SUPPLEMENTAL ANALYSIS OF DISPERSION FOR THE 1975 OROVILLE AND THE 1979 IMPERIAL VALLEY AFTERSHOCK DATA

Prepared for

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The multiple regression analyses presented in Appendix A of the June 1982 Woodward-Clyde Consultants (WCC) report provide the model parameters which give the best fit to all the data (given the selected model). The resulting model may overpredict or underpredict the median accelerations for individual events. This represents model bias for individual events. Multiple regression averages the model biases for individual events to produce zero net bias for the total data set.

In the June 1982 WCC report, based on the examination of dispersion values from several individual earthquakes and groups of aftershocks (see Table on page A-11 and Figure A-13 in Appendix A of the June 1982 report), it was concluded that the dispersion decreases significantly as the magnitude of the event increases.

The dispersion values in the June 1982 report for the small magnitude events were based on multiple events with relatively wide magnitude bands in contrast to single events for larger magnitudes. In the August 4, 1982 meeting with NRC, results of dispersion analyses were presented for the smaller earthquakes; these results are summarized on Table 1 and designated as item (a), "Narrow Magitude-Band Analyses". Comparison of these dispersion values with the corresponding values for larger magnitude bands in Appendix A (Figure A-13) of the June 1982 report shows that reducing the magnitude ranges while leaving enough data to allow meaningful statistical inferences results in dispersion estimates consistent with the selected relationship shown on Figure A-13.

Additional analyses were subsequently conducted to further demonstrate that dispersion relationships shown in Appendix A of the June 1982 report for the small magnitude events is not affected by use of multiple events with relatively wide magnitude bands. The results of these analyses are shown in Table 1, item (b), "Single-Magnitude Analyses," and Table 2 for individual aftershocks of the 1975 Oroville and 1979 Imperial Valley earthquakes.

In Table 1, the results of dispersion analyses are expressed in terms of dispersion parameters s_1 and s_2. Parameters s_1 represents the mean square error of the data about the predicted values and includes the effects of both dispersion in the data and model bias

$$s_1 = \left(\frac{\sum_{i=1}^{N} \varepsilon_i^2}{N - m} \right)^{1/2}$$

where ε_i is the difference between the observed acceleration

$\ln y_i$ and the acceleration predicted by the model, $\ln \hat{y}_i$

$$\varepsilon_i = \ln y_i - \ln \hat{y}_i$$

N is the number of data points in the subset and m is the number of parameters in the model determined by regression. s_2 represents the actual dispersion in the data. It is obtained by removing the model bias from the mean square error.

$$\delta = \frac{\sum_{i=1}^{N} \varepsilon_i}{N}$$

where δ is the model bias given by

$$s_2 = \left(\frac{\sum_{i=1}^{N} \varepsilon_i^2 - \left(\sum_{i=1}^{N} \varepsilon_i \right)^2 / N}{N - m} \right)^{\frac{1}{2}} = \left(s_1 - \frac{N}{N - m} \delta^2 \right)^{\frac{1}{2}}$$

Note that dispersion parameter s_1 which includes the effects of both dispersion in the data and model bias provides a more consistent basis for relative comparisons with the average dispersion values from the multiple regression analysis of the total data set.

Examination of calculated values for dispersion parameter s_1 summarized in Tables 1 and 2 shows that the large apparent variations in the dispersion for any given magnitude or single aftershock result only when there is too small a sample to allow stable and meaningful statistical computations to be made. For cases with adequate or even marginal sample sizes, the computed values of dispersion s_1 are within a relatively narrow range and in very good overall agreement with the dispersion values given in Appendix A of the June 1982 report for wider magnitude-band ranges and with the selected relationships shown in Figure A-13.

TABLE 1 - DISPERSION ANALYSIS RESULTS FOR THE 1975 OROVILLE AND THE 1979 IMPERIAL VALLEY AFTERSHOCK DATA

EVENT	MAGNITUDE	NO. OF DATA	s_1 (lna)	s_2 (lna)
	(a) Narrow Magnitude-Band Analyses			
OR75A*	4.0-4.3	52	0.75	0.75
	4.6-4.9	60	0.65	0.57
IV79A**	4.0-4.3	40	0.72	0.68
	4.5-4.9	40	0.77	0.77
	5.1-5.2	66	0.59	0.59
	(b) Single-Magnitude Analyses			
OR75A	4.0	26	0.68	0.57
	4.1	14++	0.71	0.48
	4.3	12++	1.18	0.76
	4.6	26	0.68	0.57
	4.7	22	0.78	0.62
	4.9	12++	0.43	0.43
IV79A	4.0	16++	0.70	0.68
	4.1	4+	0.74	0.57
	4.2	14++	1.03	0.97
	4.3	6+	0.43	0.35
	4.5	14++	0.80	0.76
	4.6	14++	0.68	0.67
	4.8	6+	1.54	0.48
	4.9	6+	0.99	0.98
	5.1	36	0.52	0.47
	5.2	30	0.70	0.64

* OR75A refers to Aftershock(s) of the 1975 Oroville earthquake.

** IV79A refers to Aftershock(s) of the 1979 Imperial Valley earthquake.

\+ Definitely too few data points to provide statistically stable and/or meaningful dispersion values.

++ Marginal number of data points to provide statistically stable and/or meaningful dispersion values.

TABLE 2 - DISPERSION ANALYSIS RESULTS FOR INDIVIDUAL AFTERSHOCKS OF THE 1975 OROVILLE AND THE 1979 IMPERIAL VALLEY EARTHQUAKES

EVENT	MAGNITUDE	NO. OF DATA+	s_1 (lna)	s_2 (lna)
OR75A*	4.0	14	0.67	0.65
	4.0	12	0.71	0.45
	4.1	14	0.71	0.48
	4.3	12	1.18	0.76
	4.6	14	0.61	0.59
	4.6	12	0.85	0.52
	4.7	6	0.66	0.55
	4.7	16	0.89	0.42
	4.9	12	0.43	0.43
IV79A**	4.0	4	1.29	0.84
	4.0	4	0.38	0.28
	4.0	4	1.79	0.57
	4.1	4	0.74	0.57
	4.2	6	1.52	0.40
	4.2	6	1.24	1.13
	4.3	6	0.43	0.35
	4.5	4	1.47	1.43
	4.5	8	0.97	0.72
	4.5	4	0.82	0.38
	4.6	8	0.80	0.77
	4.8	6	1.54	0.48
	4.9	6	0.99	0.98
	5.1	18	0.59	0.53
	5.1	18	0.49	0.44
	5.2	30	0.70	0.64

* OR75A refers to Aftershock(s) of the 1975 Oroville earthquake.

** IV79A refers to Aftershock(s) of the 1979 Imperial Valley earthquake.

\+ With few exceptions, the number of data points are either too few or marginal to provide statistically stable and/or meaningful dispersion values from these individual aftershock analyses.

Attachment 6

Literature Survey and Development of
Strong-Motion Duration for Designs
at the SONGS Site
August 6, 1982

LITERATURE SURVEY AND DEVELOPMENT OF STRONG-MOTION DURATION FOR DESIGNS AT THE SONGS SITE

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6 August 1982

1. INTRODUCTION

This report is prepared in response to Dr. Reiter's request of 4 August 1982 for information to support changing the site design strong-motion duration from 80 sec. to some smaller value. That value was selected in the early 1970s, and much has been published on the specific topic of close-in strong motion durations since that time. In addition, a model earthquake has occurred (IV-79), and the physical principles of the faulting process have become better understood. The next four sections (2, 3, 4, and 5) will present the new data, and other considerations. The final section (6) will present a recommendation for the selection of the SONGS design strong-motion duration.

2. LITERATURE SURVEY

1964 Esteva, L., and E., Rosenblueth: "Espectros de Temblores y Grandes," Bol., Soc. Mex. Ing. Sism. 2 (1), 1-18. Introduced the concept of equivalent ground motion with uniform intensity per unit of time. Pertinent equation is, $D = 0.02 \exp(0.74\ M) + 0.3\ R$ for M7R8, D = 6 to 8 sec (mid).*

1965 Housner G. W.: "Intensity of Ground Shaking Near the Causative Fault," Proc., Third World Conference on Earthquake Engineering, New Zealand, 3, 94-109.

* (mid) indicates mid-range value

Proposed an enveloping upper bound for duation close-in to moderate-size earthquakes (M>5): D = 11.2M-53 for M7R8, D = 24 sec. (Max).*

1973 Bolt, B. A., "Duration of Strong Motion," Proc., Fifth World Conference on Earthquake Engineering, Rome, 6D, 1304-1313. Proposed two definitions of duration: 1) the Brocketed Duration, D_b, "the elapsed time between the first and last acceleration excursions greater than a given level;" and the Uniform Duration, D_u, "at a particular frequency, f, the total time for which acceleration at that f exceeds a given value. By these definitions, the values of duration clearly depend upon the threshhold acceleration level, A_t, chosen as shown in Figure 1(a). Bolt's envelope of the Brocketed Duration, given in Figure 1(b), depends for its peak value solely on the 1940 El Centro duration of about 25 sec. That record has an appearance different from other close-in strong-motion recordings, as shown in Figure 2. That value was ignored in this review, so that the curve -- x -- was used for this study.

For M7R8

D_b = 16 sec (Max)

D_u = 26 sec for A_t > 0.05 g (Max)

D_u = 14 sec for A_t > 0.10 g (Max)

1975 Trifunac, M. D. and A. G. Brady: "A study on the Duration of Strong Earthquake Ground Motion," Bull., Seis. Soc. America, 65(3), 581-626. Developed durations for the time histories of acceleration, velocity, and displacement, and regressed values against several measures of earthquake size and effect. Defined

* (Max) indicates maximum value

duration as the time interval bewteen the 5th and 90th percent of the maximum of the time integral of the square of the kinematic quantity being studied (e.g., acceleration, velocity, or displacement). The resulting equation for such a duration (based on acceleration) is: $D = 2.33M + 0.149R - 4.88$ for M7R8, D = 13 sec (mid).

1975 Hays, W. W.: "A Note on the Duration of Earthquake and Nuclear-Explosion Ground Motions," Bull., Seis. Soc. of America, 65(4), 875-883. Used earthquake and close-in nuclear data to develop curves of duration as function of M and R. Defined duration as "the amount of time that the absolute acceleration is $\geq$ 5 percent g." The result is Figure 3.

1977 Hudson, D. E.: "Strong Motion Earthquake Measurements in Epicentral Regions," Proc., Sixth World Conference on Earthquake Engineering, New Delhi, 1, 323-329. Tabulated the important characteristics of sixteen avaialble close-in strong-motion recordings. The results are given in Figure 4. Neglected in this study were: El Centro 1940, a very large, massive foundation; Olympia, 1949, R not known; and Koyna, 1967, on the dam.

For M7, R8,
D_{avg} = 5.9 sec (mid)
Range = 2 to 13 sec

1977 Chang, F. K. and E. L. Krinitzky: "Duration, Spectral Content, and Predominant Period of Strong Motion Earthquake Records from Western United States," Misc. Paper 5-73-1, U. S. Corps of Engineers, WES. Performed a log-log linear regression of envelope of close-in strong-motion data. Uses Bracketed Duration for A_t > 0.05 g. The result for soil sites is shown in Figure 5. The curves are presented up to M 8.5, and do not depend heavily on the data for either their positioning or shape. Similar results for rock are shown in Figure 6.

For M7R8,
D = 32 sec for soil (Max)
D = 17 sec for rock (Max)

1977 Von Marcke, E. H. and Ss. P. Lai: "Strong-Motion Duration of Earthquakes," <u>Pub. R77-16</u>, MIT. A correlation of duration to I/axa, where I is Arias Intensity, and a is the rms acceleration. The work clearly identified the relationship between duration and acceleration, Figure 7, due presumably to an implicit relationship between acceleration and distance. The results in terms of magnitude are given in Figure 8.

For M7R8
D = < 1 sec for Amax = 0.67 g (max)
D = 8 sec for magnitude 7 at 8km per equation (mid)

1978 Dobry, R., I. M. Idriss, and E. Ng: "Duration Characteristics of Horizontal Components of Strong-Motion Earthquake Records," <u>Bull</u>., Seis. Soc. America, 68(5), 1487-1520. Correlation of duration with magnitude, distance, and site conditions. Duration defined as time between 5th and 95th of maximum of Arias Intensity curve. Results are given for rock in Figure 9, and for soil in Figure 10. In Figure 10, the close-in deep-cohesionless data are sparse, but 24 sec. seems to envelope the data, which are shown wtih brackets.

For M7R8

D = 15 sec for rock (mean)

D = 24 sec for soil (Max)

3. MODEL EARTHQUAKE

The IV-79 event provided close-in strong-motion data which are likely a good model for the postulated M7 event on the OZD at R8. Figure 11 presents the strongest motions and their durations. For PGA = 0.67 g, the enveloping duration is D = 10 sec (Max).

4. CLOSE-IN DATA

Figure 12 shows duration as a function of PGA for several well recorded recent earthquakes. For PGA = 0.67 g, D = 5 sec (mid). Figure 13 shows the same data, replotted as a function of distance. For R = 8 km, D = 10 sec (mid).

5. OZD CONSIDERATIONS

The maximum rupture length for the OZD is 40 km, by testimony to the ASLB. The site is only 8 km from the OZD, so one good approximation to the upper limit of strong-motion duration would be the time required for the rupture to take place. If the rupture progresses at 2.2 km/sec, and the rupture is unilateral, D = 18 sec (Max). If the rupture is bilateral, D = 9 sec (mid).

6. RECOMMENDATIONS

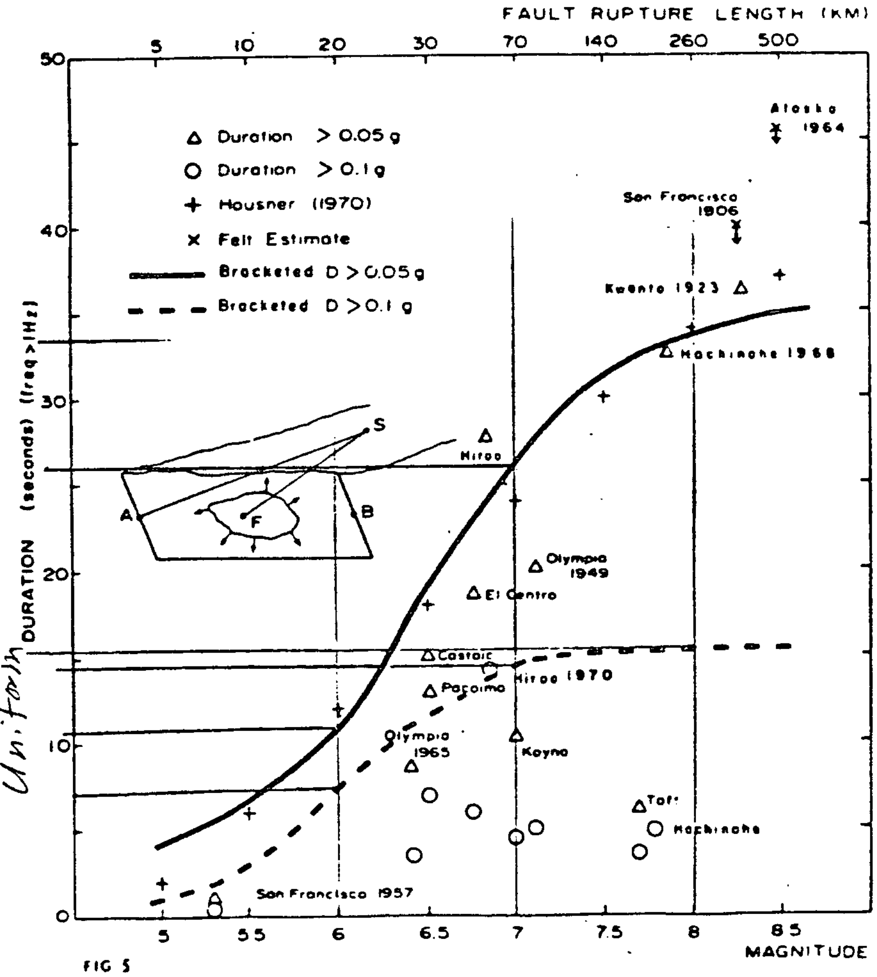
The duration of strong motions for this site will be used with ground-motion parameters which are at least 84th percentile instrumental values. For this reason, the use of the mid values in Table 1 is appropriate. These values range from 5 to 16 seconds, and the eight values average to 10 seconds. From this point of view, any mean design duration equal to about 10 seconds would be a conservatively accurate representation of the situation. Any value of mean design duration greater than about 10 seconds would be more conservative, for situations where duration affects design. As indicated in Table 1 the average of the maximum durations is 18 seconds. Therefore, the use of a 20-second or greater duration in design structure would exceed both the average max. and mid. values and is considered very conservative.

TABLE

ANALYSIS OF DURATION DATA

Author	Max (M) or mid (m)	SONGS Conditions R8 M7	R = 8		M7		Used
			M6	M8	R5	R15	
Esteva, et al (1964)	M	6.0	4.1	9.9	5.1	8.1	No
Housner (1965)	M	24	13	35	24	24	No
Bolt (1973)							
Brocketed	M	26 (16)	26	26	26	26	No (Yes)
Uniform							
a > 0.05 g	M	26	11	33	26	26	Yes
a > 0.10 g	M	14	7	16	14	14	Yes
Trifunac, et al (1975)	m	13	10	15	12	14	Yes
Hayes (1975)	m	16	9	23	19	12	Yes
Hudson (1977)	m	5.9 average, range 2 to 13 seconds					Yes
Chang et al (1977)							
Soil	M	32	17	62	-	30	Yes
Rock	M	17	10	33	-	15	Yes
Von Marcke, et al (1978							
PGA = 0.67 g	M	1	-	-	-	-	Yes
M7 R8	m	8.4	5.6	11	8.2	8.9	Yes
Dobry et al (1978)							
Rock	m	15	15	15	5.1	-	Yes
Soil	M	24	24	24	24	24	Yes
IV-79 (1979)	M	10	-	-	-	-	Yes
Close-in Data (1982)							
PGA = 0.67 g	m	5	-	-	-	-	Yes
R = 8 km	m	10	-	-	9	14	Yes
OZD, M7 R8							
Unilateral	M	18	-	-	-	-	Yes
Bilateral	m	9	-	-	-	-	Yes

Average of Maximum = 18 sec
Average of mid = 10 sec
Average of all = 14 sec



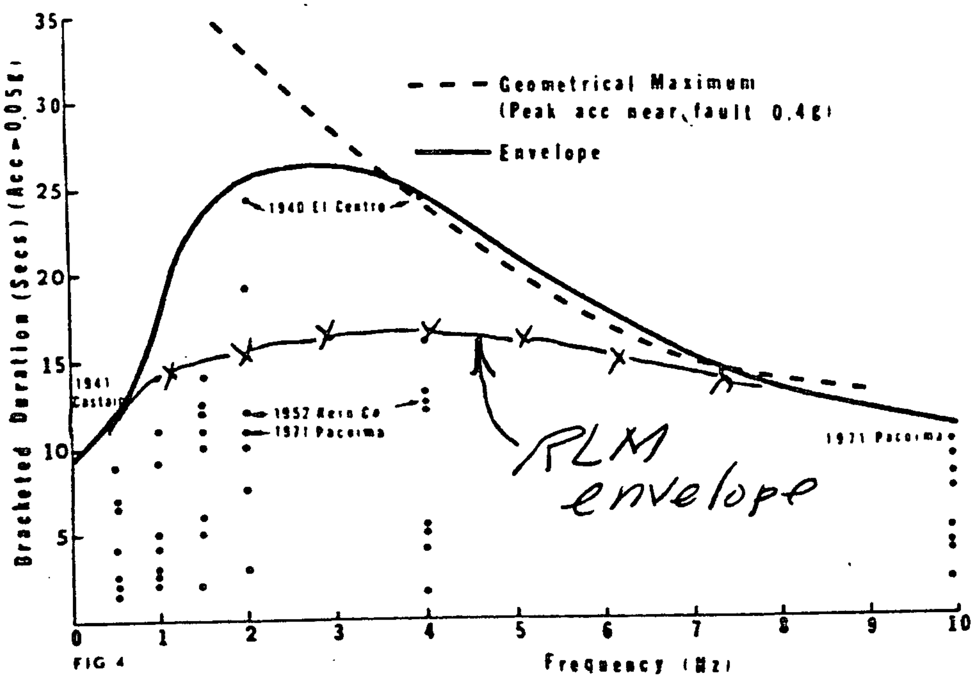
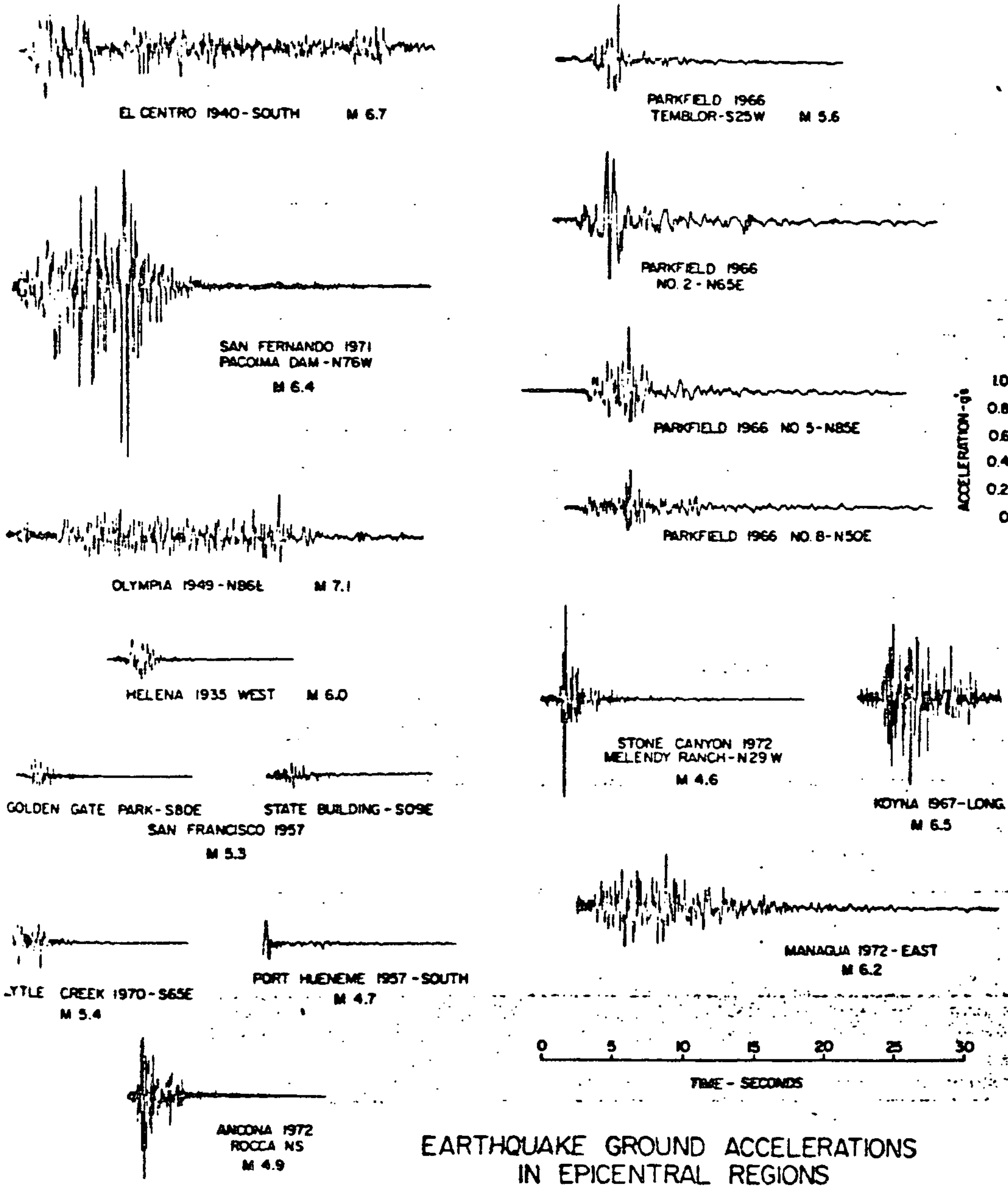


FIGURE 1: BOLT (1975)



EARTHQUAKE GROUND ACCELERATIONS IN EPICENTRAL REGIONS

Figure 1

FIGURE 2: HUDSON (1977)

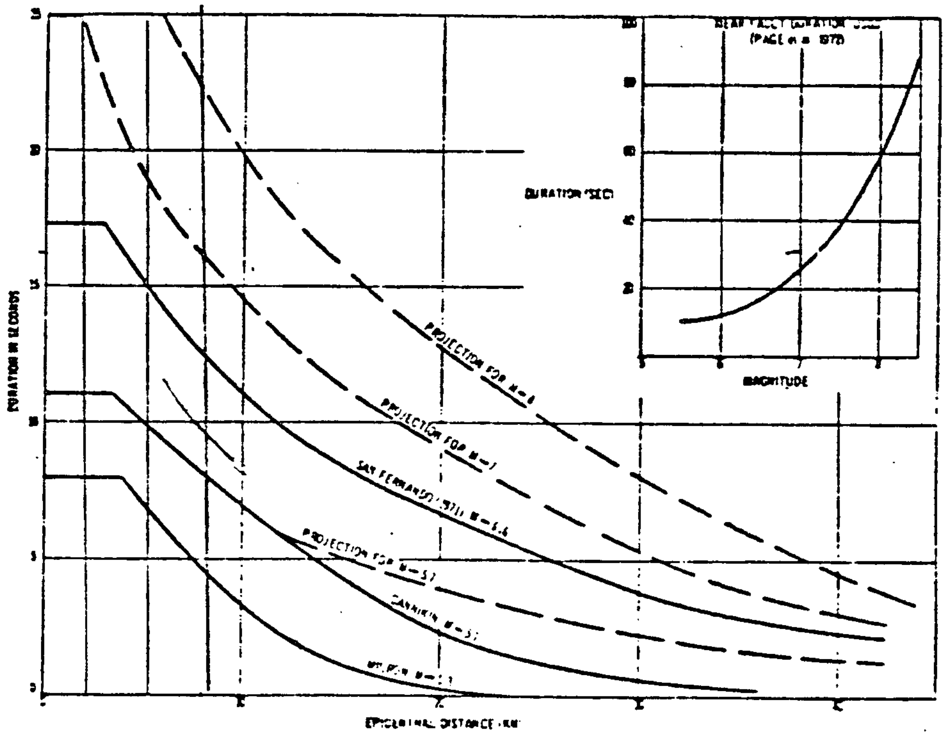


FIG. 5. Variation of duration with epicentral distance for San Fernando earthquake and the CANNIKIN and MILROW nuclear explosions.

FIGURE 3: HAYS (1975)

TABLE I

MAXIMUM GROUND MOTIONS FROM NEAR-FIELD EARTHQUAKE MEASUREMENTS

Earthquake	Peak Acceleration (g's)			Peak Velocity (cm/sec)			Peak Displacement (cm)		
	H1[I]	H2[I]	V[I]	H1	H2	V	H1	H2	V
EL CENTRO, 1940	0.36	0.22	0.28	33.4	36.9	10.8	10.9	19.8	5.6
SAN FERNANDO, 1971	1.24	1.25	0.72	113.2	57.7	58.3	37.7	10.8	19.3
OLYMPIA, 1949	0.16	0.31	0.10	21.4	17.0	6.8	8.5	10.4	4.0
HELENA, 1935	0.14	0.16	0.10	7.3	13.3	9.5	1.4	3.7	2.8
PARKFIELD, 1966 (T)	0.28	0.41	0.16	14.5	22.5	4.4	4.7	5.5	1.4
PARKFIELD NO. 2	0.51	—	0.35	77.9	—	14.1	26.3	—	4.3
PARKFIELD NO. 5	0.40	0.47	0.18	22.5	25.4	6.8	5.2	7.1	3.4
PARKFIELD NO. 8	0.28	0.28	0.14	10.8	11.8	4.5	4.4	3.9	2.1
SAN FRAN., 1957, GGP	0.11	0.12	0.05	4.9	4.6	1.2	2.3	0.8	0.7
SAN FRAN. STATE	0.10	0.07	0.05	5.1	4.0	2.3	1.1	0.9	0.6
LYTLE CREEK, 1970	0.15	0.20	0.08	8.7	9.6	3.1	2.1	1.0	1.4
PORT HUENEME, 1957	0.17	0.09	0.03	17.9	8.9	1.9	4.0	2.6	0.5
STONE CANYON, 1972	0.56	0.71	0.20	18.5	19.5	4.8	0.3	0.6	0.3
KOYNA, 1967	0.63	0.49	0.34	30.0	25.2	34.6	10.1	19.4	24.1
MANAGUA, 1972	0.33	0.38	0.33	30.0	37.7	17.5	6.2	14.9	8.7
ANCONA, 1972	0.61	0.45	0.30	9.4	9.4	4.0	0.7	0.7	0.2

[I] H1, H2 = Horizontal; V = Vertical

TABLE II

GROUND MOTION PARAMETERS FROM NEAR-FIELD EARTHQUAKE MEASUREMENTS

Earthquake	Magnitude	Max. M. M. Intensity	Peak Ground Velocity (cm/sec)[I]	Max. Response Velocity (cm/sec)[II]	Acceleration Duration (sec)[III]	$\left[\int a^2 dt\right]_{max}$[IV] ($m^2/sec^3$)
EL CENTRO	6.7	X	35	66	25	21
SAN FERNANDO	6.4	X-XI	85	150	7	109
OLYMPIA	7.1	VIII	19	32	22	13
HELENA	6.0	VIII	10	16	2	1
PARKFIELD, T.	5.6	VII	19	39	5	5
PARKFIELD NO. 2	5.6	VII	78	114	7	12[V]
PARKFIELD NO. 5	5.6	VII	24	48	7	10
PARKFIELD NO. 8	5.6	VII	11	19	13	5
SAN FRAN. GGP	5.3	VII	5	9	3	6
SAN FRAN. STATE	5.3	VII	5	10	6	6
LYTLE CREEK	5.4	VII	9	19	3	2
PORT HUENEME	4.7	VI	13	16	9	1
STONE CANYON	4.6	VI	19	37	2	10
KOYNA	6.5	VIII+	28	37	8	19
MANAGUA	6.2	IX	34	53	10	24
ANCONA	4.9	VIII+	9	21	3	7

[I] Average of two horizontal components.

[II] $(SV)_{max}$ at 10% damping. Average two horizontal components.

[III] Time to $\left[\int a^2 dt\right]_{max}$ minus first and last 5%. Average two horizontal components.

[IV] $\int_0^T (a_{H1}^2 + a_{H2}^2)dt$.

[V] One component only.

FIGURE 4: HUDSON (1977)

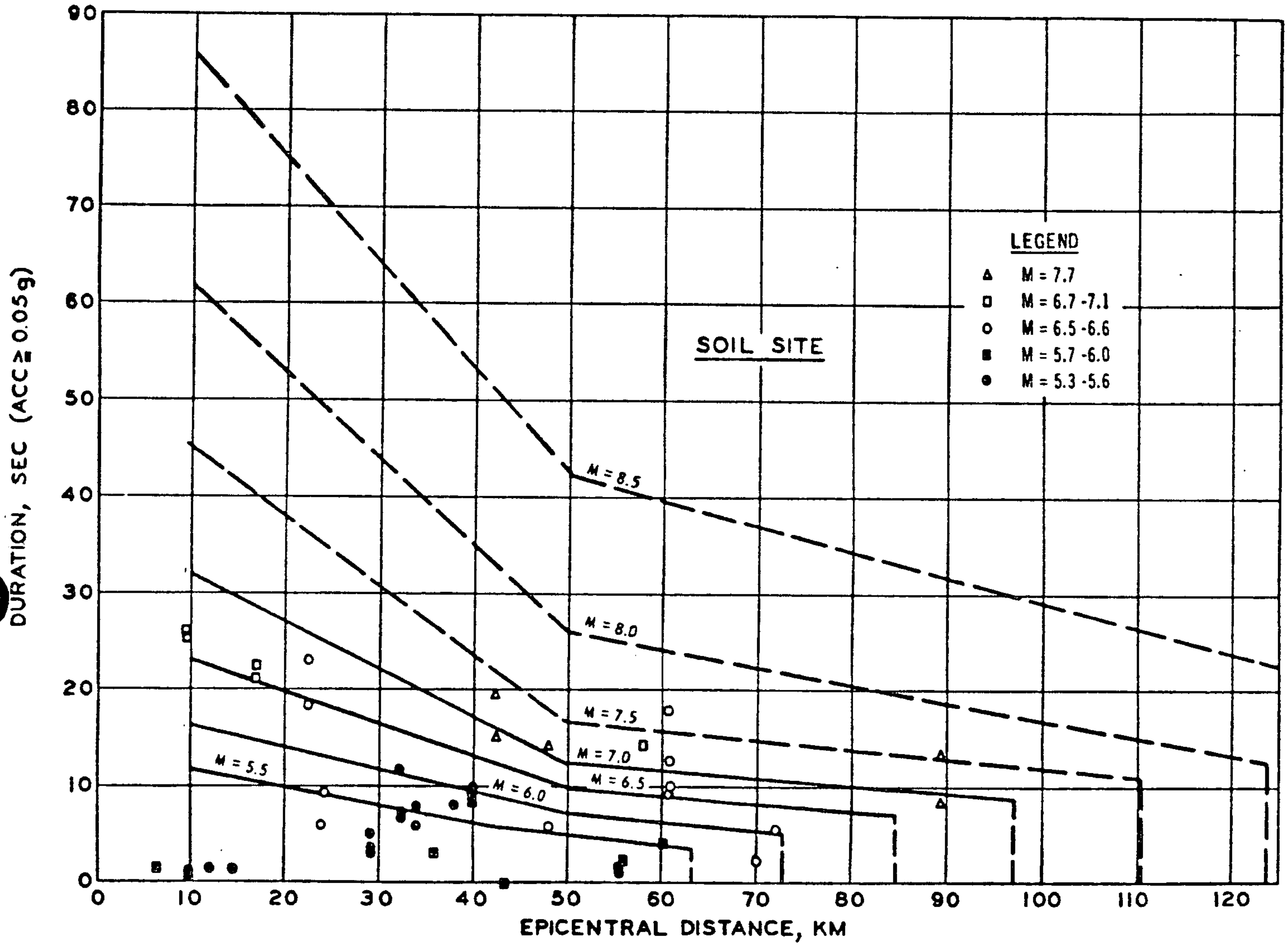


Figure 13. Duration versus epicentral distance and magnitude for the soil site

FIGURE 5: CHANG (1977)

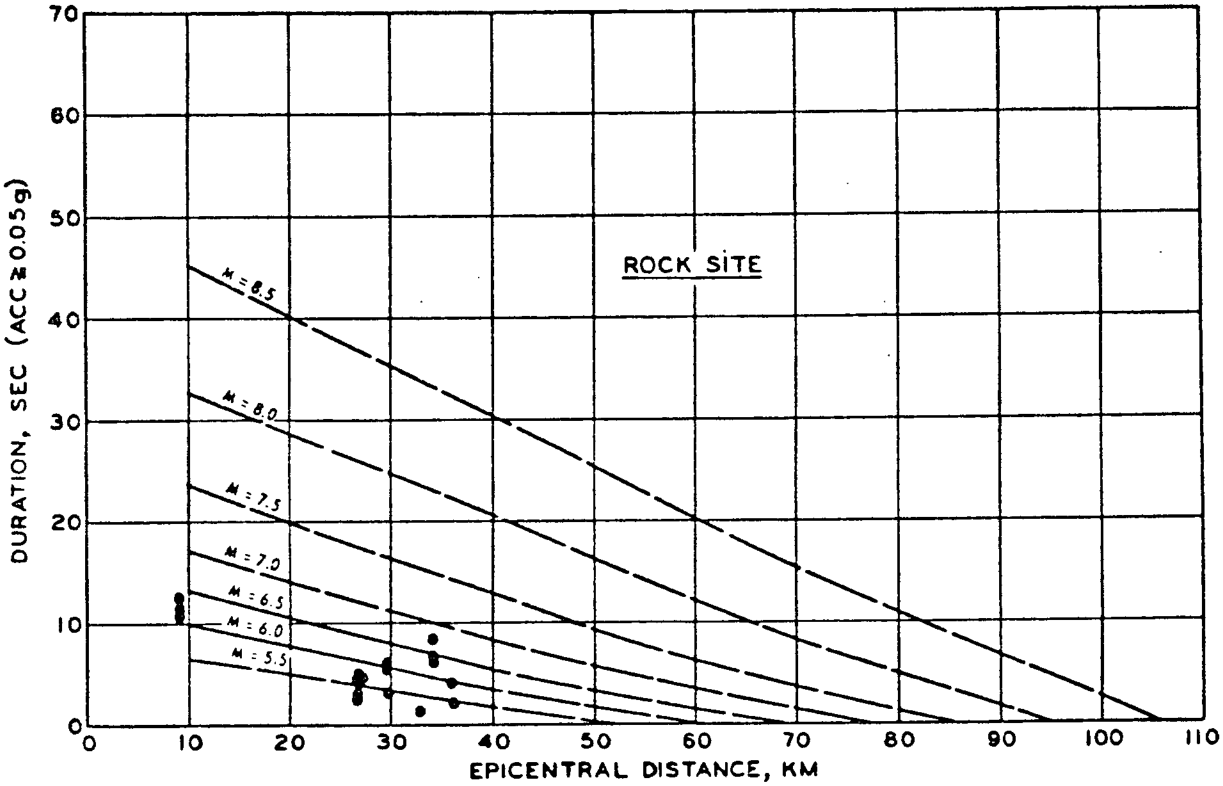


Figure 14. Duration versus epicentral distance and magnitude for the rock site

FIGURE 6: CHANG (1977)

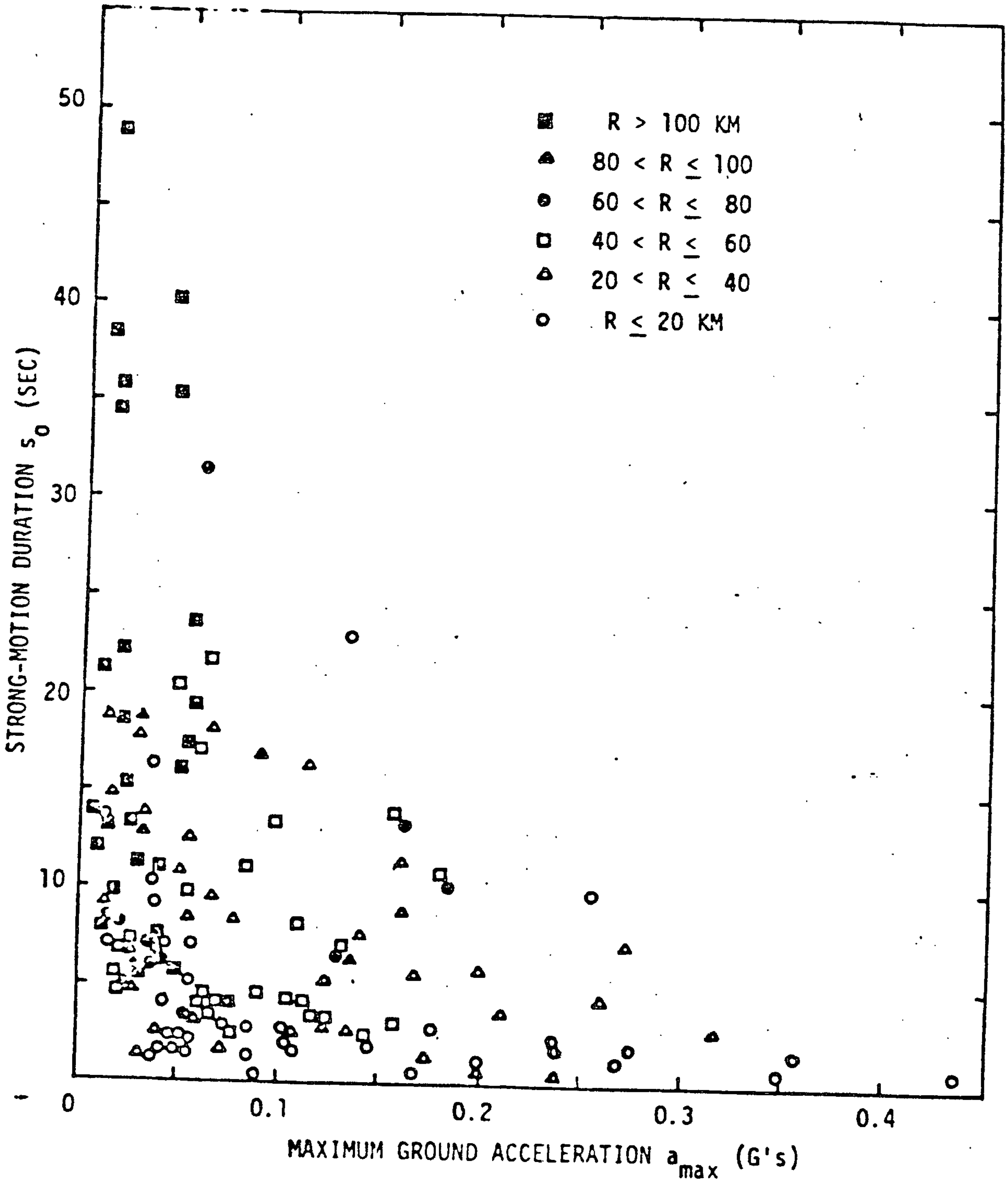


FIGURE 7: VON MARCKE (1977)

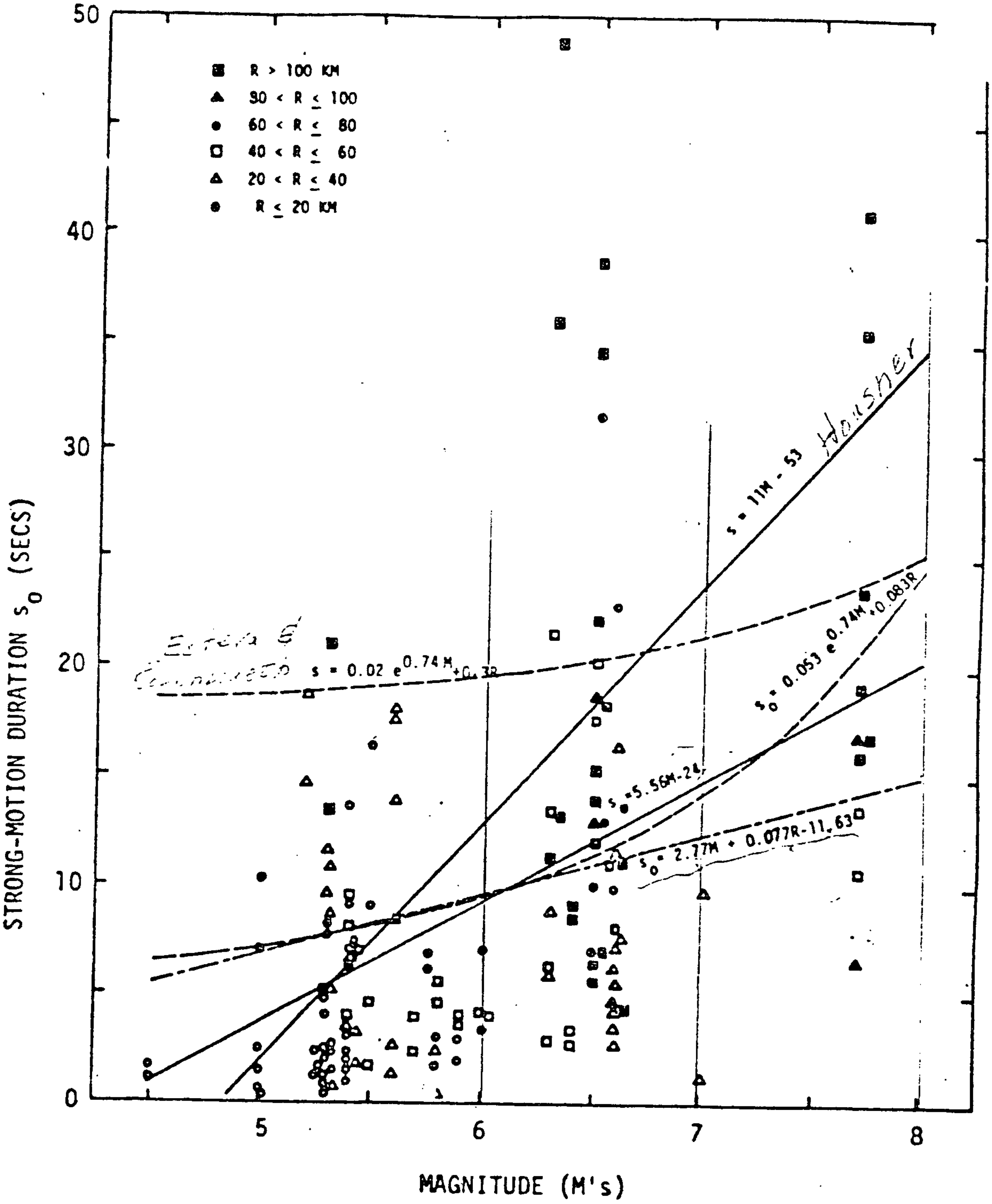


FIGURE 8: VON MARCKE (1977)

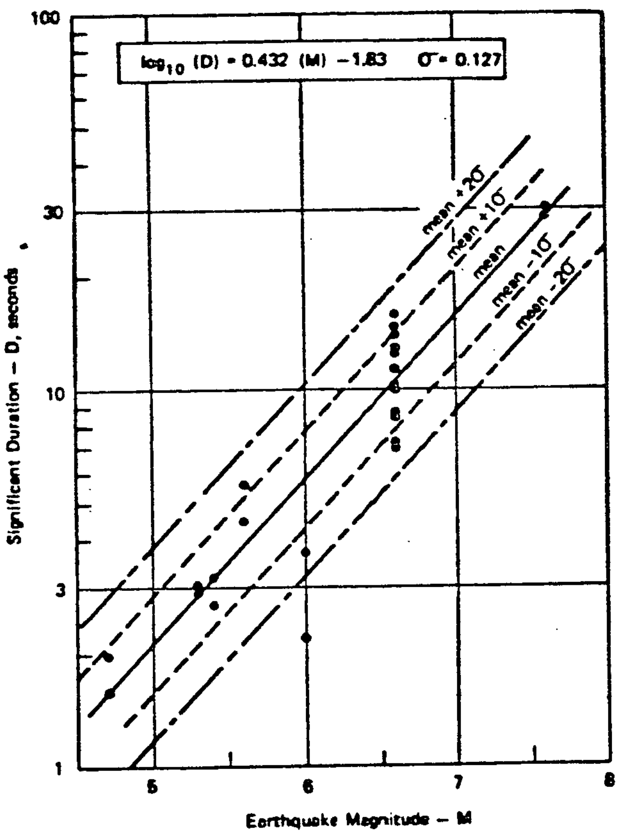


FIG. 7. Log *D* versus *M* for rock sites in the western United States.

FIGURE 9: DOBRY (1978)

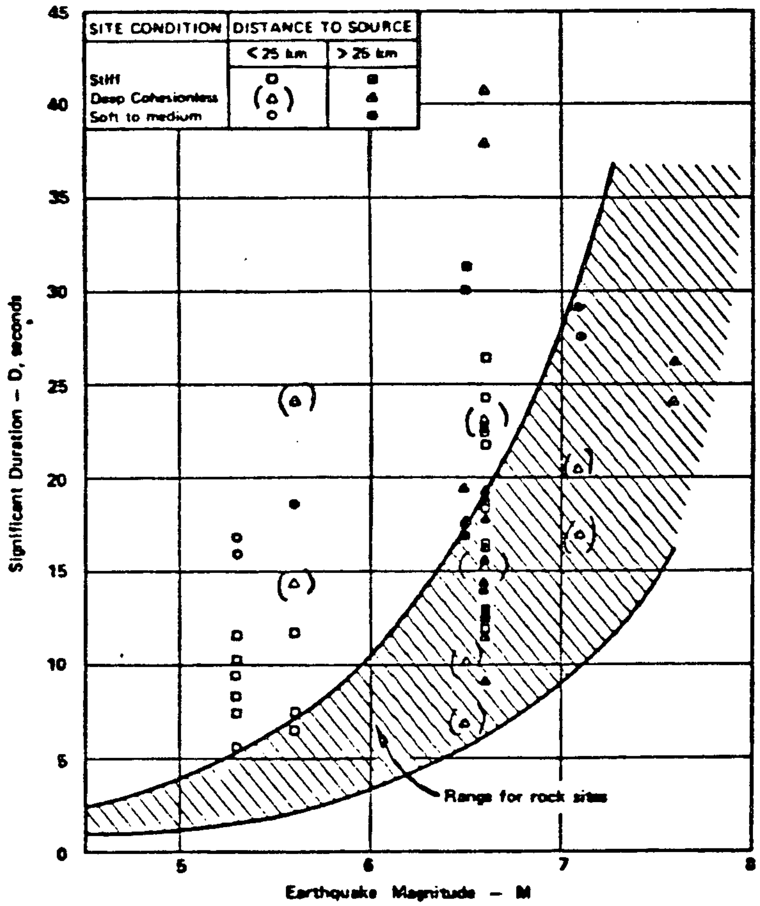


Fig. 15. *D* versus *M* for soil sites in western United States.

FIGURE 10: DOBRY (1978)

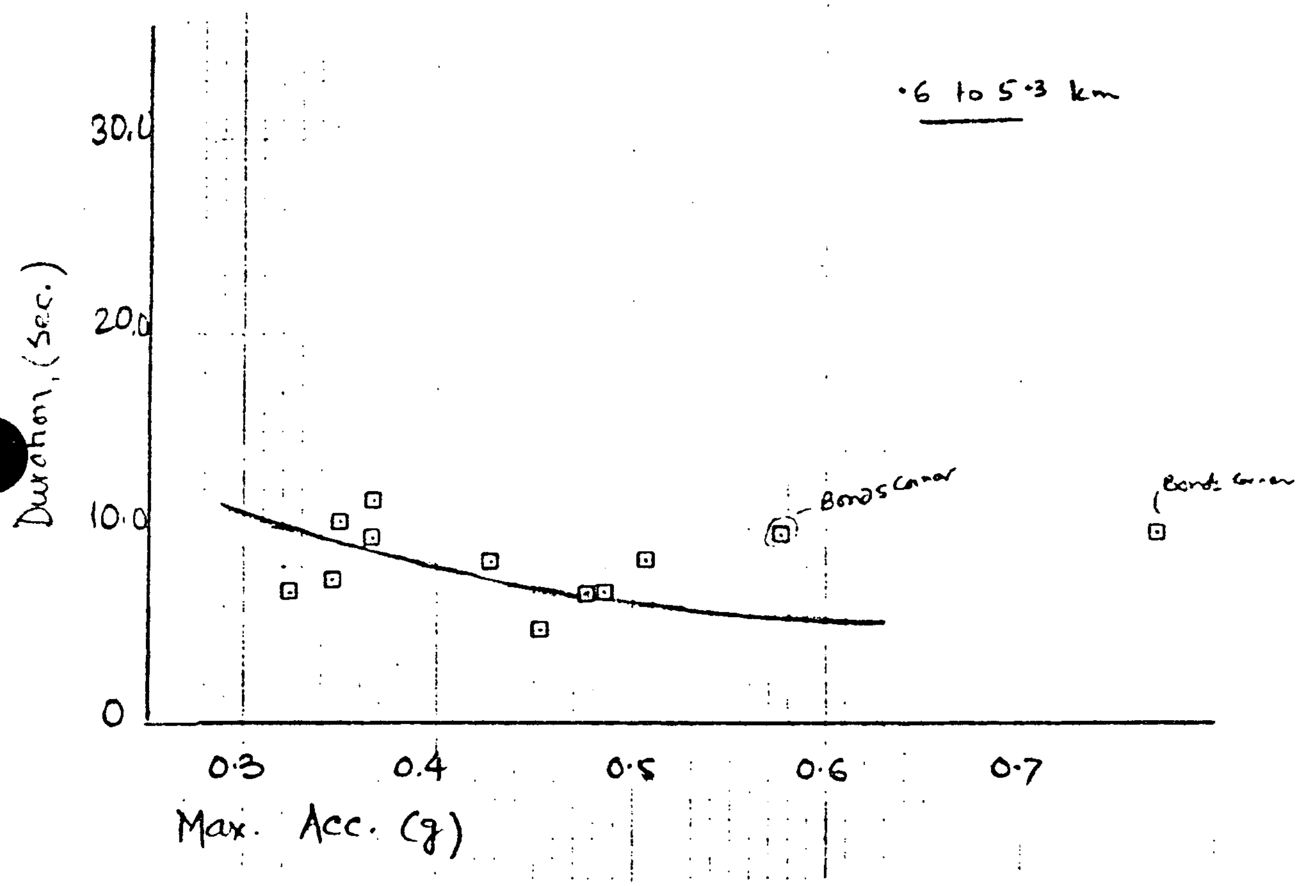


FIGURE 11: IV-79

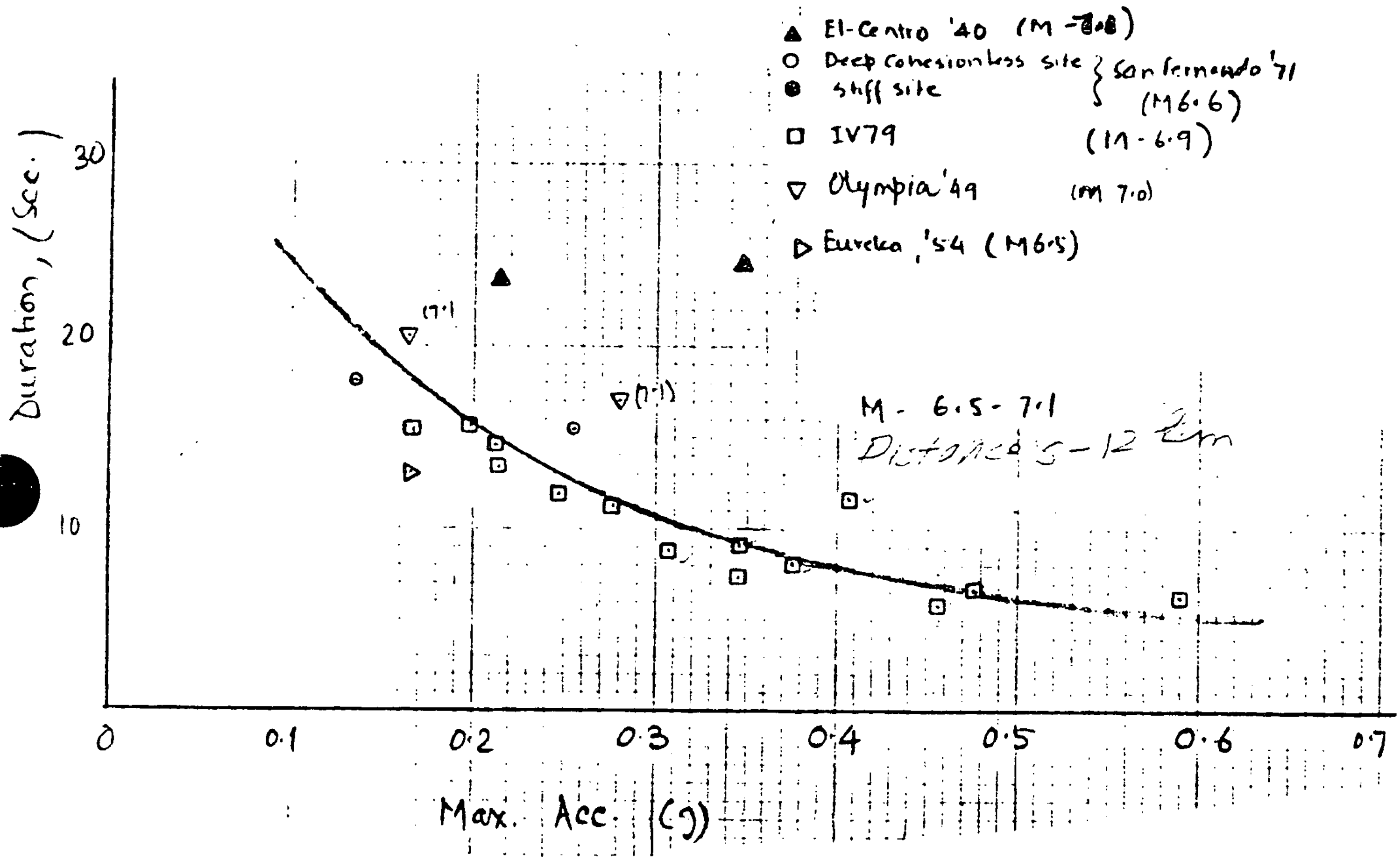


FIGURE 12: STRONG-MOTION DATA

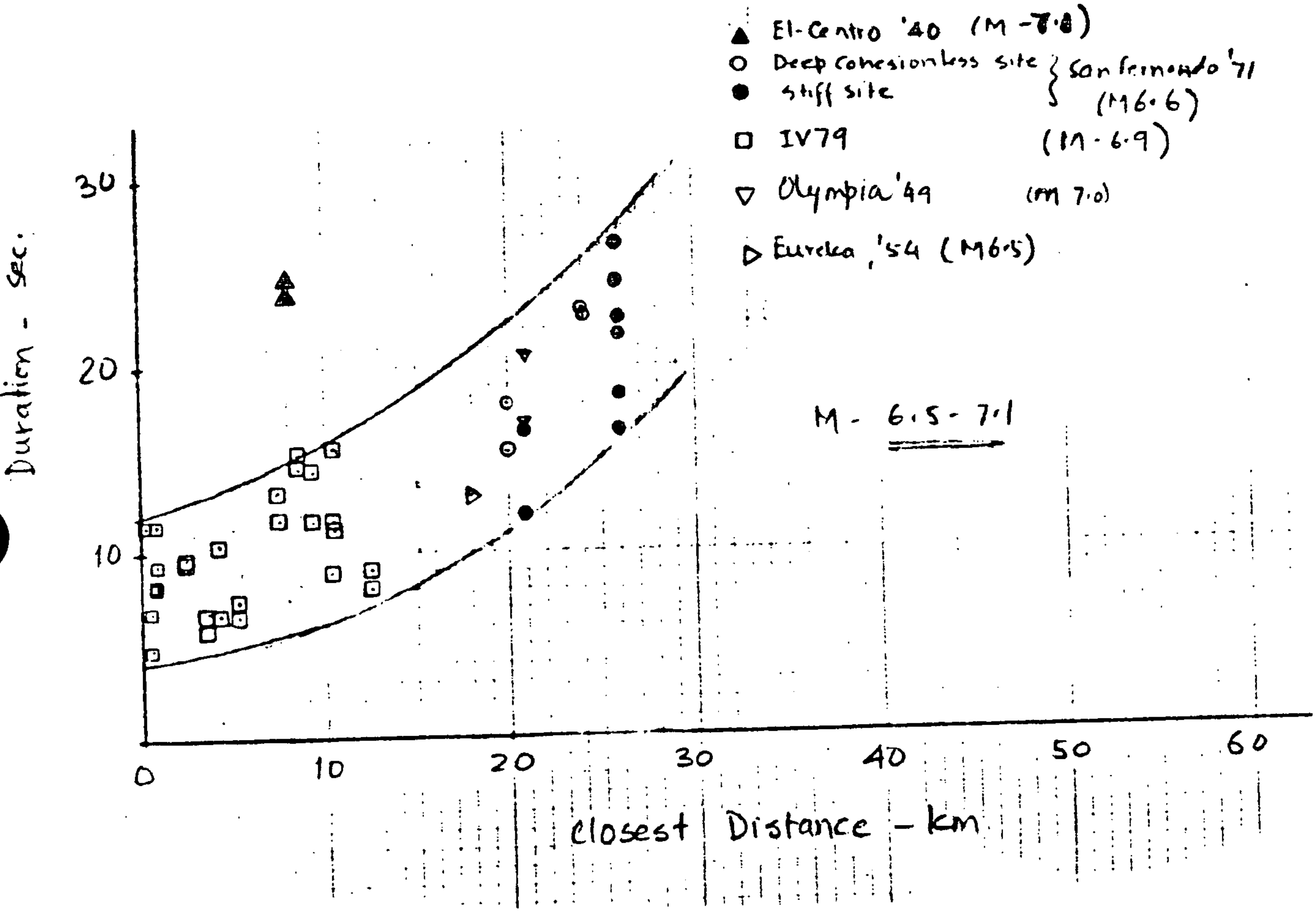


FIGURE 13: STRONG-MOTION DATA

Attachment 7

Clarification of Comparison Between
TERA Results and Joyner-Boore 1982

JOYNER-BOORE COMPARISON TABLE
FROM RESPONSE TO NRC QUESTIONS

COMPARISON ANALYSES						SV .10-5s PERCENT INCREASE	
	MODEL*	ANALYSIS*	DATA*	COMMENTS	CONTRIBUTARY FACTOR	MEDIAN	MEDIAN +1σ
1)	USGS	USGS	TERA	H_{MEAN}	(a) Use of max. horiz. comp.	13%	12%
2)	USGS	USGS	TERA	H_{MAX}**			
1)	TERA	TERA	TERA		(b) Use of J-B model	0%	0%
2)	USGS	TERA	TERA	H_2			
1)	USGS	TERA	TERA	H_2	(c) Use of J-B analysis	10-30%	20-40%***
2)	USGS	USGS	TERA	H_2			
1)	USGS	USGS	USGS	H_2	(d) Constraining $H_2 = 0$	20%	19%
2)	USGS	USGS	USGS	$H_2 = 0$			
1)	USGS	USGS	TERA	$H_2 = 0$	(e) J-B data base	0%	10%
2)	USGS	USGS	USGS	$H_2 = 0$			

* MODEL refers to functional form of the attenuation relationship.
ANALYSIS refers to either the one step technique used by TERA, fitting all coefficients simultaneously, or the two step technique used by USGS which does not optimize the fit.
DATA refers to either the complete TERA spectral data set or that used by the USGS in their analysis.

** Underline (______) indicates variation from Case (1)

*** Based on past studies, variation in other analysis parameters would likely produce the range of values shown.