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TITLE: Induced Shock Propagation on the Non-Proliferation Experiment

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INDUCED SHOCK PROPAGATION

ON THE

NON-PROLIFERATION EXPERIMENT*

by

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ABSTRACT

The Explosive Effects Physics Project at the Los Alamos National Laboratory planned and conducted experiments on the NPE as part of its effort to define source functions for seismic waves. Beyond the explosive chamber, the detonation induced shock propagated through the saturated tuff of the N-tunnel complex. The CORRTEX (COntinuous Reflectometry for Radius vs Time EXperiment) system was used to investigate the shock propagation in two drill holes and the access drift. The CORRTEX experiments fielded will be described. The data obtained are reviewed and an apparent asymmetry in the radiating shock discussed.

INTRODUCTION

The Non-Proliferation Experiment (NPE) was planned and conducted by Lawrence Livermore National Laboratory (LLNL). The global objectives of the test were to investigate whether signals are produced which may be used to seismically differentiate a large conventional explosion from a nuclear explosion and to calibrate the energy released to previous nuclear events. The experiment was conducted on the Nevada Test Site (NTS) in the N-tunnel complex, the site of numerous previous nuclear events. Therefore, the geologic media should be a constant in the analysis of seismic signals produced by the NPE detonation.

The test consisted of approximately 2.9 million pounds of a 50-50 blend of Ammonium Nitrate-Fuel Oil (ANFO) and emulsion in a 15.2 m diameter by 5.2 m high right cylinder (the explosive chamber). Detonation occurred simultaneously at three locations along the chamber axis. The defined axis of the explosive chamber was a taut steel aircraft cable anchored from back (ceiling) to invert (floor). This location was referred to for survey purposes as the Users Working Point (UWP) but was not actually coincident with the planned WP. (The planned WP was 0.177 m west and 0.061 m south of UWP, a distance of 0.178 m.) All references will be to the UWP. A complete description of the explosive emplacement, including the booster-detonator construction, their emplaced locations and the event timing is contained in the explosive performance report (*1*).

The Los Alamos National Laboratory (Los Alamos) group P-15 participated in the NPE to characterize the explosive performance and to characterize the time-dependent shock wave propagating through the saturated tuff surrounding the explosive chamber. This report addresses the second subject, the region beyond the explosive chamber. Some reference to the results reported in the explosive performance report may be necessary. The instrumentation in this region consisted of twelve CORRTEX sensing elements for the time-

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* This work supported by the United States Department of Energy
Italic numbers in parentheses refer to items in the list of references

dependent shock position or time-of-arrival (TOA) information and twelve Axially-Symmetric Magnetic (ASM) gauges for measuring the particle velocity. The particle velocity results will be the subject of a separate report and only the TOA information from the ASM gauges will be compared to the CORRTEX data. Also, the results from the accelerometers arrayed throughout the N-tunnel complex will be presented in a separate report.

CORRTEX INSTRUMENTATION(*1,4,5*)

The CORRTEX sensing elements exited the explosive chamber in four groups of three cables each. It is unfortunate that the induced shock could only be monitored in these four directions and yet the redundancy strengthens the analysis of the explosive burn results where single cables were arrayed throughout the explosive chamber. Figure 1 is an engineering site plan for the NPE, showing drill holes KH-1, KH-2 and KH-3 and the access drift, through which the sensing elements exited the explosive chamber. The sensing element designations K1, K2, ..., and K12* appear beside their respective exit routes. The drill holes were four inch diameter holes except for the first (explosive chamber end) 20 feet of KH-1 and KH-2 which were reamed to 12 inches. The CORRTEX sensing elements in the three drill holes were individually pulled taut with kellums and turnbuckles at each drill hole end. The installations in KH-1 and KH-2 were referenced to a plumb line off survey spads (called the drill hole collar reference) placed above each hole collar. The access drift sensing elements were installed on a Kevlar rope messenger along the left rib (side, facing toward WP), about 6 feet above the invert. Reference points on the access drift cables were surveyed in place.

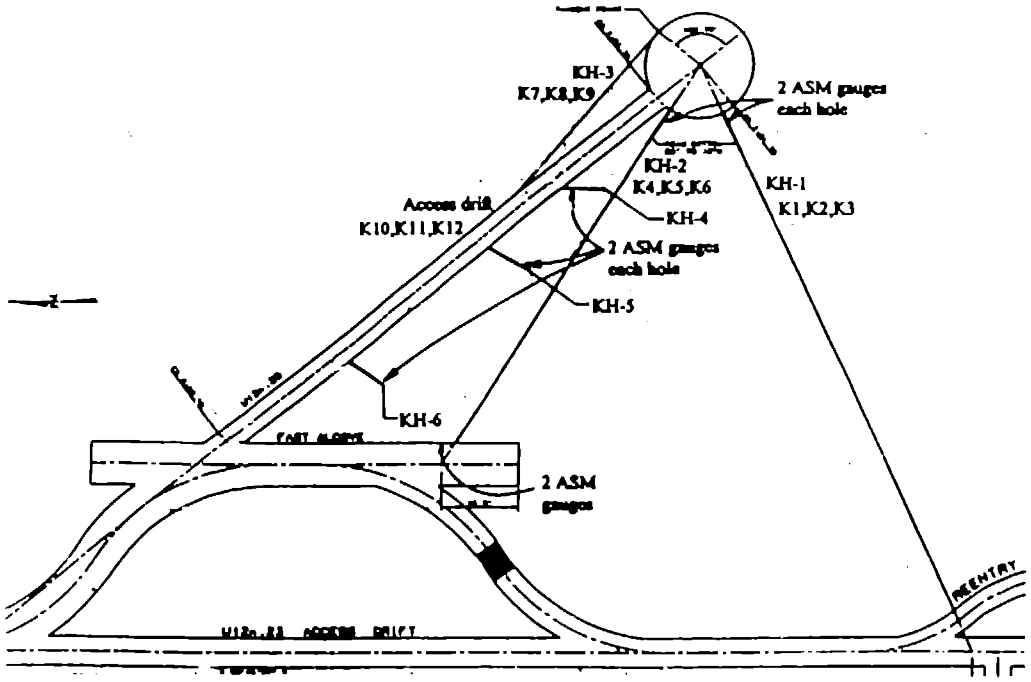

Figure 1. Engineering site plan for the non-proliferation experiment.

ASM gauges were installed at 2.0 m and 5.0 m from the drill hole collar reference in the 12 inch diameter portions of KH-1 and KH-2. Drill holes KH-4, KH-5 and KH-6 were each 12 inches in diameter and 20 feet long. Each contained two ASM gauges nominally at 19 feet and 17 feet from the drill hole collar references. A final pair of ASM gauges were installed adjacent to the portal end of drill hole KH-2. Locations for these twelve gauges are indicated in Figure 1 and their radial distances from the UWP are included in Table 1. The slant distance is to the planned elevation of the center of the explosive chamber based on the UWP. The horizontal distance is the distance at the gauge elevation to the UWP.

*The sensing element designations Kn and K-n are synonymous and will be used interchangeably.

Table 1. ASM gauge locations and times-of-arrival.

ASM Gauge/ Location	Slant Distance (m)	Horizontal Distance (m)	Time-of-Arrival (ms)*	
			ASM Gauge	CORRTEX
A1/KH-1	10.51	10.44	1.910	1.900 - 1.910
A2/KH-1	13.45	13.40	2.762	2.750 - 2.760
B1/KH-2	9.88	9.77	1.832	1.820 - 1.830
B2/KH-2	12.83	12.76	2.669	2.660 - 2.670
C1/KH-4	22.59	22.59	6.040	6.160
C2/KH-4	22.94	22.93	6.190	6.210
D1/KH-5	38.01	38.01	—	12.430
D2/KH-5	38.15	38.15	—	12.510
E1/KH-6	64.00	64.00	—	24.7±0.1
E2/KH-6	64.11	64.11	—	24.8±0.1
F1/**	64.33**	64.33	22.600	24.9±0.2
F2/**	65.35**	65.35	23.000	25.5±0.3

* Timing with respect to the capacitive discharge unit.
** Located at portal end of KH-2, measurements made and coordinates supplied by Brad Wright, Los Alamos.

The six drill holes were stemmed with a rock matching (density matching) non-slumping grout. Because these holes were stemmed in place well before the explosive detonation, the grout is considered to have reached its maximum compressive strength of 3000 PSI. The working point ends of K10, K11 and K12, the access drift sensing elements, were anchored about 60 cm inside the explosive chamber. Their linear path down the access drift passed through a steel bulkhead at the access drift-explosive chamber interface, through five feet of sand bags filled with desert fines and through three stemming zones. Because the sensing elements were installed high in the access drift and the grout mixes used for stemming the first two zones of the access drift were high slumping and topped-off with a different mix (same mix as was poured in the third zone), it is uncertain exactly which stemming material surrounded these sensing elements. The density was however, near or slightly higher than the native rock. Since detonation occurred just several days after completing stemming, neither of the grout mixes used had reached their maximum compressive strengths. All this information to state that although the sensing elements installed outside the explosive chamber are described as "free field" measurements of the induced shock traveling through saturated tuff, the reality is that they were grouted in place, and in the access drift this comprised a significant portion of the medium surrounding the sensing elements installed there.

CORRTEX DATA

The data presented and discussed in this report are, of course, an extension of that presented in reference 2. Because each CORRTEX sensing element was installed with two geometric signatures (loops) in the explosive chamber and three in the "free field" region, the data reduction process could use the known locations of the loops, to determine the propagation velocity of pulses in each sensing element at the time of the detonation. This results in a more accurate computation of the shock location along the path of the installed sensing element. Standard CORRTEX data reduction procedures were followed in producing final data sets for each sensing element. Table 2 summarizes some information relative to each sensing element. Included is the selected cable type and the time of first crush in the "free field" medium (the access drift cables are a projection because of their loop back into the explosive chamber). Different cable types are used because of differing physical characteristics (such 1/4 inch cables vs. 1/2 inch cables) and crush thresholds, the shock pressure at which the sensing element ceases to crush uniformly. The data will show which of the installed cable types have the lower crush thresholds.

Table 2. Sensing element locations, types and times of first crush in the "free field."

Designation	Location	Cable Type	First Crush (ms)
K1*	KH-1	FSJ1-50	1.444±0.005
K2*	KH-1	FSJ1-50	1.443±0.005
K3	KH-1	FSJ4-50	1.454±0.005
K4	KH-2	FSJ4-50	1.384±0.005
K5*	KH-2	FSJ1-50	1.389±0.005
K6*	KH-2	FSJ1-50	1.388±0.005
K7	KH-3	FSJ1-50	1.372±0.005
K8	KH-3	FSJ4-50	1.379±0.005
K9	KH-3	FSJ4-50	1.375±0.005
K10	Access drift	RDX1-50	N/A***
K11**	Access drift	FSJ1-50	1.304±0.015
K12**	Access drift	RDX4-50	1.305±0.015

* A 2.0 m loop was installed at the drill hole collar.
** The times given are projected from the survey point 7, located in the explosive chamber, the point to which the access drift sensing elements looped before exiting the explosive chamber.
*** K-10 was damaged during stemming at a point just outside the explosive chamber.

The data records will first be examined as recording the same induced shock along the individual installation paths, that is, K1, K2 and K3 in drill hole KH-1, etc. When comparing data between sensing elements installed together, their position reference will be their common point upon exiting the explosive chamber. In each installation path, the position on each sensing element at the drill hole collar reference was carefully fixed. For example, K1 and K2 each contained 2.0 meter loops, 28.0 to 26.0 meters, at the KH-1 drill hole collar reference. The 26.0 meter mark on K3 was made to coincide with this same position. Therefore, the position along the sensing element at the drill hole collar reference is very precisely known. The same situation held for KH-2 and KH-3. For K10, K11 and K12, the loop back into the explosive chamber was placed precisely at the 25.0 m mark on each sensing element. The second comparison will be between different exit paths, such as, KH-1 and KH-2, etc. In this case, the data position will be referenced to the UWP, that is, radial data from the UWP. Timing is to "minimum boost", the minimum time required for booster breakout(??).

The KH-1 Data

Figures 2 and 3 present and show two comparisons of the three data sets from KH-1. On the scale of Figure 2, the K1, K2 and K3 data are coincident to about 5.0 ms. The Figure 3 plots show the differences, K3 - K1 and K3 - K2 respectively, over the initial intervals. The mean difference is -0.025 m for K3 and K1 and -0.030 m for K3 and K2. This is excellent agreement between the three independent measurements of the induced shock location in the KH-1 direction, which represents ranges of 8.0 to 20.0 m from UWP. Clearly, the K3 sensing element, 1/2 inch FSJ4-50, has a lower crush threshold than either K1 or K2, both 1/4 inch FSJ1-50. Experience has shown that when data begin to stair-step, as the K3 record exhibits in Figure 2, that the shock location is the upper envelope of the data. This is indicated by the dashed curve.

The KH-2, KH-3 and Access Drift Data

The KH-2, KH-3 and access drift data will be presented and compared in less detail. Figures 4, 5 and 6 present the three records in each of these "free field" paths. The plot scales are the same as for Figure 2 so that the major differences in the induced shocks, as measured in the separate exit paths, is apparent. Geometric corrections and reference to a common point have not yet been made in these data sets. The difference information shown for KH-1 in Figure 3 is summarized for all sensing elements in Table 3. In each case, a lower crush threshold cable was selected as the standard against which the other two data records were compared in each exit path. It is apparent from Figures 4, 5 and 6 , and the mean differences in Table 3, that there is excellent agreement between the data records within each of the four exit paths. Therefore, when comparing data between different "free field" paths, a single low crush threshold sensing element will be selected for each path.

Comparing the K3 plot in Figure 2 with the K4 plot in Figure 4, it is apparent that K4 ceased responding to the induced shock wave in the KH-2 direction much earlier than K3 in the KH-1 direction. This comparison is valid because K3 and K4 are identical cable types and the drill holes were close to radial from UWP.

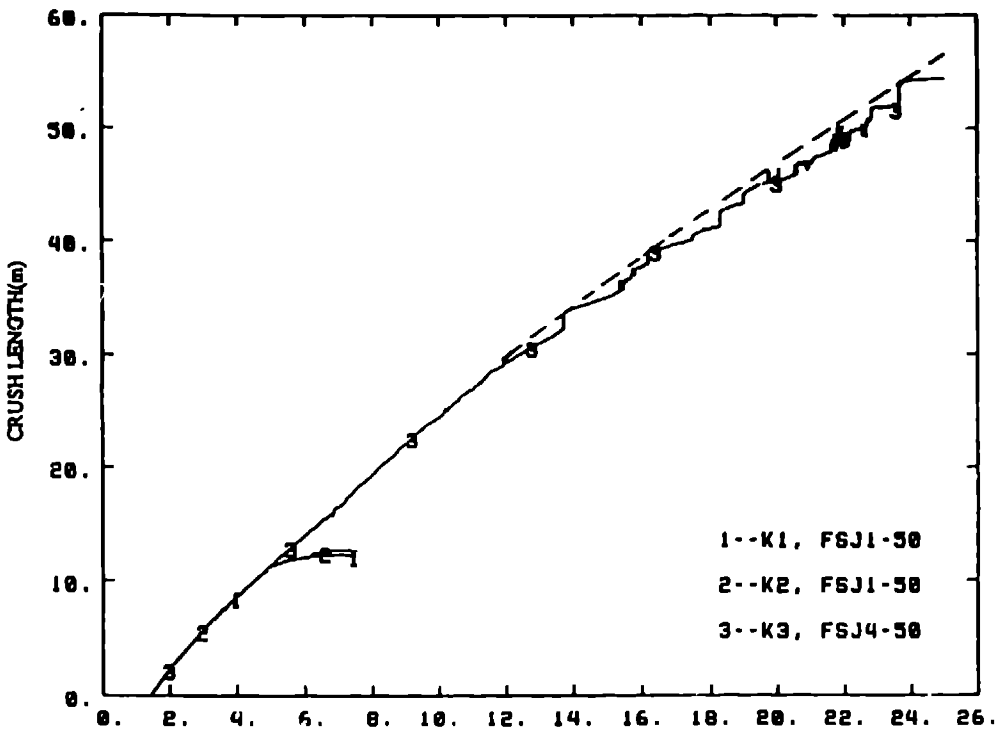

Figure 2. Drill hole KH-1 data.

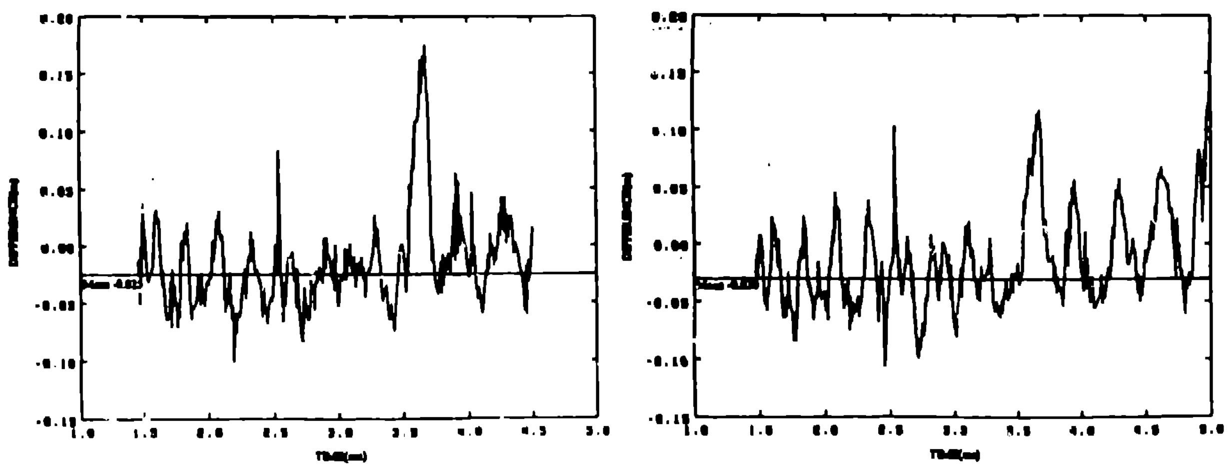

Figure 3. Difference plots of K3 - K1 and K3 - K2.

Table 3. Mean difference between data along each "free field" path

Standard	Mean Differences, Standard - Data			
	Data	Difference	Data	Difference
K3	K1	-0.030±0.019	K2	-0.025±0.019
K4	K5	-0.018±0.022	K6	-0.033±0.025
K9	K7	0.000±0.025	K8	-0.008±0.021
K10	K11	-0.028±0.023	K12	0.011±0.038

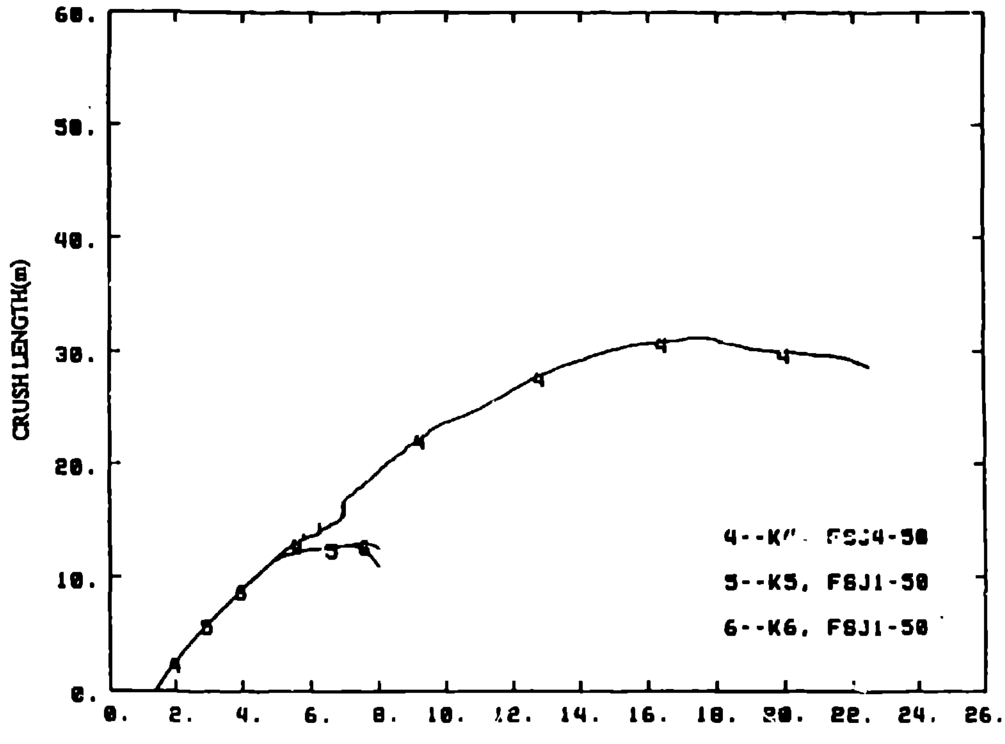

Figure 4. Drill hole KH-2 data.

The installation path for K7, K8 and K9 was through the KH-3 drill hole to the explosive chamber access drift. There, the KH-3 and access drift sensing elements joined, and as a bundle were routed linearly along the drift left rib. The transition of the sensing elements from KH-3 to the access drift is marked in the data record of Figure 5. Interestingly, at this point the KH-3 sensing element response to the induced shock improved considerably, possibly indicating a higher pressure in the grout filled access drift than in the KH-3 drill hole. As a final note, the KH-3 data can be compared to the access drift data along their common path. The 61.0 m mark on each of the KH-3 cables was installed coincident with the 57.0 m mark on the access drift cables, a difference of 4.0 m in cable length to this common point. Comparing the K9 data (KH-3) to the K10 data (access drift) over several intervals beyond the transition point yields a mean difference of 4.003 ± 0.110 m. Again, extremely consistent agreement between the independently reduced data.

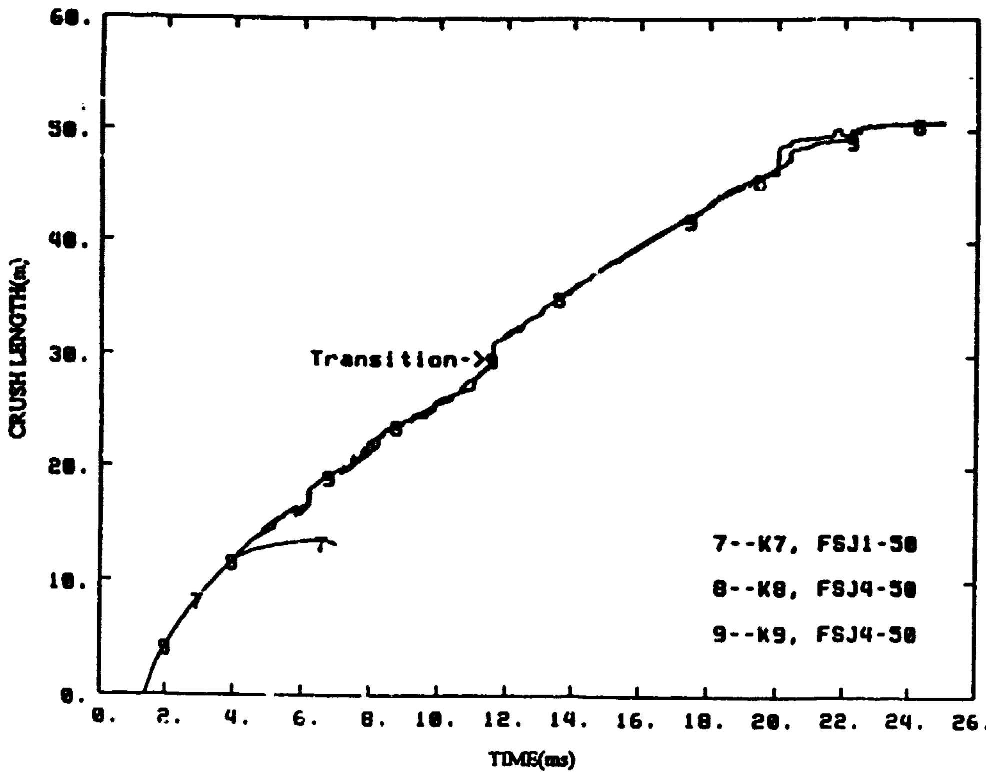

Figure 5. Drill hole KH-3 data.

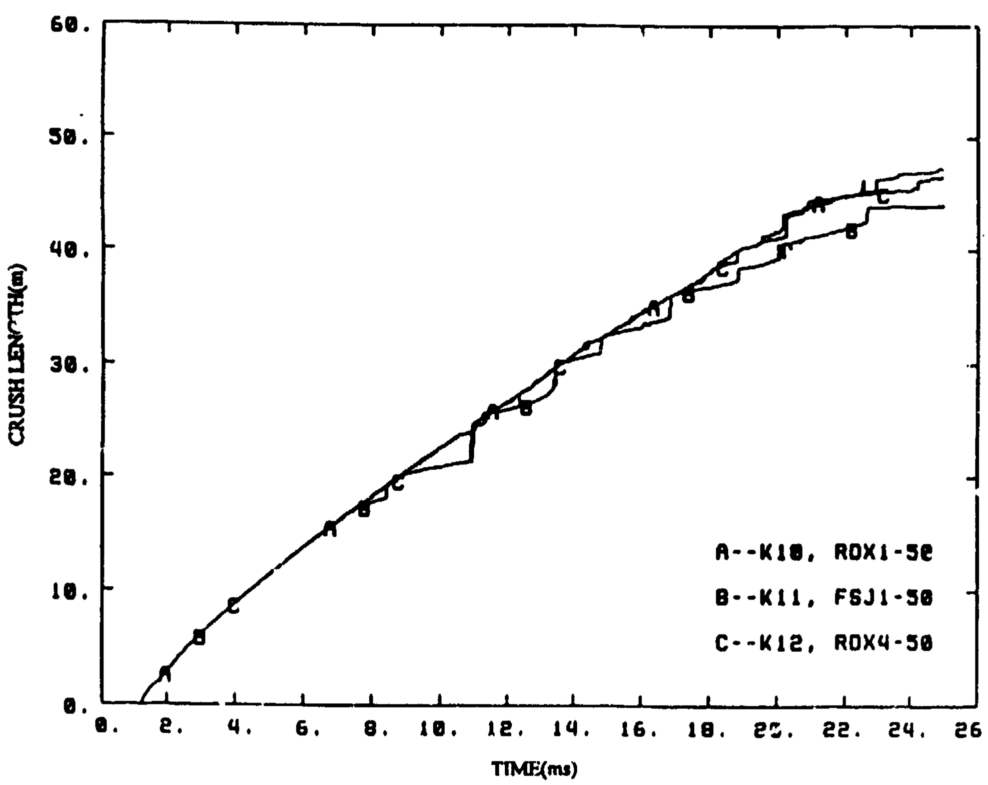

Figure 6. Access drift data.

Interpath Comparisons

Figures 2, 3, 4, 5 and 6, along with Table 3, made intrapath comparisons. The absolute consistency within each exit path permits selecting one record from each path to examine the induced radial shock wave along different paths. Figure 7 includes K3 from KH-1, K4 from KH-3 and K10 from the access drift. These records have been geometrically converted to time-dependent radial position with respect to UWP.

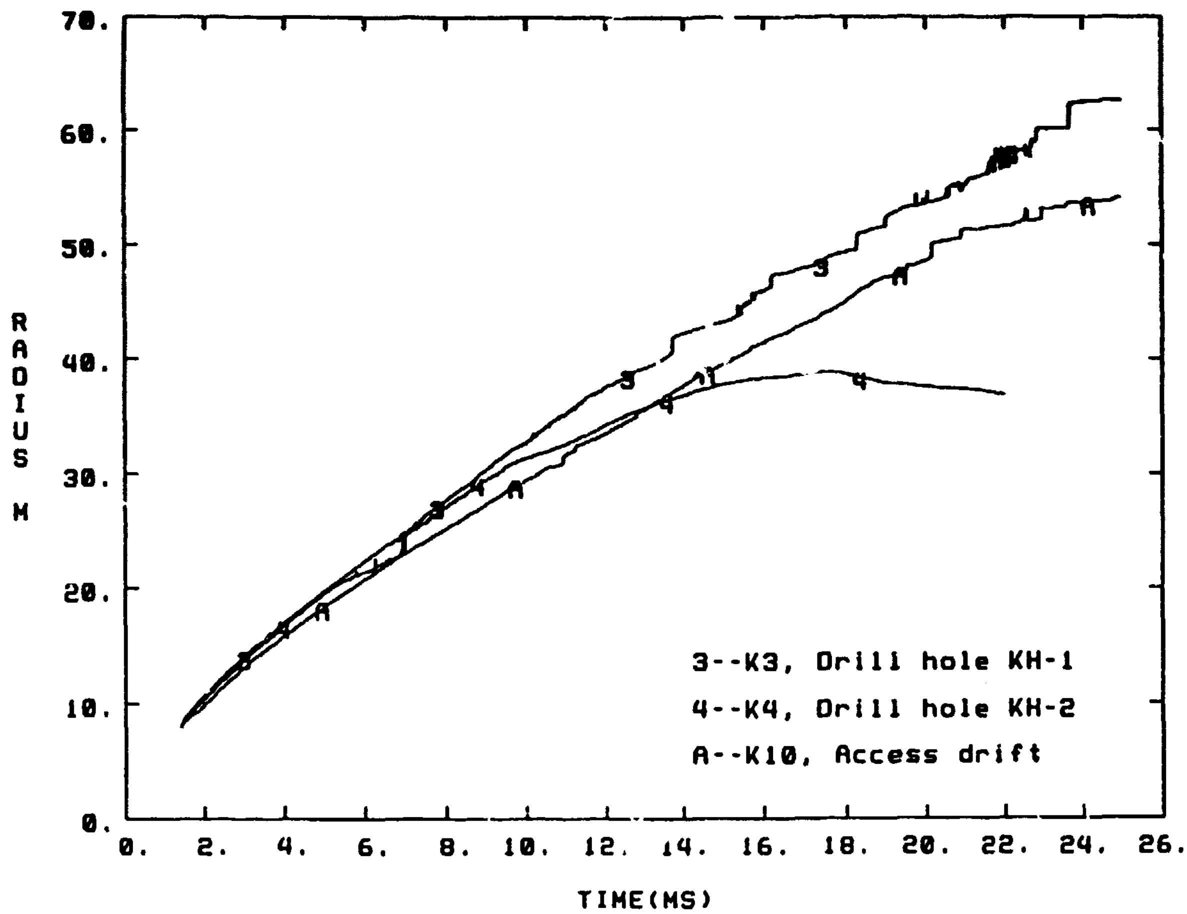

Figure 7. CORRTEX measured shock induced into the saturated tuff, beyond the explosive chamber.

It was observed earlier that K4 ceased responding to the induced shock much earlier than did K3. Figure 7, based on a common reference, makes this difference clearer. Also K10 from the access drift, although lagging behind both K3 and K4 in early time, continues to respond well beyond the range of K4 but still behind K3. K10 is a cable type which typically has a lower crush threshold than the cable type of K3 and K4. Thus, its lagging behind K3 must be due to the shock induced into the grout of the access drift versus the grout filled hole KH-1. To further support this observation, it is again noted that K8 and K9, which are both FSJ4-50, the same as K3 and K4, from their transition from KH-3 to the access drift were in excellent agreement with K10 (4.003 m vs 4.0 m difference in cable length). Therefore, in just the three instrumented directions of KH-1, KH-2 and the access drift, there are measurable differences in the induced shock wave, both in terms of the apparent shock pressure and the time-dependent radial position.

Examining the data from a different perspective, however, may perhaps yield additional insight. Although it is difficult to observe on the scale of Figure 7, there are early time differences between the K3 and K4 data. Figure 8 is an enlargement of that data which makes it clearer that there is an apparent constant difference between K3 and K4 which persists to 4.0 or 5.0 ms, before K4 begins to fall off. The insert in

Figure 8 is a plot of the K3, K4 difference with the mean difference shown as 0.338 ± 0.021 m. Figure 9 is a replot of the time-dependent radial position of just K3 and K4, but with 0.338 m subtracted from the K3 data.

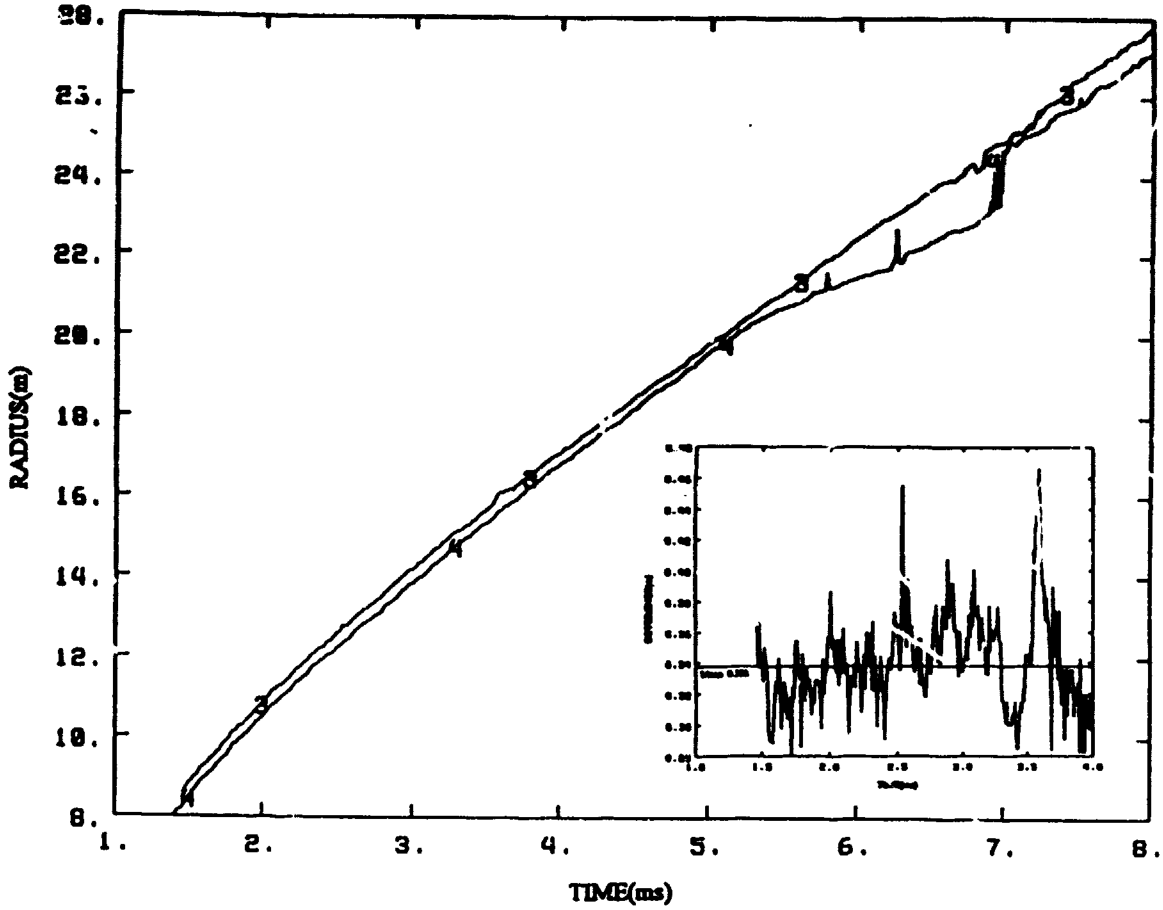

Figure 8. Enlarged view showing the difference betweeen the KH-1 data and KH-2 data.

Can this apparent constant difference be explained? For a possible explanation, it is necessary to examine the explosive burn at the collars of drill holes KH-1 and KH-2. Based on survey, the distance from UWP (note: UWP is the best location of the center or axis of explosion available) to the KH-1 collar is 8.557 m while to the KH-2 collar it is 7.910 m. Both collars were about the same elevation, which was just slightly above the lower of the three levels instrumented with CORRTEX in the explosive chamber. The time of explosive burn arrival at the collar of KH-2, as determined from the CORRTEX data, is 1.389 ms. The first recorded point by K3 in KH-1 was radially 8.615 m at 1.459 ms. However, the induced shock as measured in KH-2 was 8.248 m radially from UWP at 1.459 ms, a difference radially of 0.367 m. This difference is derived from the fact that the detonating explosive was radiating from UWP toward the greater distant KH-1 collar, faster than the induced shock was traveling in the saturated tuff/grout at KH-2. Therefore, although the shock induced at the KH-1 collar occurred later, its greater radial distance placed the induced shock into the surrounding medium radially ahead of the induced shock at KH-2. Is it just coincidence that K3 is, on the average, 0.338 m ahead of K4? The 0.367 m radial difference at KH-1 and the K3 - K4 difference of 0.338 m are well within the experimental error budget at 8.0 m from UWP!

ASM Times-of-Arrival

Determining a comparable CORRTEX time-of-arrival for the ASM gauges located in KH-1 and KH-2 is simple because the sensing elements were installed with the gauges, two each in KH-1 (A1 and A2) and

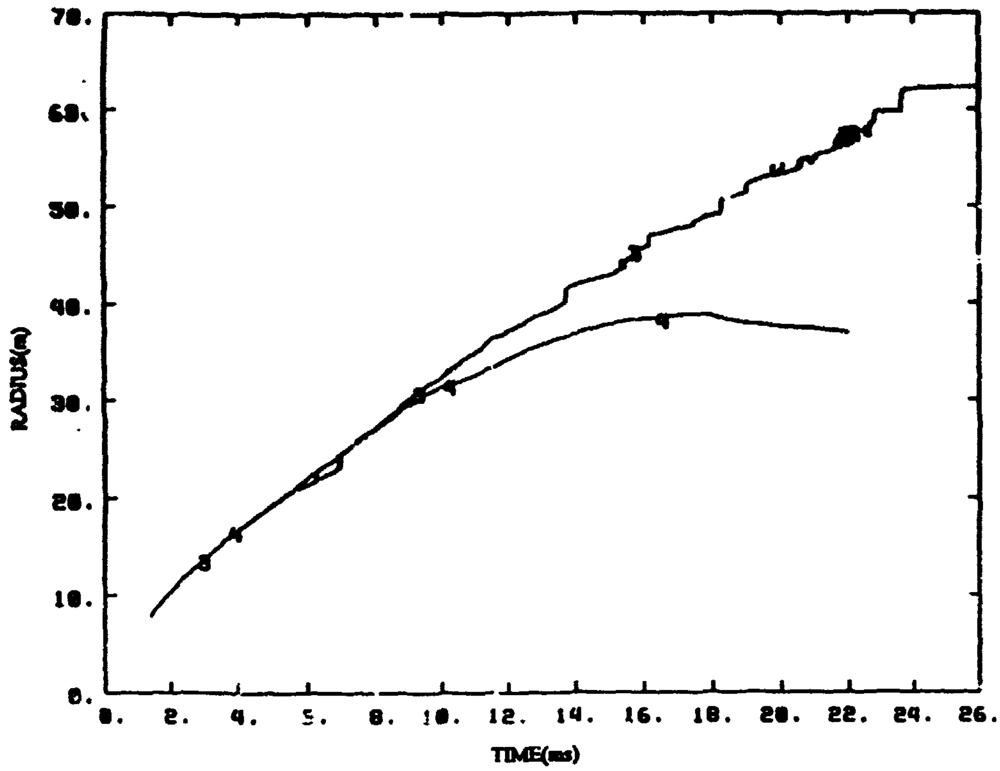

Figure 9. The KH-1 (K3) data shifted by -0.338 m and the KH-2 (K4) data.

KH-2 (B1 and B2). The gauge TOA and corresponding CORRTEX times are given in Table 1. The ranges shown for the CORRTEX times are due to there being data from three independent sensing elements. Similar values for the two gauges in each of KH-4 (C1 and C2), KH-5 (D1 and D2) and KH-6 (E1 and E2) are more difficult. The sensing elements installed in KH-2 were the closest records to these six ASM gauge locations. However, the induced shock, as monitored by the KH-2 sensing elements, fell below the crush threshold of all three installed cables before reaching the radial distances of all these gauges. The shift of the K3 data to coincide with the early time K4 data, as shown in Figure 9, permits an estimate to be made of the TOAs for these six gauges. These are the values presented in Table 1 and should perhaps be considered, no-earlier-than estimates. TOA values were obtained for C1 and C2 and they are consistent with the corresponding CORRTEX times. The failure of any KH-2 sensing elements to respond to the induced shock beyond about 38 meters, may indicate why no discernible record was observed on the KH-5 and KH-6 ASM gauges. The F1 and F2 ASM gauges were actually beyond the range of any CORRTEX data.

CONCLUSIONS

CORRTEX could instrument only four exit paths from the explosive chamber. The data reported have been shown to be absolutely consistent within each exit path and in some cases between different paths (KH-3 and access drift). Some exit paths showed different responses. The sensing elements installed in KH-2 ceased responding to the radiating induced shock at about 38.0 m while the KH-1 and access drift sensing elements, located on either side of KH-2, continued to respond to beyond 60.0 and 50.0 m respectively. Assuming that the cable response, drill hole stemming and the incident angle of the radiating shock on the sensing elements are not significantly different in each exit path and the cable response is indicative of shock pressure, there are clearly differences in the radiating shock pressure.

The induced shock monitored in KH-1 uniformly preceded the shock in KH-2 and both differed from the shock down the access drift. The difference in the data from the KH-1 and KH-2 exit paths appears to be the result of a difference in the radial distances of the KH-1 and KH-2 drill hole collars from the detonation axis. The explosive chamber was not a uniform construction, besides being a right cylinder which was "axially" detonated. What irregularities in the induced shock did this introduce? Within the range which CORRTEX was able to monitor, there were differences in both the position of the radiating induced shock and in the apparent pressure of the shock wave.

Concluding remarks

This report has been concerned with sub-millisecond differences in time and tens of centimeter differences in radial position. While these differences are significant on the time and distance scales of this report, the transmission of signals over time and seismic distances perhaps tend to obscure the differences reported here. We have moved from the explosive chamber to the very near surrounding medium and found differences. The microscope applied to the data acquired within the explosive chamber has perhaps lost some of its resolution when examining the measured induced shock in the surrounding medium. But if CORRTEX was able to measure these differences with just the very limited instrumentation of this experiment, what other differences exist and how much further out do these anomalies persist?

ACKNOWLEDGMENTS

The work reported here required the cooperation of many organizations and the assistance of many individuals. They all deserve thanks, but particularly the hard working hands of Keith Alrick, Randy Bos and Brad Wright of LANL, our LLNL colleagues and the EG&G-NTS crew, who stuck in there for the long haul and kept the systems functioning over the long delays. Thanks also to J-6, EG&G-LAO, RSN, DNA, REECO and all the rest of the alphabet soup.

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