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A DIRECT COMPARISON OF "SYNTHETIC" AND ACTUAL WOOD-ANDERSON SEISMOGRAMS

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Local magnitude M_L, which was defined by Richter (1935) specifically in terms of the Wood-Anderson (W-A) seismograph, has become widely used by both seismologists and the general public to describe the size of earthquakes. Wood-Anderson seismographs are not in widespread use today. Even where available, the limited dynamic range of about 50 dB of the W-A seismograph severely limits the magnitude range for which M_L can be estimated. Thus, seismologists are often faced with the task of estimating M_L from records written by instruments radically different from the W-A seismograph.

One technique (Bakun and Lindh, 1977; Kanamori and Jennings, 1978) for estimating M_L when W-A records are not available involves the transformation of the signals recorded on modern systems into "synthetic W-A seismograms" and making the measurements and computations prescribed by Richter (1958). The synthetic W-A seismogram is the record that would have been written at the sensor site of the modern system if a W-A seismograph (with the appropriate gain and dynamic range) had been in operation there. Previous studies have demonstrated the self-consistency of M_L estimates obtained from a suite of synthetic W-A seismograms and have noted that these estimates are in reasonable agreement with estimates of M_L obtained from real W-A seismograms written at other sites.

In this report, we describe a simple experiment to demonstrate directly that accurate synthetic W-A seismograms can indeed be derived from modern seismographs. More specifically, we produce synthetic W-A seismograms whose wave forms closely resemble those of the actual W-A seismograms recorded on the same pier.

Field Experiment

In the fall of 1970, the W-A station, designated PAC, was reestablished at the Branner vault (37°25.03′N; 122°10.94′W; 79 m elevation) of Stanford University. On October 20, 1976, a three-component short-period low-gain seismograph, designated BSF, was installed in the Branner vault on the same pier as the W-A instruments. Except for their relatively low gain (36-dB amplifier attenuator settings) these systems are typical of the instruments in the high-gain short-period seismograph networks of the U.S. Geological Survey (USGS) that were described in detail by Eaton (1977).

On January 8, 1977, an earthquake swarm occurred 10 km east of San Francisco Bay near the Briones Hills (Bolt *et al.*, 1977). Usable records for a few events in the swarm (Table 1) were obtained from both station BSF and the W-A seismographs located in the Branner vault.

Data Analysis

The signals from the three-component short-period seismograph at BSF were electronically digitized from magnetic tape at 200 samples/sec. The transfer function of the BSF systems, $T_{USGS}(\omega)$, in the 0.1 to 30 Hz spectral band were obtained from the digitized automatic daily calibration sequences using the calibration programs described by Bakun and Dratler (1976).

The transformation of a signal $f(t)$ recorded on a USGS central California network seismograph into a "synthetic W-A seismogram" $f_{WA}(t)$ can be expressed by

$$f_{WA}(t) = \mathscr{F}^{-1}\left\{\frac{T_{WA}(\omega)}{T_{USGS}(\omega)}\cdot\mathscr{F}[f(t)]\right\},$$

where $\mathscr{F}$ and $\mathscr{F}^{-1}$ represent forward and inverse Fourier transforms, $T_{WA}(\omega)$ is the theoretical transfer function of a W-A seismograph, and ω is the angular frequency. Calculations were carried out using the programs and procedures described by Bakun and Lindh (1977).

Discussion

The P-wave coda of the $M_L = 4.0$ Briones Hills event at 0858 GMT was selected to demonstrate the agreement in the wave forms of synthetic and actual W-A

TABLE 1

Amplitudes and Local Magnitudes M_L for January 8, 1977 Briones Hills Earthquakes

Event Origin Time (GMT)	Branner Vault (NS) max P-P(mm)		Branner Vault (EW) max P-P(mm)		M_L†
	Synthetic	Actual*	Synthetic	Actual*	
06^h55^m	1.6	2.0	1.2	1.7	2.61 ± 0.06‡
07^h17^m	2.2	2.2	1.7	2.5	2.73 ± 0.05
08^h58^m	Clipped	30.0	Clipped	37.5	4.01 ± 0.09
09^h38^m	Clipped	68.0	Clipped	93.5	4.36 ± 0.12
09^h43^m	2.2	2.0	2.1	2.2	2.92 ± 0.21
09^h51^m	2.7	2.6	3.1	2.8	2.93 ± 0.11

* The trace width is about 1 mm for these records so that the amplitudes listed for the smaller events are uncertain by about 20 per cent.

† Average for stations BKS (BRK), PAC, and MHC. Amplitudes from × 100 Wood-Anderson seismograph at BRK were converted to the standard × 2800 instrument.

‡ Uncertainties represent the standard deviation of the data.

seismograms; unfortunately, the S-wave arrival clearly saturates the BSF amplifiers so that the synthetic W-A traces cannot be expected to resemble closely the actual W-A traces at the time of the S-wave onset. No other Briones Hills events were of a size to allow meaningful wave form comparisons.

The original BSF seismograms, the "synthetic" W-A seismograms, and the actual W-A traces are shown in Figures 1 and 2 for the NS and EW components of motion, respectively. The character of the P-wave codas of the synthetic (*middle*) and actual (*bottom*) W-A traces for both horizontal components of motion are in excellent agreement, while those of the synthetic trace and the original BSF trace (*top*) from which it was derived are markedly different. (The degree of coherence between two nearly-identical seismograms is difficult to determine without the use of transparencies or overlays; we recommend that the interested reader construct transparencies for overlaying the synthetic and actual W-A seismograms in Figures 1 and 2.) Note also that the one area of noticeable disagreement during the P-wave codas occurs on the EW component at the time of the only clipped excursion on the BSF P-coda traces. The agreement shown here clearly demonstrates that seismic signals from modern seismographs, such as the USGS network station that was operated at BSF, can be transformed into accurate synthetic W-A seismograms.

The maximum peak-to-peak amplitudes from the synthetic W-A traces and the

actual W-A traces for all Briones Hills earthquakes for which both readings were possible at the Branner vault are listed in Table 1. The average difference in the maximum peak-to-peak amplitudes is less than 20 per cent. These data suggest that M_L, measured from synthetic W-A seismograms constructed from typical USGS short-period seismic data, will differ on average by about 0.1 unit from M_L obtained using actual W-A seismograms.

We have also listed the average of the magnitudes obtained from maximum amplitudes recorded on the W-A seismographs operated by the University of California, Berkeley, Seismographic Station at Berkeley (*BKS,* 37°52.6′N, 122°14.1′W, 276 m elevation, Δ = 5 km and *BRK,* 37°52.4′N, 122°15.6′W, 81 m

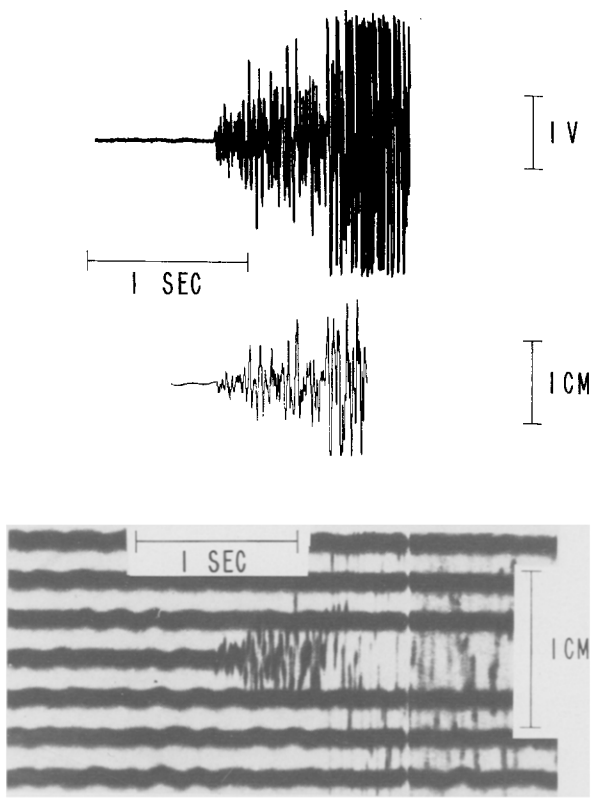

FIG. 1. N-S component of motion for the 0858 GMT event at the Branner vault on the USGS low-gain seismograph BSF (*top*), transformed "synthetic" Wood-Anderson record (*middle*), and actual Wood-Anderson record (*bottom*).

elevation, Δ = 7 km) and Mount Hamilton (MHC, 37°20.5′N, 121°38.5′W, 1283 m elevation, Δ = 78 km), and at PAC (Δ = 54 km). Station corrections were not used for these computations. The standard deviations for the estimates of M_L from the actual W-A seismograms at PAC, BKS (BRK), and MHC range from 0.05 to 0.21. Note that differences in M_L corresponding to observed differences in peak-to-peak amplitudes on the synthetic and actual W-A traces are clearly less than the scatter in M_L obtained from different stations. These data suggest that the differences in M_L resulting from use of synthetic and actual W-A traces are not significant in comparison to the normal differences in M_L estimates obtained from W-A seismographs located at several sites.

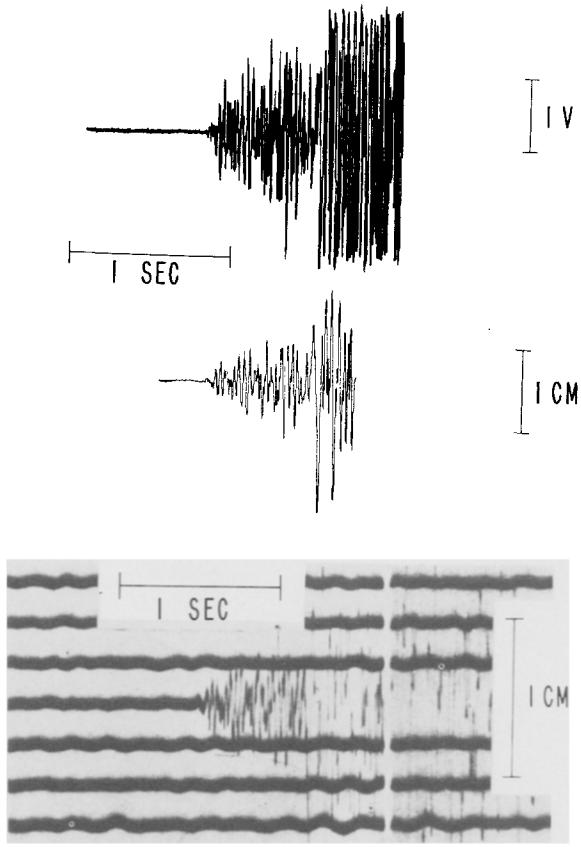

FIG. 2. Same as Figure 1 except E-W component.

REFERENCES

Bakun, W. H. and J. Dratler (1976). Empirical transfer functions for stations in the central California seismological network, *U.S. Geol. Surv. Open File Rept. 76-259.*

Bakun, W. H. and A. G. Lindh (1977). Local magnitudes, seismic moments and coda durations near Oroville, California, *Bull. Seism. Soc. Am.* **67,** 615–629.

Bolt, B. A., J. Stifler, and R. Uhrhammer (1977). The Briones Hills earthquake swarm of January 8, 1977, Contra Costa County, California, *Bull. Seism. Soc. Am.* **67,** 1555–1564.

Eaton, J. P. (1977). Frequency response of the USGS short period telemetered seismic system and its suitability for network studies of local earthquakes, *U.S. Geol. Surv. Open File Rept. 77-844.*

Kanamori, H. and P. C. Jennings (1978). Determination of local magnitude, M_L, from strong-motion accelerograms, *Bull. Seism. Soc. Am.* **68,** 471–485.

Richter, C. F. (1935). An instrumental earthquake magnitude scale, *Bull. Seism. Soc. Am.* **25,** 1–32.

Richter, C. F. (1958). *Elementary Seismology,* W. H. Freeman and Co., San Francisco, 768 pp.

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