THE EFFECT OF GASES RELEASED INTO AN EXPLOSIVE CAVITY ON THE SEISMIC RADIATION: AN EXPLOSION EXPERIMENT IN CARROLL, NH

PI: Anastasia Stroujkova
Weston Geophysical Corp
181 Bedford St. Suite 1
Lexington, MA 02420
ana@westongeo.com

Introduction

Weston Geophysical Corp. (WGC) conducted an active source explosion experiment (GAS2016 experiment) using aluminized and non-aluminized explosive pairs to study the effect of detonation products (i.e. gases) released during the explosion on seismic radiation. The experiment was conducted in August of 2016 near Carroll, NH, and included six explosions with yields between 60 and 96 kg of TNT (Trinitrotoluene) equivalent, and three calibration shots 0.454 kg of Composition B. The archived dataset includes data from 35 short-period seismometers.

The objective of the experiment is to investigate the effect of the volume of the gases released into the explosive cavity on the seismic radiation. Our analyses of the experimental data from the New England Damage Experiment (NEDE, e.g. Martin et al, 2012; Stroujkova et al, 2012) suggest that the low-frequency seismic amplitudes are determined not only by the explosion yield, but also by the amount of released gas (Stroujkova, 2015). However, the NEDE experiment used explosives that not only released different amounts of gas, but also had different detonation velocities. This explosion field experiment (GAS2016) uses explosives with similar detonation velocities but different volumes of detonation products in order to isolate the effect of the steady state gas expansion on the seismic radiation. Differences in the volumes of the detonation products are achieved by adding aluminum powder to reduce the amount of gas and increase the heat of the explosion. In addition, some of the explosions were conducted in water-filled boreholes to quantify the effect of water on seismic radiation.

The dataset can improve our understanding of seismic wave radiation generated by explosions. It can be used for research related to seismic explosion monitoring such as seismic event detection, discrimination and characterization. It may also provide ground truth events for regional seismic studies in New England.

Experiment Design and Instrument Deployment

The experiment was conducted in a granite quarry in the town of Carroll, NH. Six single-shot explosions and three calibration shots were conducted during the experiment (Table 1). The following explosives were used to conduct the shots: TNT, Tritonal (TNT/Al 80/20), Ammonium Nitrate and Fuel Oil (ANFO), aluminized ANFO (ANFO/Al 80/20). In addition, COMP B boosters were used to initiate the charges and for the calibration shots. All explosions were conducted in boreholes of similar depths between 12.5 and 13 m, which were stemmed with crushed stone after loading the charges.

To compare the performance of aluminized and non-aluminized explosives, equal weight TNT and Tritonal charges were detonated in water-drained boreholes (SH1 and SH2 respectively). Both TNT charges had assembled lengths of 1.25 m, while the Tritonal charge had a length of 1.19 Shot SH3 was conducted by detonating a charge identical to SH1, but in a water-filled borehole. In addition, a pair of aluminized and non-aluminized ANFO of equal weights was detonated in dry boreholes (SH5 and SH6 respectively). Both TNT charges had assembled lengths of 1.25 m, while the Tritonal charge had a length of 1.19 m. Thus, the emplacement geometry for the TNT/Tritonal explosion series was very similar.

For the last shot (SH7), the borehole wall was narrowed to less than 20 cm, due to the ground shock from previous shots; therefore, we were unable to use the charge with a 20 cm diameter. As a result, SH7 was composed of two segments with diameters of 15 cm and 16.25

cm. The total length of the charge was approximately 4 m, compared to the length of the ANFO charge (SH5) of approximately 2.1 m.

The deployment of the seismic network started on August 9, 2016, and was completed on August 11, 2016. The shots were conducted on August 11-12, followed by the network removal, which was finished on August 13.

A seismic network was fielded from near-source to local distances (between 1.5 m and 10 km), including short-period seismometers and high-g accelerometers (Figure 1). All of these instruments recorded three components (3C) of motion using Reftek 130 (RT130) data loggers. The near-source short-period seismometers were fielded at distances between 0.3–1.2 km (Figure 1b) from the explosions. These stations utilized PASSCAL BIHO boxes (quick deploy boxes). Six of the on-property stations were equipped with 2 Hz Sercel L22 2Hz 3C sensors. The remaining 8 stations used 1 Hz L-4C 3D sensors. These stations recorded at a sampling rate of 500 sps.

In addition, 19 stations were installed off the quarry property at local distances between 1.2 km and 9.5 km (Figure 1a). All of these stations were equipped with PASSCAL BIHO boxes with 2 Hz Sercel L22 2Hz 3C sensors. These stations were recording continuously with a sampling rate of 500 samples per second for the local stations using RT130 digitizers, with the exception of several stations (GOUL, CM01, CM02, R115, RDSX, SZAU and ARR3) recording at 250 sps. All of the local data were recovered.

Stations of the local network were fielded at distances between 1.2 and 9.4 km. The White Mountains National Forest with its rugged terrain is located to the East and South of the explosion site. Stations ZR01, ZR02, LRES, R304, CM01 and CM02 (Figure 6a) are located in the National Forest. The area to the west and north of the test site is somewhat less rugged. The stations in that area were located on the residential properties, while two of the sites, TOWN and TRAN, were located on the municipal property belonging to the Town of Carroll, NH.

In addition, a short period five-element seismic array was deployed approximately 3.75 km from the sources in order to study local phase propagation. The array configuration is shown on the insert in Figure 1a. Four of the array stations were recording with a sampling rate of 1000 samples per second, while one of the stations (ARR3) was erroneously set to 250 samples per second (possibly due to malfunctioning equipment).

The explosion time was determined using the Weston Inexpensive Timing System (WITS) designed as a loop wire forming a closed circuit with a low voltage recorded with a high sample rate digitizer (RefTek RT130). Timing accuracy for the WITS system is 2 ms.

The velocity of detonation (VOD) was measured using a MREL HandiTrap II VODR. A resistance wire is taped to the booster and lowered down the hole. As the detonation wave propagates up the borehole, the resistance wire is melted and the recorder measures the decreasing resistance at 1 million samples per second. The resistance was then converted to distance and a velocity calculated.

All of the data recorded at distances over 200 m was recovered. The area surrounding the experiment site has rugged topography and limited accessibility for the instrument deployment.

Initial Observations

The objective of the experiment was to document the differences of the waveforms and spectra produced by explosions detonated with different explosives that generated different amounts of gaseous products. Four of the shots conducted using non-aluminized explosives had similar TNT equivalent yields (Table 1). The remaining two shots conducted using aluminized explosives had the same weights of the explosives as their non-aluminized counterparts (TNT and Tritonal, ANFO and aluminized ANFO), but their TNT equivalent yields are higher due to an addition of aluminum.

Figure 2 shows seismic traces for all shots recorded by station ES02 fielded approximately 620 m from the source array. SH1 (TNT) and SH2 (Tritonal) amplitudes are nearly identical for ES02 (Figure 2a-b), as well as for other stations of the network, while SH2 has a larger yield by a factor of 1.53. The amplitudes produced by aluminized ANFO (SH6) are, however, higher than the amplitudes from the ANFO shot (SH5). SH6 shows the highest amplitudes at ES02 for both P and Rg. The amplitude ratios between the different shots recorded at other near-source (0.4 – 1.2 km) and local (1.2 – 9.4 km) stations are consistent with the ratios observed at Station ES02.

The waveforms recorded at the near-source distances have high SNR, for both larger explosions and for the small calibration shots. Figure 3 shows the local waveforms from SH1 at ranges from 1.2 km (Station TRAN) to 9.4 km (Station WFLD). As expected, the SNR decreases toward longer ranges. Cultural noise is observed at stations located close to the roads and structures (e.g. PRDX).

Examples of the data from Shot SH1 recorded by the short-period array are shown in Figure 4. The amplitude variation between the array elements are caused by the local site effects. Figure 4b shows the records for the calibration shot CA1.

A number of the permanent stations in New England recorded some or all of the shots from the GAS2016 experiment. The signal-to-noise ratio (SNR) is good at Lisbon, New Hampshire (LBNH) and low at most of other stations. Figure 5 shows LBNH records from all six shots.

Summary

The active source explosion experiment was conducted in New Hampshire in August, 2016. The purpose of the experiment was to study the seismic signatures of the explosion sources using different explosive types that each generated different amounts of gaseous products. WGC collected seismic data from 45 stations located between 1.5 m and 10 km from the sources. Data from the experiment can be used for explosion source studies, explosion monitoring, seismic event detection, discrimination and yield estimation. In addition, New England has sparse seismic activity, therefore data from this and other explosion experiments, including the New England Damage Experiment, VT, (Martin et al, 2012) and the Fracture Decoupling Experiment, NH, (Stroujkova et al, 2013) can provide ground truth events for the crustal studies, and velocity calibration in New England.

Data and Resources

Seismic data from GAS2016 were collected by Weston Geophysical Corp. and Incorporated Research Institutions for Seismology – Program for the Array Seismic Studies of the Continental Lithosphere. The data will remain under embargo until August 2018. After that date, data can be obtained from the IRIS Data Management Center at www.iris.edu (last accessed November 2016).

Acknowledgements

The experiment was supported by the Air Force Research Laboratory Contract No. FA9453-16-C-0021. The content of the information does not necessarily reflect the position of the Federal Government and no official endorsement should be inferred.

References

Martin, R., P. Boyd, A. Stroujkova, M. Leidig, J. Lewkowicz, and J. Bonner (2012) Anisotropy of Barre granite in the vicinity of NEDE, *Proceedings of 2012 Monitoring Research Review: Ground-Based Nuclear Explosion Monitoring Techniques*, 428-440.

Stroujkova, A., J. L. Bonner, M. Leidig, P. Boyd, and R. J. Martin (2012). Shear Waves from Explosions in Granite Revisited: Lessons Learned from the New England Damage Experiment, *Bull. Seism. Soc. Amer*., 102, 1913-1926, doi:10.1785/0120110204

Stroujkova, A., J. Bonner, and T. Rath (2013). Effect of Fractures on Seismic Amplitudes from Explosions, *Bull. Seism. Soc. Amer*., 103, 580-587, doi:10.1785/0120120082.

Stroujkova, A. 2015. Effect of Explosion Gaseous Products on Seismic Coupling for Underground Chemical Explosions, *Bull. Seism. Soc. of America*, 105, 2367-2378, doi:10.1785/0120140360.

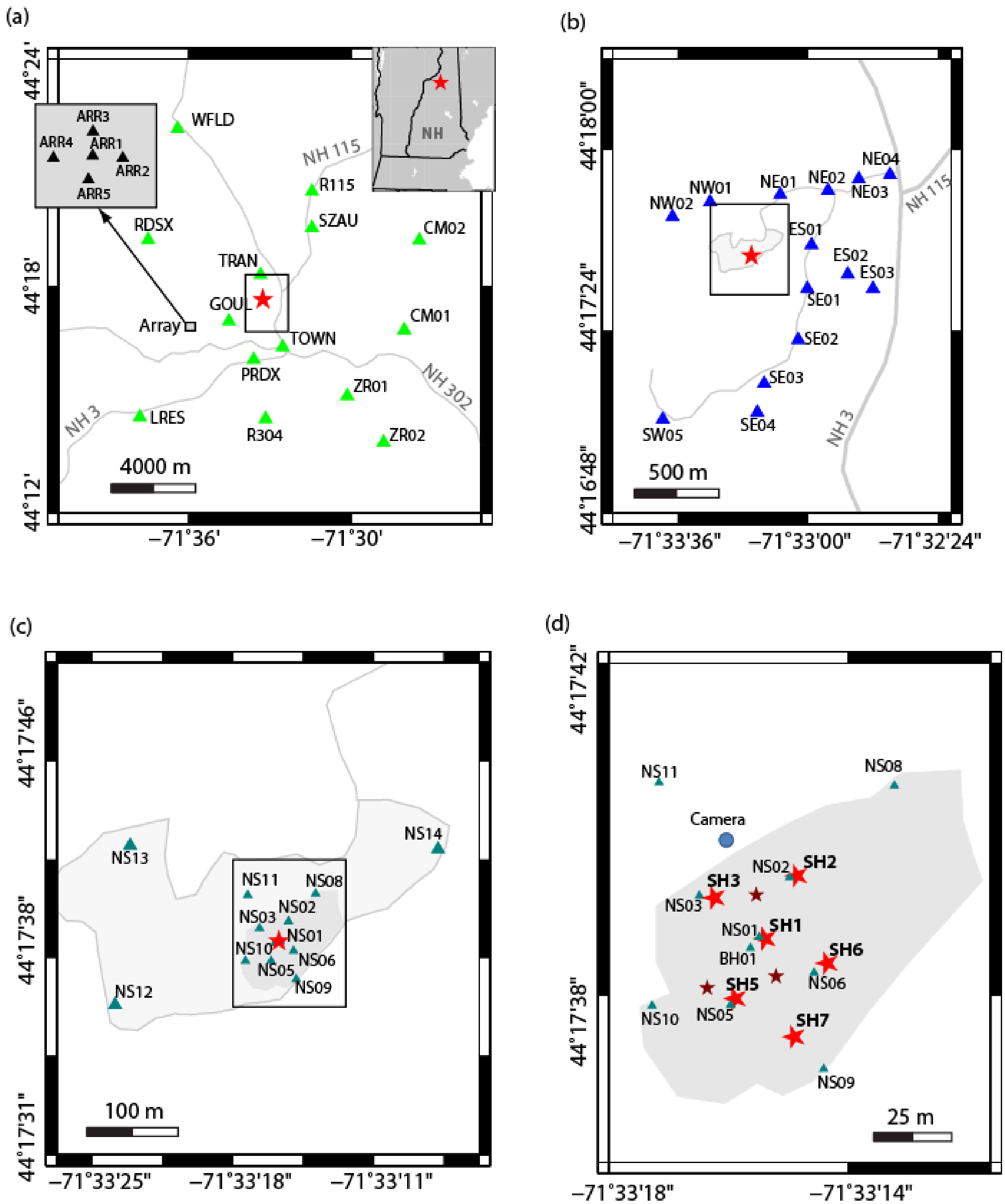
Tables

Table 1. Characteristics of the explosions

Shot	Date	Origin time (GMT)	Latitude	Longitude	Depth, m *	Explosive type	Yield (kg TNT)	Water
SH1	08.11.2016	23:30:31.045	44.29417°	-71.55435°	12.95	TNT	63.2	Dry
SH2	08.11.2016	19:08:46.404	44.29436°	-71.55422°	13.00	Tritonal	96.2	Dry
SH3	08.12.2016	14:41:35.217	44.29429°	-71.55456°	12.65	TNT	63.2	Wet
SH5	08.11.2016	22:13:25.735	44.29399°	-71.55448°	12.70	ANFO/Al	63.1	Dry
SH6	08.11.2016	21:17:56.761	44.29410°	-71.55409°	12.65	ANFO	94.1	Dry
SH7	08.12.2016	18:37:38.152	44.29387°	-71.55423°	12.50	ANFO	60.9	Wet
CA1	08.12.2016	20:00:35.512	44.29406°	-71.55430°	12.80	COMP B	0.5	Wet
CA2	08.12.2016	20:01:35.979	44.29402°	-71.55459°	12.50	COMP B	0.5	Wet
CA3	08.12.2016	20:02:36.402	44.29430°	-71.55438°	10.97	COMP B	0.5	Wet

* The depth indicates the borehole depth prior to loading of the charges.

Figures



(a)
ARR3
ARR4
ARR1
ARR2
ARR5
WFLD
NH 115
NH
R115
SZAU
CM02
RDSX
TRAN
GOUL
Array
TOWN
CM01
PRDX
ZR01
NH 302
NH 3
LRES
R304
ZR02
4000 m
44°24'
44°18'
44°12'
−71°36'
−71°30'
(b)
NE04
NW01
NE01
NE02
NE03
NW02
NH 115
ES01
ES02
ES03
SE01
SE02
SE03
SE04
SW05
NH 3
500 m
44°18'00"
44°17'24"
44°16'48"
−71°33'36"
−71°33'00"
−71°32'24"
(c)
NS13
NS14
NS11
NS08
NS03
NS02
NS01
NS10
NS06
NS05
NS09
NS12
100 m
44°17'46"
44°17'38"
44°17'31"
−71°33'25"
−71°33'18"
−71°33'11"
(d)
NS11
NS08
Camera
NS02
SH2
SH3
NS03
NS01
SH1
BH01
SH6
NS06
SH5
NS10
NS05
SH7
NS09
25 m
44°17'42"
44°17'38"
−71°33'18"
−71°33'14"

Figure 1. (a) Seismic stations deployed at local distances from the explosions near Twin Mountain, New Hampshire (USA). The green triangles show the local stations, the stars show the shot points. The insert in the upper right shows the regional map with the experiment location marked as a red star. The insert in the upper right shows the configuration of a short-period array, deployed in the area marked as a rectangle. The area surrounding the experiment site marked with a rectangle is enlarged in 1b. (b) The near-source network of the short-period seismometers. The blue triangles show the 3C stations (L22). The area within the rectangle is enlarged in 1c. (c) Enlarged view showing the near-field accelerometers (teal triangles). (d) Enlarged view of the test site, showing the shot locations (red stars) and the near-source accelerometers. Location of the video camera is shown with a blue circle.

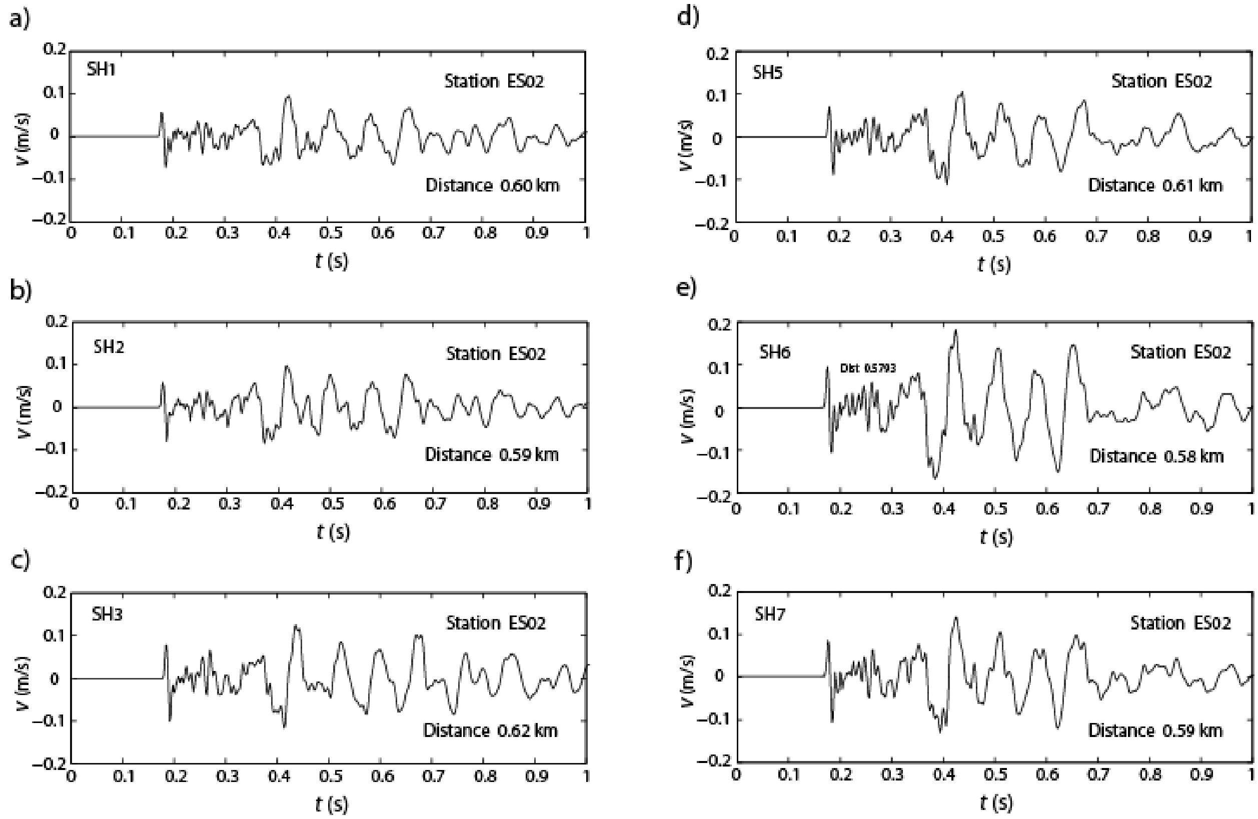


Figure 2. Vertical components of the velocity seismograms recorded by short period station ES02 for (a) SH1, (b) SH2, (c) SH3, (d) SH5, (e) SH6, and (f) SH7.

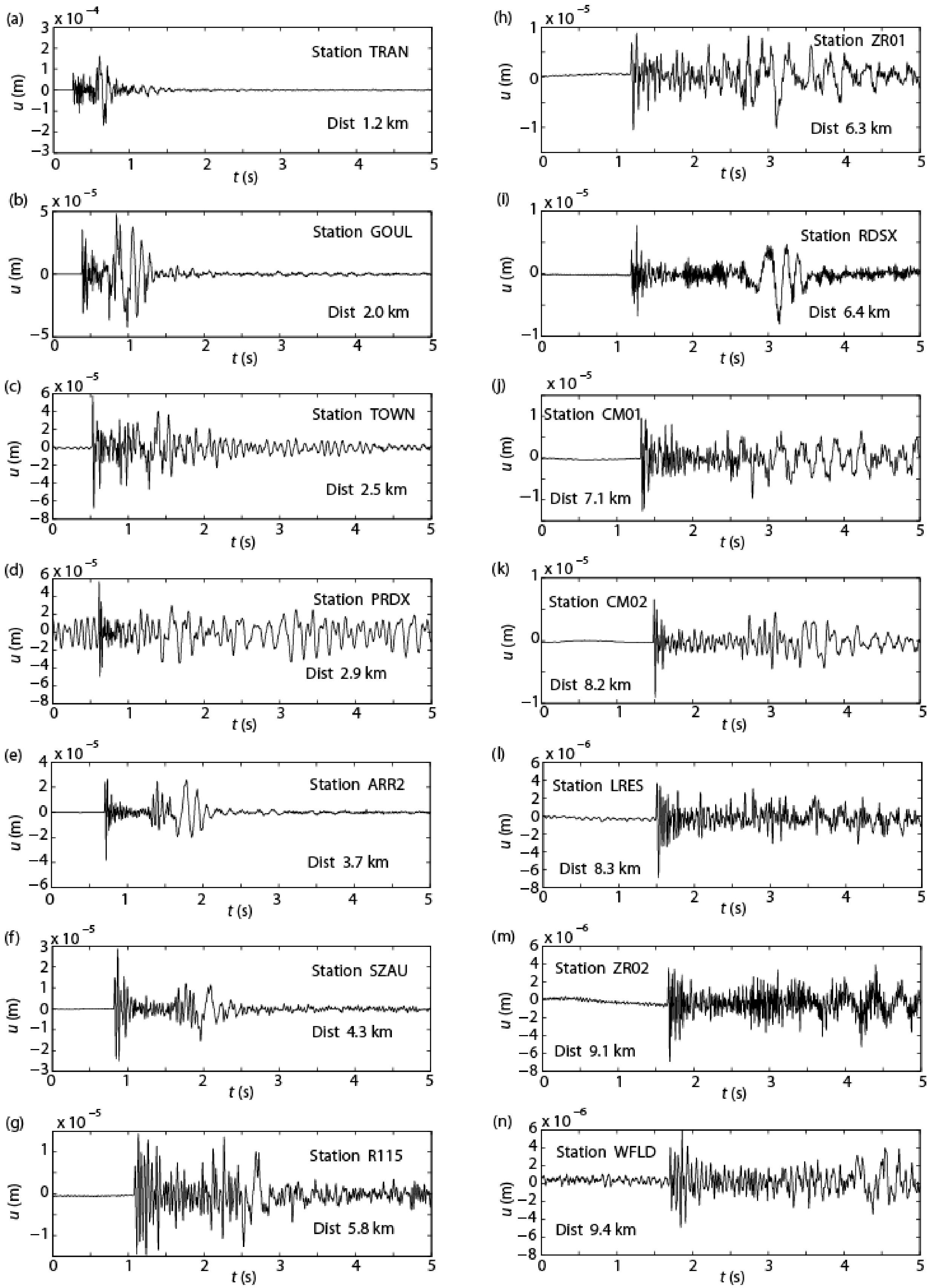

(a) Station TRAN Dist 1.2 km
(b) Station GOUL Dist 2.0 km
(c) Station TOWN Dist 2.5 km
(d) Station PRDX Dist 2.9 km
(e) Station ARR2 Dist 3.7 km
(f) Station SZAU Dist 4.3 km
(g) Station R115 Dist 5.8 km
(h) Station ZR01 Dist 6.3 km
(i) Station RDSX Dist 6.4 km
(j) Station CM01 Dist 7.1 km
(k) Station CM02 Dist 8.2 km
(l) Station LRES Dist 8.3 km
(m) Station ZR02 Dist 9.1 km
(n) Station WFLD Dist 9.4 km
u (m)
t (s)

Figure 3. Vertical components of the displacement seismograms for SH1 recorded by the local stations: (a) TRAN, (b) GOUL, (c) TOWN, (d) PRDX, (e) ARR2, (f) SZAU, (g) R115, (h) ZR01, (i) RDSX, (j) CM01, (k) CM02, (l) LREZ, (m) ZR02, and (n) WFLD.

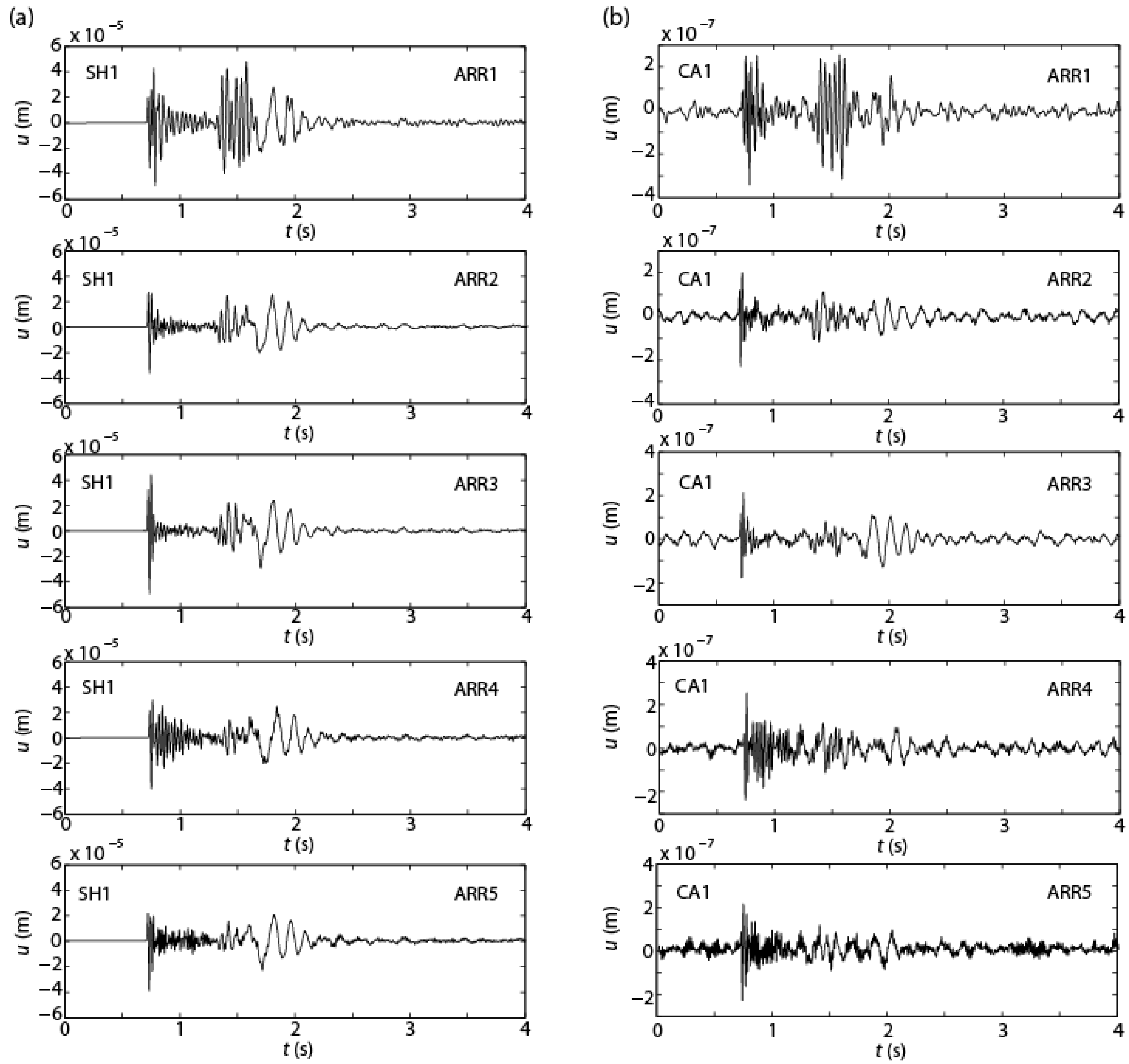


Figure 4. (a) Vertical displacements for SH1 recorded by the short-period array (Stations ARR1 through ARR5). ARR1 is the central element of the array, located approximately 3.75 km from the explosions. (b) Vertical displacements for the calibration shot CA1 recorded by the short-period array.

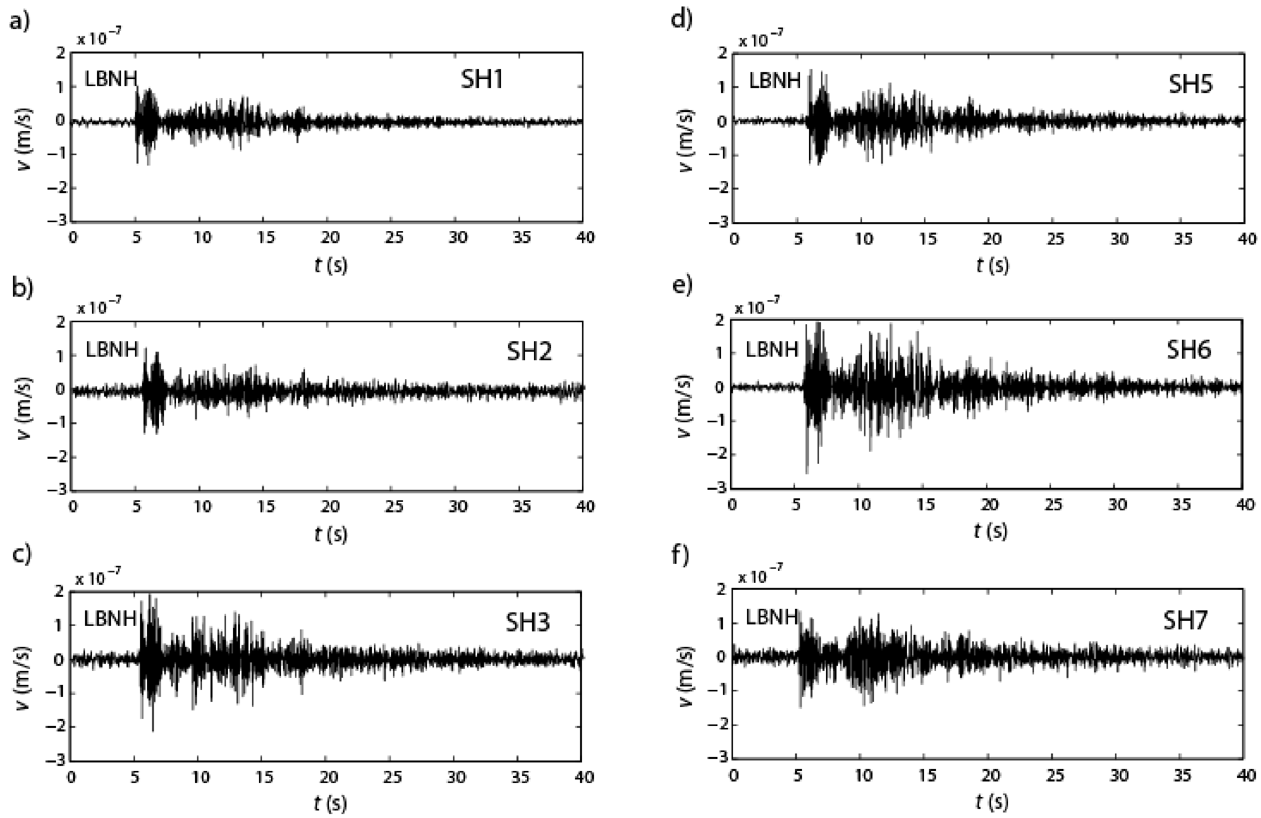


Figure 5. Vertical components of the velocity seismograms recorded by the permanent station LBNH located approximately 30.2 km from the shots in Lisbon, NH for (a) SH1, (b) SH2, (c) SH3, (d) SH5, (e) SH6, and (f) SH7.