APPLICANT EVALUATION

JOYNER - FLETCHER REPORT

VIRGIL C. SUMMER NUCLEAR STATION
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APPLICANT EVALUATION OF JOYNER AND FLETCHER REPORT ON
VIRGIL C. SUMMER NUCLEAR STATION
SEISMICITY STUDIES

Joyner and Fletcher have reviewed the "Supplemental Seismologic Investigation" Report, the Safety Evaluation Report, and Section 361 of the Final Safety Analysis Report for the Virgil C. Summer Nuclear Station. Their response is contained in a memorandum to Morris dated September 9, 1981. Joyner and Fletcher apparently have not read transcripts of ACRS subcommittee meetings or of ASLB hearings to date. The issues raised by Joyner and Fletcher are caused by misinformation or misinterpretation (indeed, Joyner and Fletcher state that, "... we did not have sufficient time for a thorough review ..."), and deserve a direct response by the Applicant to clarify the record. The form of this response follows the issues raised by Joyner and Fletcher, in order.

MAXIMUM MAGNITUDE OF THE RESERVOIR-INDUCED EARTHQUAKES

Joyner and Fletcher give values ranging from 30 to 44 bars for the August 27, 1978 earthquake. Joyner and Fletcher give three methods by which they have calculated these values: rms accelerations, numerical integration of the squared spectrum, and a "straightforward application of the Brune model," but no formulas or parameter values are given. Although it is not clear from Joyner and Fletcher's report, the major difference between their estimates of stress drop for the 1978 earthquake and those of the Applicant is the assumption of the highest frequency that can be recorded and documented in the digitization process (Fletcher, personal communication 1981). Since stress drop is an important parameter, and one which has been the subject of some debate, this point deserves further elaboration.

The peak accelerations recorded on an accelerometer during an earthquake are a function of the highest frequency which the instrument and record processing procedure can transmit, among other factors. For records obtained very close to sources of high frequency energy (e.g., rock bursts), accelerations can be almost arbitrarily high if the instrument and processing procedures are adequate to transmit the high frequencies of motion at which high accelerations occur. McGarr et al. (1981) documented accelerations as high as 12g during mine tremors in South Africa, where the magnitudes were less than 1.5 and source-to-site distances were several hundred meters. These peak accelerations occurred at frequencies of several hundred hz, and the instruments were specially designed to record ground motion at these high frequencies.

Typical strong motion instruments, including the one installed at Jenkinsville, have a natural oscillation frequency of 25 hz, meaning that the instrument itself tends to damp out motion at higher frequencies. Joyner and Fletcher have taken 25 hz as the upper limit of motion that can be recorded. However, accelerographs can easily record frequencies higher than their natural frequency. The upper solid curve in Figure 1 shows the response of an accelerograph with natural frequency of 25 hz and damping 0.6 of critical (the characteristics of the SMA-1 accelerograph at Jenkinsville, according to Brady et al., 1981) plotted as a function of frequency. Not only can the accelerograph itself record frequencies higher than 25 hz, but standard record processing procedures (including those used by Brady in the above reference) "correct" for the instrument response, effectively by dividing the recorded ground motion at each frequency by the ordinate on Figure 1. This effect can be significant: the peak acceleration of the "2nd aftershock" record, 90° component, documented by Brady et al. (1981), increases 35 percent due to instrument correction procedures.

Furthermore, the Jenkinsville data indicate that frequencies higher than 25 hz have been recorded. Brady et al (1981) find that, "... these (Jenkinsville) records have frequencies as high as 25 and 30 hz." A perusal of the Brady et al. (1981) document shows that the August 27, 1978 record, 90° component, has a peak acceleration with a 33 hz frequency, and the "2nd aftershock" record, 90° component, has a peak acceleration with a 40 hz frequency.

That there is substantial energy[1/] in the ground motion recorded at Jenkinsville can also be inferred from the plots of response spectra

1/ i.e., Above 25 Hz.

provided by Brady et al. (1981), one of which (August 27, 1978 earthquake 90° component) is reproduced here as Figure 2. Although spectra are only plotted down to a period of 0.04 seconds (up to a frequency of 25 hz), it is evident that there is no decrease of energy near 25 hz, and it is safe to assume that the spectra, if plotted at higher frequencies, would continue horizontally to frequencies as high as 35 or 40 hz, and this would indicate ground motions at those frequencies.

The Applicant has used an upper frequency of 40 hz to accurately characterize these records, making it clear that it is the record corrected for instrument response and digitized at 500 points per second to which this upper bound applies.1/ The choice of upper bound f_u affects estimates of stress drop $\Delta\sigma$ in the following way:

$$\Delta\sigma = C \frac{a_{rms}}{(f_u - f_o)1/2} \tag{1}$$

where a_{rms} is the root-mean-square acceleration from the record and f_o is the corner frequency (see the Appendix for a derivation of this).

Both the Applicant and Joyner and Fletcher have used a lower bound frequency f_o of about 10 hz (the issue of corner frequency is addressed in detail below). Therefore, for the same observation of a_{rms}, the choice of f_u = 25 hz leads Joyner and Fletcher to an estimate of $\Delta\sigma$ which is high relative to f_u = 40 hz, by the factor:

$$\frac{\Delta\sigma\ (J\ \&\ F)}{\Delta\sigma\ (\text{Applicant})} = \frac{(40-10)^{1/2}}{(25-10)^{1/2}} = 1.4 \tag{2}$$

This explains why Joyner and Fletcher obtain $\Delta\sigma$ = 35 bars for the August August 27, 1978 earthquake, and the Applicant obtains $\Delta\sigma$ = 25 bars.

1/ We note that Dr. Luco suggests an upper bound frequency of 50 Hz, which yields even lower values of stress drop than those of the Applicant.

Joyner and Fletcher have used an upper-bound frequency equal to the nominal frequency of the instrument; the Applicant has accounted for the higher frequencies evident in the strong motion record.

As a separate issue, Joyner and Fletcher assert that the Applicant did not correctly account for the corner frequency in making estimates of $\Delta\sigma$. While this is implied by the equations in section 361 of the FSAR, which Joyner and Fletcher reviewed, the effect of corner frequency was examined and found not critical by the Applicant. The Appendix to this report derives the theory with which the effect of corner frequency can be included in estimating $\Delta\sigma$; estimates using this theory were presented to the ACRS seismic subcommittee on February 26, 1981. Table 1 reproduces the data presented at that meeting, which is a matter of public record. Using the appropriate corner frequency f_o, the stress drops derived for the August 27, 1978 earthquake are still on the order of 20 bars. Thus it is the Applicant's position that 25 bars is an appropriate and conservative stress drop to use for characterizing earthquakes at Monticello Reservoir for the purposes of estimating strong ground motion characteristics.

Joyner and Fletcher have reviewed the Applicant's arguments on stress barriers, stress heterogeneities, and material properties defining maximum rupture dimensions, and find these arguments "... unconvincing." It is not clear what alternative physical explanation Joyner and Fletcher have for the observations that have been made, nor why they do not accept the Applicant's explanations. In any case, Joyner and Fletcher base their estimate of the maximum rupture dimension and of the associated magnitude on the spatial extent of observed seismicity, without consideration of whether the seismicity "lines up" or indicates any through-going structure (in fact it does not). Such an analysis is unsupported by observatons anywhere in the world, to the Applicant's knowledge, i.e., there is no location where swarm-like seismicity has indicated the size of a later, larger earthquake. Frequently in seismology the locations of after-shocks are used to infer the dimensions of a main shock (even this has been suggested as giving a conservatively large estimate of the main shock area). This is a far different procedure from using the location of diffuse seismicity to infer a main shock area. What has frequently been done by investigators is to use the length of an identified fault to estimate a maximum magnitude, and here only one-half of the entire fault length is presumed to rupture. Thus Joyner and Fletcher's procedure is without validity in terms of worldwide empirical observations, does not constitute an accepted method, and has not had the benefit of peer review.

In calculating the magnitude associated with source radii of 1 and 1.4 km, Joyner and Fletcher have used a stress drop of 40 bars. Since magnitude is proportional to the logarithm of stress drop in this calculation, this leads to Joyner and Fletcher magnitude estimates that are only marginally higher (~0.1 magnitude units) than those supplied by the Applicant at the request of NRC.

The experience of induced earthquakes at Denver is entirely irrelevant to the issues at Monticello. The Denver earthquakes were caused by cyclical fluid injection in deep wells; the correlation of earthquakes with injection is a point made by the reference cited by Joyner and Fletcher (Healy et al., 1968). Thus at Denver the causative mechanism was cyclical. At Monticello there has been a one time change in water elevation[1/]; during operations, lake fluctuations will not exceed about 2 meters total range. Thus the causative mechanisms[2/] of the two phenomena are fundamentally different, and to suggest that the experience at one site would or should guide us at the other is inapposite.

GROUND MOTION ESTIMATES

The first difference (concerning digitization rate) mentioned by Joyner and Fletcher between their and the Applicant's ground motion analysis is not a difference at all. In 1980 the Applicant used the records digitized at 100 points per second to estimate stress drop during the August 27, 1978 event, because at that time (when the relevant parts of Section 361 of the FSAR were prepared), these were the only data available. In February 1981 the digitizations at 500 points per second

1/ i.e., Initial filling of Monticello Reservoir

2/ In the sense of the scale of the changes. Also very important are the differences in the hydrologic and tectonic regimes.

were made available by USGS (Brady et al., 1981) and the Applicant confirmed that its analysis was appropriate for the higher digitization rate. Table 1 reproduces data presented at the February 26, 1981 ACRS subcommittee meeting which shows ground motion estimates made by the Applicant which are in agreement with Monticello earthquake records digitized at 500 points per second. Thus the Applicant can and has explained the factor-of-two difference in peak accelerations due to digitization rate.

Where the Applicant's procedure does differ from that of Joyner and Fletcher is in the implied digitization rate associated with the peak acceleration used to characterize ground motion for seismic analysis of the facility. To determine the appropriate digitization rate, one must consider how the peak acceleration is to be used to generate response spectra for structural analysis. Thus the structural engineering considerations cannot "... be kept separate from the seismological analysis," as Joyner and Fletcher wish.

The manner in which response spectra are derived for the seismic design and analysis of nuclear facilities is straightforward: (1) an expected peak acceleration is selected corresponding to the largest ground motion anticipated, (2) an effective acceleration is calculated from the peak acceleration, and (3) a response spectrum is scaled to that effective acceleration. For the Virgil C. Summer facility, step (2) has conservatively been ignored, i.e., peak acceleration has been assumed to equal effective acceleration. For tectonic earthquakes, a broad-banded spectrum is used to represent the wide frequency content of the motion. For reservoir-induced earthquakes at Monticello, the important events will occur close to the facility; in this case, appropriate high frequency spectra have been developed as suggested by Regulatory Guide 1.60. This development is documented in Section 361 of the FSAR.

For the high frequencies of interest, it is the high frequency components of the structure which are of concern. These frequencies lie in what is often termed the "acceleration-amplification" portion of the spectrum, that is, amplitudes of response are most sensitive to the peak acceleration of the input motion, rather than by the peak velocity or peak displacement.

The mathematical representation of this two-step procedure to calculate high frequency structural response is as follows:

$$a_{res} = a_p \times \frac{a_{res}}{a_p} \qquad (3)$$

where a_{res} is the structural response in terms of maximum response acceleration, and a_p is peak ground acceleration (step (1) above). The ratio on the right-hand-side is step (3) above, the "acceleration amplification factor" used to determine both standard spectral shapes (e.g., Regulatory Guide 1.60) and the spectral shapes used on this project to represent reservoir-induced earthquakes.

It should be evident that the peak acceleration estimated for the earthquakes of concern (the first "a_p" on the right-hand-side of equation (3)) should be determined in a consistent manner with the value of a_p used to calculate the acceleration amplification factor. This implies, among other things, that records processed in the same manner should be used to calculate a_p and the ratio a_{res}/a_p. In determining the appropriate ratio of a_{res}/a_p for near-source, hard rock sites, records digitized at 50 points per second (Johnson, personal communication, 1981) were used. It follows that peak accelerations for reservoir-induced earthquakes should be estimated for a digitized record at 50 points per second, not for some other digitization rate.

The Applicant has estimated values of a_p in an appropriate and consistent way. The effect of digitization at 50 points per second was accounted for by using an upper frequency f_u of 20 hz for the estimates of peak acceleration. For comparison, f_u = 40 hz is appropriate to estimate peak accleration from a 500 points-per-second record. This is illustrated in Table 1, as described above.

Joyner and Fletcher's procedure only uses the peak accelerations of the 500 points-per-second digitized record, and makes no attempt to account for other digitizing rates used in scaling response spectra. Under this procedure, if the instruments of McGarr et al. (1981) had recorded the August 27, 1978 earthquake with frequencies up to several hundred hz, and a peak acceleration of several g had been obtained, this high acceleration would be scaled up to estimate peak acceleration during a M_L = 4.5 earthquake. Such an extreme hypothetical example illustrates why, in addition to other considerations such as effective peak acceleration, instrument characteristics, record processing and correction procedures, and response spectrum scaling methods must be incorporated into the estimates of peak acceleration, as the Applicant has done.

In summary, the theory to estimate peak accelerations used by the Applicant is consistent with instrumental observations at Jenkinsville, with digitized versions of those observations made by USGS, and with the way in which response spectra should be scaled. Further, this methodology for calculating reservoir-induced earthquake response spectra is consistent with the methodology recommended for tectonic earthquakes (Regulatory Guide 1.60). The implications by Joyner and Fletcher that (a) the Applicant has not accounted for strong-motion records at Monticello digitized at 500 points per second, and (b) the peak accelerations from these records are the only data on which seismic evaluations should be made, are erroneous, and do not account for the way peak accelerations are used to evaluate structures.

The second difference mentioned by Joyner and Fletcher is in the area of saturation of ground motion with distance. Joyner and Fletcher imply that the Applicant has changed its position on this issue, but this is decidedly not the case, and Joyner and Fletcher's confusion apparently comes from misreading the record. The Applicant's position is illustrated in Figure 3. At a distance $R < 4r$, the use of a point-source model "... is not strictly applicable; these values (calculated at these distances) are therefore conservative." This is stated in Applicant's Table 361.17.4-2. This is shown in Figure 3 as point A, where the solid line deviates from the dotted line. At closer distances, "... extrapolation of the far-field model to a source-to-site distance of one source diameter (R=2r) gives a reasonable approximation to the saturation level." This is stated in Appendix XI of the Supplemental Seismological Investigation Report. This statement is illustrated in Figure 3 as point B, where the dotted line and dashed line cross. Whether or not Joyner and Fletcher agree with these statements, they are consistent, and the Applicant has not, " introduce(d) distance saturation in a slightly different way in Appendix XI ...," as Joyner and Fletcher state.

The Applicant agrees with Joyner and Fletcher's statement that, "... the assumption that the saturation level corresponds to the value computed at any fixed multiple of the source radius leads to the unpalitable (sic) conclusion that the saturation level decreases with magnitude." In fact the Applicant noted this effect in Appendix XI of the Supplemental Seismologic Investigation: "... earthquakes of M_L = 5.0 and 5.5 would have faulting diameters of 3.6 and 6.3 km, respectively. A blind application of the distance limits discussed above (R=2r) yield peak accelerations of 0.17g and 0.13g, respectively. This does not imply that saturated peak accelerations decrease with magnitude; rather, other factors are important." Among these is the observation that smaller magnitude ($M_L \lesssim 5$) earthquakes are not generally known to rupture the earth's surface, particularly in the Eastern U.S. Thus it is unlikely that a site on the earth's surface would ever be in the near-field, at R=2r, from such an event. Use of the R=2r distance saturation limit is thus conservative for such earthquakes.

The Applicant notes that Joyner and Fletcher do not propose any alternative to choosing saturation distance by scaling by source size. Further, Joyner and Fletcher's mention of R=r as the saturation distance appears to be motivated more by where ground motions are anticipated to decrease from any saturation level (point C on Figure 3) than what distance is appropriate to extrapolate point source models.

The peak acceleration values listed in Joyner and Fletcher's Table 1 are calculated by the following equation:

$$a_p(M) = a_p(2.8)\ 10^{.25(M-2.8)} \qquad (4)$$

where $a_p(M)$ is the predicted peak acceleration for magnitude M and a_p (2.8) is the larger of the two horizontal peak accelerations recorded during the August 27, 1978 earthquake (0.26g). Implicit in equation (4) is the use of a source-to-site distance of 0.7 km for all earthquakes. It is appropriate to make several comments on this methodology.

1. The Applicant knows of no other major facility where the proposed peak accelerations for seismic analysis are based on a single component of one ground motion record, and use such a simple scaling relation as equation (4). The physical parameters which are associated with reservoir-induced earthquakes at Monticello are not addressed adequately.
2. The values from Joyner and Fletcher are derived from an instrumental frequency peak acceleration not appropriate for scaling response spectra.
3. Joyner and Fletcher's Table 1 is critically dependent on the distance between the August 27, 1978 event and the Jenkinsville accelerometer, which was a random occurrence. Suppose this distance had been twice as far, and had caused 0.13g at the accelerometer; would they recommend values half as large as those in Table 1? In effect Joyner and Fletcher have established ground motion saturation levels and distances on the basis of a single chance occurrence.
4. Joyner and Fletcher present no observed data in the magnitude and distance range of Table 1 to support their estimates.
5. There is no method suggested by Joyner and Fletcher to limit the magnitudes for which peak accelerations can be calculated by equation (4).

The Joyner and Fletcher method of scaling peak ground acceleration (a_p) and velocity (v_p) with magnitude (M) can also be written:

$$\log_{10} a_p = -1.285 + 0.25 \ M \quad (5)$$

$$\log_{10} v_p = -1.038 + 0.50 \ M \quad (6)$$

where a_p in equation (5) is in units of gravity and v_p is in cm/sec.

It is instructive to compare these results, by extrapolation, with those given by Joyner and Boore (1981). This is an appropriate comparison because the magnitude coefficients 0.25 and 0.50 in equations (5) and (6) were taken by Joyner and Fletcher from Joyner and Boore (1981). For the case where the distance to the surface projection of the fault rupture is zero, Joyner and Boore (1981) obtain

$$\log_{10} a_p = -1.902 + 0.249\ M \qquad (7)$$
$$\log_{10} v_p = -1.282 + 0.489\ M \qquad (8)$$

Equations (7) and (8) are supported by near-field data for earthquakes in the magnitude range 5.0 to 6.5.

Equations (5) through (8) are evaluated in Table 2 for various magnitudes. Results of extrapolation are indicated by asterisks. The results of Joyner and Fletcher are not similar to those of Joyner and Boore (1981). For magnitude 6.5, equations (5) and (6) yield peak ground acceleration and velocity greater than have ever been measured for naturally-occurring or reservoir-induced earthquakes. For all magnitudes, the results of Joyner and Fletcher greatly exceed those of Joyner and Boore (1981).

There are several reasons for this difference. The Joyner and Fletcher equations are based only on a single horizontal component of one earthquake record. The peak acceleration and velocity of this horizontal component occurred during a very high frequency pulse (and should not be used to scale response spectra, as discussed above). Further, the motion recorded at Monticello Dam is undoubtedly amplified over free-field conditions due to the topographic effects (the instrument sits on an earth dam abutment). The Joyner and Boore (1981) equations are based on a large number of earthquake records from California, including near-field records, and reflect free-field conditions. Thus they are more appropriate to estimate peak accelerations and velocities for important facilities such as nuclear power plants.

SUMMARY

Joyner and Fletcher's review of Virgil C. Summer Nuclear Station seismicity studies is based, in part on a misinterpretation of certain documents and, perhaps in part, on not having had access to complete transcripts of ACRS subcommittee meetings and ASLB hearings. Two concerns of Joyner and Fletcher, the effect of corner frequency on the stress drop estimate for the August 27, 1978 earthquake, and the digitization of the record from that event at 500 points per second, are not issues at all. The Applicant has analyzed both in detail, and its recommendations incorporate those analyses. The estimates of maximum magnitude made by Joyner and Fletcher are based on the area[1/] of observed seismicity; such a method is not valid in the seismic design of important facilities. The third area of Joyner and Fletcher's concern, ground motion saturation, involves significant interpretation and judgment, and the Applicant has acknowledged this. Joyner and Fletcher offer no alternative methods to determine the distance within which ground motion amplitudes are saturated, except to use the distance between the source and recording site for the August 27, 1978 event, a chance occurrence. Further, Joyner and Fletcher use a single component peak acceleration from that event's record to scale peak acceleration and make recommendations. Such a procedure is without precedent. It takes no account of important parameters such as earthquake stress drop, distance to larger events, instrument and record processing procedures, and scaling of response spectra from the predicted peak accelerations. Joyner and Fletcher state that the methods of Newmark and Hall (1969) can be used to compute response spectra given its estimates of peak acceleration (and velocity), but the broad-band amplification factors of Newmark and Hall (1969) would be wholly inappropriate for what Joyner and Fletcher admit would be high frequency motions. This illustrates a position which the Applicant has taken since the beginning: the estimates of peak acceleration must be made in light of the overall design problem and local conditions at the facility.

1/ i.e., Spatial extent.

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1/ Additional Reference: Blume, J.A., "On Instrumental Versus Effective Acceleration, and Design Coefficients", Proceedings, 2nd USA National Earthquake Conference, August, 1979.

APPENDIX

Derivation of a_{rms} for case where lower bound is finite:

$$\tilde{a}(f) = \begin{cases} (.85)\ \frac{\Delta\sigma r}{\rho R\beta} \exp\left(-\frac{\pi f R}{Q\beta}\right)\left(\frac{f}{f_o}\right)^2 & f < f_o \\ (.85)\ \frac{\Delta\sigma r}{\rho R\beta} \exp\left(-\frac{\pi f R}{Q\beta}\right) & f \geq f_o \end{cases}$$

where symbols are as defined in Section 361 of the FSAR.

$$a_{rms}^2 = \frac{1}{T_d}\int_o^{T_d} |a|^2\, dt \equiv \frac{1}{\pi T_d}\int_o^{2\pi f_u} |\tilde{a}(\omega)|^2\, d\omega$$

$$= \frac{c^2}{\pi T_d}\left\{\int_o^{2\pi f_o} \exp\left(-\frac{2\pi f R}{Q\beta}\right)\left(\frac{f}{f_o}\right)^4 d\omega + \int_{2\pi f_o}^{2\pi f_u} \exp\left(-\frac{2\pi f R}{Q\beta}\right) d\omega\right\}$$ 1/

where $c = (.85)\frac{\Delta\sigma r}{\rho R b}$ and $2\pi f = \omega$

Neglecting, conservatively, the first integral,

$$a_{rms}^2 = \frac{c^2}{\pi T_d}\left[-\frac{Q\beta}{R}\exp\left(\frac{-\omega R}{Q\beta}\right)\right]_{2\pi f_o}^{2\pi f_u}$$

$$= \frac{c^2}{\pi T_d}\ \frac{Q\beta}{R}\left[\exp\left(\frac{-2\pi f_o R}{Q\beta}\right) - \exp\left(\frac{-2\pi f_u R}{Q\beta}\right)\right]$$

so that

$$a_{rms} = (.85)(.37)\ \frac{\Delta\sigma}{\rho R^{1.5}}\sqrt{\frac{2Qr}{2.34}}\left[\exp\left(\frac{-2\pi f_o R}{Q\beta}\right) - \exp\left(\frac{-2\pi f_u R}{Q\beta}\right)\right]^{1/2}$$

1/ Numerical correction to formula.

For f_o small and f_u large, the above is the same as equation (9) in McGuire and Hanks (1980). For f_o non-negligible and f_u non-infinite, and for typical values of R, Q, and β:

$$\frac{2\pi f_u R}{Q\beta} < 0.1$$

so:

$$a_{rms} = (.85)(.37) \frac{\Delta\sigma}{\rho R^{1.5}} \sqrt{\frac{2Qr}{2.34}} \left[\frac{2\pi R}{Q\beta} (f_u - f_o)\right]^{1/2}$$

If Δσ is being estimated from recorded a_{rms}, the above equation can be inverted to give:

$$\Delta\sigma = \frac{\rho R^{1.5} a_{rms}}{(.85)(.37)} \left[\frac{4\pi Rr}{2.34\ \beta} (f_u - f_o)\right]^{-1/2}$$

TABLE 1

DATA AND ESTIMATES ON MONTICELLO EARTHQUAKES
PRESENTED TO ACRS SUBCOMMITTEE ON FEBRUARY 26, 1981

EVENT	M_L	Δ, KM	DEPTH, KM	R, KM	F_U, HZ	$\Delta\sigma$, BARS	A_{RMS}, CM/SEC^2	A_{PEAK}, CM/SEC^2
AUGUST 27, 1978 1023 UTC	2.8	0.66	0.1	0.67	40	22	104	221
	OBSERVATIONS:						108	225
AUGUST 27, 1978 1023 UTC	2.8	0.66	0.1	0.67	20	17	53	96
	OBSERVATIONS:						--	93
OCTOBER 27, 1978 0726 UTC (?)	2.7	1.03	0.2	1.05	40	65	106	182
	OBSERVATIONS:						100	185
OCTOBER 27, 1978 1627 UTC (?)	2.8	0.15	0.5	0.52	40	11	77	173
	OBSERVATIONS:						83	169

TABLE 2

Comparison between Joyner and Fletcher

Memorandum and Joyner and Boore (1981)

Moment Magnitude (M)	Joyner and Fletcher		Joyner and Boore	
	Eq. (1) PGA (g)	Eq. (2) PGV (cm/sec)	Eq. (3) PGA (g)	Eq. (4) PGV (cm/sec)
2.8	0.26	2.3	.06*	1.2*
4.6	0.73*	18.3*	.17*	9.3*
5.0	0.92*	29.0*	.22	14.5
5.5	1.23*	51.5*	.29	25.5
6.0	1.64*	91.6*	.39	44.8
6.5	2.19*	162.8*	.52	78.7
7.0	2.91*	289.6*	.69*	138.3*
7.5	3.89*	514.9*	.92*	242.8*

* Extrapolated

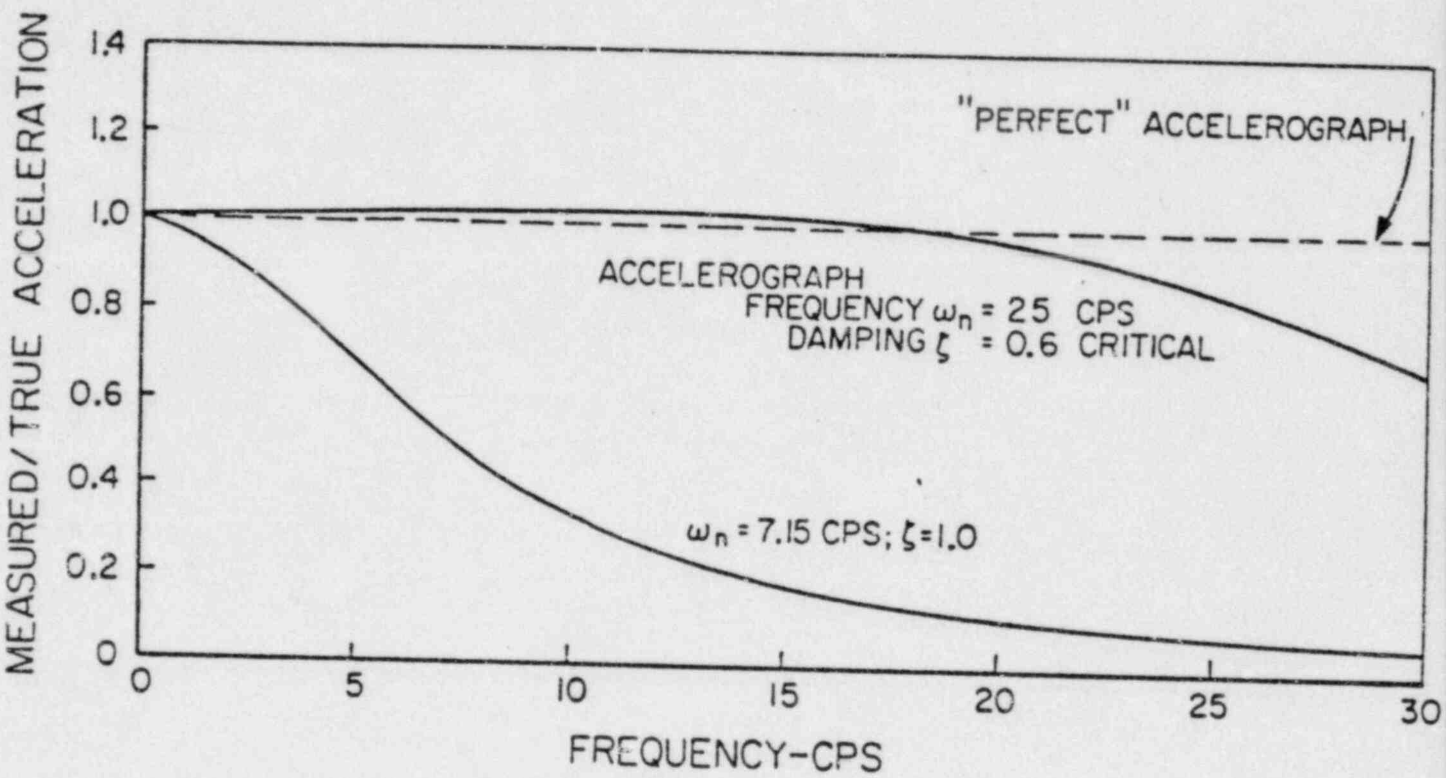

FIGURE 1

TYPICAL ACCELEROGRAPH RESPONSE AS A FUNCTION OF FREQUENCY
(AFTER HUDSON, 1979)

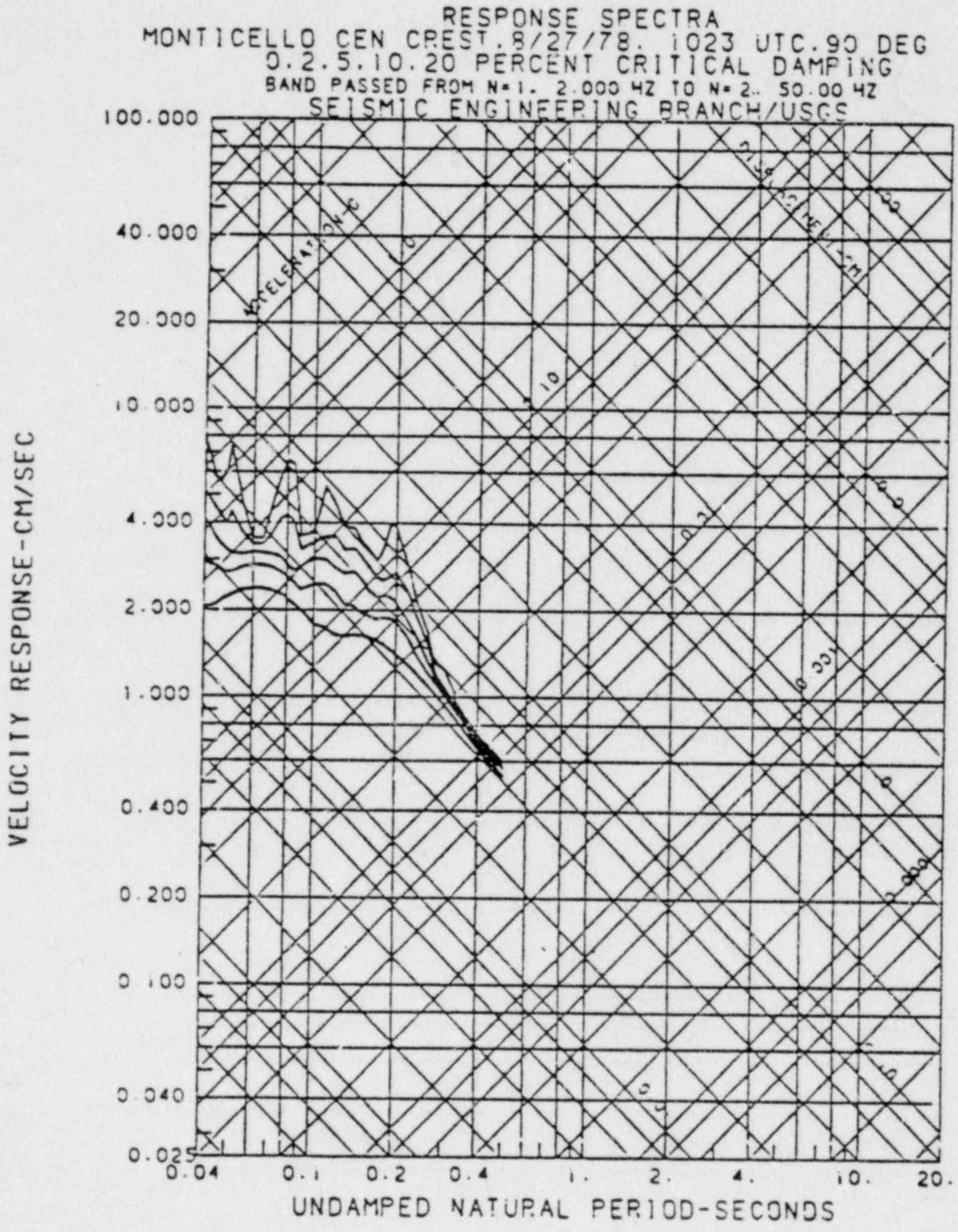

FIGURE 2

RESPONSE SPECTRA FOR 27 AUGUST 1978 EARTHQUAKE, 90° COMPONENT (AFTER BRADY ET AL, 1981)

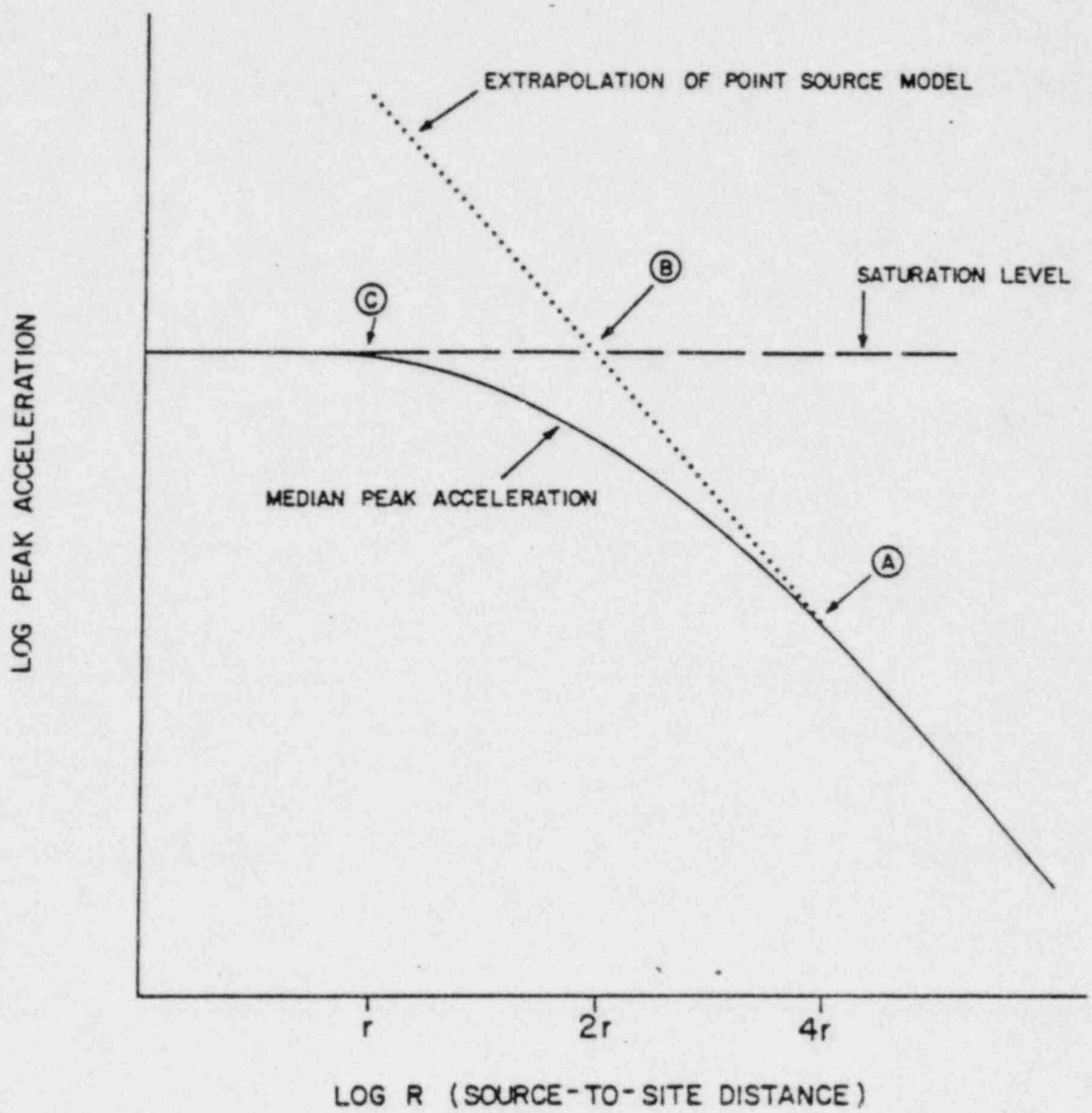

FIGURE 3

CONCEPTUAL REPRESENTATION OF
MEDIAN PEAK ACCELERATION VERSUS DISTANCE