APPLICANT EVALUATION

LUCO REPORT

VIRGIL C. SUMMER NUCLEAR STATION
DOCKET NO. 50/395
SOUTH CAROLINA ELECTRIC & GAS COMPANY
NOVEMBER, 1981

APPLICANT EVALUATION OF LUCO REPORT ON
VIRGIL C. SUMMER NUCLEAR STATION
SEISMICITY STUDIES

Prof. J. Enrique Luco has reviewed the "Supplemental Seismologic Investigation", including Appendix XI, portions of the FSAR (361.13, 361.17.4, 361.21) and portions of the Safety Evaluation Report. His response is contained in a report entitled, "Comments on Estimates of Strong Ground Motion for the V. C. Summer Nuclear Station, Unit I", dated September 23, 1981. The issues raised by Luco result from misinterpretations of the studies which have been performed by the Applicant or from the use of incorrect parameter values in his analyses. This deserves a direct response; the form of the response follows the issues raised by Luco, in order.

<u>ON THE HANKS - MCGUIRE METHOD TO ESTIMATE PEAK ACCELERATION</u>

Luco is correct in pointing out that in the usual characterization of earthquakes via the Brune model (which is done through observations of spectral amplitudes in the frequency domain), stress drops vary greatly and corner frequency and spectral decay at high frequencies are the subject of current discussions. However, the Applicant is not using the Brune model in this usual, frequency-domain application but in the method proposed by Hanks and McGuire (1981). This method (which uses observations of ground accelerations in the time domain) provides remarkably <u>stable</u> estimates of stress drops for past earthquakes (in fact, this is one of the major points of Hanks and McGuire, 1981). That this is the case is recognized later in Luco's report when he states, "The stress drop parameter appearing in the estimate of peak acceleration obtained by Hanks and McGuire has no relation with the stress drop determined by standard seismologic methods. In particular, Hanks and McGuire found that the peak accelerations for events in California could be approximated by a constant stress drop of 100 bars, independent of the stress drops calculated for these events by standard seismological methods." Hanks and McGuire also point out that, regardless of the accuracy or

inaccuracy of this methodology in characterizing corner frequency and high frequency spectral decay, the model works in predicting both root-mean-square (rms) and peak acceleration. Thus Luco's concerns about uncertainties in stress drop, corner frequency, and spectral decay are applicable to frequency domain methods, not to the Applicants' time domain method. Applicants' method does not lead to estimates of peak acceleration which are highly uncertain, as Luco implies, but rather leads to peak acceleration estimates with confidence as high as available by using other state-of-the-art methods.

ESTIMATES OF STRESS DROP

Luco implies that stress drops estimated (in the frequency domain) by standard seismological methods and presented by the Applicant are irrelevant. This is not the case. The Applicant has presented such data in Appendix VII of the Supplemental Seismologic Investigation to give as complete a picture as possible about the data which have been gathered at the site. In the context in which Luco views these data (that of the experience of Hanks and McGuire with California data), the standard stress drop data presented in Appendix VII are entirely consistent. In California, standard stress drop values range from 6 to 140 bars, and the values appropriate for rms acceleration estimates is 100 bars; at Monticello, standard stress drop values range from 1 to 5 bars and the value appropriate for rms acceleration is 25 bars.

The derivation of rms acceleration a_{rms} by Luco is slightly different from that of the Applicant because Luco explicitly includes the term $(1 + (f_o/f)^2)^{-1}$ in the integral, whereas the Applicant does not. The Applicant's derivation, which was used to calculate values of a_{rms} and peak acceleration presented to the ACRS Seismic Subcommittee on February 26, 1981, is given in the attached Appendix. To be sure, the term $(1+(f_o/f)^2)^{-1}$ appears in equations in the Applicants' FSAR section 361.17.4, but the question of whether more accuracy is gained by discarding the term and integrating from $f=f_o$, or including the term and integrating from $f=o$, is moot: the available spectra from Monticello can be fit either way with equal accuracy. The more important point is that it makes little difference

to conclusions gained by comparison of estimates to data at high digitization rates (e.g. 500 points per second, which are presumably most accurate) where f_u=40 or 50 hz is appropriate. This is shown in the attached Appendix (a typical effect on stress drop estimates for these records is 15%). At lower digitization rates there is more effect which accounts in part for the results Luco obtains in comparison to data presented by the Applicant in FSAR Table 361.17.4-1. In any event, conclusions from FSAR Table 361.17.4-1 are obsolete: relocation of the August 27, 1978 earthquake now indicates a source-to-site distance of 0.67 km rather than 0.8 km, and digitization at 500 points-per-second have become available. A more enlightened conclusion is obtained by comparison of predictions with records digitized at 500 points per second. Table 1 shows the appropriate parameters, observations, and predictions made by the Applicant that were presented at the ACRS Subcommittee meeting February 26, 1981. It also shows estimates made by Luco's equation (2) which indicate that a stress drop of 26 bars explains the observations (using Luco's preferred value of f_u=50 hz). Thus the analysis and equations developed by Luco fully support the stress drop value of 25 bars used by the Applicant for the most recent accurate data available on the August 27, 1978 earthquake. The value of 100 bars obtained by Luco in his report is based on an erroneous source-to-site distance (calculated from preliminary depth estimate) of 1.6 km; all investigators familiar with the data including USGS (Fletcher, personal communication, 1981) now agree that a source-to-site distance of about 0.67 km (as used in Table 1) is accurate.

Luco's calculation of stress drop for earthquakes at Hsinfengkiang Reservoir (his Table 2) is incorrect on two counts, thus rendering his conclusions invalid. First, Luco uses an upper frequency of 20 hz, whereas the Chinese strong motion instruments provide linear response up to 35 hz (the Applicant states this in its Appendix XI). Thus f_u=35 hz or greater would be more appropriate. Second, Luco used surface-wave magnitude M_s in place of local magnitude M_L. For the Chinese data (M_L = 3 to 5), M_s is less than M_L by about one unit. As a result, smaller source sizes and larger stress drops are obtained than is correct

for these data. In any case, the important result from the Chinese data is that stress drops determined from peak acceleration do not increase with magnitude; the Applicant made this point in Appendix XI, and Luco apparently agrees with this conclusion. One further point is that the seismological stress drop calculated for the M_s=6.1 main shock of Hsinfengkiang was 7.5 bars (Sheng et al., 1973), a value which is not inconsistent (given the above discussion) with the rms acceleration stress drops reported by the Applicant in Appendix XI.

Luco concludes that a stress drop of 150 bars is appropriate. Not only is this view unsupported by data, it is contradicted by data at Monticello, at Hsinfengkiang, and in California. For the first two locations, stress drops less than 25 bars are indicated; California data are irrelevant to the issue of very shallow induced seismicity and, in any case, indicate a stress drop for rms accelerations of 100 bars. Luco has presented no data which indicate that a stress drop of 150 bars is appropriate to use with the Hanks and McGuire method.

ESTIMATES OF PEAK GROUND ACCELERATION

The peak acceleration values shown by Luco in his Table 3 are invalid for the Virgil C. Summer Nuclear Station because they are based on a 100 bar stress drop. It is not surprising that Luco's Table 3 values agrees with the equations of Joyner et al. (1981) at R=7.3 km (zero epicentral distance)* because these equations are based on California data and Hanks and McGuire have shown that 100 bars is appropriate for California earthquakes.

Data shown by Luco in his Table 4 and his Figure 1 are misleading. He states, that "This sample may be biased towards the largest peak accelerations," (emphasis added), but in fact the sample is biased. For the Oroville data which Luco finds of particular interest, the average of the larger peak accelerations on each record for $4.0 \leq M_L < 5$ is 382 cm/sec^2, whereas, the mean of the Oroville aftershock peak accelerations on bedrock sites for the same magnitude range is 164 cm/sec^2 (Seekins and Hanks, 1978). Thus the data presented by Luco are very much

---

* It appears that Luco has misinterpreted the meaning of the parameter R=7.3 km used by Joyner et al (1981); this is not a depth estimate, so that R is not hypocentral distance as Luco states. Joyner et al (1981) simply use constant R as a parameter to fit their data.

biased toward higher accelerations and should not be used to determine peak acceleration levels. Further, the Oroville aftershocks are characterized by an rms-acceleration determined stress drop of 100 bars which the Applicant has shown is inappropriate for Monticello Reservoir earthquakes.

VERTICAL PEAK ACCELERATIONS

The Applicant agrees with Luco's observation that vertical peak accelerations are generally less than horizontal peak accelerations during earthquakes of magnitude less than 6. Data supporting this have been presented by the Applicant in Section 361.17.4 of the FSAR.

ROCK VERSUS SOIL SITES

The SMA instrument is located on the abutment between Monticello Dams B and C. An examination of the topography of this region indicates that the instrument site is located almost at the top of a hillock that is partly man-made and partly natural. The SMA recording, in all likelihood, represents amplification of the motion of the hillock relative to motion that would be observed in the free-field at either a soil or rock site. Nonetheless, the Applicant has conservatively assumed that no such amplification has occurred in its use of the SMA recording of the August 27, 1978, earthquake to evaluate seismic source parameters. The Applicant maintains, however, that the accelerograph records are not strictly representative of free-field motion, a distinction that Luco fails to draw.

In the free-field, and for short epicentral distances, peak ground accelerations are comparable for rock and soil sites (Campbell, 1981; Joyner and Boore, 1981).

RESPONSE SPECTRUM AT FOUNDATION LEVEL

Luco states that it is not appropriate to compare the 5% and 7% SSE spectra with the 2% M_L=4.5 spectrum to study the effects on equipment at the lower levels of the plant. This statement (which points to the lack of effect of structural damping for foundation equipment) would be true if a fixed base model were used in the analysis. Since foundation compliance was taken into account in the soil structure interaction analysis and the base mat response was amplified 10% relative to the input motion, it is appropriate to compare the 5% and 7% SSE spectra with the 2% M_L=4.5 spectrum for the effects on equipment at the lower levels of the plant.

The conclusions reached by Luco regarding the level of conservatism of response spectra are incorrect. The velocity amplification factor used by Luco (a value of 1.9) is in fact a mean-plus-one standard-deviation (mean + σ) amplification factor, not a mean factor. This is apparent from comparisons with Regulatory Guide 1.60 spectral amplification factors and with the (mean + σ) amplification factor developed by the Applicant for the velocity range (see Table 3). Thus Luco's pseudo-velocity spectral amplitude for 5% damping of 0.29 ft./sec. is a (mean + σ) amplitude, not a mean amplitude.

Further documentation of the Applicant's methodology is provided as follows. The response spectra developed to represent vibratory ground motion from reservoir-induced earthquakes at Monticello Reservoir were derived following requirements indicated in Reg. Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants." Specifically, Reg. Guide 1.60 states that the standard design response spectrum procedure "...does not apply to sites which (1) are relatively close to the epicenter of an expected earthquake or (2) which have physical characteristics that could significantly affect the spectral combination of input motion. The Design Response Spectra for such sites should be developed on a case-by-case basis." The Virgil C. Summer Nuclear Station would be close to the epicenter of any reservoir-induced seismicity of concern; hence site-specific response spectra were developed to represent ground motion for these events.

This procedure consisted of using response spectrum shapes for earthquake ground motions recorded at magnitudes, distances, and site conditions representative of reservoir-induced earthquakes at the Virgil C. Summer facility. These response spectrum shapes, for magnitudes in the range of interest, were then compared to other available data to ensure their applicability.

The shapes for these spectra were taken from the publication of Johnson and Traubenik (1978). These spectral shapes represent ground motions based on records obtained on rock sites for earthquakes with magnitudes (M_L) between 4.7 and 6.5, with source-to-site distances of less than 20 kilometers. The derived spectra for 5 percent damping for M_L = 4.0, 4.5, and 5.3 events scaled to 0.15 g peak acceleration are

labeled "RIS" in Figure 1. These are mean + σ spectra, based on the amplification factors reported by Johnson and Traubenik (1978). Use of the mean + σ spectrum is consistent with the procedure defined as acceptable for standard design response spectra in Reg. Guide 1.60.

Also shown in Figure 1 are the Reg. Guide 1.60 spectrum for 5 percent damping, and the Virgil C. Summer Nuclear Station SSE spectrum for 5 percent damping, both scaled to 0.15 g acceleration (the SSE acceleration at the facility). It is apparent that the derived RIS spectra generally match both the Virgil C. Summer spectrum and the RG 1.60 spectrum at the highest frequencies, but deviate at intermediate and low frequencies, the extent depending on both the earthquake magnitude and the frequency of interest. The reason for this deviation is that broad-banded design spectra typically represent ground motions for earthquakes of magnitude around 6-1/2 (they are derived from recorded ground motions during seismic events with an average magnitude of 6-1/2). The RIS spectra, on the other hand, logically reflect the lack of intermediate and low frequency energy which will be generated during magnitude 4.0 to 5.3 earthquakes with small source to site distances.

Two steps are required to generate site-specific spectra of the type shown in Figure 1, and in comparing these spectra to other results available it is convenient to break the comparison into these two steps. The first step is the estimation of a peak velocity and a peak displacement which are consistent with the peak acceleration of the earthquake of interest. In the present application, the peak velocity-to-acceleration ratio is most critical because it determines the upper corner frequency of the spectrum. The peak displacement is not important in the present application because the Virgil C. Summer SSE spectrum greatly exceeds the RIS spectra in the displacement-controlled region (at lower frequencies).

To evaluate the peak velocities derived by Johnson and Traubenik (1978), we compare them to results derived from other studies. Table 2

summarizes values of peak velocity appropriate for 1 g peak acceleration as obtained for RIS spectra and as derived from results reported by other investigators. Values for rock sites indicate that a peak velocity of about 50 cm/sec for magnitudes around 5.0 is appropriate, as used to characterize RIS spectra. Values for soil sites are generally higher, as shown in the lower half of Table 2; these are not appropriate for the Virgil C. Summer Nuclear Station and are only included here for completeness and to explain results which might be extracted from the literature. To be consistent with the work of Newmark (1973), on which RG 1.60 is based in part, the values shown for peak velocity are mean values, rather than mean + σ or some other values.

The second step in estimating response spectra is to determine amplification factors for the various frequency ranges. These are ratios of spectral response to ground motion parameters. For example, in the high frequency range, one is interested in the ratio of spectral acceleration to peak ground acceleration; at intermediate frequencies one is interested in the ratio of spectral velocity to peak ground velocity.

Table 3 compares spectral amplification factors for the acceleration and velocity ranges as recommended in RG 1.60, as derived for the RIS spectra shown in Figure 1, and as recommended by Newmark and Hall (1969). (As discussed above, the displacement - controlled frequency range is not of particular concern for reservoir-induced earthquakes because of the large degree of conservatism inherent in the design spectrum at lower frequencies.) The RG 1.60 spectra in Table 3 are mean + σ results; the RIS results are also mean + σ amplifications. The velocity amplifications shown in Table 3 for RG 1.60 were calculated from acceleration and displacement amplifications at the indicated frequencies, using an assumed peak velocity of 48 inches per second for 1 g acceleration based on the work of Newmark (1973) on which RG 1.60 is based in part.

The RIS spectral amplifications shown in Table 3 indicate that the representation of reservoir-induced earthquake ground motions is appropriate. These amplifications generally agree with those of RG 1.60, particularly for the higher dampings (5 percent to 10 percent) characterizing structures critical for safe shutdown of the facility, and particularly for the higher frequencies in each range. The Johnson and Traubenik (1978) results on which the RIS amplifications are based were derived for events recorded specifically on rock sites at small source-to-site distances, whereas the RG 1.60 results were obtained from a variety of sites and source-to-site distances. Thus, it would be logical if the uncertainty in spectral amplification would be less for the RIS spectra than for the RG 1.60 spectra; this would result in lower mean + σ spectral amplification for the RIS spectra. The results for 0.5 percent damping undoubtedly reflect this difference in the data sets. This difference in no way detracts from the RIS spectra results: the site and distance conditions of the records on which these results are based more closely reflect the conditions expected during reservoir-induced earthquakes at Monticello Reservoir than do generic broad-banded spectra.

In summary, the spectra developed to represent reservoir-induced earthquake ground motions are based on records obtained at close distances on rock sites. These spectra are consistent with published work of other investigators; they represent mean + σ spectra and have been developed to meet the requirements of RG 1.60.

FLOOR RESPONSE SPECTRA

Luco states that detailed review of structural elements and equipment with high fundamental frequencies is needed. To the extent he means that this review should take account of the high ground motion input levels which he suggests, the Applicant has shown that these levels are inappropriate. To the extent he means that a more detailed review should be undertaken than that described in Appendix X of the "Supplemental Seismologic Investigation", confirmatory studies are ongoing by the Applicant as required in the final recommendations made by ACRS.

SUMMARY

The questions raised by Luco regarding seismicity studies for the Virgil C. Summer Nuclear Station result from misinterpretations of

analyses performed by the Applicant or incorrect data used in Luco's indepedent analyses. The equations derived by Luco differ little from those used by the Applicant, and lead to an estimate of a 26 bar stress drop for the August 27, 1978 earthquake when the correct source-to-site distance is used (0.67 km). Luco's result of a 100 bar stress drop is obtained because he uses incorrect distances.

Similarly, Luco's characterization of earthquakes at Hsinfenkiang Reservoir with a 100 bar stress drop is incorrect. He has erroneously used surface-wave magnitude for local magnitude, and uses an upper fréquency of 20 hz whereas the instruments are linear up to 35 hz. Both errors result in an erroneously large estimated stress drop for the recorded events. The results provided by the Applicant in Appendix XI to the "Supplemental Seismologic Investigation" (stress drops less than 25 bars) are correct. Thus Luco has presented no new analyses or data to indicate that a stress drop greater than 25 bars should be used at Monticello Reservoir.

The predictions of peak acceleration made by Luco are invalid because they assume a stress drop of 100 bars, which is unsupported by any analysis. The peak acceleration data from Oroville aftershocks presented by Luco are biased by a factor of more than two and therefore cannot be used to choose peak accelerations for seismic evaluations. Further, most of the data presented by Luco are from California earthquakes where stress drops of 100 bars are common. It follows immediately that these data are inappropriate to characterize the very shallow, low stress drop[1/] events at Monticello.

The response spectra developed by the Applicant conform to the requirements of Regulatory Guide 1.60. They are consistent with mean +σ spectra and were developed to reflect the near-field, rock site conditions of reservoir-induced earthquakes affecting the Virgil C. Summer Nuclear Station.

1/ i.e., About 25 bars

REFERENCES

Boore, D.M., W.D. Joyner, A.A. Oliver, and R.A. Page (1978), "Estimation of Ground Motion Parameters", U.S.G.S. Circular 795, 43 pp.

Campbell, K.W. (1981), "Near-Source Attenuation of Peak Horizontal Acceleration", submitted to Bull. Seis. Soc. Am.

Hanks, T.C., and R.K. McGuire (1981), "The Character of High Frequency Strong Ground Motion," Bull. Seis. Soc. Am., Vol. 71, December (in press).

Johnson, J.A., and M.L. Traubenik (1978), "Magnitude - Dependent Near Source Ground Motion Spectra", PNC, A.S.C.E. Conf. on Earthquake Eng. and Soil Dynamics, Pasadena, pp. 530-539.

Joyner, W.B., and D.M. Boore (1981), "Peak Horizontal Acceleration and Velocity from Strong Motion Records, including Records from the 1979 Imperial Valley, California Earthquake", submitted to Bull. Seis. Soc. Am.

Joyner, W.B., D.M. Boore, and R.L. Porcella (1981), "Peak Horizontal Acceleration and Velocity from Strong-Motion Records including Records from the 1979 Imperial Valley, California, Earthquake", U.S.G.S. Open-File Rept. 81-365, March, 46 pp.

Newmark, N.M., Consulting Engineering Services (1973), "A Study of Vertical and Horizontal Earthquake Spectra", Urbana, Illinois, USAEC Contract No. AT (49-5)-2667, WASH-1255, April.

Newmark, N.M., and W.J. Hall, (1969). "Seismic Design Criteria for Nuclear Reactor Facilities," Proc, 4th World Conf. on Earthquake Eng., Santiago.

Page, R.A., D.M. Boore, W.B. Joyner, and H.W. Coulter (1972), "Ground Motion Values for Use in the Seismic Design of the Trans-Alaska Pipeline System", U.S.G.S. Circular G72, 23. pp.

Seekins, L.C., and T.C. Hanks (1978), "Strong Motion Accelerograms of the Oroville Aftershocks and Peak Acceleration Data," Bull. Seis. Soc. Am., Vol. 68, pp. 667-689.

Sheng, C.K., et al., (1973), "Earthquakes Induced by Reservoir Impounding and their Effect on Hsinfengkiang Dam," Scientia Sinica, Peking, April.

Trifunac, M.D., and A.G. Brady (1976), "Correlation of Peak Acceleration, Velocity, and Displacement with Earthquake Magnitude, Distance, and Site Conditions", Earthquake Eng. and Struc. Dyn., Vol. 4, pp. 455-471.

APPENDIX

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

$$\tilde{a}(f) = \begin{cases} (.85)\ \frac{\Delta\sigma r}{\rho R\beta}\ \exp\left(-\ \frac{\pi f R}{Q\beta}\right)\left(\frac{f}{f_o}\right)^2 & f < f_o \\ (.85)\ \frac{\Delta\sigma r}{\rho R\beta}\ \exp\left(-\ \frac{\pi f R}{Q\beta}\right) & f \geq f_o \end{cases}$$ 1/

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

$$a_{rms}^2 = \frac{1}{T_d}\int_0^{T_d} |a|^2\, dt = \frac{1}{\pi T_d}\int_0^{2\pi f_u} |\tilde{a}(\omega)|^2\, d\omega$$

$$= \frac{c^2}{\pi T_d}\left\{\int_0^{2\pi f_o} \exp\left(\frac{-2\pi f R}{Q\beta}\right)\left(\frac{f}{f_o}\right)^4 d\omega + \int_{2\pi f_o}^{2\pi f_u} \exp\left(\frac{-2\pi f R}{Q\beta}\right) d\omega\right\}$$ 1/

where $c = (.85)\frac{\Delta\sigma r}{pRb}$ 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 formulas.

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 $\Delta\sigma$ is being estimated from recorded a_{rms}, the above equation can be inverted to give:

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

Changing variables leads to

$$\Delta\sigma = C\, a_{rms} \sqrt{\frac{f_o}{2f_u}} \left(1 - \frac{f_o}{f_u}\right)^{-1/2}$$

where C is a constant. Equation (2) of Luco can be put in the same form:

$$\Delta\sigma\ (\text{Luco}) = C\, a_{rms} \sqrt{\frac{f_o}{2f_u}}\ I\,(f_u/f_o)^{-1}$$

where I (f_u/f_o) is given in Luco's equation (3).

Note that both of the last two equations must be solved by recursion because f_o is function of $\Delta\sigma$.

The difference in calculated $\Delta\sigma$ between the two methods for any given a_{rms} is a funtion of f_u/f_o:

f_u/f_o	$\Delta\sigma$ (Luco)/$\Delta\sigma$ (Applicant)
2	1.36
4	1.19
5	1.15

From the above values it is evident that the difference is only important when f_u is close to f_o. In other cases, e.g. when f_o is 10 hz and f_u is 40 or 50 hz, which is the case for the most accurate records digitized at 500 points per second, there is only some 15% to 19% difference between the method used by the Applicant and that derived by Luco.

TABLE 1

Observations and estimates of rms and peak accelerations for August 27, 1978 earthquake. (Observations and Applicant's estimates presented at February 26, 1981 ACRS Subcommittee meeting.)

Parameters	Applicant's Estimate	Estimate using Luco Equation (2)
M	2.8	2.7
M_o, dyne-cm	1.12×10^{20}	1.12×10^{20}
$\Delta\sigma$, bars	22	26
f_u, hz	40	50
R, km	0.67	0.67
a_p/a_{rms}	2.14	2.16
a_{rms}, cm/sec.^{2}	104	111
a_p, cm/sec.^{2}	221	240
Observations:		
average a_{rms}, cm/sec.^{2}	108	108
average a_p, cm/sec.^{2}	225*	241**

* Filtered/Windowed Record, as presented to ACRS.

** Volume II Record (CIT Procedures)

TABLE 2

Peak Velocity for 1 g Peak Acceleration

Site Conditions	Author	Magnitude	Distance	Peak Velocity, cm/sec
ROCK	This Study, RIS Spectra	4.0	near-field	13
		4.5	near-field	26
		5.3	near-field	51
	Joyner et al (1981) USGS OF 81-365	5.0	R = 0	50
	Trifunac and Brady (1976)	5.0-5.9	All	57
SOIL	Joyner et al (1981) USGS OF 81-365	5.0	R = 0	73
	Boore et al (1978) USGS Circ. 795	5.3-5.7	5 km	90 (small struc.)
				95 (all struc.
			10 km	80 (small struc.)
				70 (all struc.)
	Trifunac and Brady (1976)	5.0-[illegible].9	All	92
	Page et al (1972) USGS Circ. 672	5.5	3-5 km	110

TABLE 3

Comparison of Spectral Amplification Factors

	Damping	Regulatory Guide 1.60	Newmark & Hall (1969)	RIS Spectra
Acceleration Amplification	0.5%	4.96 at 9 hz 5.95 at 2.5 hz	5.8	4.5
	5%	2.61 at 9 hz 3.13 at 2.5 hz	2.6	2.6
	10%	1.90 at 9 hz 2.28 at 2.5 hz	1.5	2.0
Velocity Amplification	0.5%	3.05 at 2.5 hz 3.77 at 0.25 hz	3.6	2.3
	5%	1.60 at 2.5 hz 2.42 at 0.25 hz	1.9	1.6
	10%	1.17 at 2.5 hz 2.00 at 0.25 hz	1.3	1.3

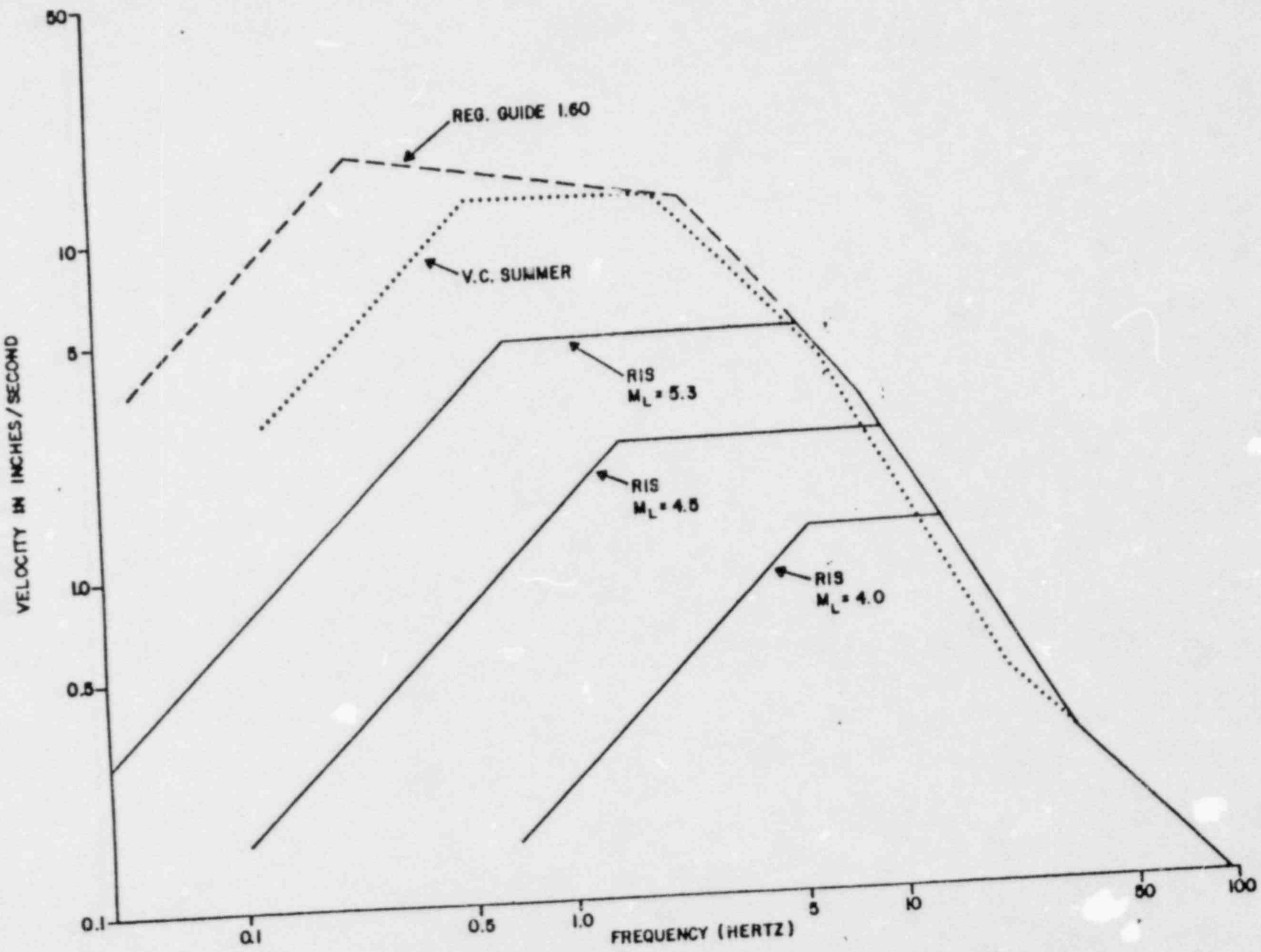

FIGURE 1 V.C. SUMMER, REG. GUIDE 1.60, and RIS SPECTRA, 5 % DAMPING

REVISED