U. S. DEPARTMENT OF THE INTERIOR
U. S. GEOLOGICAL SURVEY

DIGITAL SEISMIC RECORDINGS OF THE MAY 23, 1995, DEMOLITION OF THE ALFRED P. MURRAH FEDERAL BUILDING, OKLAHOMA CITY, OKLAHOMA

by

Christopher Dietel[1]

Open-File Report 95-594

[1] 345 Middlefield Road, Menlo Park, CA 94025
August 9, 1995

CONTENTS

SUMMARY

On May 23, 1995, The U.S. Geological Survey deployed four digital seismic recorders (GEOS) in and near Oklahoma City, Oklahoma to record ground motion produced by the demolition of the Alfred P. Murrah Federal Building damaged by the alleged terrorist bombing of April 19, 1995. Two of the recorders were co-located with permanent analog drum recorders that had recorded seismic signals from the April 19 blast. The goal was to acquire high quality digital recordings of seismic signals produced by the demolition to aid interpretation of the drum recorder signals from the alleged bombing.

One of the permanent drum recorder sites where GEOS instruments were deployed is located seven km northeast of the Murrah Building, and the other is located 26 km south of the Murrah Building near the city of Norman. These sites are maintained by the Omniplex Science Museum and by the Oklahoma Geological Survey (OGS), respectively. The third GEOS instrument was deployed at the Murrah Building site approximately 56 m north of the damaged structure. The fourth instrument was deployed near the city of Moore, 12 km south of the Federal building. This report describes the data obtained from the GEOS instruments. On-scale seismic signals produced by the demolition of the Murrah Building were obtained from all four of the GEOS sites.

The data were recorded in a 30-minute continuous recording window starting at 6:55 a.m. Oklahoma City local time, since the exact time of the demolition had not been known beforehand. After processing, the seismic signals were extracted from the long windows and stored as one-minute records. At the Murrah Building site, three components of ground acceleration (vertical, horizontal N-S, and horizontal E-W) and three components of ground velocity were obtained from the approximately eight-second-long demolition event. Timing of the initial detonation of the controlled detonation series was obtained to within 16 milliseconds. At the Omniplex Museum, three components of ground velocity were obtained, at two different gains, showing approximately 15 seconds of low-amplitude seismic signals followed by high-frequency signals lasting about 5 seconds. Filtering the data from the two more distant sites near the cities of Moore and Norman show that the three components of ground velocity recorded contain approximately 15 and 20 seconds, respectively, of low-amplitude seismic waves. The drum recorders at the Omniplex Museum and the Norman site, which had recorded signals on April 19, also recorded signals from the demolition.

The GEOS records obtained show a dispersion of seismic waves that can be used to interpret the drum recordings of the April 19 explosion and May 23 demolition of the Murrah Federal Building. The records from the Norman site are especially significant because they show, when filtered, two packets of 1-2 Hz seismic waves separated by approximately ten seconds. Similar, double-packet waveforms are observable on both the April 19 and May 23 drum records of the explosion and demolition events.

INTRODUCTION

Following the April 19 bombing of the Murrah Federal Building in Oklahoma City, the Oklahoma Geological Survey recognized the significance of seismic records of vertical velocity ground motion produced by the explosion obtained on two analog drum recorders, one at the Omniplex Museum in Oklahoma City and one at a seismic station located south of Oklahoma City near the city of Norman. Interpretations of multiple packets of seismic waves recorded on the drum recorders were varied, including speculation that two separate explosions, 10 seconds apart, were responsible for the damage. The OGS and the USGS recognized that the May 23 demolition of the Federal

Building could provide an opportunity for obtaining additional seismological information that could aid interpretation of the April 19 drum recordings and provide insight about wave propagation in central Oklahoma. The GEOS instruments were chosen for their ability to obtain 16-bit digital data that can be easily processed and analyzed using USGS computers and seismic software. The high-resolution data obtained from GEOS instruments as opposed to analog drum recorders yields much more information about seismic waves, which can be resolved in detailed interpretation. Two GEOS stations were co-located with the drum recorder sites to compare data between the two instruments. A third GEOS was deployed at the Federal Building site for a close observation of the seismic source and to pinpoint the exact time of the initial detonation of the demolition. A fourth GEOS was deployed at an intermediate site for a comparison with near and far stations.

INSTRUMENTATION AND FIELD DEPLOYMENT

The GEOS seismic recorders used to collect the data described in this report (GEOS is an acronym for General Earthquake Observation System) were developed by the USGS for use in a wide variety of seismic experiments. A detailed description of the GEOS instrument is provided by Borcherdt and others (1985).

The six-channel 16-bit system operates on 24 VDC and records data onto magnetic tape in ANSI standard format at 1600 bpi. The CMOS analog-to-digital converter provides 96 dB of linear dynamic range or signal resolution. When configured with one three-component accelerometer and one three-component velocity sensor, acquisition of seismic signals ranging in amplitude from slightly above seismic background noise to 2 g in acceleration can be recorded on-scale. Gains, filters, and sample rates (up to 1200 samples/s) are software selectable. The GEOS instrument can be programmed to operate in trigger mode, in which events are recorded when an STA/LTA (short-term average/long-term average) programmable algorithm threshold is exceeded, and/or preset mode in which recording windows as long as 30 minutes can be preset. The GEOS instruments are equipped with internal WWVB radio receivers, and the GEOS internal clocks can be synchronized with WWVB radio time code or external standards such as GOES satellite or master clock.

For accurate timing of the instruments used in Oklahoma, the instrument clock at the first station setup was synchronized to WWVB. A master clock was then synchronized to the GEOS clock, and the master clock was used to synchronize the instrument clock at Station OMN where WWVB could not be obtained, and later to compare clocks of all the instruments. At least one WWVB time code correction with respect to the instrument internal clock was also automatically written to tape on each of the three instruments set up with the WWVB antennas. Table 1 lists in milliseconds these automatic WWVB clock corrections and the master clock corrections taken when the instruments were turned off at the end of the deployment. A positive correction indicates that the GEOS clock at the listed UTC time was ahead of the WWVB time code or master clock, and a negative correction indicates that the GEOS clock was behind the WWVB time code or master clock.

Deployment in Oklahoma was performed in the two days prior to the demolition of the Federal Building. Figure 1 is a map showing the locations of the four GEOS stations deployed relative to the Federal Building. Table 2 lists the station coordinates, sensor configurations, and recording parameters for each site. A sample rate of 100 samples/s/channel was chosen for all of the instruments.

Station MUR was located 56 m north of the center of the damaged Murrah Federal Building in an area closed to the public. To ensure on-scale recording of the demolition, the GEOS instrument was configured with two sensors: a Kinemetrics three-component force-balance accelerometer (FBA), providing input into channels 1,2, and 3, and a three-component Mark Products L-22-3D velocity sensor (natural frequency of 2 Hz and sensitivity of 0.5 V/cm/s) providing input into channels 4,5, and 6. Amplifiers were set at a gain of 12 db for the accelerometer and 18 db for the velocity sensors, and filters were set at 50 Hz. The sensors were oriented with component 1 vertical , component 2 horizontal magnetic north, and component 3 horizontal east. Positive motion is up, toward north, and toward east, respectively. The sensors were placed on firm ground, which appeared to be the pre-existing street or parking lot.

Station OMN was deployed on the first floor of the Omniplex Museum near the drum recorder, also called station OMN, which recorded the April 19 explosion and is used for public display. The GEOS instrument and sensors were placed approximately 10 m south of the drum recorder on the concrete floor of an enclosed stairway . Although seismic signal amplitudes of the demolition were not expected to be large at this site, two L-22-3D velocity sensors were used at different gains (30 db and 54 db) to ensure on-scale recordings. These sensors were oriented to true north, in line with the building N-S wall. Filters were set at 33 Hz. Because of its location indoors, this station was not equipped with a WWVB time code antenna.

Station MOR was chosen as an intermediate-distance location, roughly halfway between the Federal building and the Norman Drum recorder site, near the city of Moore. The GEOS instrument and sensors were placed inside an annex of the Southern Baptist Church on 89th Street. Three single-component Mark Products L-4A velocity sensors (natural frequency of 1 Hz and sensitivity of 1.0 V/cm/s) provided input into channels 4, 5, and 6. The sensors were placed on a concrete pad floor and oriented with component 1 vertical , component 2 horizontal magnetic north, and component 3 horizontal east. Amplifiers were set at the GEOS maximum gain of 60 db. Filters were set at 33 Hz, however this caused the amplifier on channel 5 to malfunction, so a 50 Hz filter was used for that channel. The WWVB antenna was placed outside the structure and the connecting cable was routed above a doorway to the instrument.

Station NRM was co-located with the OGS drum recorder, Station FNO, which is located at a residence near the city of Norman. The L-4A sensors were placed on the FNO seismic pad and oriented to magnetic north. Amplifiers were set at the GEOS maximum gain of 60 db and filters were set at 33 Hz.

The GEOS instruments at all four sites were programmed to record a 30-minute preset continuous recording window beginning at 06:55 a.m. Oklahoma City local time on May 23 (143:11:55 UTC). This window was chosen after confirmation from Controlled Demolition International, the company conducting the demolition, that the demolition would occur between 07:00 and 07:15 a.m., May 23.

After the recording of the demolition, the GEOS instrument internal clock at each site was compared with the master clock (see Table 1), and amplifier and sensor calibration signals were also recorded.

SEISMICITY RECORDED

Seismograms of the ground motion produced by the demolition of the Murrah Federal Building were recorded by all four of the GEOS instruments. These seismograms are shown and described in Figures 2 through 8. Digital playback of the GEOS data was conducted with a Tandberg serpentine tape drive attached to a VAX cluster at the USGS in Menlo Park. The seismograms of the demolition event were extracted from the long 30-minute preset window recordings using a program called DR1SEG, written by Gary Maxwell and modified by Tim MacDonald. A detailed description of GEOS data formats is given by Dietel and others (1989).

The demolition of the Federal Building lasted approximately eight seconds during a series of controlled detonations. Figures 2 and 3 show the acceleration and velocity seismograms, respectively, recorded by the GEOS at station MUR at the Federal Building site during the eight seconds of ground motion induced by the collapse. In these figures, the three components of ground motion recorded are shown, and each trace is labeled with its corresponding component at the right of the figure. The top trace represents vertical motion (V), the middle trace represents north-south horizontal motion (N), and the bottom trace represents east-west horizontal motion (E). The horizontal axis shows increasing time, in seconds, and the start time of the recording in UTC time expressed to the nearest second is given in the figure caption. (The format is DDD+HH:MM:SS where D = Day, H = Hour, M = Minute, and S = Second.) The vertical axis shows amplitude in cm/sec/sec or cm/sec. The seismograms show a series of seismic wave packets that represent the phased detonations and portions of the building collapse. The first two seconds of the waveforms exhibit higher frequencies of ground motion caused by the initial detonations, and the following seconds exhibit slightly lower frequencies during the successive collapse. The exact time to the nearest second of the initial detonation of the demolition is evident in the seismograms by the sharp increase in ground motion that occurs just over one second into the recording, which corresponds to a time of 7:01:09 a.m. Oklahoma City local time.

Figures 4 and 5 show the velocity records obtained from station OMN at the Omniplex Museum. Figure 4 shows the three components of ground velocity recorded at a high gain of 54 db, and Figure 5 shows the three components of ground velocity recorded at a lower gain of 30 db. These records show approximately 20 seconds of ground motion resulting from the demolition. An emergent, lower frequency packet of seismic waves lasting about 15 seconds is followed by an impulsive, higher frequency packet lasting about 5 seconds.

Figures 6 and 7 show the velocity records obtained from stations MOR, near the city of Moore, and NRM, at the OGS FNO site, respectively. Seismic signals from the demolition event are partially obscured by the high-frequency ambient background noise. A 2 Hz low-pass filter, however, eliminates much of this noise and reveals distinct waveforms associated with the event, as is discussed below.

PRELIMINARY ANALYSIS

For comparison of the data, the vertical ground velocities recorded at all of the GEOS stations are shown in record-section format in Figure 8. A low-pass filter of 2.0 Hz has been applied to each recording. The vertical axis gives the time into the record in seconds. The start time in UTC time to the nearest second is 143:12:01:00. The horizontal axis shows the range of the stations in kilometers; each trace is plotted showing the relative spacing between stations, and the station names are listed at the top of each trace. The amplitudes of the traces are normalized to the maximum amplitude in the record section. The figure shows the dispersion of the waveforms as they travel to greater distance. The seismogram from station NRM shows approximately 20 seconds of increased amplitudes in frequencies below 2 Hz. The waveforms exhibit two fairly distinct envelopes of energy separated by about ten seconds, which were also seen on the FNO permanent drum recorder at the site. The seismogram from station MOR, located at an intermediate distance from the federal building, shows two less distinct packets of energy separated by only about three or four seconds and differing greatly in amplitude. In conclusion, the data from the four GEOS stations show an evolution of waveforms that should be useful for a detailed analysis to interpret the waveforms of the April 19 explosion recorded on the two drum recorders. Analysis of these recordings should also provide insight into the seismic wave velocity structure between the Federal Building and station FNO.

ACKNOWLEDGMENTS

A great many thanks to Ray Brown of the OGS for his generous help and hospitality during this experiment. James Muskoe, assistant director of the Oklahoma University police department, provided help and good conversation at the NRM (FNO) site. Greg Christenson of the Omniplex Science Museum was very helpful in the setup of the OMN GEOS station. Barry Black of the FBI was especially helpful despite his busy schedule during our setup at the Federal building site. Doug Loizeaux, Fred Nichols, and others of Controlled Demolition International provided fine coordination and help. Timothy Miller, minister of the Southern Baptist Church, generously offered his time in the setup of the MOR station, and even invited us into his house hours after the demolition to see the video of the event, which was a fascinating, although somber, experience.

REFERENCES CITED

Borcherdt, R. D., Fletcher, J., Jensen, E., Maxwell, G., Van Schaack, J., Warrick, R., Cranswick, E., Johnson, M., and McClearn, R., A General Earthquake Observation System (GEOS), *Seismol. Soc. Am. Bull.*, **75**, 1783-1823, 1985.

Dietel, C., Chouet, B., Aki, K., Ferrazzini, V., Roberts, P., and Koyanagi, R., Data summary for dense GEOS array observations of seismic activity associated with magma transport at Kilauea Volcano, Hawaii, *U.S. Geol. Surv. Open-File Rep.* **89-113**, 1-171, 1989.

Table 1: Clock Corrections:

Station:	Init. Sync. Time (UTC):	WWVB auto. correction:	Master Clock correction:
MUR	142:20:45	+4 ms @ 143:12:51	+8 ms @ 143:14:30
OMN	142:18:51	- - - -	+2 ms @ 143:13:27
MOR	141:20:11	-1 ms @ 142:04:28	+2 ms @ 143:15:30
NRM	142:16:29	-15 ms @ 143:08:43	-16 ms @ 143:12:20

Table 2: Station Coordinates, Configurations, and Recording Parameters

Station	Coordinates	Channel	Sensor Type	Sensor ID #	Orientation	Gain	Filter
MUR	+35:28.36,	1,2,3	FBA	21850	Mag. N	12 db	50 Hz
	-97:31.02	4,5,6	L-22	307	Mag. N	18 db	50 Hz
OMN	+35:31.41	1,2,3	L-22	304	True N	54 db	50 Hz
	-97:28.48	4,5,6	L-22	373	True N	30 db	50 Hz
MOR	+35:22.61	4	L-4A	5786		60 db	33 Hz
	-97:27.01	5	L-4A	5698	Mag. N	60 db	50 Hz
		6	L-4A	5687		60 db	33 Hz
NRM	+35:15.426,	4	L-4A	5789		60 db	33 Hz
	-97:24.036	5	L-4A	5684	Mag. N	60 db	33 Hz
		6	L-4A	5680		60 db	33 Hz

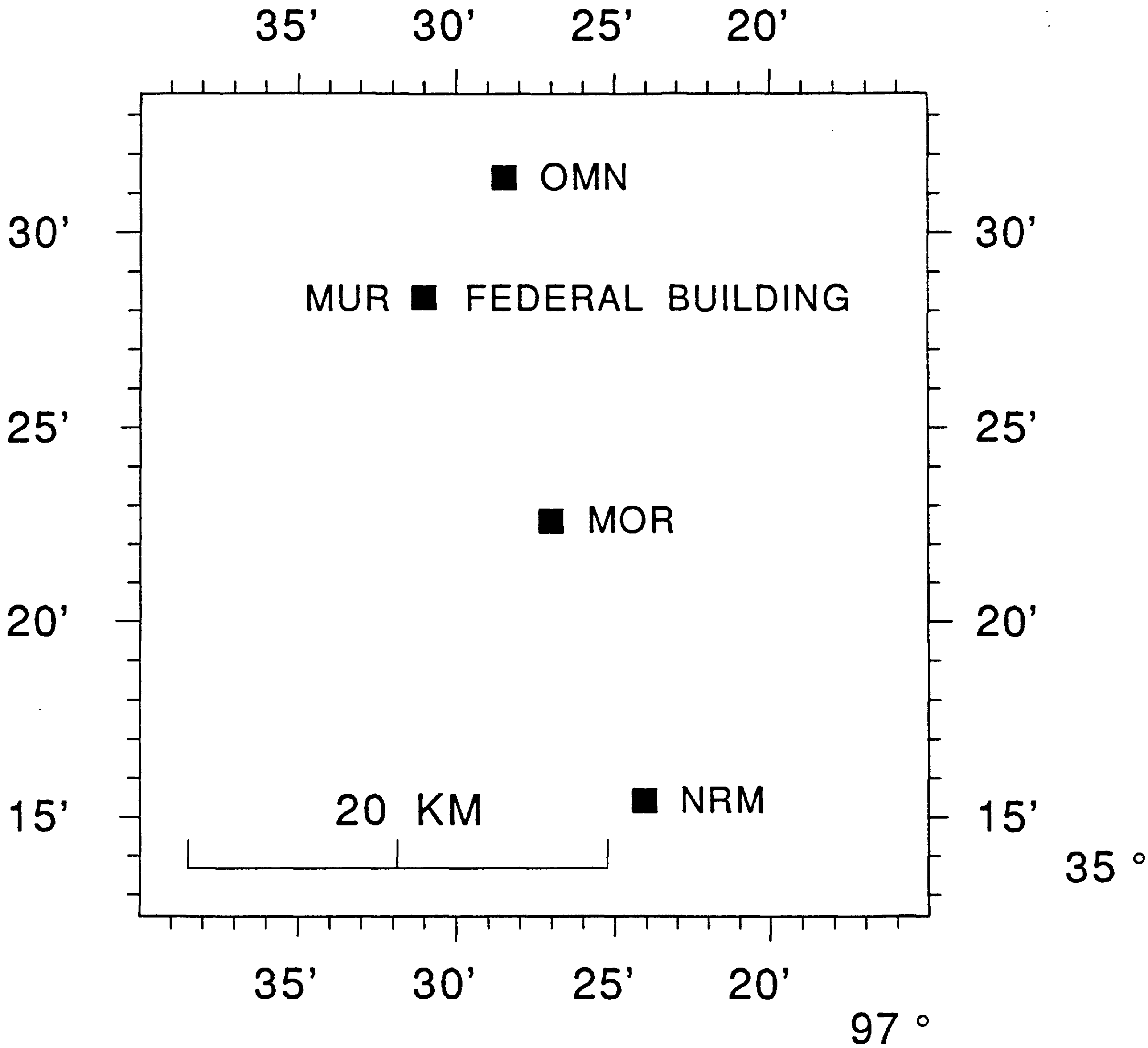

Figure 1. Map showing the locations of the four GEOS digital recorder stations in relation to the Murrah Federal Building. Station OMN and NRM were co-located with permanent analog drum recorders, OMN and FNO respectively.

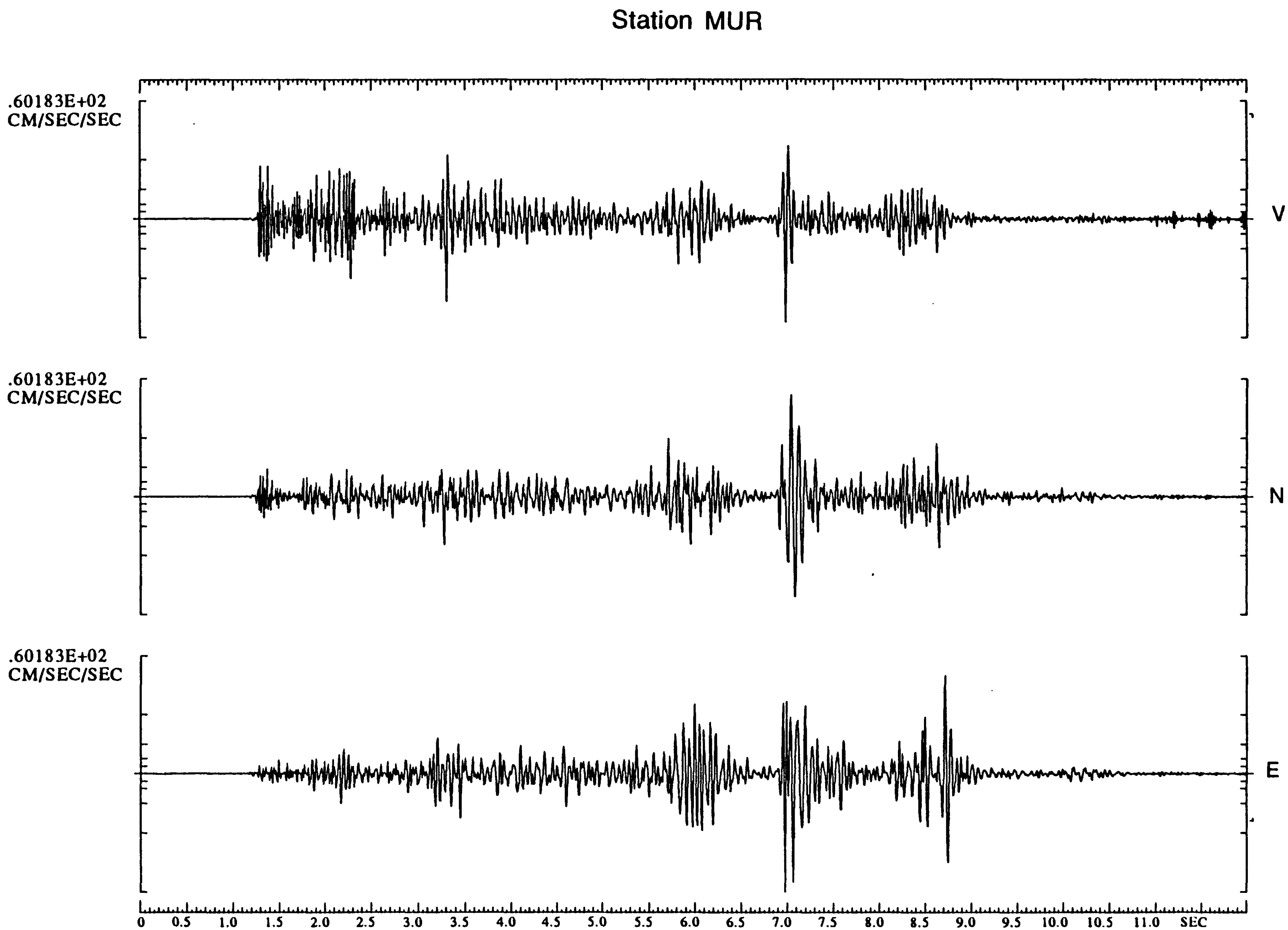

Figure 2. The three components of ground acceleration recorded at station MUR during the demolition of the Murrah Federal Building. The start time of the recording (at 0 sec) in UTC time to the nearest second is 143:12:01:08.

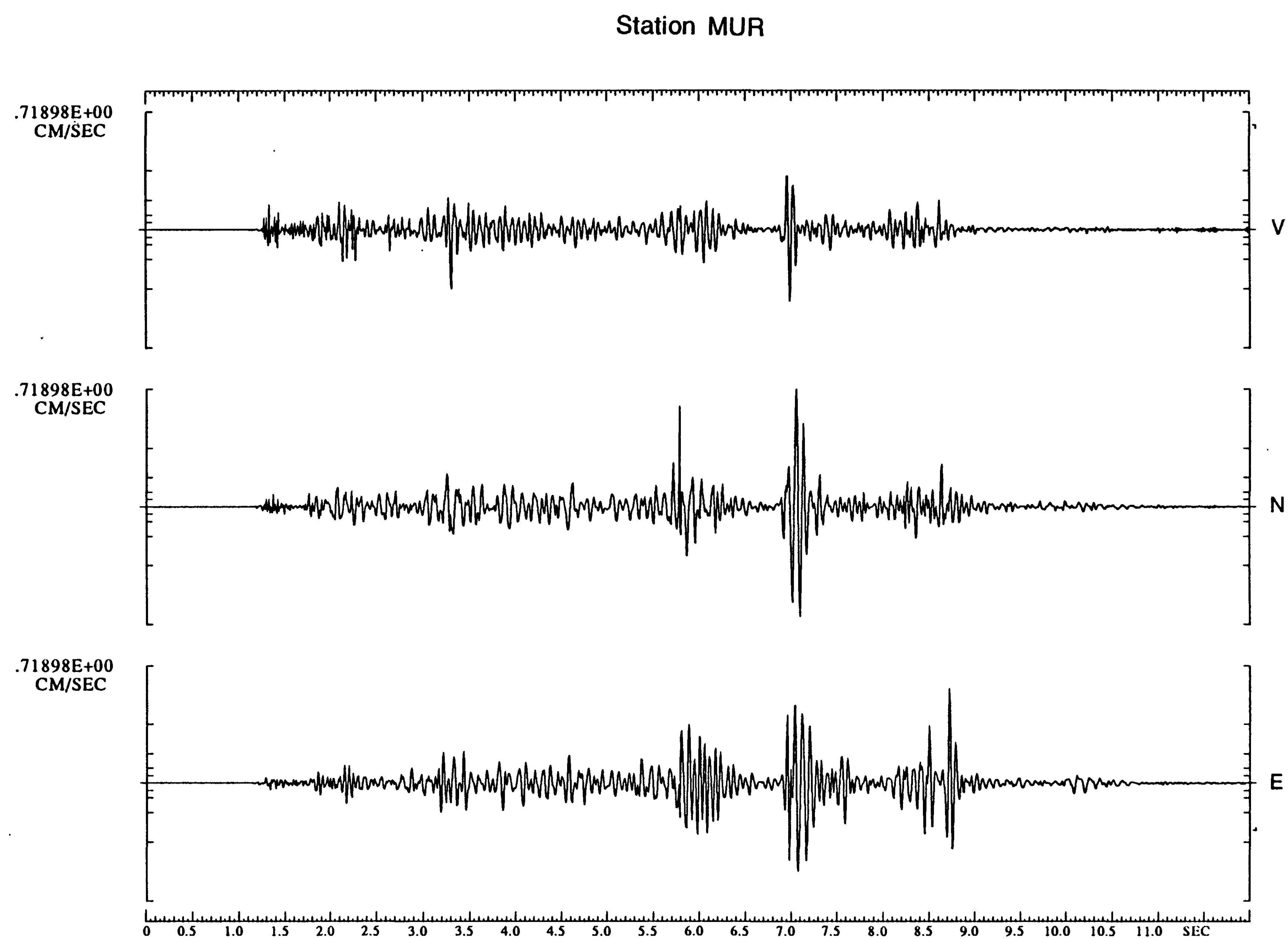

Figure 3. The three components of ground velocity recorded at station MUR during the demolition of the Murrah Federal Building. The start time of the recording (at 0 sec) in UTC time to the nearest second is 143:12:01:08.

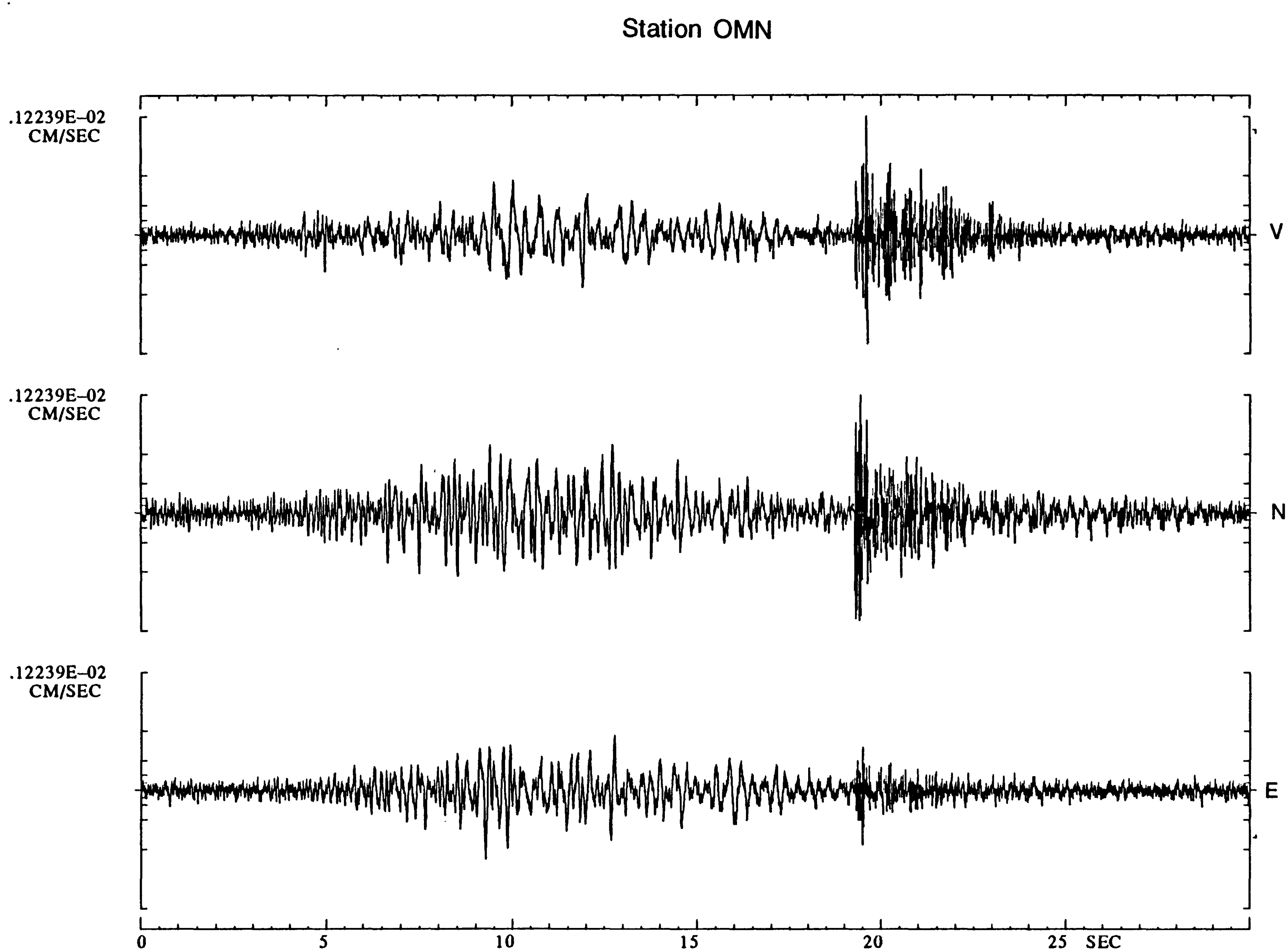

Figure 4. The three components of ground velocity produced by the demolition of the Murrah Federal Building recorded at station OMN at 54 db. The start time of the recording (at 0 sec) in UTC time to the nearest second is 143:12:01:10.

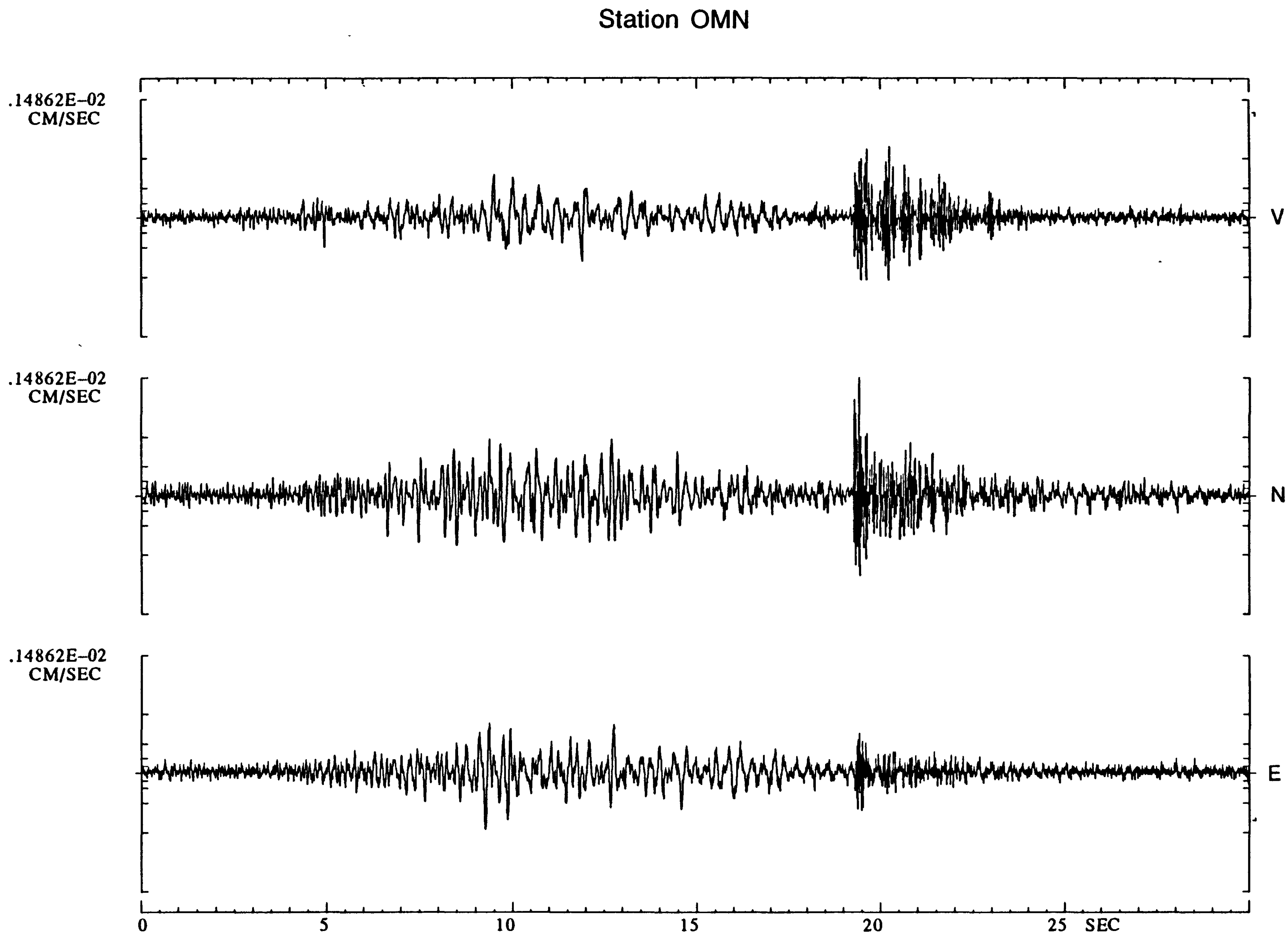

Figure 5. The three components of ground velocity produced by the demolition of the Murrah Federal Building recorded at station OMN at 30 db. The start time of the recording (at 0 sec) in UTC time to the nearest second is 143:12:01:10.

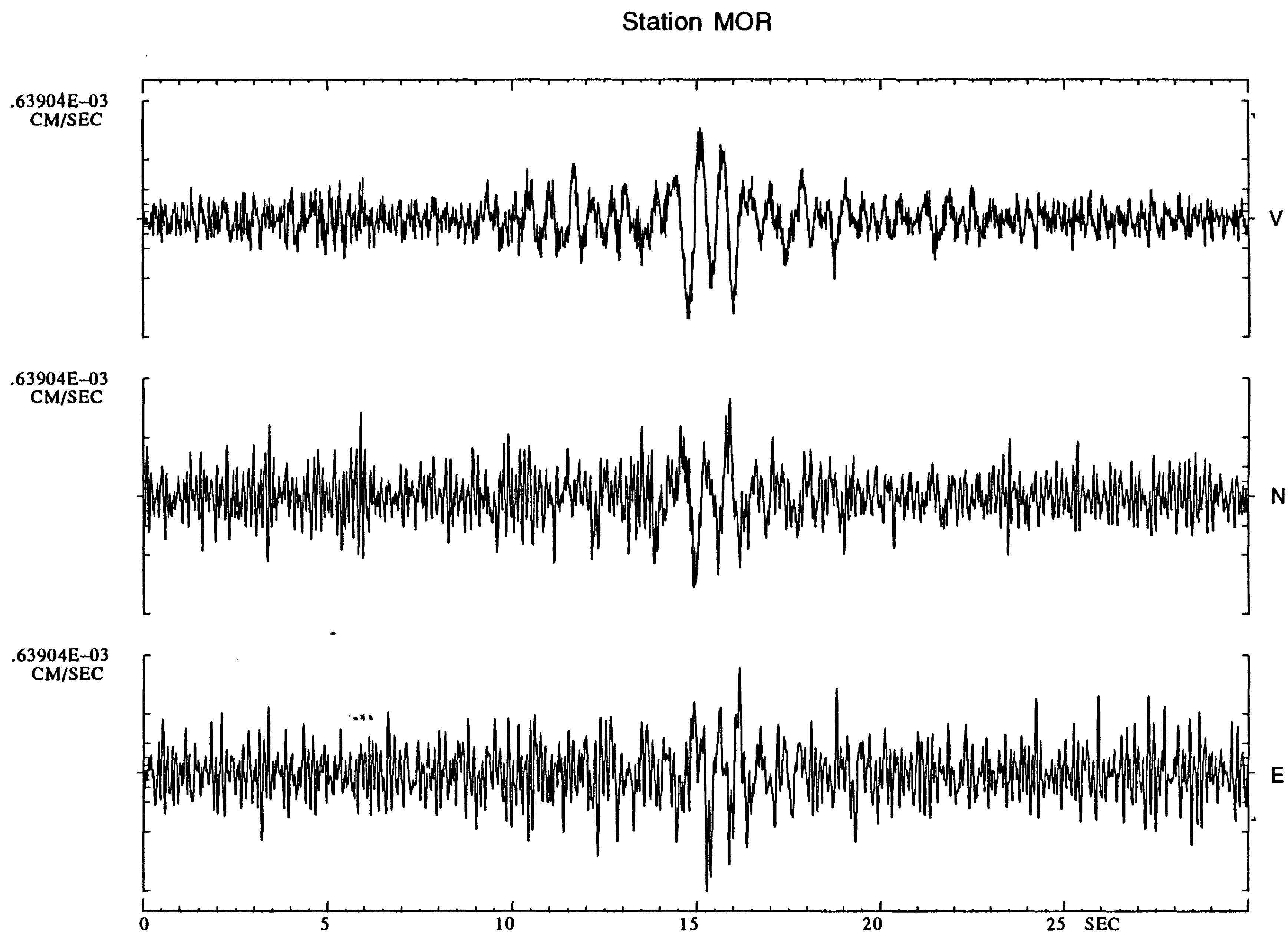

Figure 6. The three components of ground velocity produced by the demolition of the Murrah Federal Building recorded at station MOR. The start time of the recording (at 0 sec) in UTC time to the nearest second is 143:12:01:10.

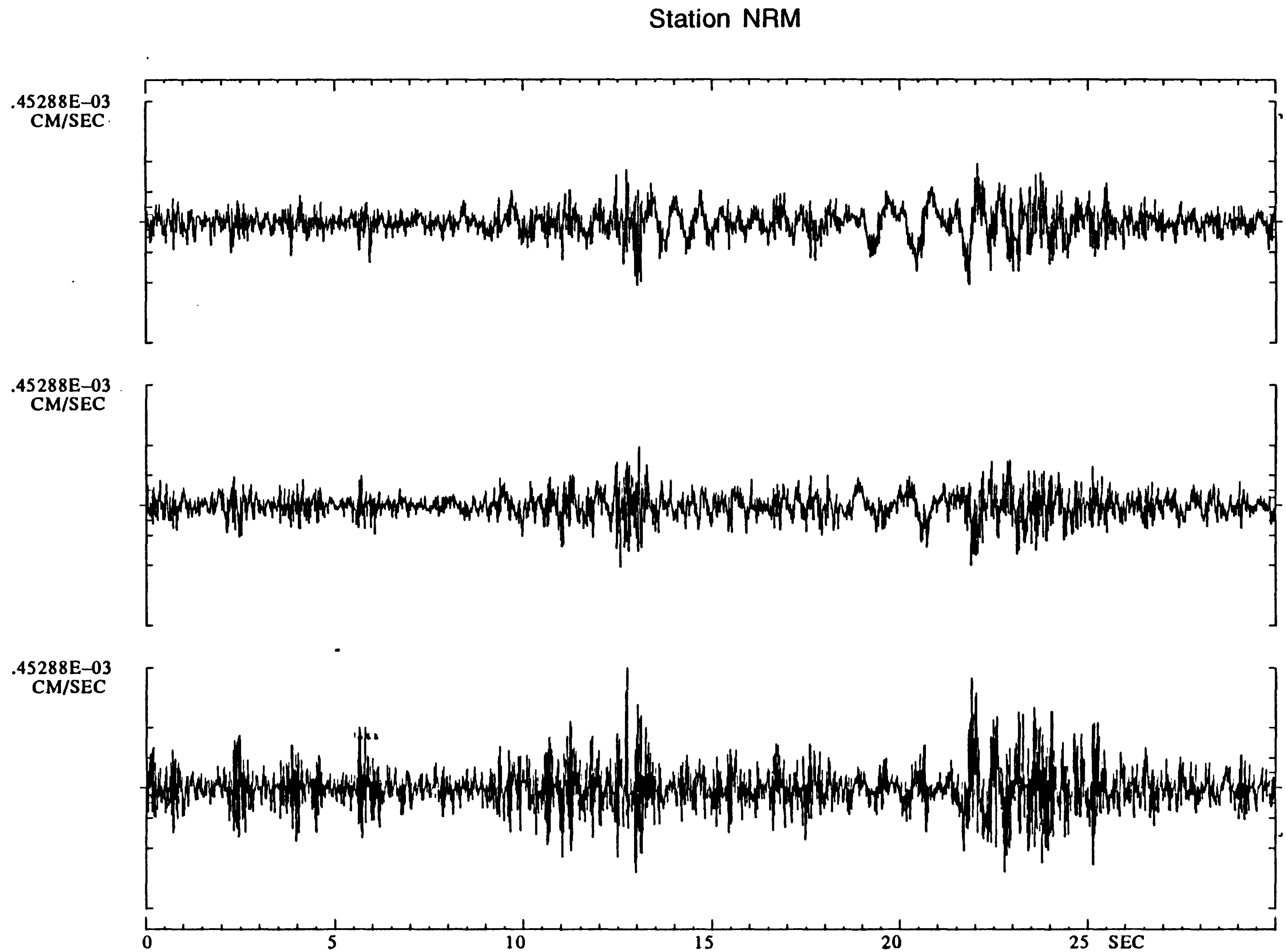

Figure 7. The three components of ground velocity produced by the demolition of the Murrah Federal Building recorded at station NRM. The start time of the recording (at 0 sec) in UTC time to the nearest second is 143:12:01:20.

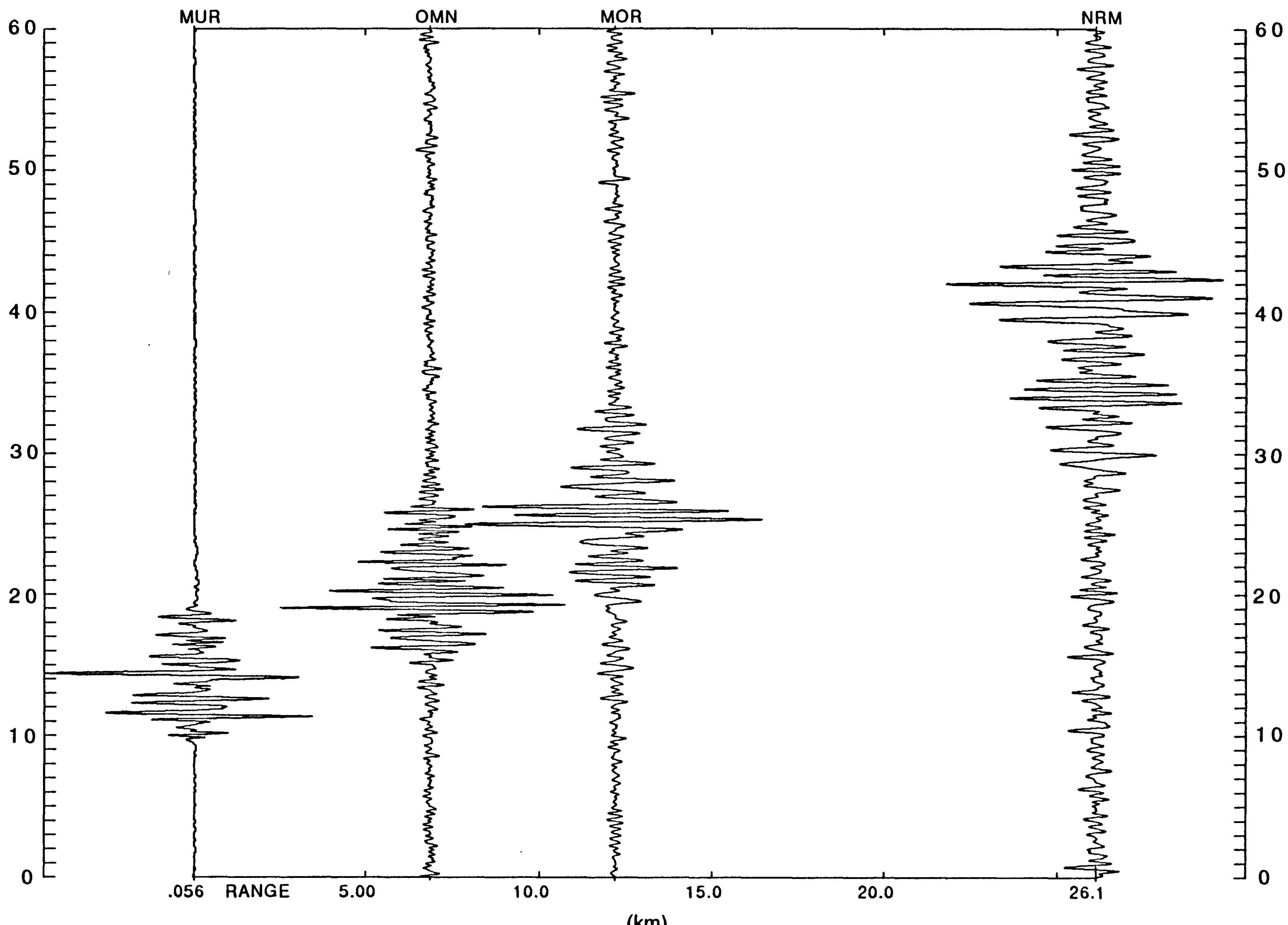

Figure 8. Record section showing 60 seconds of vertical ground velocity recorded at the four GEOS stations. Station names are listed at the top of each trace. The horizontal axis at the bottom of the figure represents the station range and relative spacing (in km). A 2 Hz low-pass filter has been applied to the data.