STRONG MOTION - RECORDS AND ACCELERATION

By

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SYNOPSIS

Ten recent strong-motion earthquake records are shown; and the upper limit, duration, and distribution of acceleration are discussed. The highest recorded acceleration to date is 0.5g, and the upper limit of acceleration recorded at various distance is approximated by $\log ({}^{a}/g) = 3.5 - 2 \log (D + 80)$. Short duration of higher level acceleration is illustrated by graphs of the total time acceleration was above various levels. On no record analyzed did accelerations above ca 0.15g add up to total duration of more than 2 seconds. Ratio of acceleration duration above any given level to record length correlated reasonably well with the standard Gaussian probability function.

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FOREWORD

In United States attempts to record strong motion during earthquakes began in 1932. In July of that year 4 newly developed strong-motion seismographs were installed in Southern California by the Coast and Geodetic Survey. Today the network, figure 1, extends from Alaska to South America, and contains 245 strong-motion seismographs, the great majority of which record in terms of acceleration. Overall responsibility for management and maintenance of the network remains with the Coast and Geodetic Survey. However, over 50% of the instruments in the network are owned by organizations and individuals outside the Survey.

Since the program started, over 100 strong-motion records of importance to Earthquake Engineering research have been obtained. However, the knowledge of earthquake motion provided by these records is far from complete. For example, no record has been obtained within 100 miles of the epicenter of magnitude 7.7 or larger earthquakes.

In the past the Survey was able to provide a limited number of full scale prints of the analog records for research purposes. With the growth of the network, distribution of records in this manner is becoming increasingly difficult. In the future, funds permitting, records will be digitized and distribution made in digital form suitable for computer application.

RECENT RECORDS

Ten strong-motion records obtained from the network since the 3rd World Conference on Earthquake Engineering are listed in Table I. Photographs of the records are shown in figures 2 through 6. Surface faulting was evident after both the Parkfield and Borrego Mountain Earthquakes. For these earthquakes distances in Table I are from station to faulting. For the other earthquakes distances in Table I are from station to reported epicenters.

MAXIMUM ACCELERATION

Maximum accelerations recorded to date by network instruments at various distances are plotted in figure 7. Attenuation of the recorded maximum accelerations with distance is roughly approximated, as indicated by the solid line envelopes, by the empirical formula $\log (a/g) = 3.5 - 2 \log (D + 80)$ or slightly less conservatively by $\log (a/g) = 3.0 - 2 \log (D + 43)$, where D = distance in miles to the closest point of observed faulting or to the earthquake epicenter in case no faulting was observed. The 0.4g acceleration recorded at Lima, Peru 100 miles or so from the epicenter of the October 17, 1966 earthquake may be less anomalous than indicated in figure 7. The high acceleration and frequency shown by the record raises doubt that the epicenter was actually the energy source at Lima. It seems more likely that faulting proceeded southward from the epicenter along an offshore fault roughly parallel to the Peruvian coast, and that the energy source for Lima was the closest point on the fault, much nearer to Lima than the epicenter.

DURATION OF ACCELERATION

As a slightly different way of analyzing accelerograms to better visualize earthquake duration we recently tried graphing the total time acceleration was above various levels. Eight digitalized accelerograms were available for analysis, and computations were made on a CDC 6400 digital computer. Character of the records analyzed can be seen in figures 3, 4A-D, 5, and 9.

Results of the analysis, figures 8A-H, show the relatively short total duration of higher level accelerations as compared to lower level accelerations. Notice, for example, that the total time acceleration was above ca 0.15g in no case exceeded 2 seconds, even on the famous 1940 El Centro, California record. Effective duration of acceleration above any level would be even shorter than indicated in figures 8A-H since earthquake motion is oscillatory rather than static. How much shorter is suggested in figure 10 by four examples of the number of occurrences contributing to total duration of acceleration above various levels.

Further analysis of acceleration duration in terms of a probability distribution function was suggested by the roughly straight line similarity of curves in figures 8A-H. If the distribution of acceleration "y" about the mean value zero were Gaussian then at any time "t" the probability that "$|y|$" would exceed a particular value "A_k" would be:

$$P(|Y| > A_K) = \int_{A_K}^{\infty} p(Y)\,dY = 1 - \operatorname{erf}\left(\frac{A_K}{\sigma\sqrt{2}}\right)$$

Where:

$$p(Y) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\left(\frac{Y}{\sigma\sqrt{2}}\right)^2}$$

$$\operatorname{erf}\left(\frac{A_K}{\sigma\sqrt{2}}\right) = \frac{2}{\sqrt{\pi}} \int_0^{\frac{A_K}{\sigma\sqrt{2}}} e^{-t^2}\,dt$$

σ = The standard deviation

The probability $P(|y| > A_k)$ was obtained from the accelerograms by *computing the ratio* of the duration for which $|y| > A_k$, to the total time of the record.

$$\text{i.e. } P(|Y| > A_K) = 1 - \operatorname{erf}\left(\frac{A_K}{\sigma\sqrt{2}}\right) = \frac{\text{Duration of } |Y| > A_K}{\text{Total Duration of Record}}$$

Twenty acceleration components were used in the comparison between the Gaussian probability function and the duration ratio. Using this limited number of components it was noted that when accelerograms were characterized by many acceleration pulses the duration ratio approached relatively close to the Standard Gaussian curve, but not so closely when the accelerograms were characterized by only a few high acceleration pulses. Average probability values for the two types of earthquakes are shown in figure 11.

ACKNOWLEDGMENT

The advice of Dr. A. G. Brady, California Institute of Technology, on probability analysis was most helpful to the authors in their preparation of this report.

TABLE I - RECENT STRONG MOTION RECORDS

FIG. NO.	STATION	MAXIMUM ACCELERATION OR DISPLACEMENT	COMPONENT	DISTANCE
PUGET SOUND, WASHINGTON 29 APRIL 1965 M=6.5				
2A	OLYMPIA	0.20 g	S 86°W	31 miles
2B	TACOMA	(1.76 cm (0.07 g	East East	21 miles
2C	SEATTLE	(1.08 cm (.05 g	S 58°W S 58°W	23 miles
PERU 17 OCTOBER 1966 M=7.5				
3	LIMA	0.4 g	N 8°E	100+ miles
PARKFIELD, CALIFORNIA 27 JUNE 1966 M=5.6				
4A	2	0.50 g	N 65°E	270 feet
4B	5	0.46 g	N 85°E	3.3 miles
4C	TEMBLOR	0.40 g	S 25°W	4.0 miles
4D	8	0.28 g	N 40°W	5.7 miles
HUMBOLT COUNTY, CALIFORNIA 10 DECEMBER 1967 M=5.6				
5	FERNDALE	0.27 g	S 44°W	20 miles
BORREGO MOUNTAIN, CALIFORNIA 8 APRIL 1968 M=6.5				
6	EL CENTRO	(7.0 cm (0.14 g	South South	41 miles

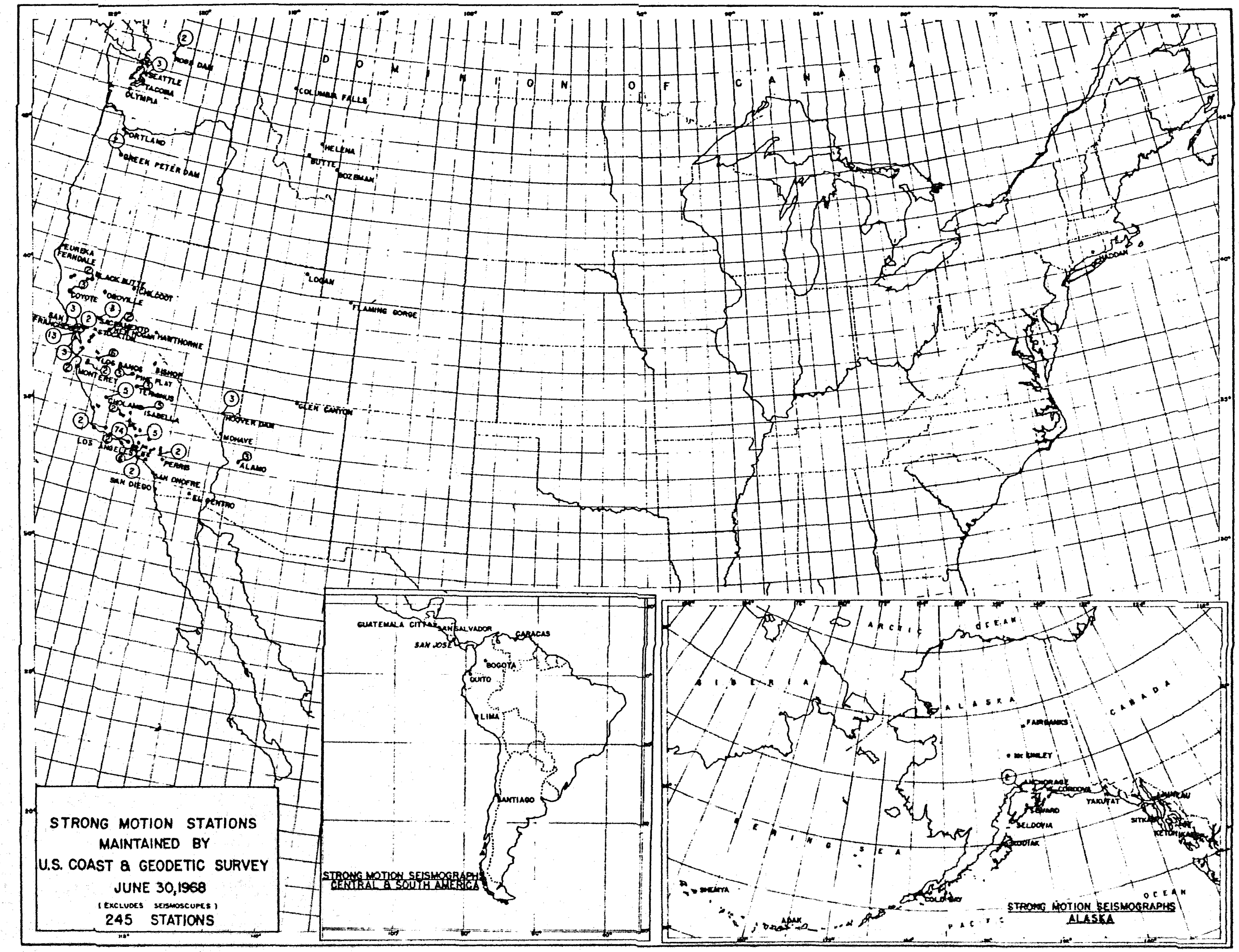


FIGURE I - STRONG MOTION SEISMOGRAPH NETWORK

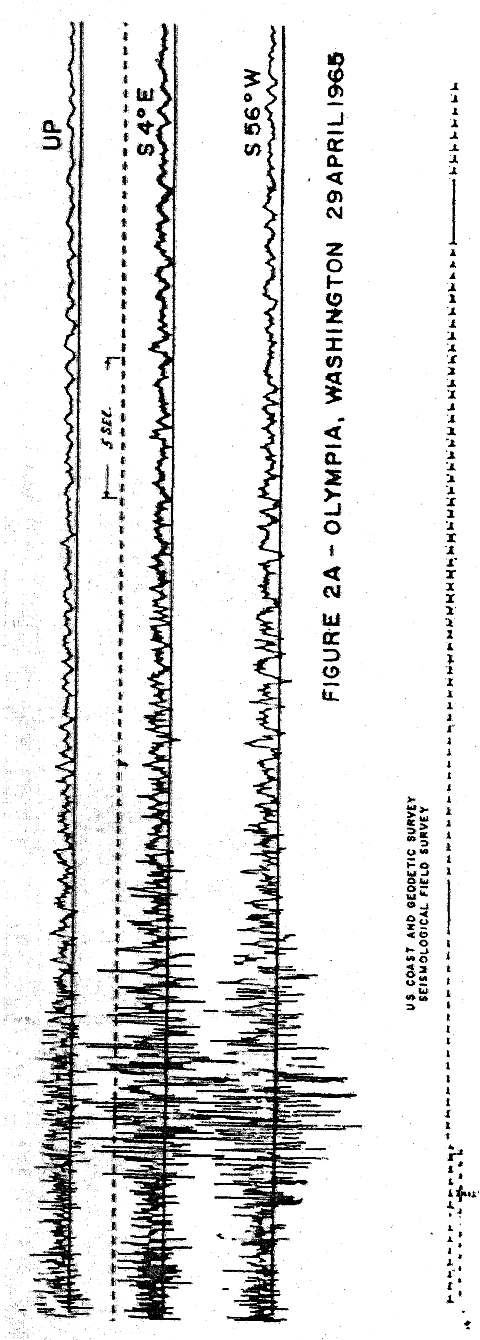


FIGURE 2A - OLYMPIA, WASHINGTON 29 APRIL 1965

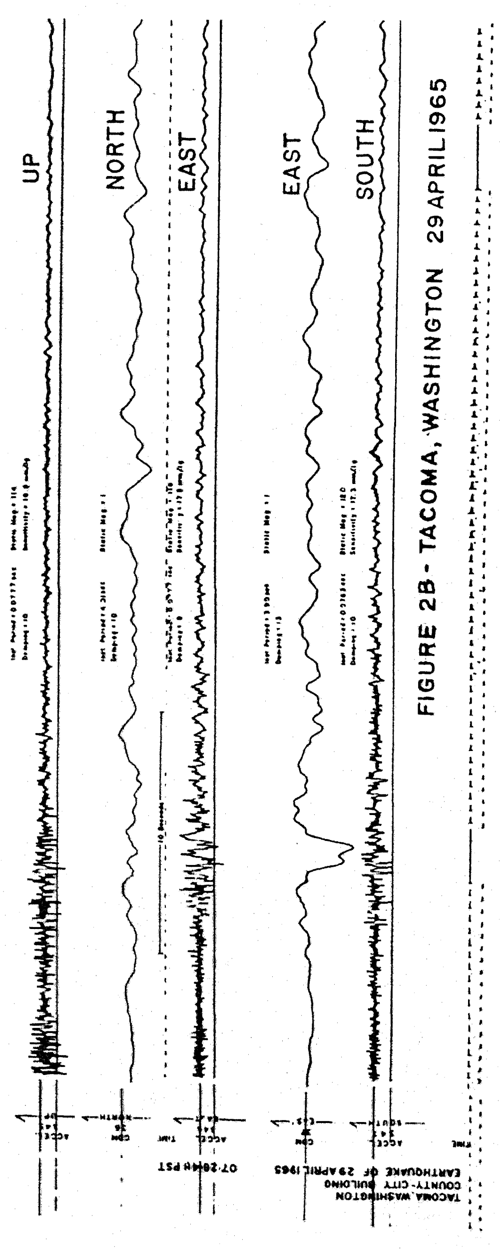


FIGURE 2B - TACOMA, WASHINGTON 29 APRIL 1965

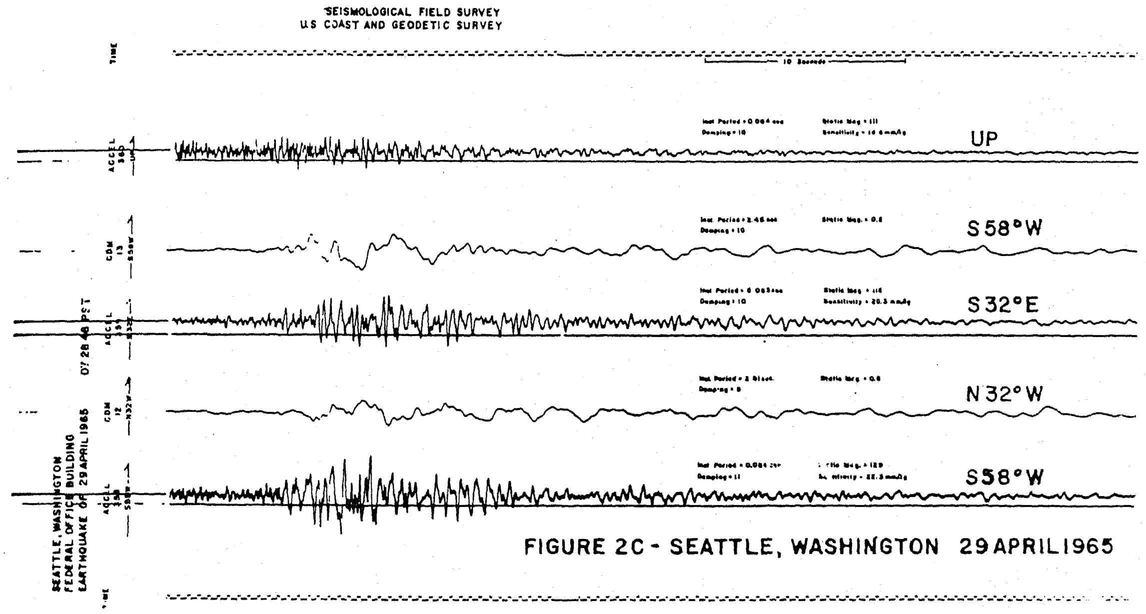


FIGURE 2C - SEATTLE, WASHINGTON 29 APRIL 1965

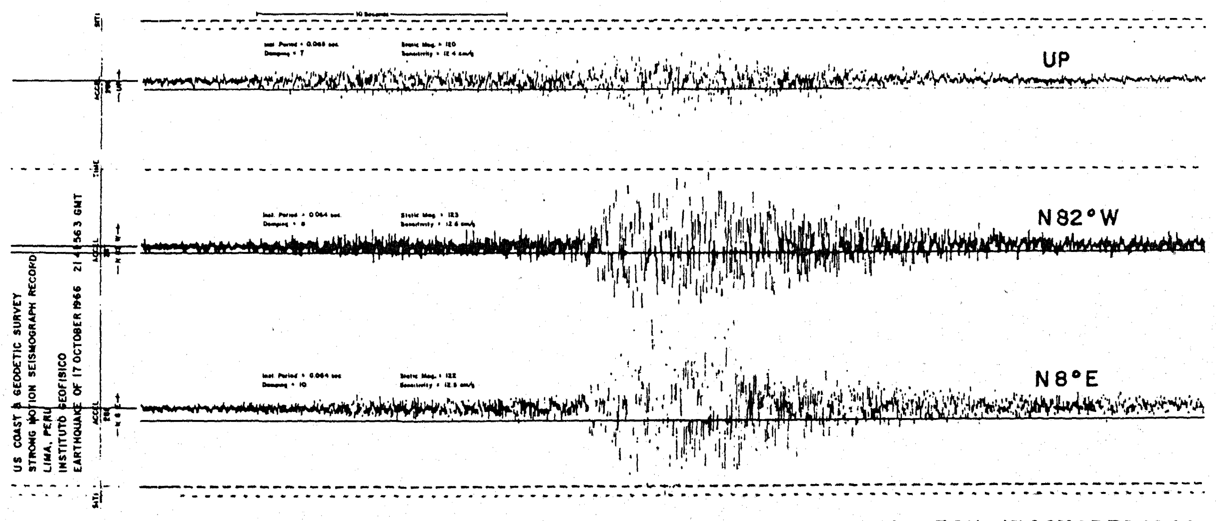


FIGURE 3 - LIMA, PERU 17 OCTOBER 1966

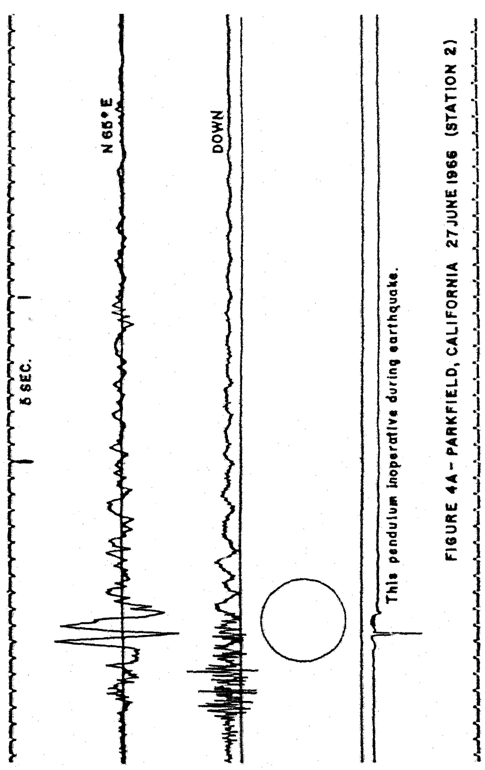


FIGURE 4A - PARKFIELD, CALIFORNIA 27 JUNE 1966 (STATION 2)

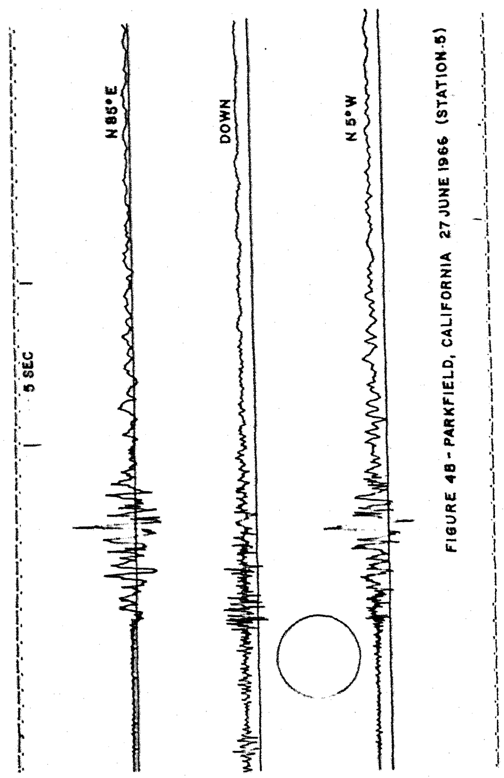


FIGURE 4B - PARKFIELD, CALIFORNIA 27 JUNE 1966 (STATION 5)

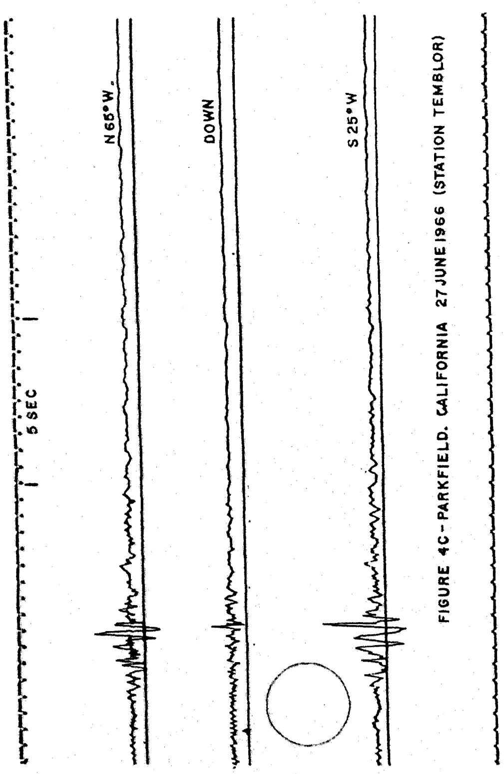


FIGURE 4C - PARKFIELD. CALIFORNIA 27 JUNE 1966 (STATION TEMBLOR)

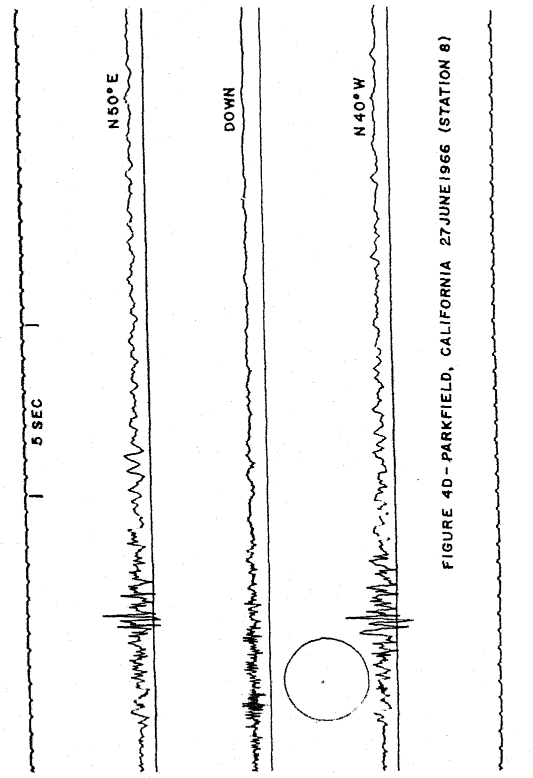


FIGURE 4D - PARKFIELD, CALIFORNIA 27 JUNE 1966 (STATION 8)

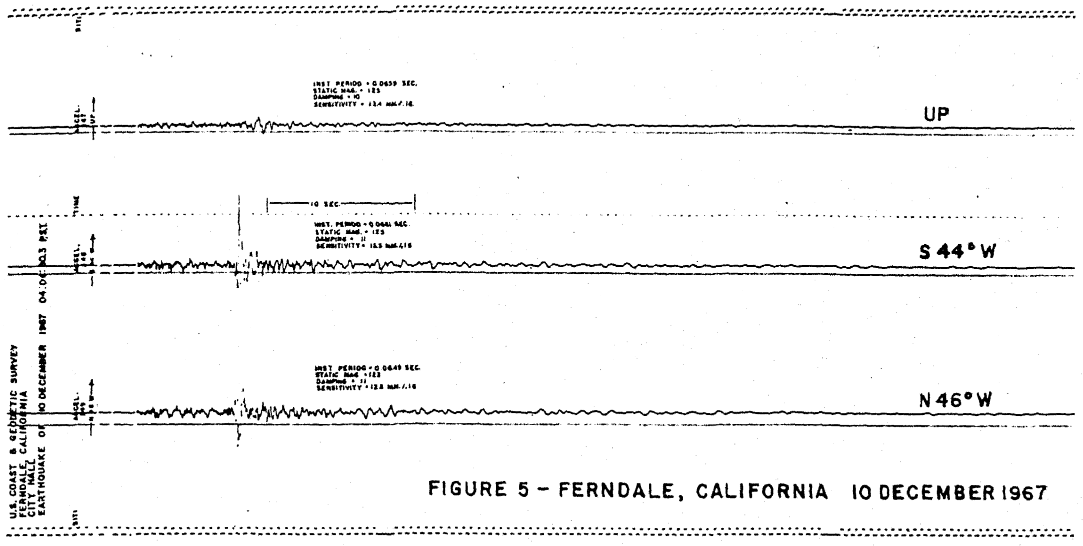


FIGURE 5 – FERNDALE, CALIFORNIA 10 DECEMBER 1967

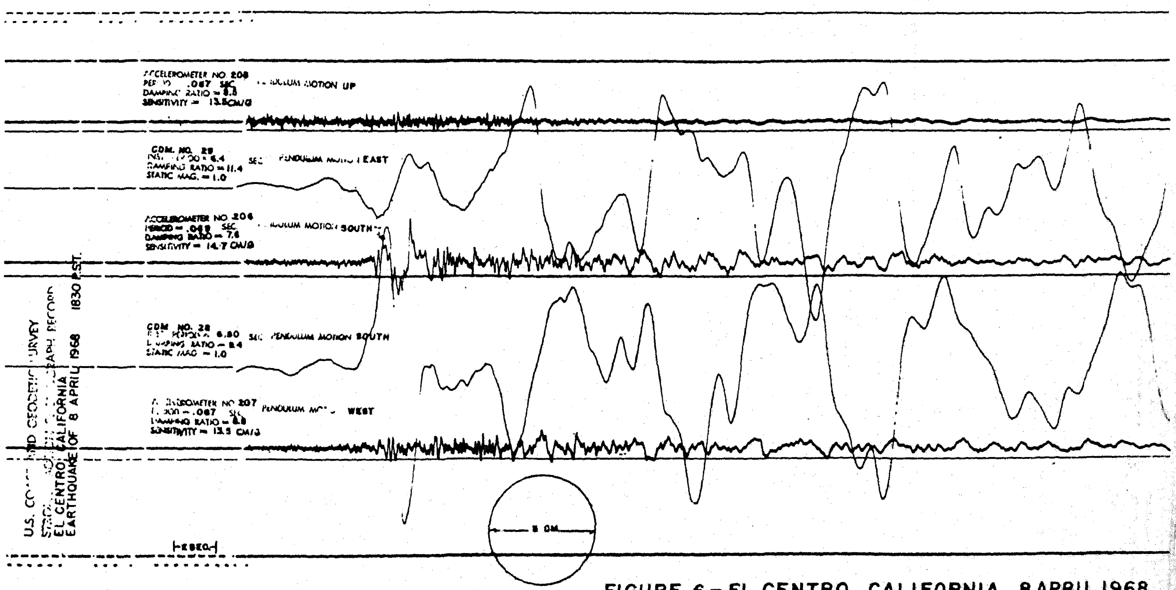


FIGURE 6 – EL CENTRO, CALIFORNIA 8 APRIL 1968

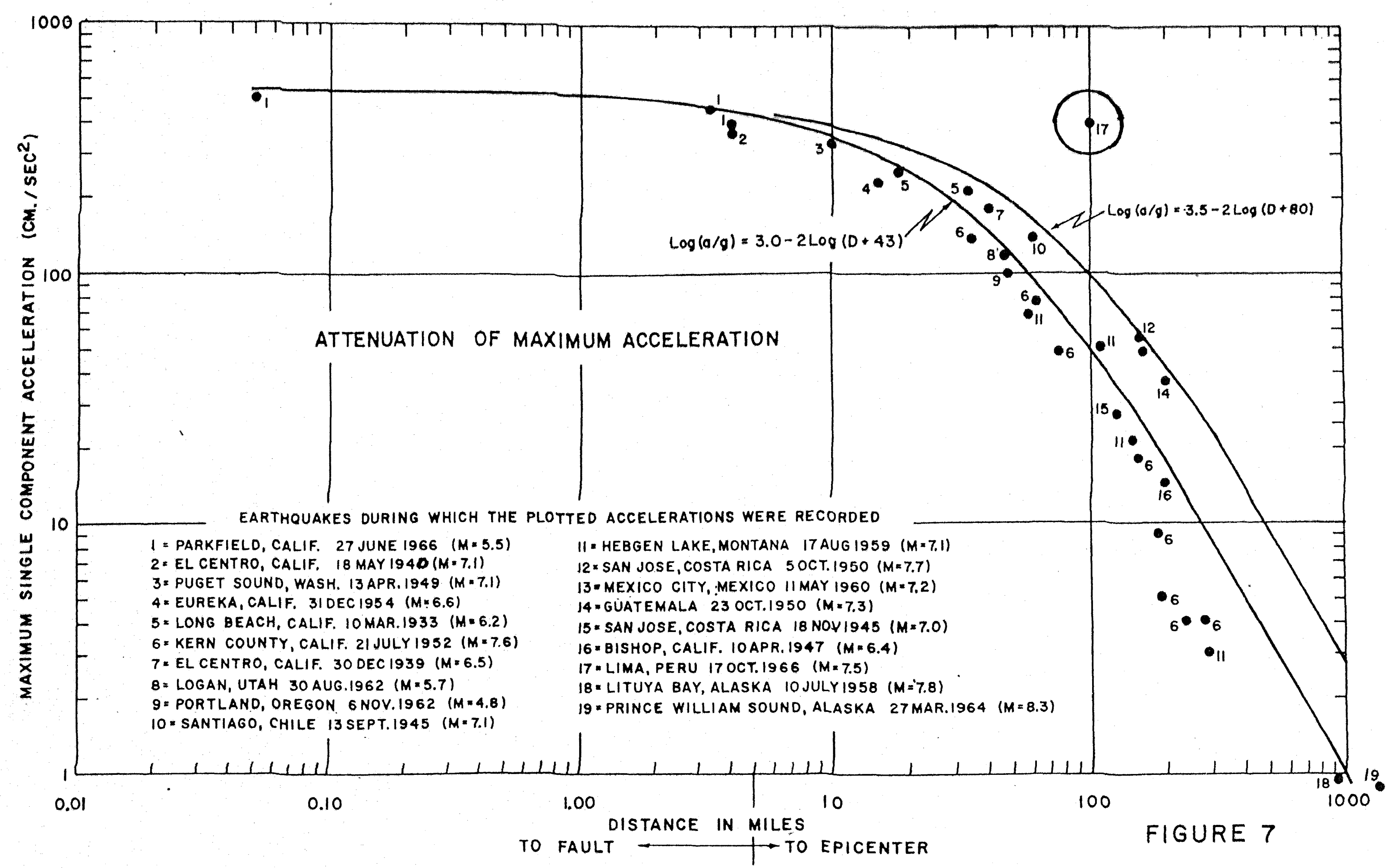
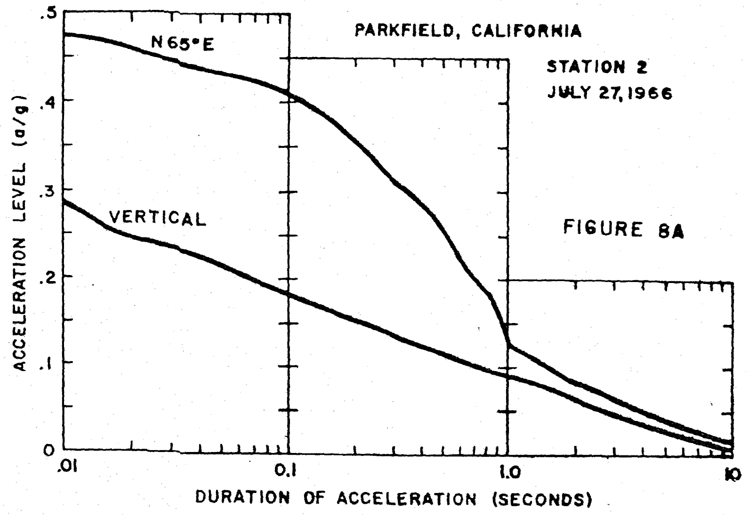
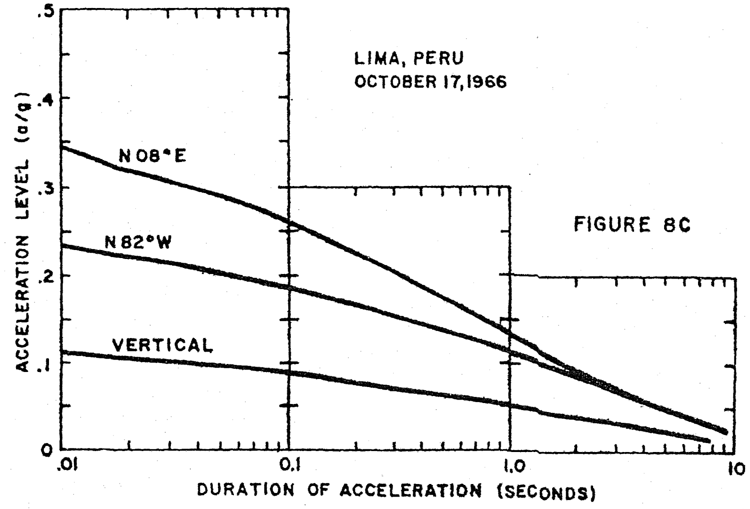
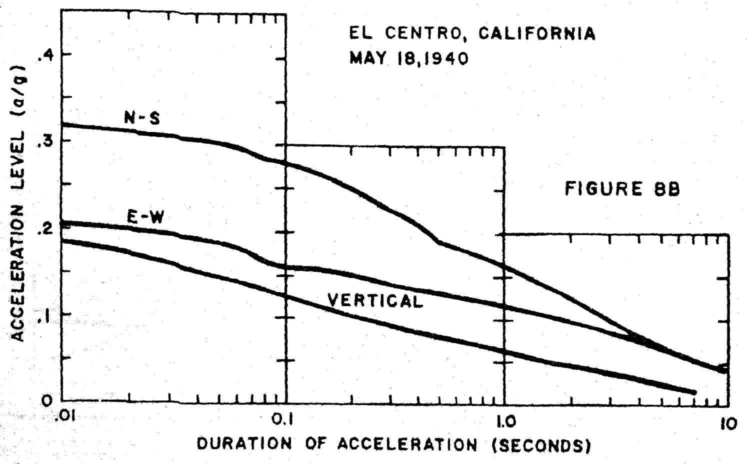
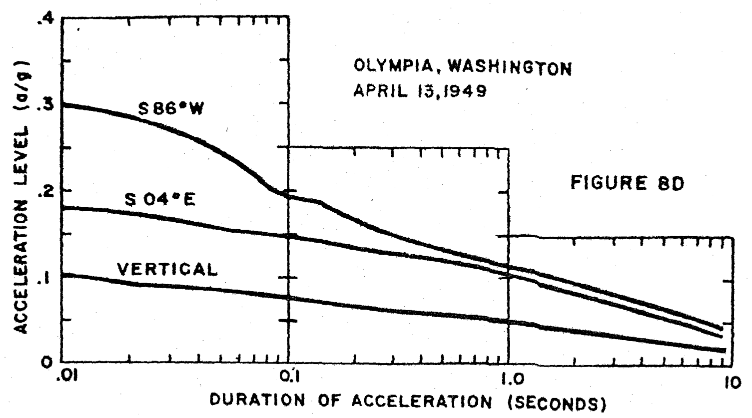

ATTENUATION OF MAXIMUM ACCELERATION
MAXIMUM SINGLE COMPONENT ACCELERATION (CM./SEC^2)
DISTANCE IN MILES
TO FAULT ← → TO EPICENTER
Log (a/g) = 3.0 − 2 Log (D + 43)
Log (a/g) = 3.5 − 2 Log (D + 80)
1000
100
10
1
0.01
0.10
1.00
10
100
1000
EARTHQUAKES DURING WHICH THE PLOTTED ACCELERATIONS WERE RECORDED
1 = PARKFIELD, CALIF. 27 JUNE 1966 (M = 5.5)
2 = EL CENTRO, CALIF. 18 MAY 1940 (M = 7.1)
3 = PUGET SOUND, WASH. 13 APR. 1949 (M = 7.1)
4 = EUREKA, CALIF. 31 DEC 1954 (M = 6.6)
5 = LONG BEACH, CALIF. 10 MAR. 1933 (M = 6.2)
6 = KERN COUNTY, CALIF. 21 JULY 1952 (M = 7.6)
7 = EL CENTRO, CALIF. 30 DEC 1939 (M = 6.5)
8 = LOGAN, UTAH 30 AUG. 1962 (M = 5.7)
9 = PORTLAND, OREGON 6 NOV. 1962 (M = 4.8)
10 = SANTIAGO, CHILE 13 SEPT. 1945 (M = 7.1)
11 = HEBGEN LAKE, MONTANA 17 AUG 1959 (M = 7.1)
12 = SAN JOSE, COSTA RICA 5 OCT. 1950 (M = 7.7)
13 = MEXICO CITY, MEXICO 11 MAY 1960 (M = 7.2)
14 = GUATEMALA 23 OCT. 1950 (M = 7.3)
15 = SAN JOSE, COSTA RICA 18 NOV 1945 (M = 7.0)
16 = BISHOP, CALIF. 10 APR. 1947 (M = 6.4)
17 = LIMA, PERU 17 OCT. 1966 (M = 7.5)
18 = LITUYA BAY, ALASKA 10 JULY 1958 (M = 7.8)
19 = PRINCE WILLIAM SOUND, ALASKA 27 MAR. 1964 (M = 8.3)

FIGURE 7


PARKFIELD, CALIFORNIA
STATION 2
JULY 27, 1966
FIGURE 8A
N65°E
VERTICAL
ACCELERATION LEVEL (a/g)
DURATION OF ACCELERATION (SECONDS)
.01
0.1
1.0
10
0
.1
.2
.3
.4
.5


LIMA, PERU
OCTOBER 17, 1966
FIGURE 8C
N08°E
N82°W
VERTICAL
ACCELERATION LEVEL (a/g)
DURATION OF ACCELERATION (SECONDS)
.01
0.1
1.0
10
0
.1
.2
.3
.4
.5


EL CENTRO, CALIFORNIA
MAY 18, 1940
FIGURE 8B
N-S
E-W
VERTICAL
ACCELERATION LEVEL (a/g)
DURATION OF ACCELERATION (SECONDS)
.01
0.1
1.0
10
0
.1
.2
.3
.4


OLYMPIA, WASHINGTON
APRIL 13, 1949
FIGURE 8D
S86°W
S04°E
VERTICAL
ACCELERATION LEVEL (a/g)
DURATION OF ACCELERATION (SECONDS)
.01
0.1
1.0
10
0
.1
.2
.3
.4

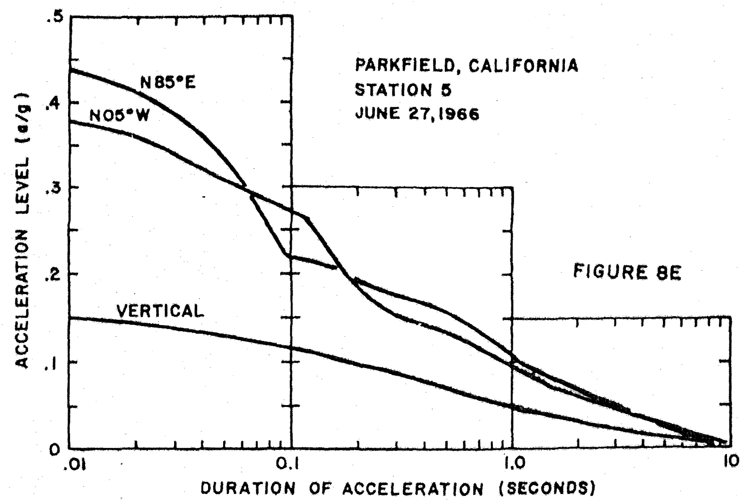


FIGURE 8E

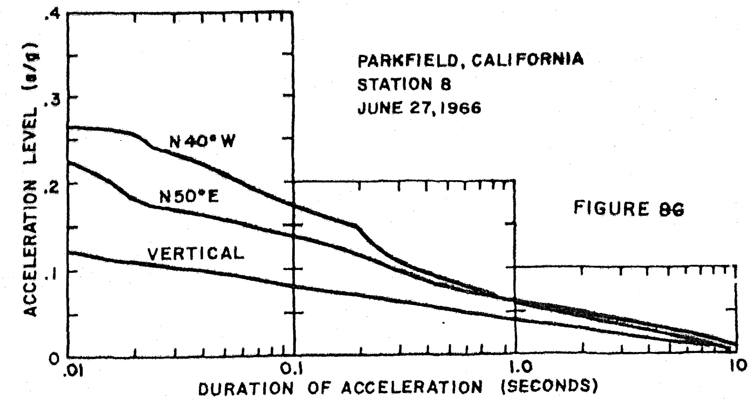


FIGURE 8G

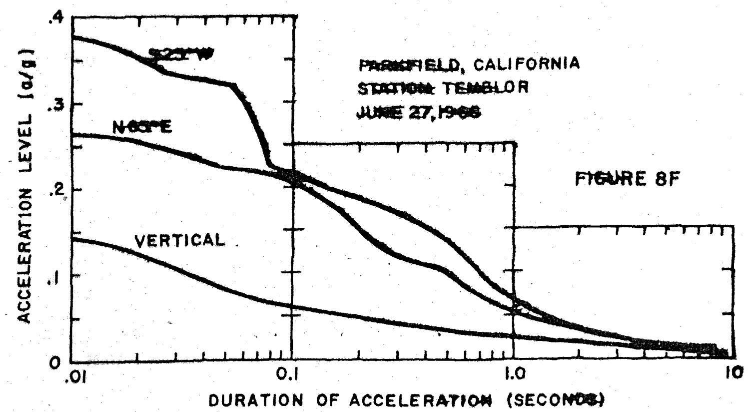


FIGURE 8F

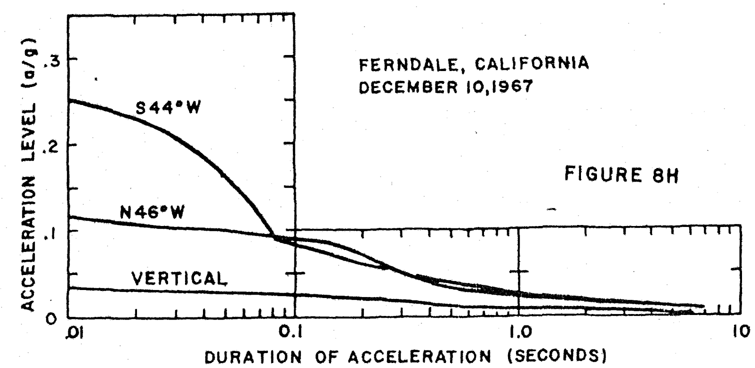


FIGURE 8H

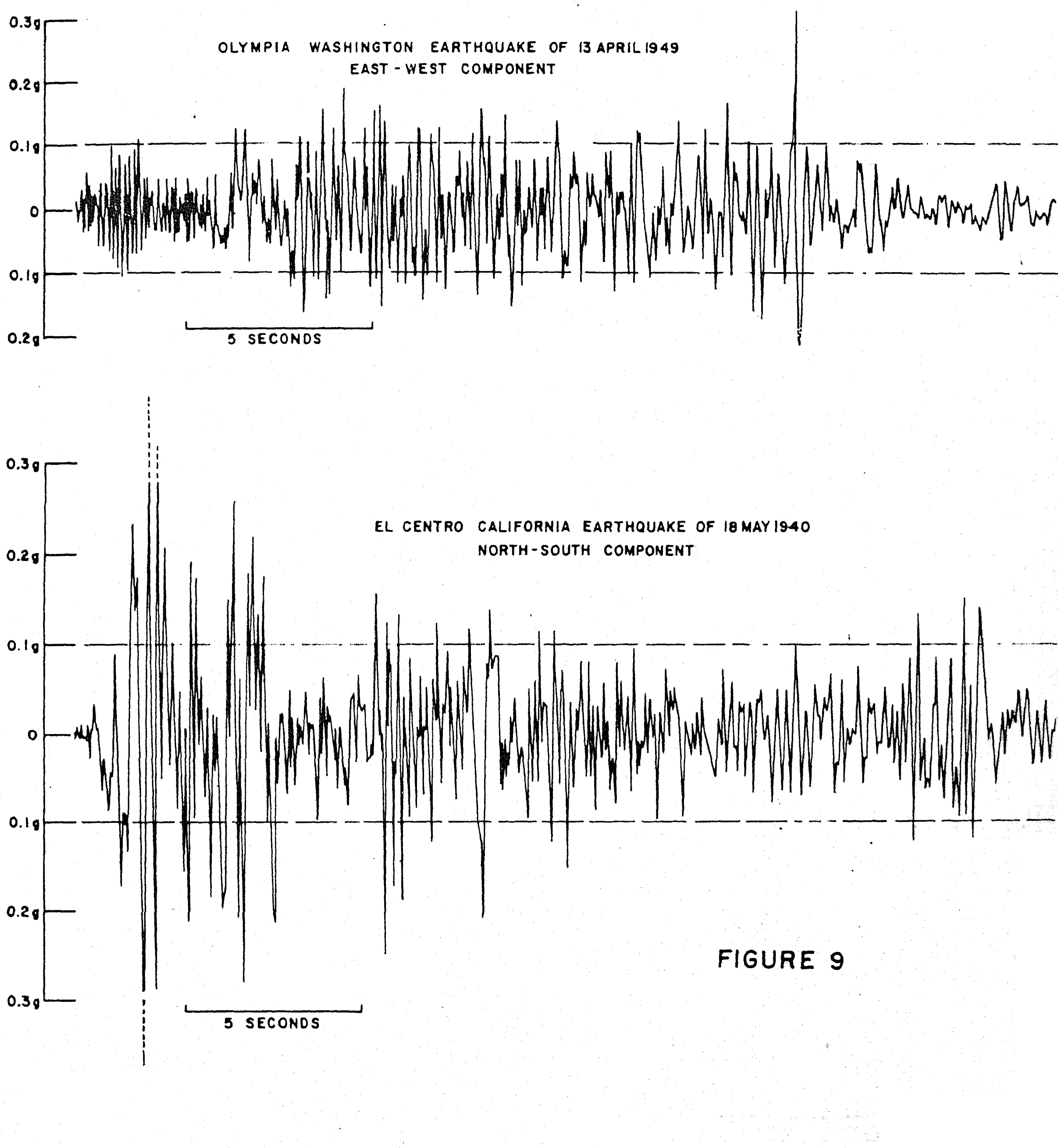

0.3g
0.2g
0.1g
0
0.1g
0.2g
OLYMPIA WASHINGTON EARTHQUAKE OF 13 APRIL 1949
EAST - WEST COMPONENT
5 SECONDS
0.3g
0.2g
0.1g
0
0.1g
0.2g
0.3g
EL CENTRO CALIFORNIA EARTHQUAKE OF 18 MAY 1940
NORTH - SOUTH COMPONENT
5 SECONDS

FIGURE 9

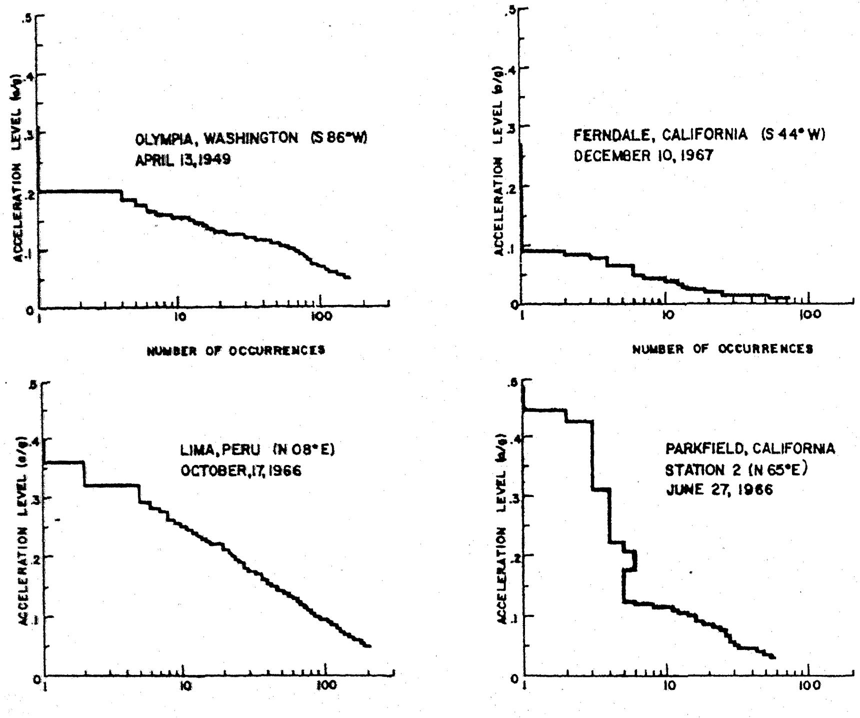


FIGURE 10

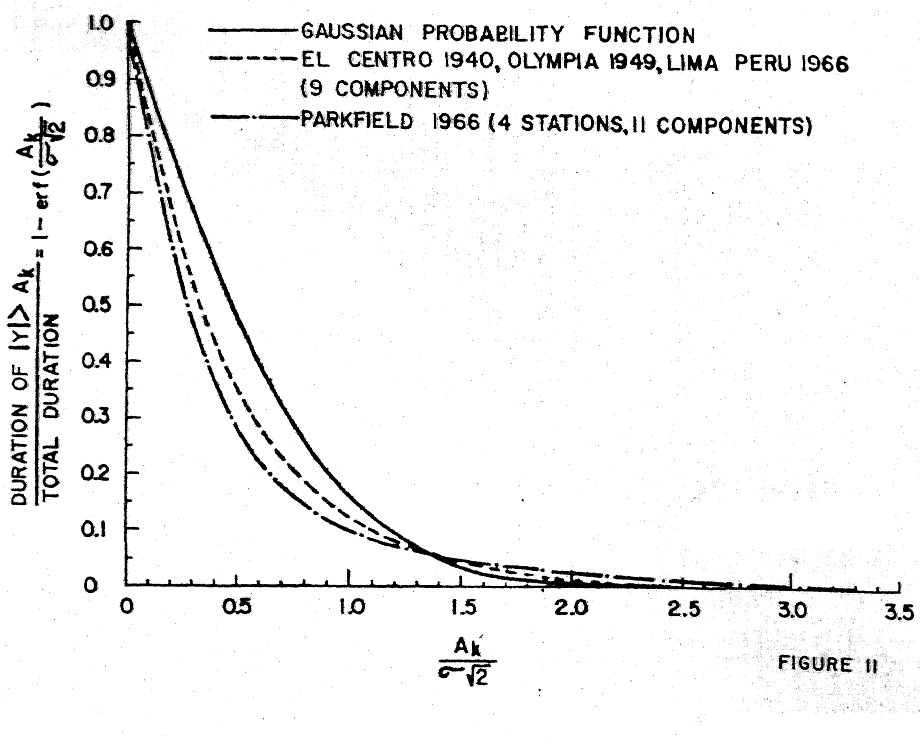


FIGURE 11