UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

DIFFERENTIAL-GROUND-MOTION ARRAY AT HOLLISTER MUNICIPAL AIRPORT, CALIFORNIA

by

G. N. Bycroft

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G. N. Bycroft

U.S. Geological Survey
Menlo Park, California 94025

ABSTRACT

This report describes the differential array of seismometers recently installed at the Hollister, California, Municipal Airport. Such an array of relatively closely spaced seismometers has already been installed in El Centro and provided useful information for both engineering and seismological applications from the 1979 Imperial Valley earthquake. Differential ground motions, principally due to horizontally propagating surface waves, are important in determining the stresses in such extended structures as large mat foundations for nuclear power stations, dams, bridges and pipelines. Further, analyses of the records of the 1979 Imperial Valley earthquake from the differential array have demonstrated the utility of short-baseline array data in tracking the progress of the rupture wave front of an earthquake.

INTRODUCTION

Aseismic design has generally assumed that all points on the ground move in unison with the free-field 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, surface waves and scattered waves propagating horizontally through surface layers may have wavelengths along the surface comparable to the dimensions of a large structure (Luco, 1969; Trifunac, 1972; Wong and Trifunac, 1974; Bycroft, 1980). 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, for example, 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 free-field motion (Bycroft, 1980), and so the input to structures on such a foundation would then be attenuated; the input motion to 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 straightforward 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 consisting of many instruments could be built. Initially, it would appear more advantageous to divide these instruments among several simpler arrays in different suitable regions of high seismicity in amplitude and occurrence. To detect surface waves of significant amplitude, regions of large contrast in wave velocity between the surface and underlying layers must be selected. 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, and secure; power should be readily available; and the regional velocity profile should be known. Further, the instrumentation should be digital with common time on all channels and be triggered from a common trigger. In order to account for the angle of arrival of waves, the array should be two-dimensional. The array should incorporate as much redundancy as possible to allow for channel failure. The differential motion between any two points is a function of their difference apart. Thus, the difference in motion between points at varying distances apart should 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 placed so 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.

HOLLISTER DIFFERENTIAL-GROUND-MOTION ARRAY

A differential ground motion array has been installed at the Hollister Municipal Airport, California. This region is reasonably secure and has power available at the west end. This array is intended to be used for determining differential motions between points. The array should also provide data useful for seismological investigations such as studying the rupture process of an earthquake, the relative importance of surface waves and body waves, their apparent velocities and wavelengths along the earth's surface, and their angles of incidence.

Figure 1 shows the location of the array in relation to the airport runways and to the San Andreas fault. One leg of the array runs parallel to and on the southern side of the E-W runway for a distance of 2000 feet and the second leg runs along a boundary of an orchard at an angle of 39° for a distance of 1000 feet. The vertex of the array is at longitude 121°26'45" and latitude 36°53'17". Figure 2 shows the geologic structure from two boring logs made at Hollister City Hall approximately two miles from the airport by Woodward-Lundgren Associates. Figure 3 shows the configuration of the array. This arrangement gives a satisfactory spread of distances between the various instruments, is two-dimensional and has two instruments close enough to each other to provide a certain redundancy at each of the three corners. The sensors are Kinemetrics FBA3 and the recorders are Kinemetrics DSA-1.

The FBA-3 is a triaxial force balance accelerometer. It is packaged in a cast aluminum base and cover, and sealed to prevent the entrance of moisture and dirt. The three accelerometers are orthogonally mounted on an internal deck plate. Provision is made for applying electrical commands which result in outputing the damped and undamped response of the three accelerometers.

The nominal specifications are:

Full scale range	± 1 g
Output	± 2.5 volts DC
Natural frequency	50 Hz
Damping	.70 critical
Supply voltages	+ – 12 VDC
Temperature effects	± 2 full scale from 0° to 160°F
Output	± 2.5 volts full scale
Calibration	Provision for damping and natural frequency commands

The DSA-1 is a triaxial strong-motion accelerograph which converts the analog outputs of the FBA-3 accelerometers into proportional digital values and records the digital data on a four-track magnetic tape cassette. The instrument includes a pre-event memory. The instrumentation is triggered by an SMA-1 accelerometer located in the recorder building.

When the seismic trigger senses the initial ground motion, it turns power on to the tape drive motor and the DSA-1 is fully actuated in less than 1.1 second. The DSA-1 operates as long as the trigger detects the earthquake, plus an additional 10 seconds (adjustable) after the motion drops below the trigger threshold. The radio time signal WWVB is also recorded.

Input Voltage	± 2.5 volts single ended
Number of Data Channels	Three
Frequency Response	DC - 50 Hz (3 dB point); -12 dB/oct rolloff above 50 Hz
Analog Channel-to Channel Sampling Skew	625 microsec 200 samples/second
Analog-to Digital Resolution	12 binary bits; 11 bits, plus sign (1 part in 4096)
Analog-to-Digital Code	Offset Binary

+2.500	0000	0000	0000
+1.250	0100	0000	0000
+0.000	1000	0000	0000
-1.250	1100	0000	0000
-2.498	1111	1111	1111

Dynamic Range	± 66dB for + 2.5 volts
Sampling Rate	200 samples/sec/channel
Recording Density	1280 bpi
Tape Speed	2.5 inch/sec
Recording Time	20 minutes
Type	Digital, phase encoded
Magnetic Tape	Certified digital cassette
Start-up Time	Less than 100 ms
Tape Tracks	4 track parallel: 3 data; 1 vertical parity (parity is odd, except for word sync)
Tape Format	Samples are formatted in 16 bit words:

2 word sync bits (fixed)

1 coded data bit

12 binary A/D Bits

1 LRCC bit

	(Each 64th sample period all zero's are recorded on all four tracks for synchronization.)
Coded Data	Track 1: instrument serial number and sampling rate.
	Track 2: for internal 2 PPS timing
	Track 3: for WWVB
	Track 4: parity
Pre-event Memory	2.56 secs.
Voltage	+12 and -12 VDC
Standby Current	0.15 ma +12V
Recording Current	300 ma from +12 VDC (nominal)
	300 ma from -12 VDC (nominal)

The recorders are housed in an air-conditioned fiberglass structure located at the west end of the array. The sensors are placed on concrete pads shown in Fig. 4 and covered by fiberglass housings.

The array recorded the Morgan Hill earthquake of April 24, 1984 at stations 1, 3, 4, 5. Stations 2 and 6 malfunctioned. The accelerations, velocities and displacements are shown on pages 12 to 44.

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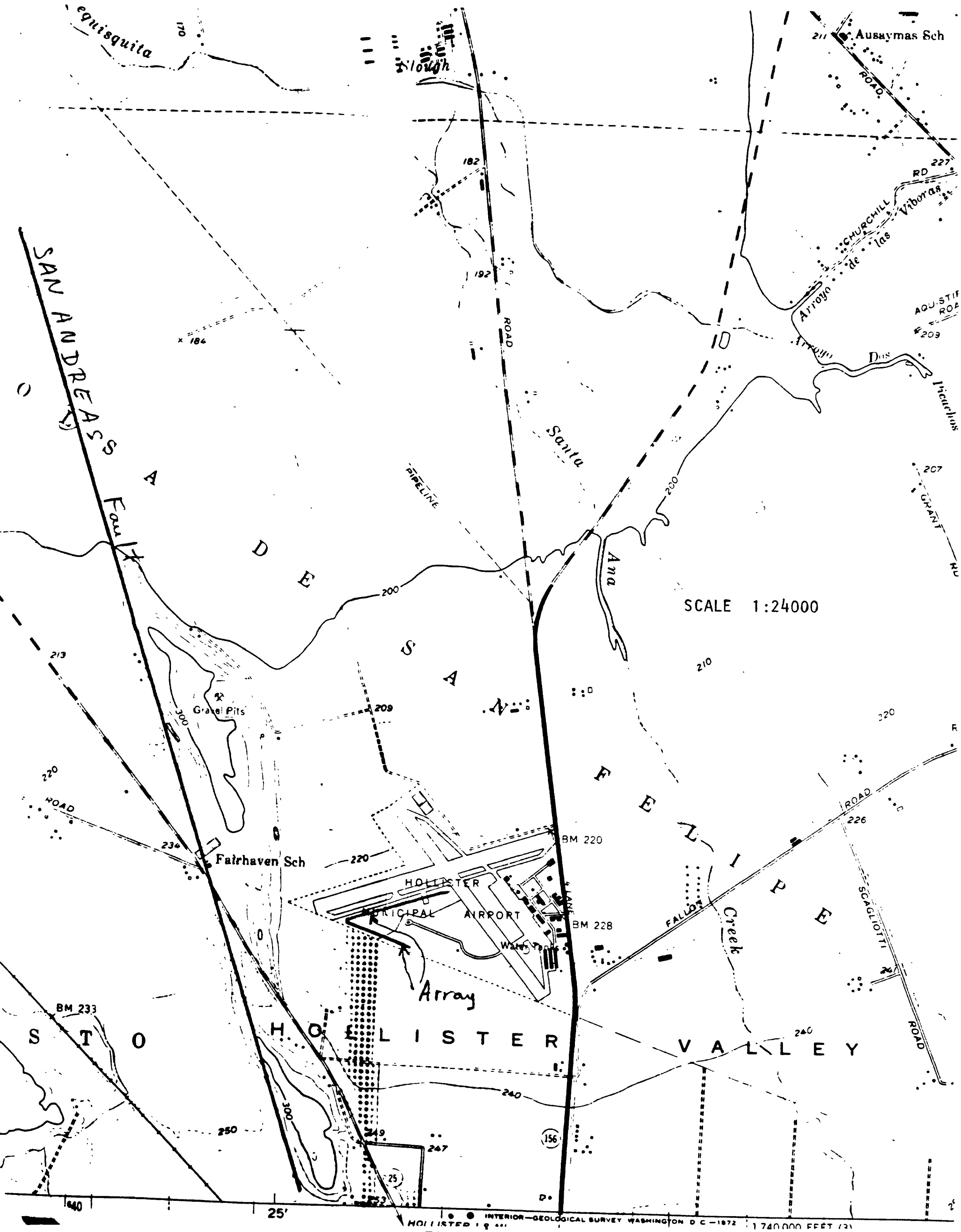
FIGURE CAPTIONS

Figure 1-- Location of the array.

Figure 2-- Geological structure.

Figure 3-- Array configuration.

Figure 4-- Concrete pad for sensor.



equisquita
Slough
Ausaymas Sch
ROAD
CHURCHILL RD
Arroyo de las Viboras
Arroyo Dos Picachos
AQUISTIF ROA
SAN ANDREAS Fault
O
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P
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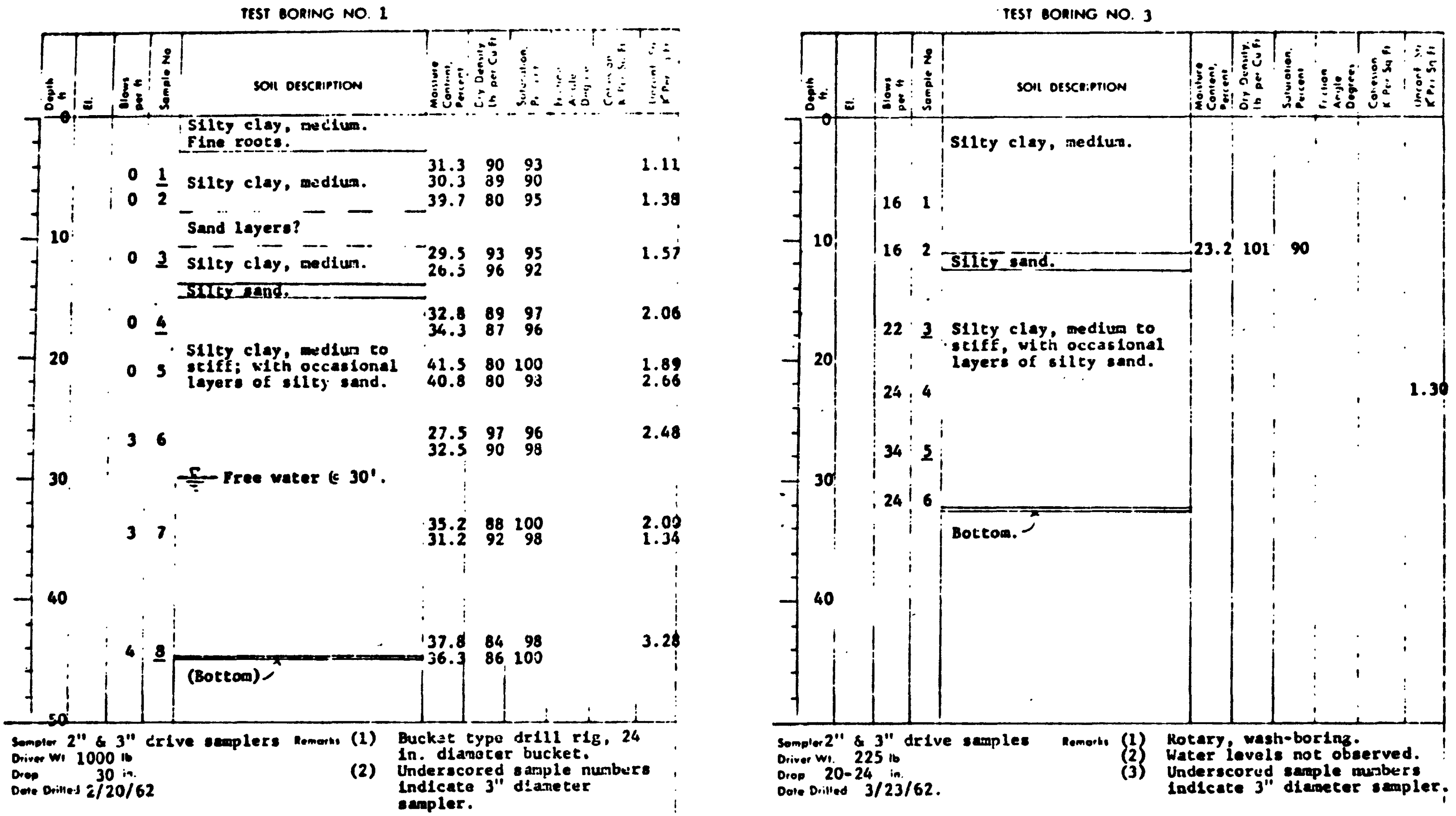
ROAD
PIPELINE
Santa Ana
SCALE 1:24000
Gravel Pits
Fairhaven Sch
BM 220
BM 228
HOLLISTER MUNICIPAL AIRPORT
Water Tank
Array
FALLON
ROAD
Creek
SCAGLIOTTI
ROAD
GRANT
BM 233
S T O
HOLLISTER
VALLEY
156
25
25'
INTERIOR—GEOLOGICAL SURVEY WASHINGTON D.C.—1972
1 740 000 FEET (3)

FIGURE 1



(After Abbot A. Hanks, Inc. 1962)

FIGURE 2

Geological Structure

BORING LOGS 1 & 3
HOLLISTER CITY HALL

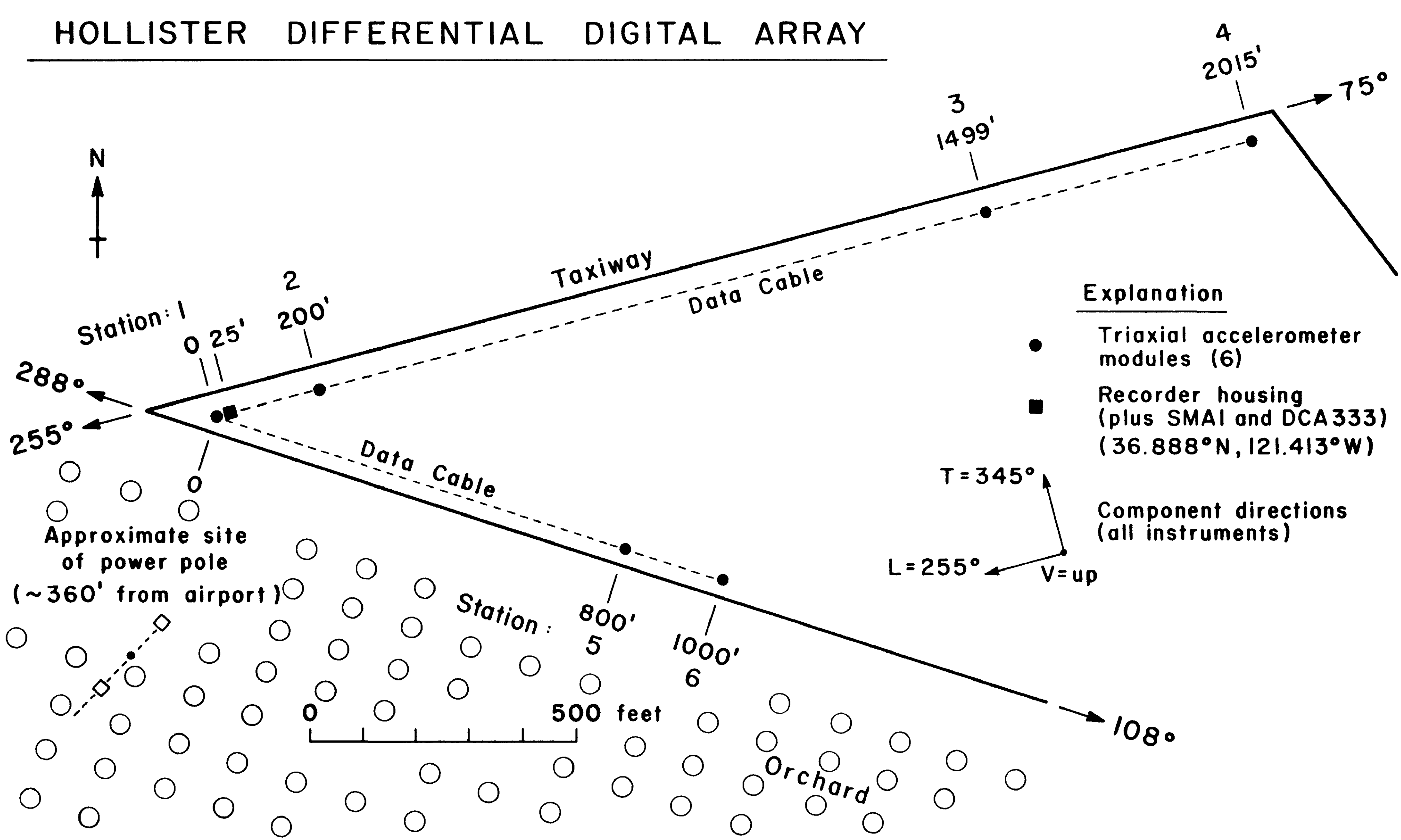


FIGURE 3

Array Configuration

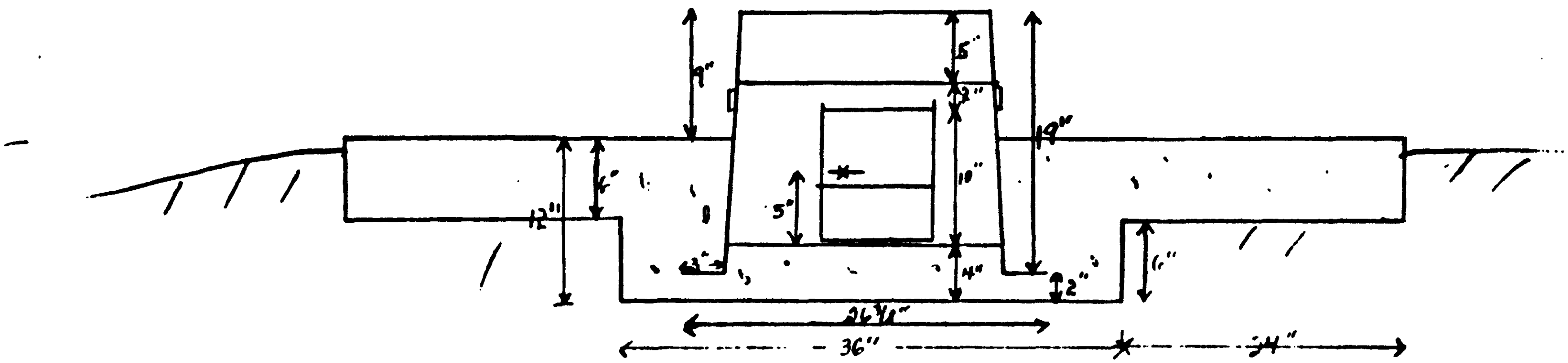


FIGURE 4

Concrete Pad for Sensor

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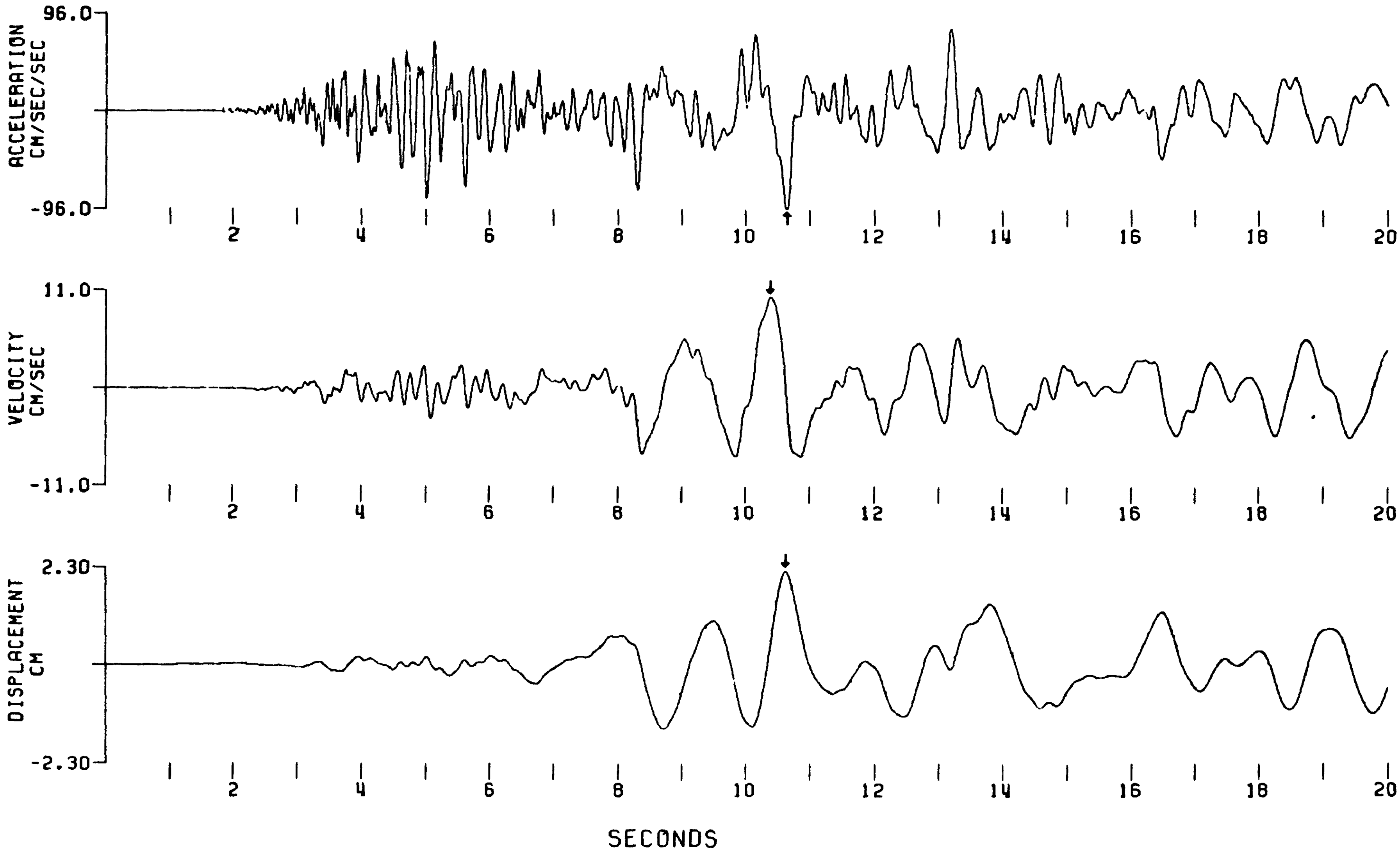
HOLLISTER, DIFFERENTIAL ARRAY NO 1
255 DEGREES
EARTHQUAKE OF APRIL 24, 1984, 2115:17 UTC
BUTTERWORTH FILTER AT .25 HZ, ORDER = 8
PEAK VALUES: ACCEL=-95.29 CM/SEC/SEC, VELOCITY=10.35 CM/SEC, DISPL=2.23 CM



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255 DEGREES
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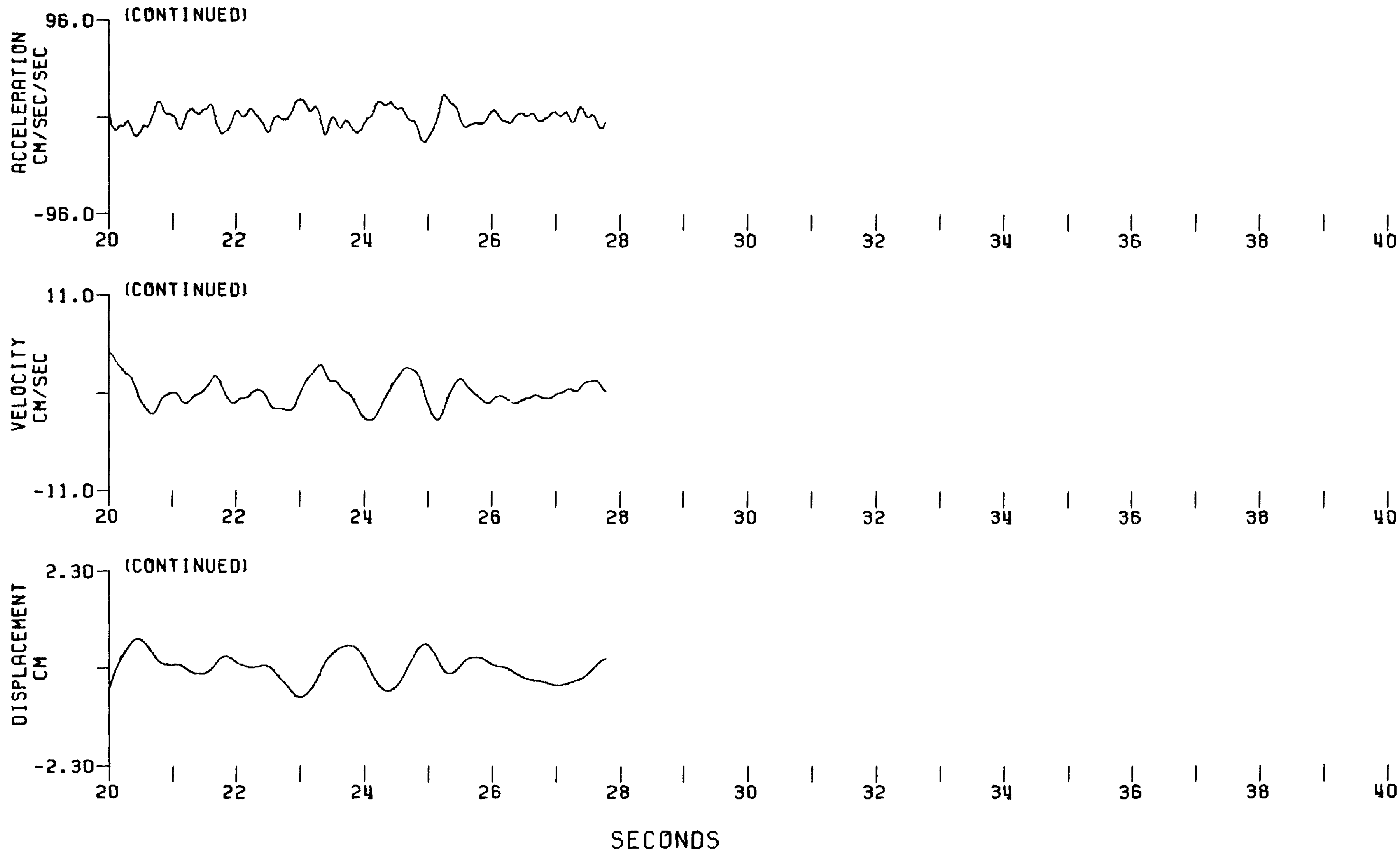
PEAK VALUES: ACCEL=-95.29 CM/SEC/SEC, VELOCITY=10.35 CM/SEC, DISPL=2.23 CM



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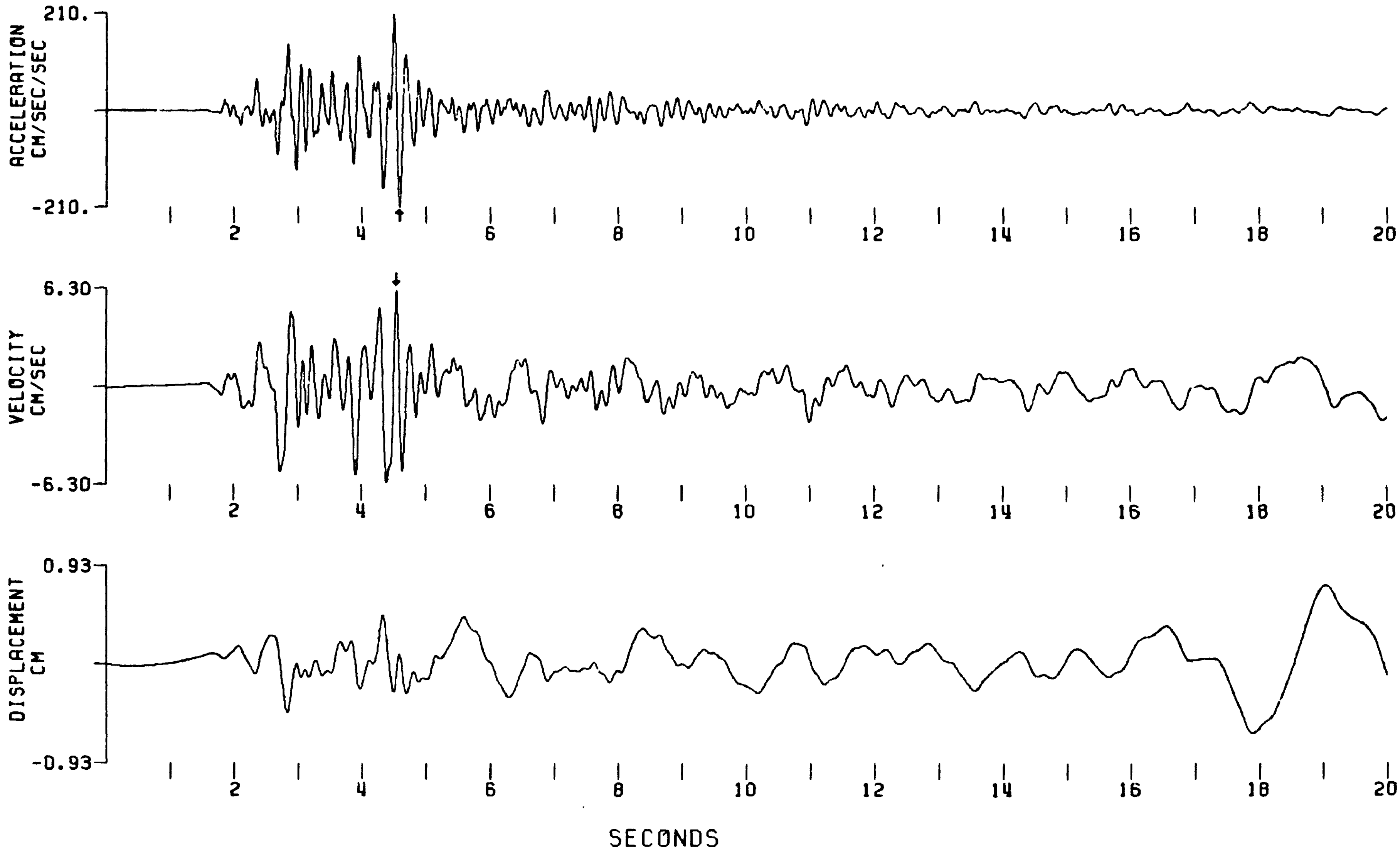

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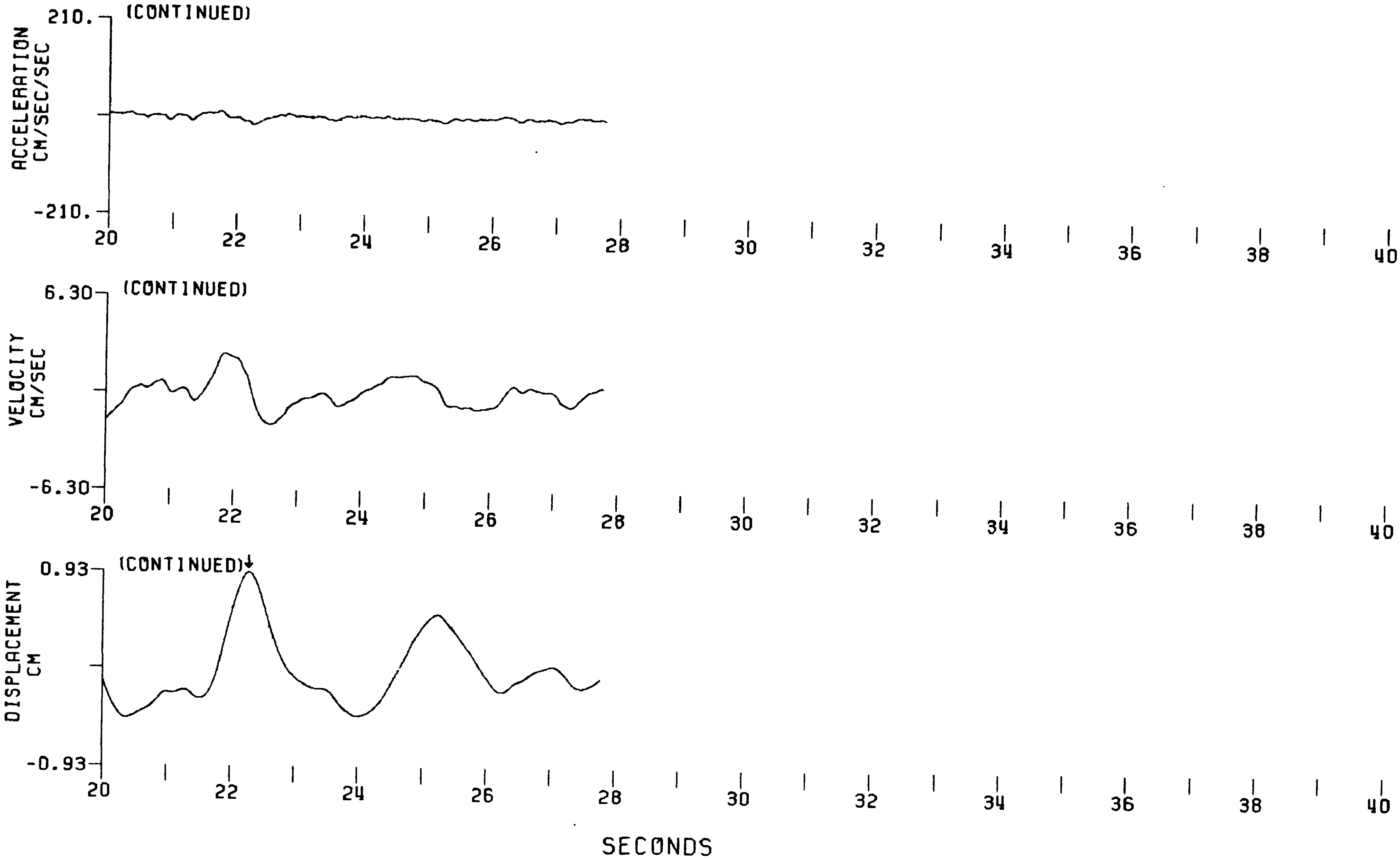

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345 DEGREES
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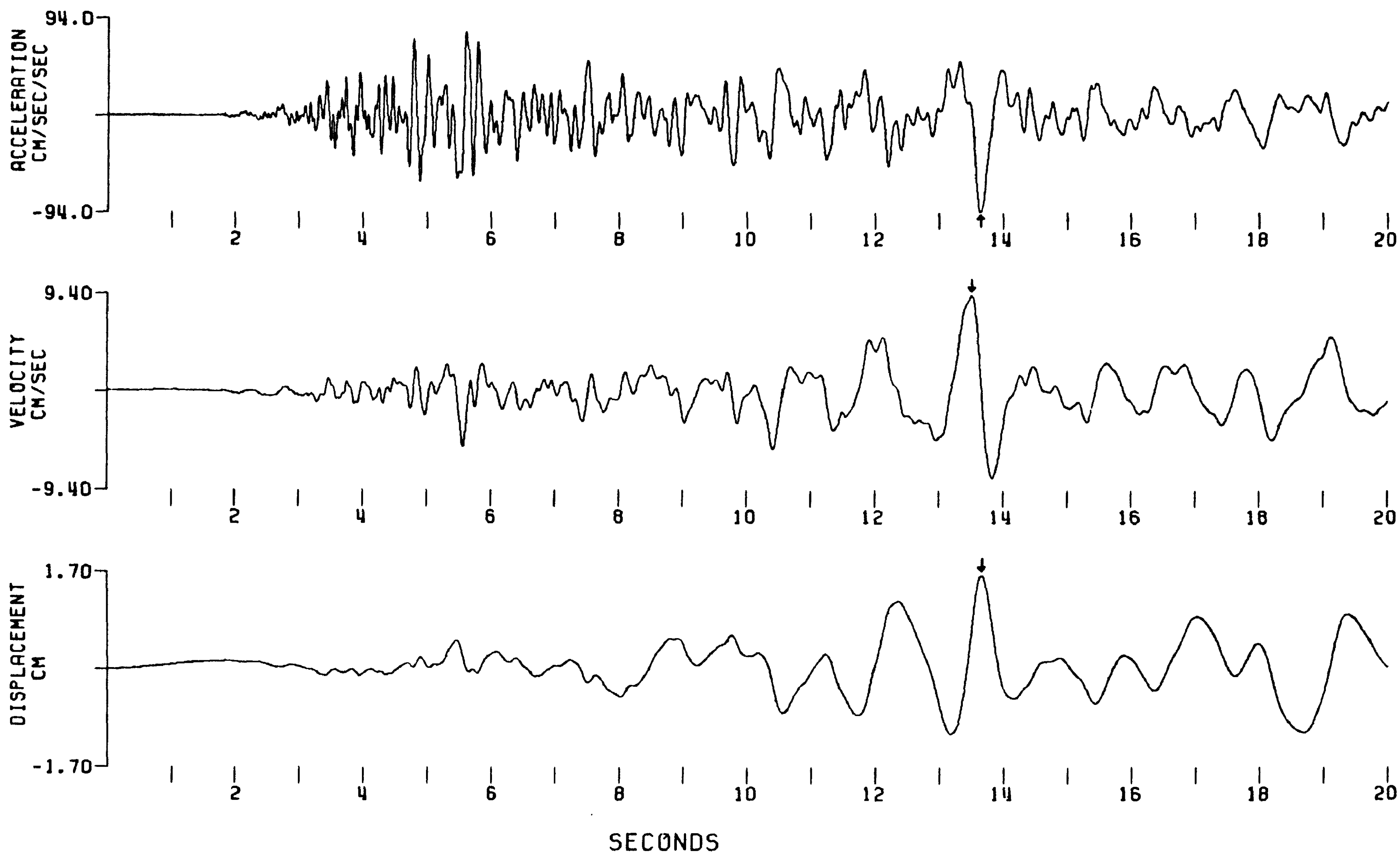

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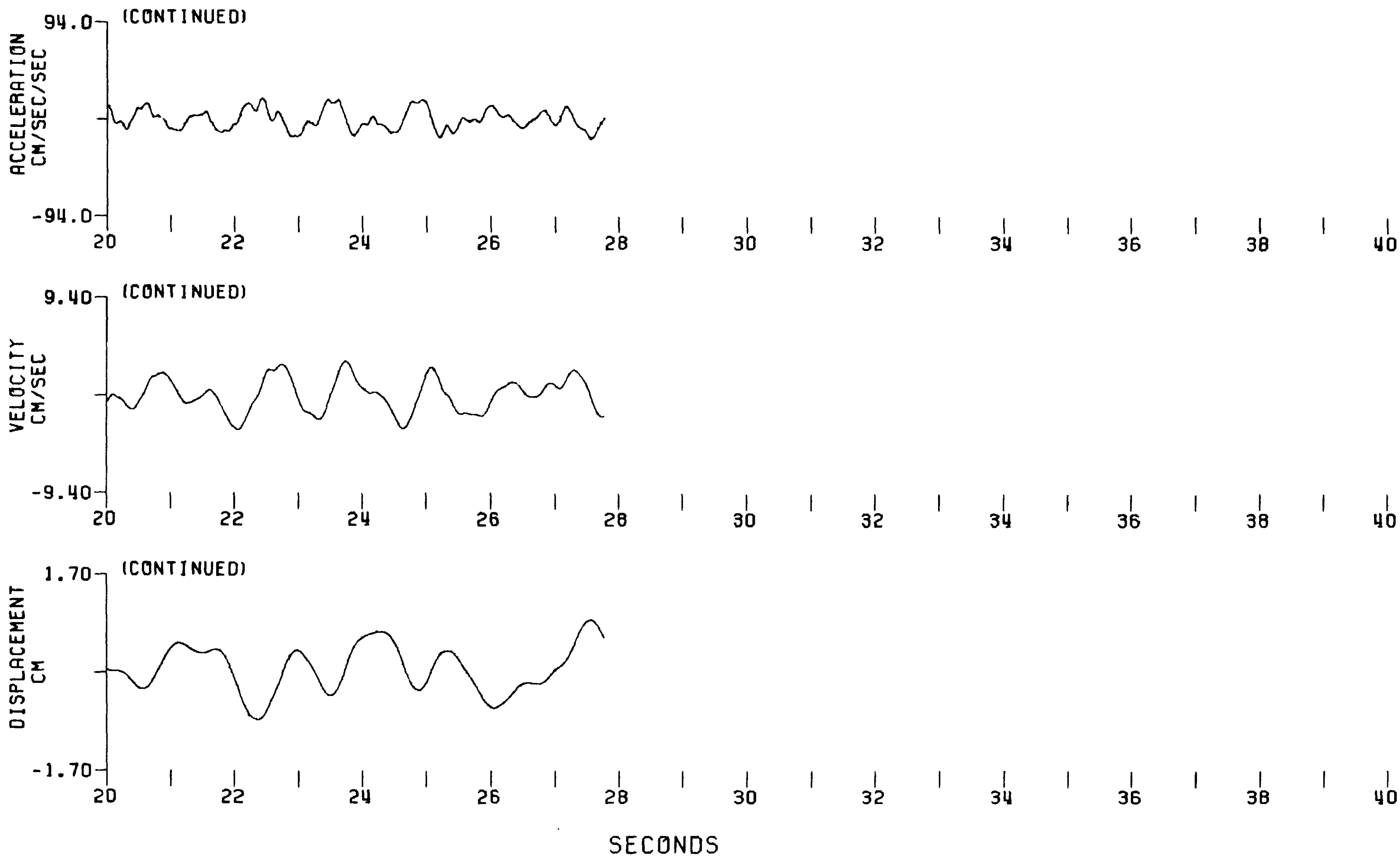

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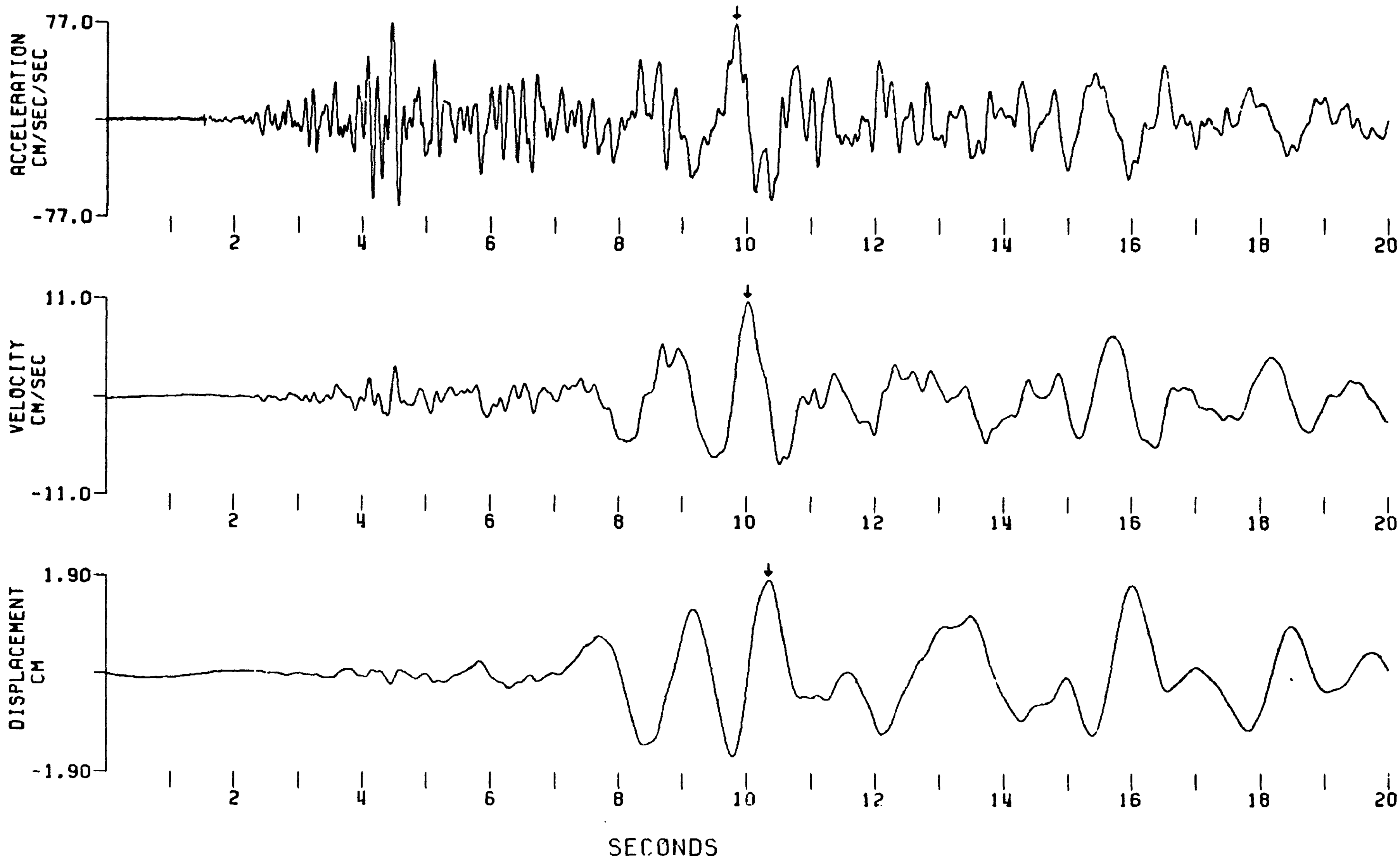

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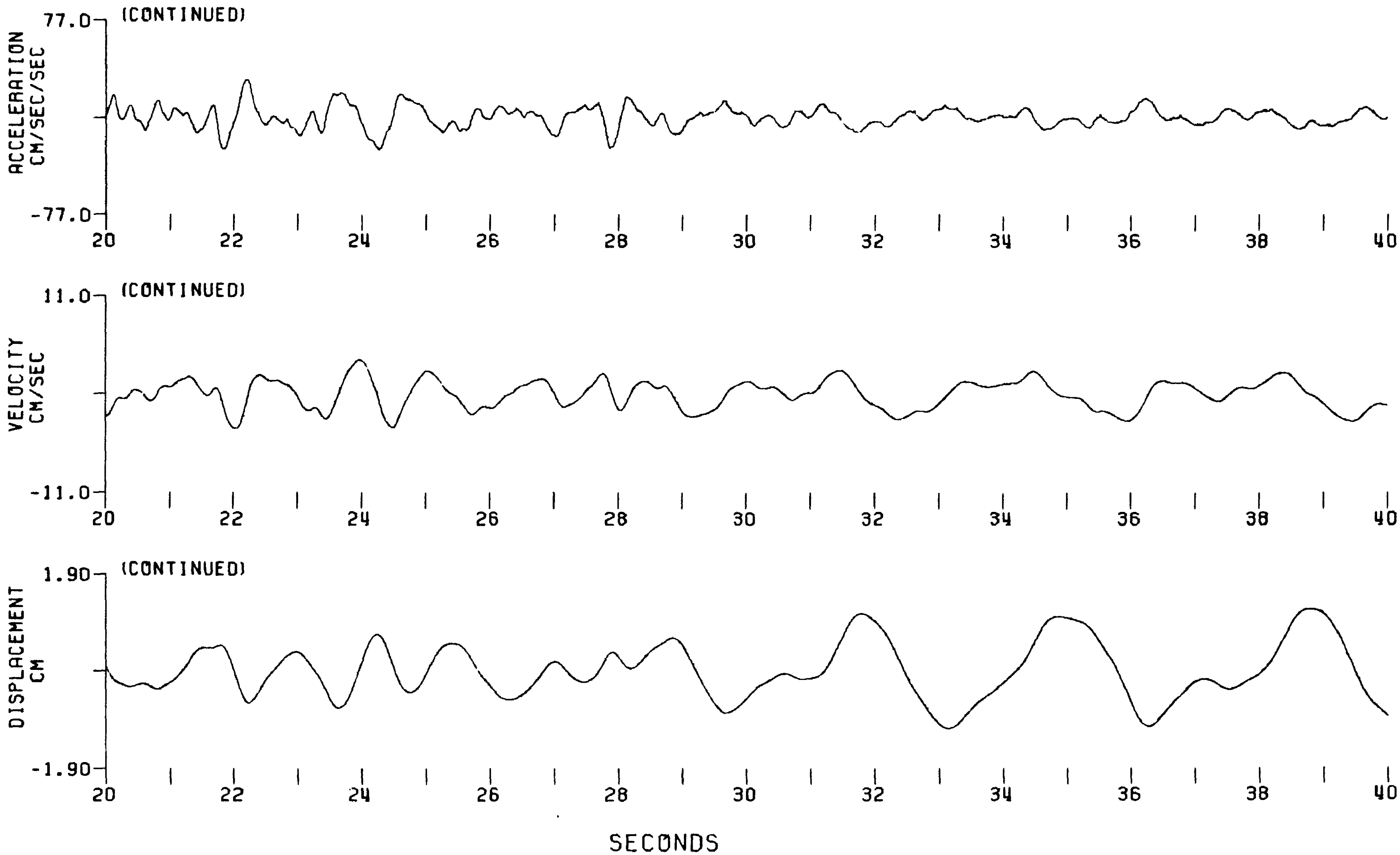

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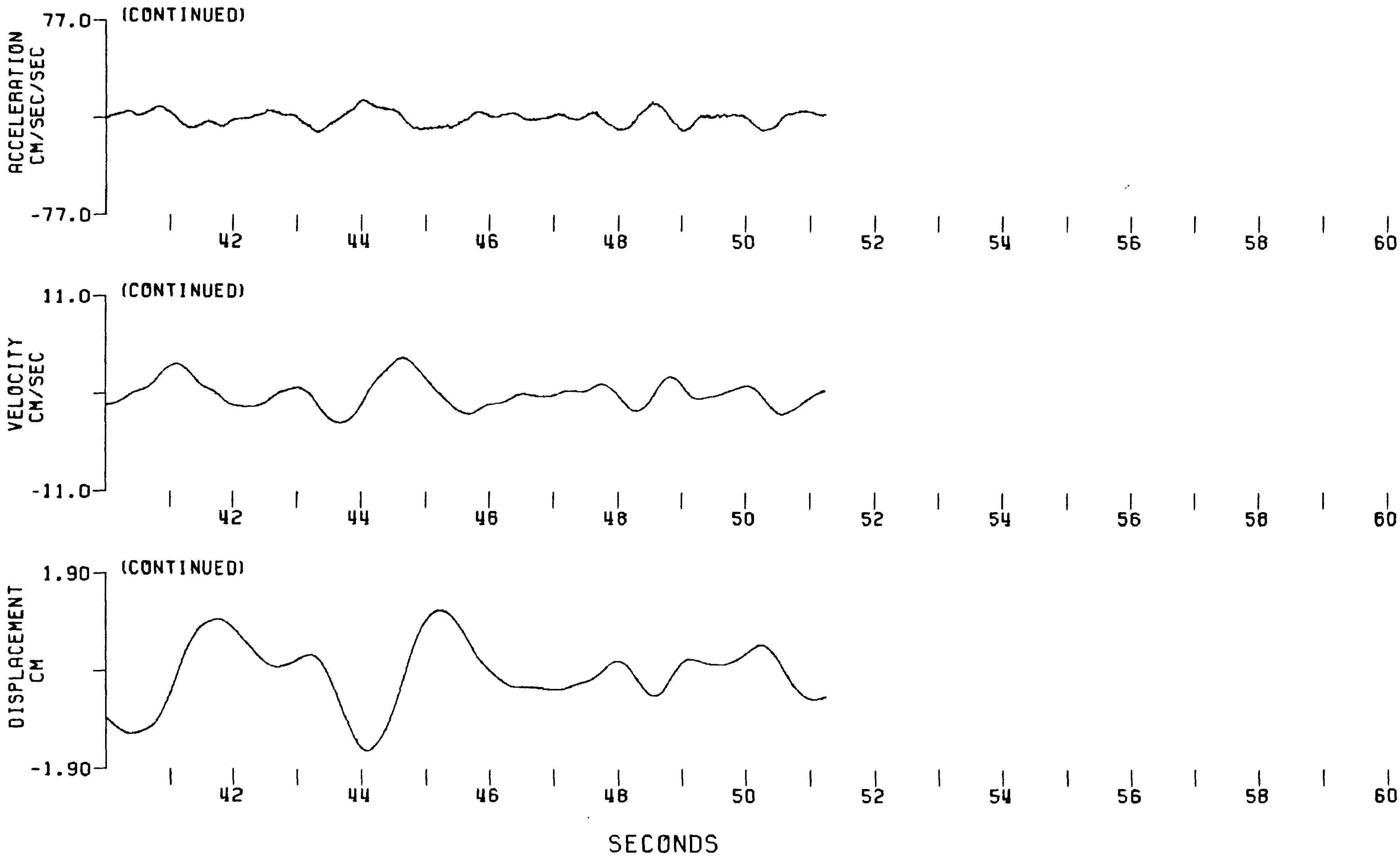

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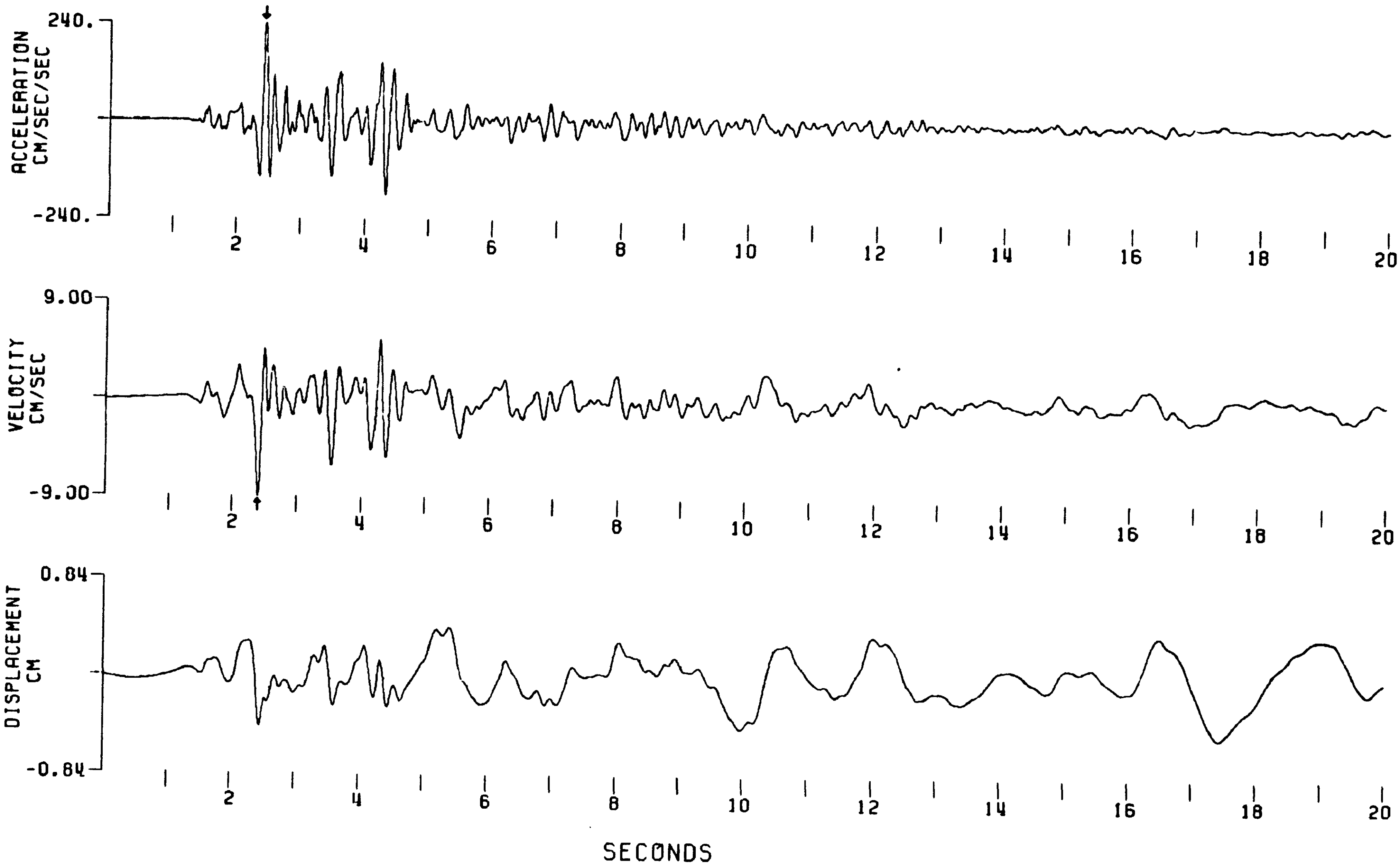

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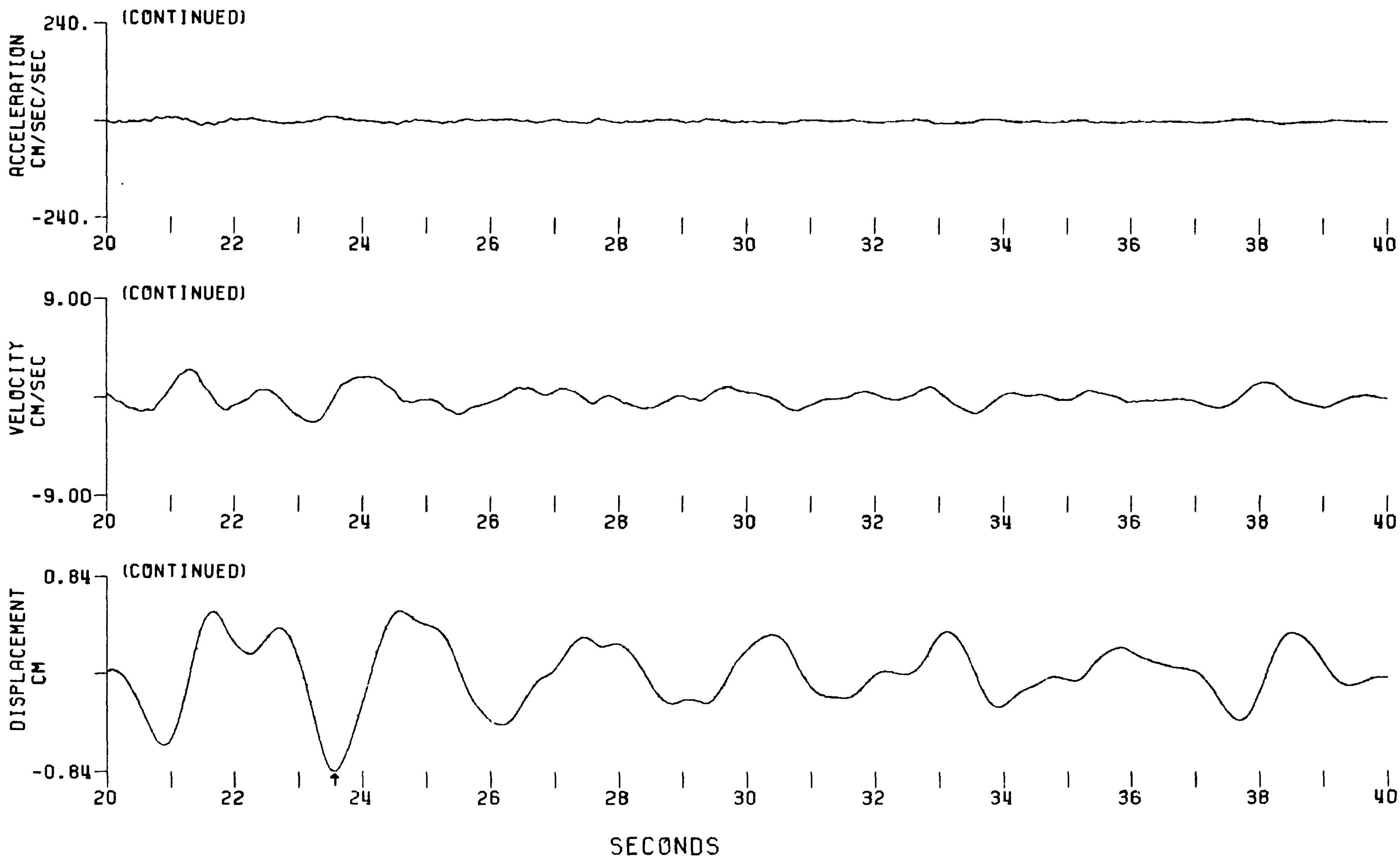

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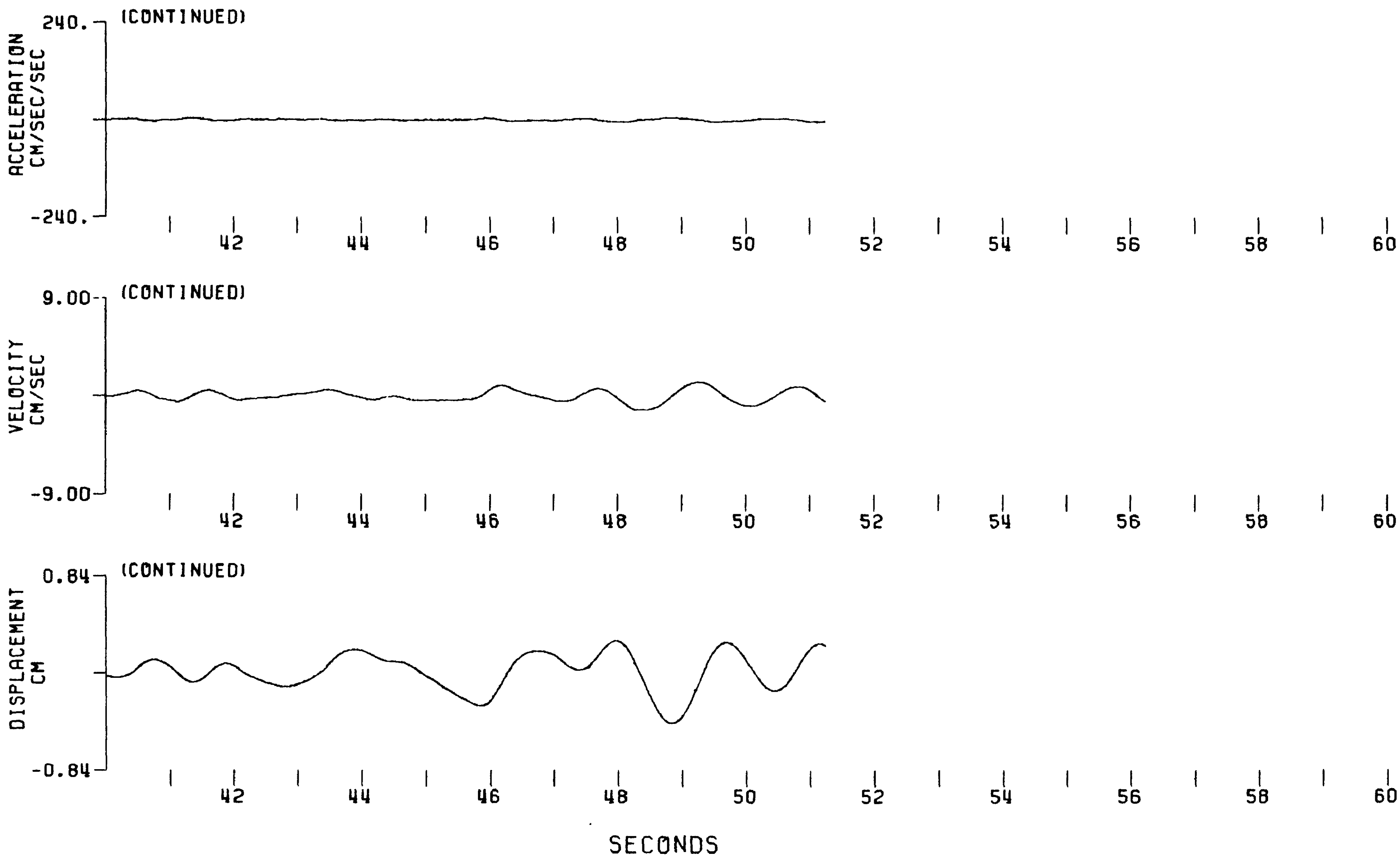

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345 DEGREES
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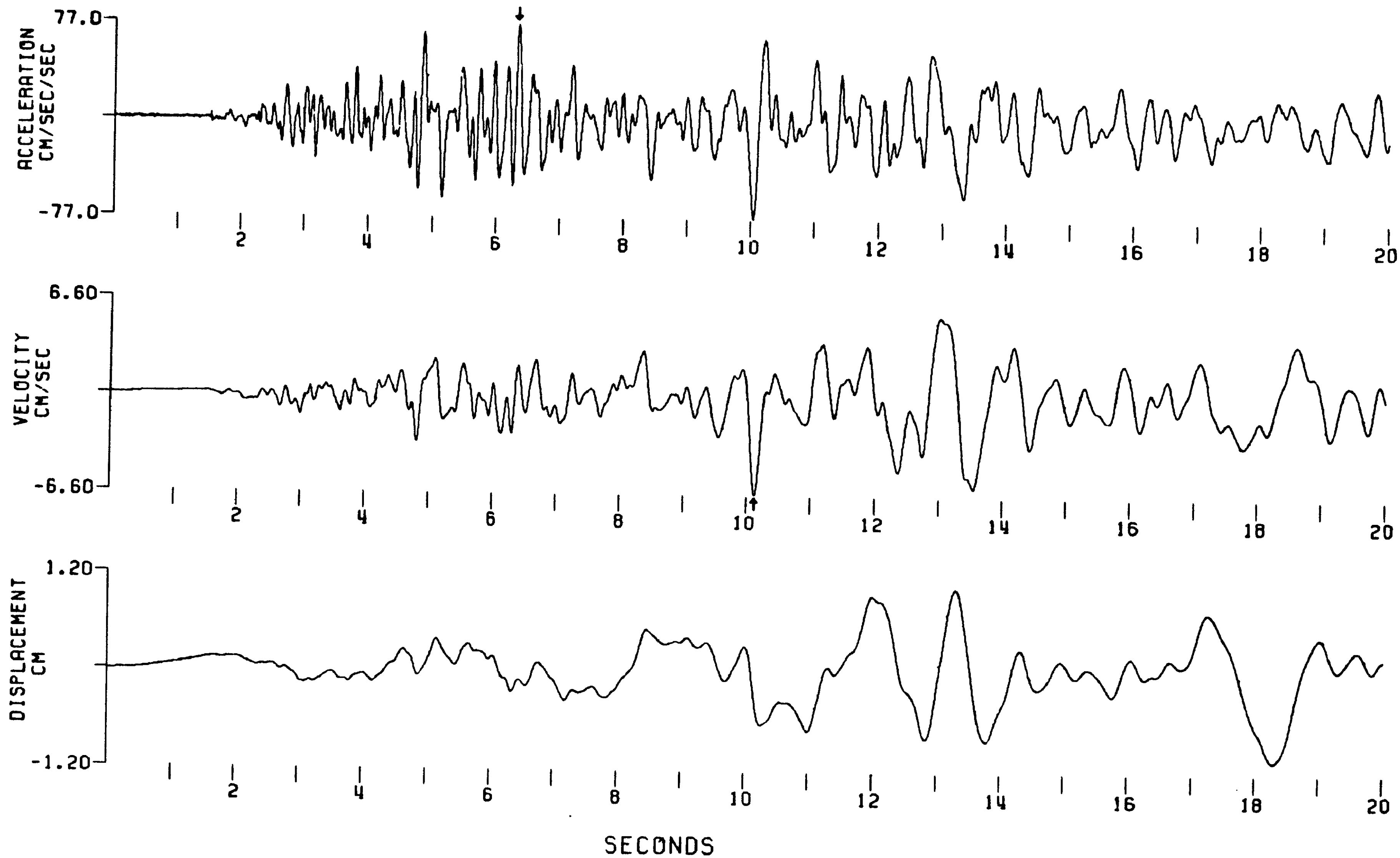

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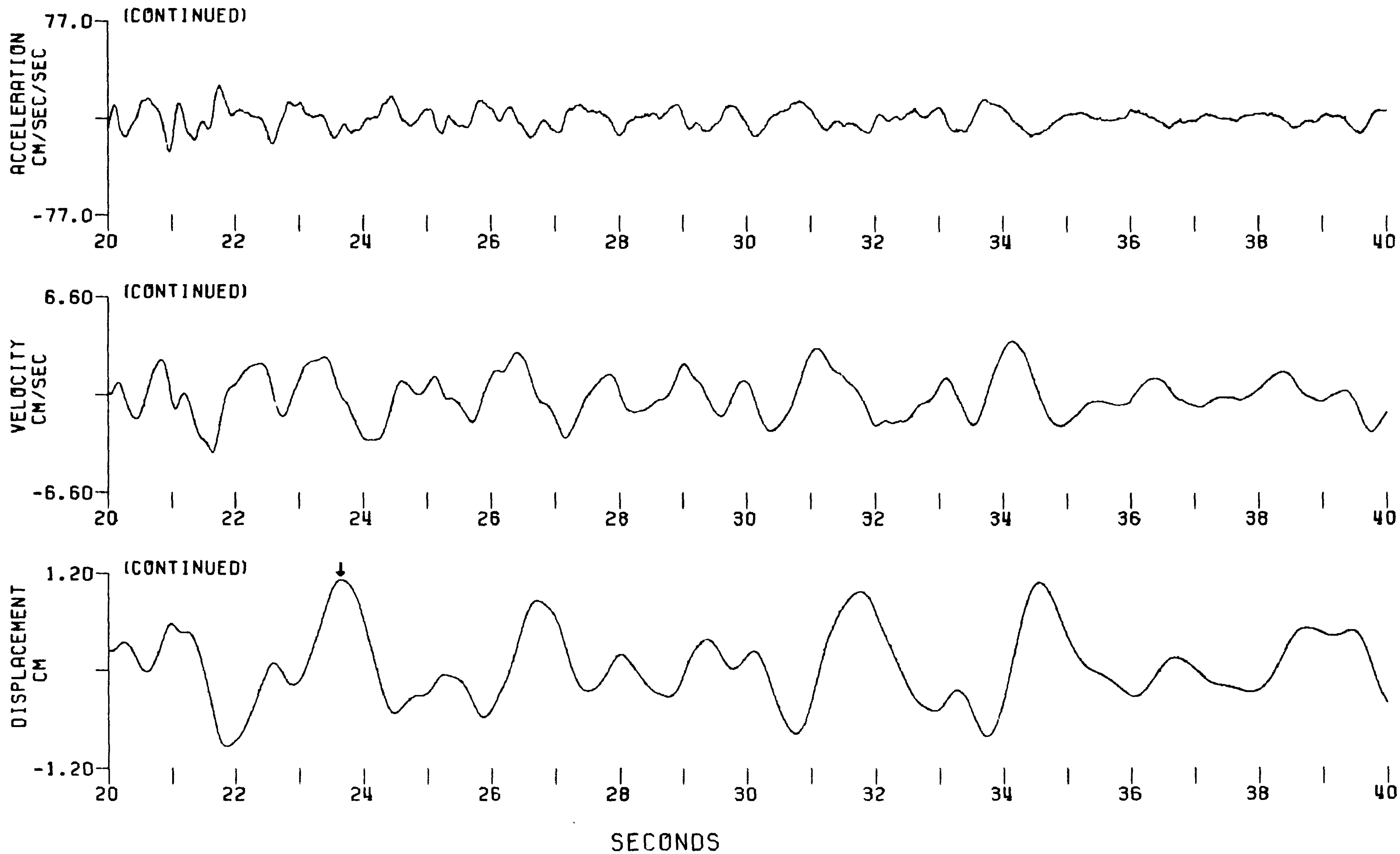

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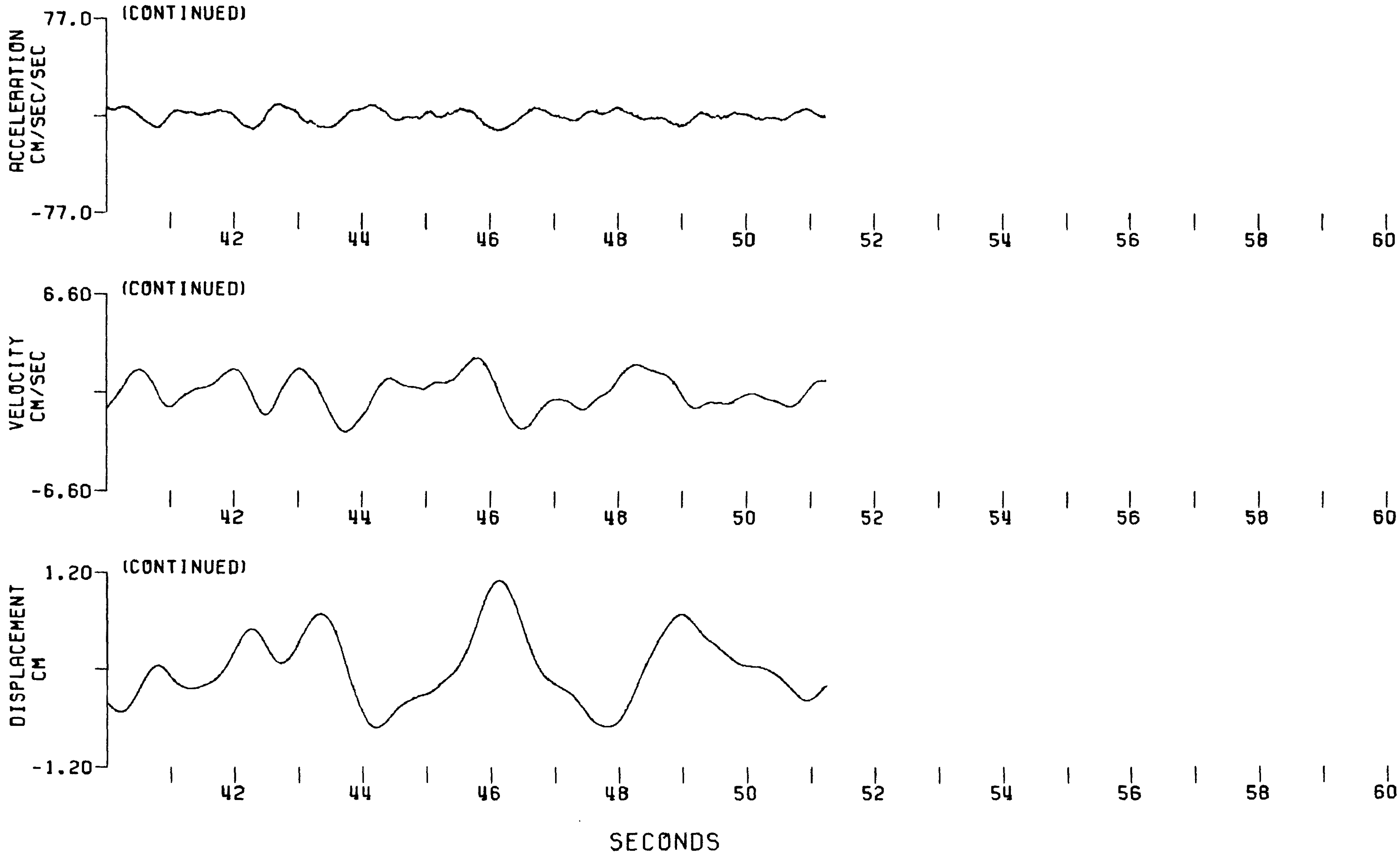

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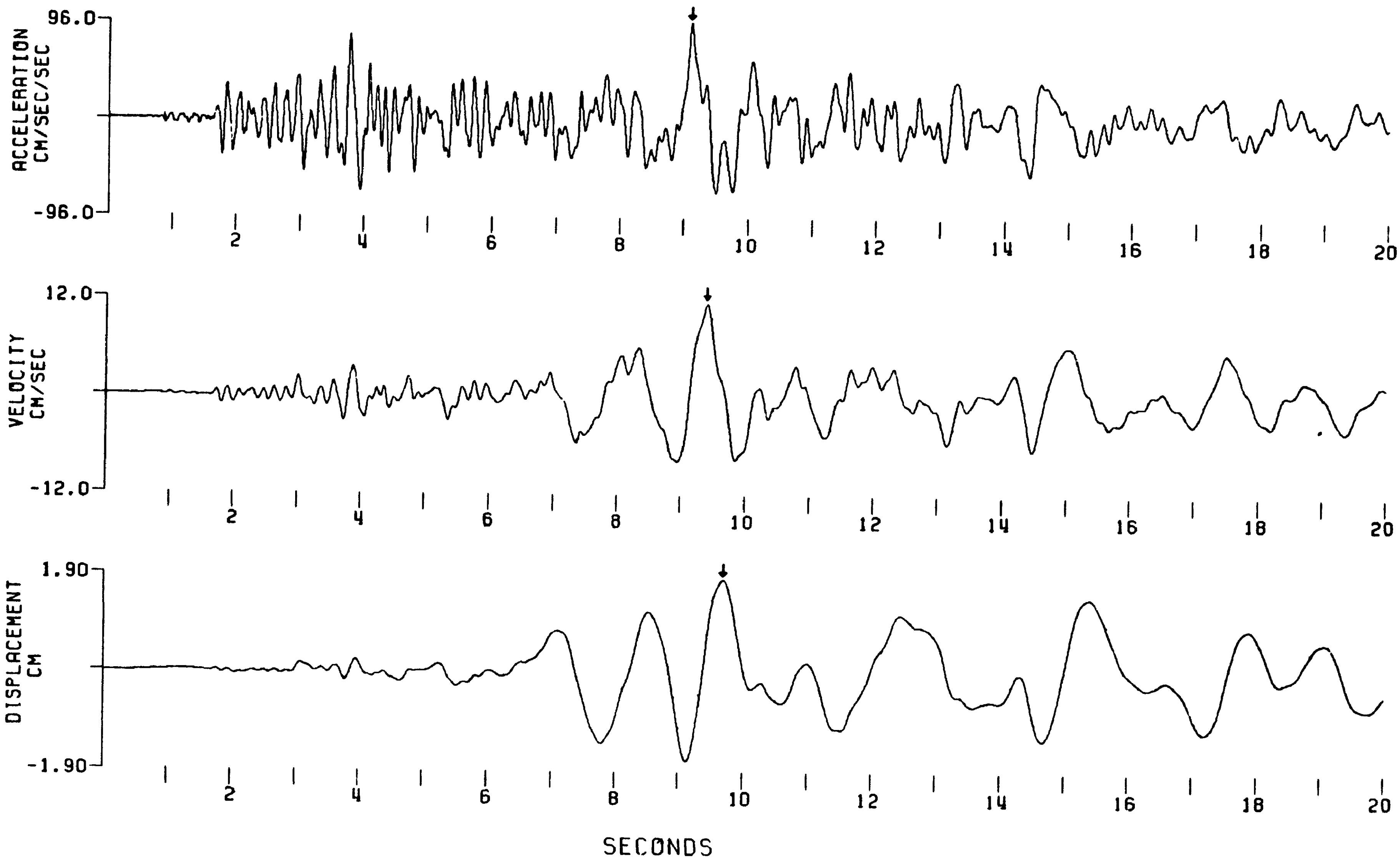

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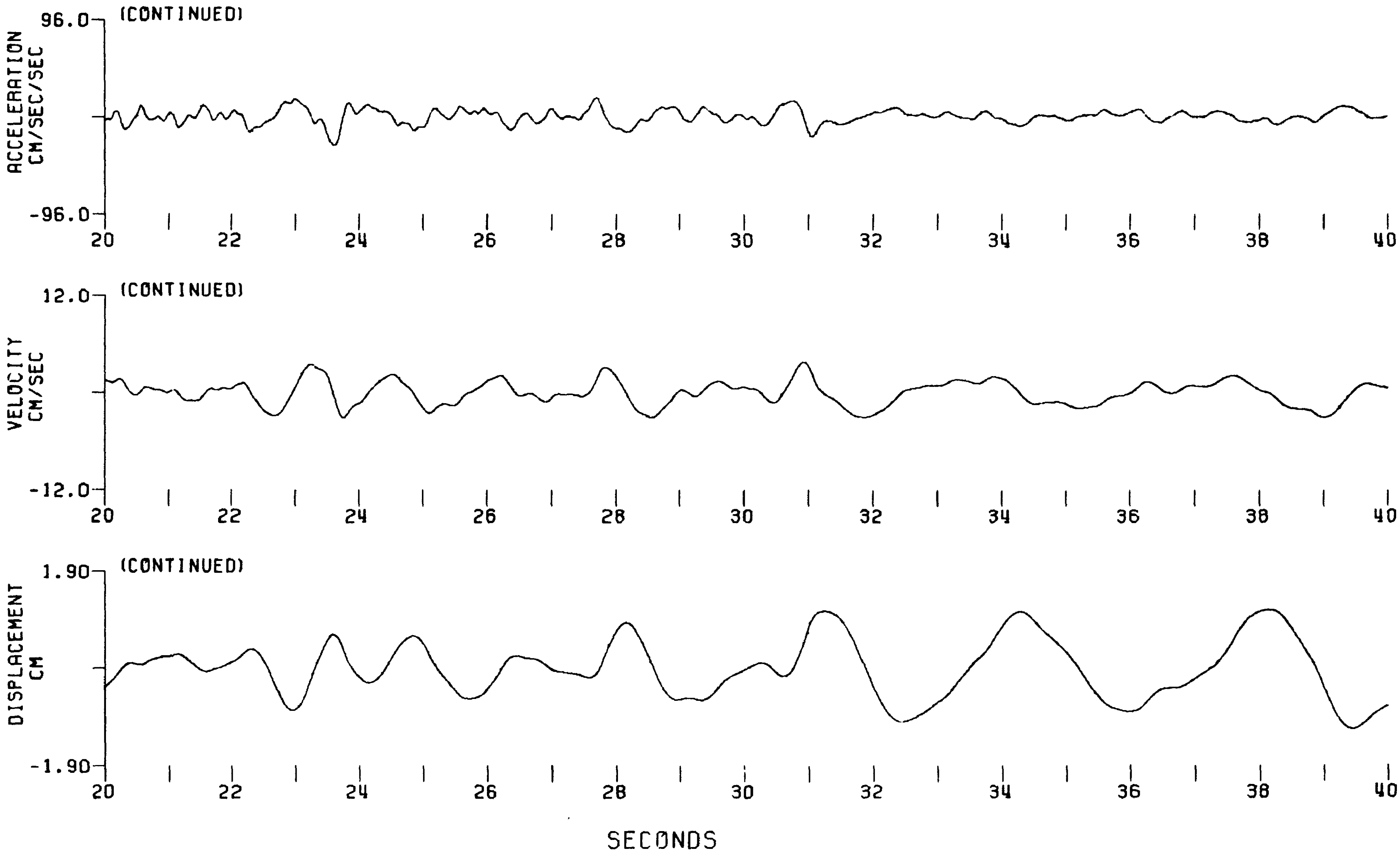

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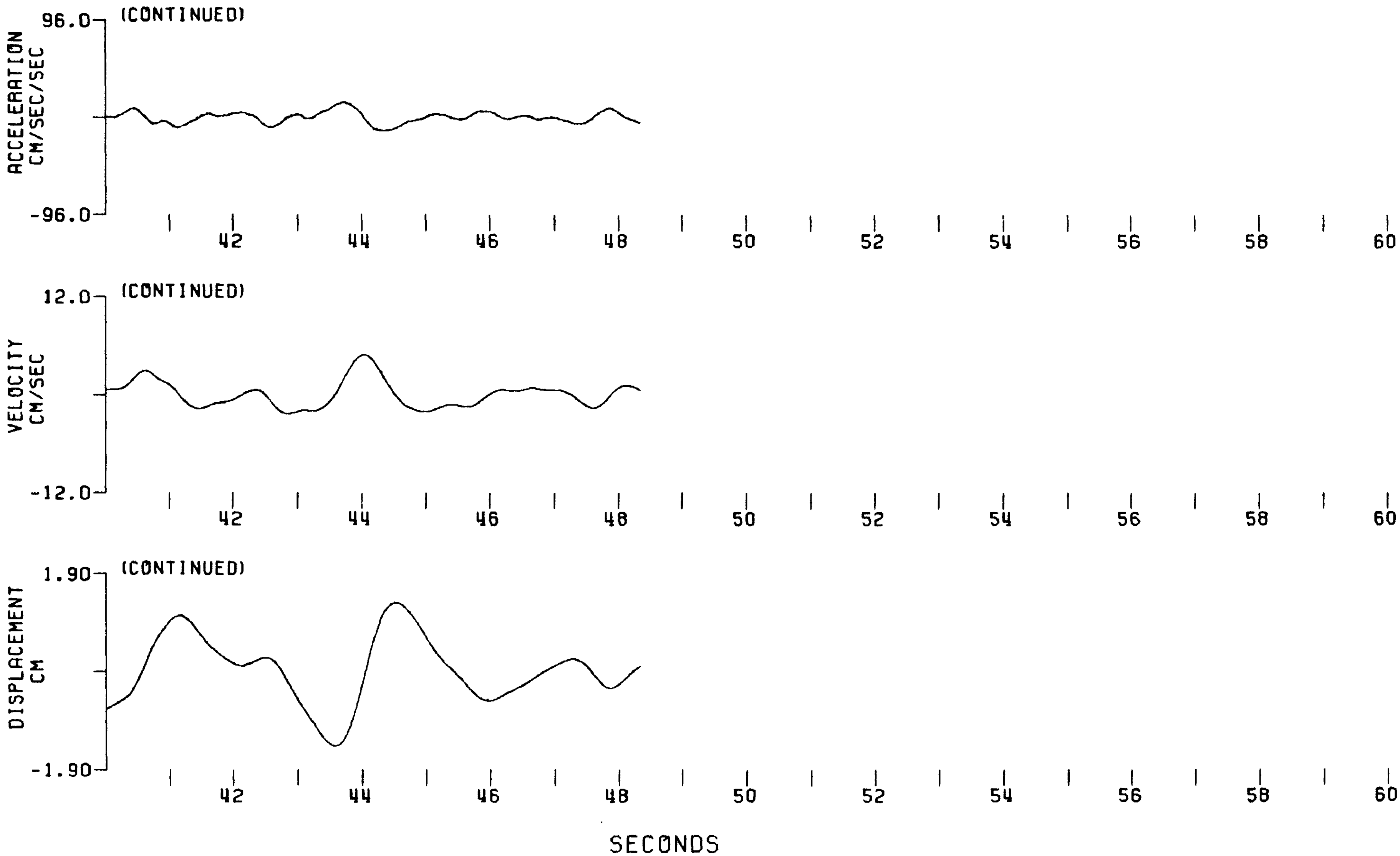

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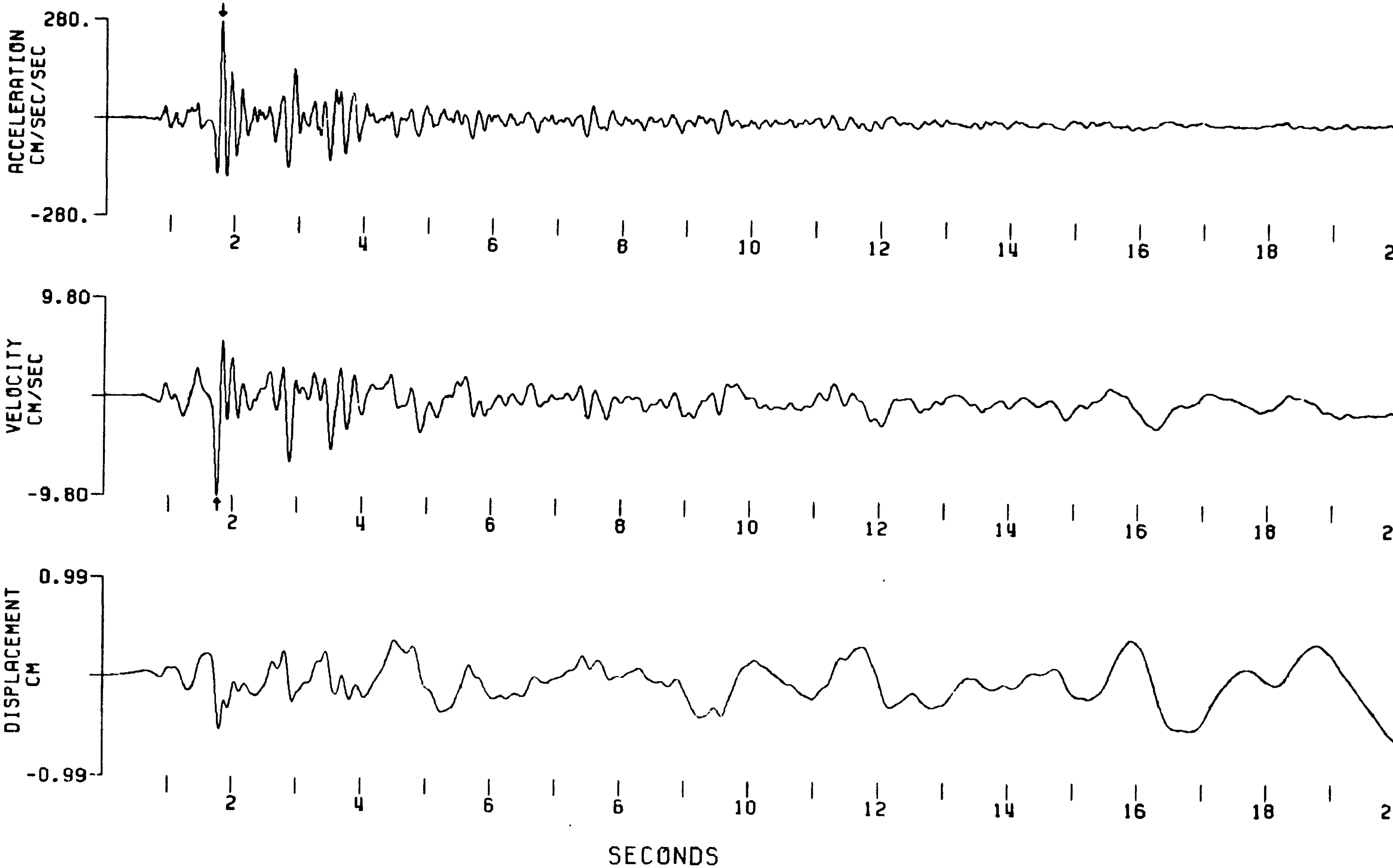

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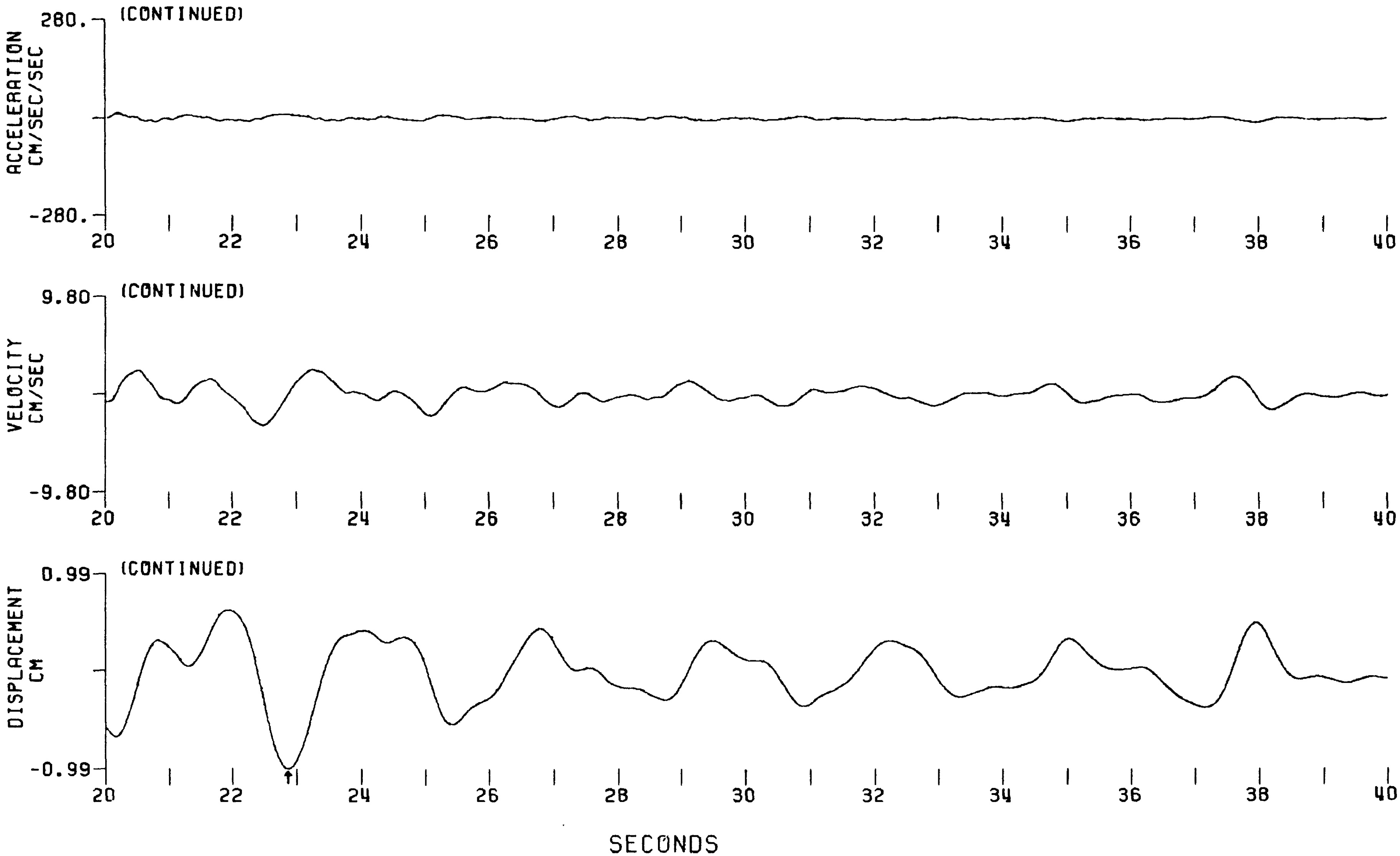

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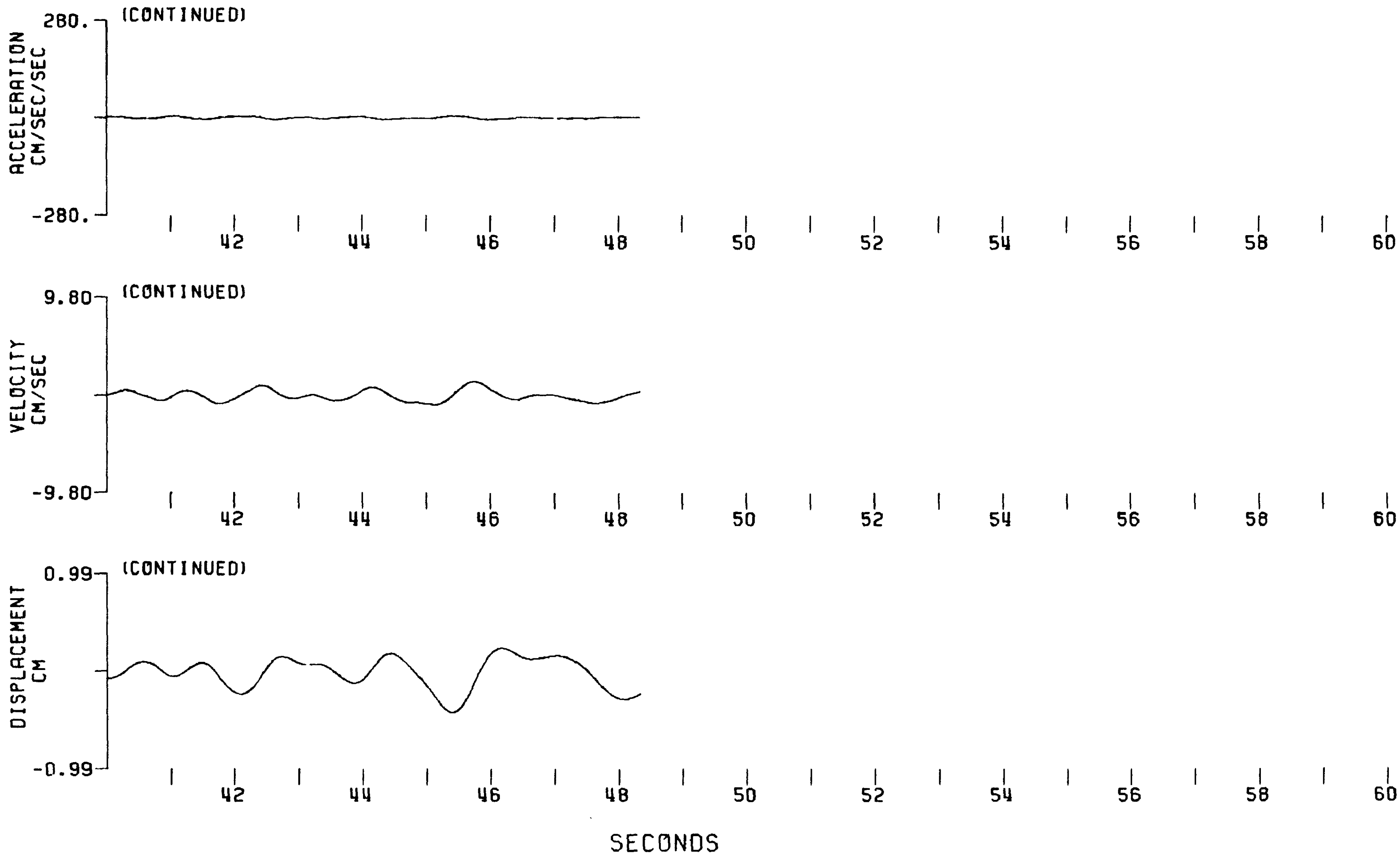

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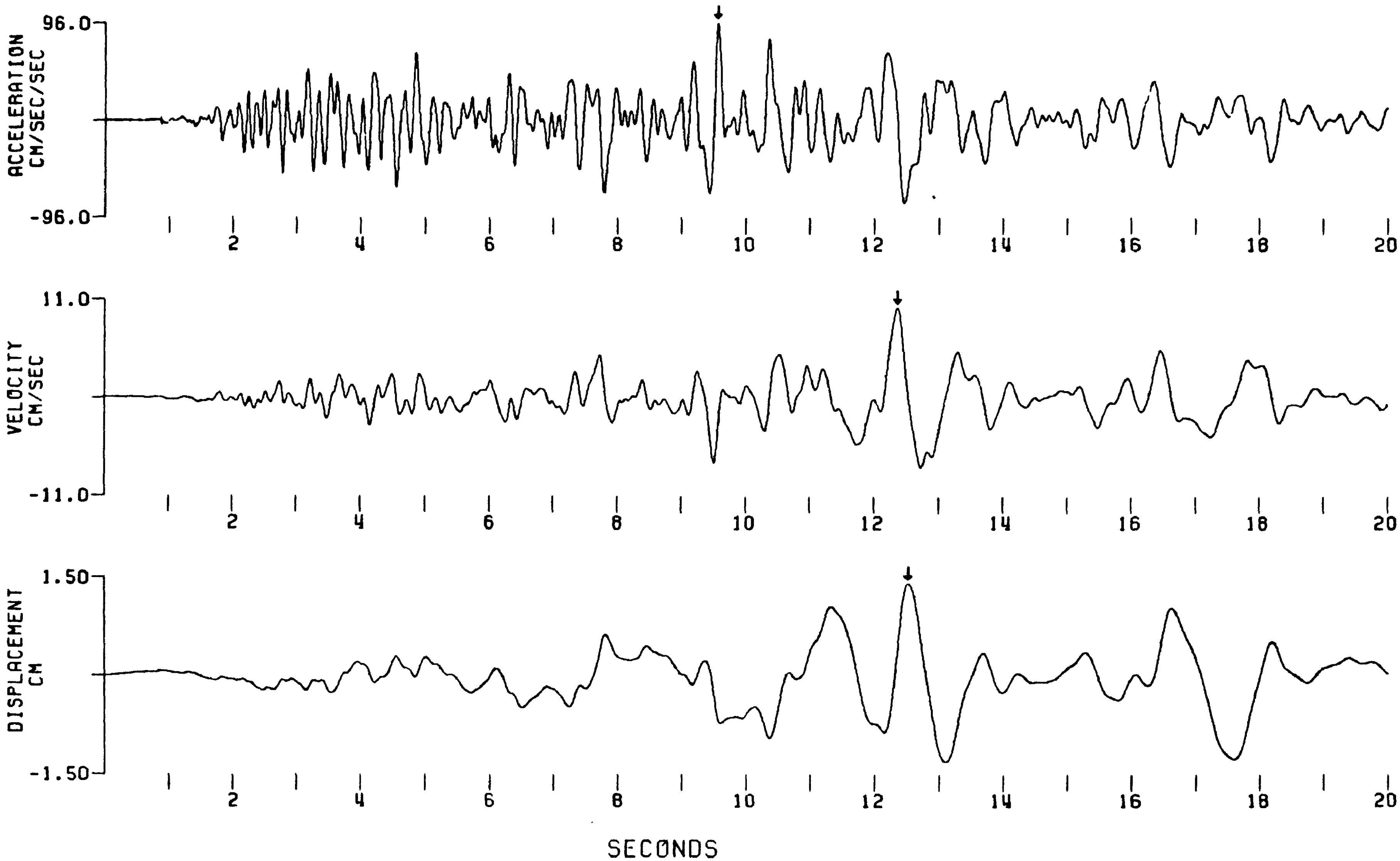

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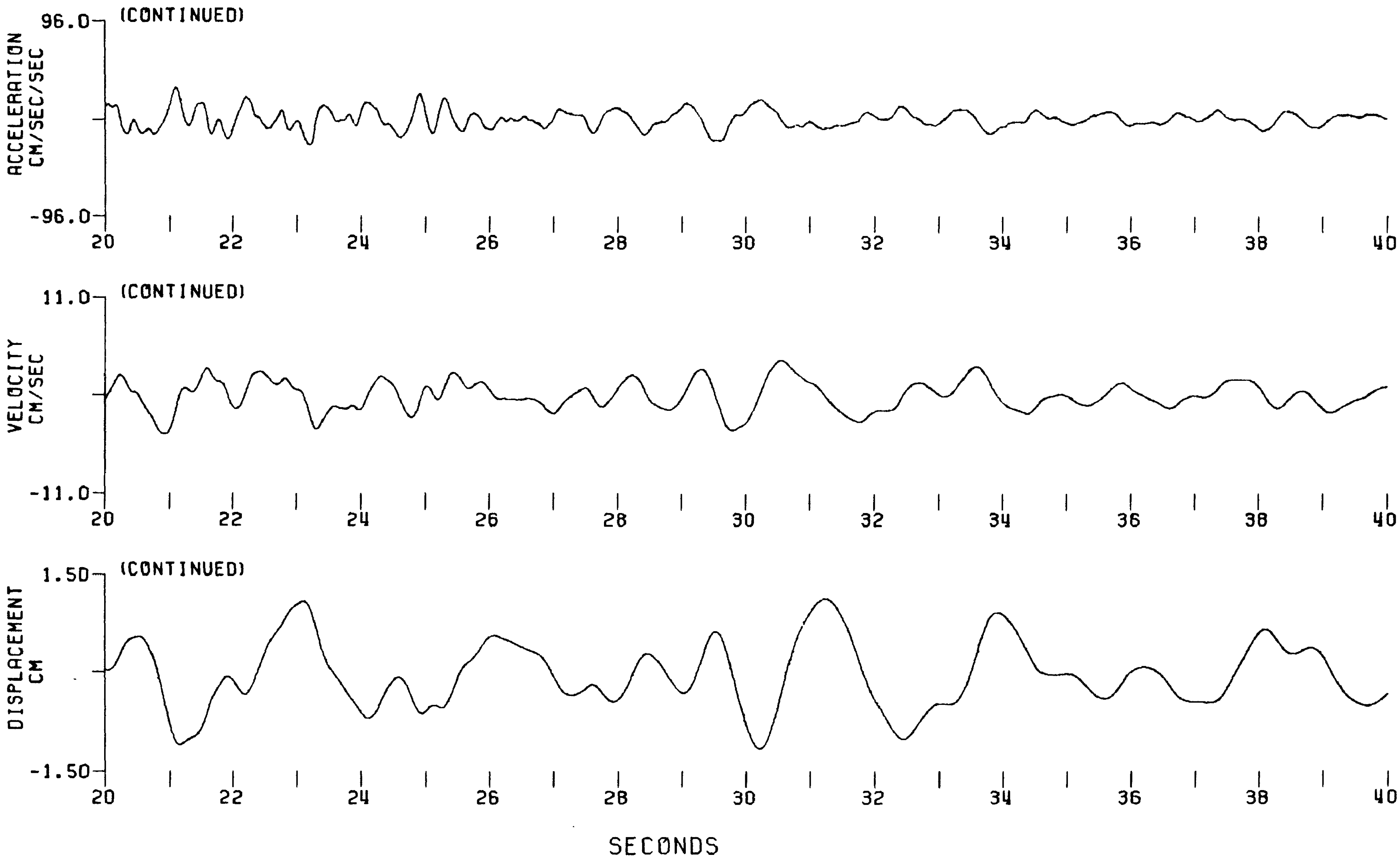
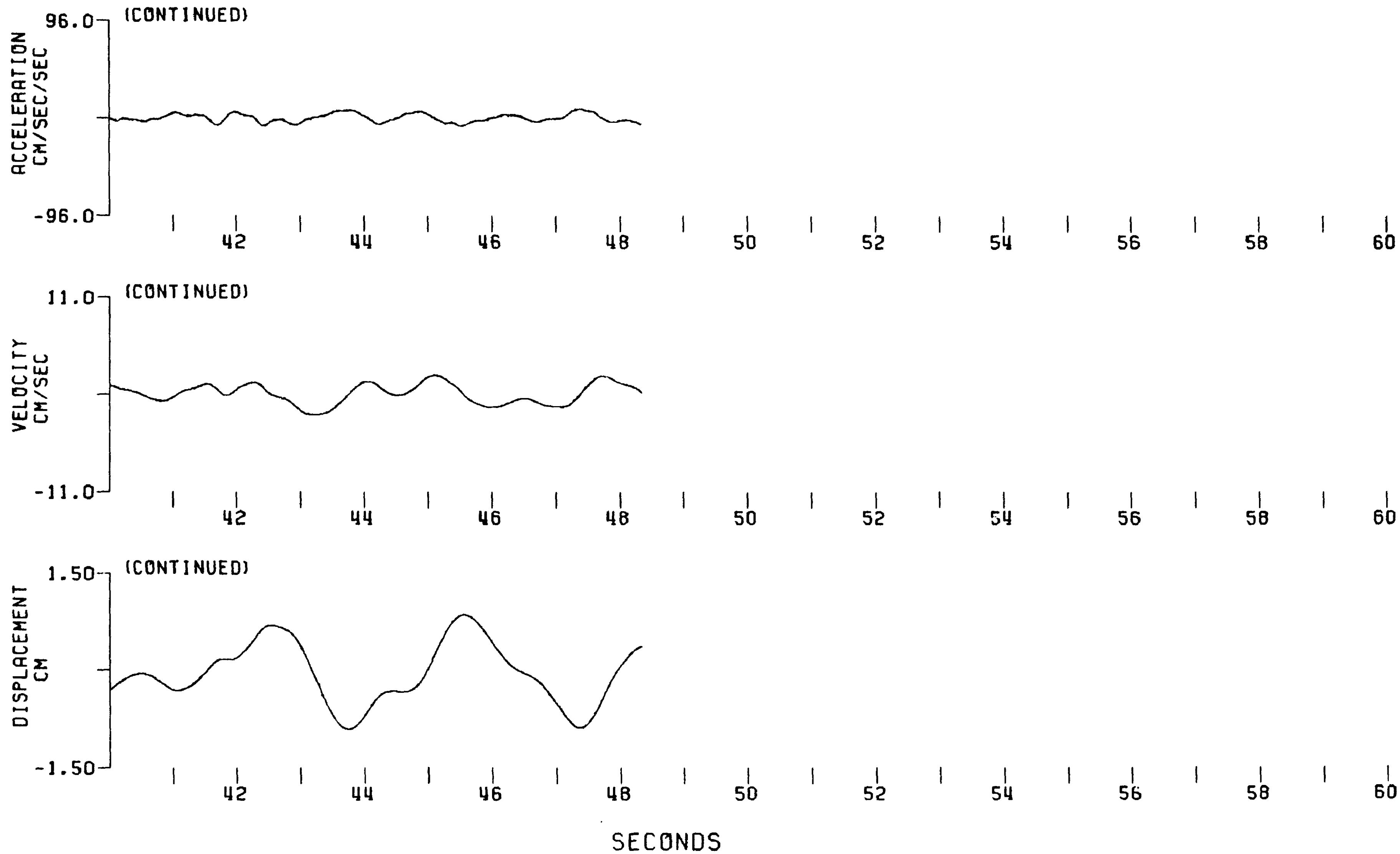
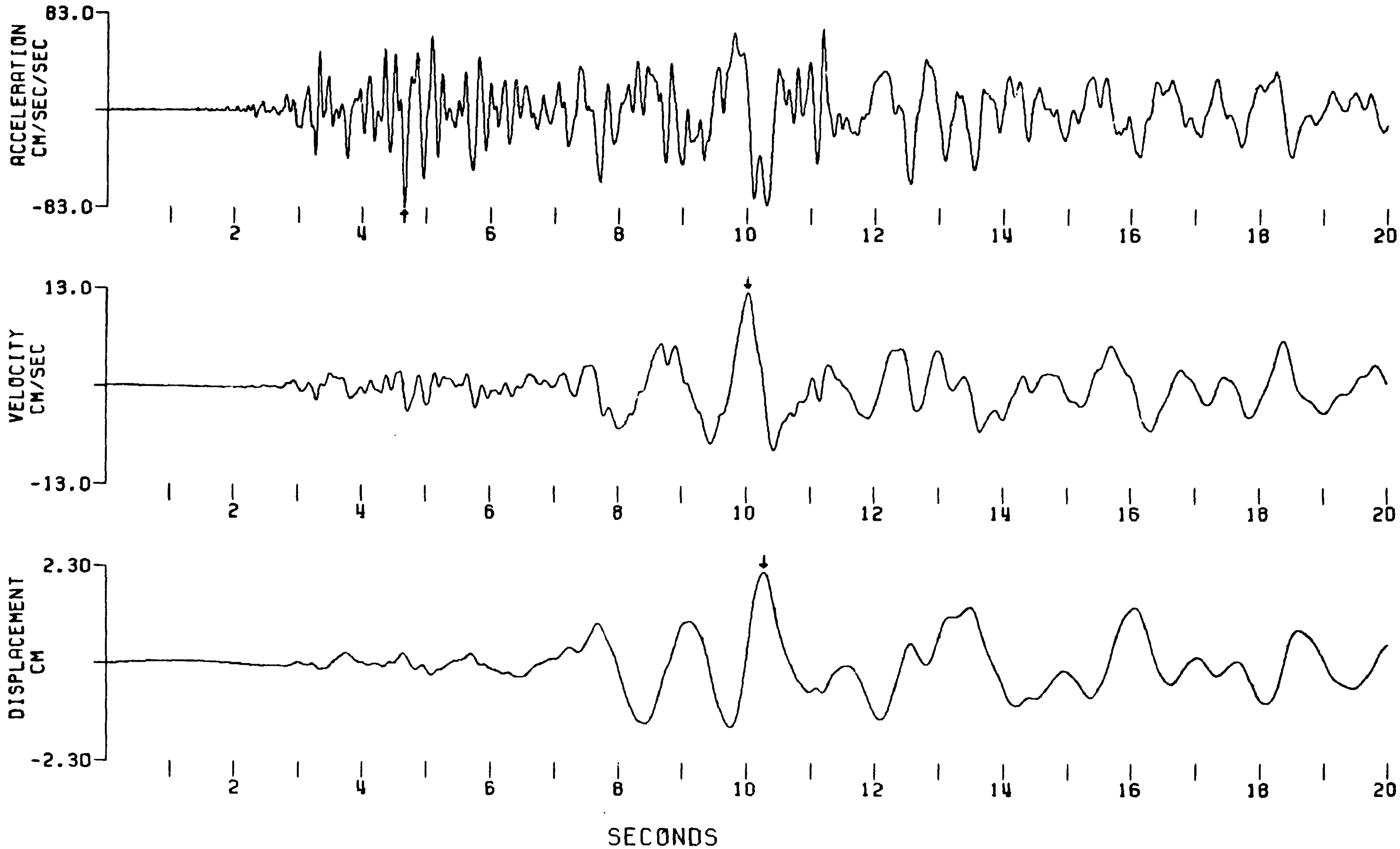
BUTTERWORTH FILTER AT .25 HZ, ORDER = 8
PEAK VALUES: ACCEL=95.54 CM/SEC/SEC, VELOCITY=10.19 CM/SEC, DISPL=1.42 CM



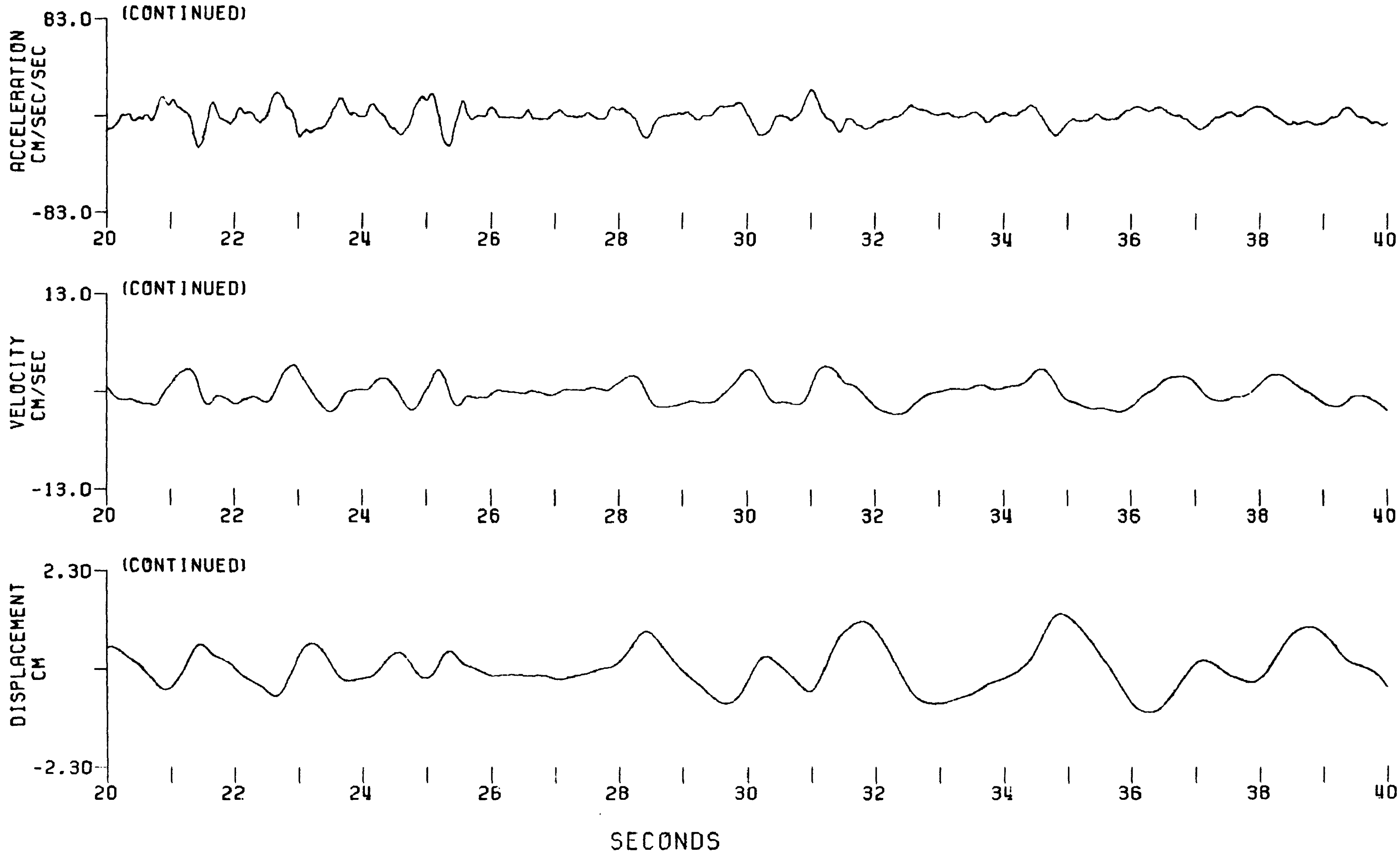
CORRECTED ACCELERATION, VELOCITY, AND DISPLACEMENT 200.00 SPS
HOLLISTER, DIFFERENTIAL ARRAY NO 4
345 DEGREES
EARTHQUAKE OF APRIL 24, 1984, 2115:17 UTC
BUTTERWORTH FILTER AT .25 HZ, ORDER = 8
PEAK VALUES: ACCEL=95.54 CM/SEC/SEC, VELOCITY=10.19 CM/SEC, DISPL=1.42 CM



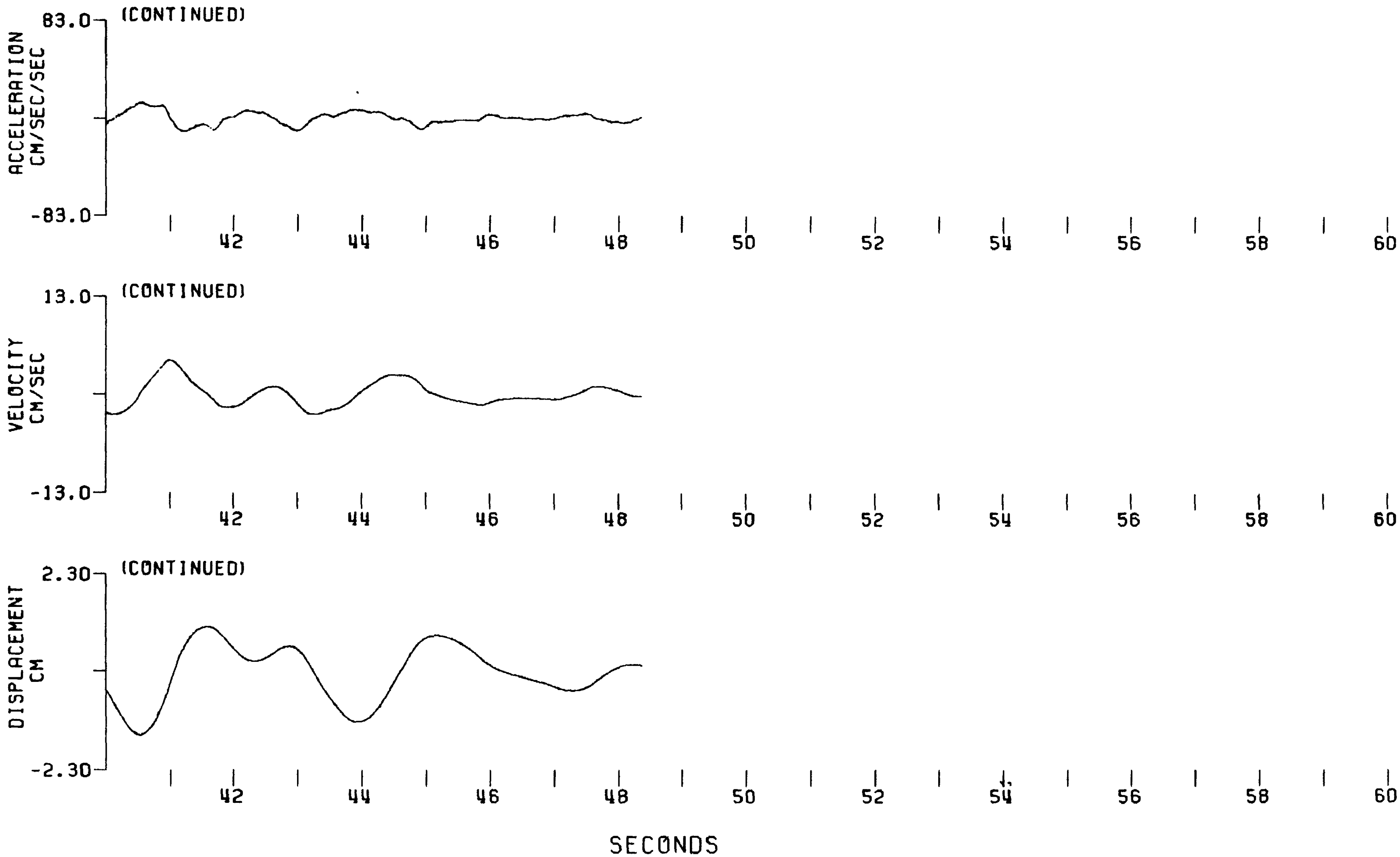
CORRECTED ACCELERATION, VELOCITY, AND DISPLACEMENT 200.00 SPS
HOLLISTER, DIFFERENTIAL ARRAY NO 5
255 DEGREES
EARTHQUAKE OF APRIL 24, 1984, 2115:17 UTC
BUTTERWORTH FILTER AT .25 HZ, ORDER = 8
PEAK VALUES: ACCEL=-82.91 CM/SEC/SEC, VELOCITY=12.62 CM/SEC, DISPL=2.21 CM



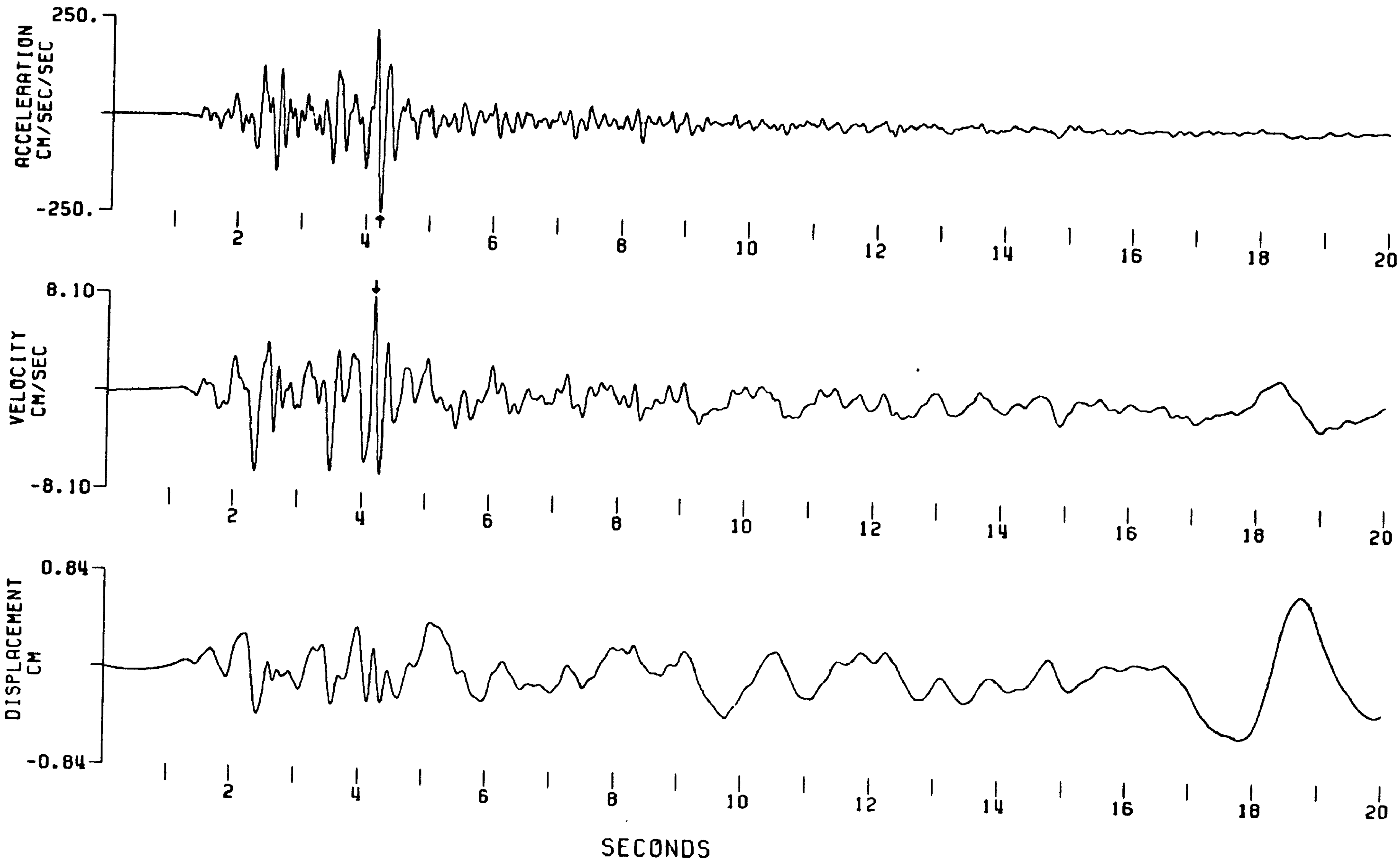
CORRECTED ACCELERATION, VELOCITY, AND DISPLACEMENT 200.00 SPS
HOLLISTER, DIFFERENTIAL ARRAY NO 5
255 DEGREES
EARTHQUAKE OF APRIL 24, 1984, 2115:17 UTC
BUTTERWORTH FILTER AT .25 HZ, ORDER = 8
PEAK VALUES: ACCEL=-82.91 CM/SEC/SEC, VELOCITY=12.62 CM/SEC, DISPL=2.21 CM



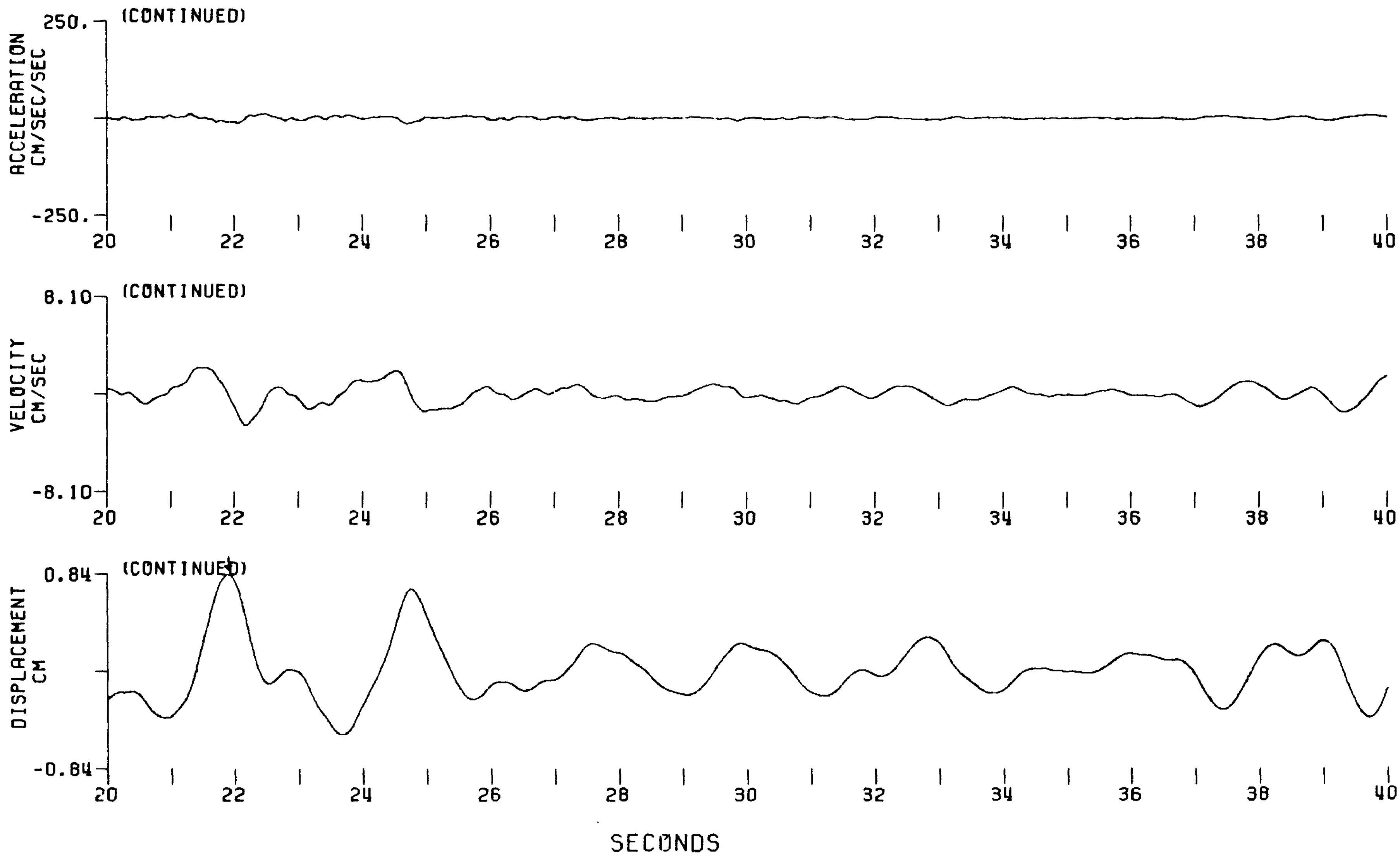
CORRECTED ACCELERATION, VELOCITY, AND DISPLACEMENT 200.00 SPS
HOLLISTER, DIFFERENTIAL ARRAY NO 5
255 DEGREES
EARTHQUAKE OF APRIL 24, 1984, 2115:17 UTC
BUTTERWORTH FILTER AT .25 HZ, ORDER = 8
PEAK VALUES: ACCEL=-82.91 CM/SEC/SEC, VELOCITY=12.62 CM/SEC, DISPL=2.21 CM



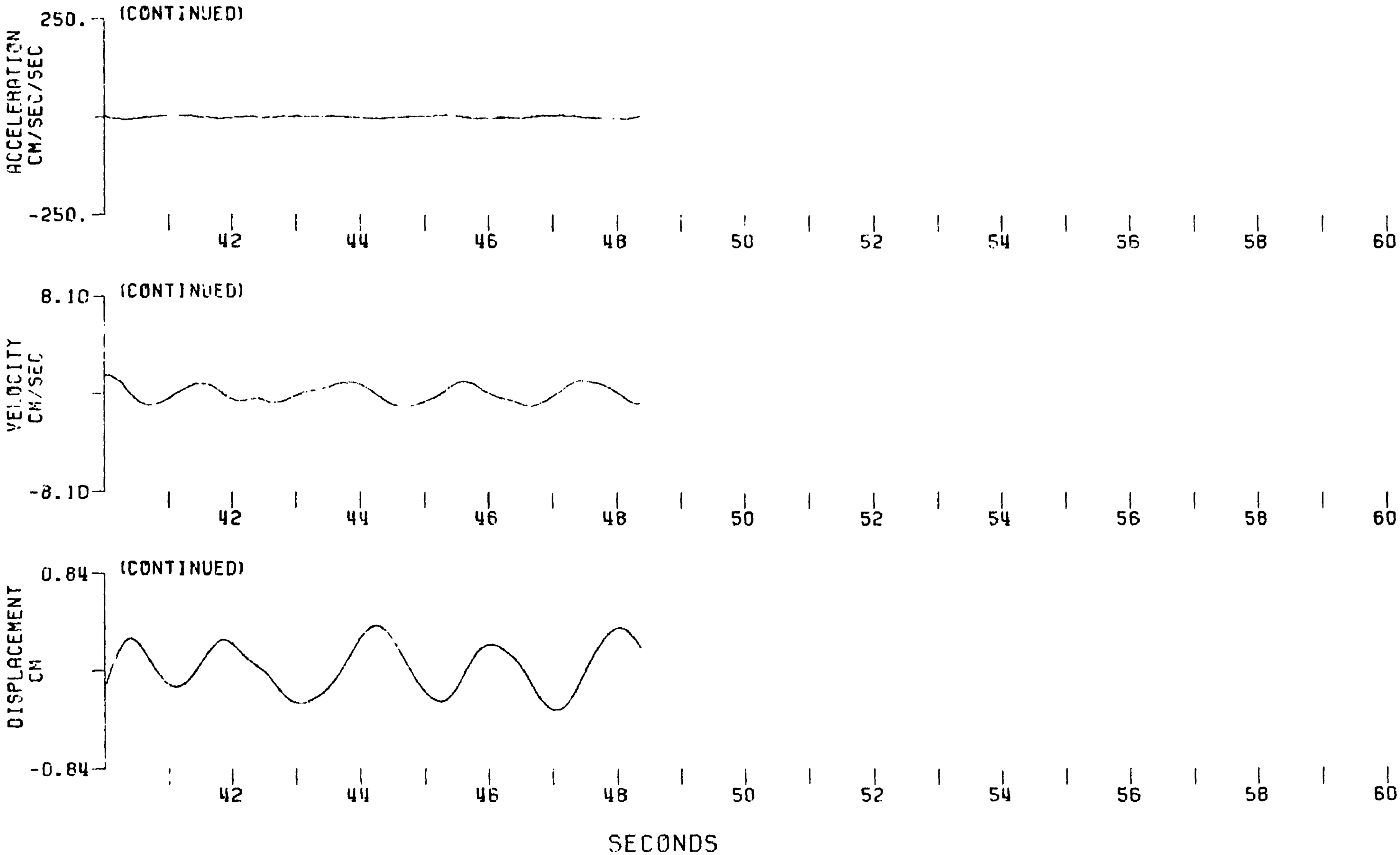
CORRECTED ACCELERATION, VELOCITY, AND DISPLACEMENT 200.00 SPS
HOLLISTER, DIFFERENTIAL ARRAY NO 5
UP
EARTHQUAKE OF APRIL 24, 1984, 2115:17 UTC
BUTTERWORTH FILTER AT .25 HZ, ORDER = 8
PEAK VALUES: ACCEL=-244.26 CM/SEC/SEC, VELOCITY=8.03 CM/SEC, DISPL=0.83 CM



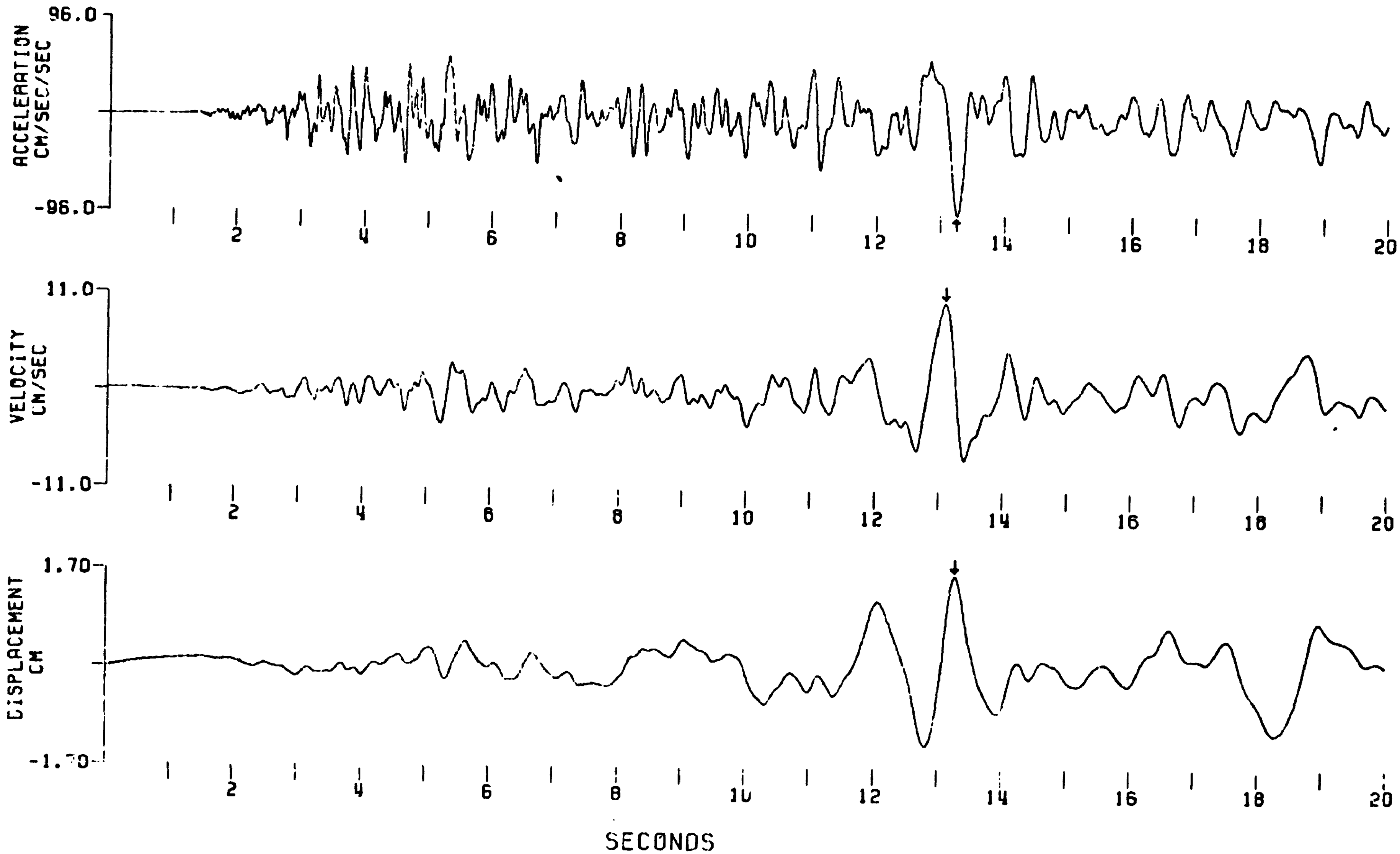
CORRECTED ACCELERATION, VELOCITY, AND DISPLACEMENT 200.00 SPS
HOLLISTER, DIFFERENTIAL ARRAY NO 5
UP
EARTHQUAKE OF APRIL 24, 1984, 2115:17 UTC
BUTTERWORTH FILTER AT .25 HZ, ORDER = 8
PEAK VALUES: ACCEL=-244.26 CM/SEC/SEC, VELOCITY=8.03 CM/SEC, DISPL=0.83 CM



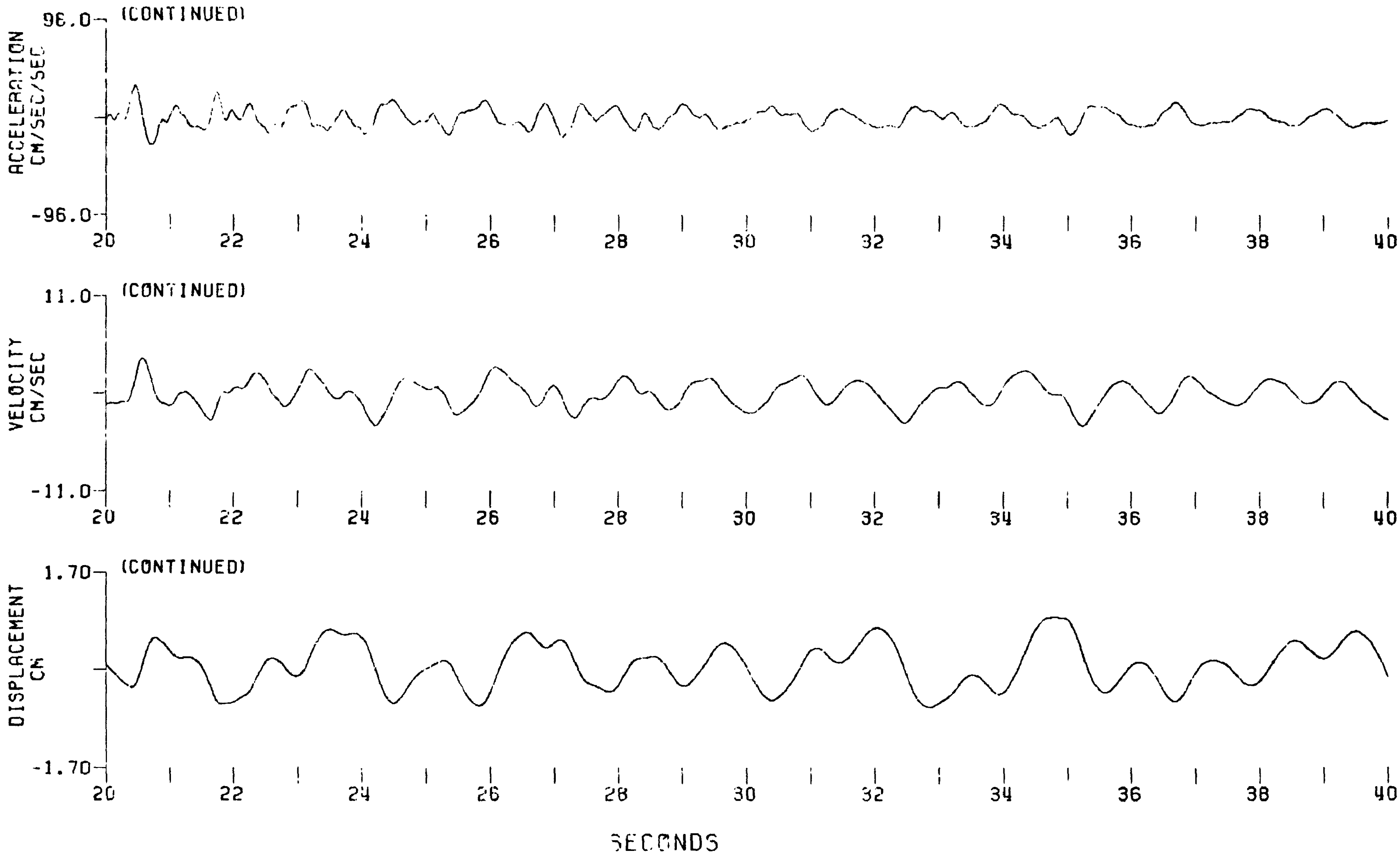
CORRECTED ACCELERATION, VELOCITY, AND DISPLACEMENT 200.00 SPS
HOLLISTER, DIFFERENTIAL ARRAY NO 5
UP
EARTHQUAKE OF APRIL 24, 1984, 2115:17 UTC
BUTTERWORTH FILTER AT .25 HZ, ORDER = 8
PEAK VALUES: ACCEL=-244.26 CM/SEC/SEC, VELOCITY=8.03 CM/SEC, DISPL=0.83 CM



CORRECTED ACCELERATION, VELOCITY, AND DISPLACEMENT 200.00 SPS
HOLLISTER, DIFFERENTIAL ARRAY NO 5
345 DEGREES
EARTHQUAKE OF APRIL 24, 1984, 2115:17 UTC
BUTTERWORTH FILTER AT .25 HZ, ORDER = 8
PEAK VALUES: ACCEL=-95.45 CM/SEC/SEC, VELOCITY=10.28 CM/SEC, DISPL=1.65 CM



CORRECTED ACCELERATION, VELOCITY, AND DISPLACEMENT 200.00 SPS
HOLLISTER, DIFFERENTIAL ARRAY NO 5
345 DEGREES
EARTHQUAKE OF APRIL 24, 1984, 2115:17 UTC
BUTTERWORTH FILTER AT .25 HZ, ORDER = 8
PEAK VALUES: ACCEL=-95.45 CM/SEC/SEC, VELOCITY=10.28 CM/SEC, DISPL=1.65 CM



CORRECTED ACCELERATION, VELOCITY, AND DISPLACEMENT 200.00 SPS
HOLLISTER, DIFFERENTIAL ARRAY NO 5
345 DEGREES
EARTHQUAKE OF APRIL 24, 1984, 2115:17 UTC
BUTTERWORTH FILTER AT .25 HZ, ORDER = 8
PEAK VALUES: ACCEL=-95.45 CM/SEC/SEC, VELOCITY=10.28 CM/SEC, DISPL=1.65 CM