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GEOLOGICAL SURVEY

EL CENTRO CALIFORNIA DIFFERENTIAL GROUND MOTION ARRAY

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El Centro, California Differential Ground Motion Array

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Abstract

Differential ground motions due to horizontally propagating seismic surface waves are important in determining the stresses developed in extended structures such as large mat foundations for nuclear power stations, dams, bridges, and pipelines. This report discusses the design of an array to measure these differential ground motions and describes one such array, recently installed at El Centro, Calif. The records from the October 15, 1979 Imperial Valley earthquake are presented.

Introduction

Aseismic design has generally assumed that all points on the ground move in unison with the freefield motion over a region that is larger than the foundation of the structure. This assumption is based on the notion that seismic waves are substantially propagated in high-wave-velocity basement rock and transmitted vertically to the region of interest through lower velocity layers. However, it is now realized that surface waves, propagating horizontally through surface layers, may have wavelengths along the surface of the same order as the dimensions of a large structure, (Luco, 1969; Trifunac, 1972; Wong and Trifunac, 1974). The foundation of the structure would then undergo differential motions that would cause additional strains to be superimposed on those due to inertial loading. Thus, adjacent bridge piers would move relative to each other and cause substantial stresses in the piers and the bridge decking. Structures built on spread footings, dams, and pipelines would be similarly affected. A large relatively rigid raft foundation, such as may be used for a nuclear power station, would move less

than the freefield motion, (Bycroft, 1980) and so the input to structures on such a foundation would be attenuated; the forcing motion on such structures would differ from the free-field motion.

To study such motion, differential ground motions must be measured and methods of utilizing this information in aseismic design must be developed. The measurement of free-field ground motion is relatively straight-forward in that no spatial parameter is involved. For differential ground motions, however, surface waves may propagate at wavelengths comparable to the size of the foundation, and so a spatial array of instruments is needed. If expense were no consideration, a fully three-dimensional array comprising many instruments could be built. Initially, it would appear more advantageous to divide these instruments among several simpler arrays in different suitable regions that should, of course, be of high seismicity both in amplitude and occurrence. In order that surface waves of significant amplitude be generated it is necessary to choose regions of large contrast in wave velocity between the surface and underlying layers. The upper layer should be of as low a velocity as possible, so that the wavelengths are as short as possible. Furthermore, the selected region should be flat, homogeneous, secure power should be readily available; and the regional velocity profile should be known.

The simplest array that would give useful information appears to be one comprising several instruments along a straight line. This line should point toward the epicenter of an imminent large earthquake to measure the maximum amplitudes of the incident transverse surface waves. It is difficult, however, to predict such an orientation, and so the best that can be done is to point the array toward a general region of recent activity. If enough

instruments are available, an additional perpendicular array would be advantageous.

The differential motion between any two points is a function of wavelength and of the magnitude of the component of that wavelength in the ground motion. Thus the difference in motion between points at varying distances apart must be measured. If n instruments are to be used, there are $n(n-1)/2$ pairs of points whose distances apart may be arranged to be different. The instruments should be so placed along the line of the array that these distances increase reasonably uniformly from smallest to largest, assuming that the region is uniform over an area somewhat larger than that of the array. The length of the array should be determined largely by the size of the largest structures envisaged.

El Centro differential array

Such an array, funded jointly by the Federal Highway Administration and the U.S. Geological Survey, was recently installed at El Centro, Calif. in time to record the earthquake of October 15, 1979. The Imperial Valley Irrigation District permitted the array to be placed in a large vacant area near El Centro steam station No. 4 that is secured by a cyclone fence and meets the other requirements discussed above. Figure 1 shows the structure, and table 1 the velocity profile, of the region; figure 2 shows the location of the array with respect to local faults. Because faults surround the area, no particular orientation appeared optimal, and so the array was laid south to north along the inside of the fence running along Dogwood Road (fig. 3). This area is remote from the power plant, and so interactional effects should be negligible. The six instruments were placed at distances of 0, 60, 180, 420, 700, and 1000 ft and numbered 1 through 6 respectively; these spacings give

distances between any two instruments of 60, 120, 180, 240, 280, 300, 360, 420, 520, 580, 640, 700, 820, 940, and 1000 ft.

The sensors are triaxial downhole force-balance accelerometers manufactured by the Terra Technology Corp., Seattle, Wash. The sensors were placed in 5-in-diameter holes 4 ft deep and tamped in with 2 to 3 mm coarse sand, and connected by wiring laid in conduit to DCA-300 recorders in an air-conditioned building at the south end of the array. The analog signal from the sensors is digitized at intervals of 1/100 s and stored on magnetic tape. The system continually remembers events as long as 1.5 s before triggering, and thus permits a record of the events that precede triggering. The six instruments are triggered from an SMA-1 seismometer and have a common clock. The radio time signal WWVB is also recorded on the tape.

The installation of this array had been delayed by many factors but, fortuitously, was completed about two weeks before the Imperial Valley earthquake of October 15, 1979. There were several malfunctions. Instrument 6 was out of tape owing to some unknown extraneous triggering before the event. There is a certain amount of noise on some records that can be removed. The instruments were not synchronized in time as planned, and the time signal was not recorded owing to a receiver problem. Consequently, common time was lost.

Analog printouts of the tapes from the five stations (figs. 4-6) are similar in shape at the five stations. The left side of these figures is not common time. The maximum acceleration of 0.67 g occurred at stations 1 and 2 in an unusual event early in the vertical component; station 5, however, recorded this event at a maximum of 0.33 g. The maximum acceleration in the horizontal direction is about 0.43 g. Although these acceleration

records appear very similar, little can be said about the displacements because they are associated with the lower frequency components. True displacements can be obtained with suitable corrections by double integration of the accelerograms. Terra Technology Corporation has translated the tapes into a computer-compatible tape and has established common time from a distinct P-wave arrival from an aftershock 2.5 min after the main event. This technique should allow the computation of the differential ground displacements. A mathematical model of the surface-wave propagation will be constructed to determine the motion at points other than the measuring stations.

References cited

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Table 1.- Low strain, shear wave velocities
El Centro

Test depth interval		Averages shear wave velocity	
(Ft)	(Meters)	(Ft/sec)	(M/sec)
0-16	0-4.9	400	122
16-32	4.9-9.8	550	168
32-72	9.8-21.9	700	213
72-116	21.9-35.4	850	259
116-225	35.4-68.6	1,000	305
225-271	68.6-82.6	1,150	351
271-344	82.6-104.9	1,320	402
344-390	104.9-118.9	1,450	442

Note: Shear wave velocities were obtained from field, downhole geophysical measurements at strain levels on the order of 10^{-4} percent. Velocities were averaged for the indicated test intervals (Shannon and Wilson, Inc., and Agbabian Associates, 1976).

Figure Captions

Figure 1. Geologic structure at El Centro Differential Ground Motion Array (Hansen, W. R., and others, 1973).

Figure 2. Map showing location of El Centro Differential Ground Motion Array (Latitude 32. 796 degrees North; longitude 115.535 degrees West). Array runs south to north.

Figure 3. El Centro Differential Ground Motion Array site. View looking north. Recording house shown in right center of photograph. Black box adjacent to house (to left) is Station No. 1; remainder of array extends north (into photo background).

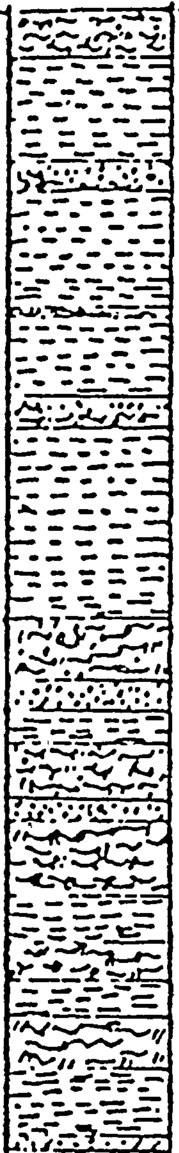
Figure 4. Vertical accelerations at the El Centro Differential Ground Motion Array.

Figure 5. East-west accelerations at the El Centro Differential Ground Motion Array.

Figure 6. North-south accelerations at the El Centro Differential Ground Motion Array.

Figure 1. Geologic structure at El Centro Differential Ground Motion Array (Hansen, W. R., and others, 1973).

Date 10/79 Station No. 5165 Station E C Differential Array Dogwood Rd.

Depth meters	P-Wave m/sec	S-Wave m/sec	Density g/cm³	Log	Site Geology
					Silty clay loam
					Clay
					Laminations of fine sand, sandy loam, & silty clay loam
					Clay
					Lens of silty clay loam
—10					Clay
					Laminations of sandy loam and silty clay loam
					Clay
					Silty clay loam
—20					Sand
					Clay
					Silty clay loam & sandy loam
					Sand
					Silty loam
					Clay
					Silty clay loam
—30					Clay
					Laminations of silty clay loam, and silty loam
					Clay
					Sand

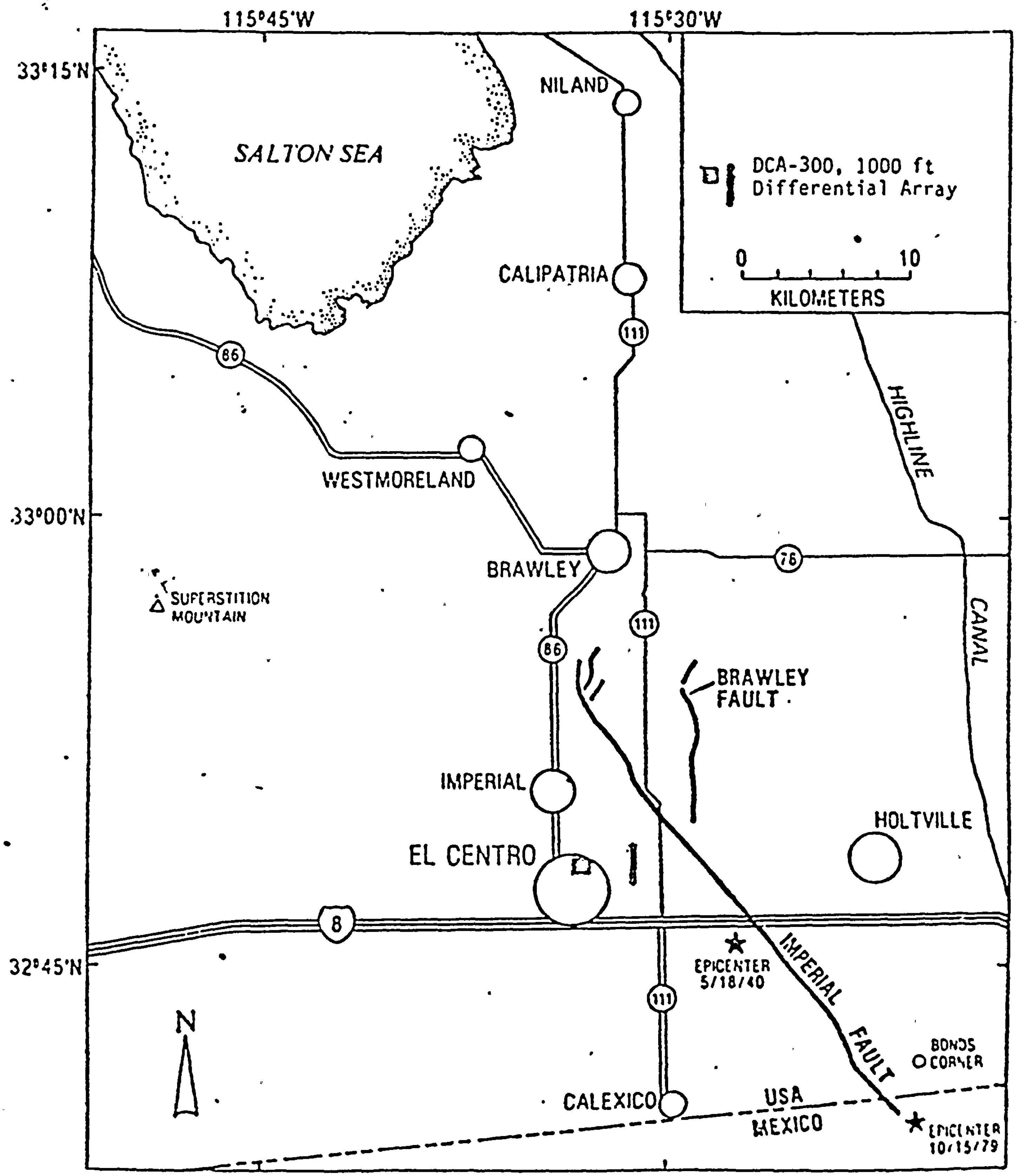


Figure 2. Map showing location of El Centro Differential Ground Motion Array (latitude 32.796 degrees North; longitude 115.535 degrees West). Array runs south to north.

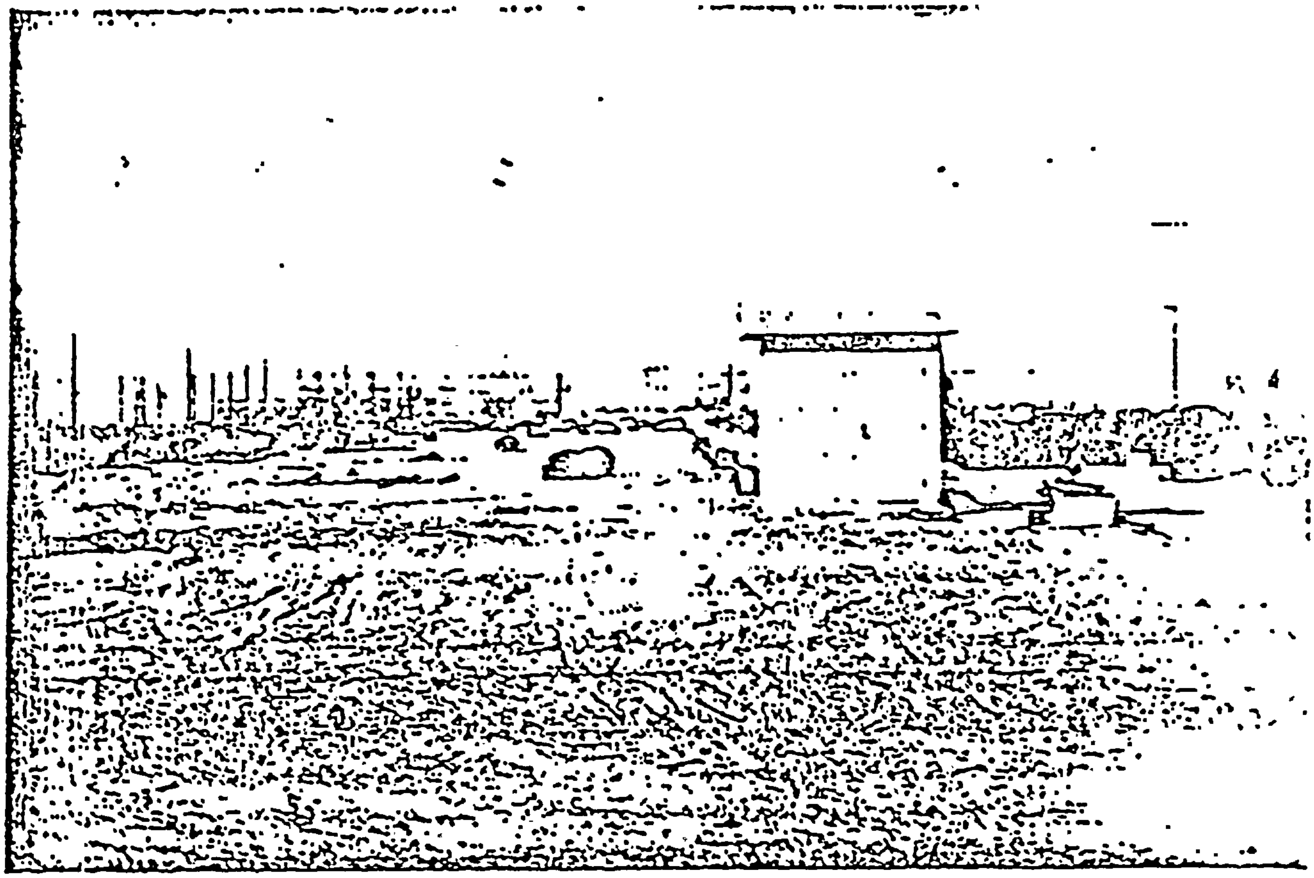


Figure 3. El Centro Differential Ground Motion Array site. View looking north. Recording house shown in right center of photograph. Black box adjacent to house (to left) is Station No. 1; remainder of array extends north (into photo background).

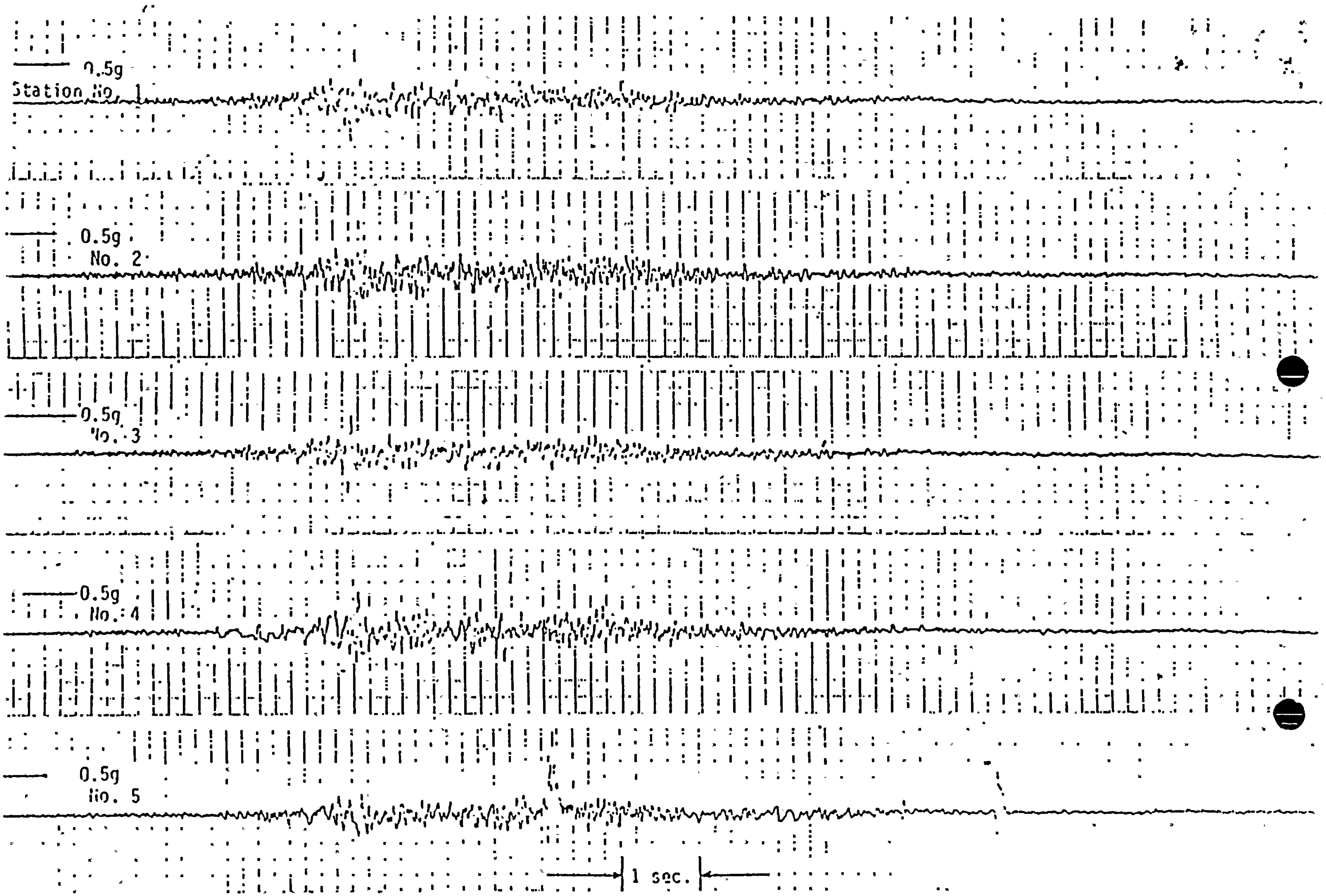


Figure 4. Vertical accelerations at the El Centro Differential Ground Motion Array.

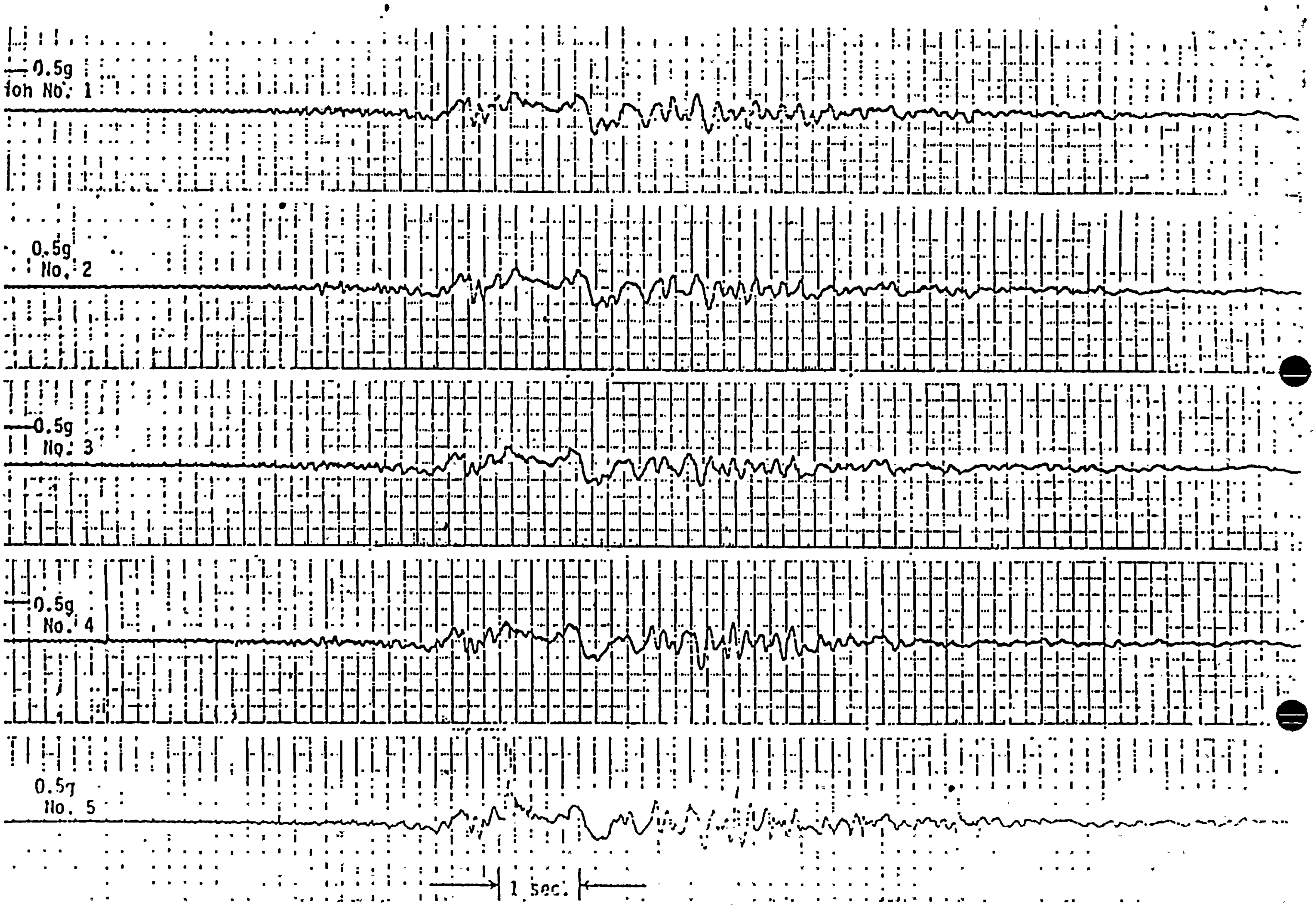


Figure 5. East-west accelerations at the El Centro Differential Ground Motion Array.

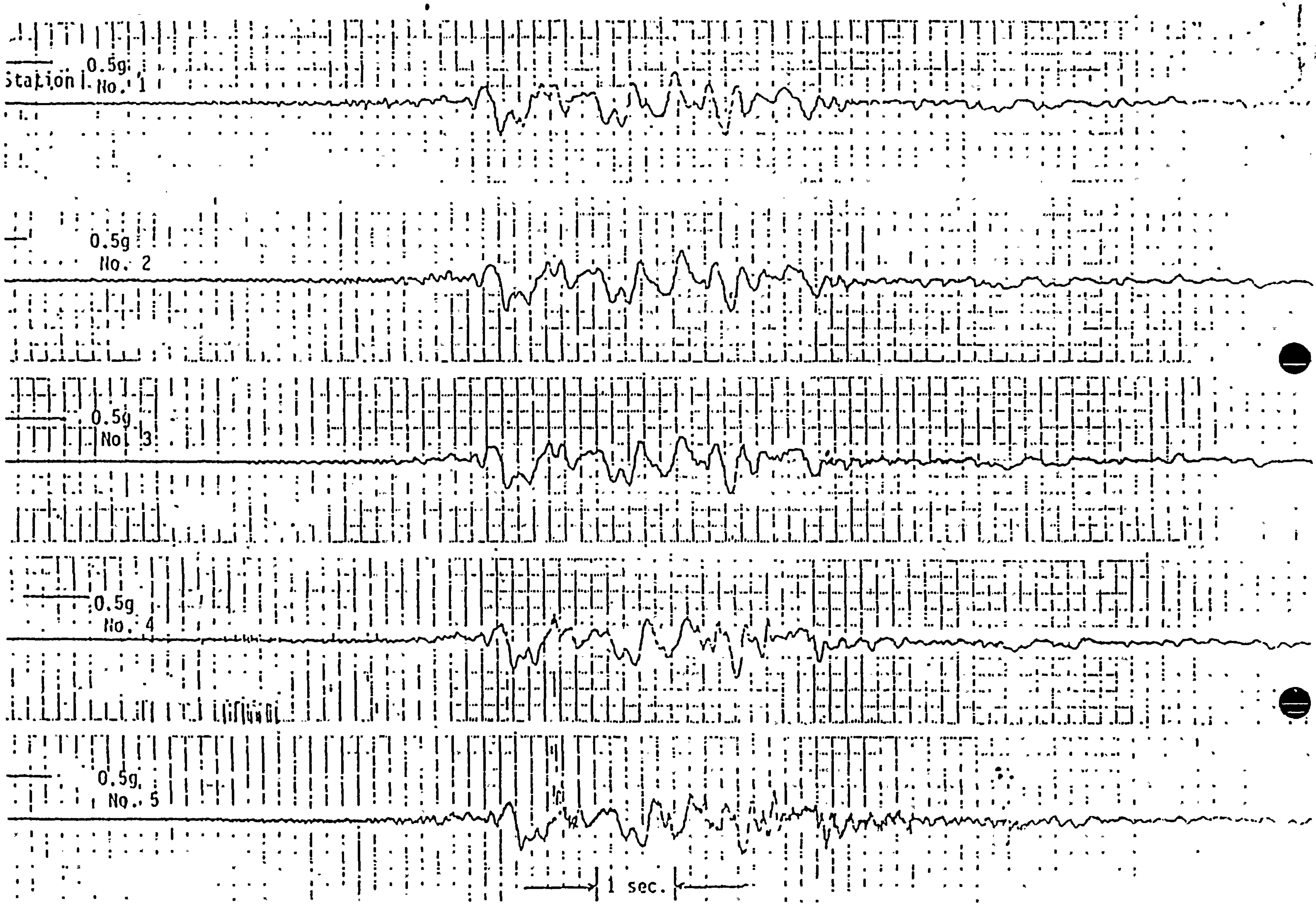


Figure 6. North-south accelerations at the El Centro Differential Ground Motion Array.