Ground Motion Values for Use in the Seismic Design of the Trans-Alaska Pipeline System

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ABSTRACT

The proposed trans-Alaska oil pipeline, which would traverse the state north to south from Prudhoe Bay on the Arctic coast to Valdez on Prince William Sound, will be subject to serious earthquake hazards over much of its length. To be acceptable from an environmental standpoint, the pipeline system is to be designed to minimize the potential of oil leakage resulting from seismic shaking, faulting, and seismically induced ground deformation.

The design of the pipeline system must accommodate the effects of earthquakes with magnitudes ranging from 6.5 to 8.5 as specified in the "Stipulations for Proposed Trans-Alaskan Pipeline System." This report characterizes ground motions for the specified earthquakes in terms of peak levels of ground acceleration, velocity, and displacement and of duration of shaking. Published strong motion data from the Western United States are critically reviewed to determine the intensity and duration of shaking within several kilometers of the slipped fault. For magnitudes 5 and 6, for which sufficient near-fault records are available, the adopted ground motion values are based on data. For larger earthquakes the values are based on extrapolations from the data for smaller shocks, guided by simplified theoretical models of the faulting process.

INTRODUCTION

The route of the proposed trans-Alaska oil pipeline from Prudhoe Bay on the Arctic Ocean to Valdez on Prince William Sound intersects several seismically active zones. Sections of the proposed pipeline will be subject to serious earthquake hazards, including seismic shaking, faulting, and seismically induced ground deformation such as slope failure, differential compaction, and liquefaction. This report is concerned only with seismic shaking that, if not accommodated in the design, could cause deformation leading to failure in the pipeline, storage tanks, and appurtenant structures and equipment and ultimately to the leakage of oil. It might also induce effects such as seiching of liquids in storage tanks and liquefaction, landsliding, and differential compaction in foundation materials, all of which could result in deformation and potential failure.

To protect the environment, the pipeline system is to be designed so as to minimize the potential of oil leakage resulting from effects of earthquakes. The magnitudes of the earthquakes which the design must accommodate are given in "Stipulations for Proposed Trans-Alaskan Pipeline System" ([U.S.] Federal Task Force on Alaskan Oil Development, 1972, Appendix, Sec. 3.4.1, p. 55), hereinafter referred to as "Stipulations." This report characterizes ground motions for the specified design earthquakes.

The seismic design of the proposed pipeline involves a combination of problems not usually encountered. In the design of important structures, detailed geologic and soil investigations of the site generally provide the background data. Such detailed site investigations are not economically feasible for a linear structure nearly 800 miles long. In addition, a structure more limited in extent can be located on competent foundation materials and away from known inelastic and nonlinear for large ground motions. Finally, smoothed tripartite logarithmic response spectra are constructed from the design seismic motions by the general procedure of Newmark and Hall (1969), outlined in Appendix B.

The initial step in the design process discussed herein characterizes ground motion appropriate to the design earthquakes. This step is based solely on seismological data and principles and does not incorporate factors dependent on soil-structure interactions, deformational processes within structures, or the importance of the structures to be designed. It involves scientific data and interpretation, whereas the subsequent steps involve engineering, economic, and social judgments relating to the nature and value of the structures.

The choice of parameters with which to specify ground motion was guided by the design approach adopted for the pipeline project. A useful set for the derivation of tripartite structural response spectra includes acceleration, velocity, displacement, and duration of shaking.

GROUND MOTION VALUES

Table 2 characterizes near-fault horizontal ground motion for the design earthquakes. The intensity of shaking is described by maximum values of ground acceleration, velocity, and displacement. In addition to the maximum acceleration, levels of absolute acceleration exceeded or attained two, five, and ten times are specified, because a single peak of intense motion may contribute less to the cumulative damage potential than several cycles of less intense shaking. Levels of absolute velocity exceeded or attained two and three times are also given.

There is substantial evidence that the duration of shaking strongly affects the extent of damage caused by an earthquake; yet the problem of how duration is related to magnitude has received little attention in the literature. In this study, the measure of duration used corresponds to the time interval between the first and last peaks of absolute acceleration equal to or larger than 0.05 g. Operational definitions of the acceleration and duration parameters are illustrated on an accelerogram in figure 2.

The values in table 2 are based on instrumental data insofar as possible. Strong-motion data have been obtained within 10 km of the causative fault for shocks as large as magnitude 6, but no accelerograms are available from within 40 km of the fault for a magnitude 7 shock and from within more than 100 km for a magnitude 8 shock. Estimates of intensity of near-fault ground motion for shocks larger than magnitude 6 are extrapolated from data obtained at larger distances or from near-fault data from smaller shocks.

The ground motion values in table 2 are subject to several conditions as follows. They are for a single horizontal component of motion. The intensity of shaking in the vertical direction is typically less than two-thirds that in a horizontal direction. They correspond to normal or average geologic site conditions and are not intended to apply where ground motion is strongly influenced by extreme contrasts in the elastic properties within the local geologic section. They characterize free-field ground motion, that is, ground motion not affected by the presence of structures. They contain no factor relating to the nature or importance of the structure

Table 2.—Near-fault horizontal ground motion

Magnitude	Acceleration (g) Peak absolute values				Velocity (cm/sec) Peak absolute values			Displacement (cm)	Duration[1] (sec)
	1st	2d	5th	10th	1st	2d	3d		
8.5	1.25	1.15	1.00	0.75	150	130	110	100	90
8.0	1.20	1.10	0.95	0.70	145	125	105	85	60
7.5	1.15	1.00	0.85	0.65	135	115	100	70	40
7.0	1.05	0.90	0.75	0.55	120	100	85	55	25
6.5	*0.90*	*0.75*	*0.60*	*0.45*	*100*	*80*	*70*	*40*	*17*
5.5	*0.45*	*0.30*	*0.20*	*0.15*	*50*	*40*	*30*	*15*	*10*

[1]Time interval between first and last peaks of absolute acceleration equal to or greater than 0.05 g.

Notes—1. Italic values are based on instrumental data.

2. The values in this table are for a single horizontal component of motion at a distance of a few (3-5) km of the causative fault; are for sites at which ground motion is not strongly altered by extreme contrasts in the elastic properties within the local geologic section or by the presence of structures; and contain no factor relating to the nature or importance of the structure being designed.

3. The values of acceleration may be exceeded if there is appreciable high-frequency (higher than 8 Hz) energy.

4. The values of displacement are for dynamic ground displacements from which spectral components with periods greater than 10 to 15 seconds are removed.

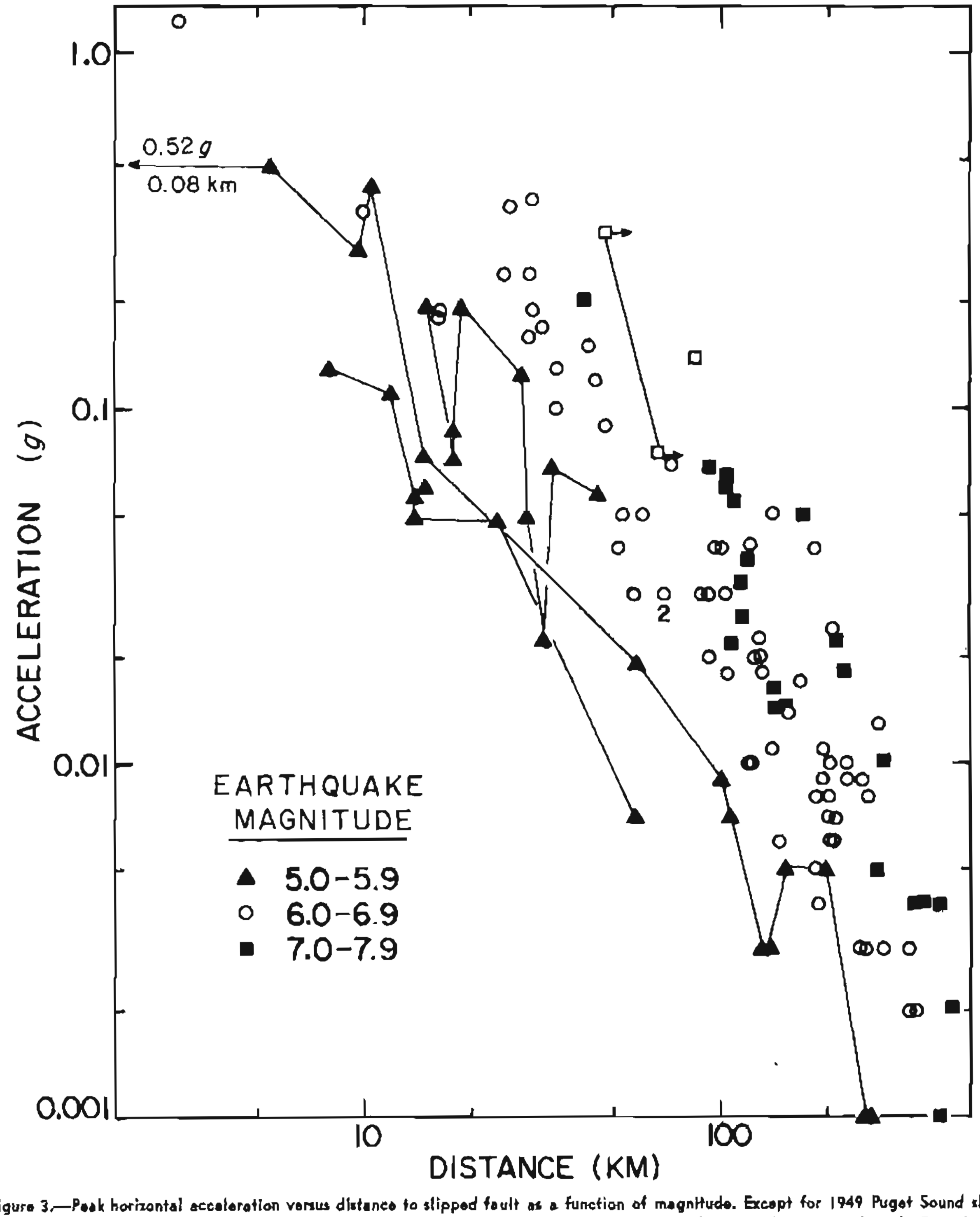
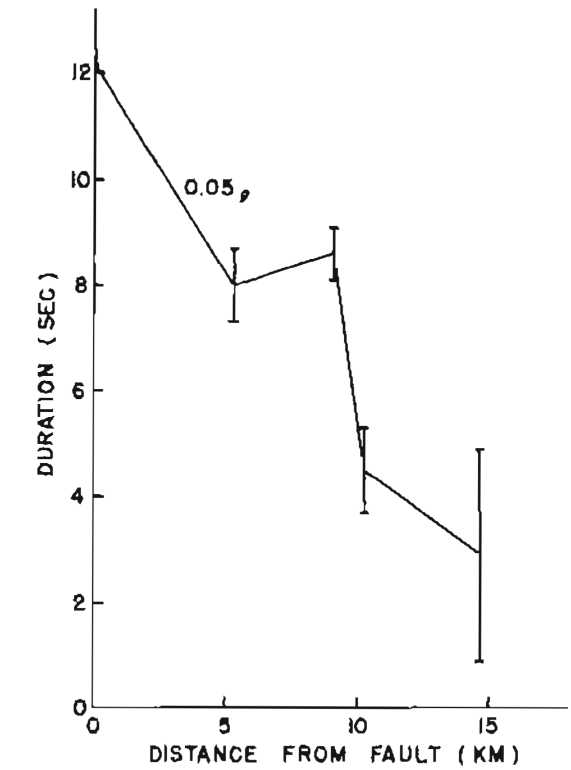
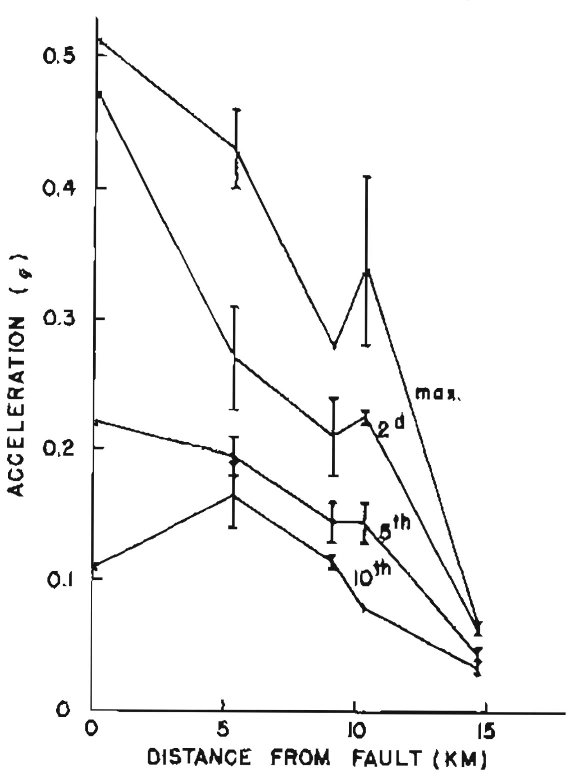


Figure 3.—Peak horizontal acceleration versus distance to slipped fault as a function of magnitude. Except for 1949 Puget Sound shock (open squares), data shown are those for which distances to fault are most accurately known (tabulated in Appendix C). Straight-line segments connect observations at different stations for an individual earthquake, for three magnitude 5 shocks and one magnitude 7 shock. From top to bottom, suites of magnitude 5 data are from 1970 Lytle Creek ($m = 5.4$), Parkfield ($m = 5.6$), and 1957 Daly City ($m = 5.3$) shocks. Closest Parkfield data point lies off plot to left at 0.08 km. For magnitude 6, most data within 100 km are from 1971 San Fernando earthquake ($m = 6.6$), and most data beyond 100 km are from 1968 Borrego Mountain earthquake ($m = 6.5$). Most magnitude 7 data are from 1952 Kern County shock ($m = 7.7$). Open squares are values from 1949 Puget Sound event ($m = 7.1$), for which distances are determined to hypocenter assuming minimum focal depth of 45 km. Arrows denote minimum values.

San Fernando earthquake (m = 6.6). This shock produced one accelerogram at a distance of about 3 km from the inferred slip surface and





more than 100 accelerograms at distances beyond 15 km. The peak acceleration from Pacoima at 3 km lies beneath a straight-line extrapolation of the trend of the data beyond 10 km; this behavior is consistent with a zone of little attenuation near the fault as observed for the Parkfield data in figure 4.

The maximum acceleration from the San Fernando earthquake was 1.25 g, nearly double the maximum acceleration recorded during any earthquake prior to 1971. The acceleration was recorded at a bedrock site adjacent to the Pacoima dam. Because the Pacoima accelerations are so much higher than those recorded in previous earthquakes, the question has arisen whether or not the record might be anomalous in the sense that the motion may have been significantly amplified by various site factors such as the rugged topographic relief, the presence of the dam, and the cracking and minor landsliding near the station. The authors are not aware of any investigations of possible site effects that conclusively demonstrate an anomalous amplification (greater than 25-50 percent) of recorded motion in the frequency range 1-10 Hz. The Pacoima ground motion in the period range 1 to 2 seconds is not inconsistent with that predicated from a simple theoretical fault model for the earthquake (Trifunac, 1972).

The near-fault acceleration values for magnitude 6.5, table 2, were derived from the Pacoima accelerograms of the San Fernando earthquake. In the Newmark and Hall method for estimating velocity response spectra (Appendix B), the spectral amplitude in the approximate frequency range 2-8 Hz is directly proportional to the peak ground acceleration. If the peak acceleration is dominated by higher frequency energy, the Newmark and Hall method overestimates the spectrum in this range. Frequencies higher than 8 Hz contributed significantly to the peak accelerations recorded at Pacoima (fig. 7); accordingly, the accelerograms were filtered to remove frequencies higher than about 9 Hz. Filtering reduced the accelerations by about 25 percent, as seen in table 3 and fig. 7. The near-fault acceleration values of table 2 for magnitude 6.5 were adopted from the filtered values.

Near-fault accelerations for magnitudes larger than 6.5 were extrapolated from strong mo-

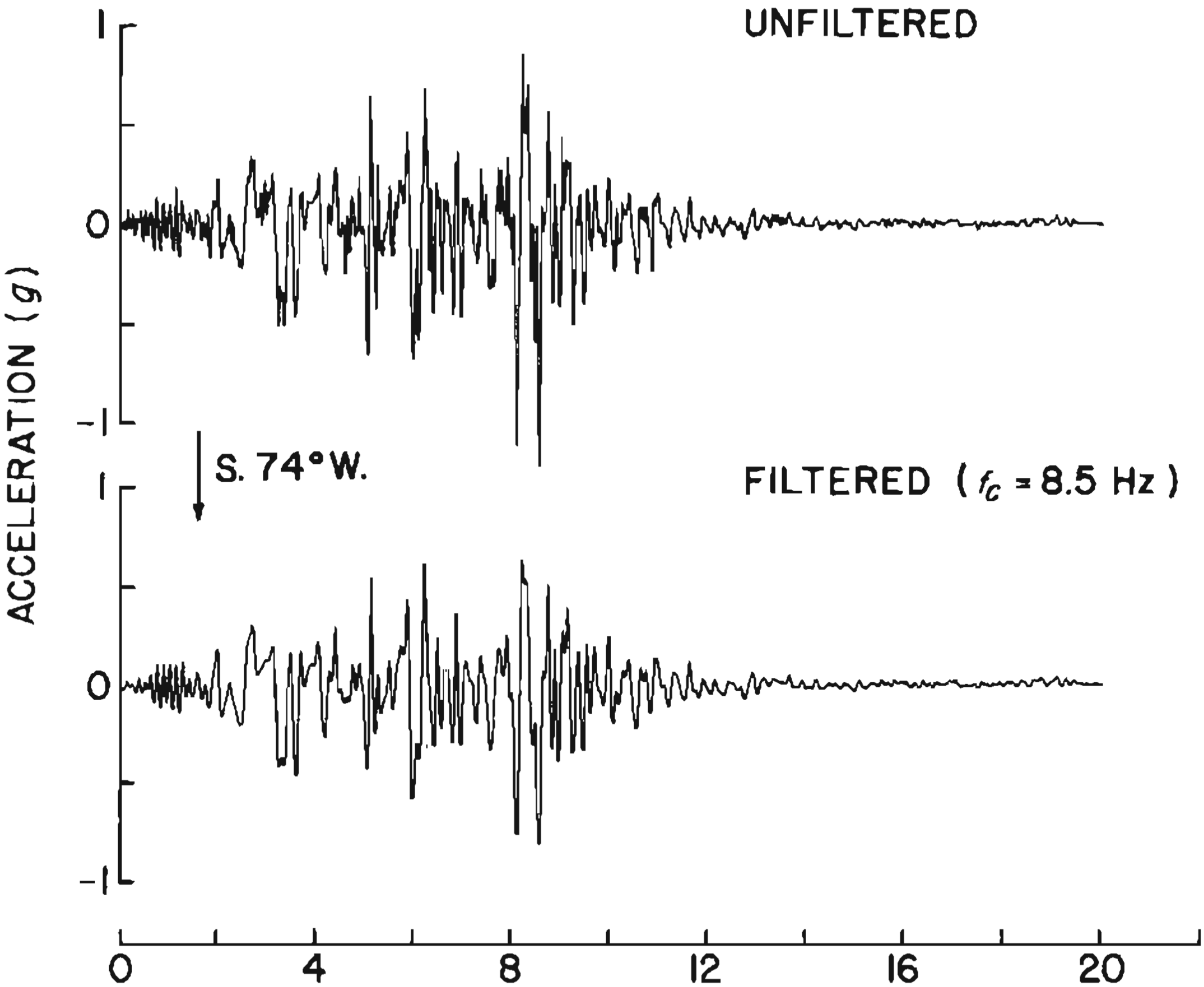


Figure 7.—Unfiltered and filtered accelerograms of the 1971 San Fernando earthquake from the S. 74° W. accelerograph component at Pacoima dam. Response of filter is 1.0 at frequencies less than 8 Hz and 0.0 at frequencies greater than 9 Hz with a half-wave cosine taper from 8 to 9 Hz.

VELOCITY

The response curve of the standard strong motion seismograph operated in the United States is flat to acceleration over the frequency range of the predominant ground motion. Accordingly, accelerations are measured directly from the strong motion recordings, whereas velocities are obtained by integration of the record. For this reason, there are few velocity data in the literature relative to acceleration data.

Peak velocity data in the magnitude range 5-7 plotted as a function of distance from the source (fig. 8) indicate that peak velocity increases with magnitude at all distance for which data exist. Those data points for which distance to the fault is accurately known (large symbols) tend to separate according to magnitude; the remaining data confirm this tendency, although their behavior is somewhat obscured by scatter arising at least partially from errors in distances. The plot reveals that beyond about 10 km, peak velocity attenuates less rapidly with distance than peak acceleration.

The near-fault velocity values for magnitude 5.5 (table 2) are averages of the Parkfield values recorded at 0.08 and 5.5 km from the fault. The values for magnitude 6.5 are based on the San Fernando observations at the Pacoima site about 3 km from the fault surface. For the larger magnitudes, the values were extrapolated from those for 5.5 and 6.5 on the asnamic displacements excluding spectral components with periods greater than about 10-15 seconds are available from double integration of accelerograms or directly from displacement meters. Both types of data are subject to uncertainties. In the double integration of digitized accelerograms, errors may arise from low-frequency noise in the digitization of the original accelerogram and from lack of knowledge of the true baseline of the accelerogram. On the other hand, there are instrumental difficulties associated with displacement meters operating with a free period of 10 seconds. The relative accuracy of the two types of data is not adequately understood (Hudson, 1970).

Peak displacement data obtained from double integration of accelerograms and from 10-second displacement meters when plotted against distance (fig. 9) show no apparent systematic difference between the two types of data within the scatter of the points. Peak displacement at a given distance from the fault, like peak acceleration and velocity, increases with magnitude.

The near-fault value of peak displacement for magnitude 5.5 (table 2) is the mean of the Parkfield values obtained at 0.08 and 5.5 km from the fault. For magnitude 6.5 the value is based on the Pacoima record for the San Fernando earthquake. How peak dynamic displacement (for periods less than 10-15 seconds) scales with magnitude for larger shocks is uncertain. An upper limit to the increase of near-fault dynamic displacement with magnitude is the rate at which fault dislocation increases with magnitude. The total fault slip in the 1964 Alaska shock (m = 8.5). Hence, an upper bound on the peak dynamic displacement for magnitude 8.5, after removal of low frequency energy, is about 2 m. In this study, a value of 1 m is assumed for magnitude 8.5, and the values between magnitude 6.5 and 8.5 are smoothly interpolated.

DURATION

The measure of duration used in this study is the time interval between the first and last acceleration peaks equal to or greater than 0.05 g. Although crude, this measure is readily applied to the existing accelerograms and approximates the cumulative time over which the ground accelerations exceed a given level. Comparison of felt reports for earthquakes of magnitude 5 and 6 with near-fault accelerograms from shocks of similar magnitude suggest that the "intense" or "strong" phase of shaking mentioned in felt reports corresponds to accelerations of about 0.05 g and greater. In comparison, the minimum perceptible level of acceleration is 0.001 g (Richter, 1958, p. 26).

Durations obtained for several earthquakes in the magnitude range 5-7 indicate that for a given magnitude, duration decreases with increasing distance from the source, and that at a given distance from the source, duration increases for larger magnitudes (fig. 10). The 0.05 g duration for magnitude 5.5 (table 2) is the mean of the maximum durations for the 1966 Parkfield shock (m = 5.5) recorded at distances of 0.08 and 5.5 km from the fault surface (fig. 5). The durations for magnitude 6.5 and 7.0 are based respectively on the measured 0.05 g durations of 13 seconds at Pacoima dam in the 1971 San Fernando earthquake (m = 6.6) and of 30 seconds at El Centro in the 1940 Imperial Valley earthquake, which was a multiple event characterized by a surface-wave magnitude of 7.1. These data were smoothed slightly to obtain a regular increase of duration with magnitude in table 2. The adopted near-fault durations of 17 and 25 seconds for magnitudes 6.5 and 7.0 are consistent with the duration data in figure 10 within the scatter of the points.

In the absence of near-fault data for larger magnitudes, durations can be estimated from theoretical calculations in corroboration with felt observations. Assume that a magnitude 8.5 earthquake is a multiple event comprised of several shocks as large as magnitude 7.5 distributed along a fault 500-1,000 km in length. Peak accelerations of 0.05 g or greater are expected for a magnitude 7.5 earthquake at distances up to 100 km (fig. 3). For a rupture propagation velocity of 2 to 3.5 km/sec, the 0.05 g duration at a near-fault station near the center of the fault would be 100 to 57 seconds, respectively. In comparison, felt reports of the duration of intense shaking in the aftershock zone of the 1964 Alaska earthquake (m = 8.5) ranged from 60-90 seconds at Whittier (Kachadoorian, 1966) to 150 seconds at Kodiak (Kachadoorian and Plafker, 1967). The tabulated duration of 90 seconds for magnitude 8.5 (table 2) is consistent with the calculated range of values and with felt data from the 1964 shock.

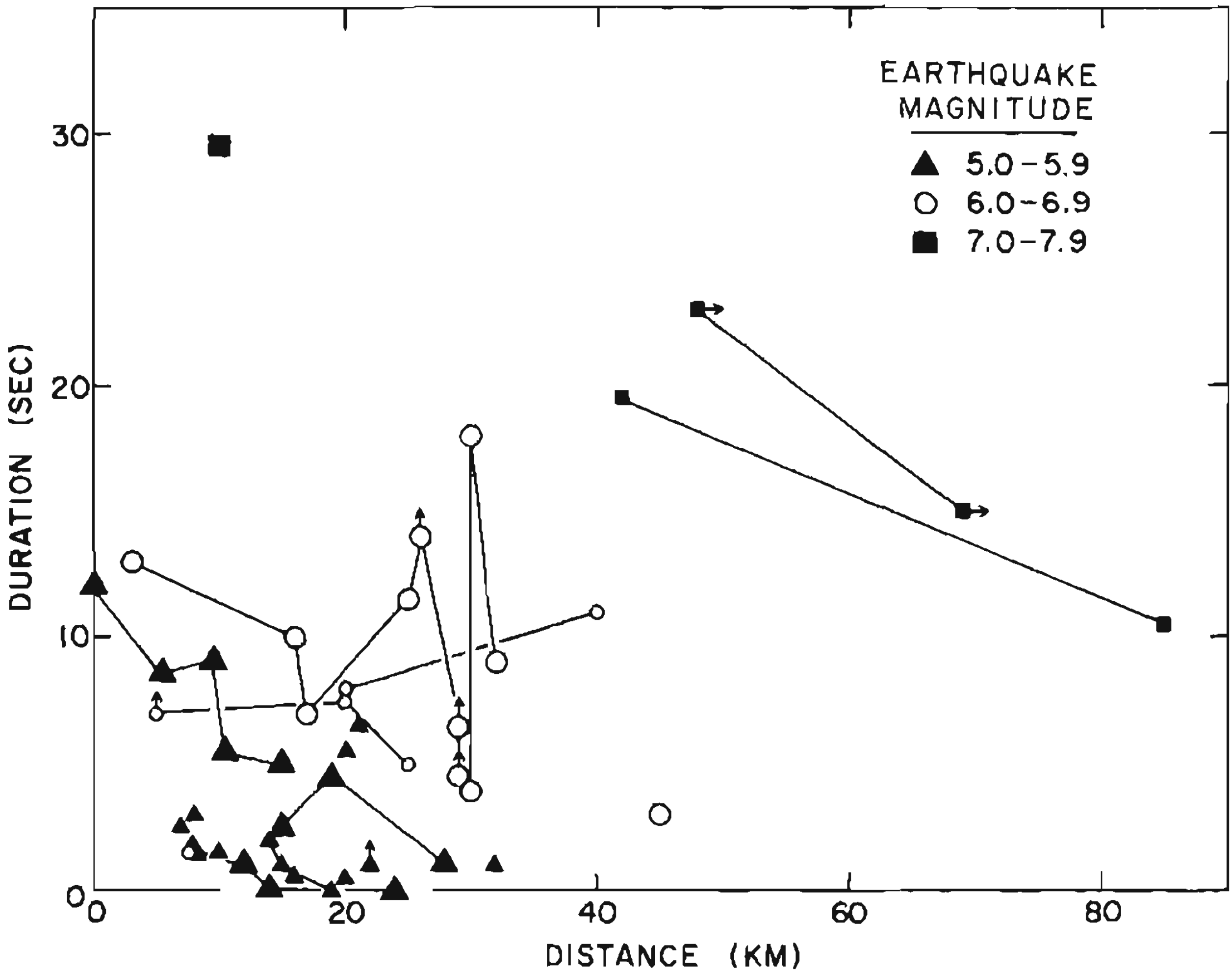


Figure 10.—Duration of shaking versus distance to slipped fault, if known, or epicentral distance for magnitudes 5, 6, and 7. Shown is 0.05 g duration (see fig. 2 for definition; plotted data are tabulated in Appendix C). Distances represented by larger symbols are uncertain by less than 5 km; those indicated by smaller symbols by 5 to possibly 25 km. Arrows denote minimum values.

The durations for magnitude 7.5 and 8.0 were interpolated between the values for magnitudes 7.0 and 8.5 to obtain a smooth increase in duration with magnitude.

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proaching the design magnitude has occurred on the pipeline route in this century, a magnitude 7.3 shock in 1937. A recurrence interval of 50 years is assumed.

In the magnitude 7.0 and 5.5 zones, there is no historic record of shocks as large as the design earthquakes. For the Willow Lake to Paxson zone, the record of earthquakes equal to or larger than magnitude 7.0 is probably complete for at least 50 years. From 67° N to Prudhoe Bay, the record for events as small as magnitude 5.5 is possibly complete since 1935, when a seismic station was established at College. Recurrence intervals of 200 and 50 years are assumed for the two zones.

APPENDIX B—PROCEDURE OF NEWMARK AND HALL FOR DETERMINATION OF RESPONSE SPECTRA

A response spectrum for a given level of damping is defined by the maximum responses (usually expressed in terms of displacement, velocity, or acceleration) of linear, single-degree-of-freedom oscillators (with different free periods but identical values of damping) when subjected to a specified time history of ground motion. A single spectrum is a plot of the maximum responses as a function of oscillator period or frequency; there is a different response spectrum for each level of damping. The usefulness of the response spectrum comes from the ability to model engineering structures by equivalent simple damped oscillators and to estimate stresses induced by the particular ground motion from knowledge of the equivalent period and damping of the structure and of the appropriate response spectrum.

The values of parameters describing the actual ground motion may be modified for nonlinear energy-absorbing mechanisms before being used in the construction of a response spectrum. In the following example of the Newmark and Hall method for constructing response spectra, the ground motion values are not modified. The example is illustrative only of the general method and not of an application to a specific problem.

Response spectra calculated from accelerograms often contain many peaks and troughs, hence prudent design requires the use of an envelope of the actual response spectrum. Newmark and Hall (1969) describe a graphical method for determining envelope response spectra. First a tripartite logarithmic "ground motion spectrum" is constructed with three lines representing ground displacement, velocity, and acceleration. These lines are then shifted upward on tripartite log paper, by amounts depending on damping, to reflect the dynamic amplification of the ground motion in the structure. The amounts by which the lines are shifted are derived empirically from recorded accelerograms and are subject to revision as new data become available. This procedure, using the amplification factors given by Newmark and Hall (1969), is illustrated in figure 11, where the velocity response spectrum for 2 per-

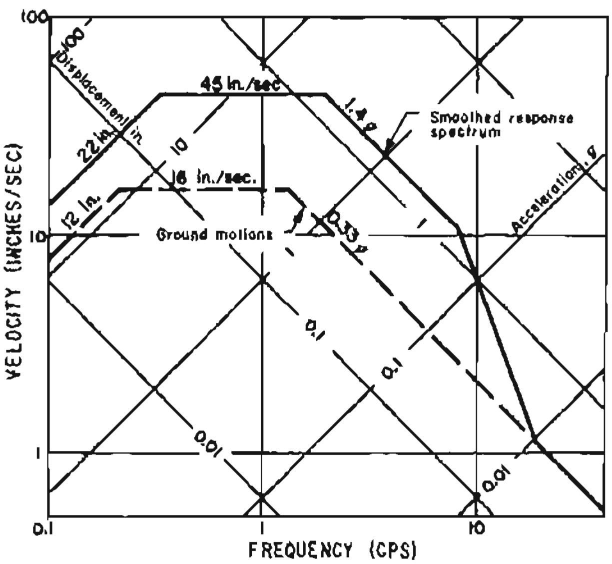

Figure 11.—Example of tripartite logarithmic ground (dashed) and response (solid) spectra (after Newmark and Hall, 1969). Accelerations and displacements may be read from the plot in addition to velocities. Response spectrum is for damping value of 2 percent of critical.

cent damping is estimated for a ground motion characterized by ground displacement of 12 inches, velocity of 16 inches per second, and acceleration of 0.33 g. At high and low frequencies, the response spectrum must theoretically equal the ground acceleration and displacement, respectively; this accounts for the slope that connects the 1.4 g and 0.33 g lines. The corresponding line at the low frequency side is off the graph to the left.

Table 4.—Peak ground acceleration data for which distances to the causative fault are most accurately known—Continued

DATE YR MO DA	EARTHQUAKE	MAG	STATION	ACC G	DIST KM	UNCER KM
70 09 12	LYTLE CK.,CALIFORNIA	5.4	WRIGHTWOOD	.195	15.	2-5
			CEDAR SPRINGS,RANCH	.087	18.	
			CEDAR SPRINGS,DAM	.072	18.	
			DEVILS CANYON	.193	19.	
			SAN BERNARDINO	.125	28.	
			COLTON	.049	29.	
			PUDDINGSTONE DAM	.022	32.	
			LOMA LINDA	.068	34.	
			SANTA ANITA DAM	.057	46.	
MAGNITUDE 6.0-6.9						
40 05 19	IMPERIAL VALLEY,CALIF.	6.4	EL CENTRO	.36	10.	2-5
68 04 09	BORREGO MTN.,CALIF.	6.5	EL CENTRO	.12	45.	2
			SAN DIEGO	.030	105.	
			PERRIS RESERVOIR	.018	105.	
			SAN ONOFRE	.041	122.	
			COLTON	.023	130.	
			SAN BERNARDINO	.018	132.	
			DEVILS CANYON	.011	141.	
			CEDAR SPRINGS	.006	147.	
			SANTA ANA	.014	157.	
			SAN DIMAS	.017	168.	
			LONG BEACH,UTIL.BLDG.	.005	187.	
			LONG BEACH,S.CAL.ED.	.008	187.	
			SANTA ANITA RES.	.004	190.	
			VERNON	.011	196.	
			PASADENA,FAC.CLUB	.009	197.	
			PASADENA,SEISMO.LAB.	.007	200.	
			L.A.,SUBWAY TERM.	.008	203.	
			L.A.,EDISON	.010	203.	
			PEARBLOSSOM	.006	203.	
			WESTWOOD	.006	208.	
			GLENDALE	.024	208.	
			HOLLYWOOD STOR.PE LOT	.007	211.	
			PACOIMA DAM	.009	229.	
			FAIRMONT RESERVOIR	.003	249.	
			LAKE HUGHES#1	.009	253.	
			DAVIS DAM	.003	259.	
			CASTAIC	.008	262.	
			GORMAN	.013	281.	
			PORT HUENEME	.003	288.	
			SANTA BARBARA	.002	341.	
			BAKERSFIELD	.003	342.	
			TAFT	.002	359.	
71 02 09	SAN FERNANDO, CALIF.	6.6	PACOIMA DAM	1.24	3.	2
			L.A., GRIFFITH PARK	.18	16.	
			PASADENA, SEISMO. LAB.	.19	17.	
			SANTA ANITA DAM	.24	25.	
			LAKE HUGHES #12	.37	26.	
			LAKE HUGHES #9	.16	29.	
			TEJON	.03	70.	

Figures 4 and 6 provide comparison of the better acceleration data for magnitudes 5 and 6, respectively, with acceleration data for which distances to the fault are less well known. The figures include accelerations recorded within 100 km of the fault or epicenter for shocks that provided one or more accelerograms within 32 km. Table 5 summarizes the data, which were obtained from several sources, including the annual issues of "United States Earthquakes." The tabulated acceleration is the larger of the two peak horizontal values. The tabulated distance is the closest distance to the slipped fault, if determinable, or epicentral distance. The uncertainty in distance is indicated by the letter A, B or C, representing estimated uncertainties of less than 2 km, 2-5 km, and 5-25 km, respectively.

Table 5 also summarizes the velocity, displacement and duration data plotted in figures 8, 9 and 10, respectively. Figure 8 illustrates the dependence of peak horizontal ground velocity upon magnitude and distance. The velocity data, derived by integration of accelerograms, were obtained primarily from three sources (Hudson and others 1971; Wiggins, 1964; and Ambraseys, 1969). The tabulated velocity is the larger of the two peak horizontal values.

The displacement data in figure 9 are derived from displacement records obtained either directly from 10-second displacement meters or analytically by double integration of accelerograms. Data from the 10-second displacement meters are taken from the annual issues of "United States Earthquakes." Displacements obtained from twice-integrated accelerograms are primarily from Hudson, Brady, Trifunac, and Vijayaraghavan (1971) and correspond to ground motion from which spectral components with periods longer than about 15 Hz are removed. The tabulated displacement is the larger of the two peak horizontal values.

The 0.05 g durations plotted in figure 10 were measured from published accelerograms. The larger of the two horizontal durations is tabulated.

Table 5.—Strong motion data plotted on graphs showing peak horizontal acceleration, velocity, and dynamic displacement and duration of shaking as a function of distance to slipped fault (or epicentral distance)

DATE YR MO DA	EARTHQUAKE	MAG	STATION	DISTANCE KM	*	ACC G	VEL CM/SEC	DISP CM **	DUR SEC
MAGNITUDE 5.0-5.9									
33 10 02	LONG BEACH	5.4	VERNON	14	C	.115			2.0
			LONG BEACH	15		.077			1.0
			L A SUB TERM	19		.082+		.8 D	0.0+
			WESTWOOD	24		.009+			
			HOLLYWOOD STOR	27		.033+			
			PASADENA	30		.005+		.2 D	
34 07 06	N CALIF COAST	5.7	EUREKA	149	C			.9 D	
35 01 02	C MENDOCINO	5.8	EUREKA	117	C			.1+D	
35 11 28	HELENA, MONT	5.2	HELENA	8	C	.082	3.9		
37 02 07	C MENDOCINO	5.8	FERNDALE	84	C		3.8	.6+D	
38 5 31	SANTA ANA MT	5.5	COLTON	47	C			.2+D	
			L A SUB TERM	78				.1-D	
38 09 12	C MENDOCINO	5.5	FERNDALE	51	C		6.1		
40 05 19	IMPERIAL VAL	5.2	EL CENTRO	16	C	.077			0.5
40 12 20	C MENDOCINO	5.5	FERNDALE	91	C		4.4		
			EUREKA	103				.5 D	
41 07 01	SANTA BARBARA	5.9	SANTA BARBARA	14	C	.175+	20.3		
			L A SUB TERM	127				.2 D	

Table 5.—Strong motion data plotted on graphs showing peak horizontal acceleration, velocity, and dynamic displacement and duration of shaking as a function of distance to slipped fault (or epicentral distance)—Continued

DATE YR MO DA	EARTHQUAKE	MAG	STATION	DISTANCE KM	#	ACC G	VEL CM/SEC	DISP CM	**	DUR SEC
55 12 17	BRAWLEY	5.4	EL CENTRO	22	C	.083+	5.1			1.0+
57 03 22	DALY CITY	5.3	S F GOLDN GATE	8	B	.129	4.9	2.3	A	1.5
			S F STATE	12		.105	5.1	1.1	A	1.0
			S F STATE	12				1.1	D	
			S F ALEXANDER	14		.056	2.9	1.3	A	0.0+
			S F SO PACIFIC	14		.049	5.0	1.4	A	0.0
			OAKLAND	24		.048	2.0	1.5	A	0.0
			SAN JOSE	58		.007				
57 04 25	CALIPATRIA	5.2	EL CENTRO	51	C			.6	D	
57 04 25	CALIPATRIA	5.1	EL CENTRO	51	C			.4	D	
60 01 19	HOLLISTER	5.0	HOLLISTER	8	C	.064				3.0
61 04 09	HOLLISTER	5.6	HOLLISTER	20	C	.193	17.1	3.8	A	5.5
62 08 30	LOGAN, UTAH	5.7	LOGAN	7	C	.12				2.5
63 02 28	FORT TEJON	5.0	WHEELER RIDGE	8	C	.058				
66 06 28	PARKFIELD	5.5	CHOLAME-SHAN 2	0.1	A	.52	72.2	22.3	A	12.0
			CHOLAME-SHAN 5	5.5		.48	27.3	8.4	A	8.5
			CHOLAME-SHAN 8	9.6		.28	12.6	6.7	A	9.0
			TEMBLOR	10.6		.42	21.0	8.1	A	5.5
			CHOLAME-SHAN12	14.9		.074	6.5	7.1	A	5.0
			SAN LUIS OBISP	59		.019				
67 06 21	FAIRBANKS,AK	5.4	COLLEGE	15	B	.06				
67 12 10	N CALIF COAST	5.8	FERNDALE	32	C	.10				1.0
70 09 12	LYTLE CREEK	5.4	WRIGHTWOOD	15	B	.195				2.5
			CEDAR SPR RCH	18		.087				
			CEDAR SPR DAM	18		.072				
			DEVILS CANYON	19		.193				4.5
			SAN BERNARDINO	28		.125				1.0
			COLTON	29		.049				
			PUDDINGSTONE D	32		.022				
			LOMA LINDA	34		.068				
			SANTA ANITA D	46		.057				
MAGNITUDE 6.0-6.9										
33 03 11	LONG BEACH	6.3	LONG BEACH	5	C	.23+				7.0+
			VERNON	20		.17	20.0			7.5
			L A SUB TERM	25		.06				5.0
33 06 25	W NEVADA	6.1	S F SO PACIFIC	302	C			.2+	D	
34 06 07	PARKFIELD	6.	PASADENA	298				.2	D	
34 12 30	MEXICALI, MEX	6.5	EL CENTRO	64	C		15.5			
			L A SUB TERM	328				.3	D	
35 10 31	HELENA	6.0	HELENA	7.5	C	.16	16.8			1.5
37 03 25	COAHUILA VAL	6.	COLTON	94	C			.2	D	
			PASADENA	160				.1	D	
			L A SUB TERM	167				.3	D	

Table 5.—Strong motion data plotted on graphs showing peak horizontal acceleration, velocity, and dynamic displacement and duration of shaking as a function of distance to slipped fault (or epicentral distance)—Continued

DATE YR MO DA	EARTHQUAKE	MAG	STATION	DISTANCE KM	*	ACC G	VEL CM/SEC	DISP CM	**	DUR SEC
71 02 09	SAN FERNANDO	6.6	PACOIMA DAM	3	B	1.24	115.	43.	A	13.0
			L A GRIFFITH	16		.18				10.0
			PASADENA,SEIS	17		.19				7.0
			SANTA ANITA D	25		.24				11.5
			LAKE HUGHES 12	26		.37				14.0+
			LAKE HUGHES 9	29		.16				4.5+
			SANTA FELICIA	29		.24				6.5+
			LAKE HUGHES 4	30		.19				4.0
			CASTAIC	30		.39				18.0+
			LAKE HUGHES 1	32		.17				9.0
			PALMDALE	35		.13				
			FAIRMONT RES	35		.10				
			PEARBLOSSOM	43		.15				
			PUDDINGSTONE D	48		.09				
			PALOS VERDES	52		.04				
			OSO PUMP PLANT	54		.05				
			LONG BEACH TRM	58		.03				
			WRIGHTWOOD	61		.05				
			TEJON	70		.03				
			PORT HUENEME	71		.03				
			GRAPEVINE	73		.07				
			WHEELER RIDGE	88		.03				
			CEDAR SPR RCH	94		.02				
			CEDAR SPR DAM	94		.03				
			COLTON	97		.04				
MAGNITUDE 7.0-7.9										
40 05 19	IMPERIAL VAL	7.1	EL CENTRO	10.8						29.5
49 04 13	PUGET SND,WASH	7.1	OLYMPIA	48+	C		21.0			23.0
			SEATTLE	69+						15.0
52 07 21	KERN COUNTY	7.7	TAFT	42	B		17.7	9.2	A	19.5
			SANTA BARBARA	85			19.3	5.8	A	10.5
			HOLLYWOOD BSMT	107			9.4	5.9	A	
			HOLLYWOOD LOT	107			8.9	6.4	A	
			PASADENA	109			9.1	2.9	A	
			PASADENA	109				4.5	D	
			L A SUB TERM	115				5.7	D	
			COLTON	156				2.6	D	
54 12 16	FALLON, NEV	7.0	S F SO PACIFIC	404				1.4	D	
			L A SUB TERM	584				3.6	D	

NOTES:

* UNCERTAINTY IN DISTANCE: A=LESS THAN 2 KM
B=2 TO 5 KM
C=5 TO POSSIBLY 25 KM

** SOURCE OF DISPLACEMENT DATA: A=DOUBLE INTEGRATION OF ACCELEROGRAM
D=10-SEC DISPLACEMENT METER