PERA Containment Data Report

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PERA Instrumentation Summary

Instrumentation	Fielded on this Event	Data Return	Present in this Report
<u>Plug Emplacement</u>	yes	yes	yes ^(a)
<u>Radiation</u>	yes	yes	yes
<u>Pressure</u>			
Stemming	yes	yes	yes
Challenge	no	-	-
Cavity	no	-	-
Atmospheric	no	-	-
<u>Motion</u>			
Free Field	yes	yes	yes
Surface	yes	yes	yes
Plug	yes	yes	yes
Stemming	no	-	-
Surface Casing	no	-	-
Emplacement Pipe	no	-	-
<u>Hydroyield</u>	no	-	-
<u>Collapse</u> ^(b)	yes	yes	yes
<u>Stress</u>	yes	yes	yes
<u>Strain</u> ^(c)	yes	yes	no
<u>Other Measurements</u>	no	-	-

- (a) Description only.
(b) EXCOR or CLIPER in emplacement and satellite holes.
(c) Strain load on emplacement pipe.

Event Personnel

Containment Physics

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Instrumentation

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Contents

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1. Event Description

1.1 Site

The PERA event was detonated in hole U10bd of the Nevada Test Site as indicated in figure 1.1. The PERA device had a depth-of-burial (DOB) of 201 m in the Paintbrush tuff of area 10, about 300 m above the Paleozoic formation and 550 m above the standing water level, as shown in figures 1.2 and 1.3⁽¹⁾. Stemming of the 2.44 m diameter emplacement hole followed the plan shown in figure 1.4. A log of the stemming operations was maintained by Holmes & Narver⁽²⁾.

Detonation time was 10:00 PDT on August 8, 1979 and collapse progressed to the surface about 12 minutes after detonation. The resulting surface crater had an average radius of 39.6 m and a maximum depth of 4.9 m.

No radiation arrivals were detected above ground and the PERA containment was considered successful.

1.2 Instrumentation

Figure 1.5 is a schematic layout of the instrumentation designed to monitor the emplacement procedures and stemming performance of the PERA event.

Pressure and radiation were monitored at eight places in the stemming material, as shown in figure 1.5. Four of the stations were in the stemming below the deepest rigid plug with two of the eight being of an experimental design. The experimental stations were placed immediately below each plug and each experimental station was accompanied by a standard station at nearly the same elevation.

Vertical motion was monitored in both rigid plugs, the ground surface, 15.42 m from SGZ and in the recording trailer.

Vertical free-field motion was monitored at twelve elevations (stations) in the satellite hole Ue10bd and eight of these stations included "flat-pack" Ytterbium stress transducers. See figure 1.6.

Data from each of the above instruments were transmitted to the recording trailer by an analog system and recorded on magnetic tape.

D-cable information was used for quality assurance during the stemming operations. One CLIPER sensor was mounted in the emplacement hole on the containment gauge pendant along with the D-cable to monitor the progression of cavity collapse. Another CLIPER was fielded in the satellite hole.

A history of the fielding operations of the instrumentation is outlined in reference 3. Details of the instrumentation are given in reference 4.

1.3. Emplacement

Both stemming plugs above the PERA event consisted of "LAE 59" rigid coal-tar epoxy (CTE) layers. The top plug was composed of a 3.0 m layer of rigid foam cubes and sand, sandwiched between layers of CTE. The total thickness of the two layers of CTE in the top plug was 4.8 m which was designed to be completely contained within the bottom portion of the surface casing, beginning about 2 m above the bottom of the casing.

A drag ring was mounted rigidly to the pipe at the location of the deepest CTE plug and the emplacement pipe was coated with hydroseal in the region of the top plug to allow free motion of the pipe through that structure. The bottom plug was expected to couple the emplacement pipe to the geologic formation at the elevation of the plug.

Stemming between the plugs consisted of layers of fines and coarse gravel. The top of the hole (above the top plug) was filled with coarse gravel and the inside of the emplacement pipe stemmed with Overton sand from the diagnostics canister to the Tau can and was grouted for the remainder of its full length above the Tau can. See figure 1.3.

Instrumentation for the satellite hole was hung on a fiber glass pipe, oriented to the device, and then grouted from depth to the ground surface. See figure 1.6.

Figure 1.1 Map of the Nevada Test Site indicating the location of hole U10bd.

Figure 1.2 East-West geologic cross section through hole U10bd including a plan map of the vicinity. Ue10bd is 18.3 m due East of U10bd.

Figure 1.3 North-south geologic cross section through hole U10bd including a plan map of the vicinity. Ue10bd is 18.3 m due East of U10bd.

Figure 1.4 As-built stemming plan for the event PERA in Hole U10bd.

Figure 1.5 As-built containment instrumentation plan for the emplacement hole (U10bd) on the PERA event.

REVISIONS		
NO.	DATE	DESCRIPTION
1	12/19/88	AS BUILT CHANGES

AS BUILT CONFIGURATION

EG&G		P.O. BOX 100, SAN MATEO, CALIFORNIA 94066	
DATE	12/19/88	DATE	12/19/88
BY	CALLAN	BY	CALLAN
CHECKED	CALLAN	CHECKED	CALLAN
APPROVED	CALLAN	APPROVED	CALLAN
SPECIAL MEASUREMENTS - PERA, Ue10bd		C/LC110461	
JUL 31 1989		JUL 31 1989	

PERA

LEGEND	
CL	CLIPER
AV	VERTICAL ACCELEROMETER
UV	VERTICAL VELOCITY
σ	STRESS

SYMBOLS	
□	CLIPER
○	COMPASS
●	STRESS GAGE
○	SATELLITE CANISTER

Figure 1.6 As-built instrumentation plan for the satellite hole (Ue10bd) on the PERA event.

2. Stemming Performance

2.1 Pressure and Radiation

Pressure and radiation were monitored on the PERA event at eight stations in the stemming of the emplacement hole and the first 5 seconds of the wave forms of six of these stations these are shown in figures 2.1–2.6. Two of the eight stations (33A and 36A) were a test of an experimental data system. Unfortunately, there were no calibration steps digitized for these stations so, at this time, the magnitude of the wave forms observed can not be accurately determined and the data are thus not presented. Wave forms spanning 1,000 s of recording time, including the collapse at about 720 s, are shown in figures 2.7-2.12. Station 31 (the deepest) and station 36 (just below the top plug) both appeared to survive collapse (figures 2.7 and 2.12) although it is unlikely that station 31 actually did survive, in view of the behavior of the stations between it and station 36 (figures 2.8-2.11). Figure 2.13 includes the entire recording time of greater than 5,000 s for station 36 and indicates a slight jump in radiation after 1,000 s probably caused by a shift in position of the source chip relative to the detector.

Oscillations seen in all pressure records prior to 0.6 s are due to ground shock in the recording trailer. Station 31 shows a peak in the pressure of 16 psia at about 2.5 s (about 3.6 psi above ambient), decaying to about 0.3 psi above ambient at collapse time (figures 2.1 and 2.7). Each of the stations above this had similar behavior, but with much lower amplitude, equilibrating, at collapse time, to ambient pressure. It is suggested that all pressure changes can be attributed to ground motion.

Most of the radiation transducers were driven off scale by the EMP and did not recover for more than 40 s and so do not show meaningful data after time zero in figures 2.1-2.6. No radiation arrival was detected before collapse at any station when they did recover.

No radiation arrivals were observed above ground at any time after the PERA event and the data are consistent with satisfactory containment.

2.2 Motion

Explosion-induced histories of the motion measured in the emplacement hole and recording trailer on the PERA event are shown in figures 2.14–2.17. Characteristics of the associated motion and transducers are given in tables 2.1–2.3. Note that the tables also include data from the satellite hole, discussed in a later section.

An early arrival seen at station 21 (figure 2.14) is likely due to motion of the emplacement pipe coupled to the rigid plug through the drag ring and is not ground motion. Its influence is seen to decrease with each successive stage of integration. The explosion-induced motion at other stations was unremarkable.

Figure 2.1 The first 5 s of pressure and radiation detected in the deepest fines plug of the emplacement hole (Station 31 at a depth of 139.9 m). The oscillations in the pressure record before 0.6 s were caused by ground motion in the recording trailer and the radiation detector was driven off-scale by the EMP.

Figure 2.2 The first 5 s of pressure and radiation detected in the second fines plug of the emplacement hole (Station 32 at a depth of 112.5 m). The oscillations in the pressure record before 0.6 s were caused by ground motion in the recording trailer and the radiation detector was driven off-scale by the EMP.

Figure 2.3

The first 5 s of pressure and radiation detected in the fines layer below the rigid plug in the emplacement hole (Station 33 at a depth of 89.9 m). The oscillations in the pressure record before 0.6 s were caused by ground motion in the recording trailer and the radiation detector was driven off-scale by the EMP.

Figure 2.4 The first 5 s of pressure and radiation detected in the fines layer above the rigid plug in the emplacement hole (Station 34 at a depth of 76.8 m). The oscillations in the pressure record before 0.6 s were caused by ground motion in the recording trailer and the radiation detector was driven off-scale by the EMP.

Figure 2.5 The first 5 s of pressure and radiation detected in the fines layer intermediate between the rigid plug and the top plug (Station 35 at a depth of 56.4 m). The oscillations in the pressure record before 0.6 s were caused by ground motion in the recording trailer and the radiation detector was driven off-scale by the EMP.

Figure 2.6 The first 5 s of pressure and radiation detected in the fines layer below the top plug in the emplacement hole (Station 36 at a depth of 38.1 m). The oscillations in the pressure record before 0.6 s were caused by ground motion in the recording trailer and the radiation detector was driven off-scale by the EMP.

Figure 2.7 The first 1,000 s of pressure and radiation detected in the deepest fines plug of the emplacement hole (Station 31 at a depth of 139.9 m). The radiation detector, driven off-scale by the EMP, recovers at about 50 s.

Figure 2.8 The first 1,000 s of pressure and radiation detected in the second fines plug of the emplacement hole (Station 32 at a depth of 112.5 m). The radiation detector, driven off-scale by the EMP, recovers at about 320 s.

U10bd

Figure 2.10 The first 1,000 s of pressure and radiation detected in the fines layer above the rigid plug in the emplacement hole (Station 34 at a depth of 76.8 m). The radiation detector, driven off-scale by the EMP, recovers at about 250 s.

Figure 2.11 The first 1,000 s of pressure and radiation detected in the fines layer intermediate between the rigid plug and the top plug (Station 35 at a depth of 56.4 m). The radiation detector, driven off-scale by the EMP, recovers at about 230 s.

Figure 2.12 The first 1,000s of pressure and radiation detected in the fines layer below the top plug in the emplacement hole (Station 36 at a depth of 38.1 m). The radiation detector, driven off-scale by the EMP, recovers at about 420 s. A brief spike of radiation is seen at collapse near 710 s.

Figure 2.13 The full recording time of about 5,000s of pressure and radiation detected in the fines layer below the top plug in the emplacement hole (Station 36 at a depth of 38.1 m). The radiation detector, driven off-scale by the EMP recovers at about 420 s. A brief spike of radiation is seen at collapse near 710 s and the offset in the radiation record after 1,000 s is likely due to a mechanical shift of the source chip relative to the detector.

Figure 2.14 Explosion-induced vertical motion of the rigid plug (station 21 at a depth of 83.6 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 2.15 Explosion-induced vertical motion of the top plug (station 22 at a depth of 32.0 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 2.16 Explosion-induced vertical motion of the ground surface, 15.24 from SGZ (station 61 at a depth of 0.9 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 2.17 Explosion-induced vertical motion of the recording trailer (station 71 approximately 224 m from SGZ). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Table 2.1 Summary of Containment-Related Motion

Gauge	Slant Range (m)	Arrival Time (ms)	Acceleration Peak (g)	Velocity Peak (m/s)	Displacement Peak (cm)	Displacement Residual (cm)
21av	116.3	84(a)	3.0	0.372	3.8	-1.3
21uv		88(a)	-	0.440	4.3	-0.5
22av	167.9	120	0.86	0.44	5.0	-2.0
22uv		124	-	0.42	4.7	-1.0
41av	37.6	23	17	4.4	23	0
41uv		-	-	6.0	55	(b)
42av	42.2	24	16	5.9	44	37
42uv		27	-	5.4	43	38
43av	46.8	(b)	-	-	-	-
43uv		32	-	3.9	23	20
44av	51.5	(c)	-	-	-	-
44uv		35	-	3.1	16	12
45av	66.9	45	6.5	0.95	7.8	10 ^(d)
45uv		44	-	0.94	7.5	1.5
46av	82.6	50	2.9	0.63	5.5	-10
46uv		60	-	0.66	5.6	-3
47av	92.3	62	2.4	0.54	5.0	-0.3
47uv		65	-	0.54	4.8	-1.2
48av	102.7	65 ^(e) , 70	2.1	0.52	5.7	0
48uv		70	-	0.45	4.0	-1
49av	112.1	70 ^(e) , 79	1.6	0.415	3.9	-0.5
49uv		78	-	0.53	4.8	0
50av	132.0	89 ^(e) , 95	1.3	0.40	3.8	-1.3
50uv		93	-	0.37	3.4	-0.6
51av	151.8	105 ^(e) , 111	1.0	0.35	3.8	-1.3
51uv		111	-	0.35	3.6	-0.8
52av	171.7	123	0.9	0.46	4.9	0.8
52uv		128	-	0.41	4.3	-2
61av	200.4	160	1.72	0.55	5.8	-3
61uv		157	-	0.54	5.7	-2
71av	224 ^(f)	182	1.3	0.70	6.5	-5
71uv		190	-	0.70	6.51	-5

(a) Emplacement pipe arrival.

(b) Signal not believable at this time.

(c) Channel missing.

(d) Approximate.

(e) Anomalous precursor, see text.

(f) Approximate: in recording trailer.

Table 2.2 Containment-Related Accelerometer Characteristics

Gauge	Natural Frequency (Hz)	Damping Ratio	System Range (g's)
21av	500	0.65	30
22av	370	0.65	14
41av	1900	0.65	4000
42av	1900	0.65	3000
43av	2200	0.65	2000
44av	1700	0.55	1200
45av	1650	0.65	400
46av	930	0.62	150
47av	535	0.65	75
48av	620	0.70	50
49av	320	0.65	30
50av	275	0.65	15
51av*	190	0.65	10
52av*	168	0.65	10
61av	410	0.75	20
71av*	185	0.75	10

* Whittaker Corporation transducer.

Table 2.3 Containment-Related Velocimeter Characteristics

Gauge	Natural Frequency (Hz)	Time to 0.5 Amplitude (s)	Calibration Temperature (°F)	Operate Temperature (°F)	System Range (m/s)
21uv	3.47	8.2	73.6	90.99	4
22uv	(a)	(a)	73.0	92.99	10
41uv(b)	4.05	43.7	74.1	77.0(c)	39
42uv(b)	4.08	28.7	75.5	76.3	30
43uv(b)	4.18	18.35	75.2	75.2(c)	20
44uv	3.55	10.10	74.8	73.97	15
45uv	3.50	11.90	75.3	72.2(c)	7.3
46uv	3.67	9.3	75.0	70.1	4.3
47uv	3.45	9.75	74.7	68.7	3.0
48uv	3.50	8.30	74.1	68.0(c)	2.4
49uv	3.52	7.70	74.8	67.41	1.8
50uv	3.55	5.90	74.8	65.7	1.5
51uv	3.57	7.20	74.7	64.7	1.5
52uv	3.33	8.60	74.7	64.3	1.5
61uv	3.44	8.15	74.5	75.02	2.4
71uv	3.00	11.06	74.2	59.67	4.9

(a) Not available.

(b) Aluminum pendulum.

(c) Measured value not available: Interpolated from surrounding points.

3 Collapse phenomena

All stations in the emplacement hole registered the effects of a surface collapse occurring about 712 s after detonation. No collapse motion was detected at the instrumentation trailer and station 71 is not represented here.

3.1 Pressure and radiation

Pressure and radiation wave forms obtained from the six standard stations during the collapse episode (a period spanning 700 s to 720 s) are shown in figures 3.1 - 3.6. Pressure histories from these six stations are also shown in figure 3.7 along with the output from the CLIPER cables (station 92, in the emplacement hole and station 53, in the satellite hole). All stations at elevations deeper than the one just below the top plug (station 36) were lost, presumably due to cable breakage.

Survival of station 31 through collapse is suggested by the data of figures 3.1 and 2.7. However, since no other station below those protected by the surface casing survived, it is improbable that 31, the deepest elevation in the hole did. The characteristics of the pressure wave form of station 31 during collapse are of a slow decrease in pressure due to stemming loss followed by an abrupt change due to cable breakage. The wave form of the radiation suggests some slight motion of the source chip relative to the detector during collapse.

Similar pressure behavior was seen at station 32 (figure 3.2), but at stations 33 and 34 the pressure behaved quite differently during collapse (figures 3.3 and 3.4). The radiation wave forms for these two stations both indicate a small radiation introduction after collapse and prior to station loss. At station 33 the peak radiation dose rate was about 0.5 R/Hr and at station it was 0.1 R/Hr. No conclusions can be made concerning station 35 (figure 3.5).

The surviving station 36 (figures 3.6 and 2.12) shows the characteristic pressure wave form of stemming fall and recompaction due to collapse. Associated with the collapse was a small (0.07 R/Hr) pulse of radiation which quickly attenuated to the level of the source chip. The slight rise in radiation level indicated in figure 2.12 at about 1000 s is attributed to motion of the source chip relative to the detector.

No radiation arrivals were observed above ground at any time after the PERA event and the data are consistent with satisfactory containment.

3.2 Motion

The collapse-induced motion associated with the emplacement hole detected on PERA is shown in figures 3.8-3.10. The system limits were exceeded on the velocity channels for stations 21 and 61 but the associated accelerations show the full range of the displacement during collapse. Of the three stations reporting, only the deepest, in the bottom rigid plug, was lost. The other two, in the surface casing and on the surface, were associated with the surface motion. Both of these indicated a permanent surface downward displacement of about 4 m.

Figure 3.1 Collapse epoch pressure and radiation measured at the deepest fines stemming layer (station 31 at a depth of 139.9 m).

Figure 3.2 Collapse epoch pressure and radiation measured in the second fines layer (station 32 at a depth of 112.5 m).

Figure 3.3 Collapse epoch pressure and radiation measured in the fines stemming below the rigid plug (station 33 at a depth of 89.9 m).

Figure 3.4 Collapse epoch pressure and radiation measured in the fines stemming above the rigid plug (station 34 at a depth of 76.8 m).

Figure 3.5 Collapse epoch pressure and radiation measured in the fines stemming intermediate between the rigid plug and the top plug (station 35 at a depth of 56.4 m).

Figure 3.6 Collapse epoch pressure and radiation measured in the fines stemming below the top plug (station 36 at a depth of 38.1 m).

Figure 3.7 Progression of the collapse as indicated by the CLIPER record in the emplacement hole (station 92) and the CLIPER record from the satellite hole (station 53). Also included are pressure histories as measured in the stemming.

Figure 3.8 Collapse-induced vertical motion of the rigid plug (station 21 at a depth of 83.7 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter. The missing portion of the velocity record is estimated to lead to an additional permanent displacement of about 1.8 m.

Figure 3.9 Collapse-induced vertical motion of top plug (station 22 at a depth of 32.0 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 3.10 Collapse-induced vertical motion of the ground surface, 15.24 from SGZ (station 61 at a depth of 0.9 m). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

4 Satellite Hole Measurements

A 24.5 cm diameter exploratory hole located 18.3 m due East of the emplacement hole was instrumented with an array of 12 motion vertical motion stations that also contained eight stress transducers. A CLIPER cable was also fielded to monitor the progression of the cavity collapse.

4.1 Motion

Explosion-induced histories of the motion measured in the satellite hole Ue10bd on the PERA event are shown in figures 4.1–4.12. Characteristics of the associated motion and transducers are given in tables 2.1–2.3. Note that the tables also include data from the emplacement hole, the ground surface and the recording trailer, discussed earlier. Two of the motion sensors in the satellite hole failed to produce useful information; the accelerometers at stations 43 and 44 (figures 4.3 and 4.4). Although apparently meaningless, the record produced by the accelerometer at station 43 is shown in figure 4.3. The velocimeter at station 41 (figure 4.1) required excessive base-line de-trending for times greater than 0.6 s and the data should not be accepted later than that. Accelerometer and velocimeter records compare favorably for all other stations.

At station 49 and above (figures 4.9 - 4.12), the accelerometer wave forms show a "noise" contribution between 0.2 and 0.3 s. For emplacement, the stations are hung in the hole on a fiber glass pipe and then grouted in place. The explosion-induced stress wave reflects from the surface and places the medium in dilatation, relieving the stress in the fiber glass pipe that was locked in by the grouting. See figure 4.13. The signature of this stress relief shows up as "noise" in the acceleration records.

Figure 4.14 shows the range dependence of the peak acceleration while the range dependence of the first peak velocity is shown in figure 4.15. A least-squares fit to the data represented by the straight lines shown in figures 4.14 and 4.15 gives the following results:

$$\text{Acceleration } A = 4611R^{-1.67[\pm 0.04]} \text{ g's}$$

$$\text{Velocity } U = 45.3R^{-0.97\pm 0.08} \text{ m/s}$$

where R is slant range in meters.

4.2 Collapse Phenomena

Only the velocity channels were digitized during the collapse epoch and the wave forms from the even-numbered stations are shown in figures 4.15-4.20. Stations 50 and 52 (figures 4.18 and 4.19) survived collapse but exceeded the system limits and the full collapse displacement is not computed. An estimate of the final permanent displacement, accounting for the missing portions of the velocity wave forms, increases the final downward displacement by 0.84 and 0.46 m for stations 50 and 52, respectively.

4.3 Stress Measurements

An array of eight Ytterbium grid "flat-pack" stress transducers was fielded in eight of the nine deepest stations (station 45 was skipped). The active element of each gauge was a grid of Ytterbium measuring about 10 x 2.5 cm and had a resistance of 100 Ω , mounted on kapton sandwiched between two thin, copper-clad sheets of fiber glass. Conductive tape was wrapped around the sandwich edges to form a Faraday cage. Thin sheets of stainless steel and epoxy replaced the copper-clad fiber glass on two of the devices.

These transducers were pressure tested in a bath of "Herkoflex" oil to a maximum pressure of about 0.25 Kbar and subjected to dynamic history having a rise time of about 130 ms and a decay time of about 2 s. A gauge resistance sensitivity of 6.1 %/Kbar was obtained for this work, translating to a uniaxial sensitivity of about 4.1 %/Kbar

The wave forms obtained from the eight transducers are shown in figures 4.21-4.24. No attempt was made to adjust the data for strain.

Figure 4.1 Explosion-induced vertical motion measured at 167.1 m depth in the satellite hole (station 41, 37.6 m distant from working point). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter. At times greater than 0.6 s, data from the velocity gauge record should not be accepted.

Figure 4.2 Explosion-induced vertical motion measured at 161.9 m depth in the satellite hole (station 42, 42.2 m distant from working point). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 4.3 Explosion-induced vertical motion measured at 156.9 m depth in the satellite hole (station 43, 46.8 m distant from working point). The accelerometer at this station was malfunctioning.

Figure 4.4 Explosion-induced vertical motion measured at 151.5 m depth in the satellite hole (station 44, 51.5 m distant from working point). The accelerometer at this station was disconnected pre-shot

Figure 4.5 Explosion-induced vertical motion measured at 135.6 m depth in the satellite hole (station 45, 66.9 m distant from working point). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 4.6 Explosion-induced vertical motion measured at 119.2 m depth in the satellite hole (station 46, 82.6 m distant from working point). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 4.7 Explosion-induced vertical motion measured at 109.5 m depth in the satellite hole (station 47, 92.3 m distant from working point). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 4.8 Explosion-induced vertical motion measured at 99.4 m depth in the satellite hole (station 48, 102.7 m distant from working point). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 4.9 Explosion-induced vertical motion measured at 89.3 m depth in the satellite hole (station 49, 112.1 m distant from working point). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 4.10 Explosion-induced vertical motion measured at 69.2 m depth in the satellite hole (station 50, 132.0 m distant from working point). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 4.11 Explosion-induced vertical motion measured at 49.3 m depth in the satellite hole (station 51, 151.8 m distant from working point). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 4.12 Explosion-induced vertical motion measured at 29.2 m depth in the satellite hole (station 52, 171.7 m distant from working point). When there is more than one trace in a plot, the heavier is derived from the associated velocimeter.

Figure 4.13 Composite of strain histories measured in the satellite hole. Values above the relative base lines show dilatation. For clarity, only the even numbered stations at and above station 46 are represented. Strain is computed assuming a spherical traveling wave, and using only the velocity gauge data⁽⁵⁾.

Figure 4.14 First peak acceleration as a function of slant range.

Figure 4.15 First peak velocity as a function of slant range.

Figure 4.16 Collapse-induced vertical motion measured at 161.9 m depth in the satellite hole (station 42, 42.2 m distant from working point). Only the velocity gauge data are here represented.

Figure 4.17 Collapse-induced vertical motion measured at 151.5 m depth in the satellite hole (station 44, 51.5 m distant from working point). Only the velocity gauge data are here represented.

Figure 4.18 Collapse-induced vertical motion measured at 119.2 m depth in the satellite hole (station 46, 82.6 m distant from working point). Only the velocity gauge data are here represented.

Figure 4.19 Collapse-induced vertical motion measured at 99.4 m depth in the satellite hole (station 48, 102.7 m distant from working point). Only the velocity gauge data are here represented.

Figure 4.20 Collapse-induced vertical motion measured at 69.2 m depth in the satellite hole (station 50, 132.0 m distant from working point). Only the velocity gauge data are here represented. The missing portion of the velocity record is estimated to lead to an additional permanent displacement of about 0.84 m.

Figure 4.21 Collapse-induced vertical motion measured at 29.2 m depth in the satellite hole (station 52, 171.7 m distant from working point). Only the velocity gauge data are here represented. The missing portion of the velocity record is estimated to lead to an additional permanent displacement of about 0.46 m.

Figure 4.22 Output wave forms from the stress transducers at stations 41 and 42 at slant ranges of 37.6 and 42.2 m from the working point. No attempt was made to adjust the records for strain.

Figure 4.23 Output wave forms from the stress transducers at stations 43 and 44 at slant ranges of 46.8 and 51.5 m from the working point. No attempt was made to adjust the records for strain.

Figure 4.24 Output wave forms from the stress transducers at stations 46 and 47 at slant ranges of 82.6 and 92.3 m from the working point. No attempt was made to adjust the records for strain.

Figure 4.25 Output wave forms from the stress transducers at stations 48 and 49 at slant ranges of 102.7 and 112.1 m from the working point. No attempt was made to adjust the records for strain.

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