DEPARTMENT OF EARTH AND PLANETARY SCIENCES

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Dear Howard:

The following is my comment on DELTA's response to Tasks 1 through 4, and my impression of the September 18th meeting.

I think that the new report from DELTA shows significant improvement over the old one, especially in the mesh-size problem and the way in which the randomness is introduced into the rupture process. It answered some of the questions raised in earlier meetings, but also generated new ones. My major questions are concerned with:

(1) The approximation in extrapolating the Green's function between mesh points,

(2) The effect of rise-time on response spectra and the basis for discarding the 2-parameter model,

(3) The choice of rupture velocity at 90% of shear velocity which contradicts some of observations on the Parkfield earthquake, and

(4) The physical ground for choosing the length of coherent fault segment to be 1 km.

<u>Green's Function extrapolation</u>

On p.2-2, it is stated that the Green's function at each point on the fault surface is approximated by the Green's function of the nearest mesh point, shifted in time to reflect the travel time delay of <u>the direct shear wave</u> from the source to the receiver.

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5.1

I was concerned with this approximation, because the seismic motions in the forward direction of rupture propagation are dominated by bow waves (or shock waves) which have horizontal phase velocity equal to the rupture velocity including their multiple reflections in the low-velocity surface layer [Bouchon, 1979].

So, I asked Dr. M. Bouchon of MIT to calculate the seismic motion for some of the cases studied in the DELTA report. Bouchon's method is exact with respect to the superposition of contributions from fault elements, but the crustal structure is mc simplified to cut down the computer time. The San Onofre velocity profiles are simulated by a single-layer over a half-space. He studied the case (b) of p.2.1, namely,

> (b) A 10-km-long horizontal band of rupture with a width of 0.2 km, and centered at a depth of 1.5 km.

Observation points are at 5 km distance backward from the starting point of fault [Fig. 2.18], and at 10 km distance forward from the end point of fault [Fig. 2.19]. We calculated the Fourier spectra (for two crustal models simulating the structure under San Onofre) and compared them with the Responce Spectra calculated by DELTA as shown in Fig. 1.

Considering the difference of Fourier vs. Response Spectra, and the difference in details of velocity profile, the agreement between Bouchon's and DELTA's results is satisfactory. For example, the spectral shape and the relative amplitude between forward (focused) and backward (defocused) stations are quite similar.

This agreement is encouraging, but may be somewhat fortuitous, because the ruptive velocity is taken very close to shear velocity in all the DELTA models. My major question here is "do we still get a good argreement when the rupture velocity becomes lower and shock waves will have significantly different horizontal phase velocity from shear velocity?"

Effect of rise-time on response spectra

I found an apparent inconsistency in the report with respect to the effect of rise time on response spectra. Fig. 3.5 (p.3-10) and 3.6 (p.3-11) show the effect for the three parameter model and the two-parameter model, respectively. In either case, the response spectra at period of 10 sec are unaffected by the change in rise time but determined mainly by the amount of final slip.

On the other hand, the results in Section 5.4 shows that the response spectra at 10 sec for the two-parameter model are almost 10 times larger than those for the three-parameter model, although both models share the same final slip.

The results of sensitivity studies with respect to rise time shown in Fig. 6-30, 6-31 and 6-32 are also inconsistent with the results shown in Fig. 3.5 and 3.6.

During the September 18th meeting, Dr. Frazier attributed the apparent inconsistency to the non-linearity involved in computing response spectra. He agreed that the Fourier spectra should be identical for 2-parameter and 3-parameter models at period of 10 sec as long as the final slip is common. The 2-parameter model was discarded on the ground that the predicted response spectra disagree with observed response spectra. On the other hand, if observed Fourier spectra were compared with the prediction, both 2-parameter and 3-parameter models equally well explain observation. I feel that some trivial matter might have caused the large discrpancy in response spectra at long period.

Choice of rupture velocity

Another crucial parameter is the rupture velocity. As shown in Fig. 6.21, 6.22 and 6.23, the increase of rupture velocity from, say, 0.6 β to 0.9 β can double the response spectra. I question the adequacy of DELTA's choice of 0.9 β. If they used, say, 0.6 β and adjusted the rest of model parameters to match observed seismograms, they would have predicted a similar response for San Onofre as that based on 0.9 β. Then, uncertainties in the rupture velocity would require the need for doubling the site-specific response spectra.

As a matter of fact, in the case of Parkfield earthquake, the rupture velocity of $0.9 \times 3.5 \sim 3.1$ km /sec and the fault length of 26 km adopted in the DELTA report cannot explain the spectral nodes observed at Berkeley by a broad-band seismograph (Filson and McEvilly, 1967). The rupture velocity of 2.2 km/sec. and fault length of about 30 km are required to explain the nodes. The direct measurement of rupture arrival by a chronograph record located near the center of fault (Gold Hill) gave the velocity 2.2 km/sec (Eaton, 1967). The velocity of 2.2 km/sec also explain the station #2 record quite well as shown by Bouchon (1979). In our opinion, the station #2 record is distinctly different from the records of other stations, lacking dispersed wave trains. The near-field effect is obviously dominating at station #2 because of the proximity to the fault (Delta uses distance of 0.2 km, but Cloud (1967) uses 0.08 km) as demonstrated by the synthetic seismograms computed by Bouchon (1979).

The question is whether we can lower the rupture velocity and extend the fault to the south of station #2, without contradicting the observations at the other stations by adjusting other source paramenters. I suspect that the answer is yes. During the September 18th meeting, S.W. Smith emphasized that the site specific spectra are insensitive to the details of models. For example, the focusing effect may be considerably reduced by lowering the rupture velocity, because the amplitude ratio of seismogram in the forward direction to that in the backward direction is roughly given by $(\beta+\upsilon)/(\beta-\upsilon)$, which is 19 in the DELTA model, but only 4, if we use rupture velocity $\upsilon=0.6\ \beta$. This may reduce the strong incoherence required in the DELTA model.

Length of the coherent fault segment

DELTA's choice of 1 km as the size of fault segment over which rupture is coherent is rather arbitrary. The choice was made because of convenience for computation, but not on any physical or geological ground. No sensitivity study was made on this most fundamental parameter controlling high-frequency waves.

The choice of 1 km implies a rather unusual physical condition in the fault zone. Since the orientation of fault segment is random, the DELTA random model consists of isolated cracks with dimension 1 km and slip 130 cm. a slip of 130 cm on a crack with diameter 1 km mean nearly 1 k bar static stress drop. This static stress drop corresponds to a slip velocity of about 10 meter/sec and rise time of around 0.1 sec instead of 2.9 sec assumed in the DELTA model (Table 5-3). Thus, there is a mechanical inconsistency among the model parameters.

This inconsistency may or may not be too serious because some times a kinematic model with physical inconsitensies can be useful (Haskell model is an example). However, the proper choice of the length of coherent segment must be done on some physical or geological ground, or by varying it until the best fit to observed seismograms is obtained. From limited data available on the fault segmentation, the length of 2 to 5 km is more appropriate for a slip of 130 cm (Aki, et al 1979).

In summary, I still feel that a 2-parameter model with rupture velocity 2.2 km/sec (∿ 60% of shear velocity) can explain Parkfield data. If so, the corresponding response spectra must be somewhat raised. In view of this non-uniqueness in model, and uncertainties in model parameters such as slip velocity, rupture velocity and length of coherent fault segment, I think the conservative estimate of response spectra should be raised by a factor of two from the DELTA's estimate, which may be the best estimate from available data.

The empirical approach taken, for example, by the Woodward-Clyde is primarily based on the data obtained at distances greater than 20 km. On the other hand, the estimate by DELTA is based on data obtained at distances shorter than 20 km. Thus, these two results should not be considered as mutually exclusive, but should be considered as supplementing each other. One might average the two estimates with appropriate weight. The weight may be determined by the relative amount of observation and physical constraints put into both estimates. I feel that the weight is 50-50 at present, but may improve in favor of the modeling approach in the future.

Reference

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Sincerely yours,

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