the method described above. We then used the steady state technique to measure the relative amplitudes of ground motion for various points in the region and for various angles of incidence and types of particle motion. The results are summarized in Figure 6 through 8, which show the measured amplitude of the particle motion ellipse as a function of frequency in RPM. Curves are shown for various combinations of source location, receiver location, and component of motion. In these figures, a "V" indicates that the motion of the excitation is primarily in the direction parallel to the general strike of the canyon, approximately N30°W, which also corresponds to dip-slip motion on the inclined thrust fault dipping beneath the recording site. The direction V was chosen to approximately correspond to the type of motion which would be represented by the two-dimensional modeling in the study of topographic amplification by Wong and Jennings (Ref. 7), i.e. pure two-dimensional SH-motion.

In order to compare the results of various site and source combinations we have made a correction for spherical spreading and Q (attenuation) assuming a Q of 13. The distance and position of the recording site relative to source site were chosen so that this correction is relatively small.

If we assume the surface shear wave velocity is 2 km/sec, as assumed by Bouchon (Ref. 3), then a frequency of 13,000 RPM in the model corresponds approximately to a frequency of 10 Hz in the earth. The peak amplitudes on the accelerogram for the 1971 San Fernando earthquake were at a frequency of about 10 Hz and there is an important point of continuing debate as to whether this peak acceleration was amplified by topography. Therefore, in the following discussion we will refer only to the results for frequencies near 13,000 RPM. The reader may obtain conclusions regarding other frequencies by study of the graphs at different frequencies.

We first discuss the results for waves of vertical incidence shown in Figure 6. This figure compares the results for the accelerograph site near Pacoima Dam, the flat area away from the topography in the town of Sylmar, and four sites at canyon bottoms. This figure shows that canyon bottoms are relatively de-amplified compared to observations on the flat area.

Perhaps the most interesting conclusion from the results in this figure is for the amplitudes at the accelerograph site relative to the flat area. Several authors have suggested that the accelerograph site was amplified (relative to a flat half-space) because the accelerograph site was on a topographic ridge. The results in this figure indicate that there is little if any such amplification. Careful analysis of this result, and results from other sites, has indicated that this is a consequence of two counteracting effects. The effect of the ridge is counteracted by the effect of the ridge itself being in the bottom of a canyon. Bouchon (Ref. 3) and Boore (Ref. 1) using two-dimensional analogs have suggested that the effect of being in the canyon would occur at lower frequencies and not counteract the effect of being on the ridge. The results from the foam rubber model seem to indicate that this is not so. Because this result is so important to the interpretation of the strong motion recorded on the Pacoima Dam record we have also checked it using a transient technique, which is not affected by reflections on the

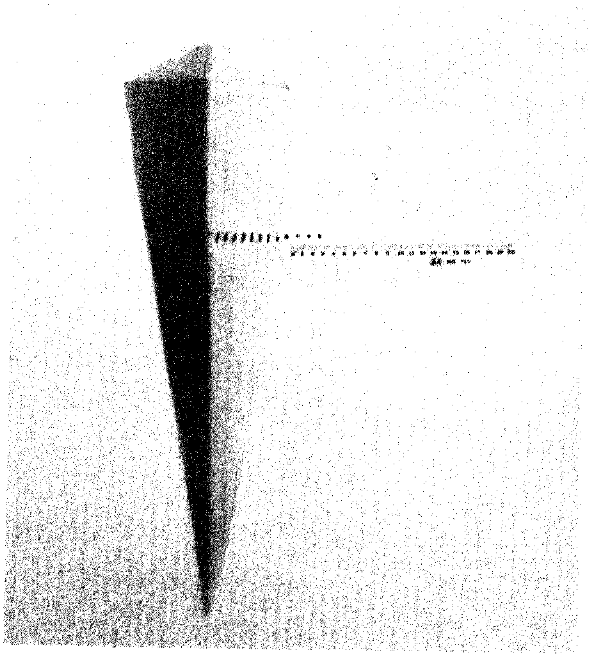

Figure 4. The model of a dipping angular ridge with an apex angle of 90°. The scale is 20 cm long.

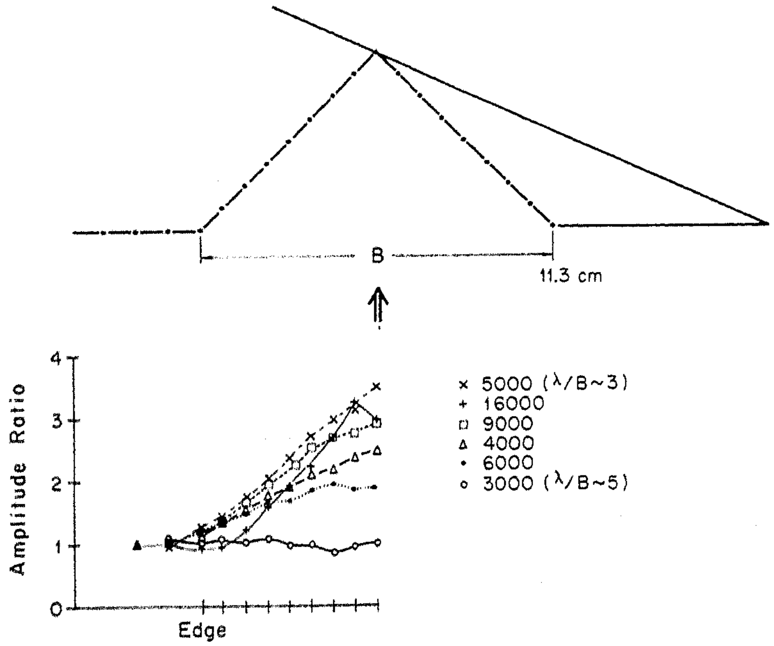

Figure 5. Particle motion amplitudes of transverse oscillation of the dipping angular ridge shown in Figure 4. Amplitudes at various points on the side of the ridge are normalized to the amplitudes on the flat block away from the ridge. Curves are given for several different frequencies in RPM.

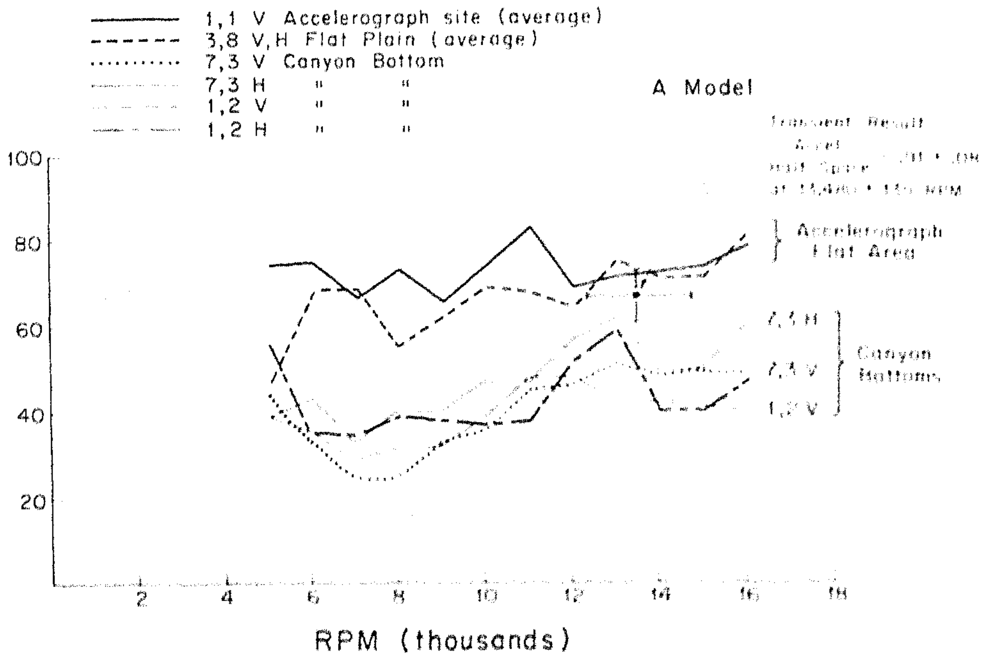

Figure 6. Particle motion amplitudes as a function of frequency for several sites on the foam rubber three-dimensional topographic model. Curves are shown for canyon bottoms, the accelerograph site, and a flat area. The solid dot with associated error bars shows the result from a transient experiment. See the text for scaling the frequency in RPM to frequency in the real earth.

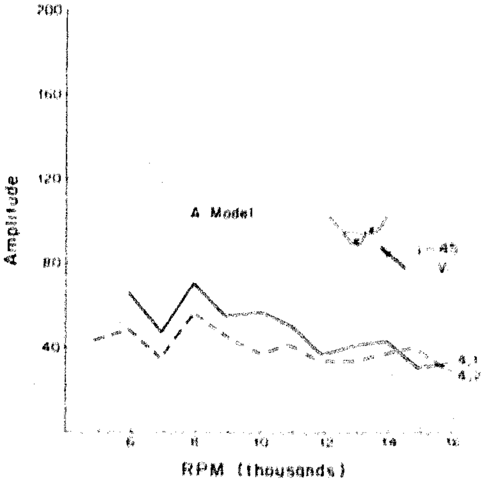

Figure 7. Amplitudes of particle motion as a function of frequency for waves incident from the right-hand (southeast) side of the canyon at an angle of incidence of 45°. This is the same model as for Figure 5.

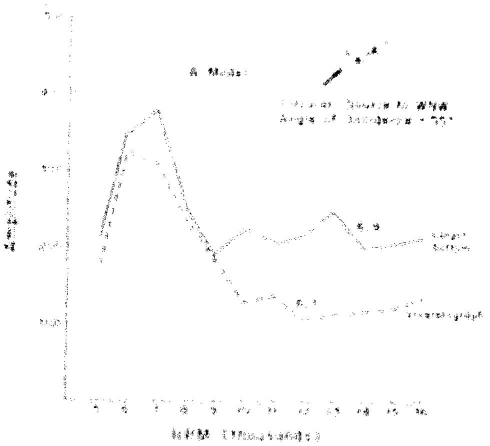

Figure 8. Similar to Figure 6 except the waves are incident from the left (northwest) at an angle of incidence of 55°.

boundaries of the model. The result is indicated by the point with crossed error bars and, within the experimental error, confirms the steady state result. As a further check on this result we have constructed another model, at a different scale, to see if the conclusion is altered. At the time of this writing we have not obtained the results from this model. We hope to have a definitive conclusion about the topographic amplification at the Pacoima Dam site by the time of oral presentation.

The results discussed above, shown in Figure 6, all refer to energy of essentially vertical angle of incidence. We have also checked the effect on the motion of different angles of incidence.

Figure 7 shows results for an angle of incidence of about 45° from the right and indicates that the amplitude at the accelerograph site is approximately the same as that at the canyon bottom and therefore presumably less than would have been recorded on a half-space, although we have not yet checked this. Figure 8 shows energy arriving from an angle of incidence of 55° from the left. For this case the accelerograph site is greatly de-amplified relative to the canyon bottom and thus relative to a flat area. This is a result of the accelerograph site being in a "shadow" of the canyon bottom. A similar "shadowing" effect was observed by Wong and Jennings (Ref. 7) in their two-dimensional numerical model.

Based on the above results and other results not shown here we can make the following tentative conclusions. Previous assumptions that motion at the accelerograph site is amplified by topography relative to corresponding motion on a flat half-space are not justified. The amplification depends on the angle of incidence of the energy. From some directions there is amplification and other directions de-amplification. For near vertical angles of incidence canyon bottoms are de-amplified relative to the accelerograph site. For near vertical angle of incidence there is essentially no amplification of the accelerograph site relative to a flat half-space. For some shallow angles of incidence the accelerograph site is in a shadow and strongly de-amplified relative to a half-space.

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