A COMPARISON OF THE SPECTRA OF SMALL AND MODERATE EARTHQUAKES

by

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SYNOPSIS

During February 1972, a unique set of seismograms was obtained at NOAA's Stone Canyon Geophysical Observatory on the central San Andreas fault, of a group of earthquakes, all of which originated at the same focus, distant 18 km from the observatory. Shocks with magnitudes spanning the range 1.1 to 4.7 were well recorded on three-component instruments. Differences in the horizontal ground displacement spectra of these shocks are interpreted in terms of source parameters and attenuation factors. Spectral studies of this type contribute to the proper assessment of the validity of scaling upward the spectral characteristics of an earthquake of a given size to yield a hypothetical "design earthquake" two or three orders of magnitude greater than the largest shock for which good recordings are available.

DATA

On February 24, 1972, an earthquake of magnitude 5.1 (BRK) occurred on the San Andreas fault in central California near the Stone Canyon Geophysical Observatory (STC) of the National Oceanic and Atmospheric Administration's (NOAA) Earthquake Mechanism Laboratory (EML) (see Figure 1). Seismograms from hundreds of aftershocks associated with the $M = 5.1$ event were recorded on magnetic tape by the three-component short-period Willmore seismometers in continuous operation at STC. On February 27, 1972, a magnitude 4.7 earthquake (see Figure 1) occurred 18 km to the southeast of Stone Canyon near the trace of the San Andreas fault. This shock triggered the strong-motion (type SMA-1) accelerometers which had been installed by NOAA's Seismological Field Survey at STC shortly after the $M = 5.1$ event. The STC accelerometers were triggered during the P-wave coda of the $M = 4.7$ event so that the entire S-wave signal was well recorded and is available for analysis (see Figure 2).

The many smaller earthquakes associated with the $M = 4.7$ event recorded by the Willmore seismometers ($T_o = 1$ sec) at STC provide an excellent opportunity to compare earthquake spectra of small events ($1 \leq M \leq 2$) with that of the $M = 4.7$ event. Typical seismograms at STC for a small event ($M = 1.67$) are shown in Figure 3. The smaller earthquakes selected for this study (Table 1) occurred within a few hours of the $M = 4.7$ event, and all have hypocenters within a few km of the hypocenter of the $M = 4.7$ earthquake. In addition, the consistent directions

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of first motion at nearby seismic stations indicate that the events listed in Table 1 all had identical focal mechanisms. In view of their tightly grouped hypocenter locations and identical fault plane solutions, it is reasonable to assume that propagation path effects such as scattering and attenuation are common for all events listed in Table 1.

SPECTRAL ANALYSIS

The horizontal component seismograms for the small ($1 < M < 2$) events and the accelerograms for the larger ($M = 4.7$) event were first converted to a digital format suitable for analysis on a CDC 6600 computer. The horizontal components then were rotated mathematically to form derived seismograms representing the longitudinal and transverse components of ground motion referred to a station-to-epicenter azimuth of 130°. Next, the Fourier transform was taken of a four-second time window of the resultant transverse component centered on the S-wave arrival, using the Cooley-Tukey algorithm to effect the transformation. The effects of instrument response were removed from the resulting spectral moduli by assuming that SMA-1 response is proportional to ground acceleration from 0 to 15 Hz and using the known response of the Willmore seismometers. The resultant SH ground displacements at Stone Canyon are plotted on a log-log scale in Figure 4 for five of the smaller events and for the $M = 4.7$ event (lower right).

The dashed lines in Figure 4 are drawn to represent approximately the gross spectral characteristics of the ground motions at Stone Canyon. Interpretations of gross spectral characteristics of these earthquakes in terms of source models, such as that of Brune(1) were reported earlier by Bakun, Bufe and Morrill(2). Modulations about the dashed lines in Figure 4 result from secondary arrivals, focusing of energy, imperfections in recordings, digitizing and knowledge of instrument characteristics, and possibly other effects, and no attempt will be made to interpret them in this paper.

Q AND SOURCE PARAMETERS

In order to compare spectra or to interpret spectra in terms of source spectral models, it normally is necessary to apply certain corrections to the raw spectra for nonelastic effects along the propagation path from source to receiver. Usually the nonelastic effects are accounted for by assuming a quality factor Q which is independent of frequency. Assuming Q to be constant along the propagation path, the observed spectra then are corrected back to the focus by multiplying each spectral point by the factor $\exp(\pi f \Delta / Q v)$ where f is the frequency in hertz, Δ is the epicentral distance and v is the phase velocity. In this study, $\Delta = 18$ km and we take $v =$ the shear velocity $\beta = 1.8$ km/sec. In Figure 5, the spectral moduli of the nine small earthquakes listed in Table 1 have been corrected back to the focus assuming $Q = \infty$ (no nonelastic attenuation), $Q = 200$ and $Q = 100$.

The dashed lines in Figure 5 again refer to the gross spectral behavior. In models of earthquake source spectra, the intersection of the spectral asymptotes (dashed lines) is termed the corner frequency and is inversely proportional to the dimension of the earthquake source.

DISCUSSION

In their earlier study on these earthquakes, Bakun, Bufe and Morrill(2) presented provisional estimates of source dimensions and effective stresses based on Brune's 1970 earthquake source model(1). Estimates of source dimension depend upon the correct identification of spectrum corner frequencies, while the spectral level at long periods gives a measure of the seismic moment M_o. From these can be derived estimates of the effective stress in the focal region and the fractional stress drop. The limited band width available for the $M = 4.7$ event allows an estimate only of a lower bound to seismic moment and to the characteristic source dimension; they estimated the latter as greater than 3.4 km, a value entirely consistent with the spatial distribution of microaftershocks of the event[I].

In the Brune model, the identical corner frequencies for the smaller events imply identical characteristic source dimensions. Under this interpretation of the data, the differences in magnitude and seismic moment result solely from differences in effective stresses operative over (presumably) the same area of the same fault surface. If we were to use these five earthquakes ($1 < M < 2$) as the basis for estimating the spectral characteristics of an event of magnitude 4.7, we would come up with a spectrum very unlike that actually observed for this earthquake.

Bakun, Bufe and Morrill(2) also pointed out that these observed spectra can be interpreted as setting a lower bound of 75 for the average value of Q along the propagation path for these events. This condition results from the work of Hanks and Wyss(3), who showed that at frequencies above the corner frequency, the spectral amplitudes must decay at least as fast as the -1.5-power of the frequency if the energy integral is to be bounded. Such a lower-bound estimate assumes that the spectral behavior at high frequencies is adequately defined by the 0.2 - 12 Hz band.

Another conclusion may be drawn tentatively from the spectra of Figure 5, wherein the observed spectra (left column) are corrected back to the source assuming that Q was 200 (center column) and 100 (right column). As the assumed value of Q is decreased, the high-frequency spectral content of the source must have been higher to produce the spectra derived from seismograms recorded 18 km from the source. If nature's value of Q is as small as 100, an unbiased observer well might question whether the corrected spectra suggest the existence of a corner frequency at all.

[I]We thank W. Ellsworth and R. Wesson of the U.S. Geological Survey, Menlo Park, California, for unpublished focal coordinate data.

BIBLIOGRAPHY

1. Brune, J. N., Tectonic stress and the spectra of seismic shear waves from earthquakes, J. Geophys. Res., 75, 4997-5009, 1970.

2. Bakun, W. H., C. G. Bufe and B. J. Morrill, Source characteristics and spectra of the 1972 Bear Valley, California, earthquakes, Earthquake Research in NOAA, 1971-1972 (NOAA Tech. Rept. ERL 256-ESL 28), pp. 46-50, 1973.

3. Hanks, T. C. and M. Wyss, The use of body-wave spectra in the determination of seismic-source parameters, Bull. Seism. Soc. Am., 62, 561-589, 1972.

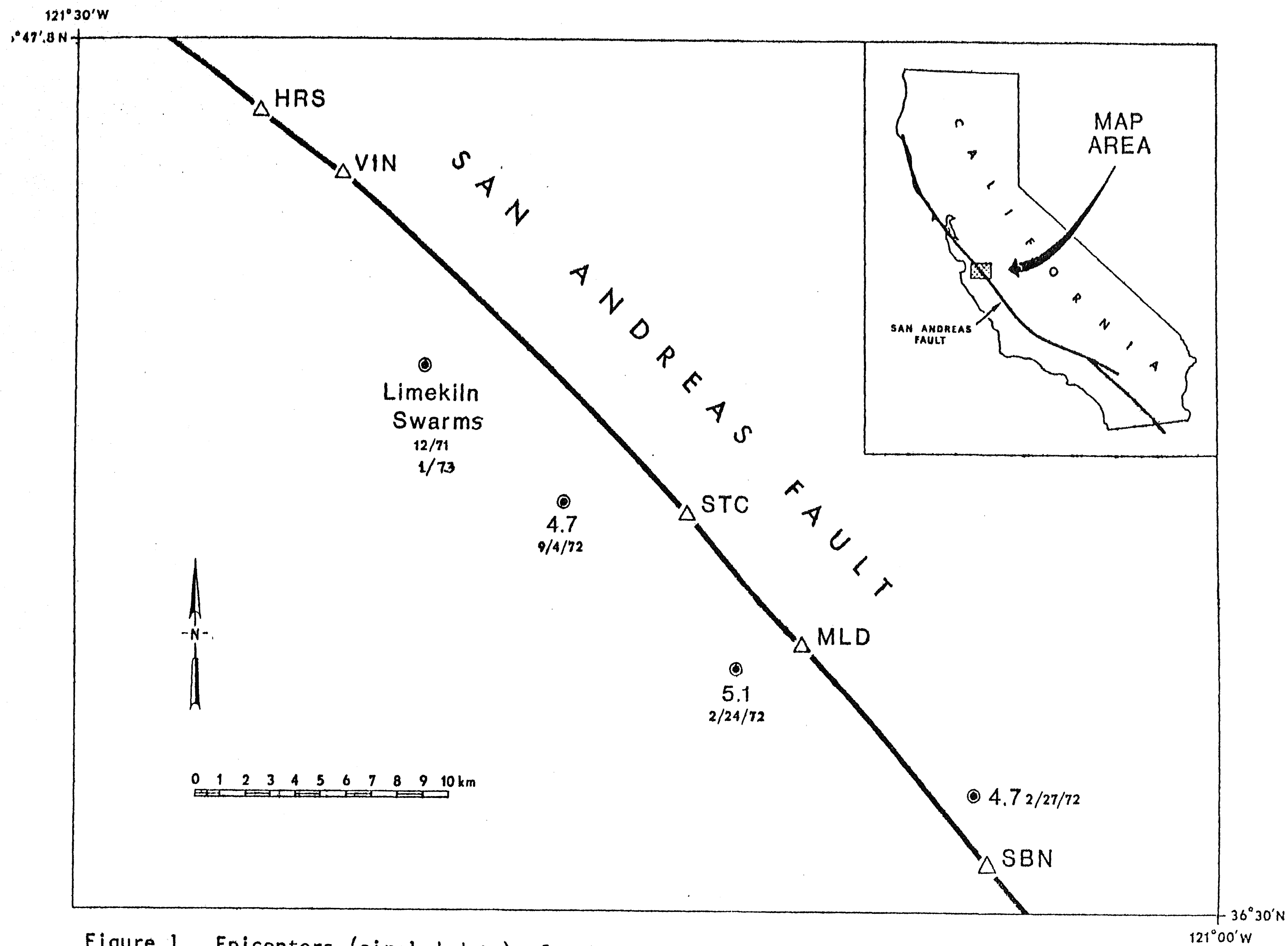

Figure 1. Epicenters (circled dots) of principal earthquakes on the San Andreas fault between Harris Ranch (HRS) and San Benito (SBN) Dec. 1971-Jan. 1973. Triangles on the fault denote creepmeter installations. Following the Melendy Ranch earthquake of Feb. 24, 1972, strong-motion accelerographs were installed at Melendy Ranch (MLD) and at the Stone Canyon Observatory (STC).

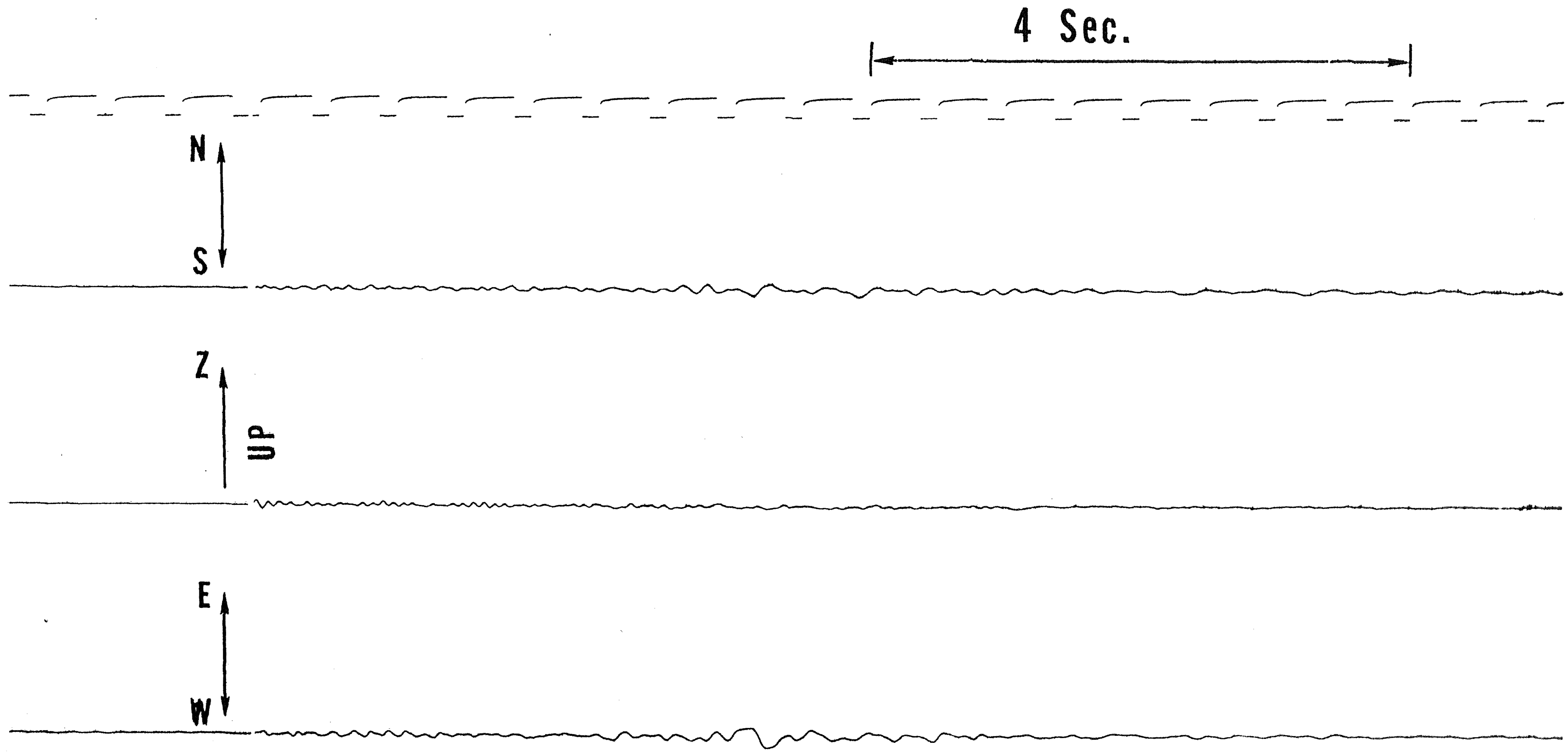

Figure 2. Seismogram of Bear Valley earthquake, February 27, 1972, magnitude 4.7(BRK), recorded by SMA-1 accelerometer at Stone Canyon Geophysical Observatory (STC). Epicenter is 18 km southeast of STC.

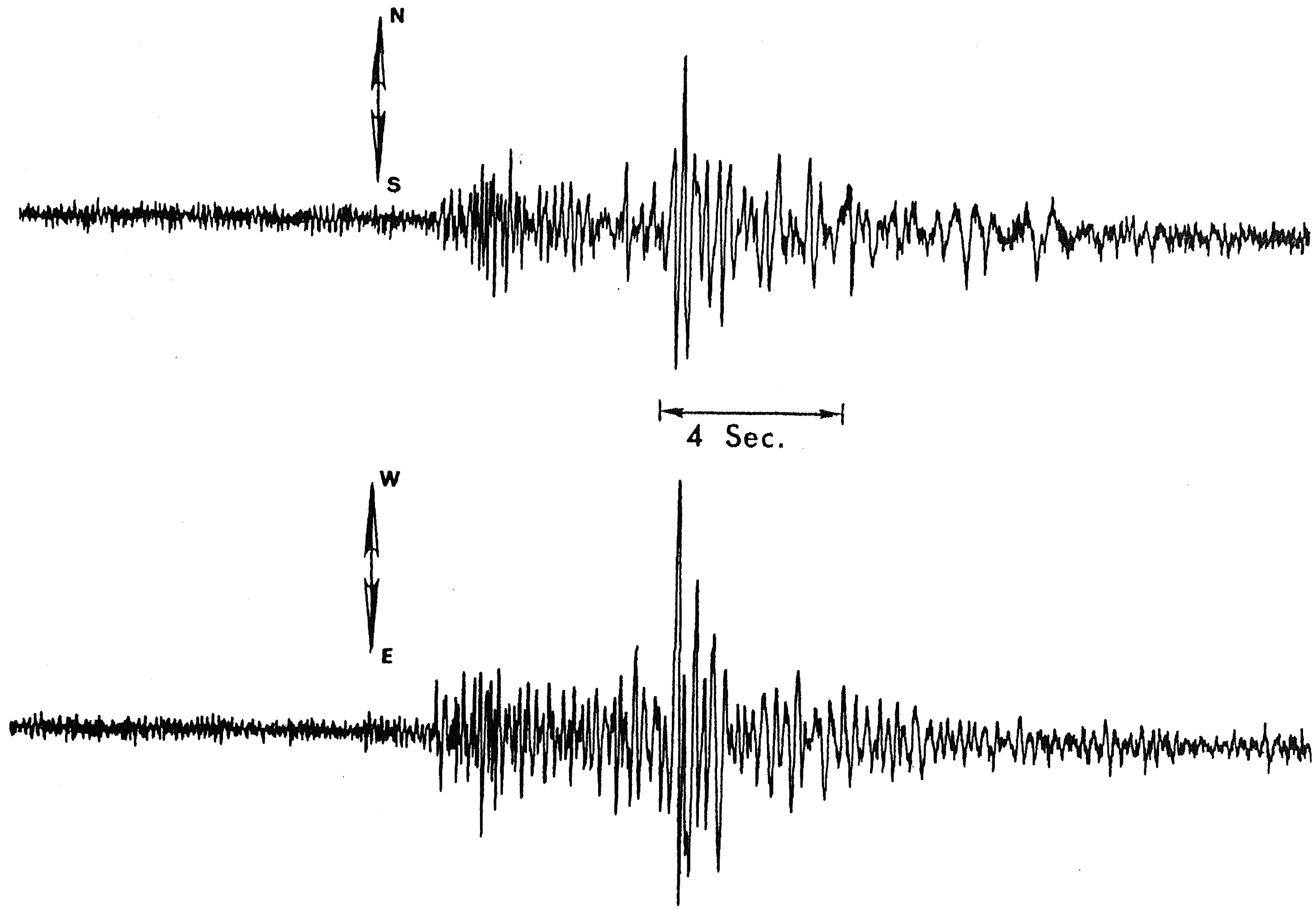

Figure 3. Horizontal-component seismograms of earthquake of February 28, 1972 at 00:18:53.2 UT, magnitude 1.67 (USGS), recorded by Willmore seismometers at STC. Epicenter 18 km southeast of STC. Willmore output proportional to ground velocity for frequencies above 2 Hz.

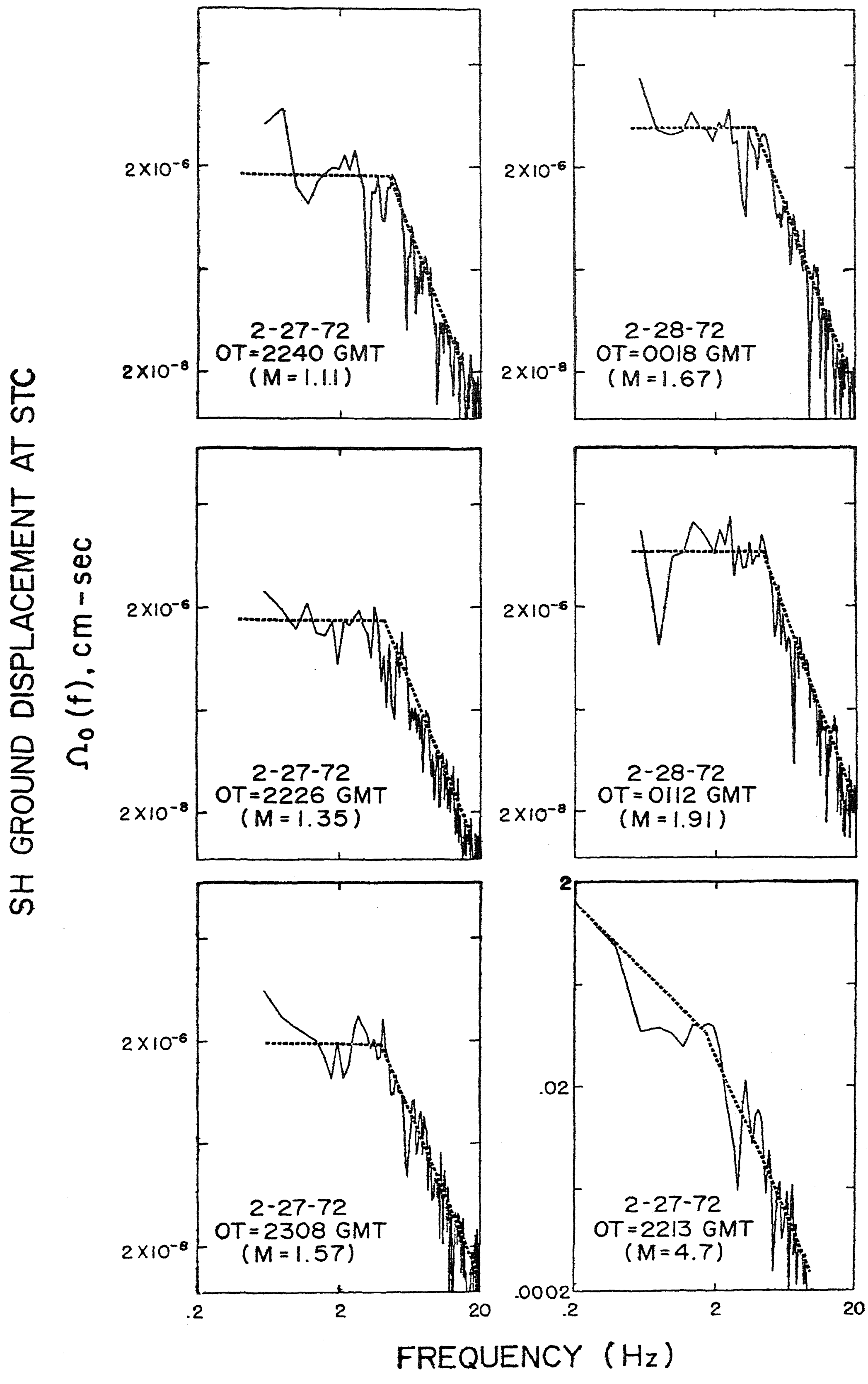

Figure 4. Spectra of SH ground displacements at STC for six Bear Valley earthquakes, magnitudes 1.11 to 4.7. All epicenters 18 km southeast of STC. Instrument response has been removed. Spectra are plotted on a log-log scale.

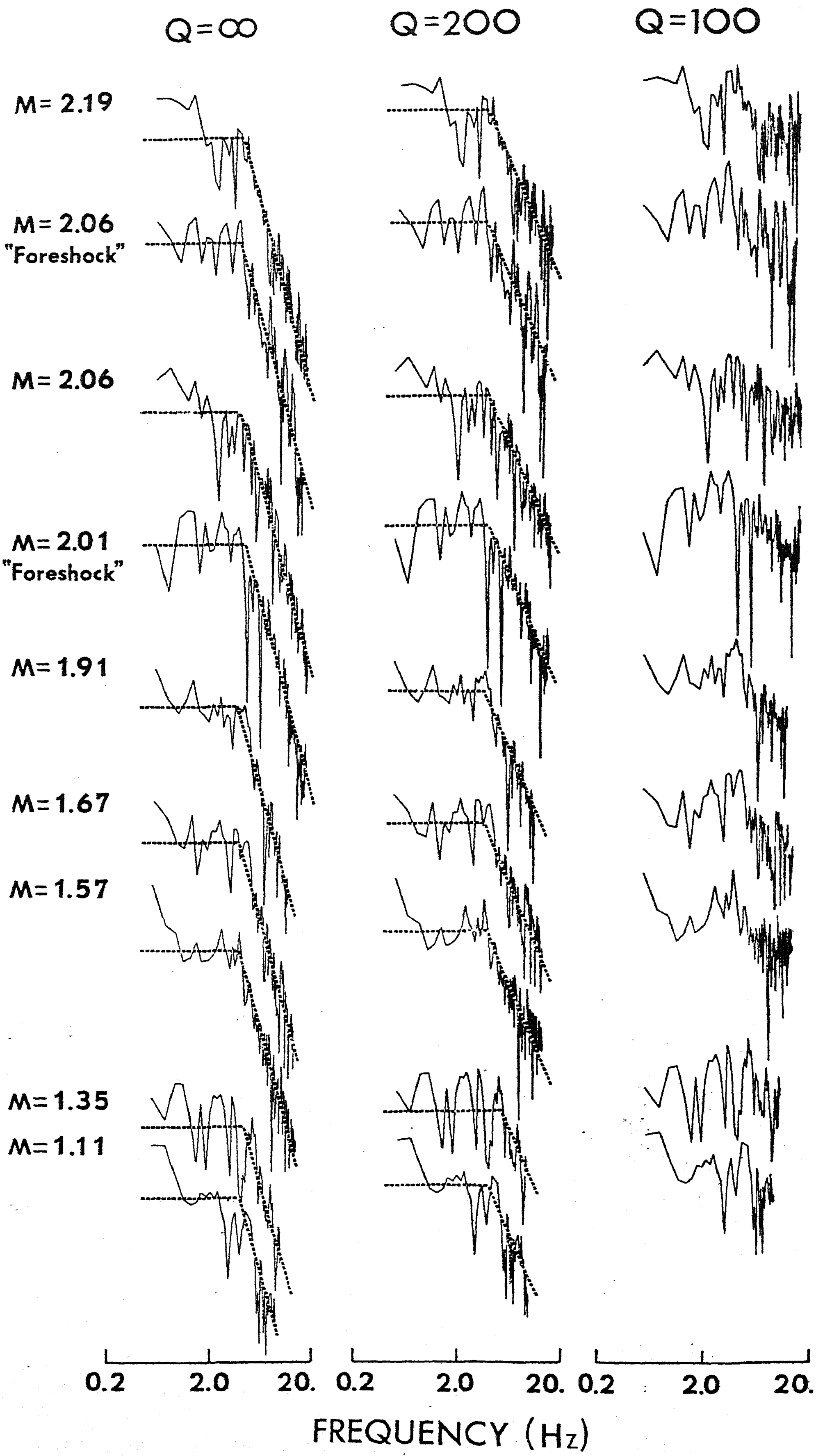

Figure 5. Spectra of SH ground displacements at STC for 9 small Bear Valley earthquakes. Instrument response has been removed. Spectra have been corrected back to the focus for nonelastic attenuation assuming Q = ∞ (left), Q = 200 (middle) and Q = 100 (right).

TABLE 1. BEAR VALLEY EARTHQUAKES - SOURCE DATA[I]

DATE	ORIGIN TIME (GMT)	LATITUDE (°N)	LONGITUDE (°W)	FOCAL DEPTH (KM)	MAGNITUDE
27 Feb 72	20:33:26.2	36°32.3'	121°04.9'	9.8	2.06
27 Feb 72	21:19:46.4	36°32.2'	121°04.9'	10.8	2.01
27 Feb 72	22:13:08.3	36°32.2'	121°04.6'	10.2	4.7 (BRK)
27 Feb 72	22:26:58.1	36°32.2'	121°04.9'	11.7	1.35
27 Feb 72	22:40:45.4	36°31.7'	121°05.8'	9.5	1.11
27 Feb 72	22:54:18.2	36°31.9'	121°05.1'	9.9	2.06
27 Feb 72	23:08:15.0	36°31.9'	121°05.4'	9.9	1.57
28 Feb 72	00:18:53.2	36°32.0'	121°05.5'	10.2	1.67
28 Feb 72	01:12:07.3	36°32.0'	121°05.3'	10.0	1.91
28 Feb 72	15:56:33.6	36°31.9'	121°05.0'	9.9	2.19

[I] Personal communication, W. Ellsworth, U.S.G.S., 1972