UNIVERSITY OF CALIFORNIA, SAN DIEGO

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October 18, 1979

Dr. Leon Reiter
Nuclear Regulatory Commission
Mail Stop P-314
7920 Norfolk Avenue
Bethesda, Maryland 20014

Dear Leon:

Enclosed please find my review of the report "Simulation of Earthquake Ground Motion for San Onofre Nuclear Generating Station Unit I, Supplement I."

Enclosed you will also find a bill for expenses and time used to prepare the review and attend the meeting of Sept. 18, 1979.

Sincerely yours,

J. Enrique Luco

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Review of the Report "Simulation of Earthquake Ground Motions for San Onofre Nuclear Generating Station Unit 1, Supplement I"

A Report prepared for the Nuclear Regulatory Commission

J. Enrique Luco

8 October 1979

I. Methodology

1.1 Integration over fault surface. Some improvements have been made on the method of integration over the fault surface. The comparisons presented indicate that the present version may be sufficiently accurate to calculate smoothed response spectra. Errors in the calculated values for peak accelerations and peak velocities are probably more significant.

1.2 Randomness. A number of sources of incoherence have been introduced in the methodology. These sources of incoherence are clearly described. Some of the incoherence introduced tends to reduce the high frequency content of the motion and may cover inadequancies of the integration method which neglects the effects of dispersion over distances of the order of 1 km. Other sources of randomness tend to increase the high frequency content of the motion in the area away from the focussing region while reducing the focussing effects at high frequencies.

1.3 Slip model. A three-parameter slip function $s(t) = \Delta t\ v_o(t-to/\Delta t)^p$ is used where $p = \ell n(S_\infty/\Delta t\ v_o)/\ell n(t_R/\Delta t)$. The parameter v_o is erroneously called initial slip velocity.

More precisely, it corresponds to the average slip velocity over the interval (to,to+Δt). The initial slip velocity (t = to) is infinite for $p < 1$. The parameter p is determined from the values of the static offset, rise time and v_o. For v_o = 800 m/sec, the calculated values of p for Parkfield and San Onofre are 0.235 and 0.394, respectively. These values for p are not acceptable since they would be associated with a nonintegrable stress singularity (infinite energy) at the crack tip (for a theoretical crack in an elastic medium $p = 0.5$).

As in the previous report the rise time, t_R, is defined as the width of the fault divided by the shear wave velocity. In my review of July 12, 1978, I suggested the use of half of that value. The recent study conducted by Systems, Science and Software (Three-dimensional simulation of rectangular fault dynamics, 1979) confirms this recommendation. If this recommendation had been followed more realistic values for the parameter p would have been obtained.

For the Parkfield and San Onofre models spatially uniform static slips are used. This assumption is unrealistic in that it requires non-physical stress concentration along the perimeter of the fault.

II. Comparative Studies

2.1 Imperial Valley Earthquake Model. Delta's model for the 1940 Imperial Valley Earthquake is highly questionable on several grounds. The seismic moment calculated on the basis of the static offsets used in the model is reported as 3.6×10^{26} dyne-cm. (Report of May 1978 and Response to Proposed Task 4, August 1979). The values calculated by Trifunac and Brune (B.S.S.A, 60, 137-160, 1970) on the basis of the observed surface outbreaks range from 1.2 to 1.4×10^{26} dyne-cm. The values obtained by these authors based on the records at Tinemaha and Haiwee are 1.1 and 1.3×10^{26} dyne-cm, respectively. The larger seismic moment used by Delta results in part from the use of an erroneous slip of 500 cm at the S-E end of the fault (Frazier, personal communication). An additional reason for the increase is the use of a constant slip in depth equal to the surface slip. If the rupture extended to the free surface, the average slip is only about 0.75 of the surface slip.

A value of 90 bars is reported for the average static stress drop. Based on the values used by Delta, $M_o = 3.6 \times 10^{26}$ dyne-cm, L - 48 km, w = 12 km. I calculate the average stress drop to be 33 bars (66 bars if the rupture did not cut the free surface). For a seismic moment of 1.4×10^{26} dyne-cm the average stress drop would be 13 bars (26 bars if the rupture did not cut the free surface). (In the previous report-May 1978- the rupture was assummed to extend to the surface, in Supplement I the rupture is stopped 1 km from the free-surface).

Delta's model of the Imperial Valley earthquake assumes a bilateral rupture extending to the N-W and S-E of the epicenter. Richter (1958) based on the reported damage suggests that "The main earthquake fracture began near the instrumental epicenter at 8:36 and continued southeastward, while the small northwestward trace developed with the aftershock at 9:53." Trifunac and Brune (1970) in their interpretation of the rupture process as a sequence of events found that all of the events were located on the fault to the S-E of the epicenter. Hartzell (Ph.D dissertation UCSD, 1978) also models the main shock as a unilateral rupture propagating to the S-E of the epicenter. The evidence seems to indicate that a unilateral rupture is a more appropriate model. In this case, El Centro, located 12 km to the N-W of the epicenter, would be in the defocussed zone. The peak acceleration at El Centro was 0.35 g. Stronger motion would be expected in the focussed region. As an indication, Hartzell found that the motion at El Centro would have seen twice the recorded motion if the rupture had started at the SE end of the fault and propagated to the N-W. In Hartzell's work aftershocks recorded at El Centro were used as empirical Green's functions. It must be noted that the peak displacements calculated by Delta (20, 49 and 11 cm) are twice as large as those observed (10, 20 and 6 cm) suggesting that a better match could be obtained by a unilaterial rupture model.

2.2 Parkfield earthquake model. The model of the Parkfield earthquake considered in Supplement I is different from that used in the May 1978 report. The length of fault has been shortened from 32 km to 26 km in an attempt at improving the comparison at station 2. The static slip was increased from 50 cm to 60 cm and the static stress drop has been increased from 24 to 30 bars. The previously reported value for the seismic moment, 0.39×10^{26} dyne-cm, seems to be inconsistent with the value quoted in the report on Task 4, 0.51×10^{26} dyne-cm. The larger value for the seismic moment apparently stems from the use of erroneous densities in the geologic model for Parkfield (Table 5-2).

Comparison of the calculated peak accelerations with the observed values (Table 5-4) indicates that the model overestimates the response at stations 2 and 12 by a factor of two while underestimating the response at station Temblor also by a factor of two. The calculations match the peak accelerations only at stations 5 and 8. At station 5 the calculated the caluclated peak displacements are almost twice as large as the observed values.

III. Estimates for San Onofre Site

3.1 Delta's estimates. Delta's estimate of the high-frequency ground motion at San Onofre is not significantly different from a straightforward arithmetical average of the response at El Centro for the Imperial Valley earthquake and at stations 5 and 8 for the Parkfield earthquake. The average of the peak accelerations 0.35g (El Centro), 0.45 g (station 5) and 0.30g (station 2) in 0.37g which should be compared with 0.39g (San Onofre NE). A comparison of the corresponding response spectra is shown in Figure 1. Due to a combination of unfortunate circumstances the apparent sophistication and expense of the method have no searing on the results and, in my opinion, the results have no more value than those that could be obtained by a straightforward average. The circumstances alluded to are the following:

(i) model of the Imperial Valley earthquake as a bilateral rupture. By this choice (apparently against the evidence) all of the records to be matched are assumed to be in the focussed region

(ii) choice of records to be matched at similar distances to the fault

(iii) at high frequencies the calculated response of the model is essentially controlled by the average initial slip velocity v_o. As a first approximation we can write

$$a_{s.o.} = G(S_{o_{s.1.}}, \Delta_{s.o.}) v_o \qquad (1)$$

where $a_{s.o.}$ denotes the calculated peak acceleration at

San Onofre, $G(S_{s.o.},\Delta_{s.o.})$ denotes an influence function which depends on the geologic structure ($S_{s.o.}$) and distance to the fault ($\Delta_{s.o.}$). The parameter v_o is selected by matching the response at El Centro, sta. 5 and sta. 8. At these locations it is possible to write

$$a_{sta.5} = G(S_z,\Delta_{sta.5})S_o \qquad (2)$$

and similar equations for the other stations. Since the effects of the geologic structure are not predominant and since the distance to the fault are similar it is not surprising to find that

$$a_{s.o.} = \text{average}(a_{El.C.},a_{sta.5},a_{sta.8}) \qquad (3)$$

It may be seen that the costly influence functions $G(S,\Delta)$ and the discussion of the accuracy of the method or lack of it are irrelevant from the point of view of the high frequency estimates.

The estimates obtained are based on the assumption that the parameter v_o is independent of the earthquake characteristics. A value of σ_o = 800 cm/sec has been found matching the observed motion at station 5 and 8 during the Parkfield equthquake. The same value is obtained for the Imperial Valley earthquake by assuming a bilateral rupture. If a more realistic unilateral rupture model were used for this earthquake a significantly higher value of v_o would be required to match the records at El Centro.

Delta's estimates of the high-frequency motion at San Onofre probably correspond to average conditions in the focussed at a distance of 8 km to the fault of a earthquake with local $M_L \approx 6.0$. Some caution must be exercised since Delta's calculations at station Temblor (9.5 km from fault) underestimates the observed motion by a factor of two. Also, the NE San Onofre spectrum falls below the sta. 5 N85E spectrum for frequencies higher than 5 cps (Figure 1). This effect may be caused in part by the unrealistically low values of Q used which tend to eliminate the high frequency components of motions.

3.2 Recommendation. In my opinon, for an earthquake with local magnitude $M_L = 6.5$, Delta's estimates should be multiplied by a factor of the order two. Response spectra consistent with peak accelerations of 0.8g and peak velocities of 60 cm/sec would seem appropriate for the possible conditions at San Onofre for an earthquake of this magnitude. This recommendations is based on the following observations:

(i) Delta's estimate is essentially based on the recorded motion at stations 5 and 8 during the $M_L \approx 6.0$ Parkfield earthquake. No estimate of the standard deviation of the parameter v_o has been provided. In general, standard deviation for peak acceleration and velocities correspond to a factor of the order of two.

(ii) Delta's estimate for the motion at Temblor (9.5 km from fault) for the Parkfield earthquake underestimate the recorded motion by a factor of two.

(iii) It is very likely that the peak acceleration of 0.35g recorded at El Centro (epicentral distance of 12 km) for the Imperial Valley earthquake (M_L~6.4) is associated with a defocussed zone. Calculations by Hartzell indicate that if the rupture had propagated in such a way as to focus energy in the direction of El Centro, the amplitude of motion would be increased by a factor of the order of two.

(iv) The calculated NE San Onofre spectrum falls below the El Centro N-S and station 5 N85 E spectra for frequencies higher than 5 cps. (Figure 1)

(v) a peak acceleration of 0.8g for an earthquake of magnitude $M_L = 6.5$ at a distance to the fault of the order of 10 km is consistent with the recommended values in USGS circular 672 and with Trifunac's correlations.

IV. Conclusions

The use of the methodology proposed by Delta to estimate the characteristics of earthquake ground motion seems promising but its use at the present time is premature. Realistic values for attenuation must first be obtained and the effects of spatial variations of slip on the high-frequency components of motion must be established. Detailed study of a significant number of recorded events and matching of the recorded data in the range from 30-100 km must precede its use for licensing purposes.

In regards to the San Onofre site, Delta's calculations are essentially independent of the model employed and correspond to an average of the motion recorded at El Centro (Imperial Valley earthquake) and at stations 5 and 8 (Parkfield). As such, the estimates for San Onofre, in my opinion, are too low to reflect the strong motion on the focussed region of a M_L = 6.5 earthquake.

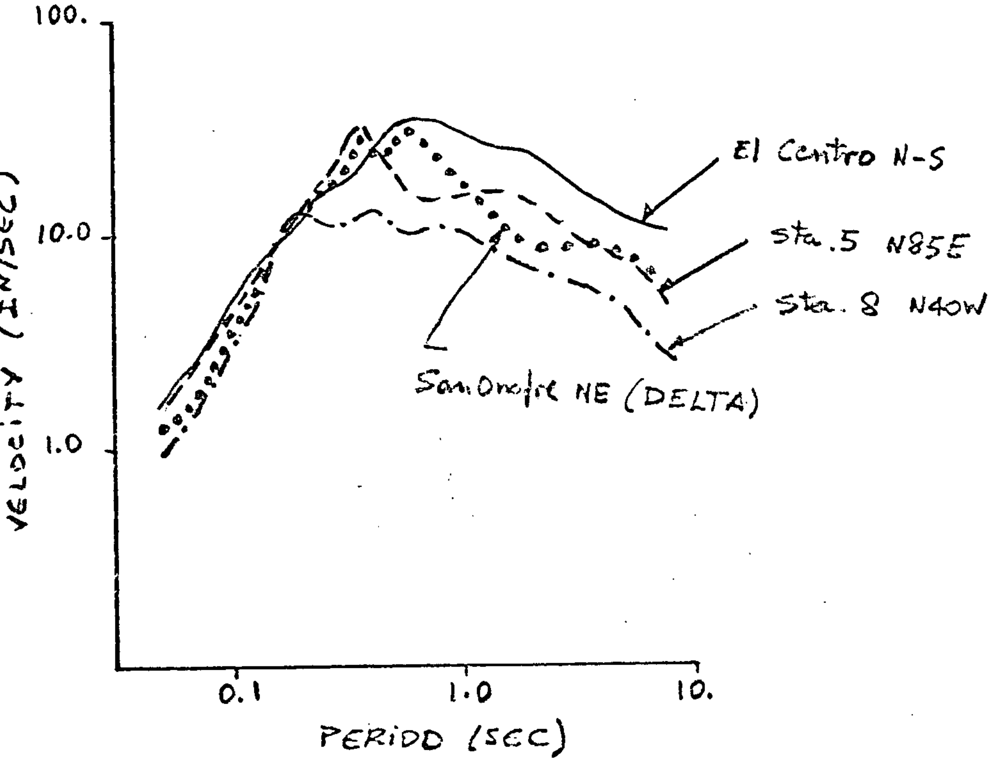

FIG. 1 SMOOTHED 2% VELOCITY RESPONSE SPECTRA