1

LA-UR -85-321

CONF-850143--3

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--85-321

DE85 006704

TITLE: USE OF CORRTEX TO MEASURE EXPLOSIVE PERFORMANCE AND STEM BEHAVIOR IN OIL SHALE FRAGMENTATION TESTS

AUTHOR(S): G.G. Schmitt, P-15
R.D. Dick, ESS-3

NOTICE
PORTIONS OF THIS REPORT ARE ILLEGIBLE.
It has been reproduced from the best available copy to permit the broadest possible availability.

SUBMITTED TO Society of Explosive Engineers, 11th Annual Conference
on Explosives and Blasting Techniques
San Diego, CA, January 27 through February 1, 1985

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO 836 R4
ST NO 2629 5/81

USE OF CORRTEX TO MEASURE EXPLOSIVE PERFORMANCE AND STEM BEHAVIOR IN OIL SHALE FRAGMENTATION TESTS

by

Gerald G. Schmitt, Neutron Measurments Group P-15
and Richard D. Dick, Geophysics Group ESS-3
Los Alamos National Laboratory
Los Alamos, N.M. 87545

ABSTRACT

Continuous Reflectometry for Radius vs Time Experiments (CORRTEX) was used to monitor several conditions of blasts such as the detonation velocity of the explosive column, the functioning of different types of initiators and initiation schemes, and the behavior of the stemming column confininig the explosive. The CORRTEX data were also used to deduce the occurrence of dead-pressing of ANFO slurry. Measurements of propagation speeds of shock waves in the stem column with various cables allowed some conclusions concerning bridging, stem failure, and stress levels in the stem.

CORRTEX used time-domain reflectometry to interrogate the two-way transit time (TWTT) of a coaxial cable. As the shock front advanced the cable was shorted or destroyed and the resultant TWTT was shorter. Interpretation of these changes as a function of time allowed the position of the shock front to be inferred also as a function of time. This paper describes in some detail the CORRTEX technique and how it was applied to in-situ measurements. Detonation velocities are provided for pelletized ANFO and TNT as well as various ANFO slurries. Observations are made on stem performance as well as shock propagation velocities in several stem materials. Cable characteristics and methods of cable selection are discussed as are techniques for instrumentation of complex blasts to provide initiation time and burn velocity.

INTRODUCTION

The CORRTEX system[1] was developed as a possible verification technique for the Peaceful Nuclear Explosion Treaty (PNET) between the Soviet Union and the United States. This treaty is a companion to the Threshold Test Ban Treaty (TTBT) that limits nuclear tests to 150 kilotons total yield. The PNET allows higher aggregate yields if needed for specific engineering tasks but limits these yields to salvos of several nuclear explosives, each being no more than the 150 kilotons allowed by the TTBT. To ensure compliance each signatory is allowed nonintrusive access for the purpose of confirming salvo yield in the event of a high-yield PNE. However, neither treaty has been ratified by the U.S.

The CORRTEX system is based on a second generation pulsed time-domain reflectometer.[2,3] The instrument samples cable length 4000 times at pulse periods of 10 us to 90 us. For each sample it stores three digital words of two-way transit time information and one real-time clock word. Resolution of the TWTT is 125 ps resulting in 3-cm resolution of the relative cable length over a several-kilometer-cable length. Pulsed time-domain reflectometry consists of a series of pulses sent down a cable. At the start of each pulse a clock is started; when the pulse encounters an impedance discontinuity, it reflects and returns to the unit. When the return pulse is detected, a stop pulse is issued. The clock gives a gross count to 1 ns,and the stop is further interpreted to 125 ps by pulse-stretching circuitry. This sequence (Fig. 1) is repeated for each of the pulses, and the results are stored in a long life memory. The entire system is packaged in a 19.5-kg package that can be carried and deployed by one man.

In order to improve the technique and develop new equipment, the CORRTEX group participates in selected U.S. nuclear events and has participated in high- explosive diagnostics both in support of government and private efforts. As part of the Los Alamos National Laboratory policy of technology exchange, we participated in a series of oil-shale fracturing experiments in support of the U.S. Department of Energy, Science Applications International, and a consortium of oil companies. This series of experiments was carried out on the Naval Oil Shale Reserves at Anvil Points, Colorado.

At the outset the CORRTEX experiment had four objectives: measurement of explosive performance, stem behavior, shock-wave speed in shale, and crater formation. As a direct result of experimental observations additional tasks were conducted. Timing of initiation to a very high degree of accuracy was provided, and confirmation of explosive burn as a safety factor became a necessity as the experiments became more complex. Confirmation of experimental timing was also provided on dry runs to assure acquisition of digital data when it became necessary to use commercial blasting caps instead of explosive bridge-wire (EBW) detonators.

As a result of the Anvil Points experiments we have determined burn velocities for a number of blasting agents and high explosives. We have observed both deadpressing and explosive failure when pins alone were not able to do so. The uncertainty of timing of commercial blasting caps was demonstrated to be considerably greater than manufacturers' claims, and the safety factor of direct observation of explosive performance in experimental geometries was most graphically demonstrated.

EXPERIMENTAL PROCEDURE

Selection of Sensor Cables

One of the first considerations in designing an experiment was the selection of the sensing elements to be used. Since virtually any 50-ohm coaxial cable can be used, the experimental parameters can be varied just by the cable selection. The characteristics of some commonly used CORRTEX cables are illustrated in Table 1. To measure explosive-burn velocity we normally used FSJ1-50. If shock speed in the stem is also required, an RG-174F would be added. Although the RG-174F did not give quite as good data as the FSJ1-50, it did crush at lower pressures; thus the use of both gave the best data in the explosive as well as in the stem. For rock motion studies we used the higher crush-threshold cable such as RG-214. This cable, installed in the rock away from the explosive column, will survive the shock wave and only show shortening when crater formation severs it. To measure both phenomena both RG-174F and RG-214 might be used. For the early series of experiments the sensing elements were made only long enough (30 m) for the connectors to remain clear of the blast and debris. Jumpers then carried the signals to recording instruments. In later experiments much longer (100 m) elements were used to make multiple measurements with a single cable. With high-quality cable there is little practical limit to the length of a cable. In practice, sensing elements of several kilometers have been fielded.

Table 1. Sensor Cable Characteristics

Cable Type	Size(mm)	Crush Threshold	Application
RG-174 (common)	2.5	60-90 bars	Stem/grout shockwave
RG-174 (foam)	2.5	30-40 bars	Stem/grout shockwave
FSJ1-50	6.4	1 kbar	Explosive/grout shockwave
RG-223	6.4	2-3 kbar	Explosive/complex shots
RG/RF-214	12.7	20-25 kbar	Rock motion/cratering
RG-225	12.7	30 kbar	Rock motion/cratering

Other cables such as air dielectric or twin lead have been made for special applications; the only constraint is that they be 50 ohm.

Selection of Pulse Period

The CORRTEX units recorded 4000 measurements and pulsed at 10 to 90 us. This gives 40 to 360 ms of recording time. If only a short column of explosive is to be measured, the most rapid rate would be selected to allow the gathering of the maximum amount of data. For longer duration phenomena, such as crater formation or a long duration series of timed detonations, a longer pulse period and associated long recording time might be selected.

Triggering

The latest CORRTEX units can be triggered in a number of ways. The primary method is by a 5-volt fiducial. This type of signal was computer generated at Anvil Points for most blasts and generally was 2 ms prior to detonation to give reasonable baseline data. If an accurate estimate of the blast time cannot be made, the CORRTEX can be placed in prepulsing mode. When this is done the unit constantly interrogates the TWTT of the cable and stores the information in a rotating buffer. Each pulse is compared to its predecessor, and if four successive pulses showed a decrease of at least 1 ns, the unit assumes that an event has commenced and takes the 4000 data points of information. The first points are kept by virtue of the rotary memory and thus all shot data are gathered. This system was implemented and proof tested at Anvil Points and is now standard on CORRTEX units. An additional system exists to assure valid data are taken. The unit is triggered and data taken; the last eight points of data are then averaged. This average is then compared to the prezero mean. If the difference does not exceed a preset variable, the unit rearms and is once again ready to take data.

Calibration

The CORRTEX unit is able to calibrate in the field any cable that is intended for use by one of the following methods. For long runs of sensing elements the cable is attached to an appropriate jumper, and an average TWTT for the combination is determined. A section, typically 5 m, is then cut off the element and the TWTT is again determined. This process is repeated several times with the change in TWTT and physical amount removed being recorded. The changes in TWTT and length are related to the propagation velocity by the following formula:

$$V_p(\text{m/ms}) = 2\text{Lm}/(\ \text{TWTT}),$$

where TWTT = Full Length TWTT - Cut Length TWTT, and Lm is the length removed in meters.

For shorter elements or to get propagation velocity of the cable in-situ the TWTT for the entire cable is determined, the sensing element is removed, and the TWTT of the jumper is determined. The difference along with the length of the sensing element is used in the same manner as above. This technique has several advantages: the change in propagation velocity due to environmental changes can be determined; excessive changes tell the experimenter that the cable might have been damaged before the experiment is conducted. This method was the one used primarily at Anvil Points.

Calibration of the timing and firing system was another task that CORRTEX undertook during this series of experiments. To do this a piece of expendable cable was attached to one of the jumpers in place of a shot element. Detonators or caps were then attached to the piece of cable. The system was then dry run, and the detonator or caps cut the cable. The CORRTEX data was then reviewed and the firing time or times were determined to the precision of the pulse period used. This capability became much more important as the number of detonations and complexity of the experiments increased.

Installation of Simple Experiments

In the single borehole and simpler multiple borehole experiments, the cables were all installed in a similar fashion. The cable was attached to the booster usually with one meter wrapped or folded over the booster to provide initiation times. The CORRTEX cable was then used to lower the booster detonator combination into the hole. The CORRTEX cable was centered in the hole and tensioned so that the cable was straight in the hole. This was critical to an accurate measurement. If the cable sagged or bowed, more cable would be destroyed by the shockwave than the linear distance that the shockwave traveled, thus inferring an erroneously high shock velocity. The meter excess at the booster allowed a more precise determination of first point of data. We felt that centering the cable in the hole assured us of measuring the explosive velocity and not a shock or compression wave traveling up the side of the hole. This could be of particular importance in applications with a high media sound speed combined with explosives of slow burn speed. The installation of a typical simple experiment is illustrated in Fig. 2, and a typical data set is found in Fig. 3.

Complex Blast Installations

For multiborehole shots, ones with more than one charge in a borehole, or shots that combined both, the number of burns sometimes exceeded the number of CORRTEX units available to make the required measurements. In this case we used longer elements and measured several burns that were separated in time with a single element. This type of installation is illustrated in Fig. 4, and a typical data set is given in Fig. 5. In addition to the burn information the separation in time of the burns was also determined to the precision of the pulse period. Even in cases where the geometry made the burn measurement impossible, it was often still possible to obtain this relative timing.

In time-staged shots with multiple-timed blasts we found some protection might be needed at the collars of the holes. This was particularly true when the stemming was grout. The impedance discontinuity at the grout interface caused the shock wave to reflect, and the associated jetting cut the cable. These phenomena were observed on several occasions. Protective schemes included Armorflex, high-pressure hose, pipe, and neoprene sheeting. Any of the schemes will work as long as the expected pressures are accurately estimated and allowed for.

Special Installations

In order to maximize information gathered on selected blasts, some complex and interesting geometries were designed. In an effort to measure shock wave speed in shale of events A1 and A2, satellite holes and crush enhancers were employed. The holes were placed at 1 and 2 m, and cables were started in the 1-m holes and looped into the 2-m holes. The RG-174 was taped to threaded rod and oriented so that the propagating shock wave would press the cable into the threads to short it. This had limited success. On the A2 shot, heavy slabs of shale were placed on the cables on the floor outside of the blast hole. We expected the shockwave from the floor to sever the cable, thus giving a shock-arrival time at the surface. This was quite successful. On a cratering shot a hole was drilled completely through the invert. Cables were installed in this hole in both directions to determine how the crater formed. Some success with this effort indicated a technique that should be pursued.

Loading Safety and Final Hookup

As a safety measure the CORRTEX sensor was disconnected before installation of the booster and loading of the hole. Once the holes were loaded and the area cleared, the final CORRTEX hookup was made just prior to the detonator hook-up. After the final sweep and securing of the area, the CORRTEX was pulsed and the full cable length TWTTs were compared to those determined during calibration. This insured that good connections had been made and data would be obtained.

EXPERIMENTAL RESULTS

Explosive Performance

We achieved a great deal of success in blast agent measurements. The overall data comprise some 400 pages, but typical examples and some significant averages are given in Table 2.

Table 2. EXPLOSIVE PERFORMANCE TABLE - ANVIL POINTS

Shot/hole #	Explosive		Burn Velocity km/s	Std. Dev.
A1	ANFO prills		4.07	0.06
A2	TNT prills		5.03	0.05
A3	TNT prills		4.70	0.07
A7	TNT prills		5.02	0.14
A9	1205C ANFO		4.80	0.06
A10	1115 ANFO		5.82	0.05
B1 H1	TNT prills		4.81	0.02
B1 H2	TNT prills		5.03	0.08
B1 H3	TNT prills		5.90	0.09
B1 H4	TNT prills		6.29	0.05
B1 H5	TNT prills		5.35	0.03
B2 H1	TNT prills		4.91	0.03
B2 H2	TNT prills		4.43	0.10
B2 H3	TNT prills		5.00	0.06
B2 H4	TNT prills		4.46	0.08
B2 H5	TNT prills		5.26	0.06
B3 H1	TNT prills		4.83	0.02
B3 H2	TNT prills	211-mm	5.09	0.09
B3 H3	TNT prills	diam	5.04	0.08
B3 H4	TNT prills	borehole	5.73	0.08
B3 H5	TNT prills		5.37	0.05
B4 H1	TNT prills		no detonation, see Fig. 6	
B4 H2	TNT prills		4.91	0.02
B4 H3	TNT prills		4.98	0.10
B4 H4	TNT prills		4.58	0.03
B4 H5	TNT prills		4.79	0.07

Average values from all data:

ANFO prills in 4" (10.16 cm) diam borehole	3.14 km/s
ANFO prills in 6" (15.24 cm) diam borehole	3.95 km/s
TNT prills in 6" (15.24 cm) diam borehole	4.98 km/s
TNT prills in 8" (20.32 cm) diam borehole	5.21 km/s
IRECO 1115 gel in 6" (15.24 cm) diam borehole	5.57 km/s

These data represent the averages for a number of blasts using these materials and blast hole diameters.

Blasting Cap Performance

A number of different brands and type of blasting caps were employed in these tests. In general commercial caps did not have the precision claimed or required for the experiments. With the exception of some experimental high technology caps provided and fielded by Atlas, none approached the 1 ms repeatability considered desirable. A summary of blasting cap performance is given in Table 3.

Table 3. SUMMARY OF BLASTING CAP DELAY TESTS FOR DuPONT, HERCULES, AND ATLAS BLASTING CAPS

Caps	Nominal Delay (ms)	Average Delay (t ms)	Standard Deviation (S ms)	S/t x 100	Caps Tested
Std DuPont	50	53.1	4.8	9.0	6
NT DuPont	75	65.0	4.0	6.1	28
Hercules	50	46.7	8.0	17.0	6
Atlas					
Before Test C-2	50	56.2	3.9	6.9	14
After Test C-2	50	62.2	6.8	10.9	15
Period 0	0	3.7	0.7	20.2	10
Period 3	75	70.4	1.6	2.3	11
Period 4	100	104.9	9.4	9.0	8

Stem Behavior and Performance

The emplacement of CORRTEX sensor cables in a borehole not only resulted in the measurement of the detonation velocity of the explosive but also a measurement of the propagation velocity for the induced shockwave in the stem column above the explosive column. This data provided information on the effectiveness of the stemming from an analysis of the signal records, a post-test measurement of the sensor cable length, and an inspection of the condition of the cable after the blast. In addition an approximate value for the dynamic pressure in the stem associated with the shockwave could be deduced by comparing the position at which the cable stops crushing with the calibrated crush strengths shown in Table 1. Sensor cable crushing occurred in the stemming in a similar fashion as in the explosive. The sequence of events producing a CORRTEX signal were as follows: 1) at the explosive-stem interface a dynamic pressure wave of a few tens of kilobars depending on the explosive was transmitted into the stem material; 2) the wave speed was considerably smaller than the detonation velocity of the explosive causing a noticeable change in slope on the time-distance plot; 3) as the wave traveled through the stem column, the amplitude attenuated significantly resulting in a monotonically decreasing time-distance curve; and 4) when the pressure wave decreased to threshold crush strength of the cable or when the wave reached the collar of the borehole, the CORRTEX signal no longer indicated crushing and the resulting time-distance curve showed a constant length (zero wave speed).

Several CORRTEX signals were analyzed to provide propagation speed of the pressure wave in the stem for several different explosives (ANFO and TNT pellets and IRECO slurry 1205C). Figure 3 is an example of a CORRTEX record showing the crush of the cable in the stem. TNT and 1205C were considered more brisant explosives than ANFO pellets. Propagation speed vs distance for ANFO indicated that initially the wave in the stem was propagating about 2200 m/s at 0.1 m from the explosive-stem interface. At 1.0-m distance from the interface the wave speed was decreased to about 100 m/s. For the higher brisant explosives the wave propagates about 2700 m/s 0.1 m from the interface decreasing to 100 to 150 m/s after a run of 1.0 m, similar to the explosive with a lower brisance. In these instances the wave speed appeared to decay exponentially for the gravel and a combination of gravel and grout materials used to stem or confine the explosive. The backward wave propagation speed (the wave traveling in a direction opposite to the detonation front in the stemming materials below the initiation point) began at about 1000 m/s, which is much lower than in the stem column above the charge. After 0.5 m run the wave speed had decreased to about 300 m/s and at 1.0 m the wave was moving at about 120 m/s. This backward wave also decayed exponentially to a speed similar to that in the forward direction.

In many tests a 0.15-m thickness of clay was placed between the top of the explosive and the column of -10 or -19-mm-sized crushed gravel to contain the explosive gases more effectively. Preliminary analysis of the CORRTEX records from tests containing clay indicated that even this small thickness mitigated the shock wave considerably. In quantitative terms, the propagation speed of the shock wave in the crushed gravel at the clay-gravel interface was approximately 1100 m/s and decreased to about 220 m/s after traveling 0.3 m. This was a significant reduction in the initial propagation speed compared to tests in which clay was not used. A grout plug was used in the center or at the top of the stem column in the tests to evaluate an intermediate stem design. The group plug material was hydrostone containing crushed stone aggregate, and the dynamic response was monitored by a CORRTEX sensor cable placed through the stem column. A typical CORRTEX record with a grout plug as a stem ingredient is shown in Fig. 7.

The CORRTEX records from a few tests incorporating the group plug in a single borehole geometry showed the normal explosive burn curve followed by a length-time curve typical of shock wave propagation in the gravel stem column. At the gravel-grout interface the signal indicated constant length. This feature suggested that the shockwave did not propagate beyond the bottom of the plug. We concluded that the plug effectively mitigated the shockwave in a stem column.

In one particular test, the stem column composed of 0.15 m of clay and 3.5 m of -10 mm crushed gravel completely confined a 3.4-m column of TNT. CORRTEX sensor cables were used to monitor the explosive and stem performance. The CORRTEX signal indicated normal explosive burn and an initial wave speed in the stem of 1000 m/s, which decayed to 150 m/s after running 1.9 m. Post-test inspection revealed that an accelerometer gauge was still in place at the collar and the CORRTEX sensor cables were crushed within 0.6 m of the collar and were undamaged beyond this location. Using the wave speed of 150 m/s measured from CORRTEX and the particle velocity of 40 m/s determined from an accelerometer gauge and assuming the initial density of this stem was 1.75 g/cm^3, the shock pressure was calculated to be approximately 110 bars (1620 psi) at the center of the stem column. This illustrates the usage of the CORRTEX data to determine physical quantities for the stem performance.

Conclusions

The CORRTEX method has proved a powerful tool in the investigation of explosive performance and safety. The technique is simple and easy to field. With the automatic triggering and addition of a clock, blasts can be measured and timed even when the initiation time is unknown. In addition to total failures the CORRTEX will monitor partial failures such as deadpressing and other lowered performance phenomena. In the area of stem performance this technique has added greatly to our understanding. Further CORRTEX studies could significantly increase our understanding of fragmentation and crater formation.

A Look to the Future

A new generation of CORRTEX, EXCOR Extended CORRTEX is coming on-line. This unit is self triggering, will record over a period of days, will outpout to a remote computer and then start the recording cycle again. This technology could be applied in several areas of mine safety, such as slope stabilization or settling in a room and pillar mine. Subsidence phenomena could readily be observed with more accurate subsidence predictions resulting.

Acknowledgments

The CORKTEX system was developed by E. K. Hodson, Los Alamos National Laboratory. Assistance at Anvil Points was given by D. D. Eilers, T. O. McKown, W. H. Storey, Jr., Los Alamos, and R. X. O'Connor,Jr., EG&G.

References

1. C. F. Virchow, G. E. Conrad, D. M. Holt, and E. K. Hodson, "Microprocessor-controlled time domain reflectometer for dynamic shock position measurements," Rev. Sci. Instrum. 51(5), 642-646, May 1980.

2. R. G. Deupree, D. D. Eilers, T. O. McKown, and W. H. Storey, "CORRTEX: A Compact and Versatile System for Time Domain Reflectometry," Proceedings of 1981, ISA, 101-106.

3. William H. Storey, Donald D. Eilers, Thomas O. McKown, David M. Holt, and Goerge C. Conrad, "CORRTEX II, a Dual Microprocessor Controlled Instrument for Dynamic Shock Position Measurements," Vol. II Proceedings of Conference on Instrumentation for Nuclear Weapon Effects, March 30-April 1, 1982, 98-111.

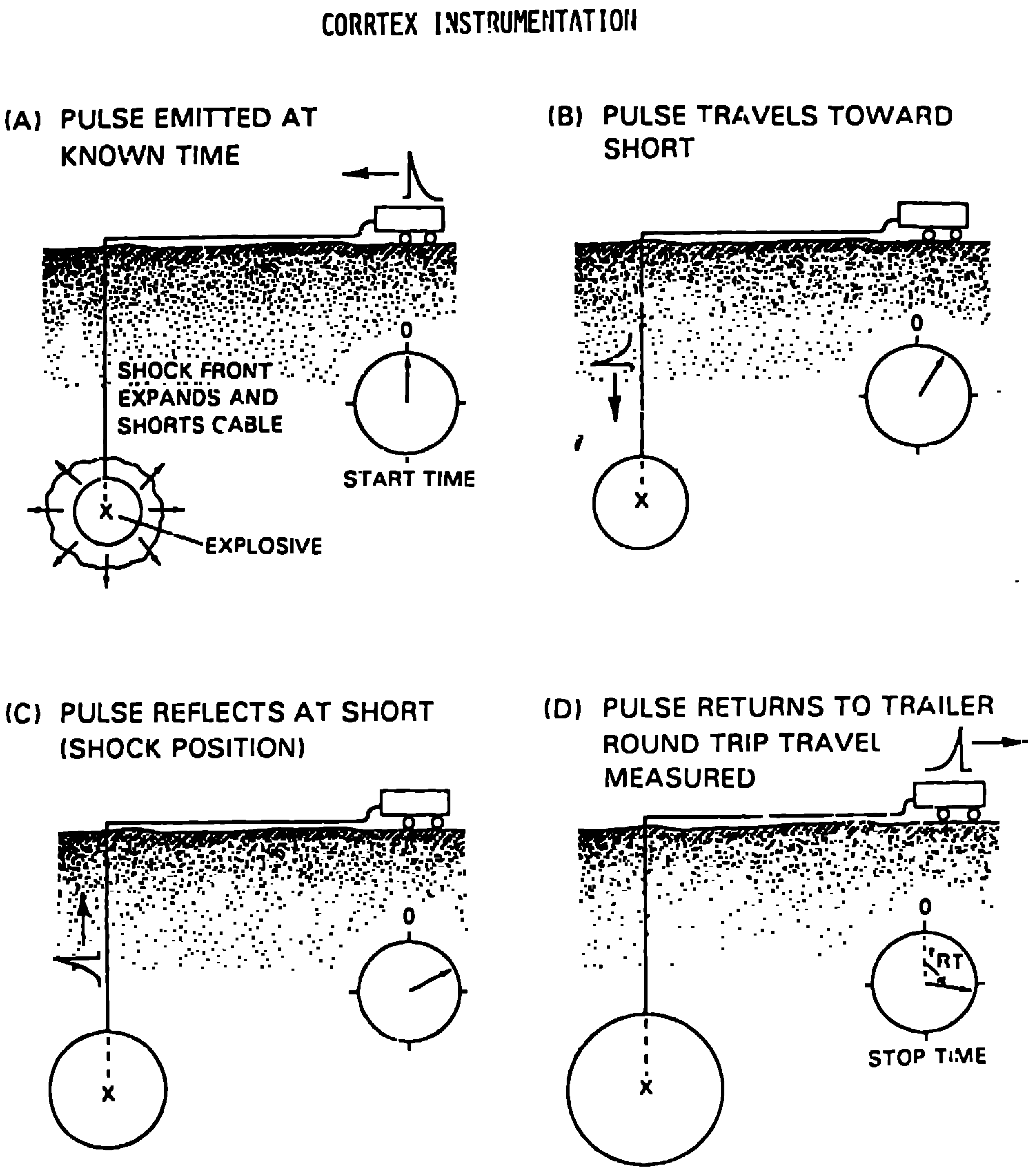
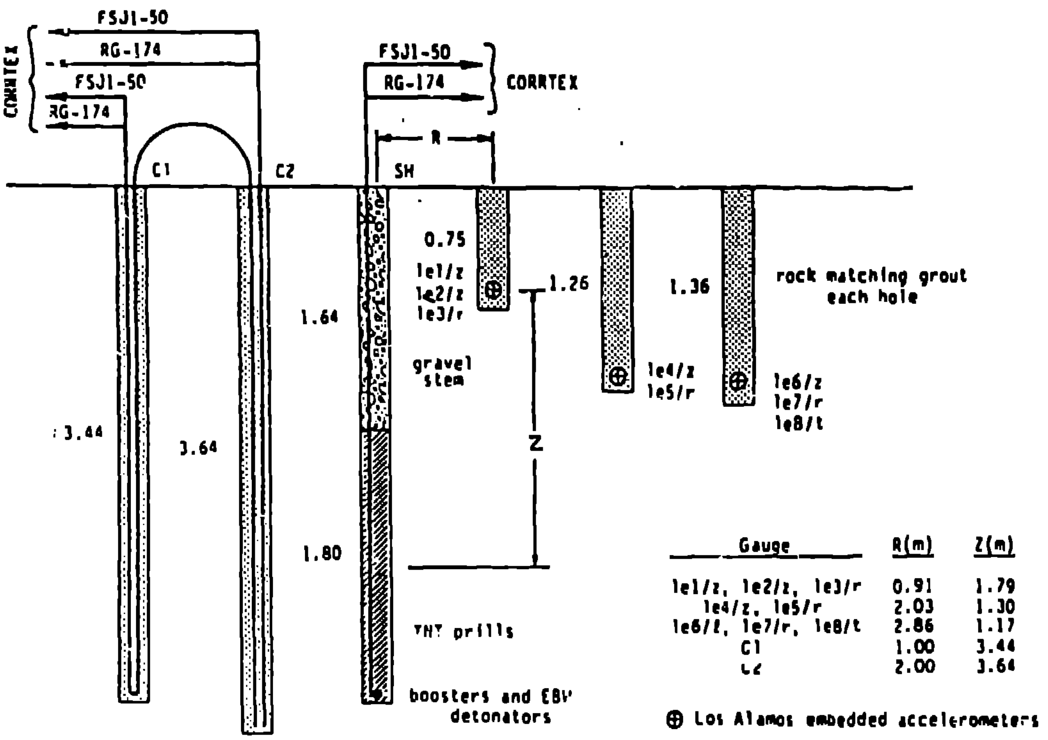


Fig. 1. Schematic of CORRTEX system operation.



Gauge	R(m)	Z(m)
1e1/z, 1e2/z, 1e3/r	0.91	1.79
1e4/z, 1e5/r	2.03	1.30
1e6/z, 1e7/r, 1e8/t	2.86	1.17
C1	1.00	3.44
C2	2.00	3.64

Fig. 2. Single explosive borehole installation.

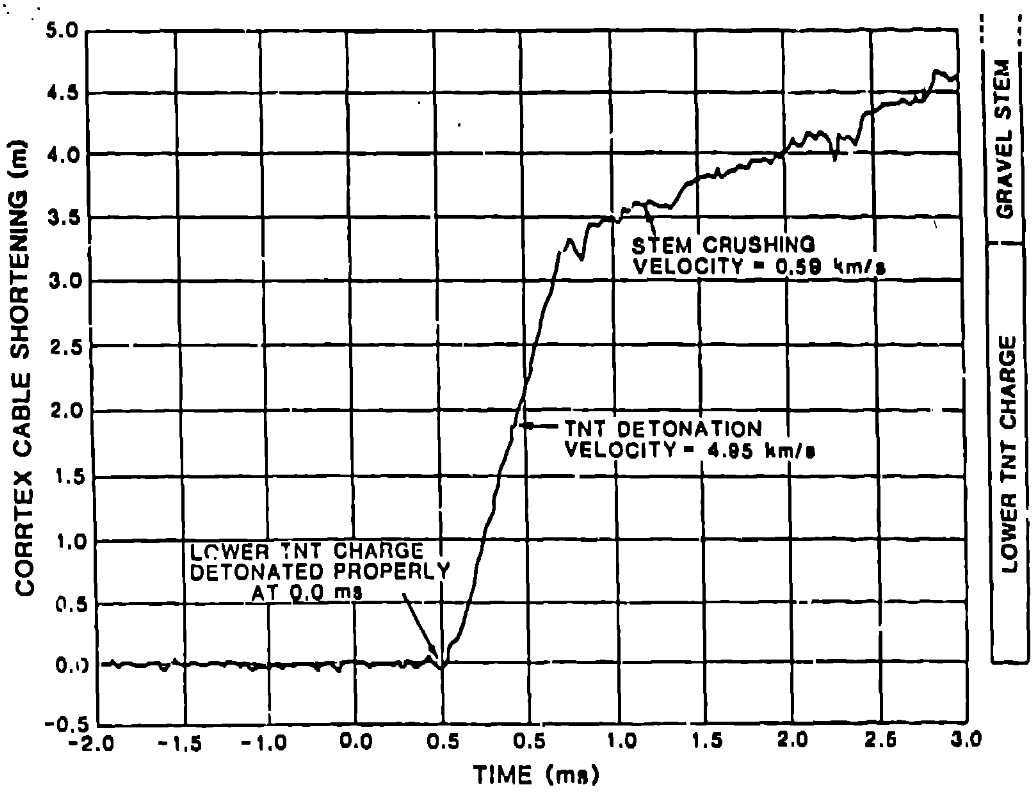


Fig. 3. Data from a single borehole shot.

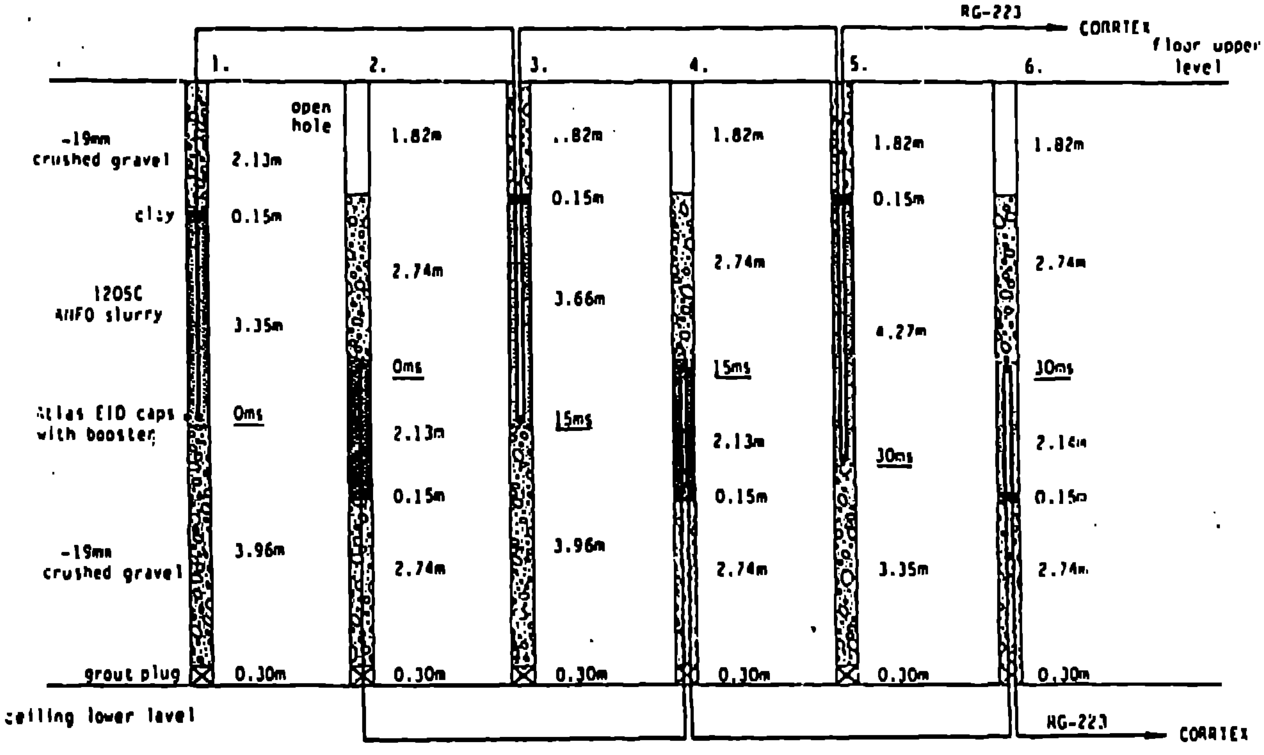


Fig. 4. Multi-borehole multi-timed complex installation.

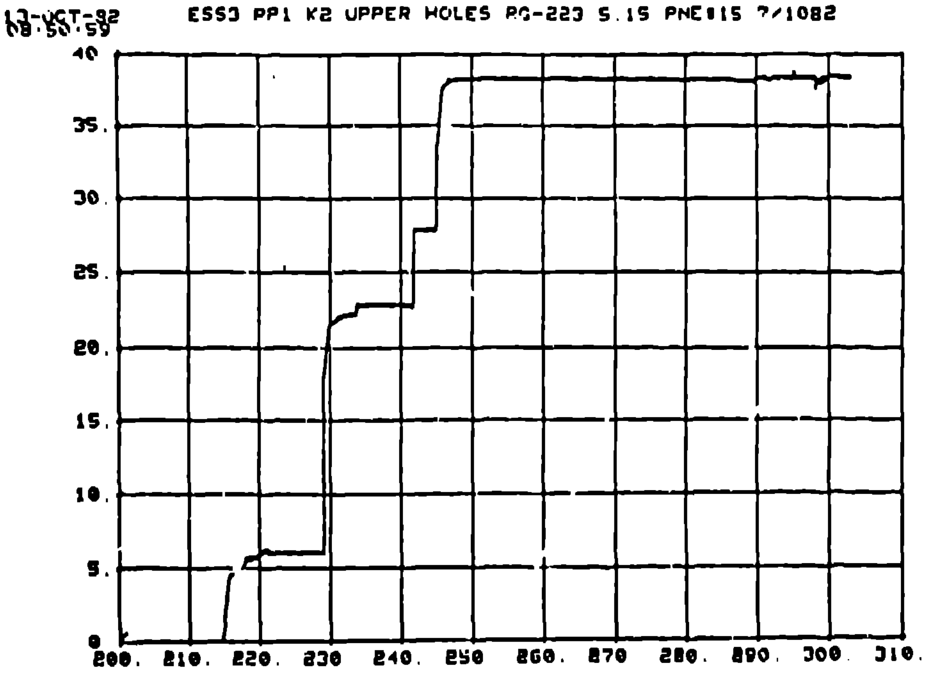


Fig. 5. Data from a multi-borehole multi-timed shot.

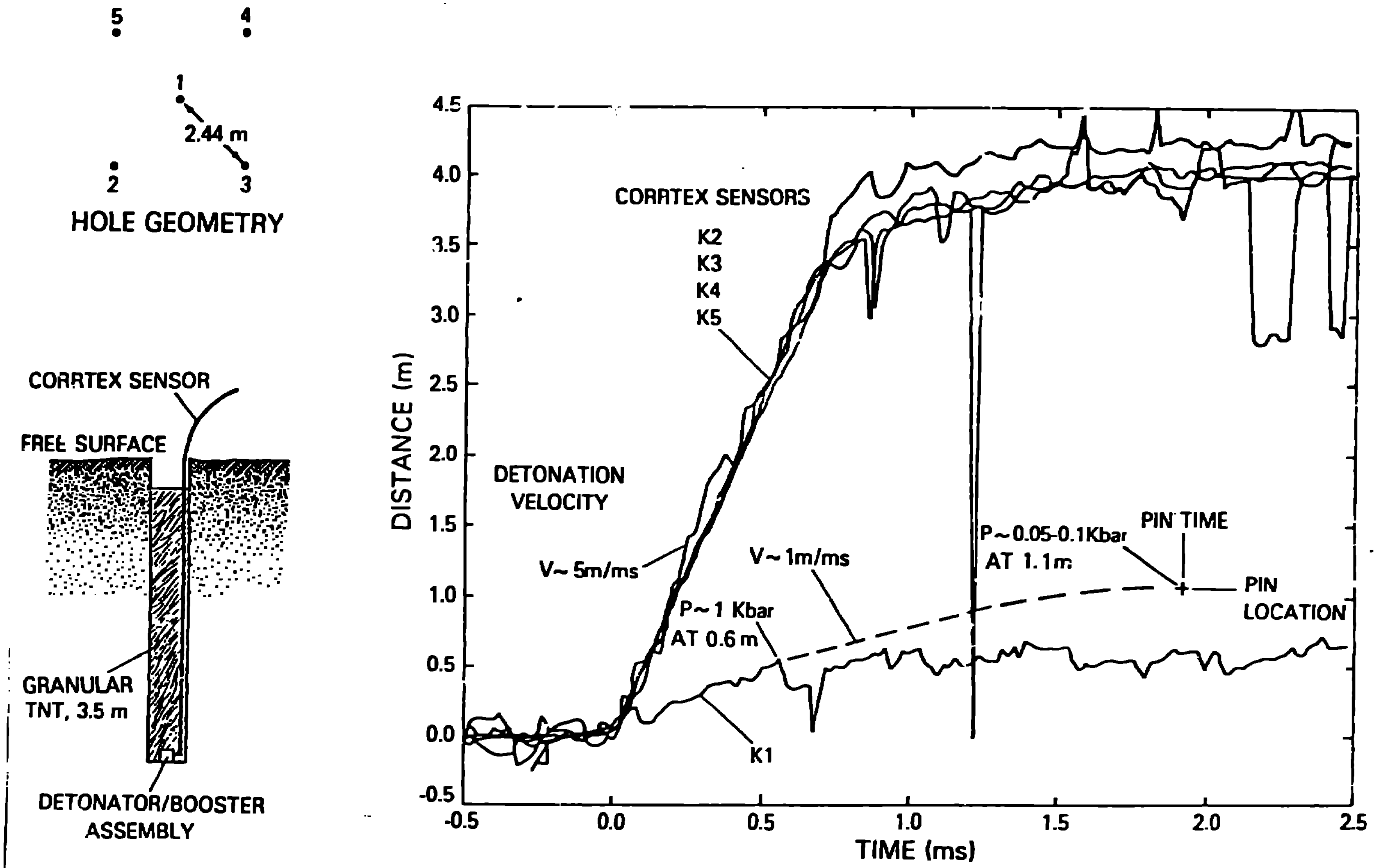


Fig. 6. Los Alamos data for Anvil Points experiment B-4 conducted on January 7, 1982. Pressure levels inferred from FSJ1-50 and RG-174 sensor crush thresholds.

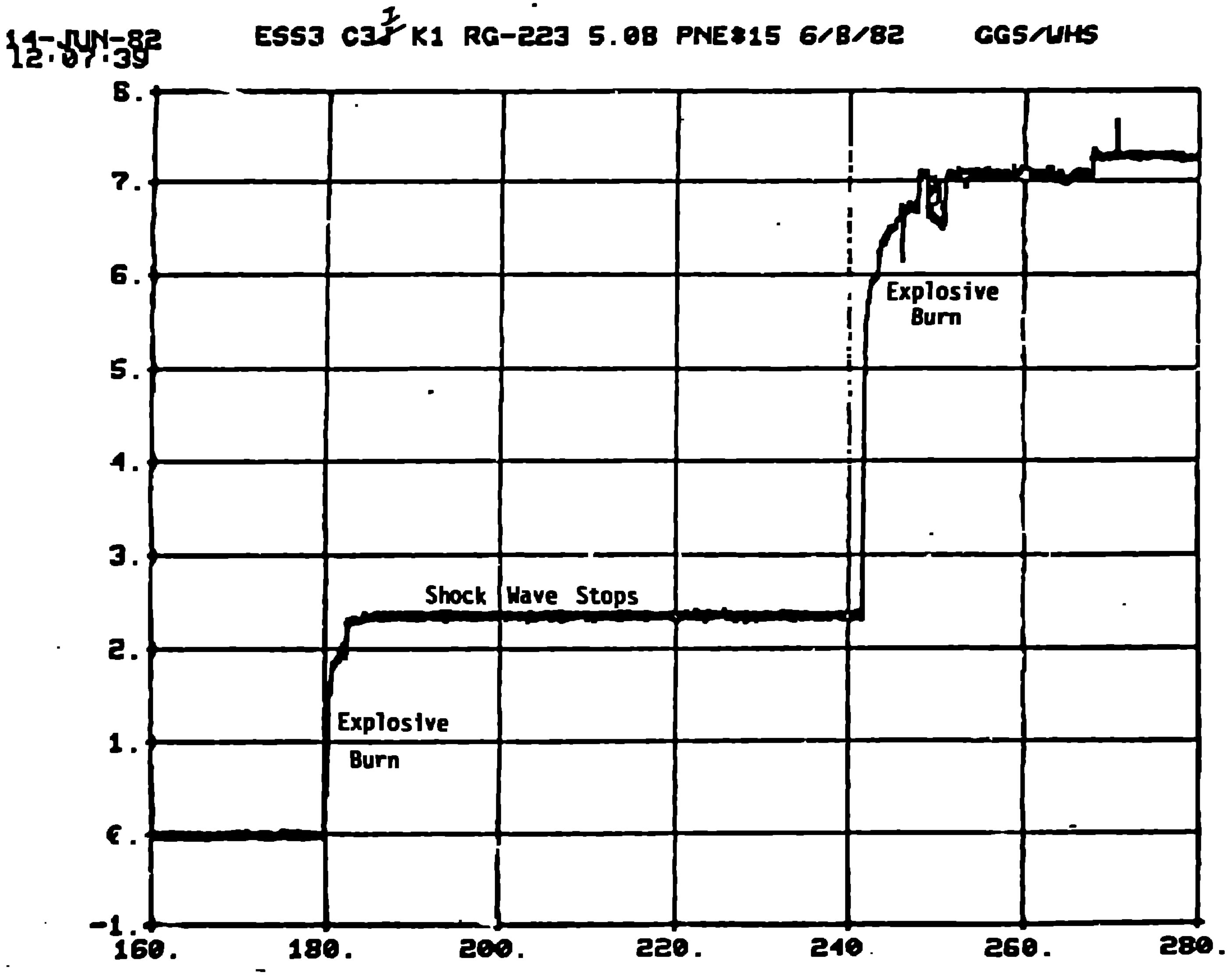


Fig. 7. Data from a single borehole with multiple explosive charges. Note the shock wave stops in the stem.