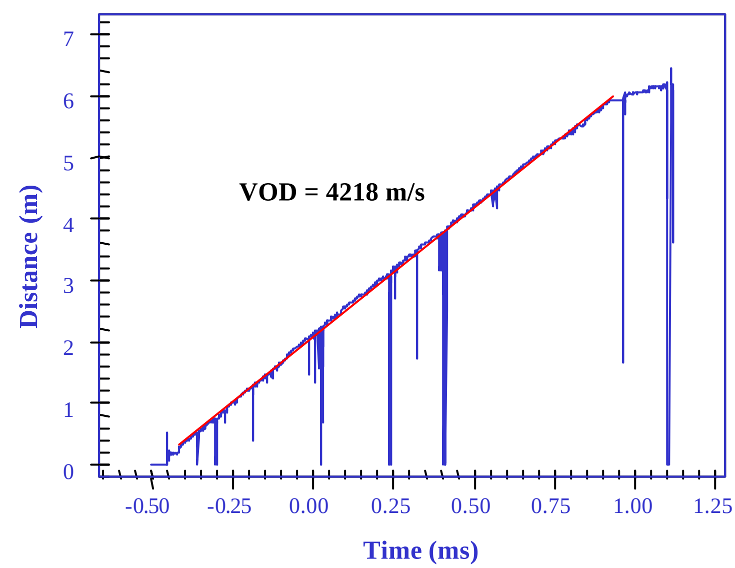
EVALUATION OF EXPLOSIVES PERFORMANCE THROUGH IN-THE-HOLE DETONATION VELOCITY MEASUREMENT

An S&T Project funded by Ministry of Coal
Government of India



Project Code. MT/96/96
August 2001

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FINAL REPORT
FOR
S&T PROJECT

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SUMMARY

The velocity of detonation (VOD) is one of the most important properties of explosives. It is essential that the explosive in the field condition detonates at its optimum rate and induces sufficient detonation pressure leading to good fragmentation. An S&T project on **"Evaluation of explosives performance through in-the hole detonation velocity measurement "** was taken up by National Institute of Rock Mechanics (NIRM) in collaboration with Singareni Collieries Company Limited (SCCo Ltd.). The objectives of the studies were

1) To measure VOD in blastholes in order to understand the effect of explosive compositions (for bulk), primer to base ratio (for cartridge explosives), hole diameter, water, contamination, primer location and size, sleep time etc.,

2) To rate the performance of different explosives and to evaluate the blast performance.

3) To compare the measured VOD values with those claimed by the manufacturers and standardise an index based on confined and unconfined results.

4) To establish a system for the selection of explosives through VOD measurements.

In this project, resistance wire continuous VOD measurement systems: MicroTrap, VODSYS-4 from MREL, Canada and VODMate from Instantel, Canada were used. Experiments were conducted at OCP-1 and OCP-3 of Godavari Khani area of SCCo Ltd, besides two limestone mines, namely Jayanthipuram limestone mines of Madras Cement Ltd and Walayar limestone mine of Associated Cement Companies Ltd. A total of 58 blasts were monitored at Singareni and another 11 blasts at two limestone quarries to complete the wide range of experiments stated in the objectives.

The measurement of VOD of explosives in the hole required a shock tube initiations system with zero delay such as EXEL detonators to attain bottom initiation. Experiments were carried out to test VOD and their performance for both cartridged and bulk explosives. An attempt was also made to monitor VOD with detonating cord.

The measured in-the-hole VODs of cartridges explosives were higher than the quoted values by their manufacturers. In case of bulk explosives, the VOD values were nearly matching with the quoted ones. The VOD of ANFO, primed with cap sensitive cartridged explosives

did not vary significantly by increasing percentage of primer/booster from 14 to 49. In case of cartridged slurry explosives also, the measured VOD was in the range of 3800-3900 m/s when the percentage of primer/booster was increased from 20 to 40. Kelvex-P of about 4 per cent reliably initiated ANFO but when the primer was reduced to 2 per cent, the explosive did not attain its steady state VOD. The VOD of the SMS explosive, primed with cast boosters with 0.17 to 0.40 percentage of primer/booster was within the range of 4364-4726 m/s and did not show increasing trend with the increase of primer/booster ratio. The cast boosters about 0.2 per cent were sufficient for priming the site mixed slurry. A single point priming was sufficient to reliably initiate and sustain the steady state VOD of explosives up to 10m long column without any additional booster charge.

The contamination of SMS explosive while charging resulted in lower VOD. The analysis of VOD records in dragline benches confirmed that SMS explosives can be loaded in blastholes up to depth of 30m without the risk of attaining dead density of the explosive due to hydrostatic pressure. The experiments conducted with SMS explosives containing 0 to 9 per cent of aluminium powder indicated that the VOD values did not increase with the increasing aluminium percentage. The experiments conducted in completely wet holes were not successful due to inefficient shorting of probe cable. The VOD decreased by about 25 per cent when SMS 654 had a sleep time of 25 days. The VOD value of ANFO was greater in 250 mm diameter than in 115 mm diameter holes. However, the influence of blast hole diameter was not so conclusive for bulk explosives tested in 150 mm and 250 mm diameter holes.

It was found that confined VODs were 1.2 to 1.4 times greater than the corresponding unconfined VOD values. Provided that the stemming length was adequate, the VOD of explosives did not vary with the stemming length. Based on VOD measurement, a framework for selection of explosives has been suggested.

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CHAPTER 1

INTRODUCTION

A large quantity of explosives is used for blasting in coal mines. The consumption of explosives in 2000 A.D. was more than 400,000 tonnes. At an average price of Rs. 15000/tonne, coal mines are spending approximately Rs. 60 crores in explosives alone. Presently various types of explosive (NG-based, Slurry, Emulsions, ANFO and Heavy ANFO) are manufactured in India by more than 25 companies under different trades names. The availability of large number of manufacturers and types of explosive provides flexibility in the explosive selection to suit a wide range of rock mass condition and blasting applications. However, too many manufacturers and trade names of explosives in the market have made the selection process very difficult and confusing. It is difficult to accept or reject any explosive without assessing their performance in the field. The current practice of selection of explosive gives undue importance only to the cost and powder factor, ignoring many other equally important parameters including degree of fragmentation, ground vibration produced and safety in charging and handling of explosives.

The explosives are characterised by their properties such as strength, density, velocity of detonation etc. The rate at which the detonation wave travels through an explosive column is called the velocity of detonation. It is the most important property for selection of explosives. Velocity of detonation is specified by explosive manufacturers in their product literature. Usually these VOD values are based on the measurement in laboratories. However, the laboratory values do not match with the VOD measured in the hole. Evaluation of a blast design is carried out with the assumption that the explosives have performed as per the specifications, which may not be true in all cases. A reduction in the VOD will produce a reduction in the detonation pressure as well as in the availability of the shock energy of the explosive. It is important that the explosive detonates at its optimum rate and induces sufficient detonation pressure leading to good fragmentation. The VOD of an explosive can, therefore, be used as one of the indicators of its performance.

VOD measurements in the field using discrete system were carried out by NIRM at Malanjkhand Copper Project as a part of an S&T project for the first time in India (Venkatesh et al, 1994). However, it was felt that discrete measurement systems do not provide a comprehensive information along the charge length as the calculated VOD is only the average velocity of the explosive between two points. Any change in velocity in the measured region, such as the run-up to detonation, or even the onset of failure, will not be evident with this system. With the development of blast monitoring systems, continuous VOD monitoring systems are also recently available. The VOD measurement in the hole helps in comparing and in evaluating the relative performance of explosives. Blasting performance is directly related to the characteristics and efficiency of the explosives used. The selection of the proper explosive for a particular blast conditions and objectives depend on the ability to characterise the performance of different explosives.

Therefore, an S&T project on **"Evaluation of explosives performance through in-the hole detonation velocity measurement "** was taken up by National Institute of Rock Mechanics (NIRM) in collaboration with Singareni Collieries Company Limited (SCCo Ltd.). The project was approved in the 23rd meeting of SSRC held on April 25, 1996. The total cost of this project was Rs. 23.84 Lakhs.

In this project, resistance wire continuous VOD system was used from two different manufacturers namely MREL and Instantel from Canada. Four types of probe cables were used. A total of 58 blasts were monitored at Singareni coal fields and another 11 blasts at two limestone quarries to determine the influence of various parameter on VOD of explosives.

OBJECTIVES OF THE STUDY

1) To measure VOD in blastholes in order to understand the effect of explosive compositions (for bulk), primer to base ratio (for cartridge explosives), hole diameter, water, contamination, primer location and size, sleep time etc.,
2) To rate the performance of different explosives and to evaluate the blast performance.
3) To compare the measured VOD values with those claimed by the manufacturers and standardise an index based on confined and unconfined results.
4) To establish a system for the selection of explosives through VOD measurements.

WORK PROGRAMME

The study was mainly conducted in OCP-1 and OCP-3 of Godavari Khani area, Singareni Collieries Company Limited. The work was executed in close association with R&D Department, Mining department and Explosives manufacturers. The study was planned for in-the-hole continuous VOD monitoring of blastholes with the following work plan:

a) VOD measurements for existing explosives (cartridge and bulk).

b) VOD measurements for changed composition such as Al, etc.

c) Effect of primer size and position on VOD.

d) Effect of hydrostatic pressure in deep holes on VOD.

e) Effect of sleep time on VOD.

f) Effect of hole diameter on VOD.

g) Effect of contamination and water on VOD.

h) Effect of stemming length.

STRUCTURE OF THE REPORT

This report documents the field investigations, the results and analysis, practical problems encountered during the study. Apart from this chapter, the report is divided into five more chapters.

Chapter 2 describes the properties of explosives, state-of-the-art in VOD measurement techniques and application of measured of VODs.

Chapter 3 presents elaborately about the field investigation including site selection, site descriptions, the instruments and accessories used, the number of blasts monitored and the number of events successfully recorded.

Chapter 4 presents the experimental set-up for the blasts monitored and the VOD records for each set of experiments. It also discusses the results obtained.

Chapter 5 presents a framework for explosive selection

Chapter 6 brings out the conclusions and recommendations from this study.

CHAPTER 2
REVIEW OF LITERATURE

2.1 PROPERTIES OF EXPLOSIVE

The selection and evaluation of explosive performance depends on the properties of the explosive. The important properties of explosives include:

1. Density
2. Velocity of Detonation (VOD)
3. Detonation Pressure
4. Sensitivity (hazard, performance, initiation, propagation)
5. Energy output/strength
6. Water resistance
7. Thermal stability
8. Fume characteristics

Density

Density is defined as the mass per unit volume, expressed in g/cc. Density affects sensitivity and performance of the explosive. An explosive sensitivity can be reduced by too much increase in density. If the density of explosive exceeds the critical density even a good primer may not detonate it.

A useful expression of density is loading density, which is the weight of the explosive per unit hole length. This helps in determining the weight of the explosive loaded per running meter of the blast hole. The density of most explosives vary between 0.8 to 1.35 gm/cc

Velocity of Detonation

Velocity of Detonation is the rate at which the detonation front travels through a column of explosive. Every explosive has an ultimate or ideal detonation velocity known as steady state velocity of the explosive. VOD of any explosive is influenced by its chemical composition, diameter of the blast hole, confinement, temperature, degree of priming etc. VOD of commercial explosives falls in the range of 2500 – 5000 m/s.

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Detonation Pressure

It is the pressure in the reaction zone behind the detonation front, at the Chapman - Jouquet (C-J) plane, expressed in kilobars. Detonation pressure is a function of charge density, VOD and the particle velocity of the explosive material.

Detonation pressure is different from explosion pressure, which is the pressure after the adiabatic expansion back to the original explosive volume. The explosion pressure is theoretically about 45% of the detonation pressure. The detonation pressure can be approximated as follow:

$$P = 2.5 \text{ x } 10^{-6} \text{ x } \rho \text{ x } V^2$$

where P is detonation pressure (kilobars), V = velocity of detonation (m/s) & ρ = density (gm/cc). The values of detonation pressure help in blast design to attain desired fragmentation. It is also important in priming for effective and reliable initiation that the primer exceeds the detonation pressure of explosive charge.

Sensitivity

Sensitivity of an explosive is it's ability to propagate through air at which a primed half cartridge (donor) will detonate an unprimed half cartridge (receptor), under unconfined conditions. It is expressed in several forms such as hazard sensitivity, performance sensitivity, initiation sensitivity, propagation sensitivity, gap sensitivity, etc.

Strength / Energy Output

The strength of an explosive is related to the theoretical available chemical energy in the explosive composition. It is a measure of its ability to do useful work. Different explosive manufacturer use different expression to indicate their explosive strength. The terms used to express explosive strength are Absolute Weight Strength. (AWS), Absolute Bulk Strength (ABS), Relative Weight Strength (RWS) & Relative Bulk Strength (RBS).

Absolute Weight Strength (AWS) is the measure the absolute amount of energy (in calories) available in each gram of explosive.

Absolute Bulk Strength (ABS) is the measure of the absolute amount of energy (in calories) available in each cubic centimeter of explosive. ABC is the product of AWS & density of the explosive.

Relative Bulk Strength (RWS) is the measure of the energy available per unit volume of explosive as compared to an equal volume of bulk ANFO at 0.81gm/cc density.

Water Resistance

It is the ability of the explosive to withstand water penetration without losing sensitivity or efficiency. The liberation of brown nitrogen oxide fumes from a blast often indicates inefficient detonation caused by water deterioration and implies need for better water-resistant explosives.

Water resistance is expressed as the number of hours a product may be submerged in static water and still be detonated reliably. The water resistance property depends not only on inherent ability of explosive to withstand water but also on the water condition. Static water at low pressure will not affect as quickly as dynamic fast moving water, specially at high pressure. All slurry and emulsion explosives are having good water resistance. ANFO is having no water resistance. By mixing emulsion, ANFO is made water-resistant.

Thermal Stability

The temperature at which explosive is stored and used may have a detrimental effect upon it's ultimate performance during the use. The explosives used in below freezing temperatures are specially formulated so that they do not lose their characteristics. For example, dynamite will freeze and become hazardous to tampering, slurries become stiff and insensitive and fail to detonate. All types of NG - based explosives are prohibited to be used in hot holes. Only slurries and emulsions are permitted to be used in hot hole having maximum temperature up to 80^o C.

Fume Characteristics

The explosion gases consist mainly of carbon dioxide, oxides of nitrogen, carbon mono-oxide etc. The explosive composition is balanced when the oxygen contained in the ingredients reacts with the carbon and hydrogen. If there is negative oxygen balance (insufficient oxygen) then the tendency to form carbon monoxide is increased. If there is positive oxygen balance (excess oxygen), oxides of nitrogen are formed. The excessive liberation of toxic fumes are due to insufficient charge diameter, inadequate priming, water deterioration, reactivity of the product with rock or other material being blasted, incomplete product reaction etc.

2.2 IDEAL AND NON-IDEAL DETONATIONS

When an explosive charge confined within a blasthole is detonated, the previously stable condensed ingredients of the explosive are rapidly converted into gaseous products at very high pressure and temperature. The chemical reaction or detonation front travels along the explosive column generally at a speed of 3000-6000 m/s which is defined as the velocity of detonation (VOD). The detonation reaction may be considered as a self-sustaining exothermic reaction, at the steady state velocity of detonation. The term detonation indicates that the chemical reaction is moving through the explosive at a faster rate than the acoustic velocity of the unreacted explosive. Consequently, a shock condition is created. Instantaneously after the passage of the shock front the gaseous products of the detonation are confined to the original charge volume at very high temperatures and pressures

In ideal detonations, a plane shock wave travels through the explosive which heats and causes the chemical reaction that supports the shock wave. The speed of the shock wave is called as the "Velocity of Detonation". The detonation zone is thin and is bounded at the rear by the Chapman-Jouget (CJ) plane and at the front by the shock wave. In ideal detonation it is assumed that all the potential energy of the explosive is liberated almost instantly in the thin detonation zone. Behind the CJ plane are the stable detonation products which are mainly gases at high temperatures and extreme pressures. This zone is referred to as the explosion state and it is envisaged that the detonation products in this zone occupy the same volume as the original explosive. The important features of ideal detonation of an explosive are illustrated in Figure 2.1

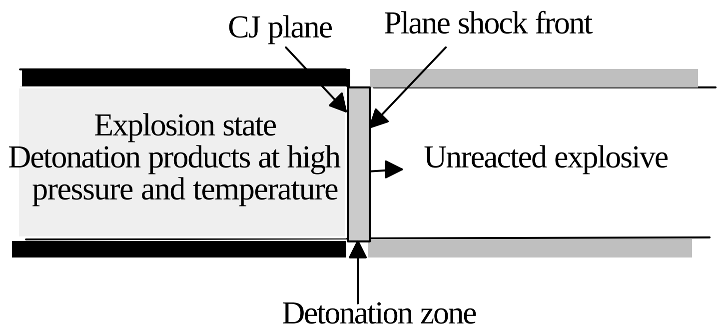


Figure 2.1 Features of ideal detonation process of explosive (Brinkmann, 1990)

In reality, the detonation of most commercial explosives is non-ideal because a significant degree of chemical reaction takes place behind the CJ plane. The shock front is not planar but curved because of the reduced pressures and the reaction rates near the edge of the explosive. The detonation zone represents the volume where the reaction energy supports the shock wave and is bounded at the rear by the CJ surface. The proportion of energy released in this zone is higher for ideal explosives. Further reaction in the zone behind the CJ surface does not support the shock front but will contribute to the rock breakage process since the gases do work until they escape into the atmosphere. The non-ideal detonation process is illustrated in Figure 2.2.

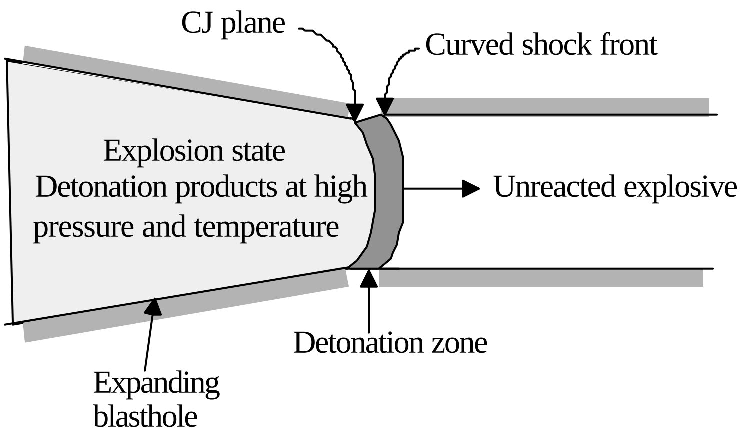


Figure 2.2 Features of non-ideal detonation process (Brinkmann, 1990)

2.3 FACTORS WHICH CAN AFFECT VOD

The factors that can affect the VOD of an explosive include (Chiappetta, 1998):

- Confinement
- Formulation characteristics
- Density
- Sensitising agent (s) - (chemical, gas, solid, metallic)
- Temperature and temperature cycling
- Primer size and type
- Sleep time in blasthole
- Nearness to critical diameter
- Nearness to critical density
- Borehole loading techniques
- Drop impact in borehole
- Blast design (confinement, relief, delay timing, initiation direction)
- Dynamic desensitising effects
- Explosive column length
- Blast environment
- Manufacturing
- Transportation

- Storage-shelf life
- Mixing in bulk loading system

2.4 PARTITIONING OF EXPLOSIVE ENERGY

The total usable energy released by the detonation of explosive charge in a blasthole can be split into shock energy and heave energy. The shock component of the energy can be produced by the high pressure of detonation front as it progresses through the explosive charge and impacts on the walls of the blasthole. This is a very transient pulse and it's magnitude is related to the density of the explosive charge and it's velocity of detonation. The shock energy contributes to the primary breakage of the rock in the blast.

The heave energy is the energy in the high pressure and temperature gases in the blasthole after the detonation front has passed. These gases exert a force on the walls of the blasthole and this causes the primary displacement of the material in the blast. Useful energy is performed by the explosive until the time when the high pressure gases vent to the atmosphere causing the pressure to drop to zero.

The split between the shock and the heave components of the energy released depends on the composition, density and velocity of detonation of the explosive. In general the higher the velocity of detonation of the explosive the more the energy split will favour the shock component.

2.5 TYPES OF VOD MEASUREMENT SYSTEMS AND CHARACTERISTICS

Various experimental methods, testing apparatus and procedures are used for the experimental determination of detonation velocity. Its measurement is based on the application of some detonation wave properties and various ultrafast signal recording techniques. The experimental methods used for the determination of detonation velocity may be classified into several groups (Table 2.1).

Table 2.1 Classification of experimental methods for determination of detonation velocity (Suceska, 1997)

Method	Principle of method
Dautriche method	Two processes that propagate at different linear velocities travel different distances in the same time interval. The ratio between the lengths of these distances is a simple function of the velocities of these two processes.
Optical methods	Detonation is an autoluminous process. This property makes possible continuous viewing of detonation wave propagation through an explosive by suitable high-speed cameras. The detonation velocity is then calculated from the obtained detonation wave distance-time curve.
Electrical methods	a) The detonation products, in detonation wave front, are highly ionised, which makes them capable of conducting the electric current. This property is applied for the creation of a short circuit between two conductors at the moment of the detonation wave passage. In combination with suitable ultrafast signal recording technique, it enables the recording of instantaneous position of the detonation wave front. b) The action of detonation wave pressure may be used for the mechanical closure (or breakage) of an electric circuit between two conductors. Thus, it is possible to detect, and to record, by ultrafast signal recording technique, the instantaneous position of the detonation wave front.
Methods based on the application of optical fibers	Optical fiber is capable of detecting and transmitting a light signal accompanying the detonation wave front. This light signal may be recorded by optical methods (using a high-speed camera), or may be transformed into an electric signal (by fast photodiode) which is then recorded by suitable ultrafast signal recording technique.

The transitory nature of the detonation phenomena, as well as its destructive character, make experimental methods applied for the determination of the detonation velocity of an explosive very specific. Since the detonation velocity for known explosives can reach nearly 10 mm/μs, and the total duration time of an experiment usually equals only a few microseconds. The recording of such high speed phenomena requires the use of special ultra-fast signal recording techniques. At the same time, the signals must be transmitted from the firing area in real time and over a distance of several meters before being recorded in an appropriate shed.

A number of VOD systems are commercially available today. These systems can be broken down into two broad types: a) Point to point VOD systems, and b) Continuous VOD systems

2.5.1 Point to Point VOD Systems

Point to point VOD systems are essentially start and stop devices which are based on an electronic timer. The first sensor cable (i.e. channels) starts a clock and the following channels stop the clock in cumulative time relative to the start signal or relative to each other subsequent channel. It is important to accurately measure and record the distances between the probe ends.

VOD measurements with a point-to-point system are acceptable for some measurements, but will be limited in providing information for critical experimental measurements when trying to detect the degree of malfunctioning explosives and/or transient VOD's within the column.

The simplest method of detonation velocity determination consists of the measurement of the time interval needed for the detonation wave to travel a known distance between two points through an explosive charge. For such measurements the measuring equipment should provide:

- the detection of the arrival of the detonation wave at a given point of explosive charge.
- the measurement of very short time interval (on a microsecond scale) needed for the detonation wave to travel a known distance through the sample, between two points.

An example of field set-up for point to point VOD monitoring system using fiber optic probe is shown in Figure 2.3.

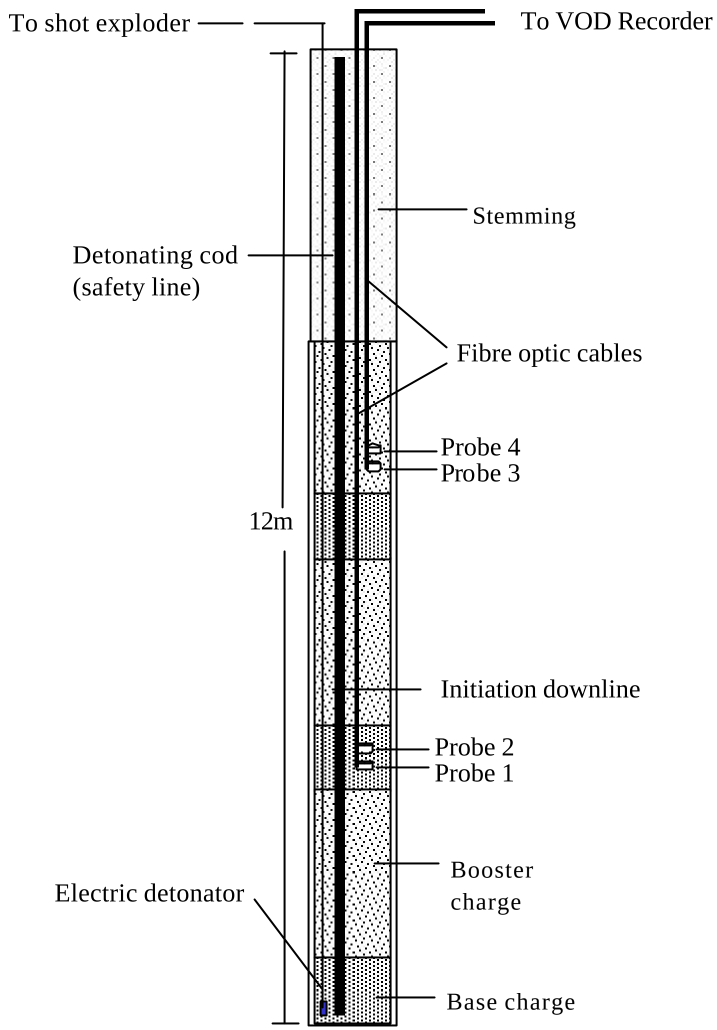


Figure 2.3 Field setup for in-the-hole point to point VOD measurements

2.5.2 Continuous VOD Systems

Resistance wire continuous VOD system

The continuous resistance wire method was developed in the early 1960s by the United States Bureau of Mines (USBM). Operation is based on the basic Ohm's law, ($E = RI$), where E = Voltage, R = Resistance and I = Current. When the current is held constant against a shortened (i.e. detonated) wire of known resistance per unit length, a voltage drop can be measured instantaneously at any point in time. The voltage drop is equivalent to the length of resistance wire consumed in the detonation (Figure 2.4). Resistance wire probes actually consist of two wires which must be physically shorted out by the detonation through ionisation. Some resistance wire probes consist of just two insulated wires twisted together and other probes consist of one coated wire placed inside of a small metal tube which acts as the second wire.

Providing that the wires are adequately shorted during the detonation, the resistance wire method does provide a truly continuous VOD along the explosive column due to the high sampling rates ranging from 1.25 MHz to over 10 MHz. If the wires are not adequately shorted in a continuous and reliable fashion, erroneous results, excessive electronic noise and severe drop outs are the norm. In such cases the results are usually undeciphered or no readings are obtained.

SLIFER continuous VOD system

The SLIFER (Shorted Location Indication by Frequency of Electrical Resonance) system was originally developed by Sandia National Laboratories to measure the propagation of shock waves from nuclear explosions. It consists of a shorted length of coaxial cable placed in an explosive.The cable forms part of an oscillator circuit, the frequency of which is governed by the length of the cable. As the explosive detonates and crushes the cable, the effective length of the cable decreases and the frequency of oscillation increases.By monitoring this frequency as a function of time, the rate of cable length change can be determined, leading directly to the measurement of VOD.An on board electronics package, enables the measured frequency to

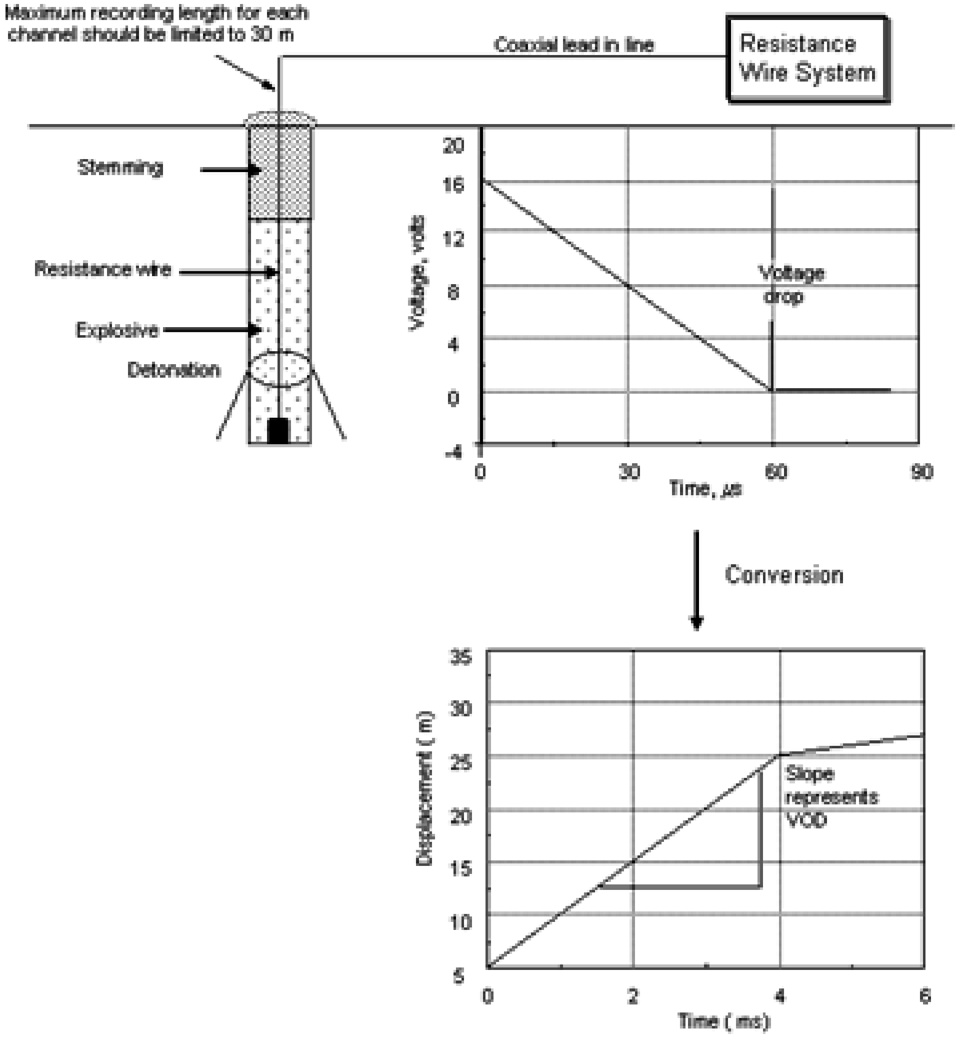


Figure 2.4 General field set-up and operation for the resistance wire VOD technique

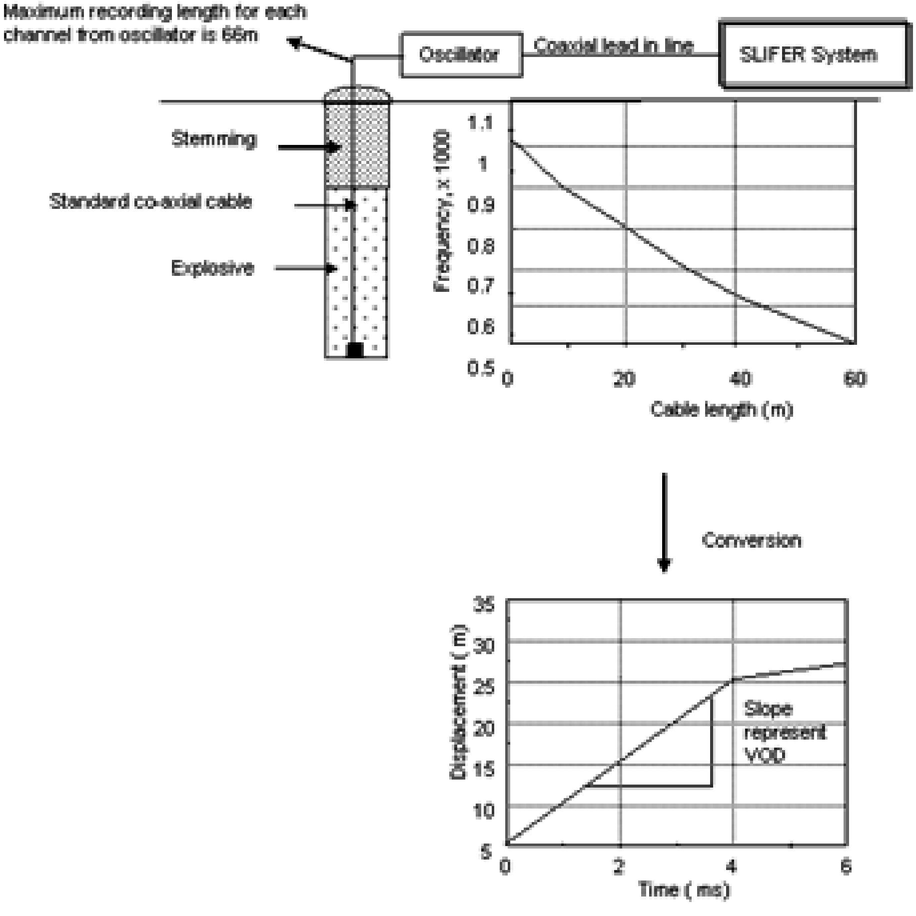


Figure 2.5 General field set-up and operation for the SLIFER VOD technique

be converted to a voltage in real time. This information is then linearised and VOD derived from the slope of the resulting trace; a plot of cable length with time (Figure 2.5).

It is an excellent system for laboratory work, but with a reasonable overlap of applications for full scale field tests. One of the field limitations of SLIFER system is that the recording cable length beyond the oscillator is restricted to 66 m per channel. Each channel must have an oscillator in line, and this means that the oscillator must be placed fairly close to the hole or shot area.

TDR continuous VOD system (VODR-I)

The first TDR (Time Domain Reflectometry) system was originally developed by the Los Alamos National Laboratory to test and verify nuclear reaction yields, and stress velocities into the surrounding medium. This system was known as the CORRTEX system but was later changed to the VODR-I when the system was declassified for commercialisation. Any standard 50 Ω coaxial cable can be used for the measurement of commercial explosive performance or reaction rates.

Operation is similar to that of RADAR where a radio pulse of radio waves is sent out and an echo or reflected pulse is returned to give ranging information. The VODR-I uses standard coaxial cables to carry a fast, rise time electrical pulse, (with a pulse width of 200 nanoseconds), back and forth every 5 to 200 μs. The pulse travels in the cable at 70 to 99% the speed of light, depending on the characteristics speed rating of the cable (Figure 2.6). The original raw data is always UNFILTERED so that what is recorded is exactly what you get. Also because the pulse width is so narrow, there is almost zero energy in the cable during operation, making the TDR system one of the safest to use with any commercial or military explosive.

One of the unique features of the TDR systems is that the electrical pulse is always reflected from the cable end, regardless of whether the coaxial cable is shorted or not. In comparison to the resistance wire system and/or coaxial cables used in the SLIFER system, the TDR does not require the sensing cables to be shorted in order to acquire data.

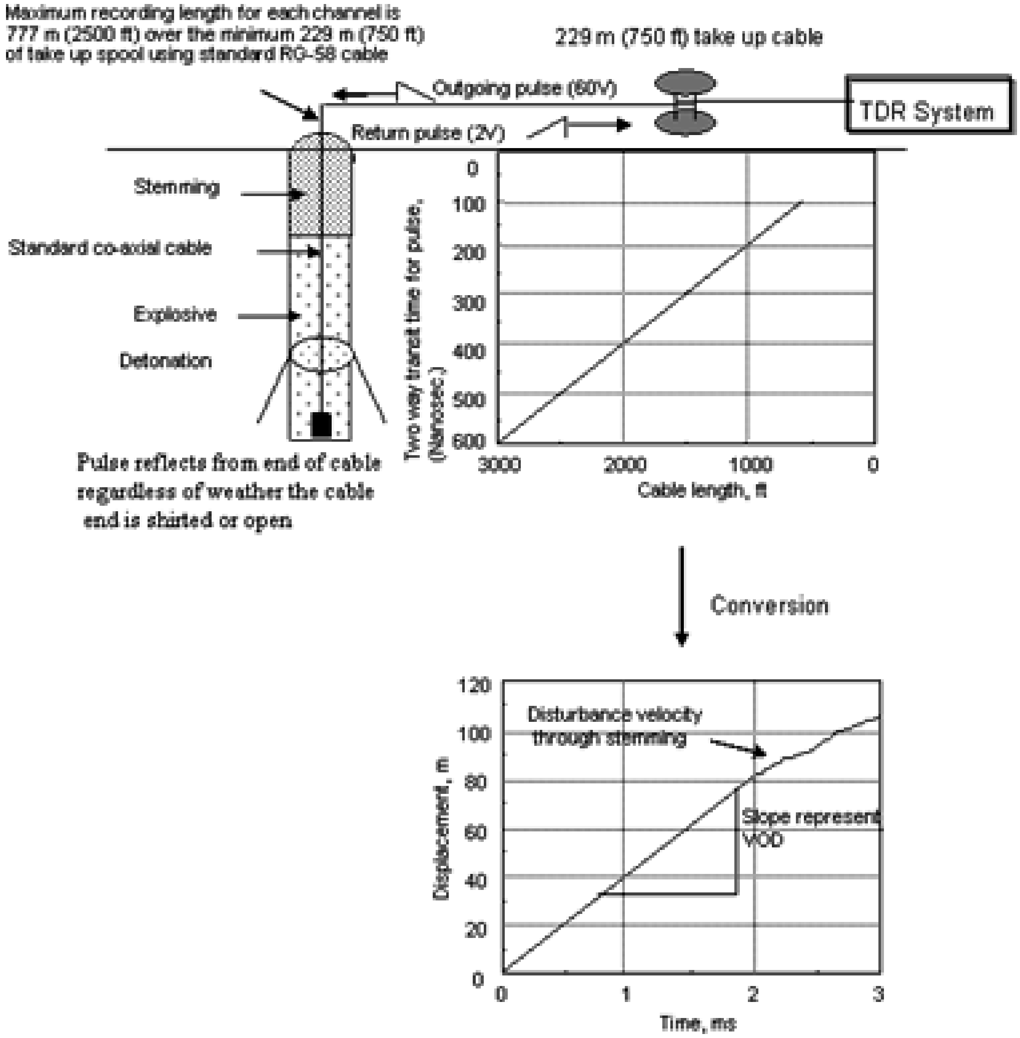


Figure 2.6 General field set-up and operation for the TDR VOD technique

2.6 APPLICATION OF MEASURED VODs

The velocity of detonation (VOD) of an explosive can be used to indicate a number of important characteristics regarding the explosive's performance, under specific field and test conditions. When correctly interpreted, the results can be used to

1. Evaluate the consistency of detonation
2. Confirm whether detonation, deflagrations or failures have taken place
3. Study the influence of primer size on explosive performance.
4. Compare laboratory and field VODs
5. Rate the performance of explosives

Because VOD is a direct measurement of the source function, it can provide valuable information with respect to shock, stress waves, kinetics, ground vibration, airblast, fragmentation and undesirable noxious fumes.

2.6.1 To Evaluate the Consistency of Detonation

Ouchterlony et al (1997) have reported VOD values for Emulan 7500, a gassed heavy ANFO type emulsion, measured in smaller and larger diameters. The VOD values were highest near the primer and decaying towards the top of the holes, as the density of the explosive decreased. The VOD values of the production holes were about 10% higher than for the smaller holes. The differences between the VOD values of the diameter of 140 mm and 165 mm holes were, however, too small to be significant compared to the scatter, which was about 5-10%. This shows that the explosive held a consistent quality during the tests.

Chiappetta (1998) has provided with illustrations for

a) stable detonation in bulk explosive charges
b) unstable detonations in bulk explosive charges
c) detonation in cartridged explosives
d) partial, low order detonation in explosive charges

2.6.2 To Confirm Whether Detonation, Deflagration or Failures

During the early stages of the box cut mining at the Arthur Taylor Colliery, Opencast Mine (ATCOM), problems were experienced with blasting results. Very large boulders and portions of completely unfragmented rock were commonly encountered. A full blast monitoring programme was instigated by the mine and the explosive supplier to solve the problems and to optimise future blasting operations at the mine.

Eight experimental blasts were monitored (Ladds, 1993). Three of the blasts were bulk emulsion blasts and the remaining five blasts were shot with Heavy ANFO. Detailed instrumentation included measuring VOD in about 20 holes per blast.

The VOD record shows a deflagration in the bottom portion of a blasthole at about 500 m/s and detonation in the top portion. The detonation occurred following the initiation of the top primer. The portion where deflagration occurred, the pressures in the detonation front were not sufficient to crush the sensor cable cleanly, with the result that the signal in this portion of the hole was very noisy.

There was consistency of ANFO's performance with most readings falling in a narrow band at 5200 m/s. As with the bulk emulsion, a few deflagrations did occur. The performance of the hot emulsion was variable with VOD generally ranging from 3100 m/s to 6300 m/s. A significant number of misfires were detected in the hot emulsion blasts and were found to be associated with primer failure. It was established through the VOD results that the shock tube assemblies used as down-lines were failing near the hole bottom and were therefore not compatible with the hot emulsion being used. This prompted a change to cold emulsion based heavy ANFO.

2.6.3 To Study the Influence of Primer Size on Explosive Performance

It is generally regarded that if a primer is too small, the explosive may require a considerable time or run-up to reach its steady state VOD. Similarly, the use of too large a primer can lead to overpriming resulting in waste of explosive energy and increased costs. Through the continuous measurement of VOD in-the-hole, Moxon et al, (1992) studied the degree of the influence of primer on the explosive performance for three different types of explosives. The conclusions of their study are:

- ANFO in 187 mm blastholes shows no discernible run-up for a wide range of primer sizes from 150 to 2260 g. A steady state of VOD of 4100 m/s was attained.

- Emulsion and watergel explosives exhibit run-up in both 187 and 311 mm diameter blastholes. This occurred over a distance of 7 to 10 blasthole diameters. The steady state VOD was 5100 -5400 m/s for Ex-70 (a blend of emulsion and ANFO) and 5200-5600 m/s for GX-20 (a watergel).

- Primer as small as 150 g may be used to initiate ANFO charges. Large (400 g) primers are recommended for the emulsion and watergel explosives.

Slightly different conclusions were reached by Mainardi and Robinson (1997). They found that, within the limits of experimental accuracy the steady state VOD of emulsion/ANFO products was independent of the primer size or type. No gradual build up of VOD was observed in the part of the hole immediately adjacent to the primer cartridge with any of the explosive types assessed.

2.6.4 To Compare Laboratory and Field VODs

The difference between the value of VOD measured in laboratory for an unconfined explosive and the value of VOD measured in the hole increases when the behavour of the detonation of the product is not ideal (Mainardi and Robinson,1997). This difference increases for the less homogeneous products (ANFO) while the difference is not as great for the dynamites and watergels.

2.6.5 To Rate the Performance of Explosives

With an objective to have a performance rating of different explosives under field conditions, in-the-hole VOD measurements using fiber optic probes were carried out at Malanjkhand Copper Project (Venkatesh *et al*, 1998). The project consumes about 2500 tonnes of cartridged explosive per annum supplied by several manufacturers.

Single hole blasting tests under identical conditions were conducted. The standard loading pattern being practiced at the mine was employed. Three different manufacturer's two product system was chosen for the experiments. A two product system is a combination of primer charge and base charge from the same manufacturer. Each explosive system was tested twice to ascertain the repeatability.

The measured VOD values varied between 5661 m/s and 4298 m/s (Table 2.2). The overall system VOD is primarily dependent on the VOD of base charge than the VOD of the booster charge. The significance of the booster ceases the moment the base charge attains its steady state VOD.

Table 2.2 Measured VOD values with performance rating (Venkatesh et al, 1998)

Company	Explosive type	Density gm/cc	Declared VOD m/s	Measured VOD m/s	Average VOD m/s	Performance Ranking
A	A - Booster			4,785 &	4,796.5	3
	A - Base			5,437 &	5,549.0	1
	A - System			5,120 &	5,370.0	1
B	B - Booster	1.16	4000	4,952 & 4,790	4,871.5	2
	B - Base	1.13	3900	4,298 &	4,299.5	3
	B - System			4,476 &	4,413.5	3
C	C - Booster	1.15	4200	5,376 &	5,143	1
	C - Base	1.25	4000	5613 &	4,618	2
	C - System			5,395 &	4,620	2

Booster: cap sensitive cartridged explosive &   Base: Non-cap sensitive cartridged explosive
System: a combination of cap sensitive and non-cap sensitive cartridged explosive

The first experiment values for company C explosives are higher than their corresponding second experiment values (Table 2.2). This is due to excessive confinement as observed by the crater formed around the hole. Even though the VOD in this case is the highest blast result was not good due to excessive burden. Judging from the VOD values, it is concluded that the relative system performance of the explosive combinations of company A, B, C can be rated as 1, 3, 2 respectively. This conclusion was supported by the observations of the muckpile and fragmentation. Since the rocks at MCP are very hard and strong, a high VOD explosive would be desirable at the mine.

2.7 CONCLUDING REMARKS

A variety of equipment and measuring techniques for VOD are now commercially available. However, only a limited number of field investigations have been carried out. The measured VODs can be used to evaluate the performance of explosive, to determine minimum primer requirements, to confirm whether detonation, deflagrations or failures have taken place.

From the literature survey, it is felt that detailed field investigations are required using continuous system. The following have been identified for this study.

1. Measurement of in-the-hole VOD for bulk (different series) and cartridge explosives
2. Study on effect of Aluminium and cup density on VOD.
3. Study on the effect of sleep time on the VOD and effect of primer size on VOD.
4. Study on the effect of hole diameter and water on VOD.
5. Study on the effect of explosive contamination and explosive column dead weight on VOD.

CHAPTER 3

FIELD INVESTIGATIONS

3.1 SITE SELECTION

In consultation with Singareni Collieries Company Limited (SCCo Ltd), OCP-1 of Godavari Khani area was selected for the field experimentation. Later on OCP 3 of Godavari Khani was also included so as to monitor more number of blasts with various types of explosives used. Two limestone mines were also selected for VOD monitoring of ANFO in small diameter holes and to study the influence of primer size on VOD. These are Jayanthipuram limestone mines of Madras Cement Ltd (MCL) and Walayar limestone mine of Associated Cement Companies Ltd (ACC). The description of these mines are:

3.1.1 Open Cast Project-1 (OCP-1)

Open cast project-1, Godavari Khani falls within the South Godavari lease hold of the Singareni Collieries Company Limited. The estimated total reserve is about 54.4 million tonnes and the annual production from the mine is about 2 million. The topography of the quarry area is flat and gently undulating and is covered with a thin mantle of subsoil. The coal seams are gently sloping on both sides of the property from 9^0 to 16^0. Almost half of the reserves of No. 3 and 4 seams combine to make a composite seam of 14m. The overburden consists of massive grey white medium to coarse grained felspathic sand stone inter collated in some horizons with thin bands of shale, clay and carbonaceous sand stone.

Conventional opencast mining method using shovel - dumper is adopted in this mine. EKG 4.6 m^3 shovels in conjunction with 50T dumpers are used for hauling the waste rock/coal from the mine. Rotary drills of 250mm diameter are used for production blasts. A walking dragline of 24/96 is deployed to work in extended bench method with a cut width of 60m with a bench height of 24m.

3.1.2 Open Cast Project-3 (OCP-3)

Open cast project-3, Godavari Khani forms part of Godavari Khani No. 7 & 7A Inclines of Singareni Collieries Company Limited. The mine was initially developed by underground mining methods. Part of the seams has worked by longwall and board & pillar methods. The estimated total mineable reserves are about 66.72 million tonnes. The annual coal production for the mine is about 2.75 million tonnes.

The topography of the mine area is flat and gently undulating with a thin mantle of subsoil. The cumulative thickness of the coal varies from 3m to 23m having an average gradient of around 1 in 9.5. There are 7 quarriable seams occurring in this block which are numbered from top to bottom as 1A, 1, 2, 3B, 3A, 3 & 4 seams. The overburden consists of massive grey white medium to coarse grained sand stone inter-collated in some horizons with thin bands of shale, clay and carbonaceous sand stone.

Conventional opencast mining method using shovel - dumper is adopted in this mine. Rope shovels of 10 m^3 in conjunction with 85/50T dumpers are used for hauling the waste rock/coal from the mine. Rotary drills of 250mm diameter are used in the waste rock while 150 mm diameter drills are used in coal and stone parting for production blasts. A walking dragline of 24 cu. yard is deployed to work in extended bench method.

Keeping in view that the experiments should not at all disturb the normal mining operations, almost all experiments were conducted in overburden benches of OCP 1 and OCP 3. Only one blast was monitored in coal bench. Experiments were conducted both in shovel and dragline benches, restricting some of the experiments such as the influence of contamination and sleep time in shovel benches only. The dragline blasts were considered for the experiments related to the influence of hydrostatic pressure on the VOD of the explosives. The overburden rock consisted of soft to hard sandstone. The hole diameter used for the experiments was 250 mm except for small diameter trials.

3.1.3 Jayanthipuram Limestone Mine (MCL)

Jayanthipuram Limestone Mine of M/s. Madras Cements Ltd., stared in 1986 with total mineable reserve of 35.693million tones. It holds "Mining Leases" over an extent of 852.22 Ac., including recently granted 18.0 acres in parts of Jayanthipuram village, Krishna district to cater the raw material requirement of 1.50 million tonnes/annum to produce 1.10 million tonnes of clinker per annum. The mine is located about 4 kms SSE of Jaggaiahpet and the road distance is about 8 kms.

Geologically the limestone bearing area has been divided into 17 main line each spaced 150m apart along the strike. At present the mine is being worked in two areas namely, pit 1 and pit 2. In order to stream line the production requirements and to control the quality, the mine management had started a third pit i.e., pit 3. The mine is worked by opencast mining system, fully mechanised and following deep hole drilling and blasting. The whole mine area is worked in three pits, namely pit-I, II, III, with 4, 5 and 3 no. of benches respectively each 8-10 m deep.

In this mine, the study was conducted to see the effect of different percentage of cap sensitive explosives in 115 mm diameter holes. The percentage of primer was varied from 20 to 100%. Besides, experiments were conducted with ANFO in 115 mm diameter holes.

3.1.4 Walayar Limestone Mine, ACC Ltd.

Walayar limestone mine belongs to the Associated Cement Companies Ltd. (ACC). It located at about 40 km from Coimbatore city and is producing about 2000 tonnes of limestone per day respectively.

The limestone deposit in Walayar extends in an almost East-West direction in the mining lease area and has a strike length of 2.5 km. The dip is very steep and at places it is vertical. The deposit is flanked by calc granulite both to the north and south. The limestone deposit is broadest at the central portion and gradually tapers at its western and eastern ends. The topography is gently undulating to flat towards the southern side while there are ridges of calc granulite towards the north. The reddish brown clay, locally known as 'oda' is intimately associated with limestone and such clay patches are found to occur close to limestone pegmatite contact.

The mine is being worked by mechanised system of open cast mining. Blasthole drills of 115 mm diameter, hydraulic shovels of 3.6 and 2.8m^3 bucket capacity and dumpers of 35 tonnes are employed. The mine benches advance towards the slope of the hill as well as along the strike direction. The planned height of the benches is 10m.

In this mine the experiments were conducted to study the percentage of primer using Kelvex- P and ANFO in 115 mm diameter holes.

3.2 SELECTION OF INITIATION SYSTEM

The measurement of VOD of explosives in the hole requires a shock tube initiations system. It is important to note that each hole must be point initiated at the bottom of the charge. Initiation anywhere in the charge column will immediately cut the probe cable. Detonating cord downlines may also damage the probe cable or cause side initiation of the explosive. The shock tube detonators do not effect the probe cable.

Down-the-hole initiators (shock tube) are supplied in India by ICI, IDL and PEL. The basic operation of in-the-hole initiation is dependent on a nominal constant delay down the hole and the duration of this delay is depending on the size of the blast. Generally a delay of 250, 300, 325, 450 and 475 milliseconds are in vogue. In the hole zero delays are not used for production blasts. For our R&D purpose, the zero delay EXEL detonators were supplied by ICI. In order to carry out the experiments the existing detonating cord down line system had to be replaced entirely with in-the-hole system or using down-the-hole delay in the experimental holes and balancing the delay interval in the blast. By doing so the chances of cut off due to partial use of shock tube in some of these experimental holes are very high and it was also found true during our experiments. Keeping this in view, it was appropriate to use zero delays down-the-hole so that the experimental holes become an integral part of the routine production blasts (using detonating cord and cord relays). By doing so, the cost on initiators was kept at minimum for the experimental blasts. In case, entire blast is initiated with in the hole delays, zero delays are not required. The nominal delay time of 250, 300, 325, 450 and 475 milliseconds does not have any bearing on the VOD results.

As the mine selected for this S&T project was using detonating cord downline system, purchase of EXEL detonators were made through SCCo Ltd. Though the requirement of shock tube detonators of specified length of zero delay was clearly mentioned, SSCo Ltd received 250 ms delay detonators instead of zero delay detonators. After having discussed the problems likely to be encountered with 250 ms delay with the Chief R&D of SSCo Ltd., the supplier was requested to replace 250 ms detonators with Zero delay detonators. The zero delay detonators reached the site on 22 April 1998. Thus there has been undue delay in procurement of zero delay shock tubes.

3.3 THE EXPLOSIVES USED FOR TESTING OF VOD

Both cartridged and bulk explosives, routinely used at selected mines were used for testing of VOD and their performance. We have tested the same explosives procured and used by the mine during that year. The process of supply of cartridged explosive is from one or two suppliers during that year. The same explosives may or may not be available in the following year as it depends upon the procurement procedure. Random samples were taken for testing.

In the beginning of the project, cartridged explosives from Nava Bharat Explosives were predominantly used at GDK OCP-1. Cartridged explosives of KEL, Maruti explosives and Ideal were also monitored during the field investigations. The properties of cartridged explosives as quoted by their manufacturers are given in Table 3.1. Different series of site mixed slurry explosives were tested in the actual field conditions. Since emulsions were not introduced in these mines during the study period, VOD was not measured for emulsions.

Table 3.1 Properties of cartridged explosives as quoted by their manufacturers

Name of the explosives	Manufacturer	VOD, mm/s	Density, gm/cc
Indoboost	IBP	4000±100	1.16
Indo prime	IBP	3900±200	1.11
Indogel 210	IBP	3800±200	1.12
Bharat prime	Nava Bharat	4000±200	1.10-1.25
Bharat column	Nava Bharat	3800±200	1.05-1.22
Maruti boost	Maruti	4000±200	1.20 – 1.25
Maruti column	Maruti	4000±200	1.15 – 1.25
IDEAL Boost	Ideal	Not Available	Not Available
IDEAL Gel	Ideal	Not Available	Not Available
Kelvex 600	KEL	4000±200	1.18-1.22
Kelvex 500	KEL	4400±100	1.20-1.23

SMS constitutes non-explosive ingredients such as oxidiser solution of ammonium nitrate, diesel, aluminium powder and other trace additives like gassing and cross-linking agents. Different products of varying energies can be manufactured with SMS. The products were named 614, 634, 654, 674 etc. in the order of increasing energy levels. The energy is increased by adding increased percentage of aluminium and balancing the oxygen required. Any three products could be calibrated on the truck and could be pumped in the same hole depending on the energy requirements of the rock. The density ranged from 0.6 to 1.28 g/cc. Due to auto-compressibility, the explosive is so distributed as to give higher density at bottom and gradually decreasing density towards top exactly sending the energy requirements of a blast. The properties of SMS explosives are given in Table 3.2

Table 3.2 Properties of site mixed slurry of IBP Company Limited

Indogel series	614	634	654	674
Weight strength (ANFO= 1)	0.76	0.82	0.89	0.97
Bulk strength (ANFO=1)	1.02	1.12	1.23	1.46
Density, g/cc	1.10	1.12	1.13	1.15
Velocity of detonation, m/s	4200 ± 200	4200 ± 200	4200 ± 200	4200 ± 200
Water resistance	Satisfactory	Satisfactory	Satisfactory	Satisfactory
Blasthole sleep time	Two weeks	Two weeks	Two weeks	Two weeks
Critical diameter, mm	83	83	83	83
Recommended diameter, mm	150	150	150	150
Recommended depth, m	Up to 35	Up to 35	Up to 35	Up to 35

3.4 THE INSTRUMENT USED IN THE STUDY

3.4.1 VODSYS-4, MREL, Canada

VODSYS-4 (Figure 3.1) was a battery operated, portable instrument. It houses a notebook computer, data acquisition card, constant voltage supply, and rechargeable batteries. It was supplied with RG-58 cable, probe cable and probe rods. The instrument was operated through the note book computer and the system software provided by MREL. The notebook computer was a 486 machine of Austin Make and was detachable from the VODSYS-4. The salient feature of VODSYS-4 were:

Resolution/accuracy:	12 bit, 1 part in 4096
Number of channels:	2
Sampling rate	1 KHz-500 KHz
Power	Internal rechargeable batteries, 110-240VAC
Dimension:	47 cm x39cm x17.5cm
Weight	12 kg

Figure 3.1 VODSYS-4, MREL, Canada

3.4.2 MicroTrap VOD Recorder

The MicroTrap (Figure 3.2) is a portable, one channel, high resolution, explosives continuous VOD recorder. The software provided along with this instrument allows the operator to analyse VOD traces. The MicroTrap uses the continuous resistance wire technique for monitoring VODs. The MicroTrap is capable of monitoring the continuous VOD profile along the entire length of an explosive column. It can measure the VOD of relatively short explosive samples such as cast boosters or explosive cartridges. The instrument can also measure the VOD of explosives loaded in blastholes, in single or multiple holes. The MicroTrap provides a regulated constant excitation signal to the probe and monitors the voltage across them. The software runs under 32 bit MS Windows '95, '98 and NT. The main features of the MicroTrap for VOD recording are:

- One VOD channel is capable of recording at up to 2 MHz (2 million data points/sec).

- Capability to record VODs using up to 900 m of Probe cable-LR. This ensures that the instrument can record the VODs in several holes per test.

- A large memory (4 billion data points) to store the recorded data in the MicroTrap. This allows the instrument to record for relatively long periods (2 seconds) when recording at a speed of 2 MHz.

- A high, 12 bit vertical resolution. This means that even for a very long 900 m length of probe cable

- The data is downloaded to any personal computer through the LPT printer port. The downloading is five times faster than with RS 232 cable connections.

- When recording VODs, the MicroTrap outputs a low voltage (< 5 VDC) and an extremely low current (<50 mA) to the probes. This low excitation signal ensures that the instrument will not prematurely initiate explosives and /or detonators.

Figure 3.2 MicroTrap, MREL, Canada

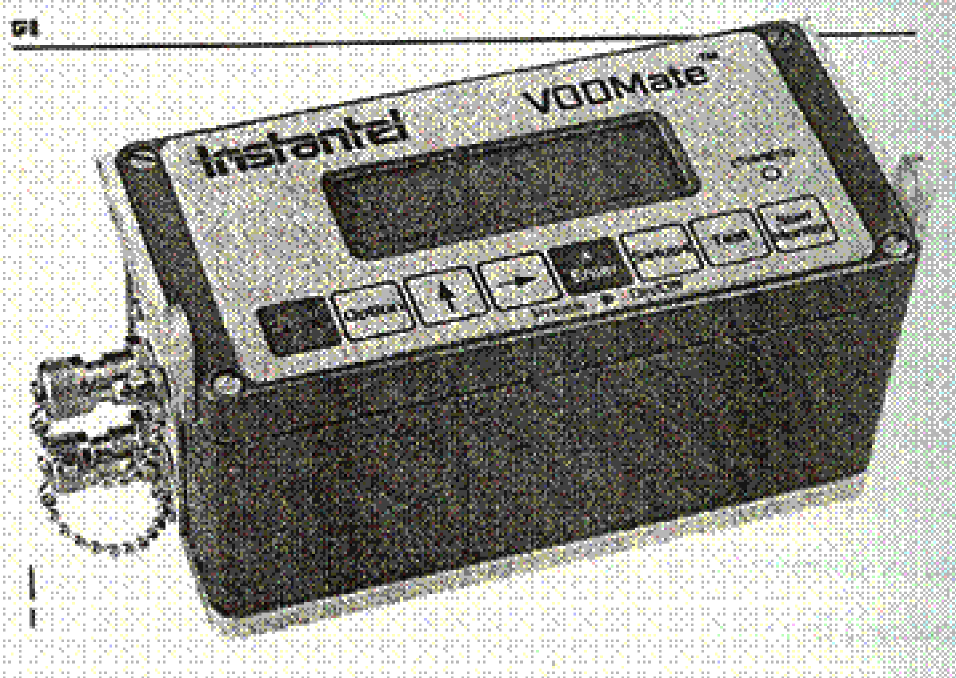


Figure 3.3 VODMate, Instantel, Canada

- The MicroTrap contains electronic circuitry and internal rechargeable battery within a plastic case measuring approximately 21x16x9 cm and weighing 2.5 kg.

3.4.3 VODMate, Instantel

The VODmate (Figure 3.3) from Instantel, Canada offers easy and accurate measurements of an explosive's VOD, at sample rates of up to 2MHz per channel with 14 bit resolution. It is a small, portable, rugged and light weight. The instrument works by providing a constant current source to drive a high resistance length of VOD sensing cable and works on the resistivity principle of VOD measurement. VODMate can supply up to a maximum of 40 mA of electrical current and 27 volts to the VOD sensing cable. Along with the hardware, an window based software called BLASTWARE III is provided for analysis of the records and setting up of the instrument

3.5 PROBE CABLE USED TO MEASURE VOD

3.5.1 MREL Probe Cables

Two types of flexible resistance wire were procured from MREL: Probe cable (green colour) and Probe cable-LR (blue colour). These are co-axial cables where the high resistance wire is the central core and the braided shield acts as the return lead. A dielectric material placed between the resistance wire and the return lead provides both electrical insulation and physical barrier between them. The green probe cable has a unit resistance of 10.01 ohm/m while blue probe cable has a unit resistance of 3.31 ohm/m.

The instrument cannot monitor blasts where the total resistance in a circuit is more than 3000 ohm. 30 holes being monitored of depth 12m, the total resistance using 10 ohm/m would exceed 30 x 12 x 10 = 3600 ohm which is higher than what the instrument can monitor. In such cases it is recommended to use LR (low resistance) probe cable where the total resistance in the circuit would be only 1/3rd of that with HR (high resistance) probe cable. The software has provision to input values for which probe cable has been used during the experiments. However in no case we have tested VOD in more than 6 holes and the total resistance in the circuit using 10 ohm/m or 3.3 ohm/m does not have any bearing on the results.

3.5.2 Instantel/Globe Cable

Before procuring the VODMate from Instantel was confirmed through the Globe Agencies that that VODMate would work with MREL green cable. However the VOD signals recorded at Jayanthipuram limestone mine with this probe cable and VODMate were not good. Hence, the Globe Agencies was asked to supply a sample of Instantel probe cable to ascertain whether the instrument was working or not. A sample of 100 m length of Instantel cable was sent to NIRM. The cable was strong with a resistance of 8 ohm/m. The Globe Agencies also send about 150 m of equivalent probe cable, black in colour and manufactured in India. The resistance of the cable was 7.84 ohm/m. After testing both the probe cables at Walayar limestone mine and at Singreni, 500 m of the black probe cable was procured from the Globe Agencies as the VOD signal were satisfactory and this cable was much cheaper than the Instantel cable.

3.6 CO-AXIAL CABLE USED TO CONNECT THE PROBE CABLE AND THE VOD RECORDER

The coaxial cable is different from the probe cables. This is specifically used as a connection cable between the blasthole top and the recorder (Figure 3.4). A low resistance co-axial cable is used for connecting the probe cable to the VOD recorder, placed at a safe distance from the blast. In RG-58 type co-axial cable, the high resistance wire is the central core and the braided shield acts as the return lead. A dielectric material placed between the resistance wire and the return lead provides both electrical insulation and physical barrier between them. The cable should be strong to withstand the tension when it is pulled while laying out the cable in the field.

All VOD experiments conducted during 1996-98 used the RG-58 coaxial cable supplied by MREL, Canada along with VODSYS-4. The cable had a unit resistance of about 1 ohm/25m. As the length of the cable became insufficient because of the damage due to blasts, a survey was made to find the same or equivalent cable in Bangalore. The RG-58 coaxial cable of Delton, manufactured in India was found suitable. This cable was used for all experiments conducted during March-July 2001.

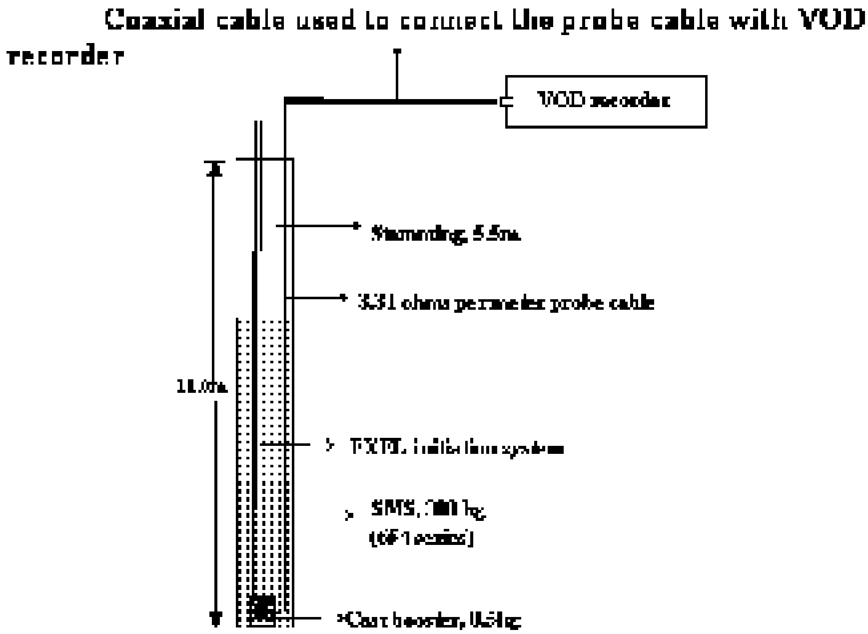


Figure 3.4 Experimental set up showing co-axial cable connecting probe cable and VOD recorder

3.7 FIELD PROCEDURE FOLLOWED FOR MEASURING THE VOD

The field set-up for VOD monitoring with VODSYS-4, MicroTrap and VODMate was more or less the same. Figures 3.5 shows the field photographs. The steps followed are enumerate below:

- Choose a hole or a few holes for the experiments.
- Short the end of the probe cable and lower the VOD sensing cable into the first hole along with the primer.

Figure 3.5 Field photographs showing lowering of probe cable and EXEL initiation system (top) and charging with SMS explosives (bottom)

- In case of multiple holes, place the probe cable into the second hole and so on. Each hole will have the cable going into the hole and coming out of it.
- Cut the probe cable after all experimental holes are connected.
- Place the explosives in the blastholes.
- Stem the holes as per normal procedure.
- Check the resistance of the probe cable.
- Lay the RG-58 cable from the blast to a safe distance where VOD recorder is kept.
- Connect the end of the probe cable to the RG-58 cable and connect the other end of the RG-58 cable to the VOD recorder through a BNC connector.
- Start monitoring only after getting clearance from the Blasting -in-Charge.
- Disconnect the cables after switching off the instrument.
- Inspect the damage of the RG-58 cable after each blast.
- Connect the cable properly, if it is cut during the blast.
- Check the continuity of the cable for outer as well as inner wire separately.
- Measure the resistance and estimate the length of cable.
- Connect additional length of cable, if required.

3.8 MONITORING THE BLASTS WITH VODSYS-4

3.8.1 General Procedure

To start with, the procedure to collect and analyse data as per the operation manual for VODSYS 4 was studied and practised at the institute. Field connections were simulated in the laboratory using 330 ohm and 490 ohm resistors and experiments were carried out and established field procedure as per the manufacturer's recommendations. The experiments were carried out using one of the two channels of the VODSYS-4 and mostly with single hole experiments. EXEL detonators were used only in the experimental holes and the rest of the round was initiated using conventional downline and trunkline of detonating cord. Cord relays of 25 ms or 50 ms were used to provide delays in the same pattern followed in the mines. Only a few blasts were successfully recorded using multiple holes. However, multiple hole monitoring was common with MicroTrap and VODMate, after perfecting the field procedures and getting confidence in the VOD recorders.

In order to avoid further delay in initiating the field work for want of EXEL zero detonators, experiments were commenced at GDK OCP 1 with 250 ms during September 1997. Only a few records were successfully recorded due to anticipated cut off problem. Some experiments were conducted with detonating cord by carefully lowering the probe cable and detonating cord. However, this was not successful except for a blast. After getting required EXEL zero detonators, experiments were carried out and the lost time was reasonably made up. Table 3.3 gives the consolidated information on VOD experiments carried out with VODSYS-4. Table 3.4 gives the number of visits and duration by the research team for the entire period. More than 30 observations were recorded but due to display and floppy drive problem with the note book computer which was supplied with VODSYS-4 and subsequently the corruption of the hard disk, only 9 in-the-hole observations and 3 surface test observations could be retrieved. As the majority of the VOD experiments data was not recoverable, the available data were not sufficient for preparation and submission of the report. Having discussed the problem with all concerned with this project, the extension of the project was sought for up to March 2001 and a VODMate from Instantel, Canada was purchased from NIRM funds.

3.8.2 Reasons for unsuccessful VOD records

1. Some of the readings were not picked up by the instrument. The instrument was waiting for the signal even after the blast for unknown reasons.
2. A few records were of no use because the graph was black
3. Cable connecting to VOD recorder was cut off by the flyrock/rock movement.
4. The record of VOD signal was not satisfactory probably due to inefficient shorting because of water, bunching of probe cable etc.
5. At the 11th hour it was found that there was no continuity of the connection as the joints in RG-58 cables gave way while laying out the cable due to drag, excessive temperature etc.

3.9 MONITORING WITH VODMATE AND MICROTRAP

Six trials were carried out with the VODMATE at Jayanthipuram Limestone Mine, Madras Cements Limited between 18/10/2000 and 24/10/2000 in order to ascertain the performance of the instrument and its compatibility with the MREL 10 ohm/m probe cable. Experiments were carried out in one hole to six holes in a loop. (Table 3.5). ANFO and slurry explosives were used in 115 mm diameter holes during the experiments. The field records were analysed and the same were sent to M/s Globe Agencies, the authorised Indian agent for Instantel Canada to seek suggestions on the operation of the analysis Software supplied by their principals.

After receiving samples of Globe probe cable (8 ohm/m), supplied by Globe Agencies, New Delhi – Indian agent for M/s Instantel Canada, five field trials were carried out with VODMATE instrument at Walayar Limestone Mine, ACC Limited between 16/11/2000 to 21/11/2000. Experiments were carried out in single hole. ANFO and slurry explosives were used in 115 mm diameter holes. Experiments on the percentage of prime charge were organised successfully (Table 3.6).

VODMate developed some problems and it was sent to Globe Agencies, New Delhi on 5 Feb. 2001 for warranty repair. They in turn sent the instrument to Instantel, Canada for warranty repair. The instrument was received in the middle of April 2001 after repair.

By explaining the problem with VODSYS-4 because of which we could not complete the project to MREL and to M/s Sowar Pvt. Limited, the Indian agent for MREL, we arranged for free replacement of VODSYS-4 with MicroTrap. VODSYS-4 along with a spool of 10 ohm/m probe cable was sent to M/s Sowar Pvt. Limited, on 8/11/2000 for replacement with MicroTrap and 2 km length of LR (low resistance, 3.31 ohm/m) – Probe cable free of cost. MicroTrap VOD data recorder and 2 km length of LR – Probe was received on 6 Dec. 2000. As the MicroTrap VOD recorder needs to be operated with a computer in the field, arrangements were made for the procurement of a new notebook computer. Got conversant with the analysis software supplied with the MICROTRAP VOD recorder.

Field experiments were resumed at GDK OCP 1 & GDK OCP 3 from 21 March to 3 April, 2001 with the MICROTRAP VOD recorder using 3.31 ohms/m Probe cable – LR supplied by MREL. Initially a couple of blasts could not be successfully monitored as the field settings for the new instrument were to be established.

Field investigations were conducted in four visits during March-July 2001. They were supposed to be completed by the end of June 2001. However, due to 13-day strike by the workers at SCCo Ltd, the experiments planned for 3rd visit were forced to discontinue and the balance of experiments were completed in the first week of July 2001. Table 3.7 to 3.8 gives the records with VODMate and MicroTrap recorders while Table 3.9 gives the summary of all the VOD measurements carried out for the entire period.

Table 3.3 Consolidated information on VOD experiments carried out with VODSYS-4

Sl. No.	Trial No.	Date	Comments	Remarks
1 *	GDKtri1	26.9.97	Successful	
2	GDKtri3	26.9.97	Unsuccessful	Misfire
3	GDKtri4	26.9.97	-	Could not monitor when refired
4 *	GDKtri5	29.9.97	Successful	
5 *	GDKtri6	16.11.97	Successful	
6	GDKtri7	18.11.97	Unsuccessful	
7 *	GDKtri8	19.11.97	Successful	
8 *	GDKtri9	21.11.97	Successful	
9	GDKC1	22.11.97	Unsuccessful	Misfire
10 *	GDKtri10	23.11.97	Successful	
11	GDKtri11	26.11.97	Unsuccessful	
12	GDKtri12	22.1.98	Triggered	
13 *	GDKtri13	23.1.98	Successful	
14	Sur 1	24.1.97	Triggered	
15 *	GDKtri14	26.1.98	Successful	
16	GDKtri15	27.1.98	Unsuccessful	
17	GDKtri16	27.1.98	Unsuccessful	
18	GDKtri17	28.1.98	Unsuccessful	
19	GDKtri19	30.1.98	Unsuccessful	
20	Sur 2	31.1.98	Triggered	
21	Sur 3	31.1.98	Triggered	
22 *	GDKCOL 2	1.2.98	Successful	
23	GDKtri20	9.3.98	Triggered	
24	GDKtri21	27.4.98	Unsuccessful	
25	GDKtri22	28.4.98	Unsuccessful	
For serial number 26 to 35, Data lost due to computer virus				
26	GDKtri23	3.5.98	Partly successful	
27	GDKtri24	4.5.98	Successful	
28	GDKtri25	14.7.98	Successful	
29	GDKtri26	15.7.98	Successful	
30	GDKtri27	18.7.98	Partly successful	
31	GDKtri28	16.9.98	Successful	
32	GDKtri29	29.12.98	Successful	
33	GDKtri30	31.12.98	Successful	
34	GDKtri31	2.1.99	Successful	
35	GDKtri32	4.1.99	Successful	
36	GDKtri33	25/4/99	**Did not trigger henceforth**	**Instrument Problem** (a) Floppy drive of the computer (b) Probable corruption of the software (c) Probable hardware problem in the recorder

*Note: * Indicates print outs for analysis available*

Table 3.4 Field visits made by the research team between November 1996 and July 2001

Period	No of days in the filed	Team	Activity
7/10/96-12/10/96	6	HSV & GRA	Site selection - OCP - I
10/06/97-12/06/97	3 (9)	HSV	Visit to R&D for procurement of shock tubes
18/09/97-30/09/97	13 (22)	HSV & AIT	I field study (200 ms) -Gdktr 1 to 5, Valid 2 (1 and 5) Reason: misfire, did not pick up
10/11/97-30/11/97	21 (41)	HSV & AIT	II field study: Gdktri 6 to 11, 4 valid (6,8,9,10) Reason: misfire, did not pick up
19/01/98-03/02/98 28/01/98-03/02/98	16 (57) 7	HSV & AIT GRA	III field study: Gdktri 12 to 19 and surface trials - 6 valid, 13,14,sur1,sur2, sur3 & col 2
02/03/98-13/03/98	12 (69)	HSV & AIT	IV field study: Offloading started. Gdktri 20 only one D/L blast, cut off. Went to KTDM for insisting on Zero delays
20/04/98-05/05/98	16 (85)	HSV & AIT	V field study: Zero delay arrived on 22/4/98. Gdktri21 on 27/4/98 instrument did not trigger, Gdktri22 on 28/4/98 instrument triggered but false reading, Gdktri23 on 3/5/98 x and Gdktri24 on 4/5/98 successful
08/07/98-21/07/98	14 (99)	HSV & AIT	VI field study: 3 blasts, one successful Met Director, CPP at Kothagudem
07/09/98-28/09/98	22 (121)	HSV & AIT	VII field study: One D/L blast monitored
27/12/98-12/01/98	5 (126)	HSV & AIT	VIII field study: - 5 blasts, - 4 successful Met Dy. CME R&D, Met Director, CPP at Kothagudem on 11/01/99
21/04/99-09/05/99	19 (157)	HSV & AIT	IX field study: Instrument problem (VODSYS-4 did not trigger)
16/10/00–25/10/00	10 (167)	HSV & AIT	X field study: VODMATE trials (MCL)
16/11/00-21/11/00	6 (173)	HSV, GRA & AIT	XI field study: VODMATE (ACC)
20/03/01–04/04/01	16 (189)	HSV & NSR	XII field study with MicroTrap (VODMATE was sent for repair)
18/04/01–03/05/01	16 (205)	HSV & GRA	XIII field study with MicroTrap & VODMATE
06/06/01–14/06/01	8 (213)	HSV & GRA	XIV field study with MicroTrap & VODMATE
01/07/01-07/07/01	7(220)	GRA & AIT	XV field study with MicroTrap & VODMATE

Note: HSV: H. S. Venkatesh, GRA: G. R. Adhikari, AIT: A. I. Theresraj and NSR: N. Sounder Rajan

Table 3.5 VOD Measurements at Jayanthipuram limestone mine, MCL

Blast Number	Date of blast	No. of holes tested	No. of holes successfully recorded
1	18/10/2000	2	1
2	19/10/2000	4	3
3	20/10/2000	6	3
4	21/10/2000	5	--
5	23/10/2000	1	--
6	24/10/2000	1	1
			Total 8

Table 3.6 VOD Measurements at Walayar limestone mine, ACC

Blast Number	Date of blast	No. of holes tested	No. of holes successfully recorded	Remarks
1	17/11/2000	1	1	Successful
2	18/11/2000	1	1	Successful
3	20/11/2000	1	--	Initiation with D-cord
4	20/11/2000	1	--	Failure, reason unknown
5	21/11/2000	1	1	Successful
			Total 3	

Table 3.7 Available VOD records measured with MicroTrap, MREL

Blast Number	Date of blast	Mine	No. of holes tested	No. of holes successfully recorded
1	23/30/2001	GDK OCP 1	1	--
2	24/03/2001	GDK OCP 1	1	--
3	27/03/2001	GDK OCP 3	1	1
4	29/03/2001	GDK OCP 1	1	--
5	30/03/2001	GDK OCP 3	1	1
6	01/04/2001	GDK OCP 3	2	2
7	02/04/2001	GDK OCP 1	1	1
8	21/04/2001	GDK OCP 3	4	2
9	23/04/2001	GDK OCP 3	3	2
10	24/04/2001	GDK OCP 3	2	1
11	25/04/2001	GDK OCP 1	2	1
12	26/04/2001	GDK OCP 3	2	--
13	27/04/2001	GDK OCP 1	1	1
14	28/04/2001	GDK OCP 1	4	3
15	29/04/2001	GDK OCP 3	1	--
16	02/05/2001	GDK OCP 3	3	--
17	03/07/2001	GDK OCP 1	2	1
18	03/07/2001	GDK OCP 3	2	1
				Total 17

Table 3.8 Available VOD records measured at SSCo Ltd. with VODMate, Instantel

Blast Number	Date of blast	Mine	No. of holes tested	No. of holes successfully recorded
9	23/04/2001	GDK OCP 3	2	2
10	24/04/2001	GDK OCP 3	1	1
12	26/04/2001	GDK OCP 3	2	2
14	28/04/2001	GDK OCP 1	1	1
15	29/04/2001	GDK OCP 3	1	1
16	02/05/2001	GDK OCP 3	2	2
17	06/07/2001	GDK OCP 3	2	2
				Total 11

Table 3.9 Summary of experimental blasts, instruments used and number of events successfully recorded

Mine	Instrument used	Condition	No. of blasts recorded	No. of events available
GDK OCP-1	VODSYS-4, MREL	Confined (in-the-hole)	33	9
Walayar Limestone Mine, ACC	VODMATE, Instantel		5	3
Jayanthipuram Limestone Mine, MCL	VODMATE, Instantel		6	9
GDK OCP-1 and OCP-3	MicroTrap, MREL		18	17
GDK OCP-1 and OCP-3	VODMATE, Instantel		7	11
GDK OCP-1	VODSYS-4, MREL and MicroTrap, MREL	Unconfined (surface)	7	7
		Total	**76**	**56**

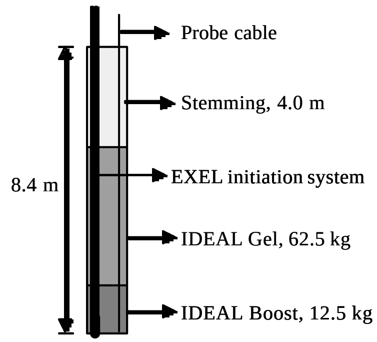
CHAPTER 4

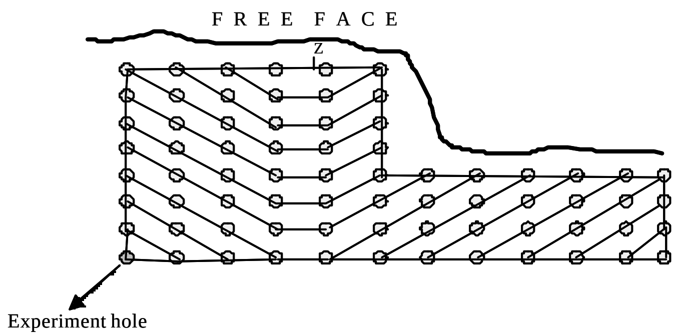
RESULTS AND ANALYSIS

4.1 MEASURED VODs FOR CARTRIDGED AND BULK EXPLOSIVES

During 1997–1998, most of the VOD measurements were carried out for cartridged slurry explosives. The diameter of the holes was 150/250 mm. All the blasts were bottom initiated with down the hole detonators except GDKTRI 22 which was initiated with detonating cord. In general, overall VOD of the explosives was calculated. Incase, the VOD was not uniform along the explosive column, VOD values at the bottom and top were also calculated. Some more tests for cartridged slurry explosives and bulk slurry explosives of different series used at OCP1 and OCP 3 were tested during March-May 2001. Figures 4.1 to 4.32 give details of the experimental hole(s) and the corresponding VOD graphs. In case of multiple holes, two or more VOD graphs are presented separately for each of the holes tested. Table 4.1 presents VOD values for the cartridged and bulk explosives monitored at OCP-1 and OCP-3.

In some records, VOD was uniform along the charge column while in some others it was not so. Consistency in explosive performance could be observed as most of the values for SMS explosives fall within 4200 $\pm$ 200 m/s which match with the quoted values. There were downward spikes on the VOD traces though the trend was apparent. This may be due to insufficient shorting of the probe. In some records where there were both upward and downward spikes, the VOD was calculated based on two points, selected from the trend. In Blast No. 6 there was problem to calculate VOD at the upper portion of the charge as there was no indication of the VOD trend. For cartridged explosives the recorded VODs vary depending on the trade name and manufacturer and application conditions. Some more values of SMS explosives and cartridged explosives can be found in the subsequent sections. An attempt was also made to monitor VOD with detonating cord downline. Except for GDKTri22, VOD trace could not be recorded due to disruption of probe cable by the detonating cord.





Monitored on 26.9.97

Drilling and hookup plan

Date of blast: 26.9.97

Location: I Bench

Explosive: Ideal Explosives

Charge per hole:75 kg

Hole diameter: 150mm

Figure not to scale

Figure 4.1 Details of the experimental hole for blast No. GDKtri1 at OCP-1

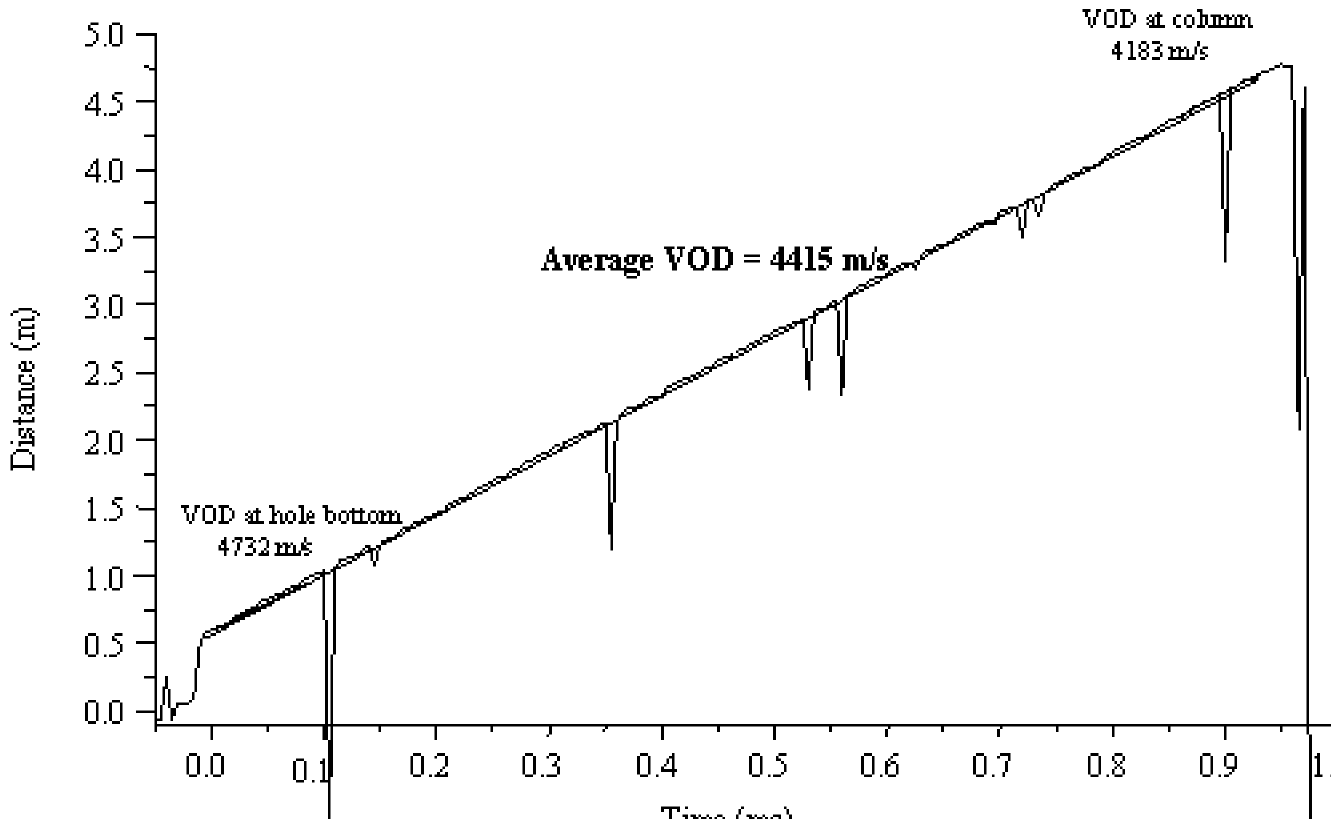


Figure 4.2 VOD result for GDKtri 1 at OCP-1

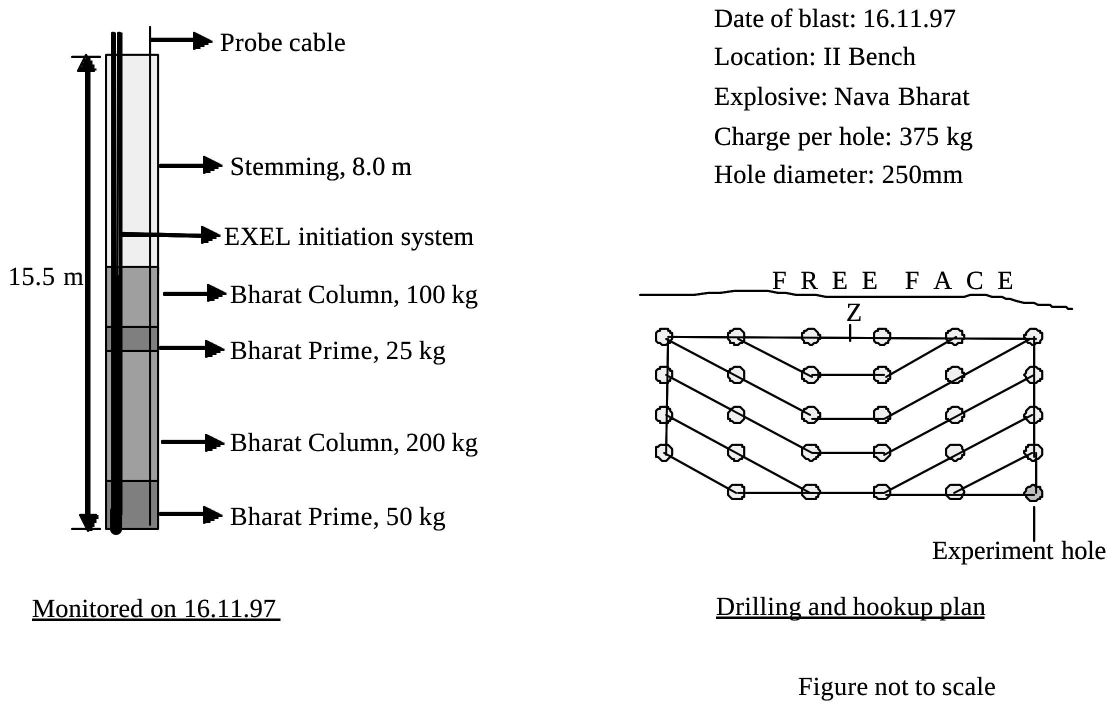


Figure 4.3 Details of the experimental hole for blast No. GDKtri6 at OCP-1

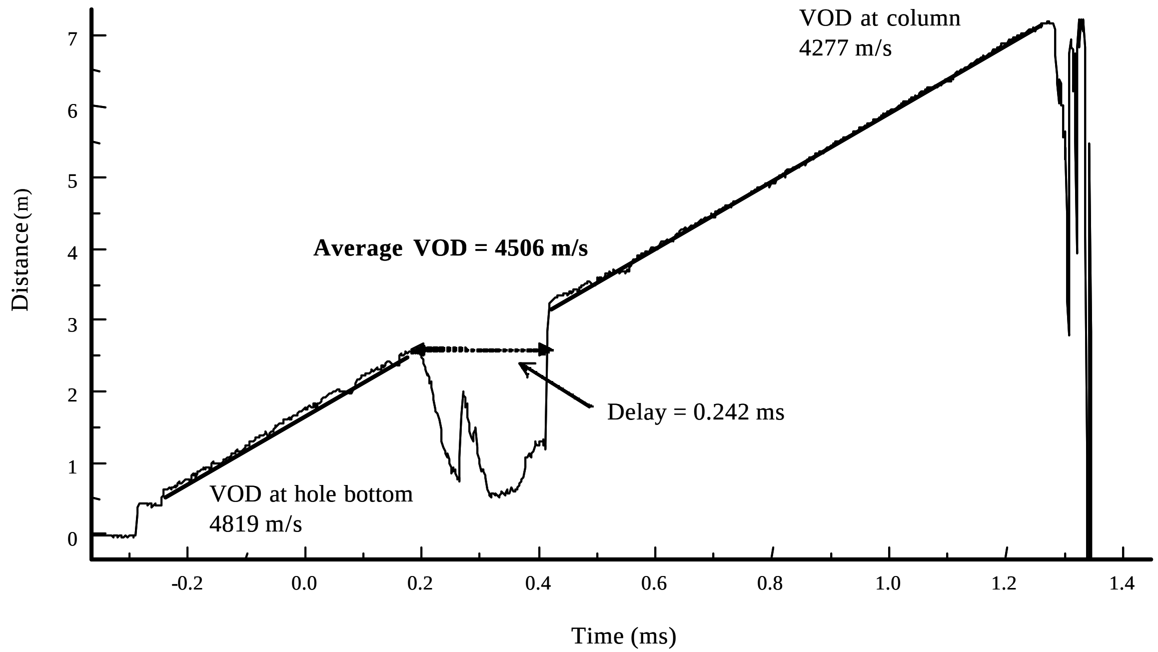
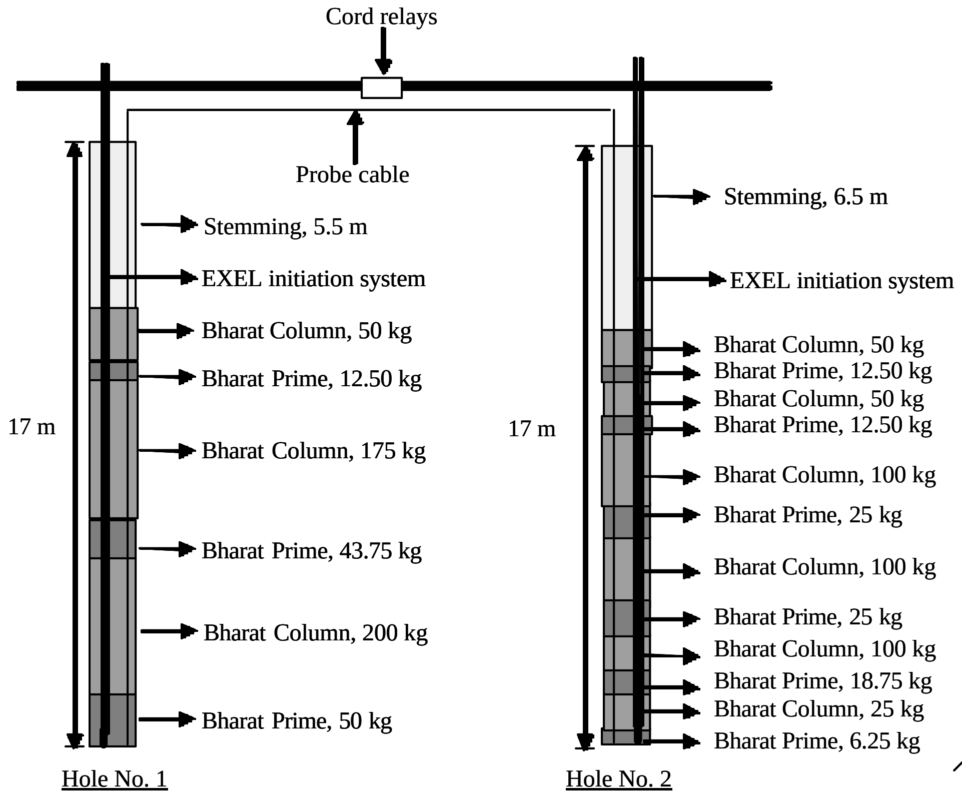


Figure 4.4 VOD result for blast No. GDKtri 6 at OCP-1



Monitored on 19.11.97 (Two holes were connected)

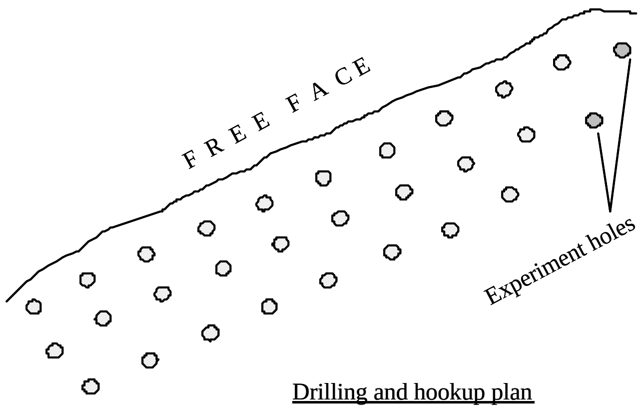
Date of blast: 19.11.97

Location: III Bench

Explosive: Nava Bharat

Charge per hole: Hole No. 1, 531.25 kg
and Hole No. 2, 450 kg

Hole diameter: 250mm



Drilling and hookup plan

Figure not to scale

Figure 4.5 Details of the experimental hole for blast No. GDKtri8 at OCP-1

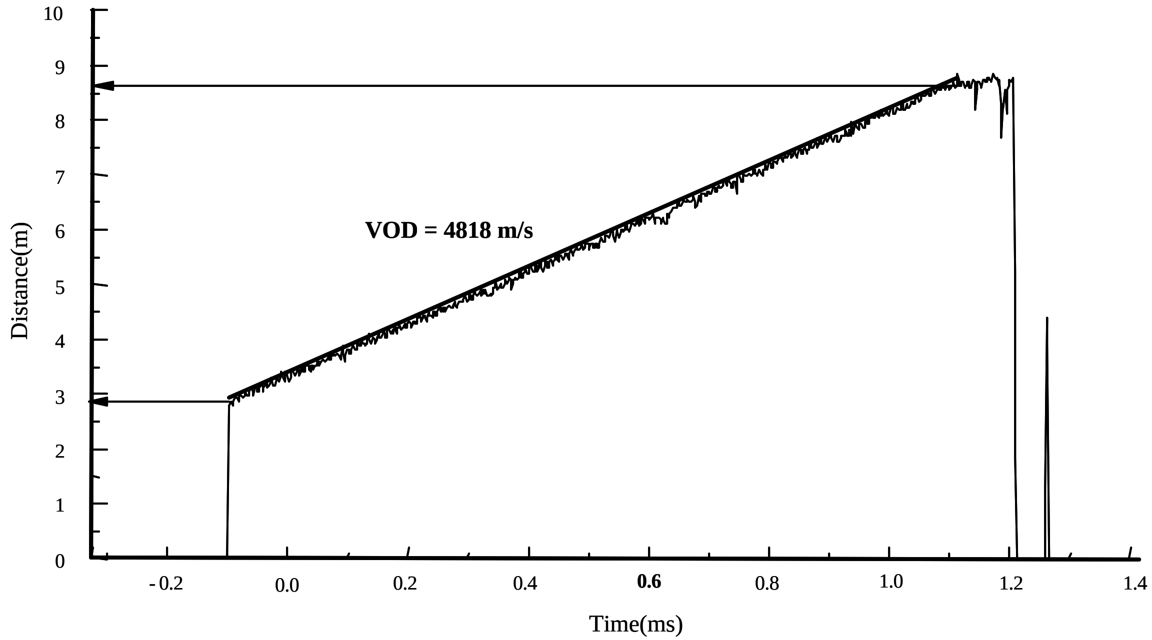


Figure 4.6 VOD result for GDKtri 8 at OCP-1

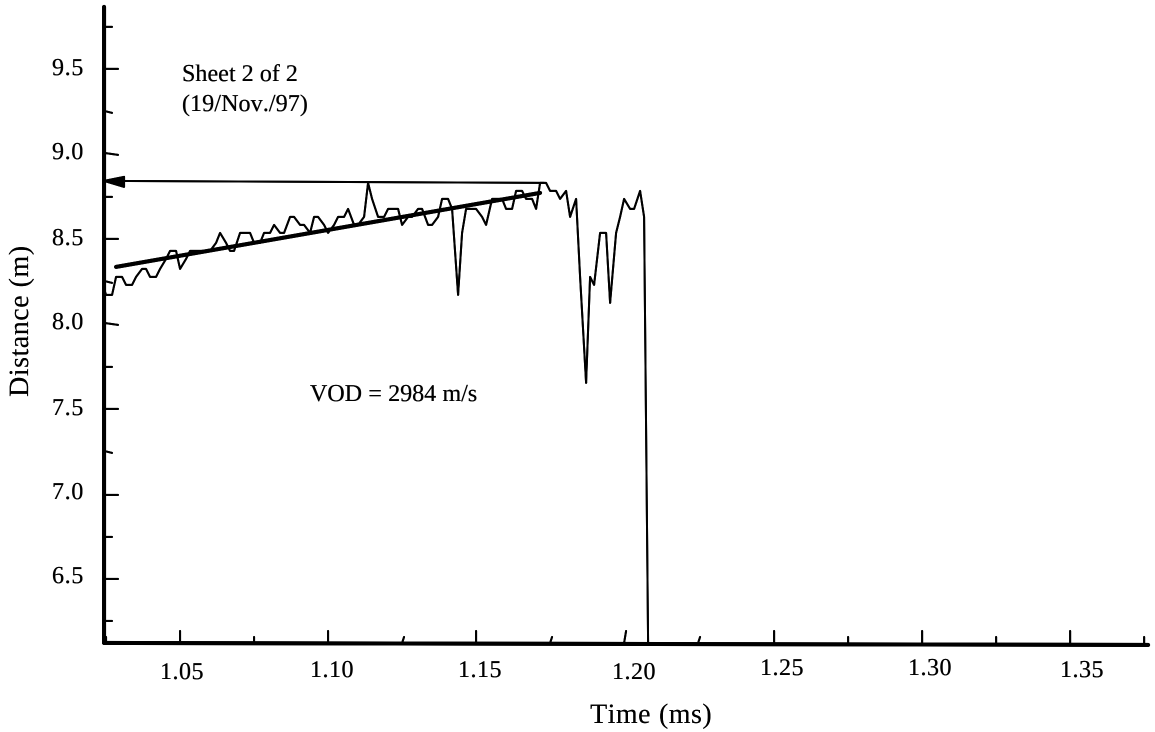


Figure 4.7 VOD result for GDKtri 8 at OCP-1

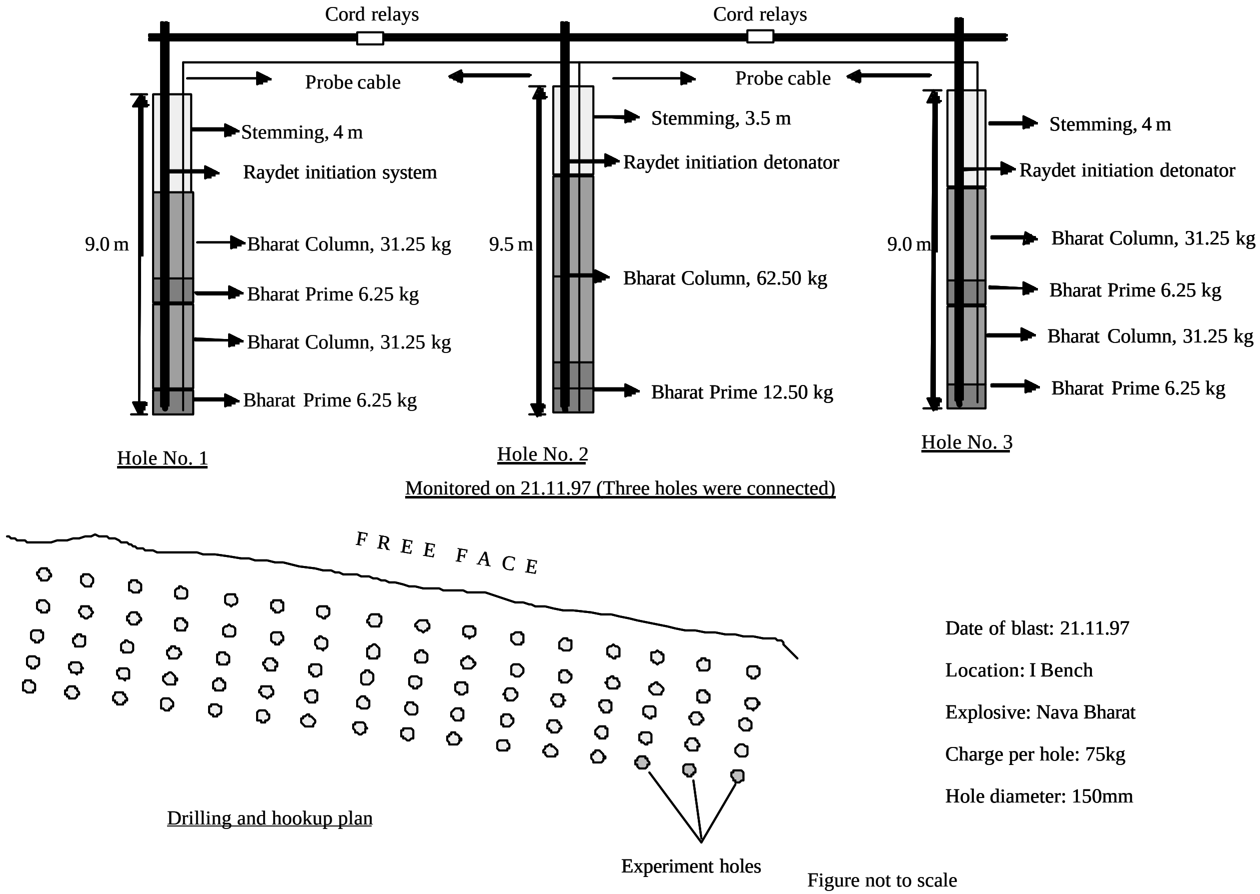


Figure 4.8 Details of the experimental holes for blast No. GDKtri9 at OCP-1

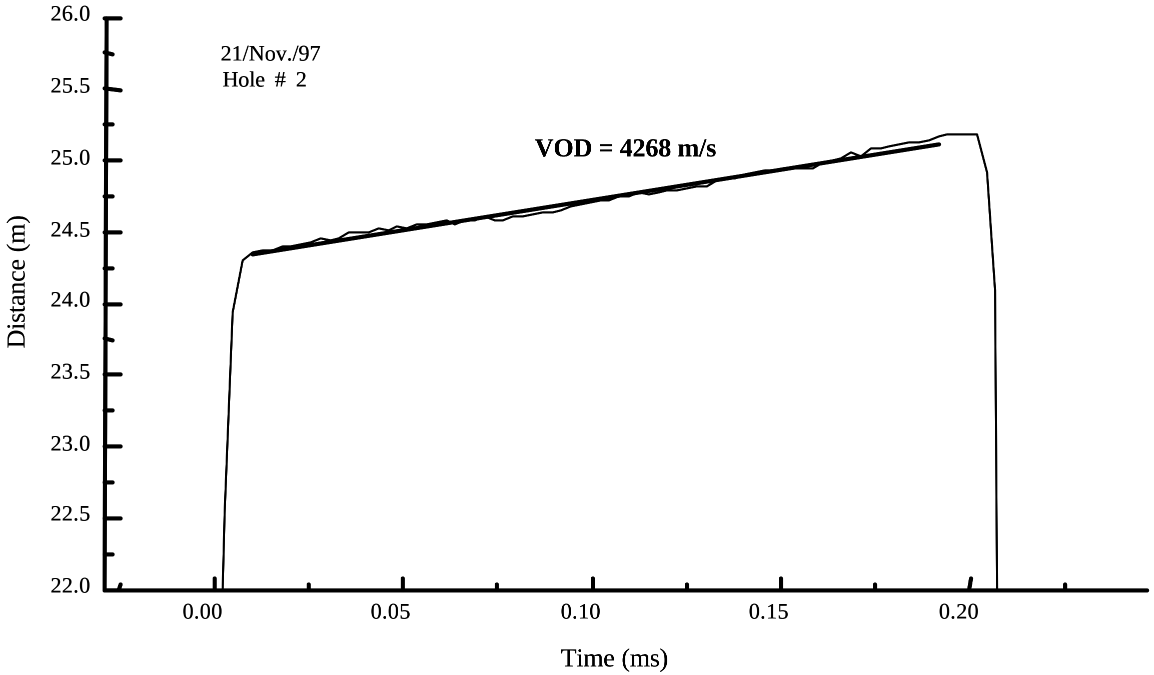


Figure 4.9 VOD result for GDKtri 9 at OCP-1

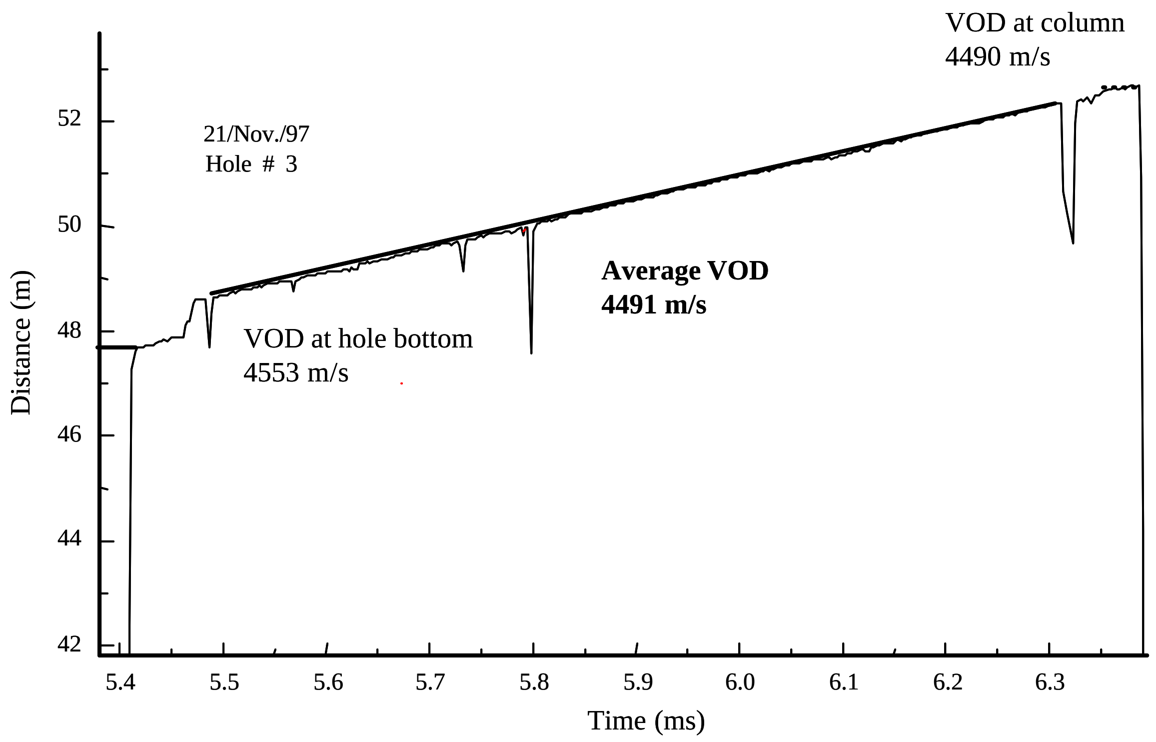
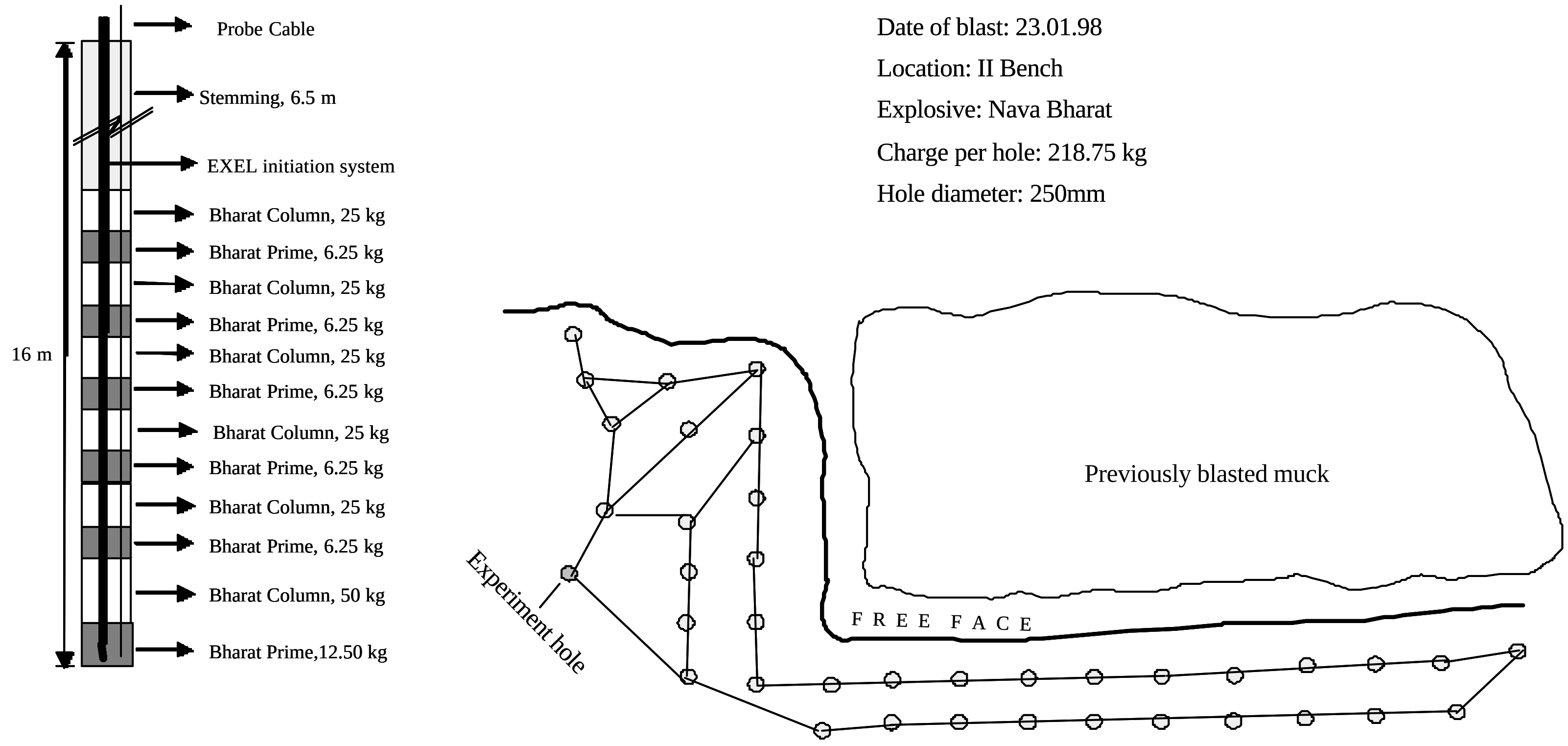


Figure 4.10 VOD result for GDKtri 9 at OCP-1



Monitored on 23.01.98

Drilling and hookup plan

Figure not to scale

Figure 4.11 Details of the experimental hole for blast No. GDKtri13 at OCP-1

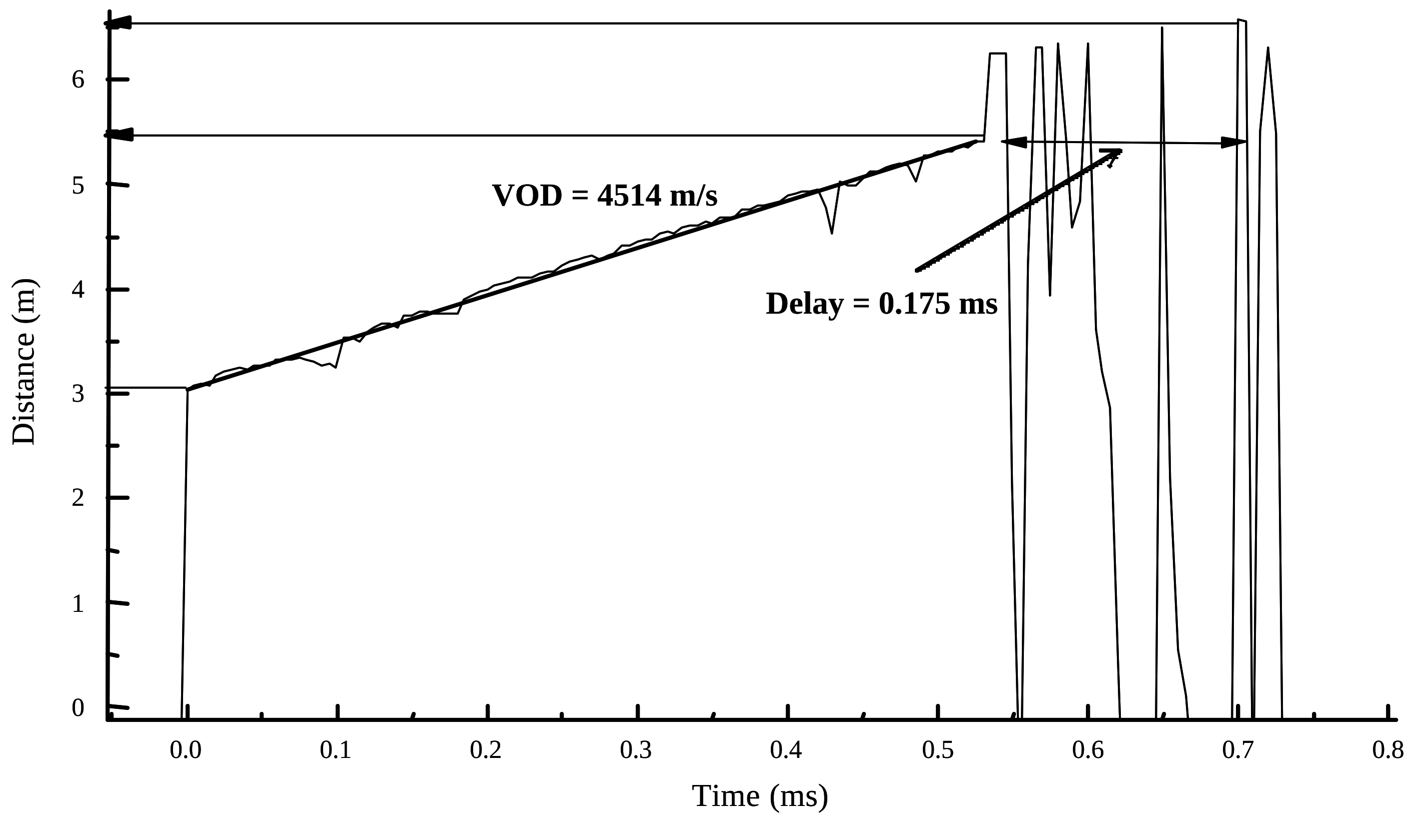
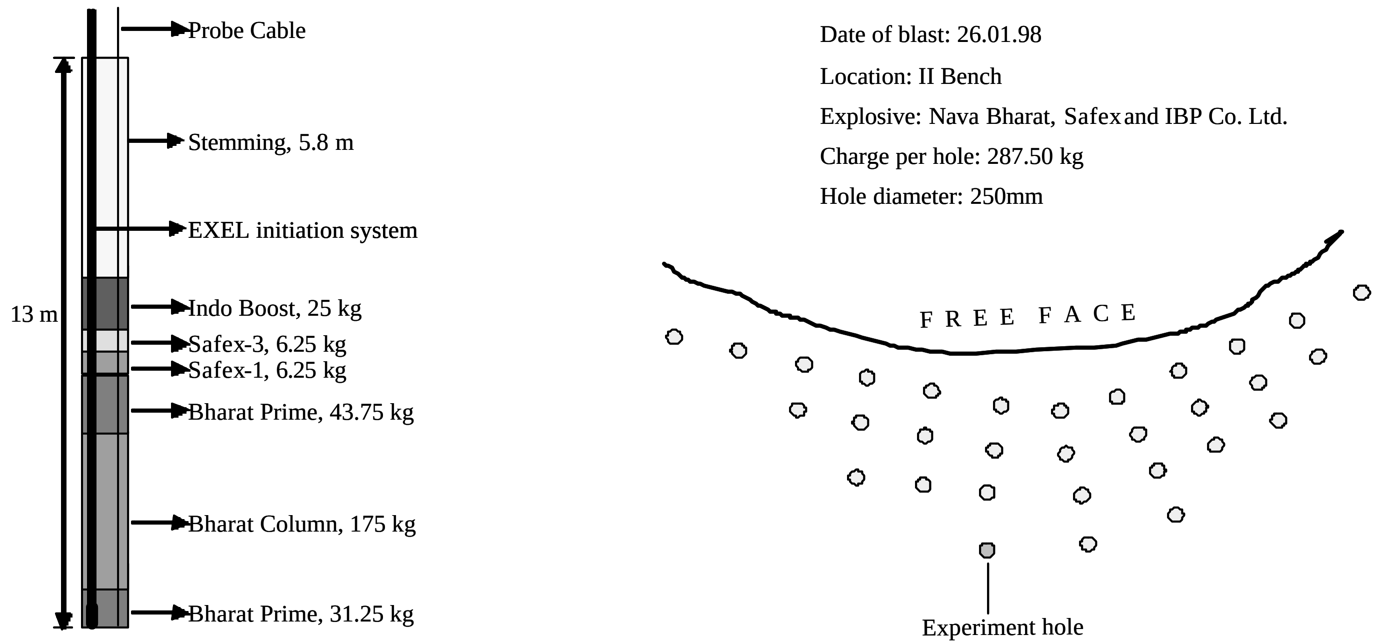


Figure 4.12 VOD result for GDKtri 13 at OCP-1



Monitored on 26.01.98

Drilling and hookup plan

Figure not to scale

Figure 4.13 Details of the experimental hole for blast No. GDKtri14 at OCP-1

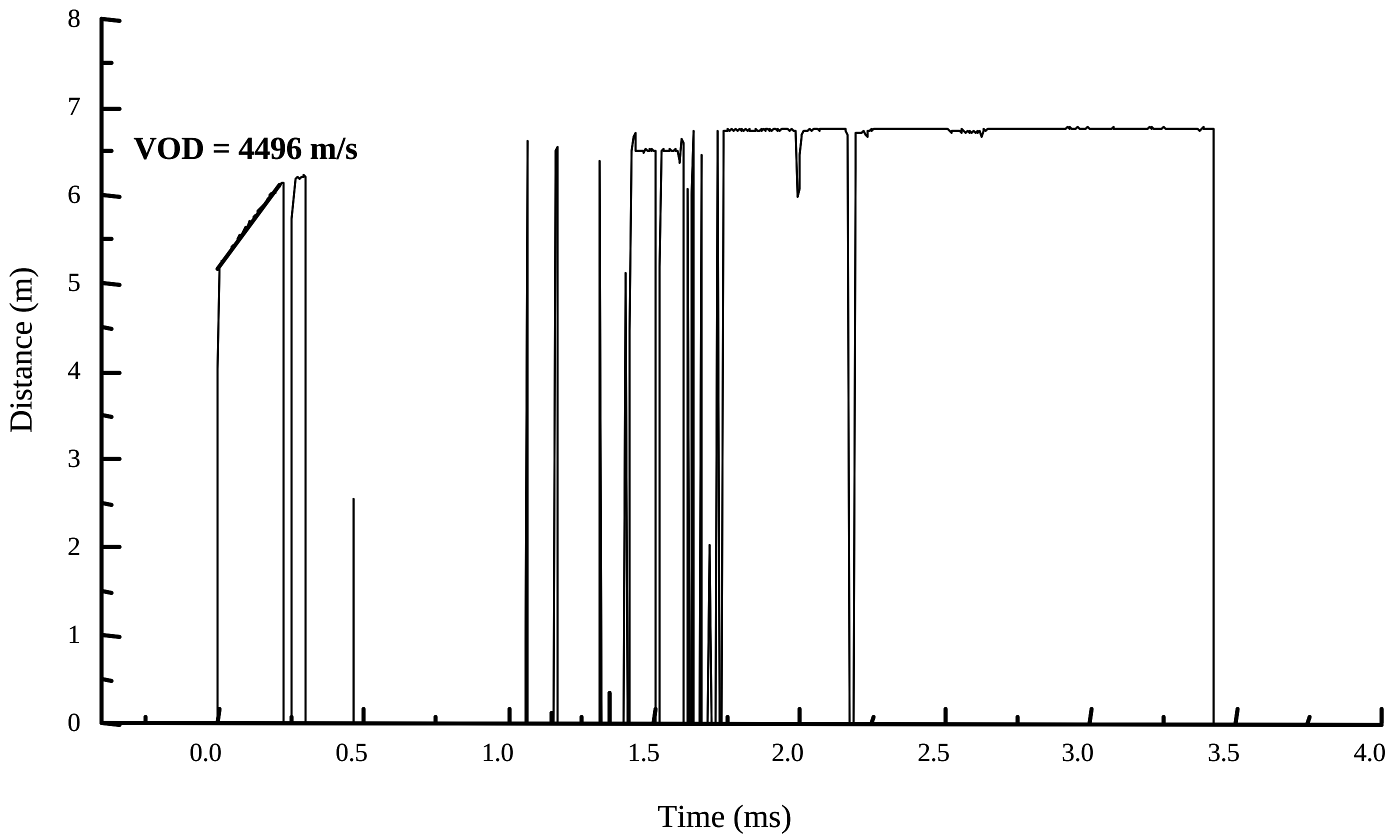
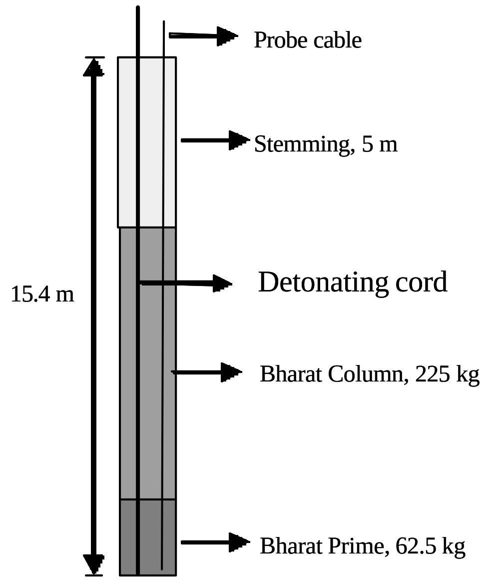
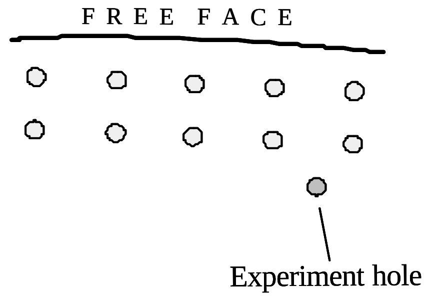


Figure 4.14 VOD result for GDKtri 14 at OCP-1



Monitored on 01.02.98

Date of blast: 01.02.98
Location: Coal Bench
Explosive: Nava Bharat
Charge per hole: 287.50 kg



Drilling and hookup plan

Figure not to scale

Figure 4.15 Details of the experimental hole for blast No. GDKtri22 at OCP-1

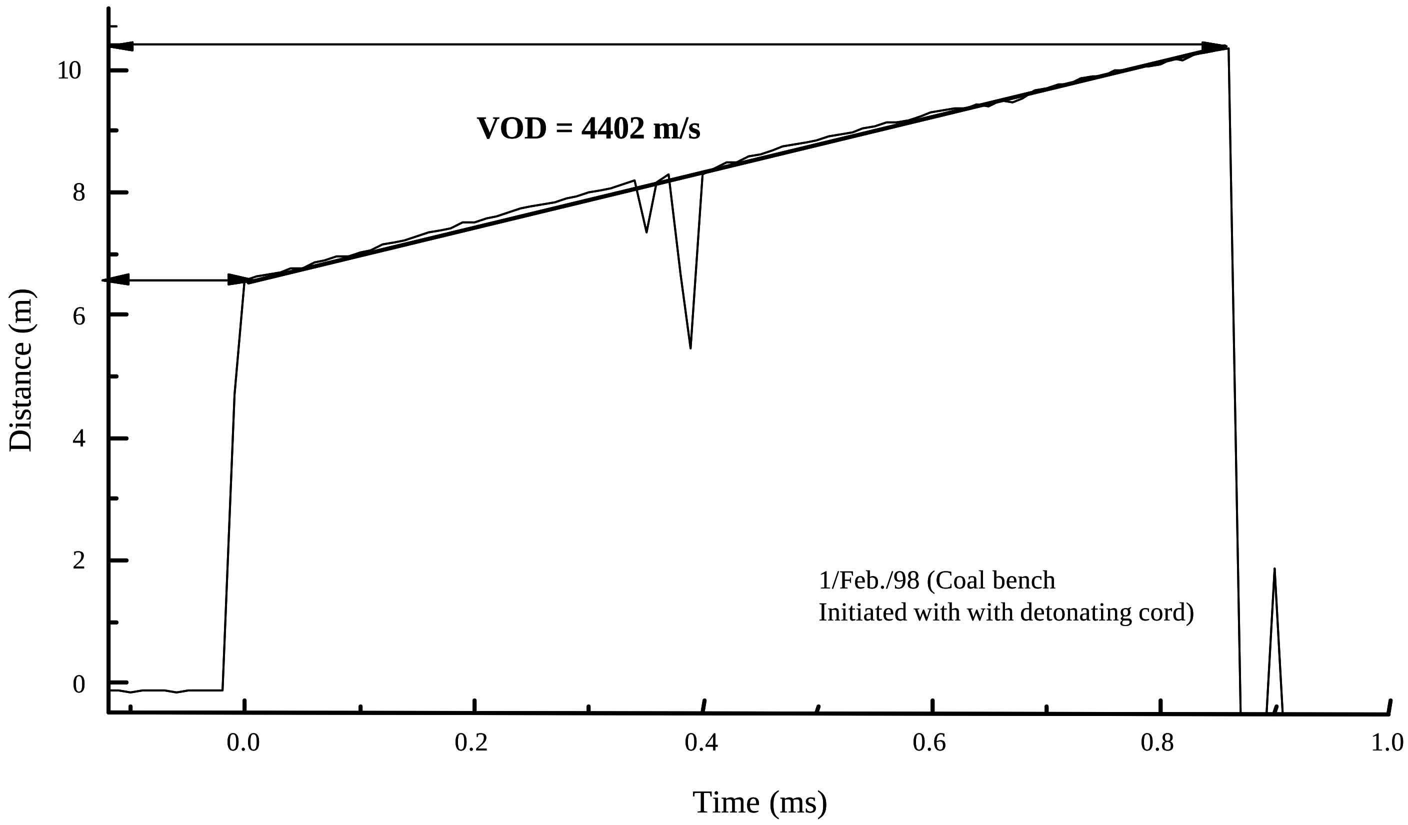


Figure 4.16 VOD result for GDKtri 22 at OCP-1

Blast # 6 (01/4/01)
Location: OCP-3, DM15

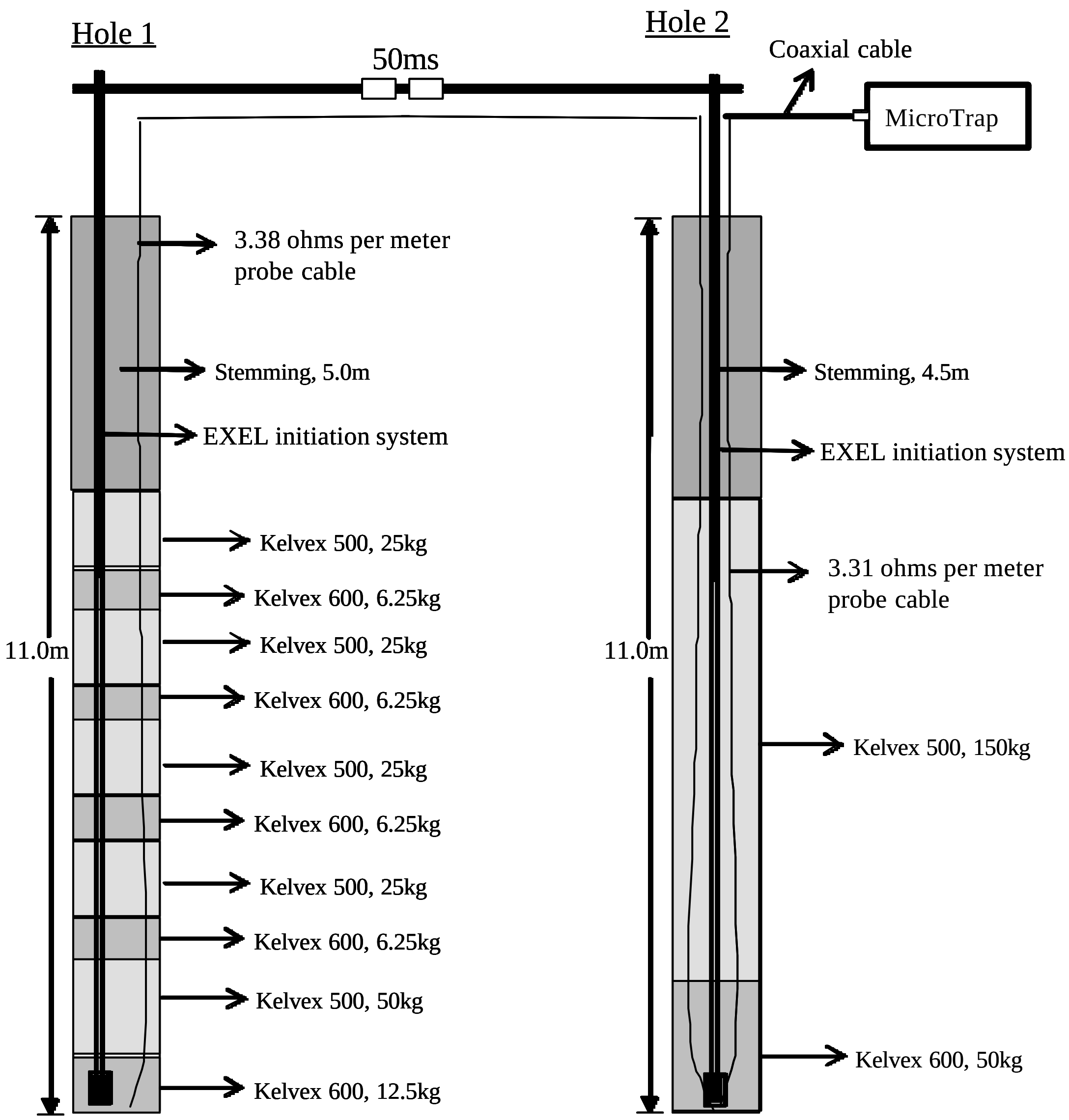


Figure not to scale

Figure 4.17 Details of the experimental holes for blast No. 6 at OCP-3

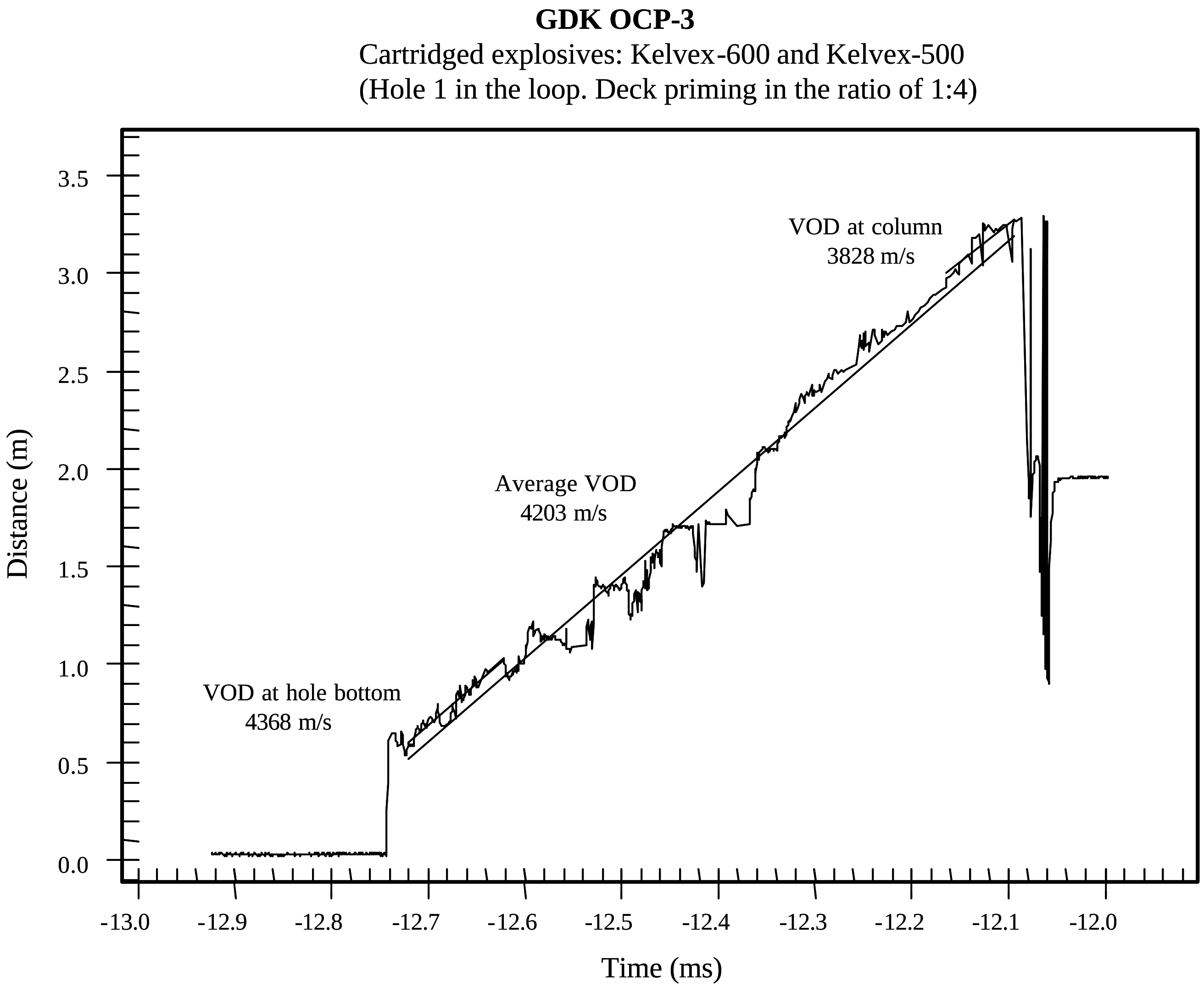


Figure 4.18 VOD result for blast No. 6 at OCP-3

GDK OCP-3

Cartridged explosives: Kelvex-600 and Kelvex-500

(Hole 2 in the loop. Deck priming in the ratio of 1:3)

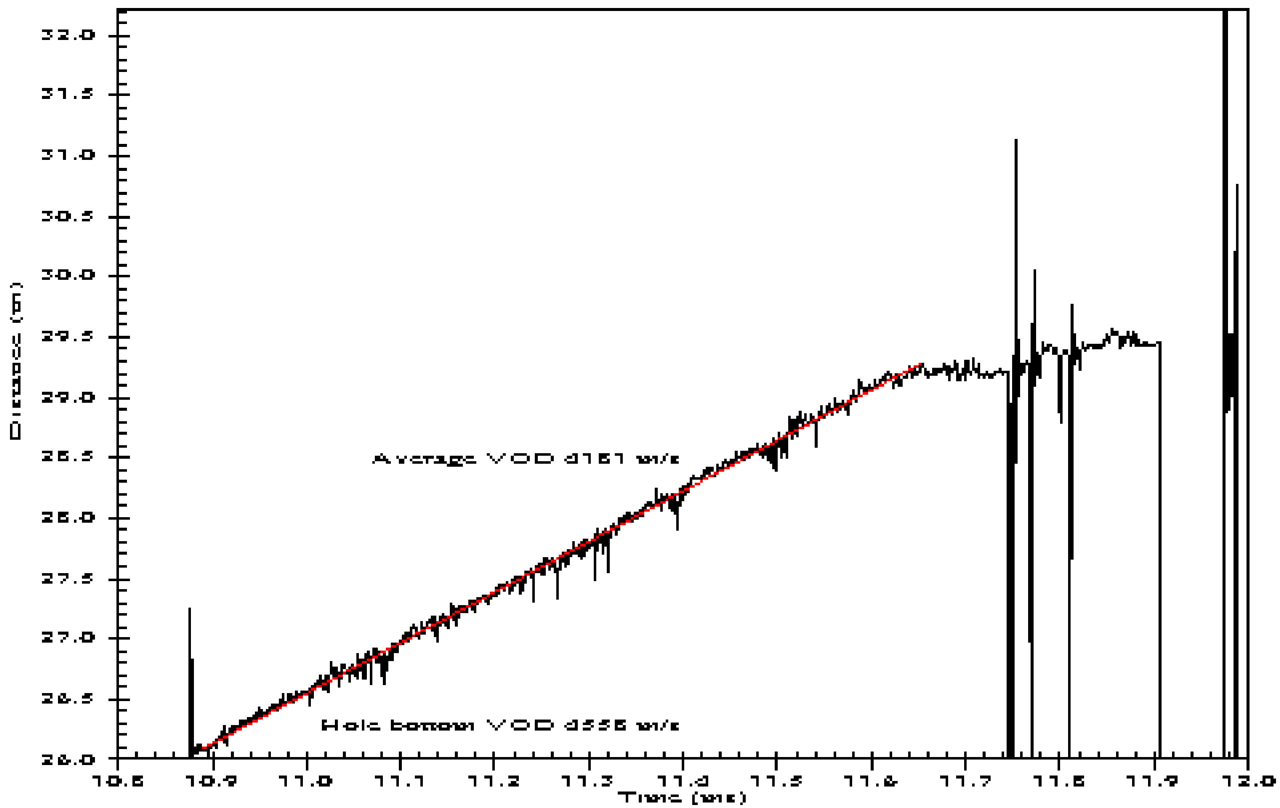


Figure 4.19 VOD result for blast No. 6 at OCP-3

Blast # 11 (25/4/01)
Location: OCP-1, Top bench

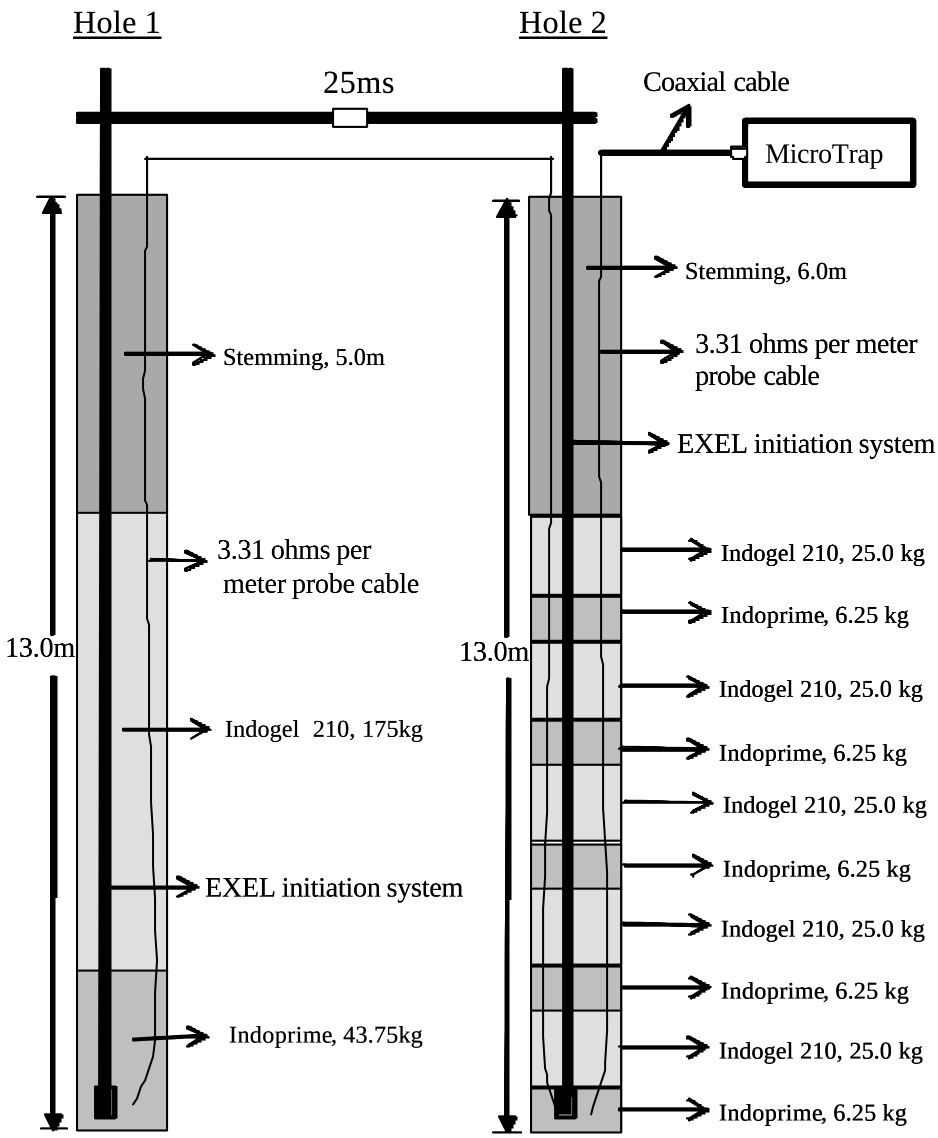


Figure not to scale

Figure 4.20 Details of the experimental holes for blast No. 11 at OCP- 1

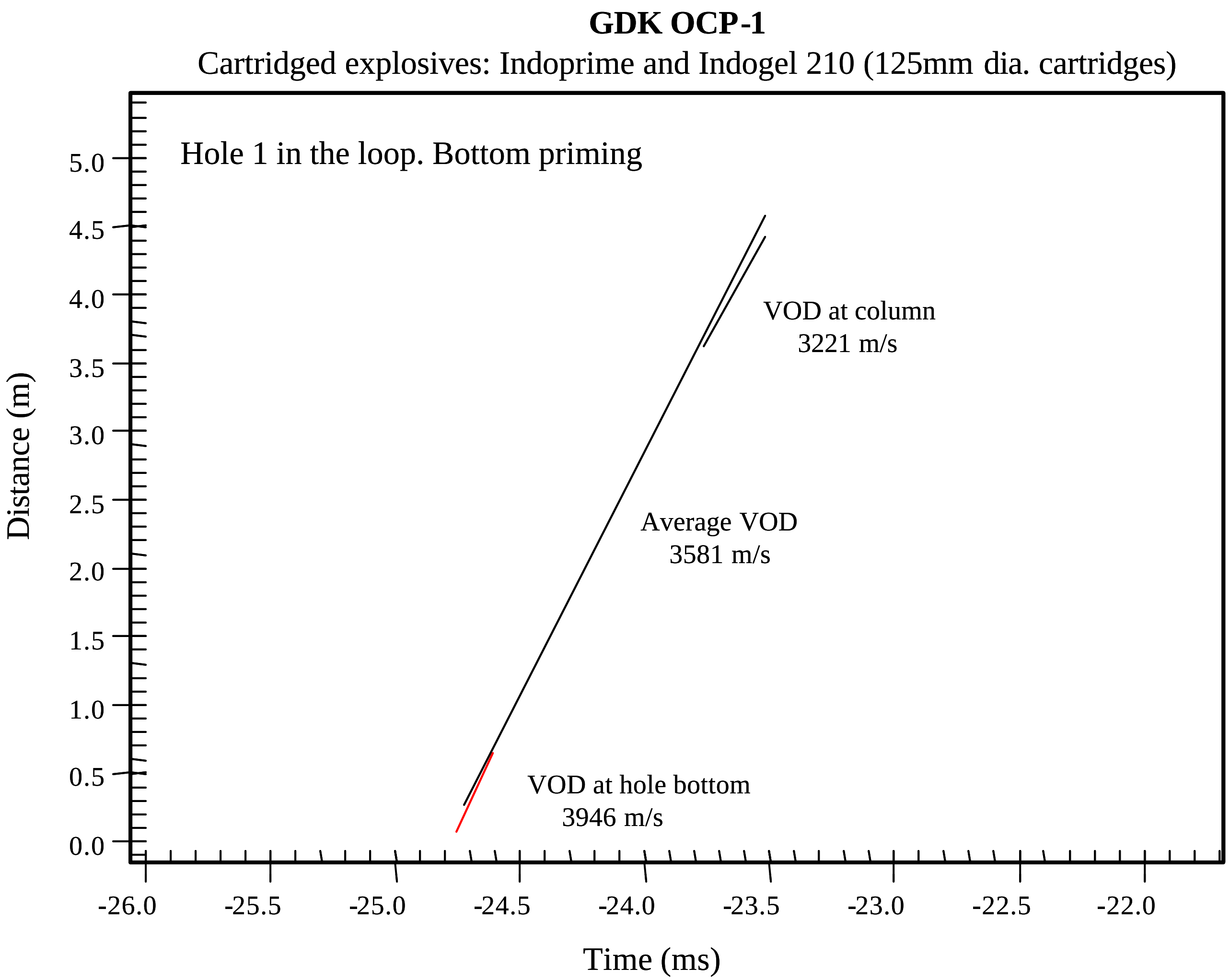


Figure 4.21 VOD result for blast No. 11 at OCP-1

Blast # 3 (27/3/01)
Location: OCP-3, DM 6 II bench

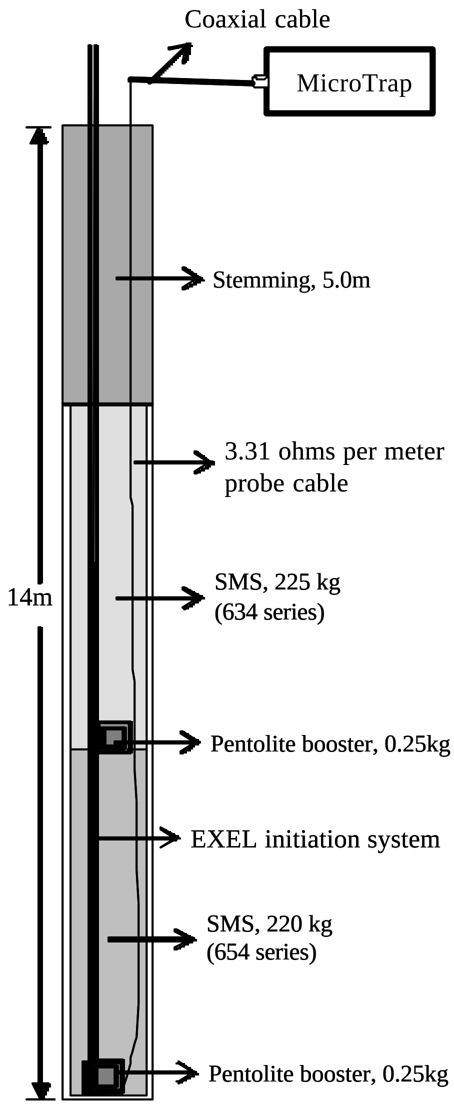


Figure not to scale

Figure 4.22 Details of the experimental hole for blast No. 3 at OCP-3

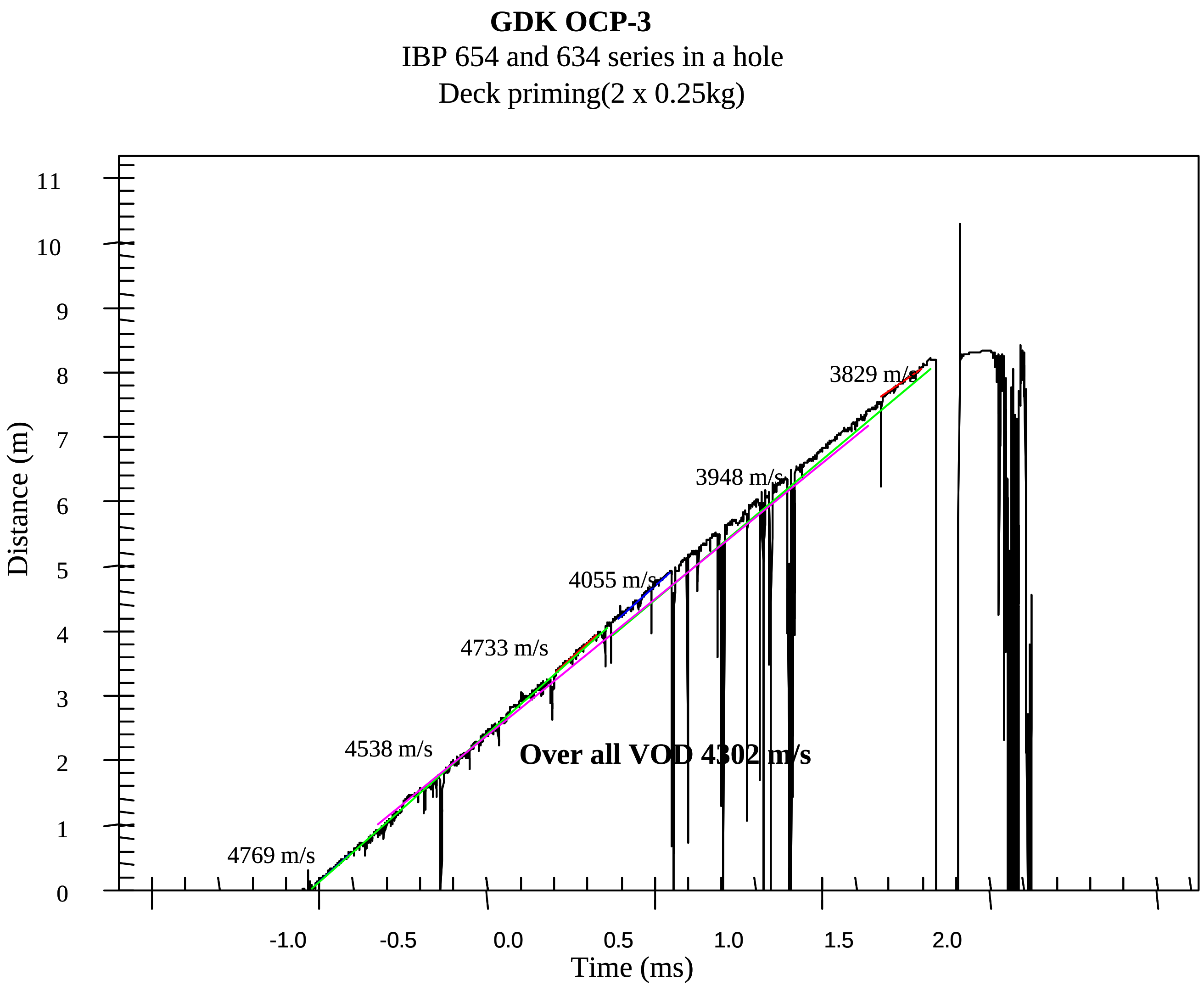


Figure 4.23 VOD result for blast No. 3 at OCP-3

Blast # 5 (30/3/01)
Location: OCP-3, DM15 III bench
(Above dragline bench)

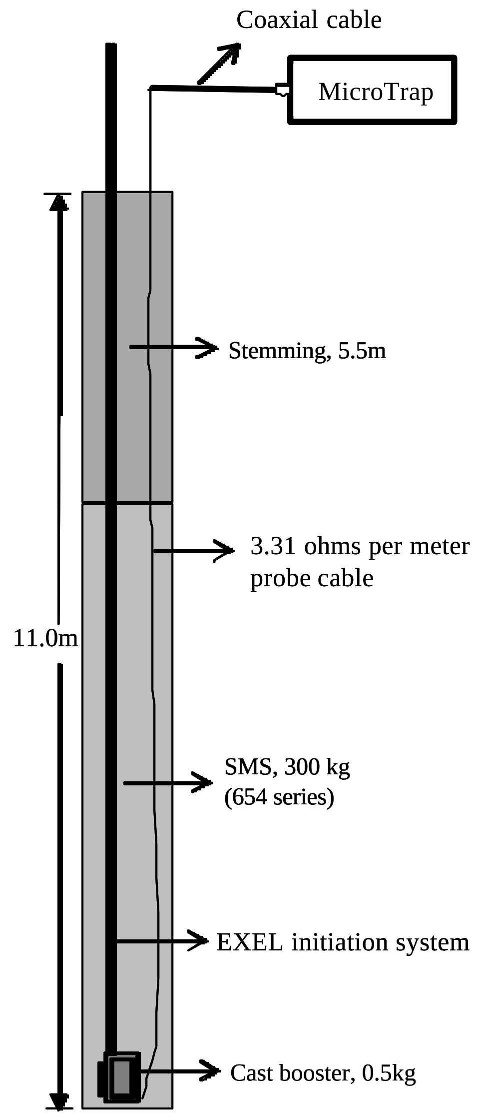


Figure not to scale

Figure 4.24 Details of the experimental hole for blast No. 5 at OCP - 3

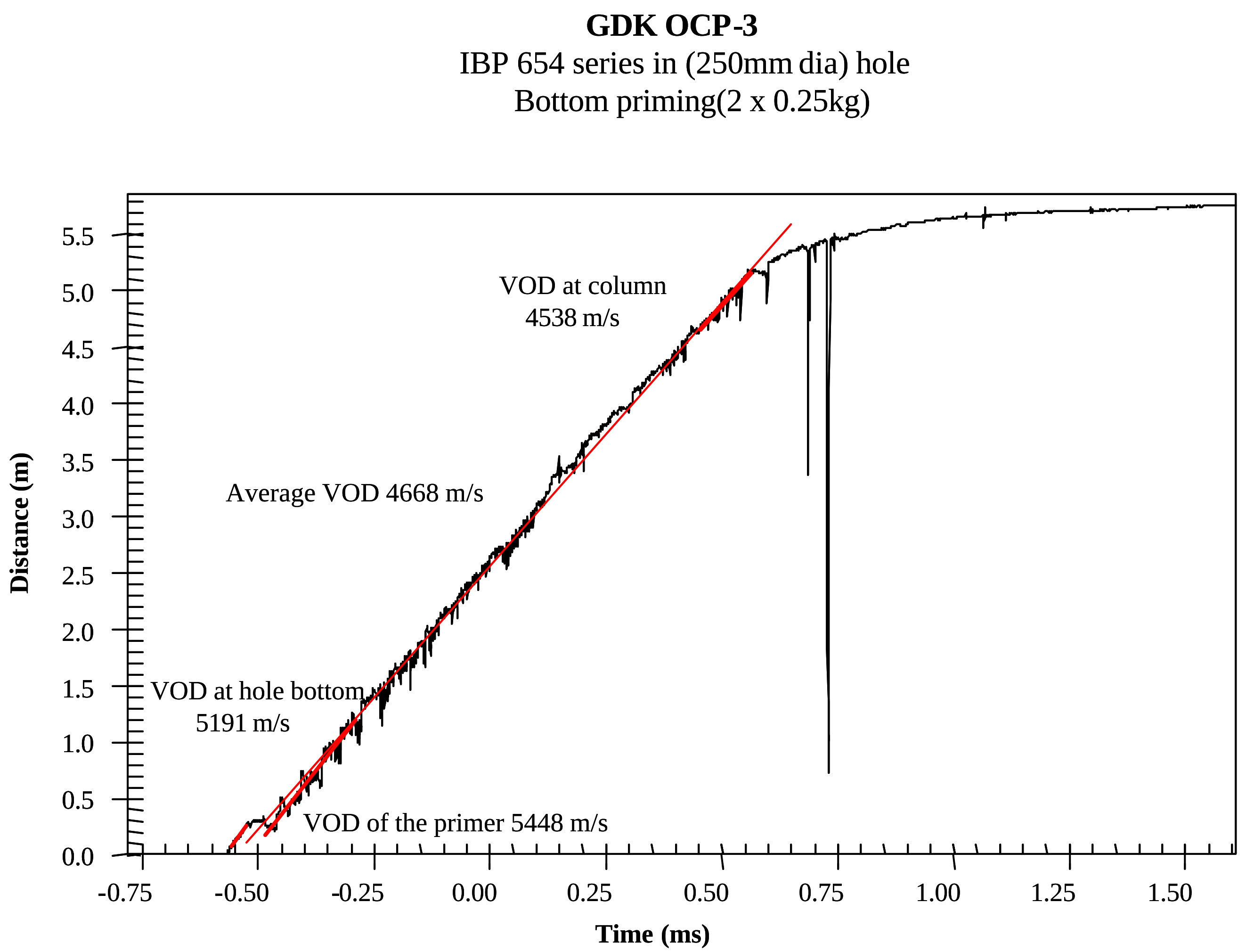


Figure 4.25 VOD result for blast No.5 at OCP-3

Blast # 7 (2/4/01)
Location: OCP 1, DM10 Top bench

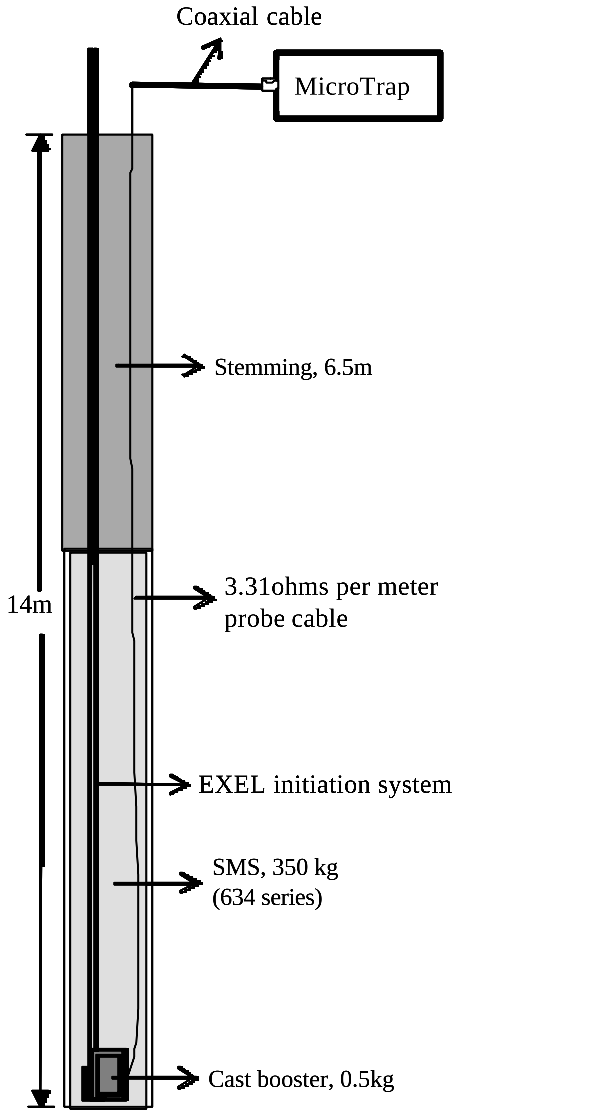


Figure not to scale

Figure 4.26 Details of the experimental hole for blast No. 7 at OCP- 1

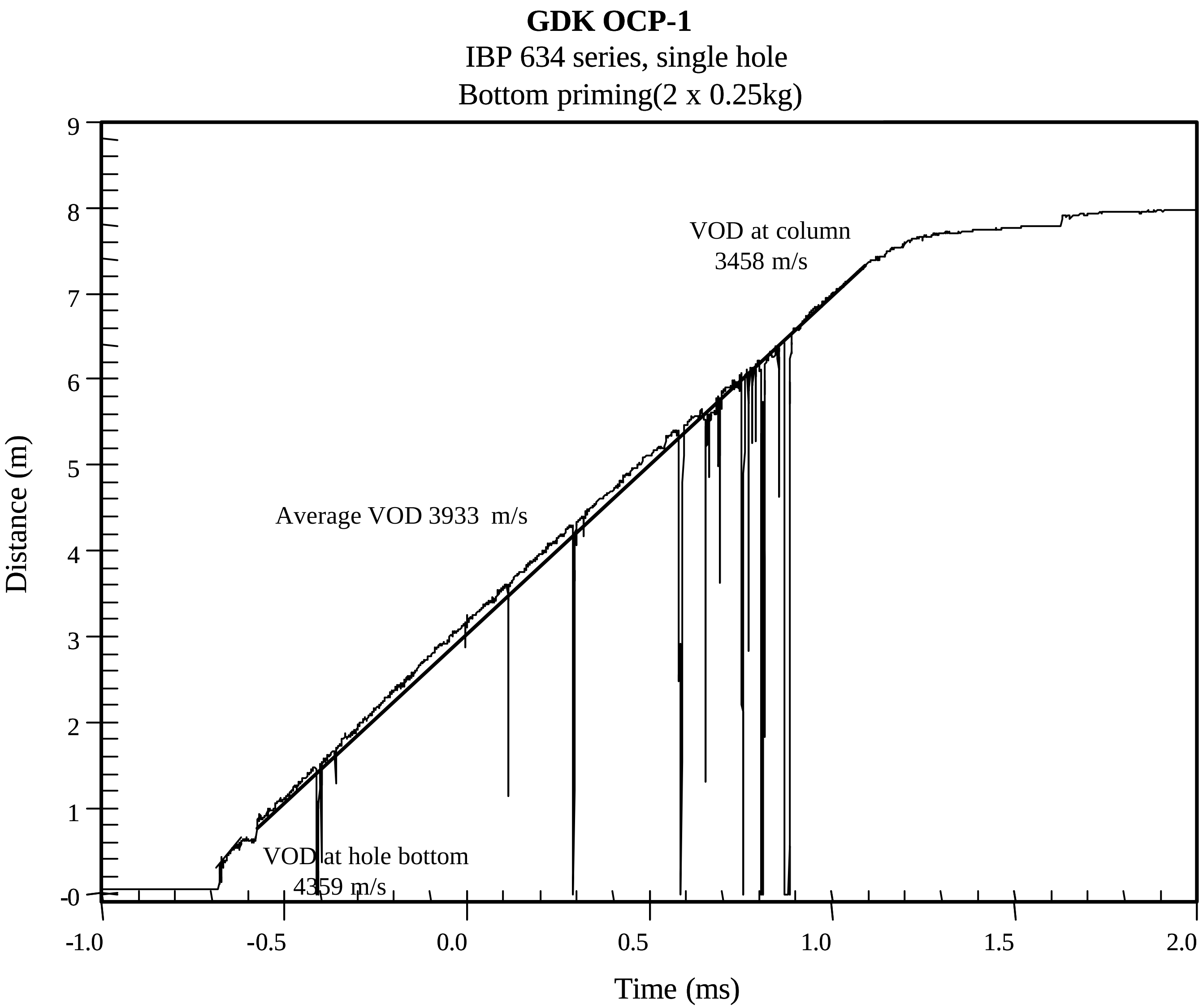


Figure 4.27 VOD result for blast No.5 at OCP-1

Blast # 13 (27/4/01)
Location: OCP-1, OB soft

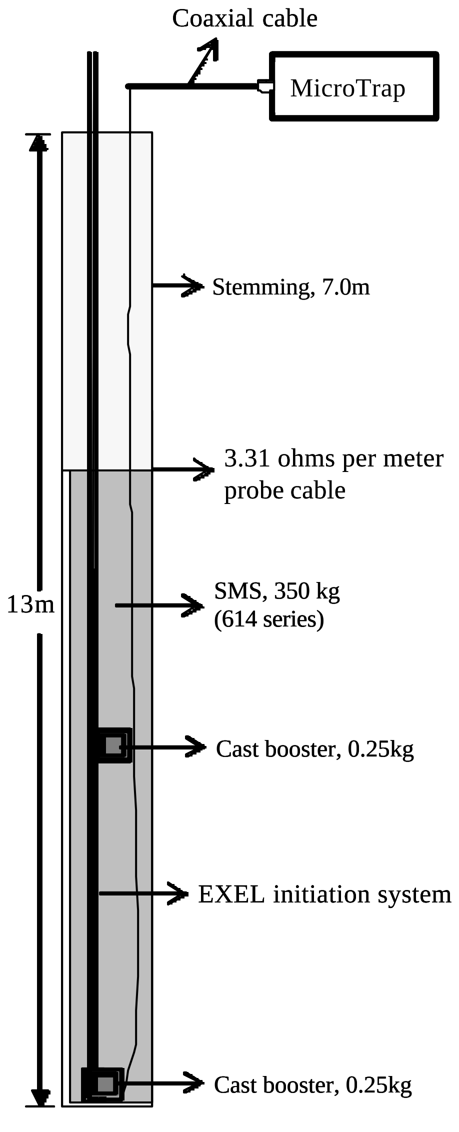


Figure not to scale

Figure 4.28 Details of the experimental hole for blast No. 13 at OCP-1

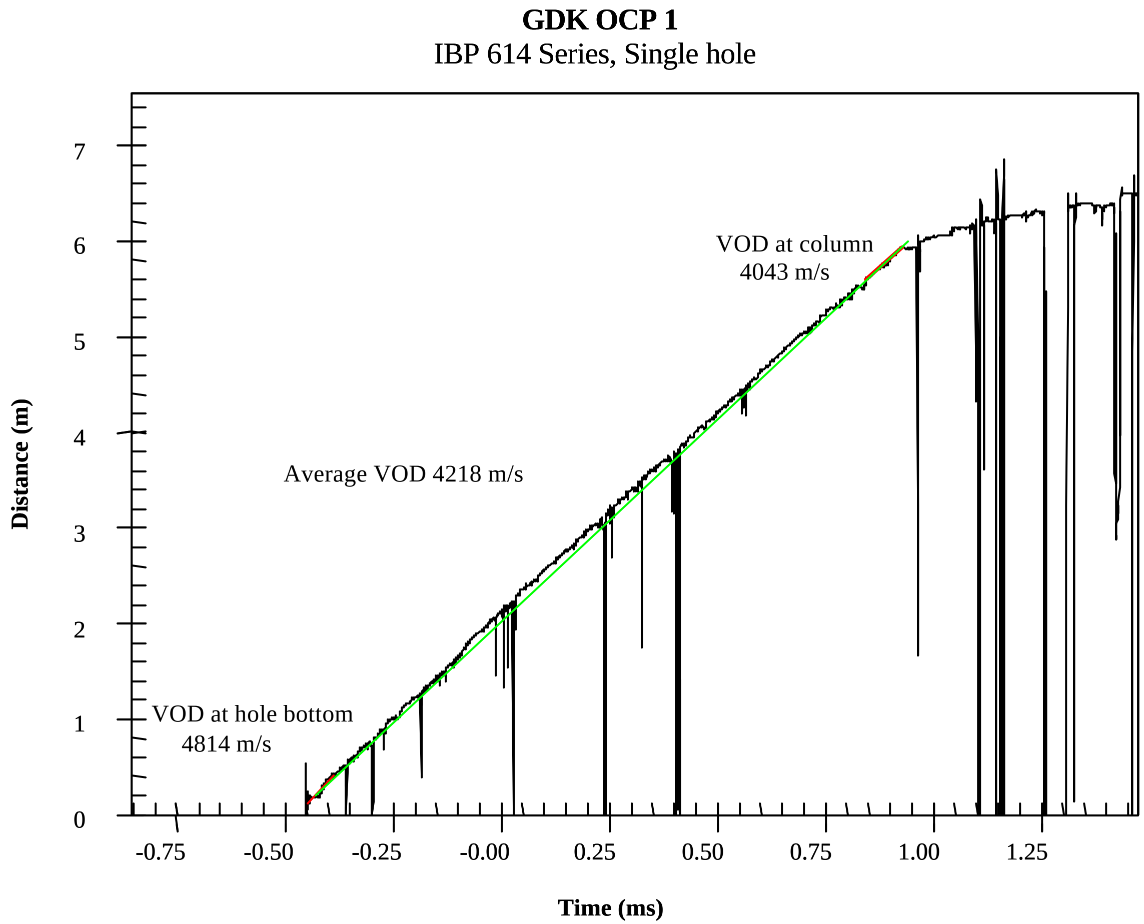


Figure 4.29 VOD result for blast No. 13 at OCP 1

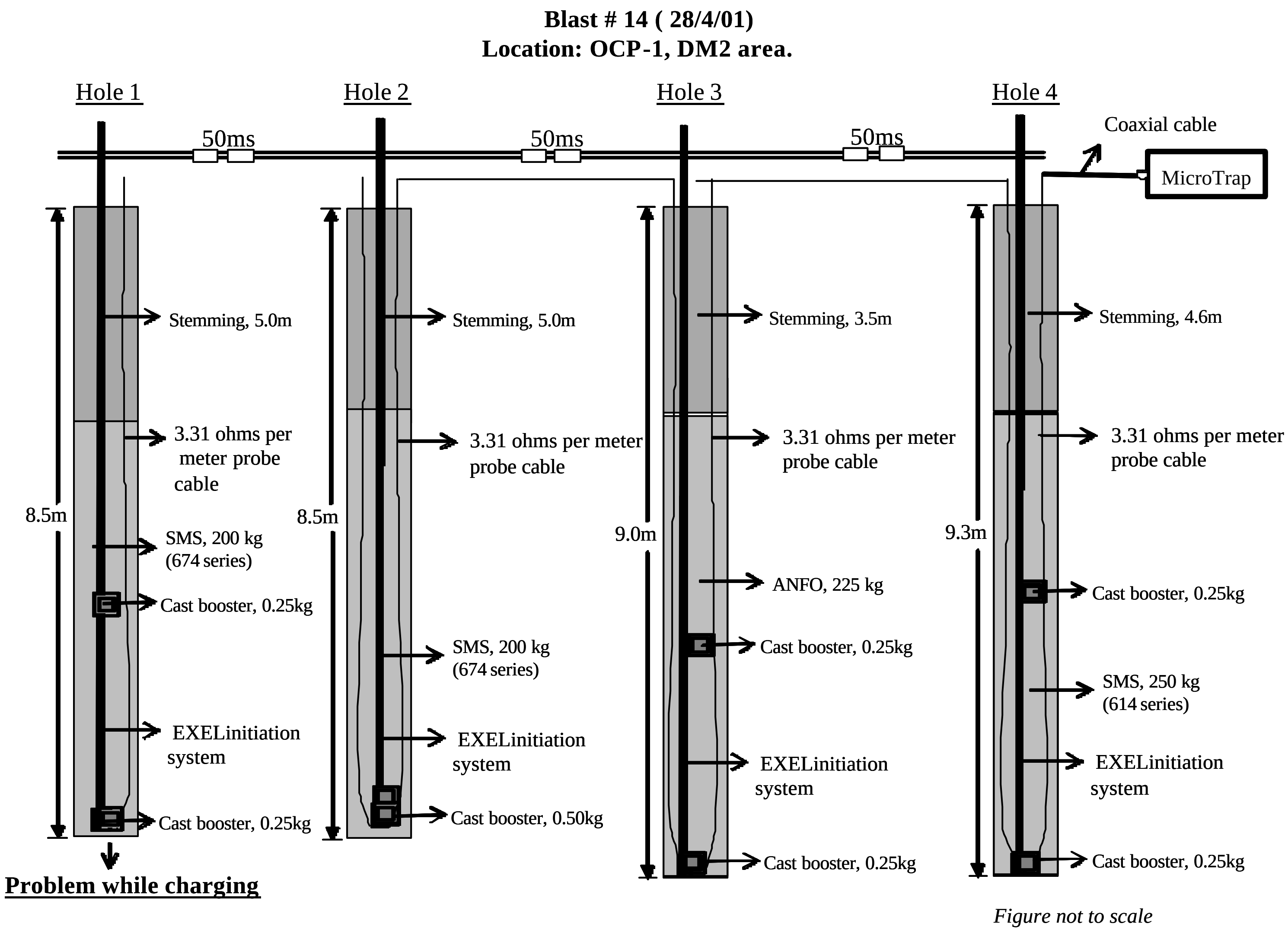


Figure 4.30 Details of the experimental holes for blast No. 14 at OCP-1

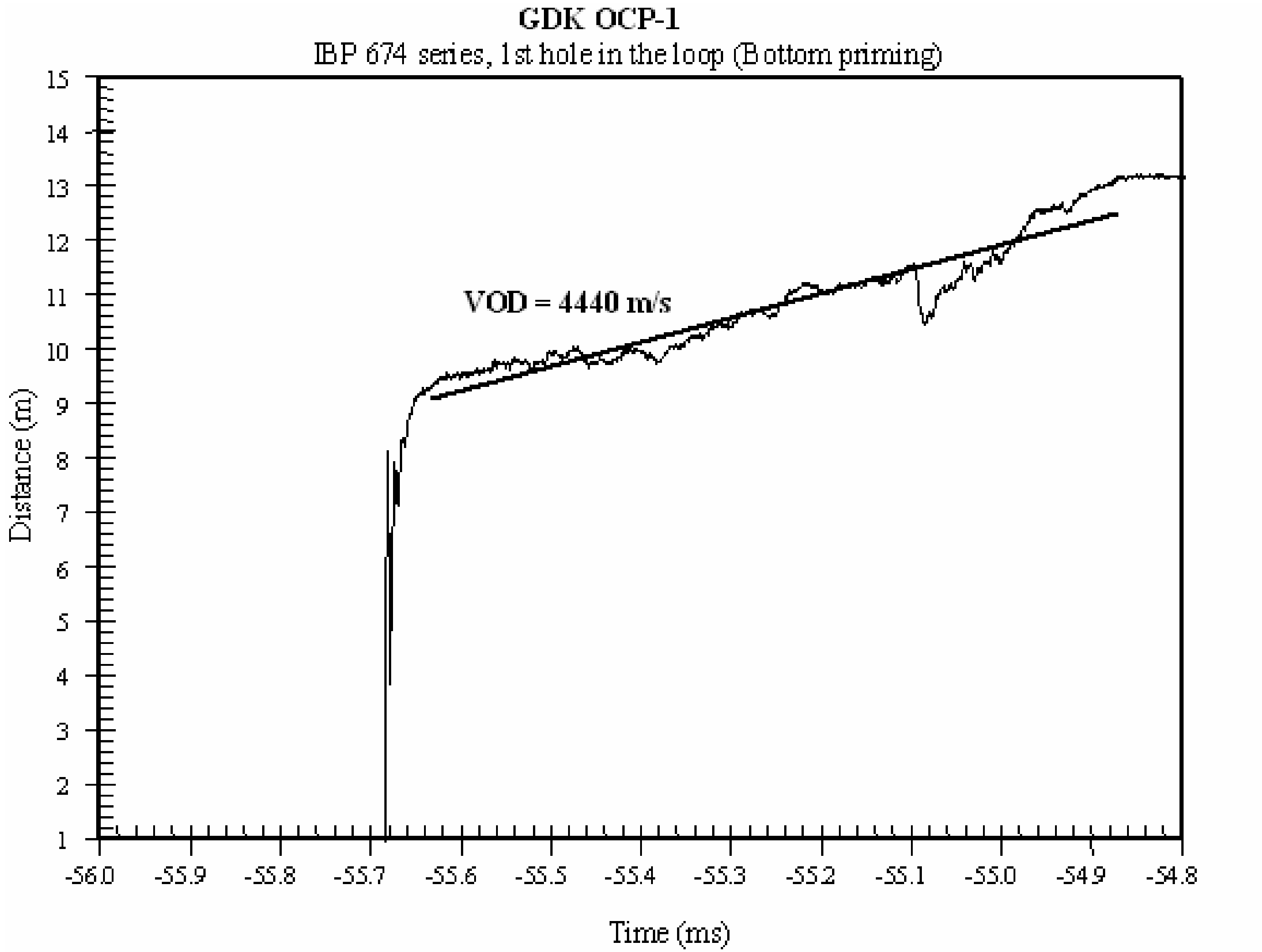


Figure 4. 31 VOD result for blast No.14 at OCP-1

GDK OCP-3
IBP 614 series, 4th hole in the loop
(Deck priming)

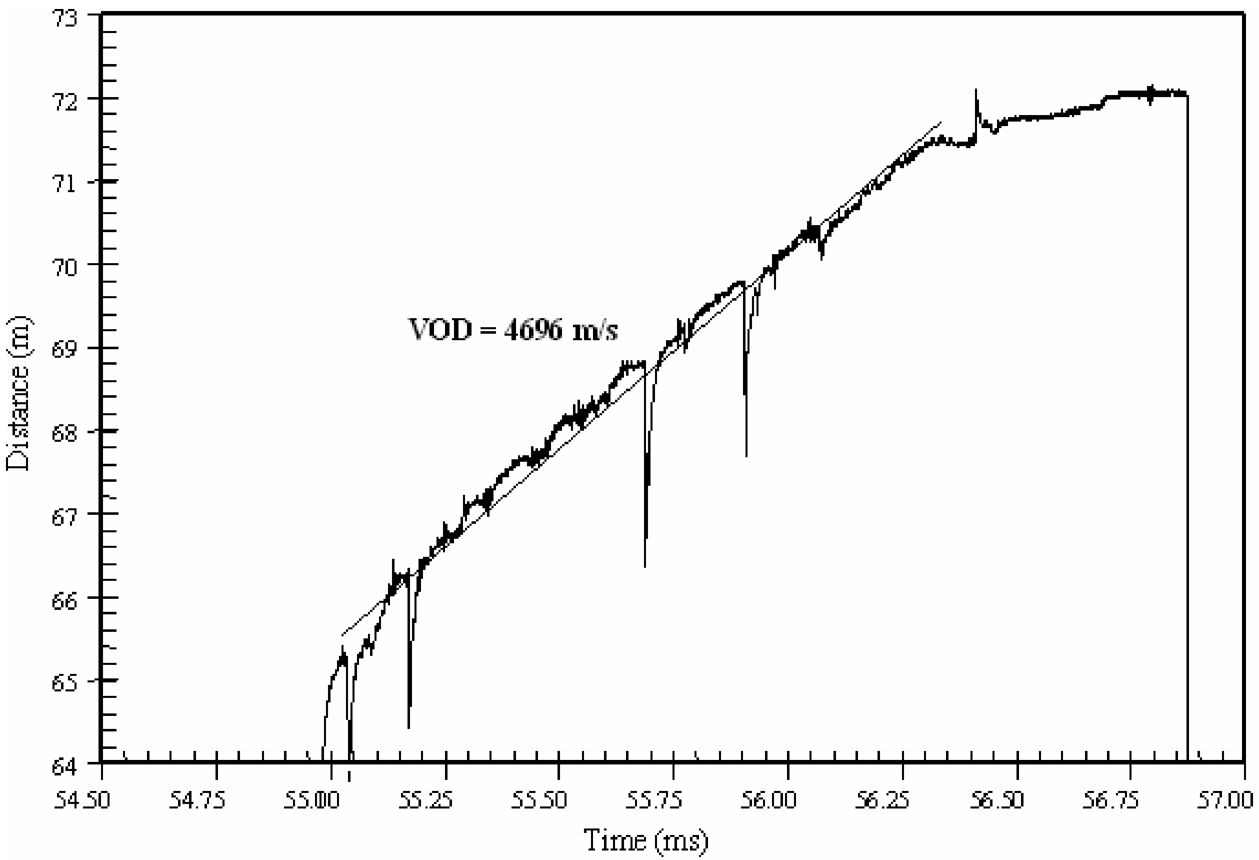


Figure 4. 32 VOD trace for blast No. 14 at OCP-3

Table 4.1 VOD values for the cartridged and bulk explosives monitored at SCCL.

Blast No.	Date	Explosive tested	VOD bottom (m/s)	VOD top (m/s)	VOD Average (m/s)	Quoted VOD, mm/s	Figure No.
GDKTRI 1	26.09.97	Ideal Boost Ideal Gel	4732	4183	4415	N. A.	4.2
GDKTRI 6	16.11.97	Bharat Prime & Bharat column	4819	4277	4506	4000 ± 200	4.4
GDKTRI 8	19.11.97	Bharat Prime & Bharat column	-	2984	4818	4000 ± 200	4.6 4.7
GDKTRI 9 Hole 1 Hole 2	21.11.97	Bharat Prime & Bharat column	 - 4553	 - 4490	 4268 4491	4000 ± 200	 4.9 4.10
GDKTRI 13	23.01.98	Bharat Prime & Bharat column	-	-	4514	4000 ± 200	4.12
GDKTRI 14	26.01.98	Bharat Prime & Bharat column	-	-	4496	4000 ± 200	4.14
GDKTRI 22	01.02.98	Bharat Prime & Bharat column	-	-	4402	4000 ± 200	4.16
Blast No. 6 Hole 1 Hole 2	01/04/01	Kelvex 600 & Kelvex 500	 4368 4558	 3828 -	 4203 4181	4200 ± 200	 4.18 4.19
Blast No. 11	25/04/01	Indoprime & Indogel 210	3946	3221	3581	4200 ± 200	4.21
Blast No 3	27/3/01	SMS 654 & SMS 634	4769 4055	4733 3829	4538 3948 4302*	4200 ± 200	4.23
Blast No 5	30/03/01	SMS 654	5191	4538	4668	4200 ± 200	4.25
Blast No 7	02/04/01	SMS 634	4359	3458	3933	4200 ± 200	4.27
Blast No. 13	27/4/01	SMS 614	4814	4043	4218	4200 ± 200	4.29
Blast No. 14 & Hole 1	28/04/01	SMS 674	-	-	4440	4200 ± 200	4.31
Blast No. 14 Hole 4	28/04/01	SMS 614	-	-	4696	4200 ± 200	4.32

*Overall VOD of both the series

4.2 INFLUENCE OF PRIMER SIZE AND PRIMER LOCATION ON VOD

A primer is a cap sensitive explosive which contains an initiator (detonator or detonating cord) inserted in it. Primers can be Pentolite cast boosters or small diameter primers such as Dynex-C or Kelvex-P or any cap sensitive explosive. Compared to cast booster and cap sensitive explosives, blasting agents are inexpensive, hence the percentage of primer is usually kept as minimum as possible. If the main charge in the bore hole is inadequate, the explosive can not attain its steady state VOD and hence reduces the delivery of the explosive energy, causing poor fragmentation with increased effects on the environment.

When cap sensitive and non-cap sensitive cartridged explosives are loaded in the hole alternatively, it becomes the case of multiple priming because the detonating cord will initiate the cap sensitive explosives whenever it meets them. Multiple priming also occurs with detonating cord initiation with bulk explosives using cast primers which are placed at two or more locations with regard to depth of holes. With shock tube initiation system, single point initiation near the bottom of the hole is possible. Cap sensitive explosives or cast booster placed in the charge column above the primer position acts as booster charges.

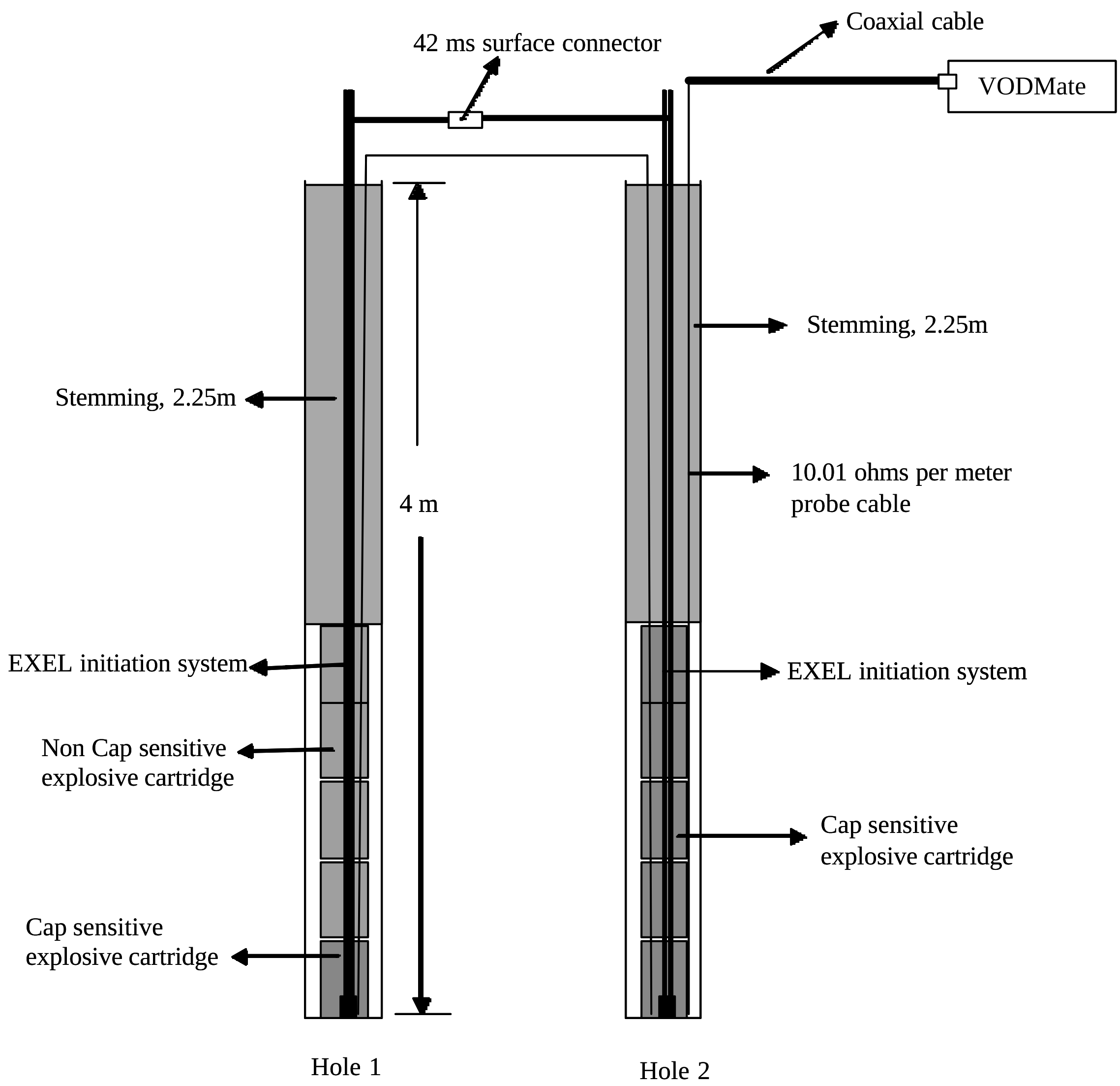
4.2.1 Measured VODs of ANFO Primed with Cartridged Slurries

Six experimental blasts were conducted at Jayanthipuram limestone mine to study the influence of primer/booster percentage on VOD of ANFO and cartridged slurry. Though the mine wanted to maximize the use of ANFO, slurry explosives were used in wet holes. Maruti Boost, a cartridged cap-sensitive slurry was used as primer/booster charges for ANFO as well as for Maruti Column, a cartridged non cap sensitive slurry. The percentage of primer/booster varied widely from 20 per cent to 100 per cent. Blastholes charged fully with cap sensitive explosives were arranged for the experimental purpose only. The VOD measurements were carried out with VODMate and the experiments consisted of single and up to six holes. No VOD record was found for Blast No 4 and 5 and the VOD record were not good for other holes also. The probable cause for not getting good quality VOD signatures was incompatibility of the probe cable used, though the suitability of the probe cable was confirmed by the supplier of the equipment. Since VOD recorded were not clear, the original signals were sent to the Globe Agency, the authorised Agent of Instantel, Canada seeking their advice. Figures 4.33 to 4.44 give details of the experimental hole(s) and the corresponding VOD graphs. In case of multiple holes, two or more VOD graphs are presented separately for each of the holes tested. Table 4.2 presents VOD values for the explosives tested at MCL.

Table 4.2 VOD measurements at Jayanthipuram, Madras Cements Limited

Blast No.	Date	Explosive Tested	Percentage of primer/booster	No of holes tested	VOD, mm/s
1	18/10/2000	Cartridged slurry	Hole 1= 20	2	Hole 1 = 3957
2	19/10/2000	Cartridged slurry Cartridged slurry Cartridged slurry	Hole 2=100 Hole 3= 40 Hole 4= 20	4	Hole 2 =3308 Hole 3 =3903 Hole 4 = 3825
3	20/10/2000	ANFO ANFO Cartridged slurry	Hole 2 =14.3 Hole 3 =17.2 Hole 4 = 21.0	6	Hole 2=3712 Hole 3= 3855 Hole 4= 3917
6	24/10/2000	ANFO	49.3	1	3668

The VOD of ANFO did not vary significantly by increasing primer/booster from 14 to 49 per cent and remained within 3700-3800 m/s. In the case of cartridged slurry explosives, the measured VOD was in the range of 3800-3900 m/s when primer/booster was increased from 20 to 40 per cent. The VOD of a hole loaded fully with cap sensitive was only 3308 m/s, which should have been at least 4000 m/s. There was no noticeable difference in VOD whether all the cap sensitive explosive was placed at the bottom or it was distributed in the charge column. As the rock breakage is more difficult at the lower portion of the bench, all cap sensitive explosives which have higher VOD, hence more shock energy can be loaded at the bottom. Using these results, Venkatesh and Rao (1999) have presented a case study to emulate bottom initiation with detonating cord and to reduce cost.



Note: Hole diameter 115 mm
Cartridge diameter 83 mm and weight 2.78kg
(Slurry explosive)
Average loading density 8 kg per meter

Figure not to scale

Figure 4.33 Details of the experimental holes for blast No. 1 at MCL

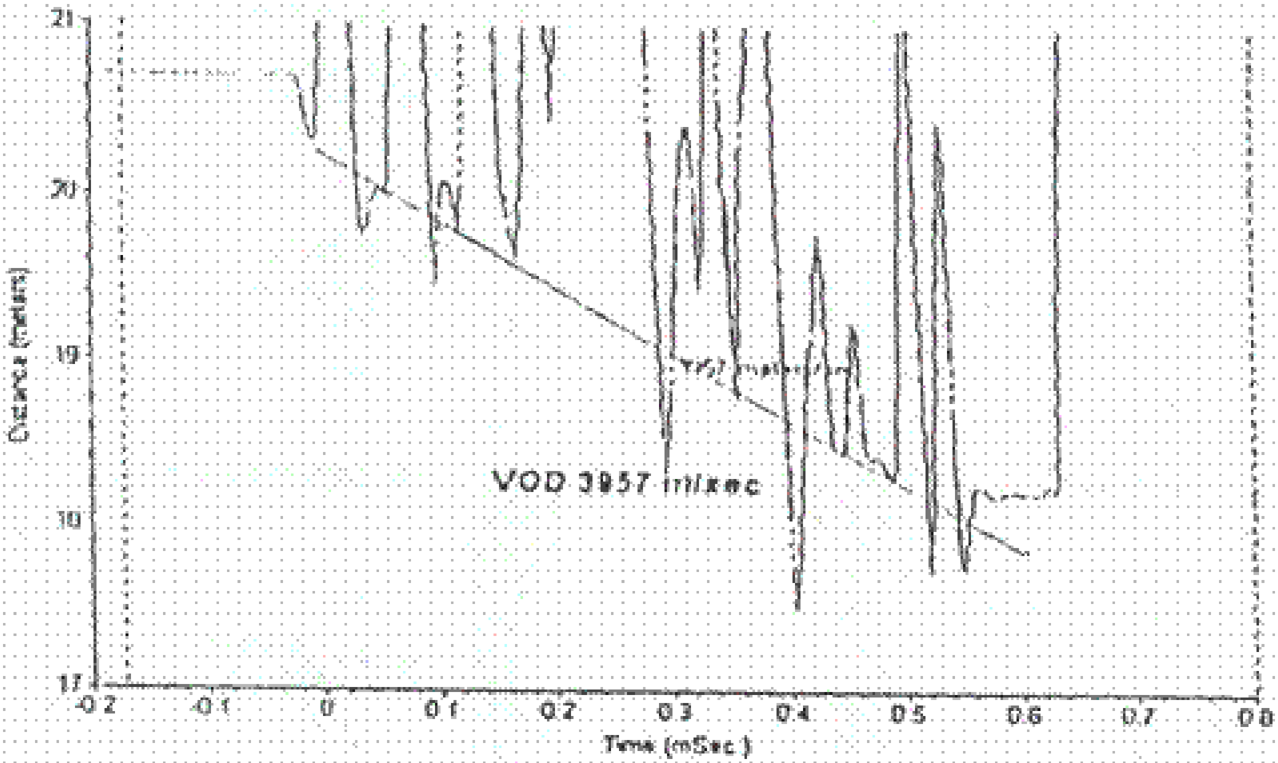


Figure 4.34 VOD result of hole No. 1, blast No. 1 at MCL

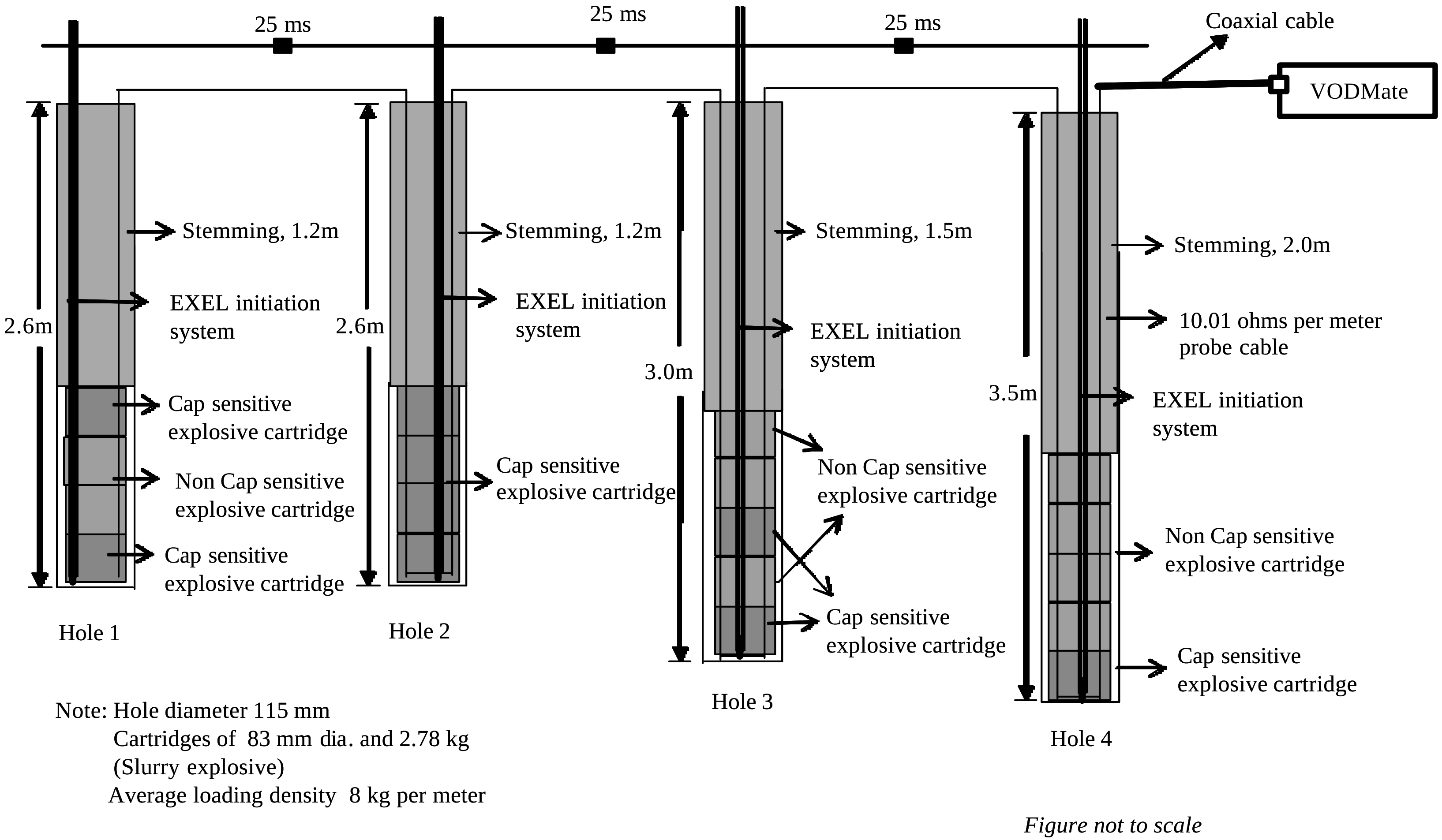


Figure 4.35 Details of the experimental holes for blast No. 2 at MCL

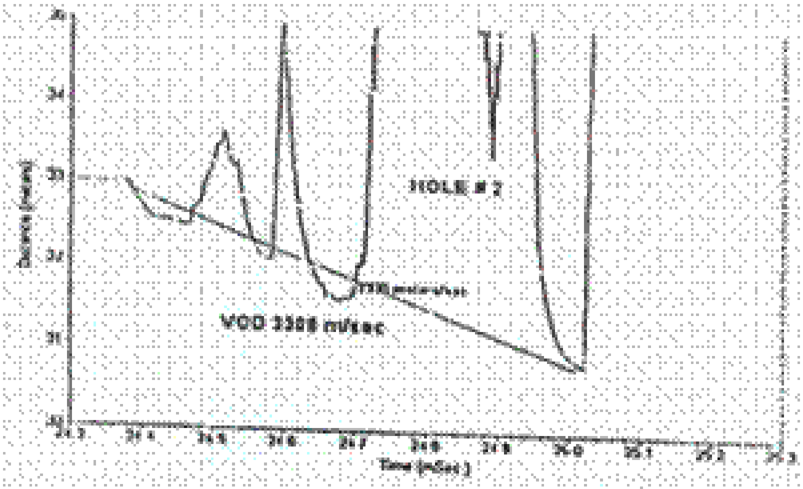


Figure 4.36 VOD result of hole No. 2, blast No. 2 at MCL

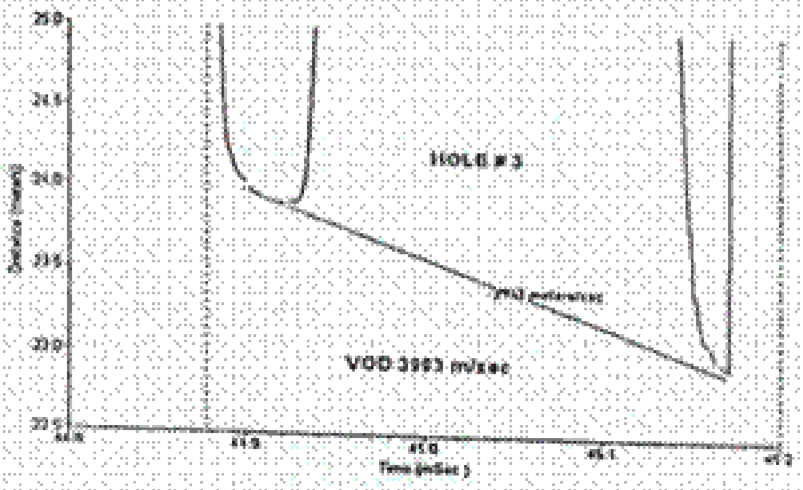


Figure 4.37 VOD result of hole No. 3, blast No. 2 at MCL

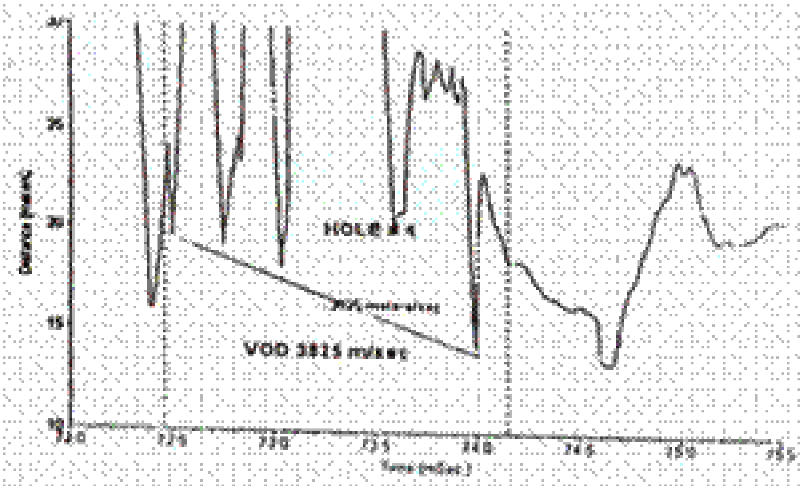
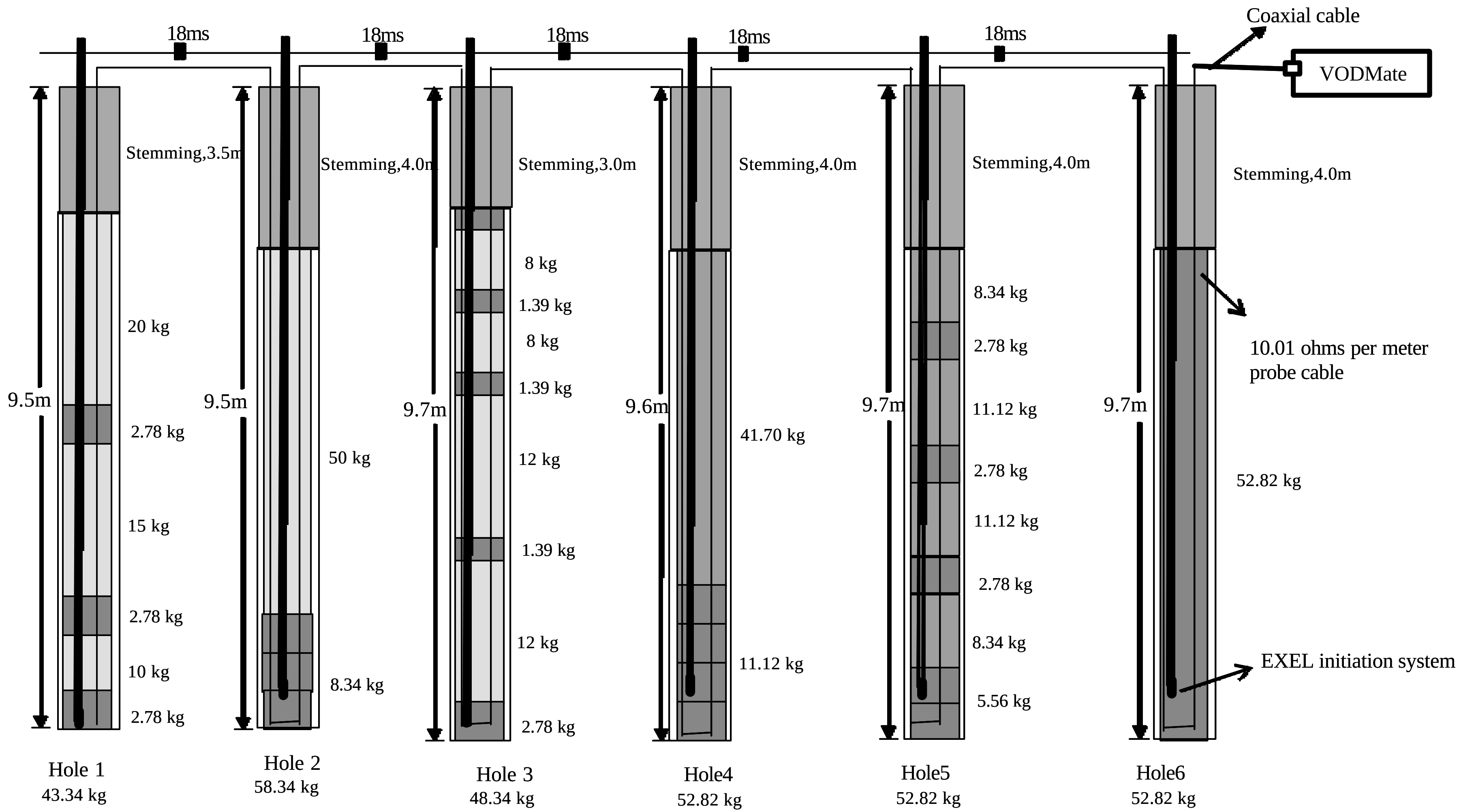


Figure 4.38 VOD result of hole No. 4, blast No. 2 at MCL



Note: Hole diameter 115 mm
Cartridges of 83 mm dia. and 2.78 kg (Slurry explosive)
Average loading density 8 kg per meter

Cap sensitive | Non cap sensitive | ANFO

Figure not to scale

Figure 4.39 Details of experimental holes for blast No. 3 at MCL

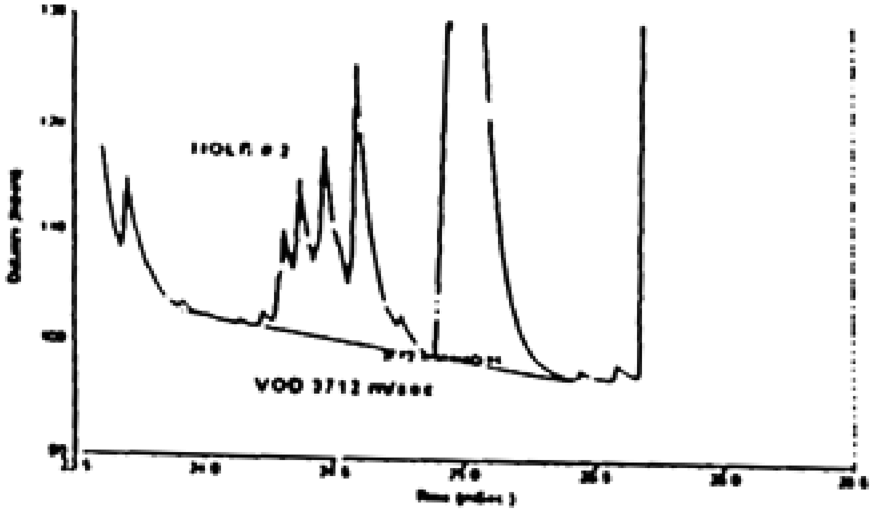


Figure 4.40 VOD result of hole No. 2, blast No. 3 at MCL

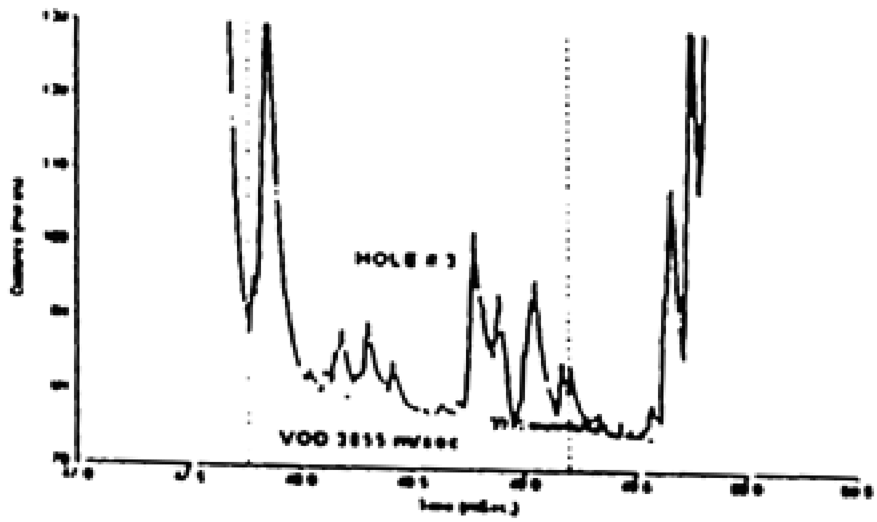


Figure 4.41 VOD result of hole No. 3, blast No. 3 at MCL

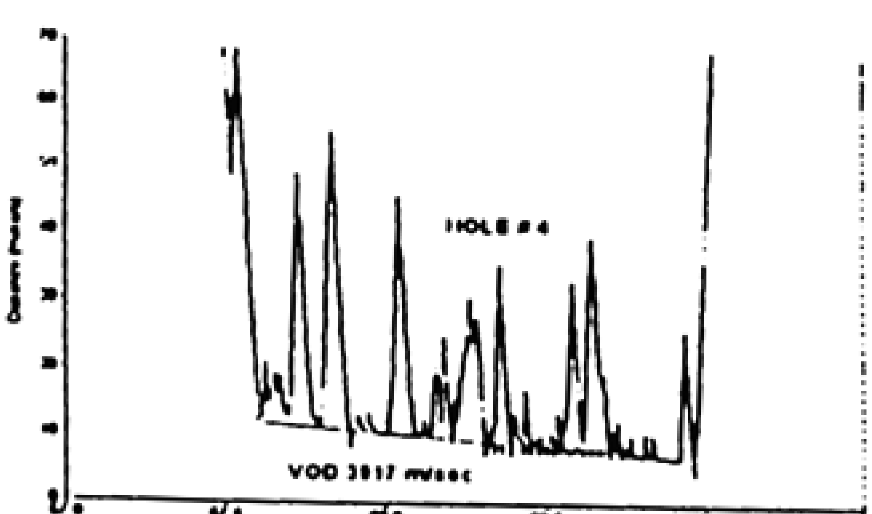
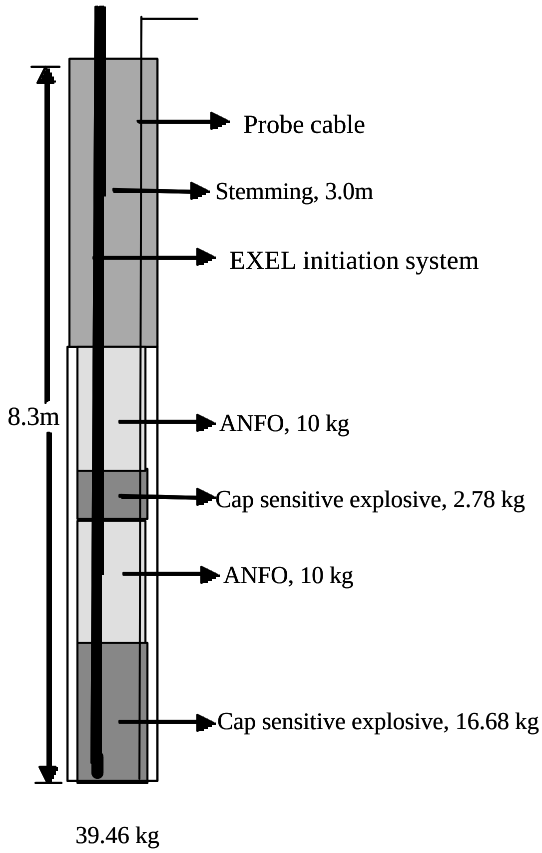


Figure 4.42 VOD result of hole No. 4, blast No. 3 at MCL



Note: Hole diameter 115 mm
Cartridges of 83 mm dia. and 2.78 kg
(Slurry explosive)
Average loading density 8 kg per meter

Figure not to scale

Figure 4.43 Details of experimental holes for blast No. 6 at MCL

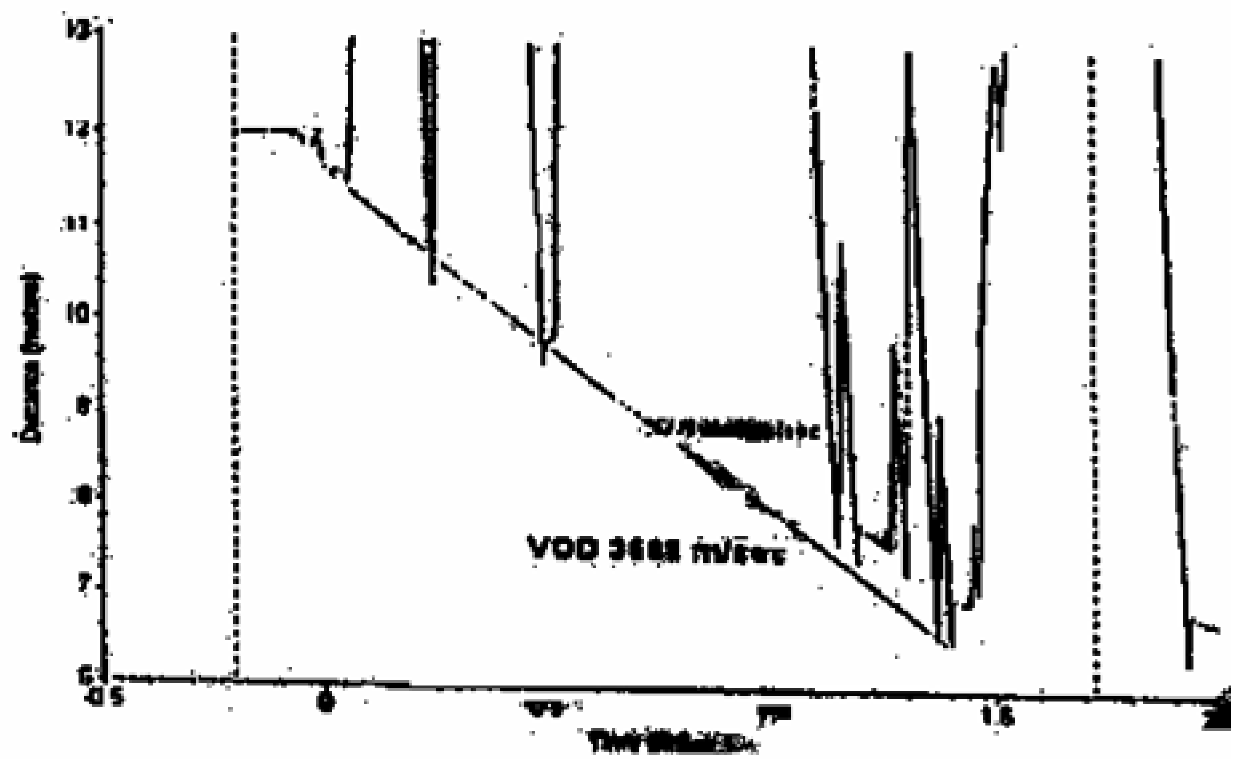


Figure 4.44 VOD result of blast No. 6 at MCL

4.2.2 Measured VODS of ANFO Primed with Small Diameter Kelvex -P

In order to study the influence of primer size on VOD of ANFO primed with small diameter primer, five experiments were conducted at Walayar limestone mine, ACC. The main explosive used in the mine was ANFO, primed with Kelvex-P (0.5 kg). Usually, one or two additional Kelevex-P were loaded in the ANFO column to ensure sustainable detonation of the charge, limiting the primer/booster charge at about 4 per cent. Raydet detonators having 475 ms delays were used for initiating blastholes. The entire blast was initiated with 475ms down-the-hole delays in conjunction with surface relays. For blast No. 5, the test was in a single hole. Experiment No 1, 2 and 5 were successful whereas the other two were unsuccessful. Blast # 3 was experimented using detonating cord instead of shock tube as shown in Figure 4.45a. To avoid multi point initiation, cap sensitive explosives were placed at the bottom. The probe cable and the detonating cord were placed diametrically opposite to each other in the blast so as to avoid any blast damage to the probe cable while initiating. However, this experiment was not successful as the detonating cord damaged the probe cable despite sufficient care being taken. In case of blast # 4, the experiment was in a single hole using shock tube initiation. The instrument did not trigger and this was not understandable. Figures 4.45b to 4.50 give details of the experimental hole(s) and the corresponding VOD graphs. In case of multiple holes, two or more VOD graphs are presented separately for each of the holes tested. The experimental results are summarised in Table 4.3.

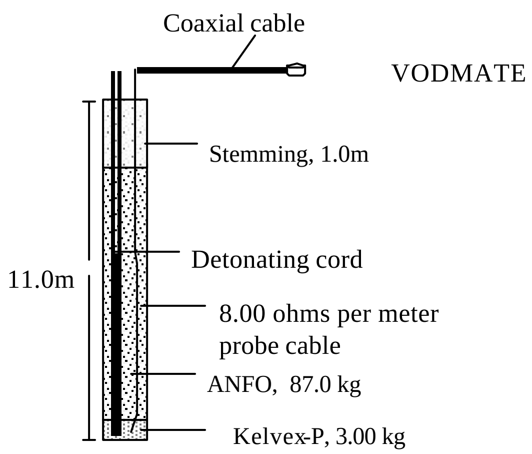
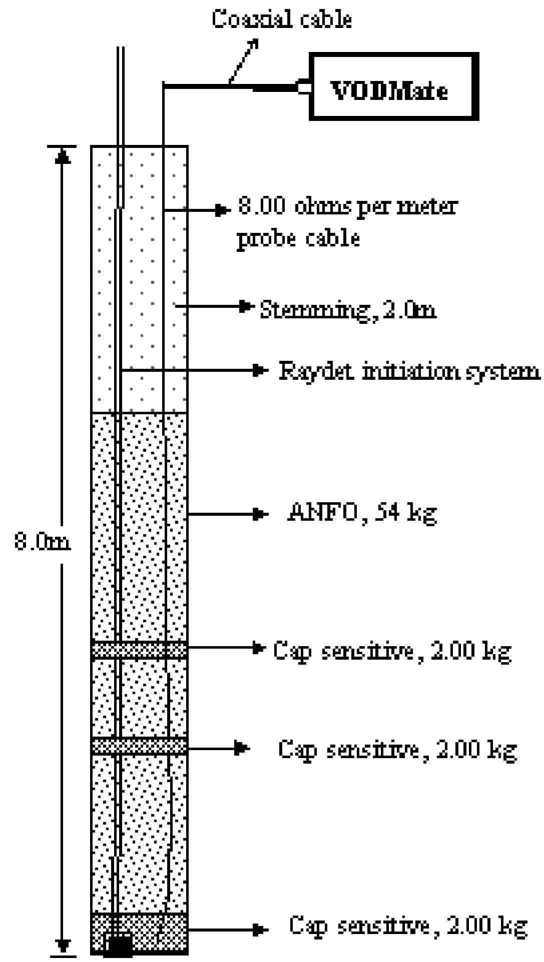


Figure 4.45a Single hole experimental set up for blast No. 3 using D-cord



Note: Hole diameter 115 mm
Cartridges of 50 mm dia. and 0.5 kg
(KelvexP- Slurry explosive)
Average loading density 8 kg per meter

Figure not to scale

Figure 4.45b Details of the experimental hole for Blast No. 1 at Walyar Limestone Mine

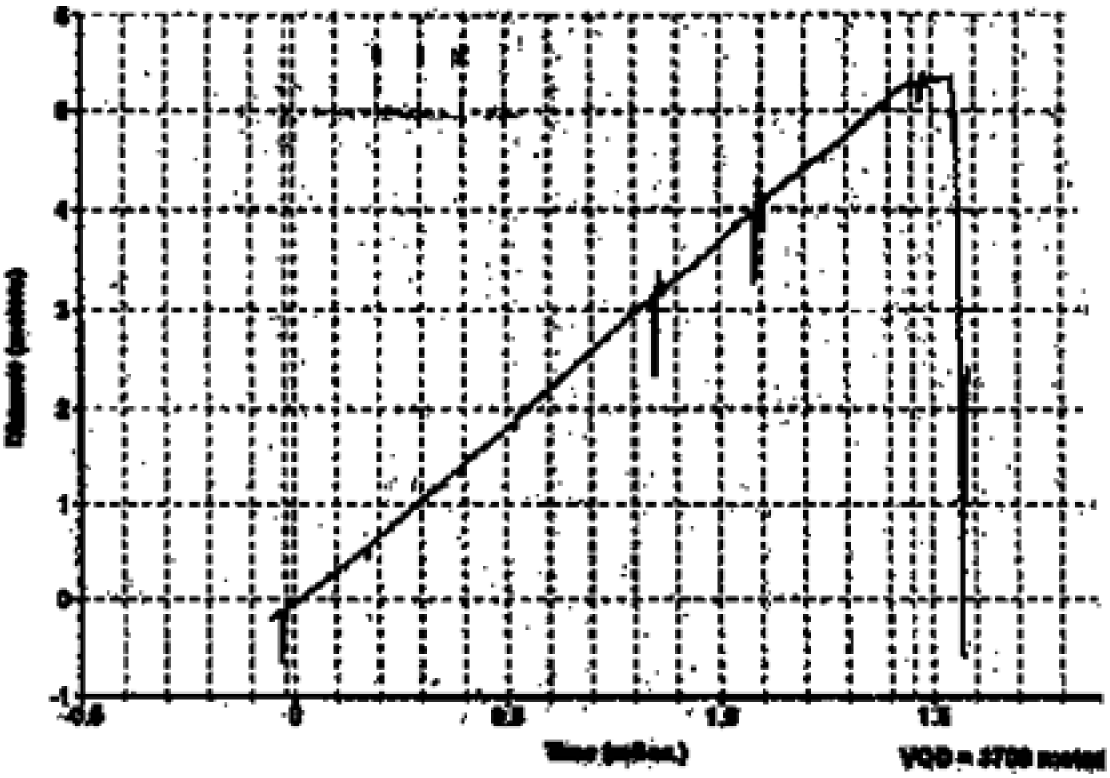


Figure 4.46 VOD result with 6 percent primer, blast No. 1 at Witkyar Limestone Mine

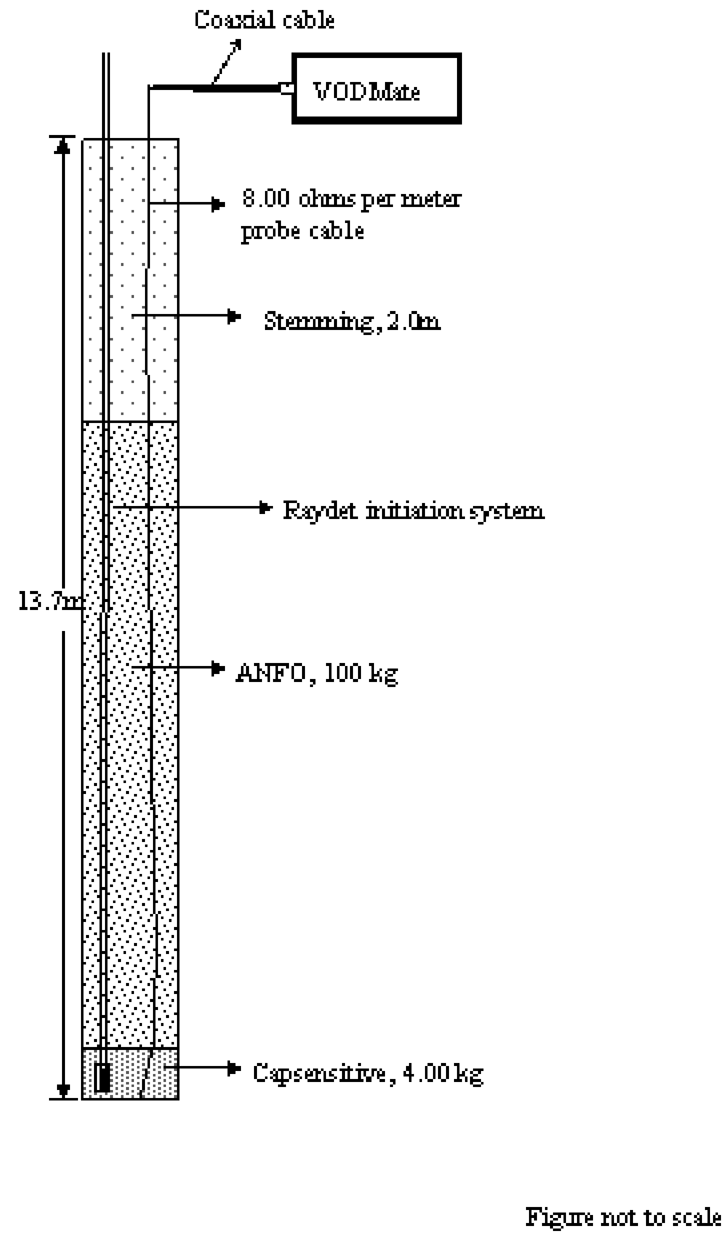


Figure 4.47 Details of the experimental hole for Blast No. 2 at Walyar Limestone Mine

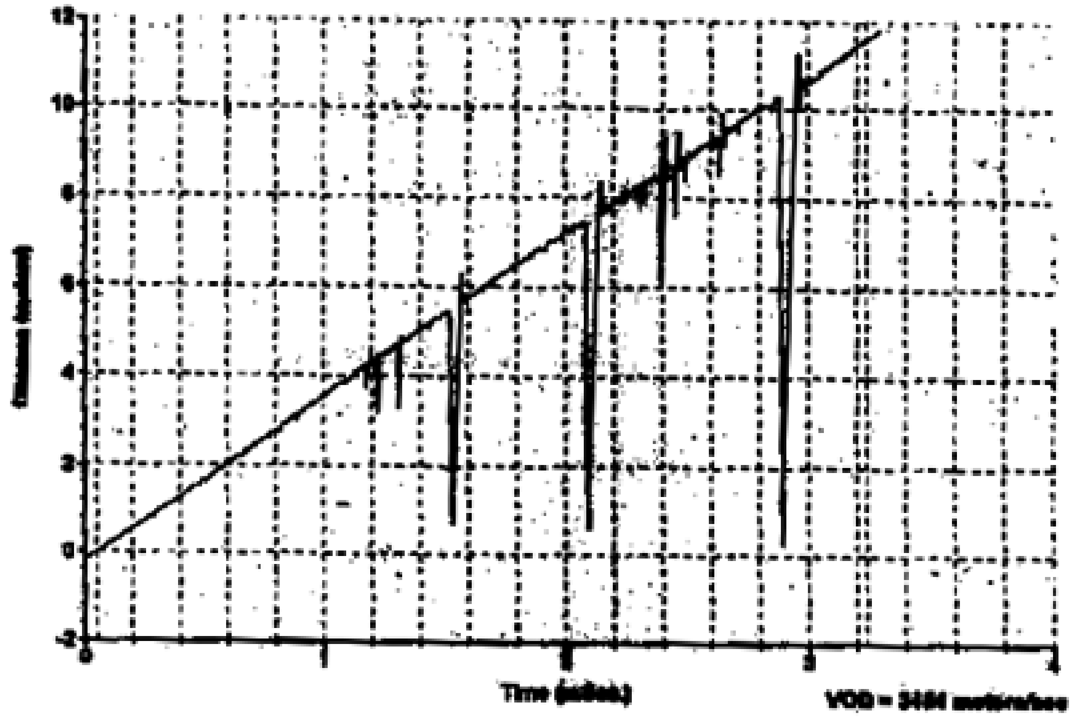


Figure 4.46 VOD result with 4 percent primer, Blast No.2 at Walayar Limestone Mine

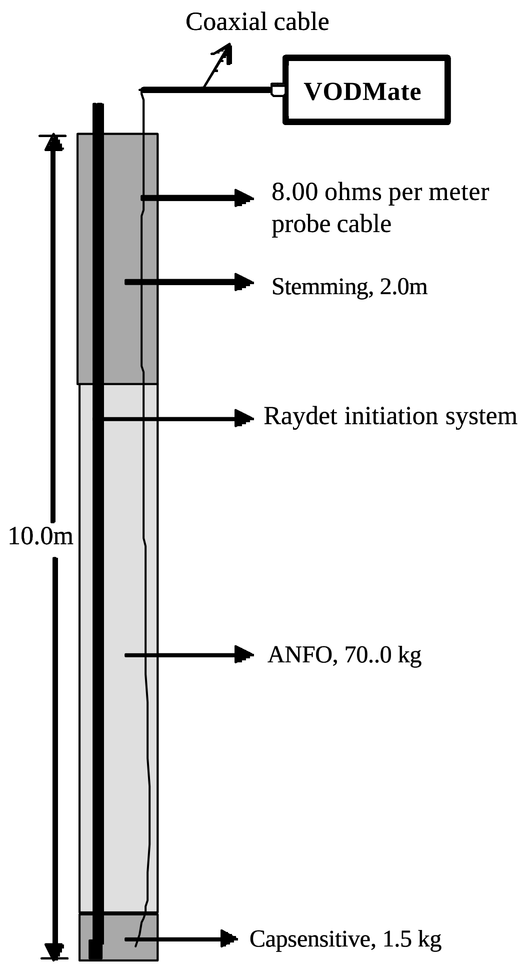


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Figure 4.49 Details of the experimental hole for Blast No. 5 at Walyar Limestone Mine

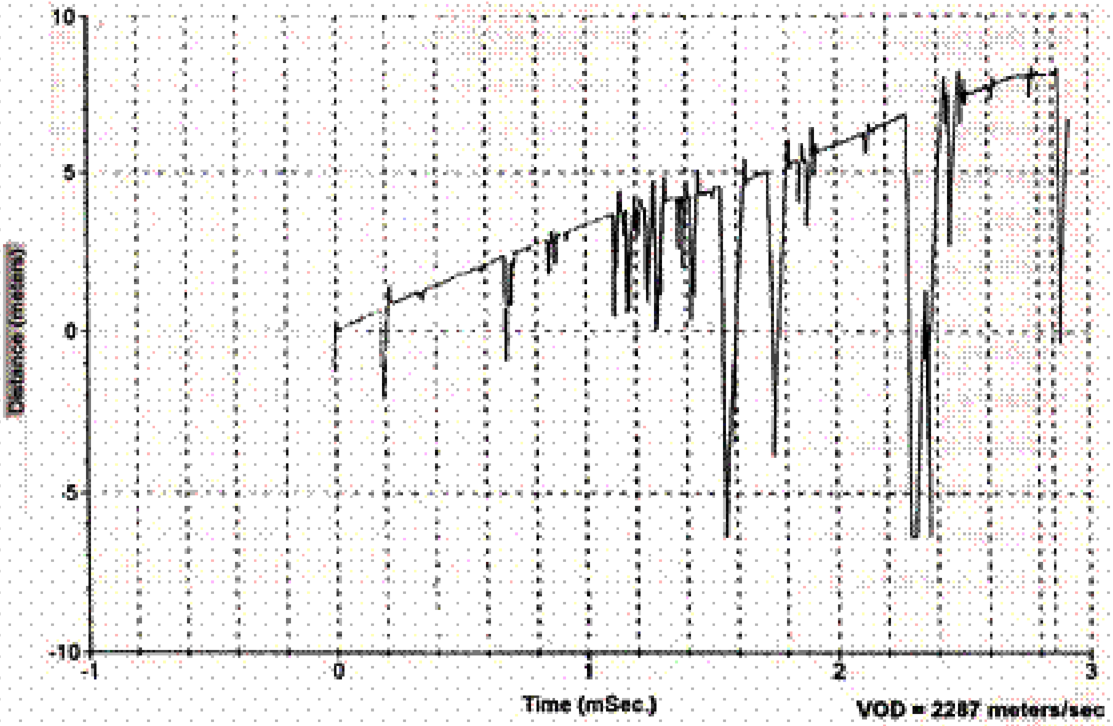

Figure 4.50 VOD result with 2 percent primer, blast No.5 at Walayar Limestone Mine

The VOD of ANFO at about 2 per cent of primer was only 2287 m/s, which was significantly less than the expected VOD of ANFO. The VODs of ANFO with 3.8 per cent and 5.3 per cent of primer/booster charge were within the expected range of 3500-3600 m/s. On the basis of these experiments, it is concluded that Kelvex-P of about 4 per cent can reliably initiate the ANFO and higher percentage of the primer/booster charge may not be cost effective. Even though small diameter Kelvex-P is not common for priming in coal mines, the study was carried out in this limestone mine to cover different priming practices being carried out in India.

As shown in the blasthole sections, Kelvex-P was loaded at the bottom in all the experiments except the first one. From the VOD studies, it was established that the single point priming was sufficient to reliably initiate and sustain the steady state VOD up to 10 m long ANFO column without any booster charge. As a result of these experiments, mines management gained confidence that even with detonating cord initiation, all cap sensitive explosives can be loaded at the bottom of the hole so that toe problem prevailing in the mine can be effectively tackled.

Table 4.3 Influence of primer size on VOD of ANFO at Walayar limestone mine

Experiment No.	Date	Percentage of Primer	VOD of ANFO, mm/s	Remarks
1	17/11/2000	5.3	3708	Monitored by VODMate
2	18/11/2000	3.8	3454	Monitored by VODMate
5	21/11/2000	2.1	2287	Monitored by VODMate

4.2.3 Measured VODs of Cartridged Slurries Primed With Cartridge

The cartridged explosives for which VOD were presented in Table 4.1 were also analysed to know whether the primer/booster percentage was adequate. The percentage of primer/booster was calculated from the blasthole loading patterns and varied from 17 to 22 (Table 4.4). It was found that the ratio of the cap sensitive to non-cap sensitive cartridges used by the mine was adequate.

Table 4.4 Influence of primer percentage on VOD of cartridged explosives

Date	Mine 1	Explosives tested	Primer/ Booster, %	Average VOD (m/s)
26.09.97	OCP 1	Ideal Boost & Ideal Gel	17	4415
16.11.97	OCP 1	Bharat Prime & Bharat Column	20	4506
19.11.97	OCP 1	Bharat Prime &Bharat Column	17	4818
21.11.97	OCP 1	Bharat Prime & Bharat Column	17	4628 4491
23.01.98	OCP 1	Bharat Prime & Bharat Column	20	4514
01.02.98	OCP 1	Bharat Prime & Bharat Column	22	4402

4.2.4 Measured VODs of SMS Primed With Cast booster/Cartridge

The influence of the size and location of primer/booster charge on VOD of bulk explosives using cast primers/boosters of different size at locations were tested at OCP 3. Details of experimental holes (s) and corresponding VOD graphs are given in Figures 4.51 to 4.56. The measured VOD values are summarised in Table 4.5.

Table 4.5 Measured VOD values of different explosives

Date	Mine	Explosive tested	Primer/booster, %	Location of primer/booster	VOD, mm/s
21/04/2001	OCP 3	SMS 654	0.18	Bottom priming	4656
21/04/2001	OCP 3	SMS 654	0.17	Deck priming	4726
23/04/2001	OCP 3	SMS 654	0.40	Deck priming	4364
23/04/2001	OCP 3	SMS 654	0.37	Bottom priming	4643

The VOD of SMS 654 was within the range of 4364 - 4726 m/s and did not show increasing trend with the increase of primer/booster. It is therefore concluded that the cast boosters about 0.2 per

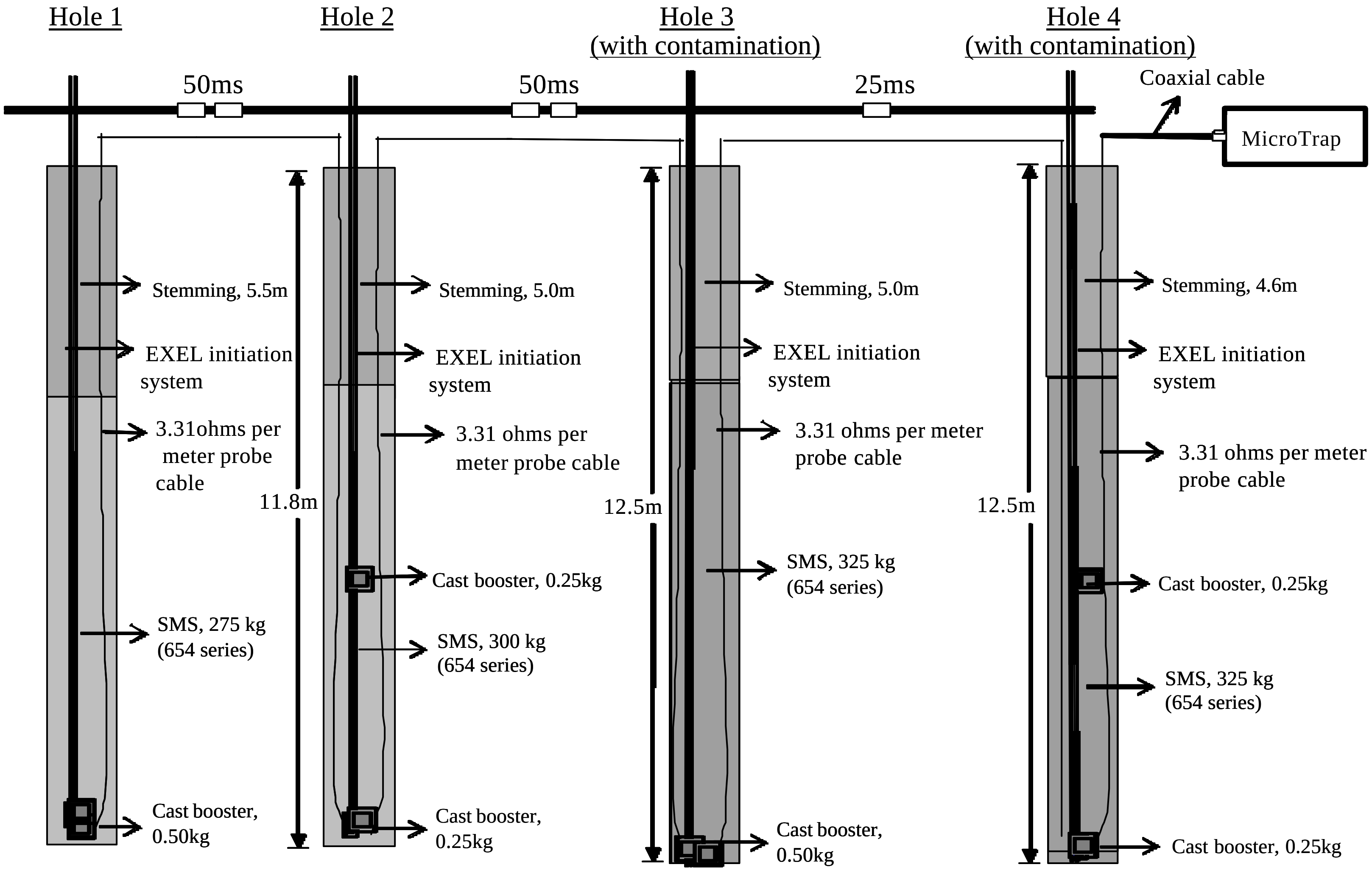

Figure not to scale

Figure 4.51 Details of the experimental holes for blast No.8 at OCP-3

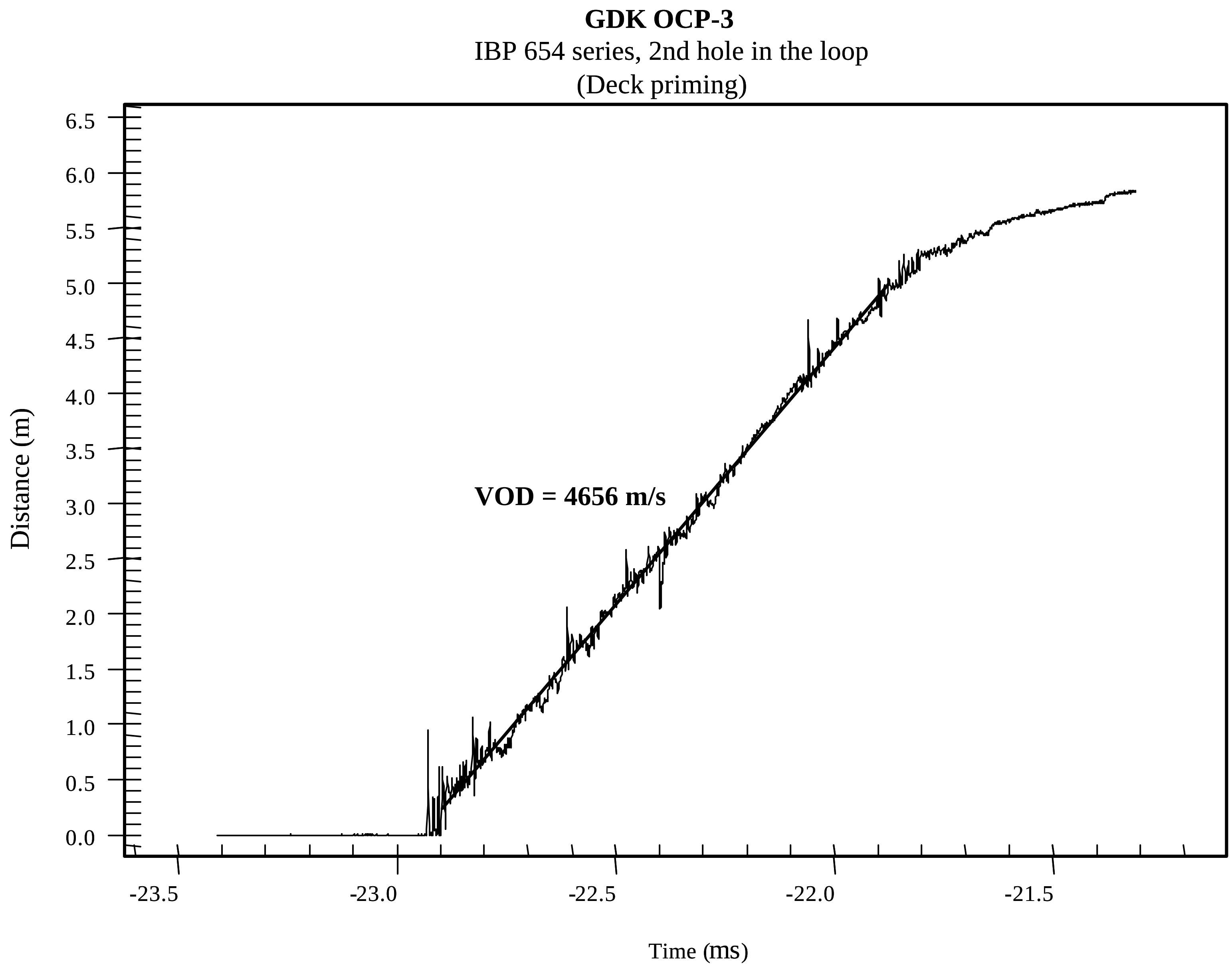

Figure 4. 52 VOD results for blast No.8 at OCP-3

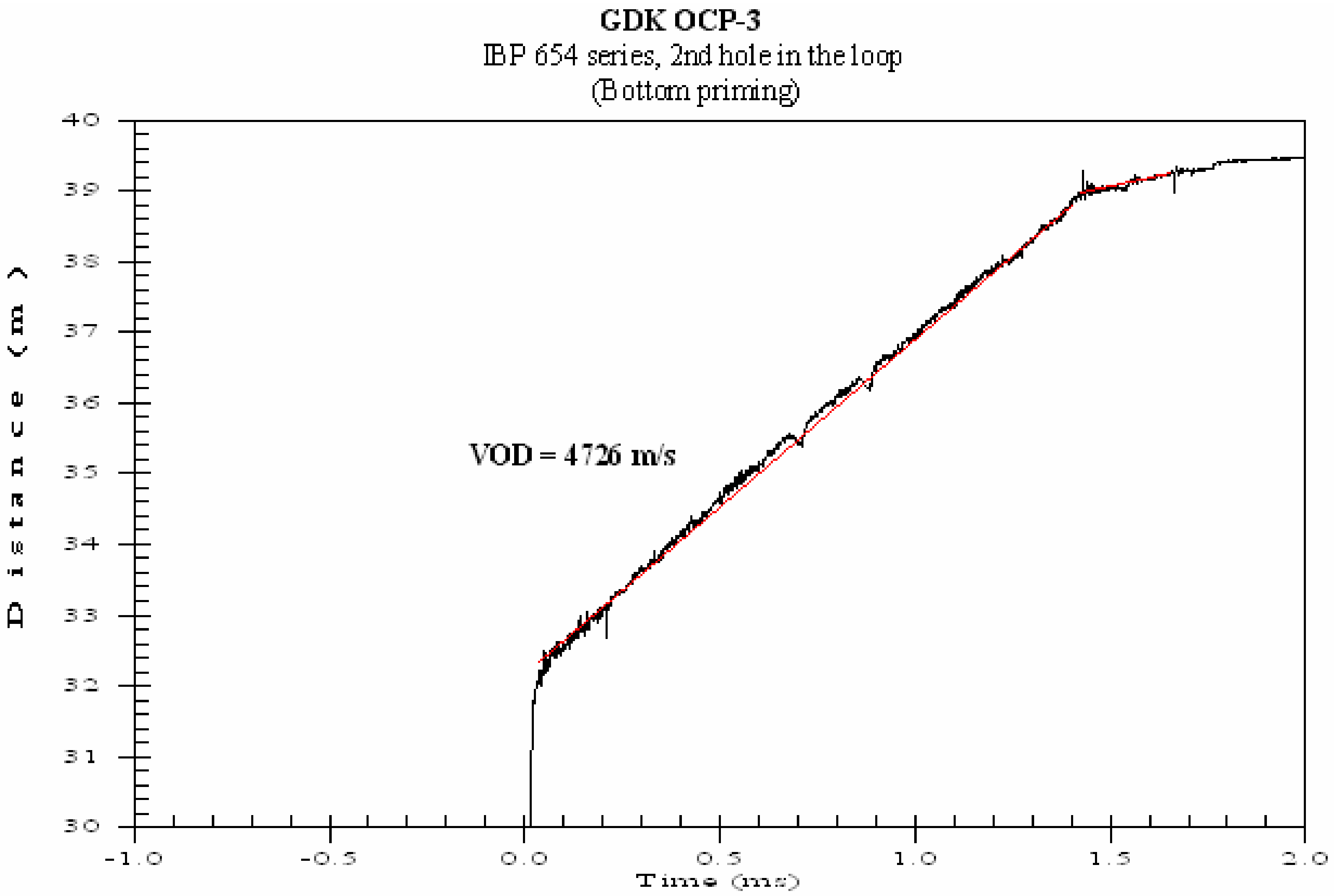

Figure 4. 53 VOD trace for blast No.8 at OCP-3

Blast # 9 (23/4/01) , Location: OCP3, DM8 area
(to determine the size of primer)

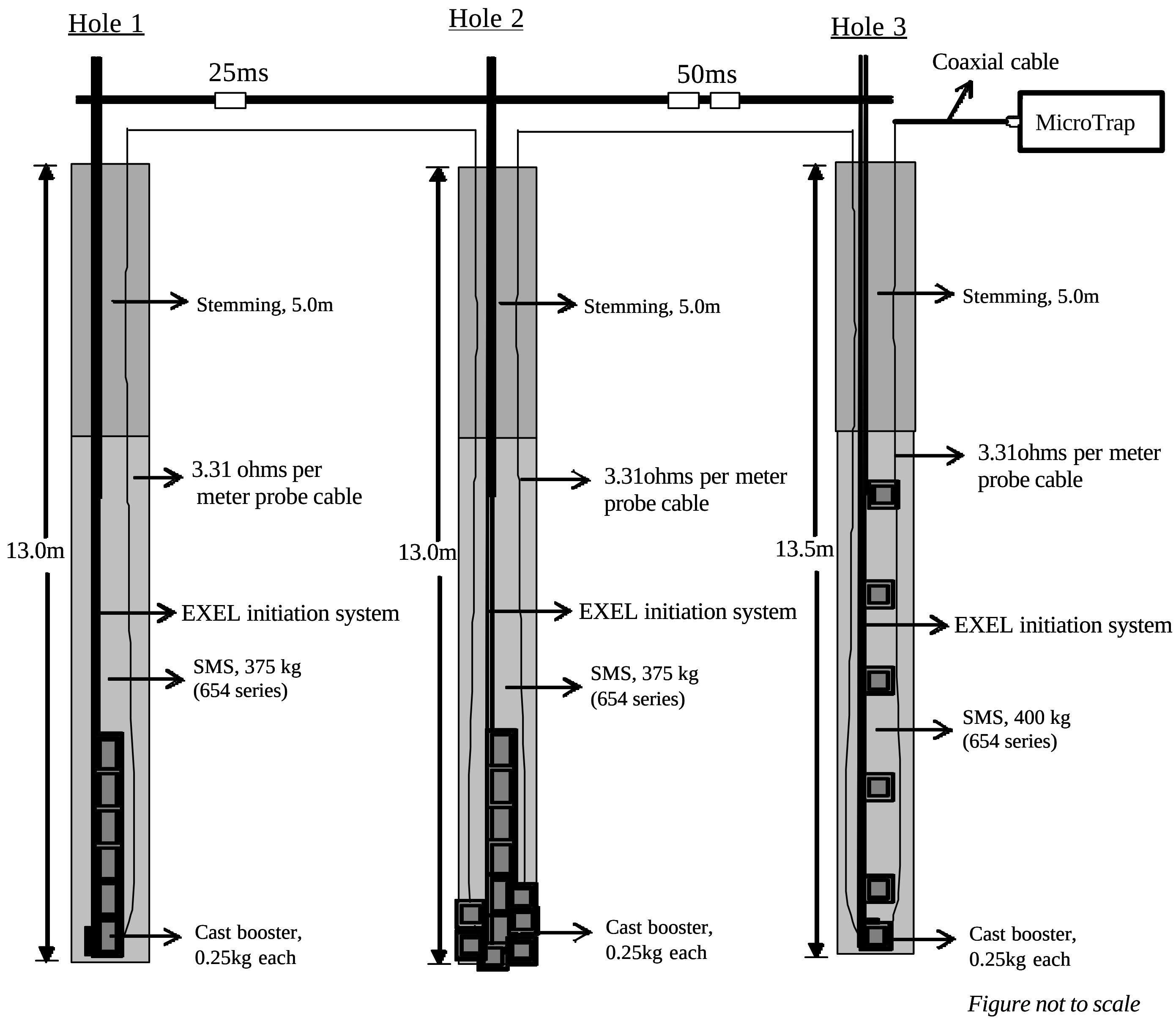

Figure 4.54 Details of the experimental holes for blast No. 9 at OCP - 3

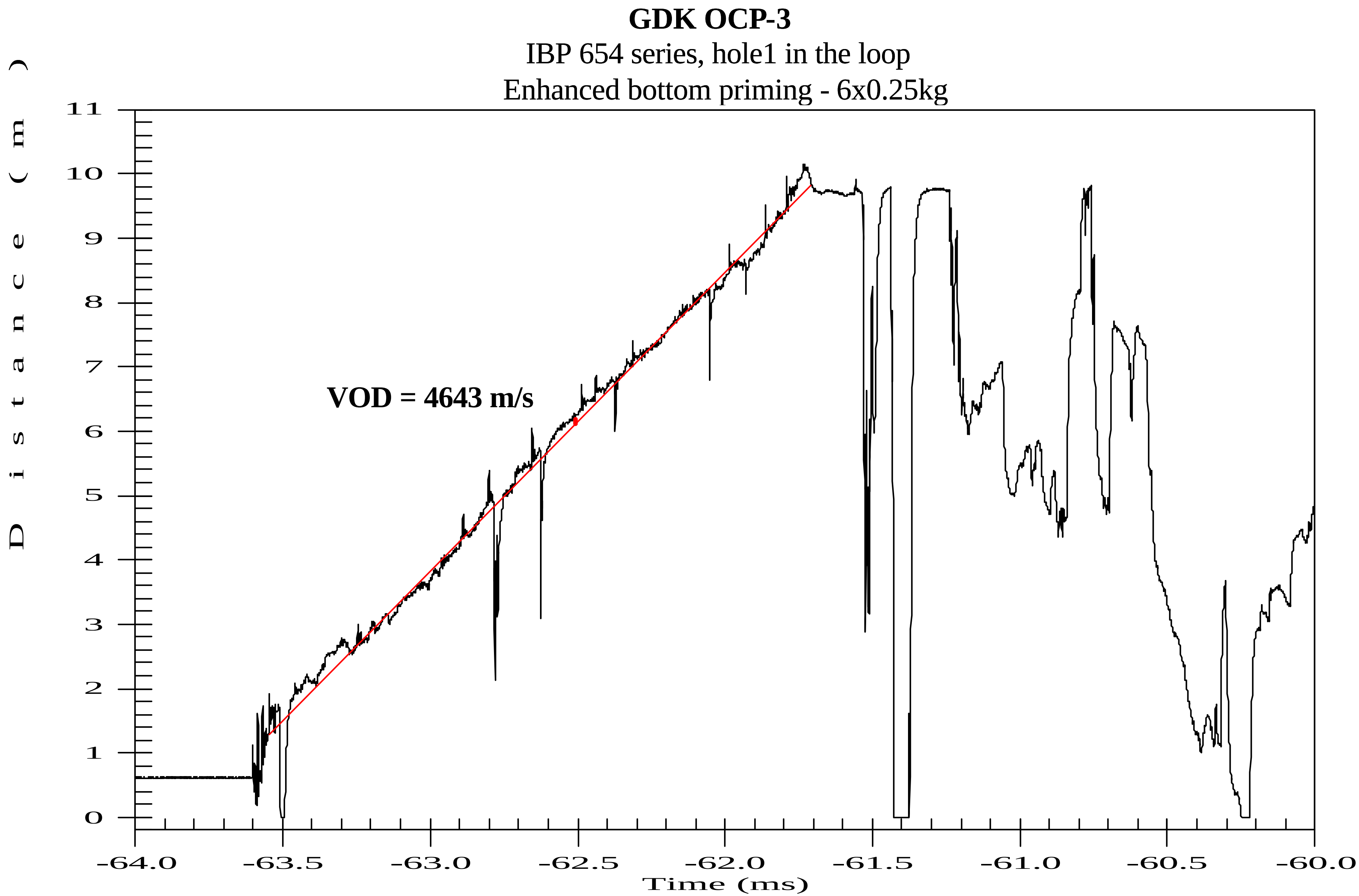

Figure 4. 55 Details of the VOD trace for blast No.9 at OCP-3

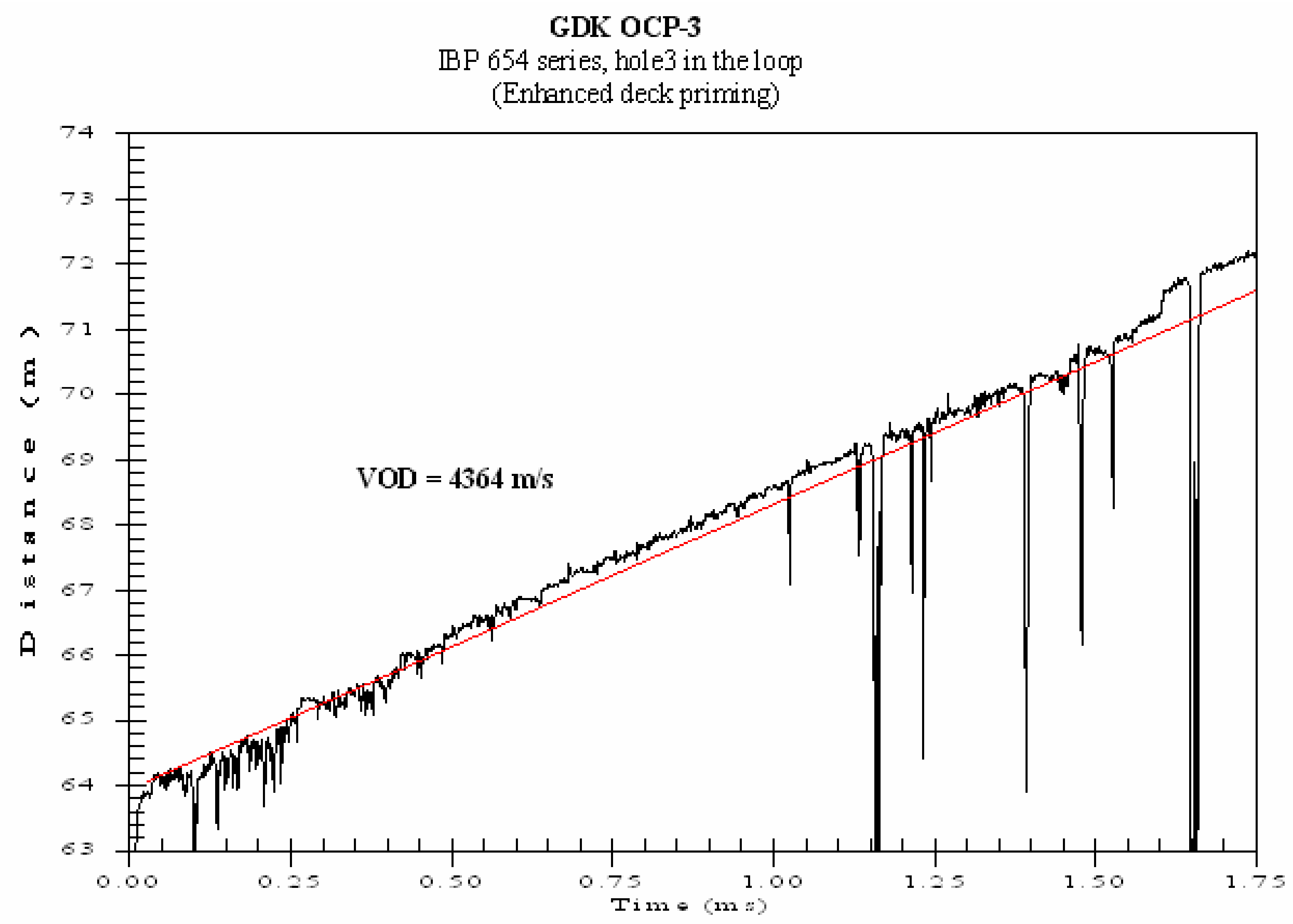

Figure 4.56 VOD result for blast No. 9 at OCP-3

cent are sufficient for priming the site mixed slurry and they need not match the blasthole diameter for efficient priming. Secondly, there was no obvious advantage of bottom or decked priming in respect of VOD values or the release of shock energy of the explosive.

4.3 INFLUENCE OF CONTAMINATION ON VOD

In the past, Indian mining companies were mostly using cartridged explosives. These explosives are manufactured under controlled environment of the factory and the products are generally consistent in quality, stable and unaffected by transport and handling. Recently there has been trend towards the use of bulk explosives. In the bulk loading of explosives, the ingredients are carried to site and final mixing takes place inside the blasthole. As such bulk explosives are vulnerable to the effects of contamination. The most common contaminants are the drill cuttings, which are not cleared at the mouth of the hole at the time of charging of explosives. Keeping the above in view, VOD testes with contamination with drill cuttings were conducted for bulk explosives. About 10 kg of drill cuttings were poured into hole at a uniform rate such that the explosive was contaminated throughout its entire column. In order to enable the comparison of the explosives with and without contamination, four experiments were conducted with the same explosive. The charging patterns of blastholes for all the four experimental holes and corresponding VOD graphs are given in Figures 4.57 to 4.63. The average VOD of SMS 654 with contamination is given in Table 4.6.

Table 4.6 VOD for SMS with contamination

Date	Mine	Explosives tested	Instrument used	Average VOD, m/s	Remarks
23/04/2001	OCP 3	SMS 654	VODMate	4235	
23/04/2001	OCP 3	SMS 654	VODMate	4393	
24/04/2001	OCP 3	SMS 654	VODMate	4157	
28/04/2001	OCP 1	SMS 654	VODMate	3114	Sleep time of 8 days

Blast # 9 (23/4/01)
Location: OCP-3, Below 2 seam
To test the effect of contamination

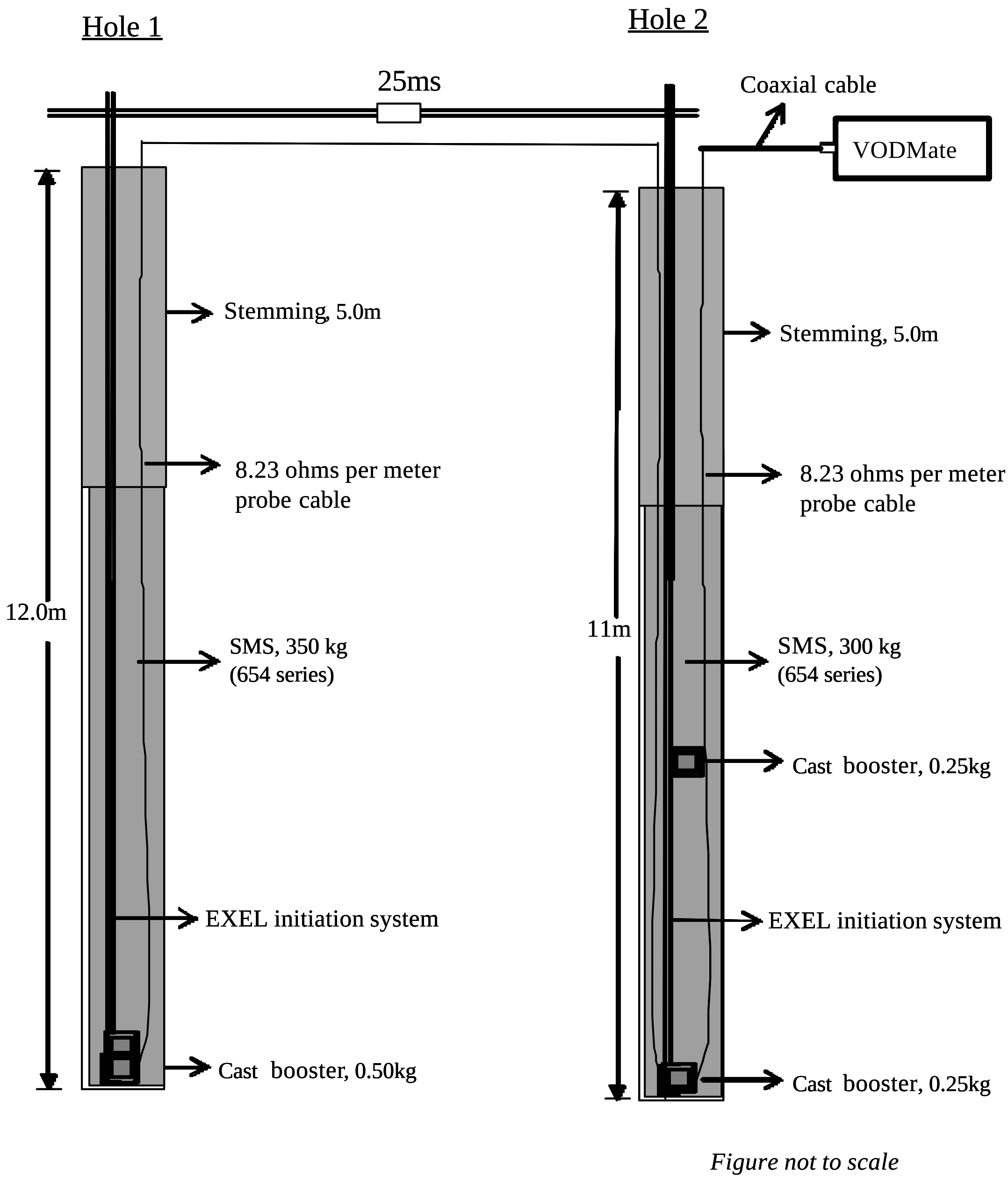

Figure 4.57 Details of the experimental holes, blast No. 9 at OCP-3

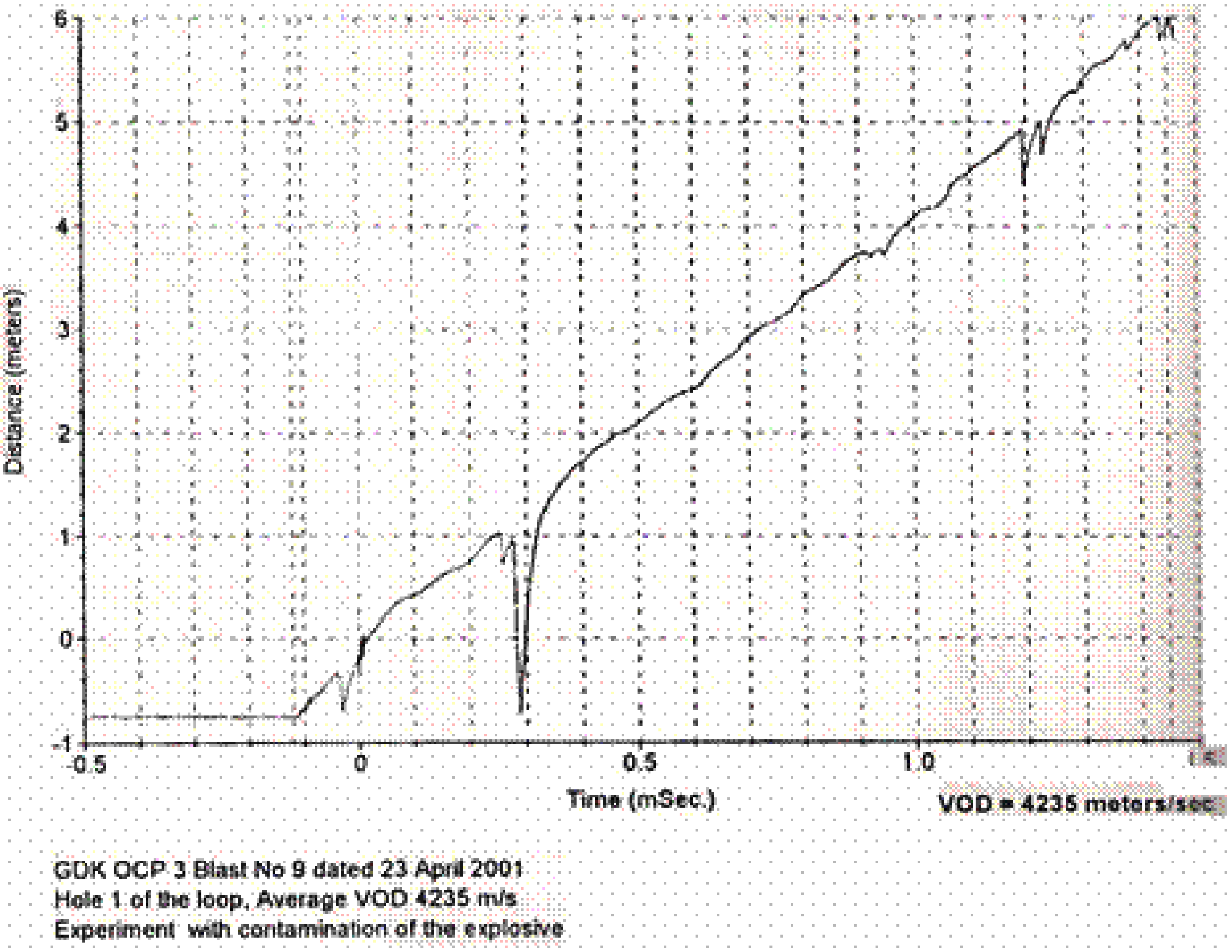

Figure 4.58 VOD result for blast No. 9 (Hole 1 in the loop) at OCP-3

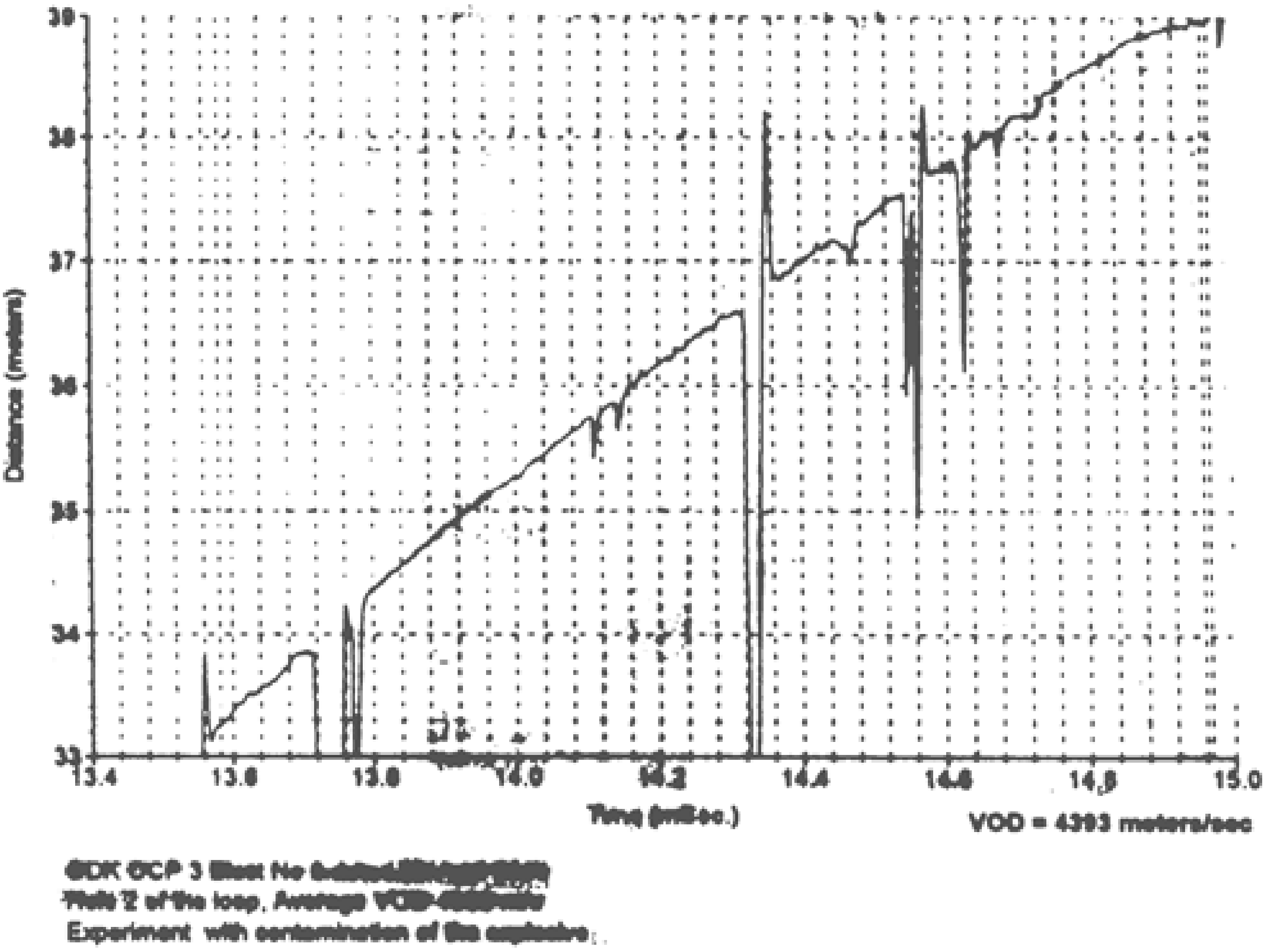

Figure 4.99 VOD Graph for blast No. 9 (Hole 2 in the loop) at OCP-3

Blast # 10 (24/4/01)
Location: OCP-3, Above 3B seam
To test the effect of contamination

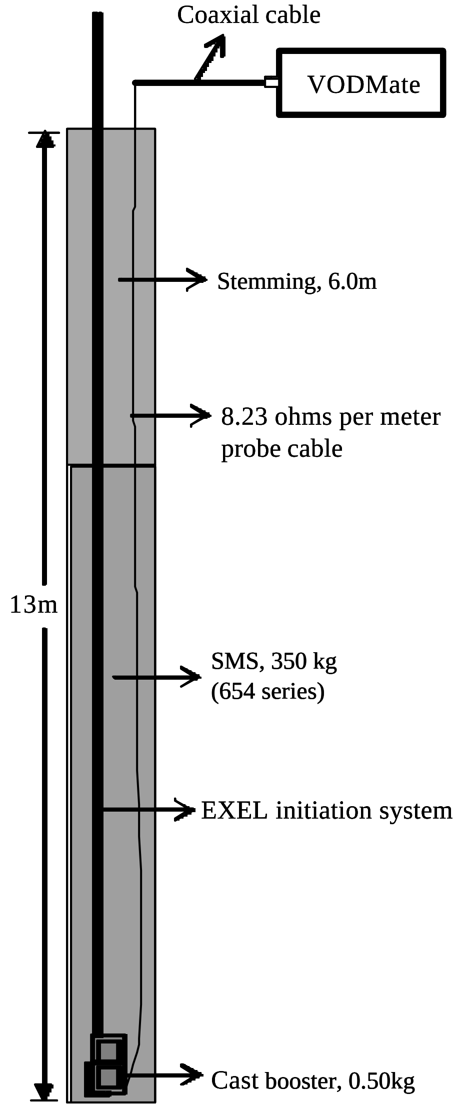

Figure not to scale

Figure 4.60 Details of the experimental hole, blast No. 10 at OCP-3

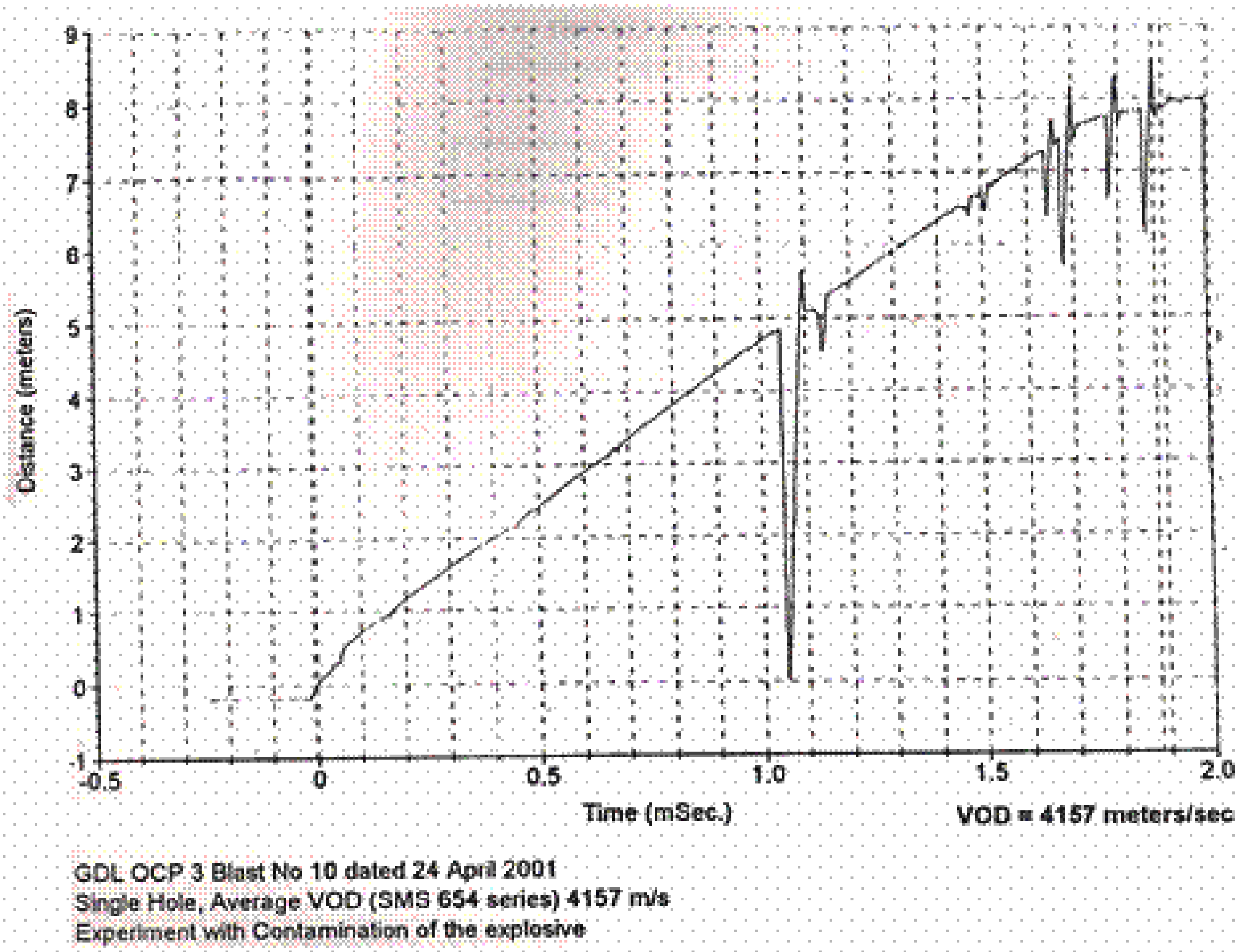

Figure 4.61 VOD result for blast No. 10 at OCP-3

Blast # 14 (28/4/01)
Location: OCP1, OB Soft
To test the effect of contamination

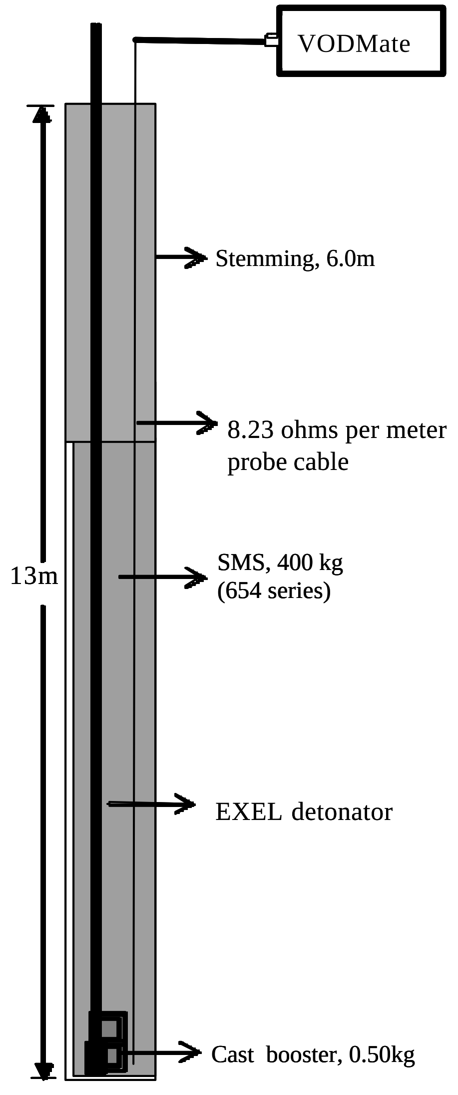

Figure not to scale

Figure 4.62 Details of the experimental hole, blast No. 14 at OCP-1

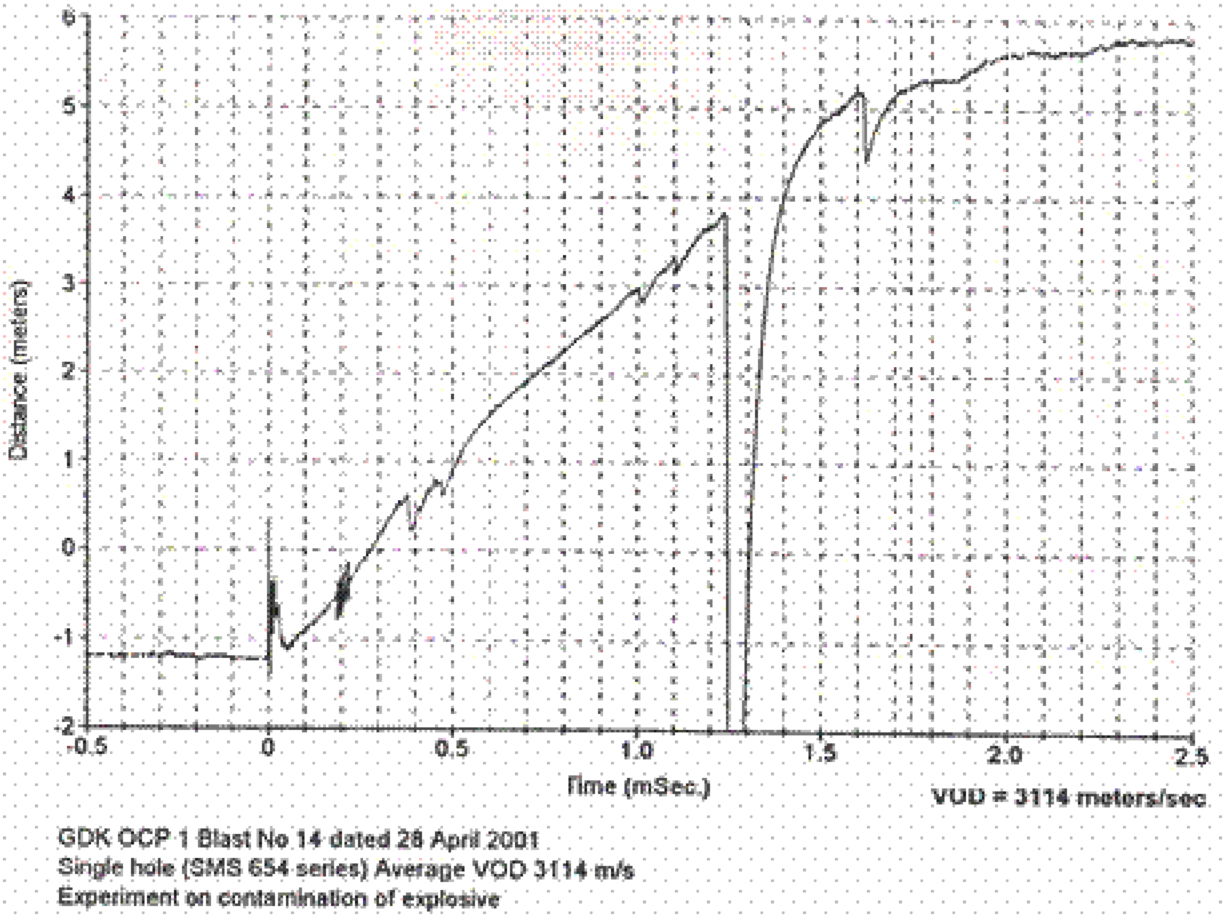

Figure 4.63 VOD result for blast No. 14 at OCP-1

The VOD of SMS 654 series with contamination tested at OCP 3 varies from 4200 to 4400 m/s against its value of 4400 - 4700 m/s without contamination. The variation may be attributed to the degree of contamination. At OCP 1 the hole was charged on 20/04/2001which was blasted only on 28/04/2001. The VOD was found to be much less in the case because of higher degree contamination. The hole was contaminated by three times that of what normally happens in the regular blasts. This will not happen in routine blasts but the experiments indicate the effect of contamination on VOD. The manufacturers do permit a sleep time of one week and thus in this experiment the influence of sleep time may not have played a decisive role.

The above experiments established that the drill cuttings should not be allowed to contaminate the explosive while loading into the hole.

4.4 INFLUENCE OF DENSITY OF AN EXPLOSIVE ON VOD

The density of an explosive relates to its mass to the volume it occupies in a blasthole. The density of an explosive can affect its performance. 'Cup density' is the term used where site mixed slurry is bulk loaded, indicate the density of the explosive at normal temperature and pressure. The cup density of the SMS series varies from 0.8 to 0.9 gm/cc. For most bulk explosives, as density increases, velocity of detonation increases and sensitivity decreases. If the density is too high the explosive will not sustain the detonation reaction and the charge will misfire.

When bulk explosive is charged into the blasthole the density increases due to hydrostatic pressure at different depth. In case of deep holes, it is essential to know whether the hydrostatic pressure at the bottom portion of the explosive column may reach the dead density of the explosives. The influence of hydrostatic pressure was carried out at dragline benches of OCP 1 & 3. The details of experimental hole(s) and the corresponding VOD graphs are given in Figures 4.64 to 4.70. A summary of the measured VOD values is given in Table 4.7.

Date of blast: 09.3.98

Location: Dragline Bench Cut No. 42

Explosive: IBP Co. Ltd. (Cartridges, Cast boosters and SMS)

Charge per hole:1376.75 kg

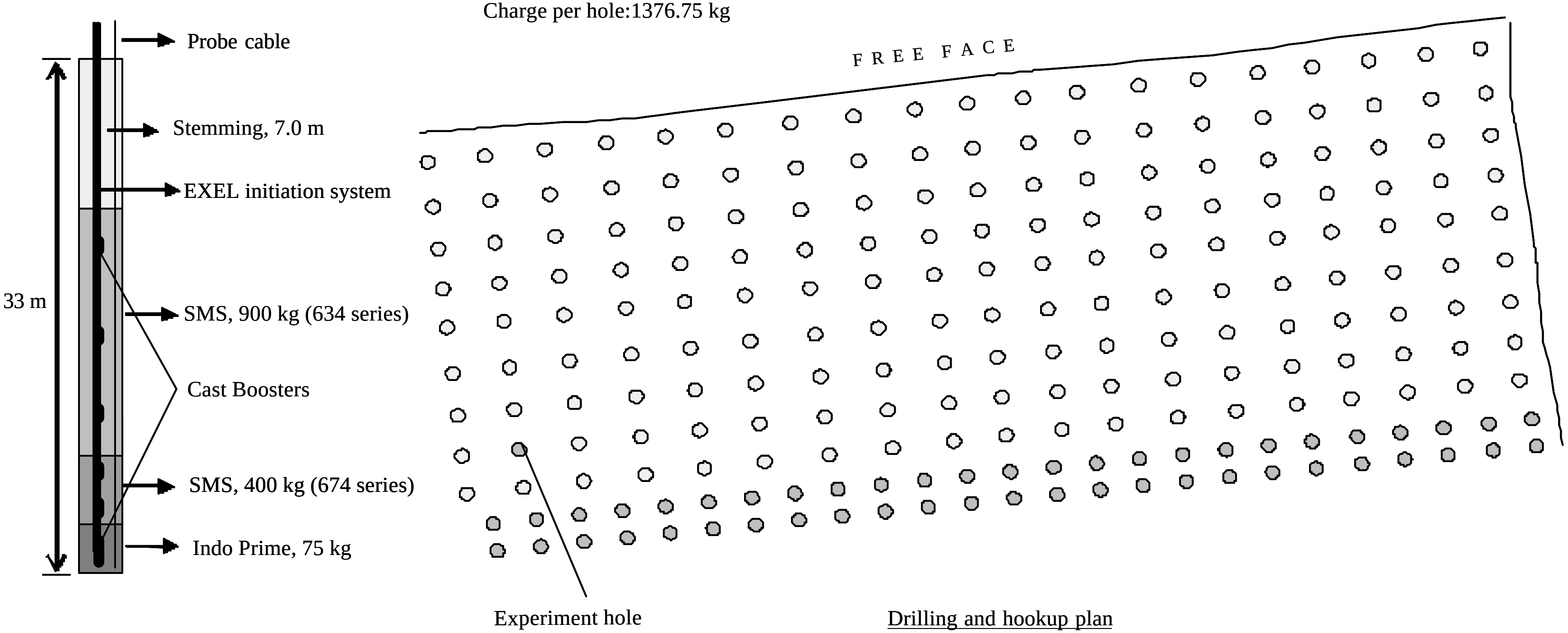

Figure not to scale

Figure 4.64 Details of the experimental hole for blast No. GDKtri20 at OCP-1

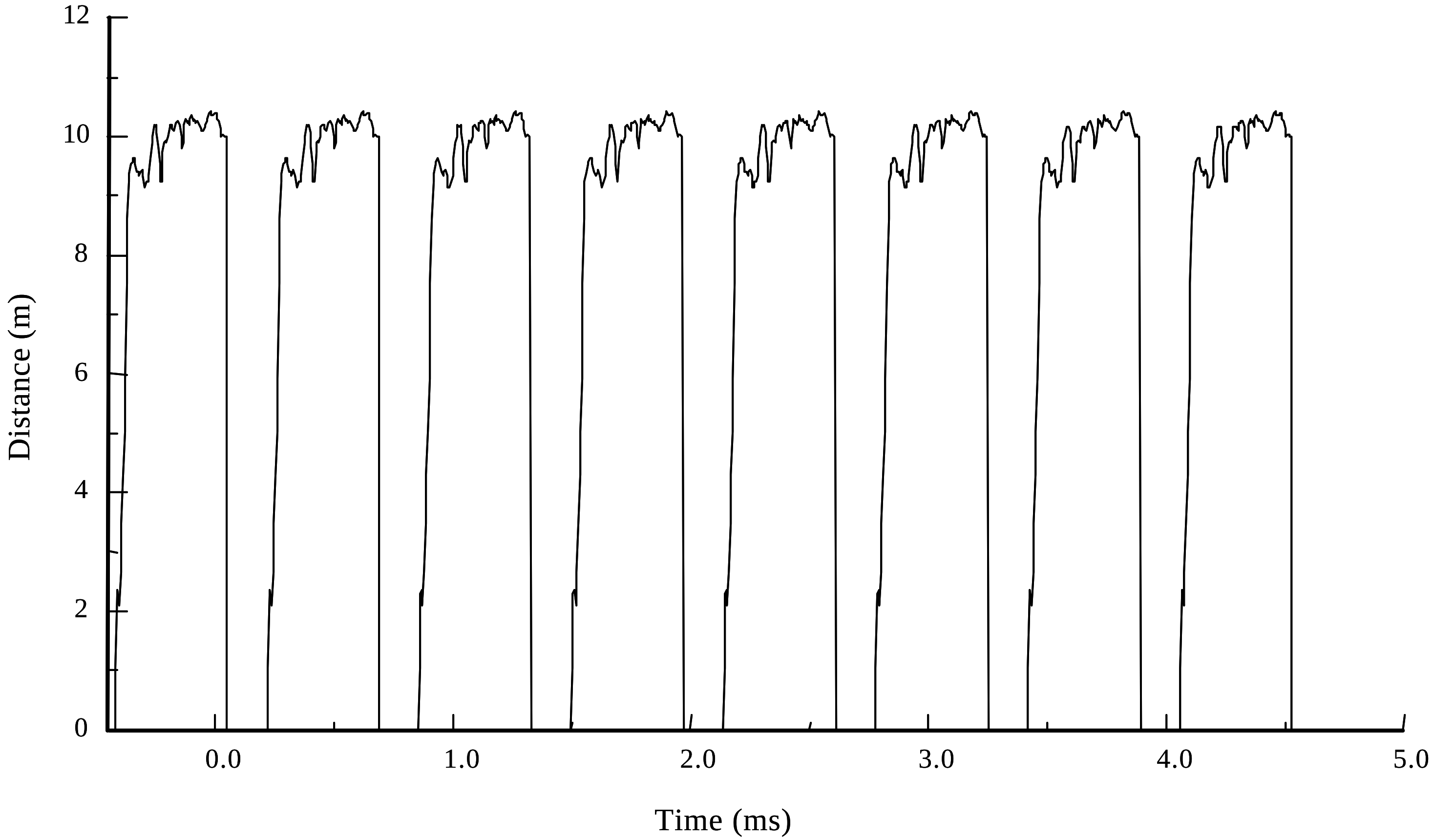

Figure 4.65 VOD trace for GDKtri 20 at OCP-1

Date of blast: 29.9.97

Location: Dragline Bench Cut No. 40

Explosive: IBP Co. Ltd. (Cartridges and SMS)

Charge per hole:1050 kg

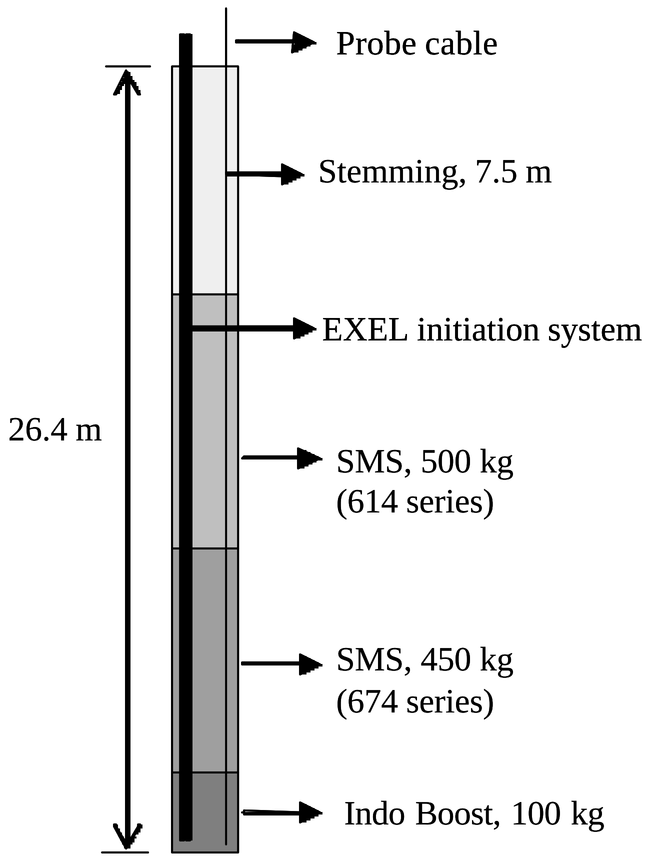

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Figure 4.66 Details of the experimental hole for blast No. GDKtri5 at OCP-1

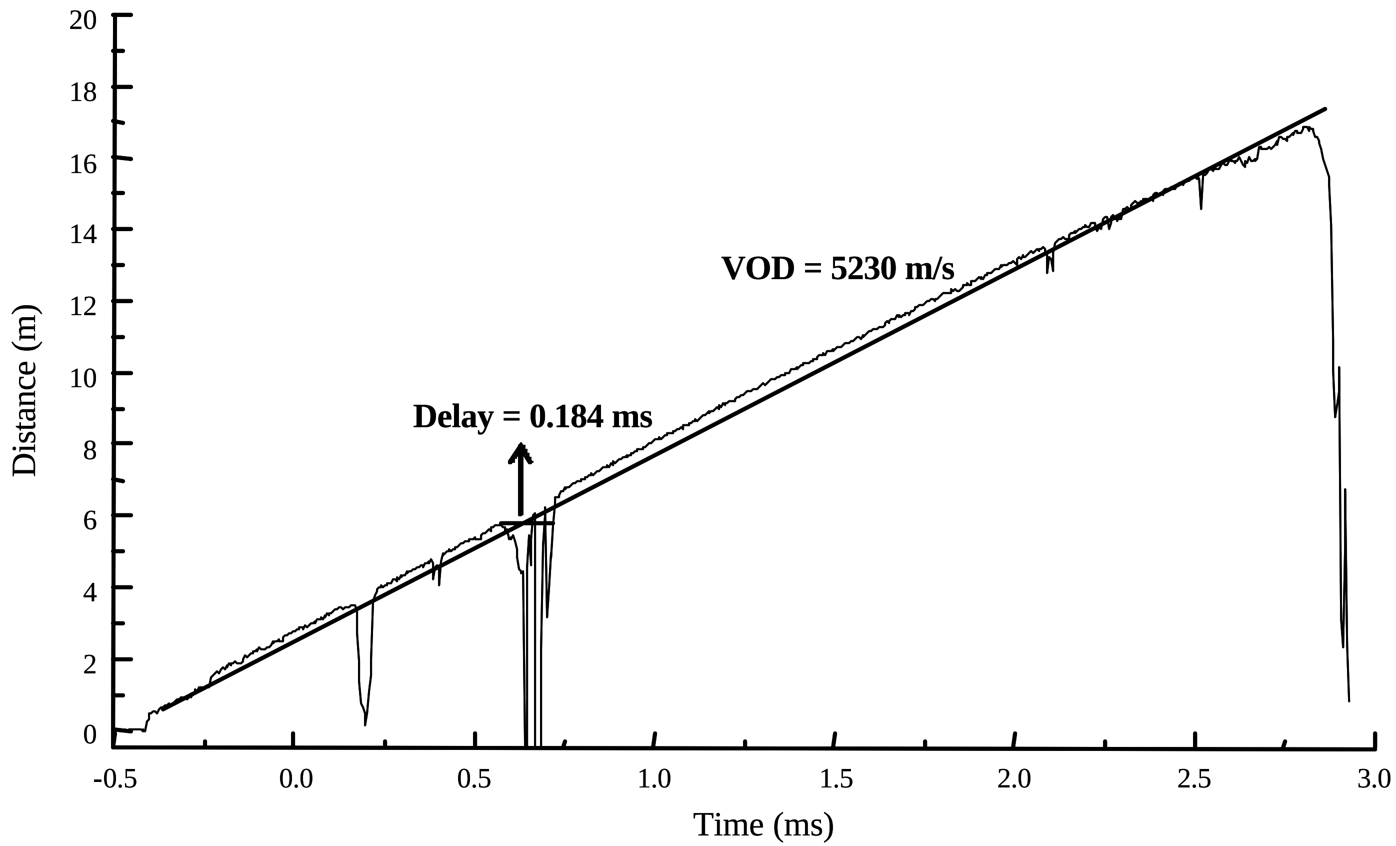


Figure 4.67 VOD result for GDKtri 5 at OCP-1

Blast # 12 (26/4/01)
Location: OCP-3, DL ben.

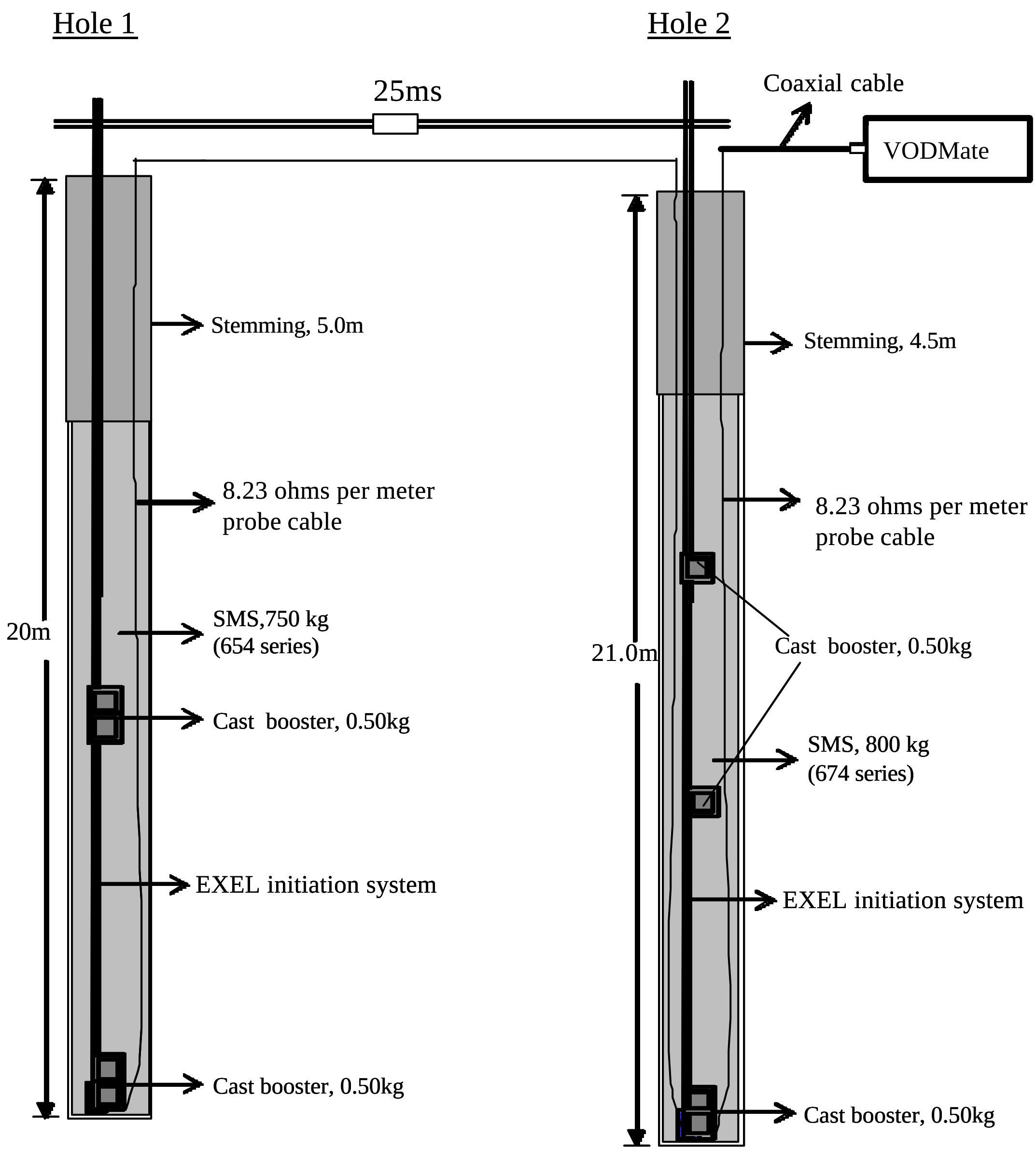
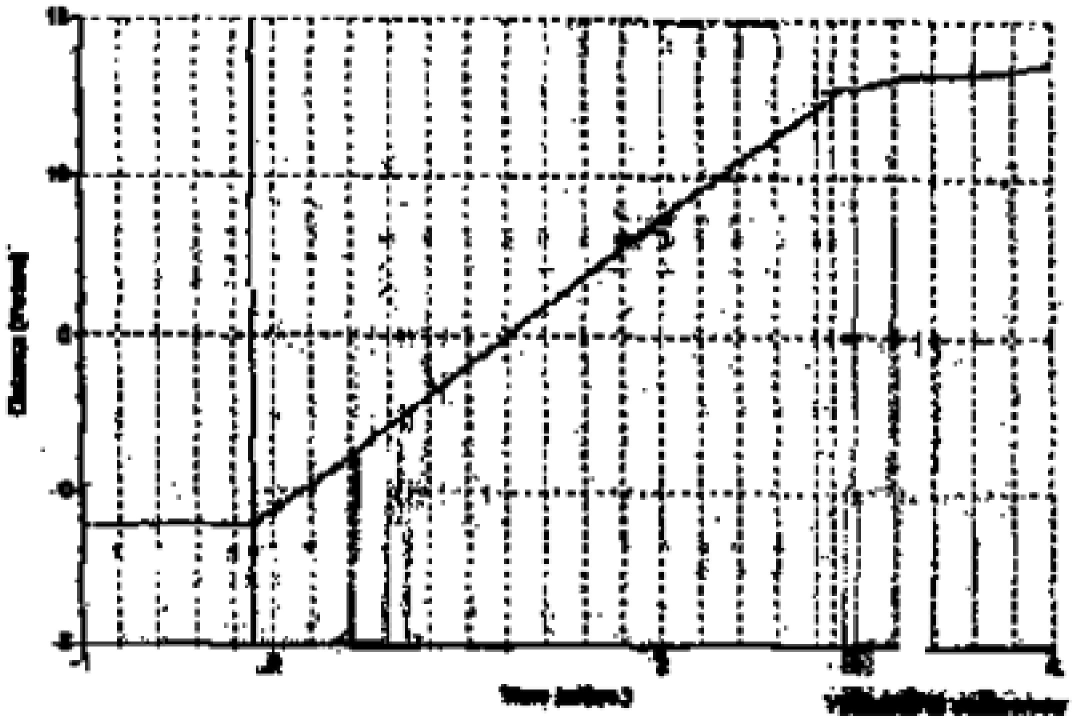
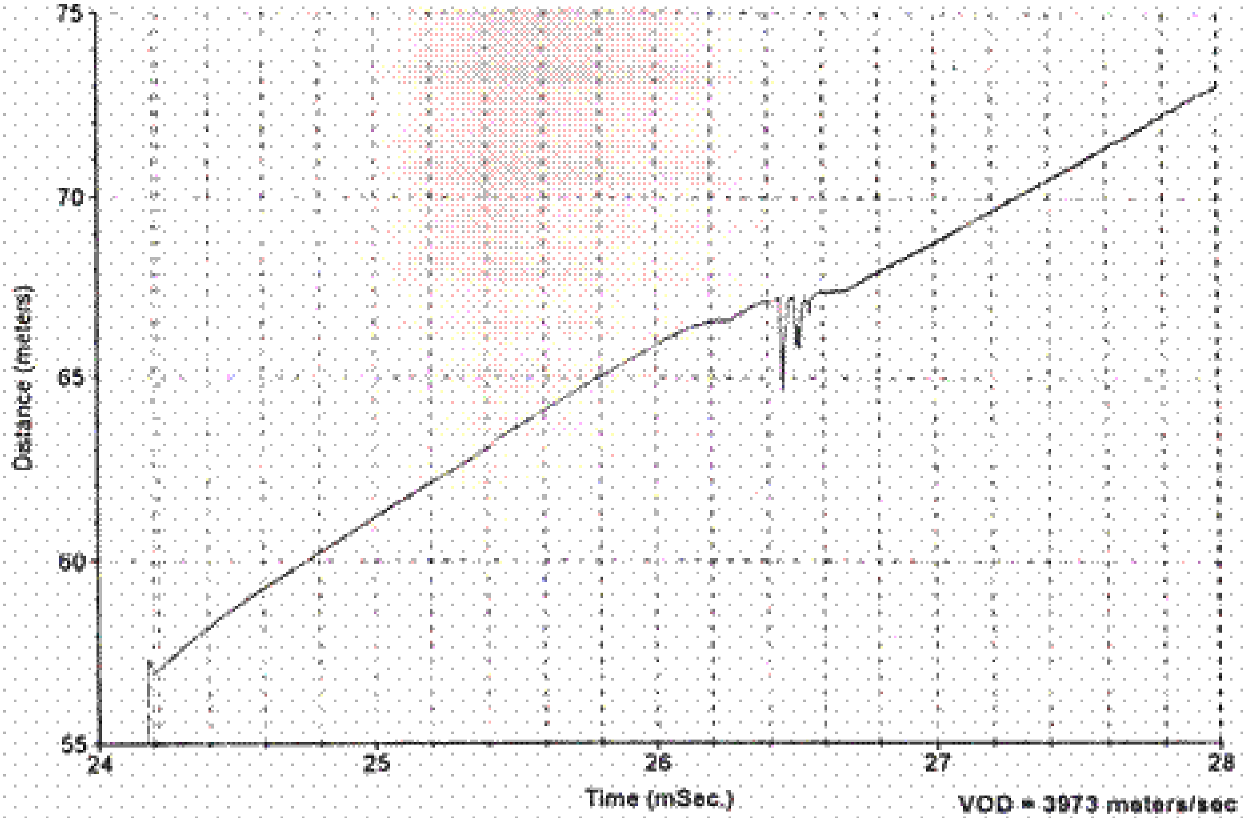


Figure not to scale

Figure 4.68 Details of the experimental hole(s) for dragline bench (blast no 12) at OCP-3





GDK OCP 3 Blast No 12 dated 26 April 2001
Hole 2, Dragline blast, (SMS 674) Average VOD 3973 m/s
Experiment on dead weight on explosive column

Figure 4.70 VOD result for blast No. 12 (Hole 2 in the loop) at OCP-3

Table 4.7 Measured VOD values in Dragline benches at Ramagundam area

Date	Blast No.	Depth of holes, m	Mine	Explosives tested	VOD, mm/s
29/09/1997	GDKTri5	26.4	OCP 1	Indoboost, SMS 674 & SMS 614	5230
09/03/1998	GDKTri20	33	OCP 1	Indoprime, SMS 674 & SMS 634	Erratic trace (Fig. 4.65)
26/04/2001	Blast # 12	20	OCP 3	SMS 654	4618
26/04/2001	Blast # 12	21	OCP 3	SMS 674	3973

For blast No. GDKTri20, the VOD signal was not good and its value could not be calculated. As the VOD of SMS 654 in the dragline bench was 4618 m/s against its average VOD of 4621 m/s in shovel benches, it is concluded that there was no influence of the hydrostatic pressure for 21m deep blastholes in the dragline bench. Moreover, the VOD signal was very good indicating stable and uniform rate of reaction of the explosives. As the SMS 614 series was loaded in the upper portion of the hole, hydrostatic pressure in this region is not expected to be greater compared to the conditions prevailing in shovel benches. The overall VOD of 3973 m/s is within the range of VOD of SMS 674 measured in shovel benches. The VOD of Indoboost, a cartridged explosive from IBP loaded at the bottom of the blasthole was 5801 m/s, which indicates that there was no influence of hydrostatic pressure.

From the measurement of VOD values it can be inferred that SMS explosives can be loaded into blasthole up to 30 m, without the risk of attaining dead density of the explosive.

4.5 INFLUENCE OF ALUMINIUM PERCENTAGE ON VOD OF EXPLOSIVES

Different SMS series have varying percentages of aluminium. The aluminium content of SMS 614, 634, 654 and 674 are given in Table 4.8. In order to study the influence of higher percentage of aluminium, SMS 724 with 9 per cent aluminium was tested although this series was not used in OCP 1 and OCP 3. A similar experiment with SMS 674 (4.3 per cent of aluminium) was also carried out. Details of the experimental hole and corresponding VOD values are given in Figures 4.71 to 4.74. A summary of VOD values from these experiments along with some VOD values from the preceding sections are given in Table 4.8. Contrary to the expectations, VOD values did not increase with the increase in aluminium percentage. This indicates the VOD is not dependent on the theoretical energy content in an explosive.

Table 4.8 Measured VOD values of different explosives

Date	Blast No.	Mine	Explosive tested	Percentage of aluminium	VOD, mm/s	Figure No.
27/03/2001	Blast #3	OCP 3	SMS 634	1.5	4302	4.22
30/03/2001	Blast #5	OCP 3	SMS 654	2.6	4668	4.24
02/04/2001	Blast #7	OCP 1	SMS 634	1.5	3933	4.26
21/04/2001	Blast #8	OCP 3	SMS 654 (Hole # 1)	2.6	4656	4.51
21/04/2001	Blast #8	OCP 3	SMS 654 (Hole # 2)	2.6	4726	4.51
24/04/2001	Blast#10	OCP 3	SMS 674	2.6	4439	4.73
26/04/2001	Blast #12	OCP 3	SMS 674 (Hole # 2)	4.3	3973	4.68
26/04/2001	Blast #12	OCP 3	SMS 654 (Hole # 1)	2.6	4618	4.68
27/04/2001	Blast #13	OCP 1	SMS 614	0	4218	4.28
28/04/2001	Blast #14	OCP 1	SMS 674 (Hole # 2)	4.3	4440	4.30
28/04/2001	Blast #14	OCP 1	SMS 614 (Hole # 4)	0	4696	4.30
29/04/2001	Blast #15	OCP 3	SMS 724	9.0	4059	4.71

Blast # 15 (29/4/01)
Location: OCP 3, DM 13A
(Experiment with 9% Aluminium)

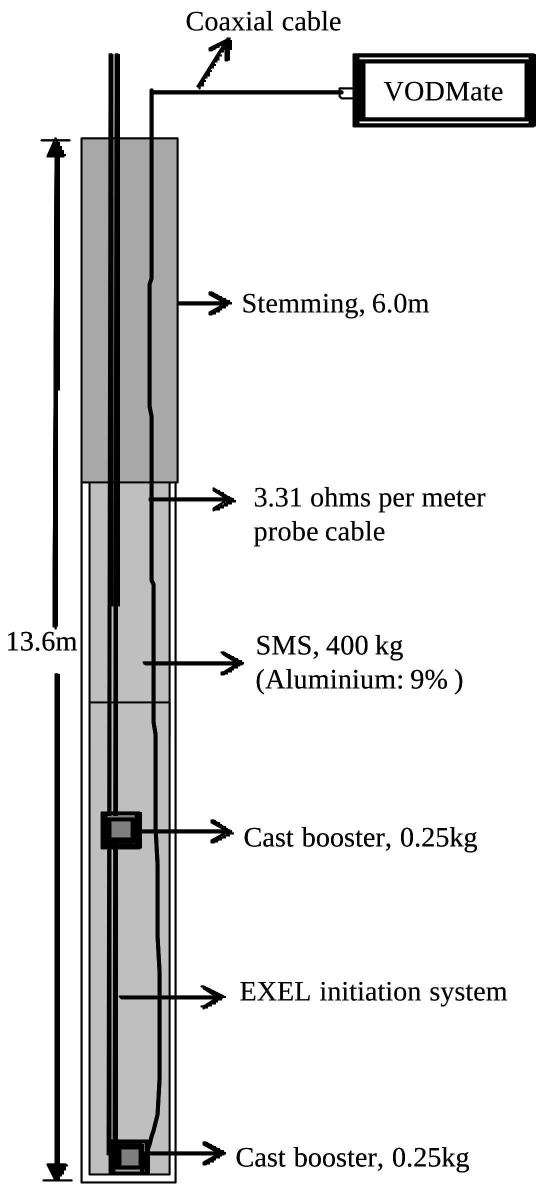


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Figure 4.71 Details of the experimental hole, blast No. 15 at OCP-3

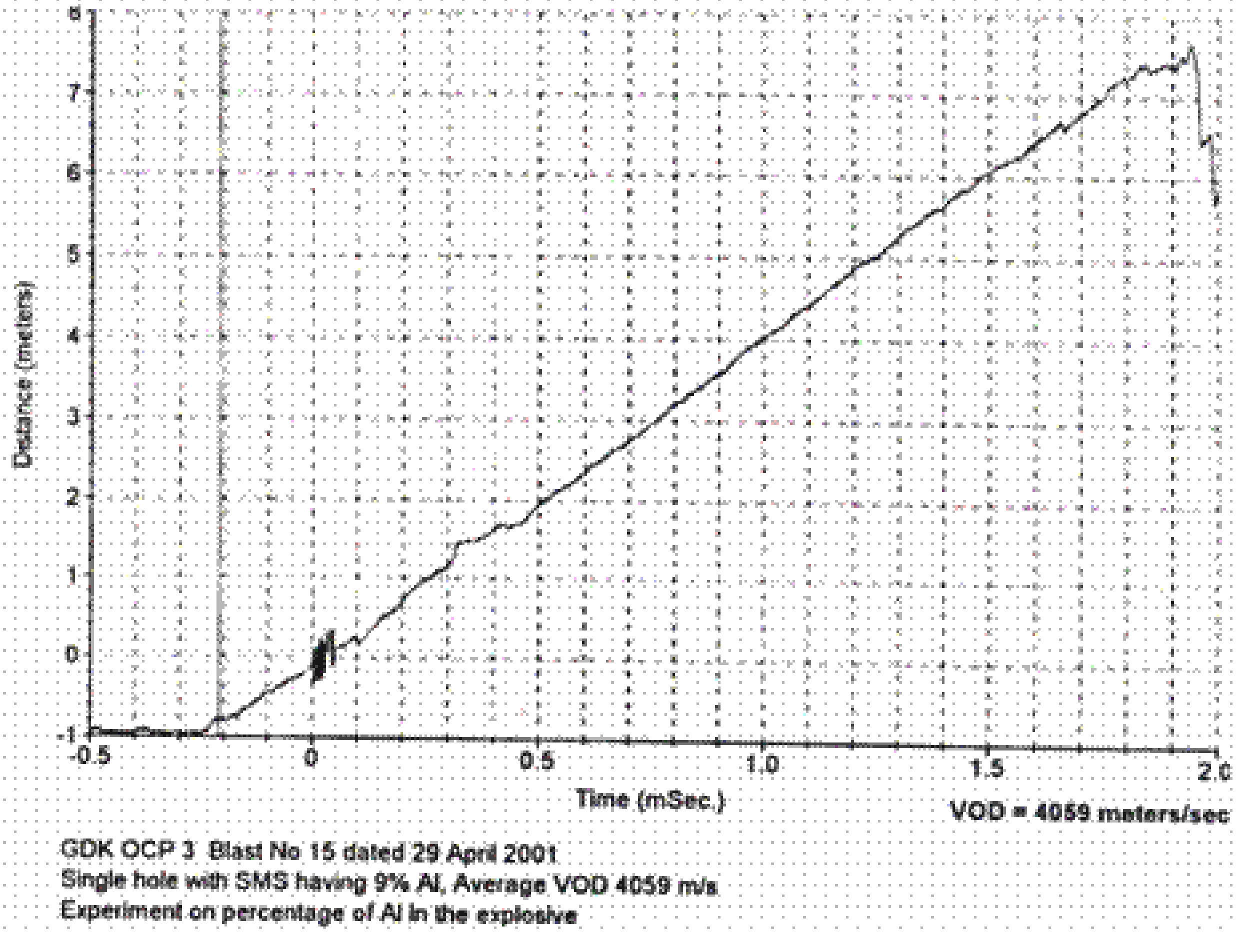

Figure 4.72 VOD result for blast No. 15 at OCP-3

Blast # 10 (24/4/01)
Location: OCP-3, Top of 3B seam

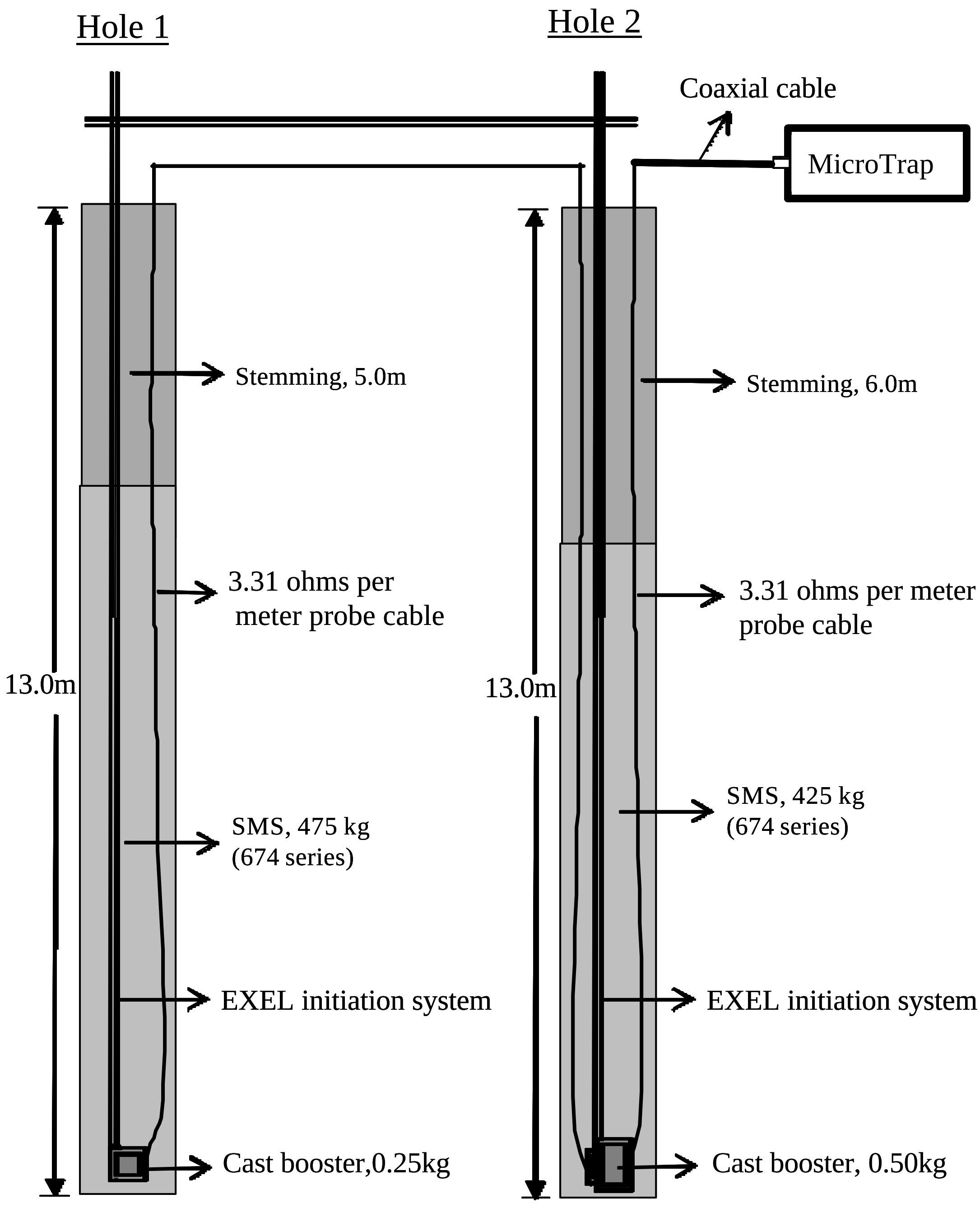

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Figure 4.73 Details of the experimental holes, blast No. 10 at OCP-3

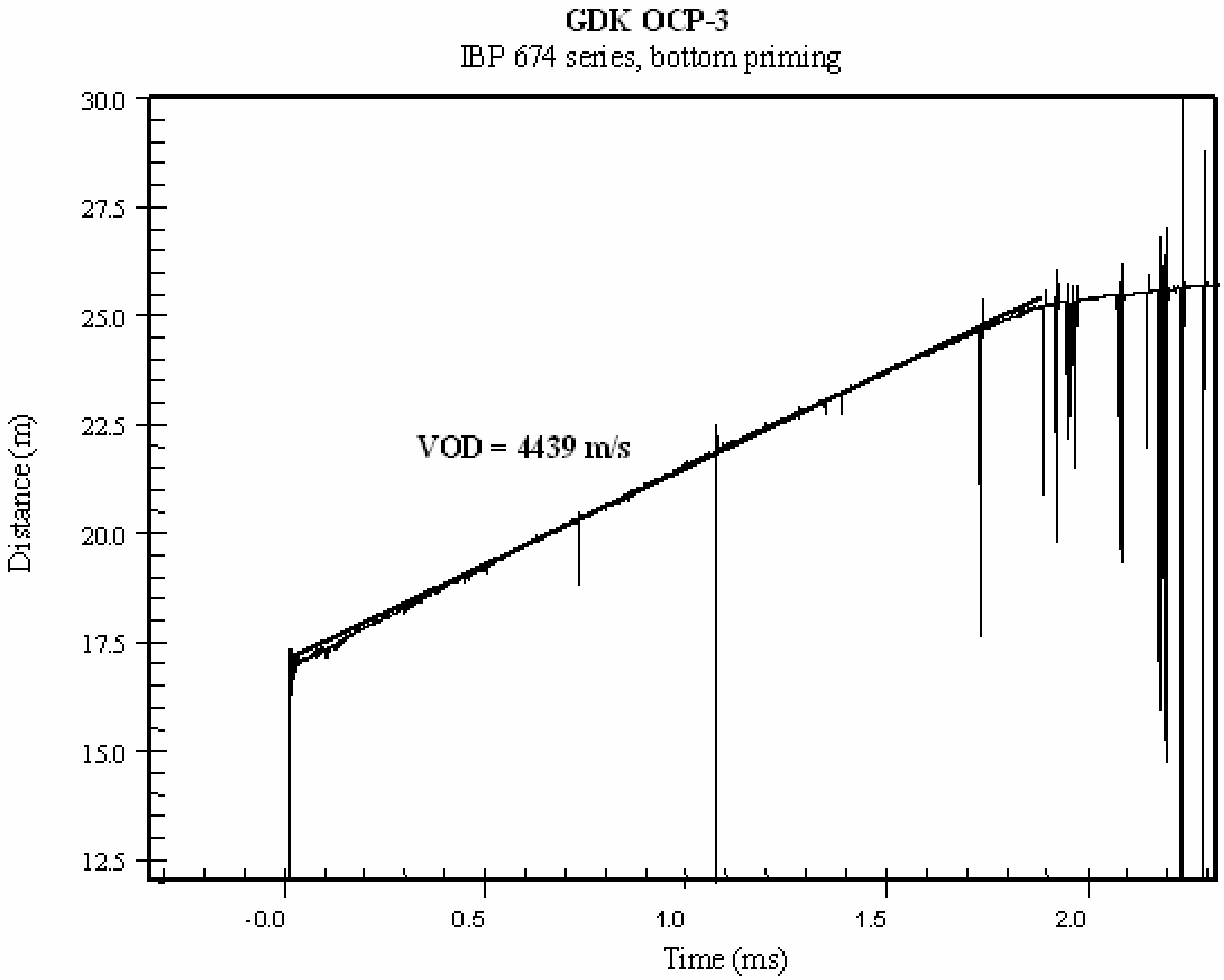

Figure 4. 74 VOD result for blast No.10 at OCP-3

Aluminium powder is often added to slurry and emulsion explosives in order to improve the energy output. With the addition of a small amount of aluminium to the slurry or emulsion, the theoretical potential energy release can be increased considerably. However, experiments indicate that the aluminium powder does not react completely within the detonation reaction zone; therefore, not all of the aluminium combustion energy is released during the important early expansion phase where the rock fragmentation occurs. Generally, all of the aluminium reacts; part of it, however, in the low-pressure after burning phase, where it only contributes to heating the escaping reaction products. The use of high percentages of aluminium in the explosive composition is costly and, considering that only a fraction of the added energy is utilised for the rock fragmentation, aluminium contents in commercial explosives generally range between 0 and 5 per cent by weight (Persson et al, 1994).

4.6. INFLUENCE OF WET BLASTHOLES ON VOD

All explosives deteriorate progressively in wet holes; the amount of deterioration increases with the severity and period of exposure. The performance of a highly water-resistant explosive (emulsion) when loaded into dry blastholes compared to wet holes indicated that the explosive's ability to fragment and displace rock in a blast would be significantly reduced when explosive is charged into wet blastholes (Cameron and Grouchel, 1990).

Figure 4.75 shows the loading pattern in the experiment while measuring VOD in a shovel bench at OCP 1, conducted on 23.11.97. The VOD value at the bottom was 4036 m/s, while the VOD at the top was almost about 1000 m/s thus indicating deflagaration of the explosive (Figure 4.76). The hole was full of water and the problem may be due to non-continuous sustainable detonation. This observation is in agreement with the observations of Lee (2001) who has reported that the performance of bulk-loaded blasting agents in very wet holes was highly variable, with low order detonations being common. In other experiments, signals were not satisfactory in watery holes. The problem of not getting satisfactory signals in watery holes could be either due to inefficient shorting of probe cable in watery conditions. This appears to be the limitation of the VOD monitoring system used. Therefore a conclusion with regard to the influence of water on VOD could not be drawn.

Date of blast: 23.11.97

Location: III Bench

Explosive: IBP Co. Ltd.

Charge per hole: 125kg

Hole diameter: 250mm

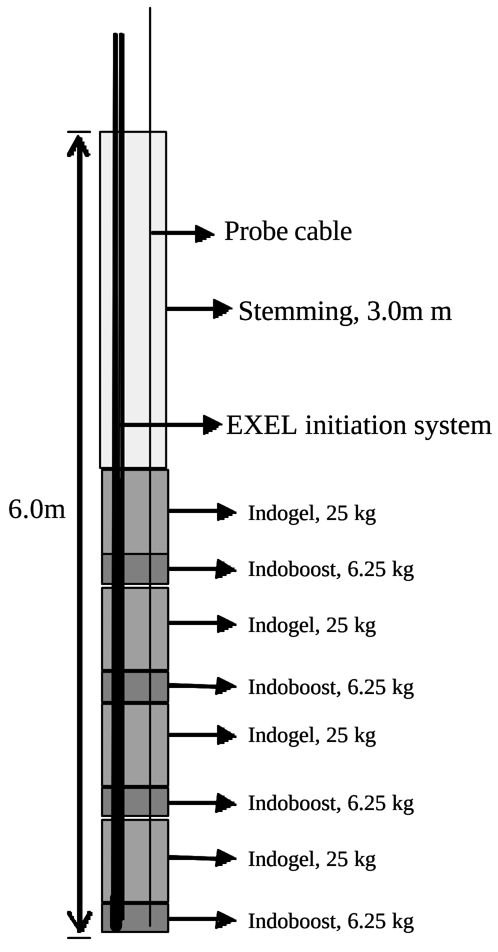

Figure not to scale

Figure 4.75 Details of the experimental hole for blast No. GDKTri10 at OCP-1

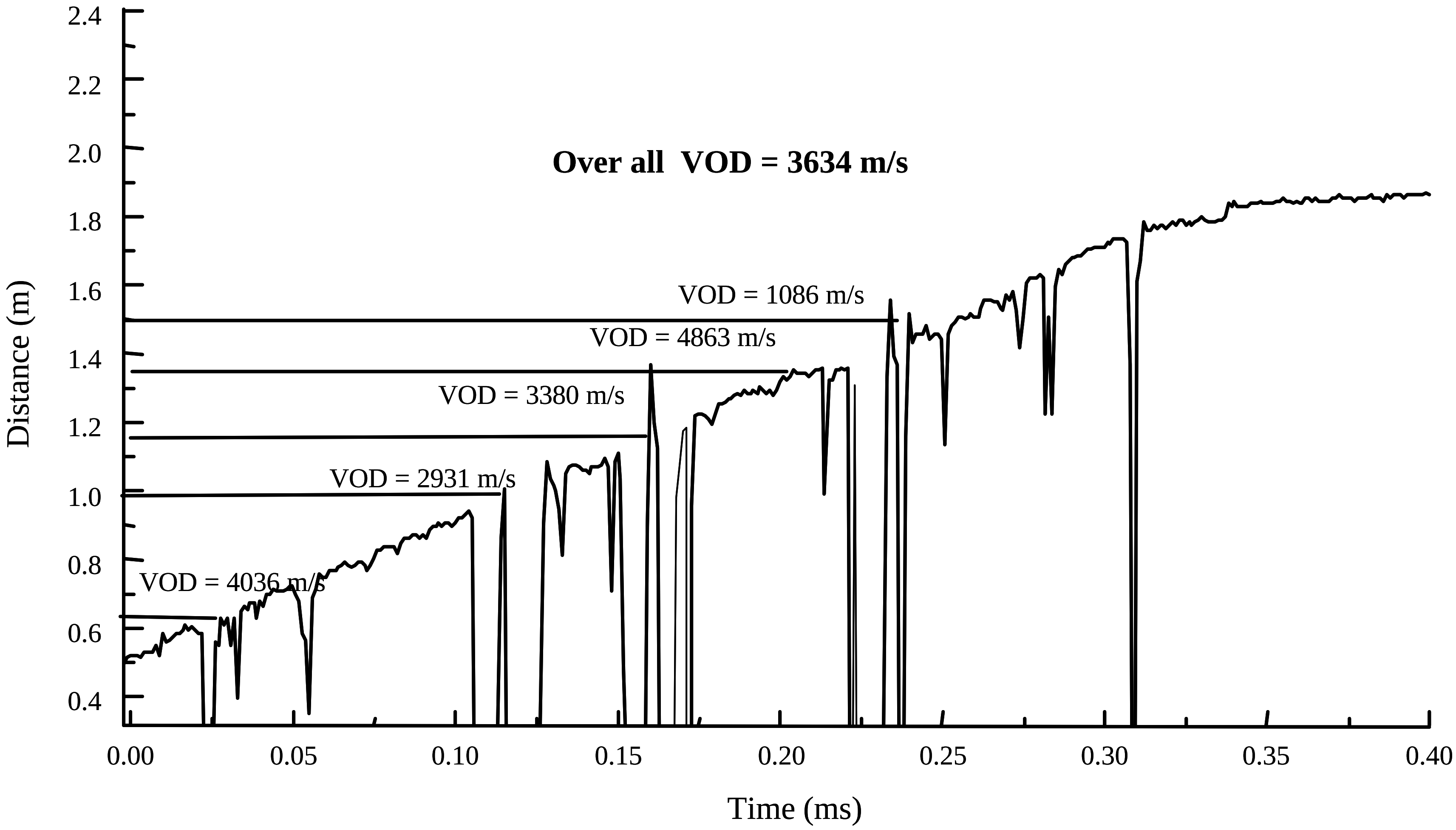

Figure 4.76 VOD result for GDKtri 10 at OCP-1

4.7 INFLUENCE OF SLEEP TIME ON VOD

The length of time an explosive remains in the blasthole is called ‘sleep time’. It should not be too long so that an explosive can remain in a blasthole without a change in the chemical composition or its physical properties. Earlier work shows that the VOD of a highly water-resistant bulk explosive (water gel) deteriorated rapidly with increasing sleep time in wet blastholes (Cameron and Grouchel, 1990). The product literature of SMS series recommends a sleep time up to two weeks. At Ramagundam area, the permitted sleep time is one week. It was understood that there was no noticeable change in the performance of explosives when holes were allowed to sleep for about one week. Some of the blastholes were charged in the dragline bench at OCP 1 on 6th and 8th of June 2001. Due to the 13-day workers’ strike at SCCo Ltd, these holes were blasted on 24th June 2001. Thus the holes had a sleep time up to 18 days. Though there would have some reduction in the VOD of the explosive due to the sleep time, no noticeable difference in the blasting performance of SMS explosive was noted.

To determine the effect of sleep time of SMS explosives exceeding the maximum sleep time recommended by the manufacturer, two holes in weathered sandstone in the DM 10 area of OCP 1 were charged with SMS 634 on 8th June 2001 and left for sleeping. SMS was the bulk explosive being used at Ramagundam area during the entire study period where in these experiments were planned and conducted. These holes were blasted on 3rd July 2001. The loading patterns for these holes are given in Figure 4.77. The VOD of the first hole was found to be 3333 m/s (Figure 4.78). It means a reduction in VOD by 25 per cent due to the sleep period of 25 days, indicating the deterioration in the quality of the explosive. By visual assessment, the performance of the explosive in the first hole was satisfactory and that of the second hole was unsatisfactory.

In the light of these experiments, it is not recommended to allow the sleep time for SMS explosives more than two weeks. Preferably, blasts should be carried out within one week from the date of charging, particularly in watery holes.

(Sleep Time Experiment)
Blast No. 17 on 3.7.01, Location: OCP 1, DM 10 area

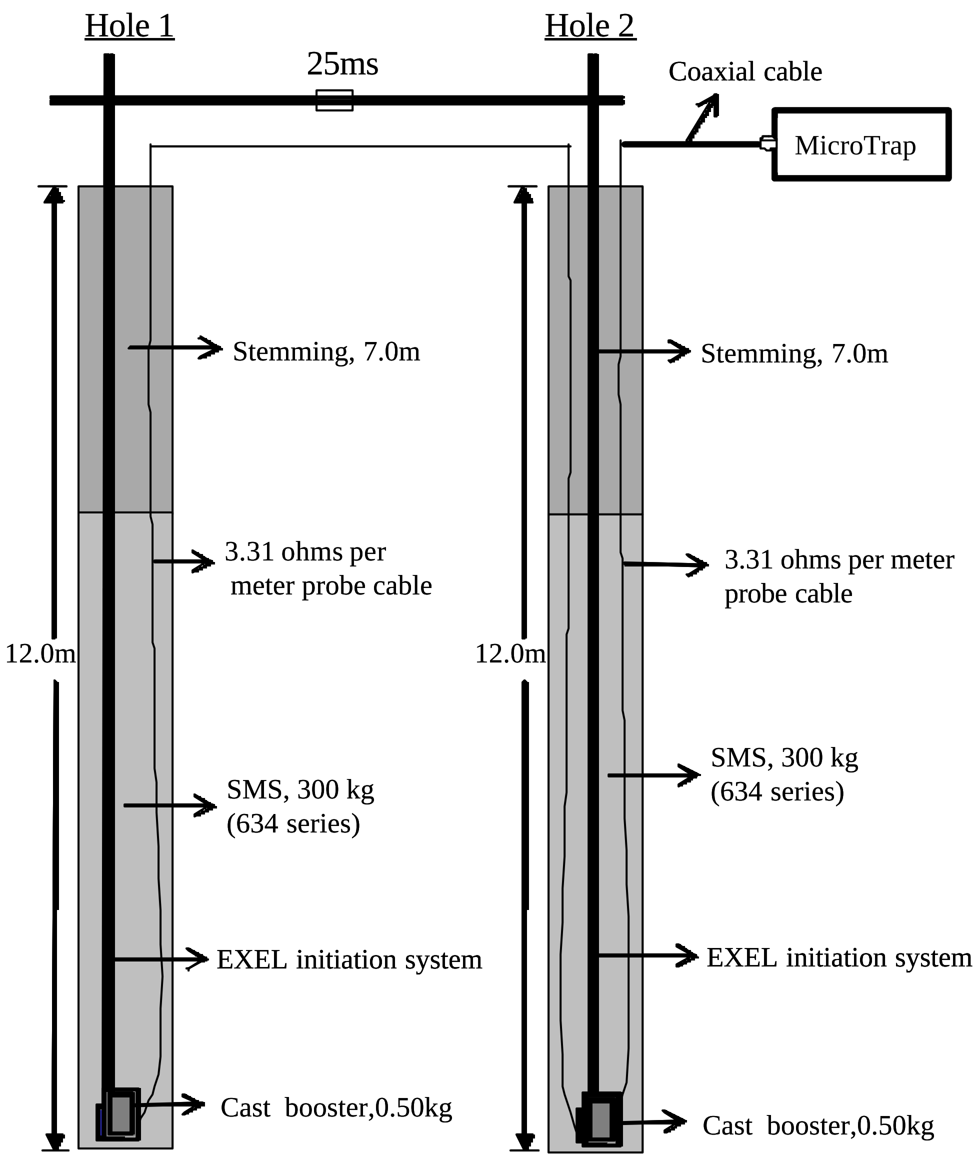

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Figure 4.77 Details of the experimental holes for blast No. 17 at OCP- 1

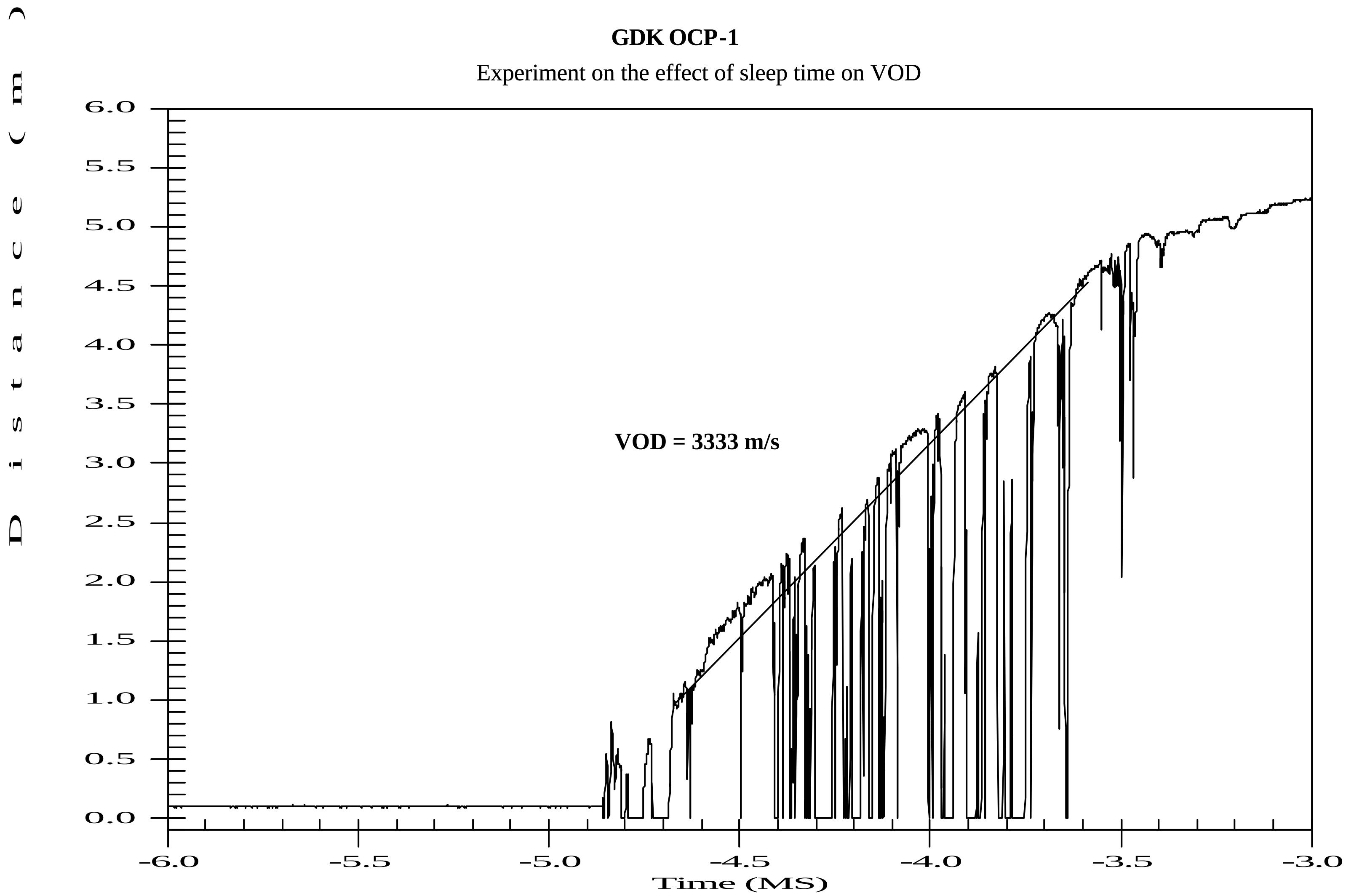


Figure 4. 78 VOD results for blast No.17 at OCP-1

4.8 INFLUENCE OF BLASTHOLE DIAMETER ON VOD OF EXPLOSIVES

In opencast mines, blasthole diameters are equal to or greater than 100 mm, which are greater than the critical diameter of the explosives being used. It is expected that a stable detonation will propagate through the entire length of the explosive column. In general, the larger the diameter, the higher the velocity of detonation until the explosive's maximum velocity is reached. The VOD values of a gassed heavy ANFO type emulsion explosives, monitored at the Aitik open pit mine in Sweden were about 10 per cent higher in production holes (311 mm diameter) than for the smaller (140 or 165 mm) diameter holes. The differences between the VOD values of 140 mm and 165 diameter holes were however too small to be significant compared to the scatter which was about 5 –10 per cent (Ouchterlony et al, 1997).

In course of this study, ANFO* was tested at two different diameters; 115mm diameter at Walayar and Jayanthipuram limestone mines and at 250 mm at OCP1 although ANFO was not used for blasting in the mine. The details of the charging pattern is given in Hole 3 of Figure 4.30. The VOD record is given in Figure 4.79.

The VOD of the explosive in 250 mm diameter hole at OCP 1 was 4253 mm/s whereas the VOD of ANFO in 115 diameter hole at Walayar was 3472 mm/s and it was 3600-3800 m/s at MCL. It can be seen from Table 4.9 that the VOD of ANFO increases with hole diameter. However, ANFO can be used in 115 mm diameter holes as the detonation of the ANFO column in 115 mm diameter was stable and the blasting performance was satisfactory in both the limestone mines.

Table 4.9 VOD of ANFO and SMS at different diameters

Mine	Hole diameter, Mm	Explosive used	Measured VOD, mm/s	Remarks
Jaynathipuram limestone mine	115	ANFO	3600-3800	Refer Table 4.2
Walayar limestone mine	115	ANFO	3450-3708	Refer Table 4.3
OCP 1	250	ANFO	4200	Refer Figure 4.79

* ANFO refers to prilled ammonium nitrate mixed with fuel oil.

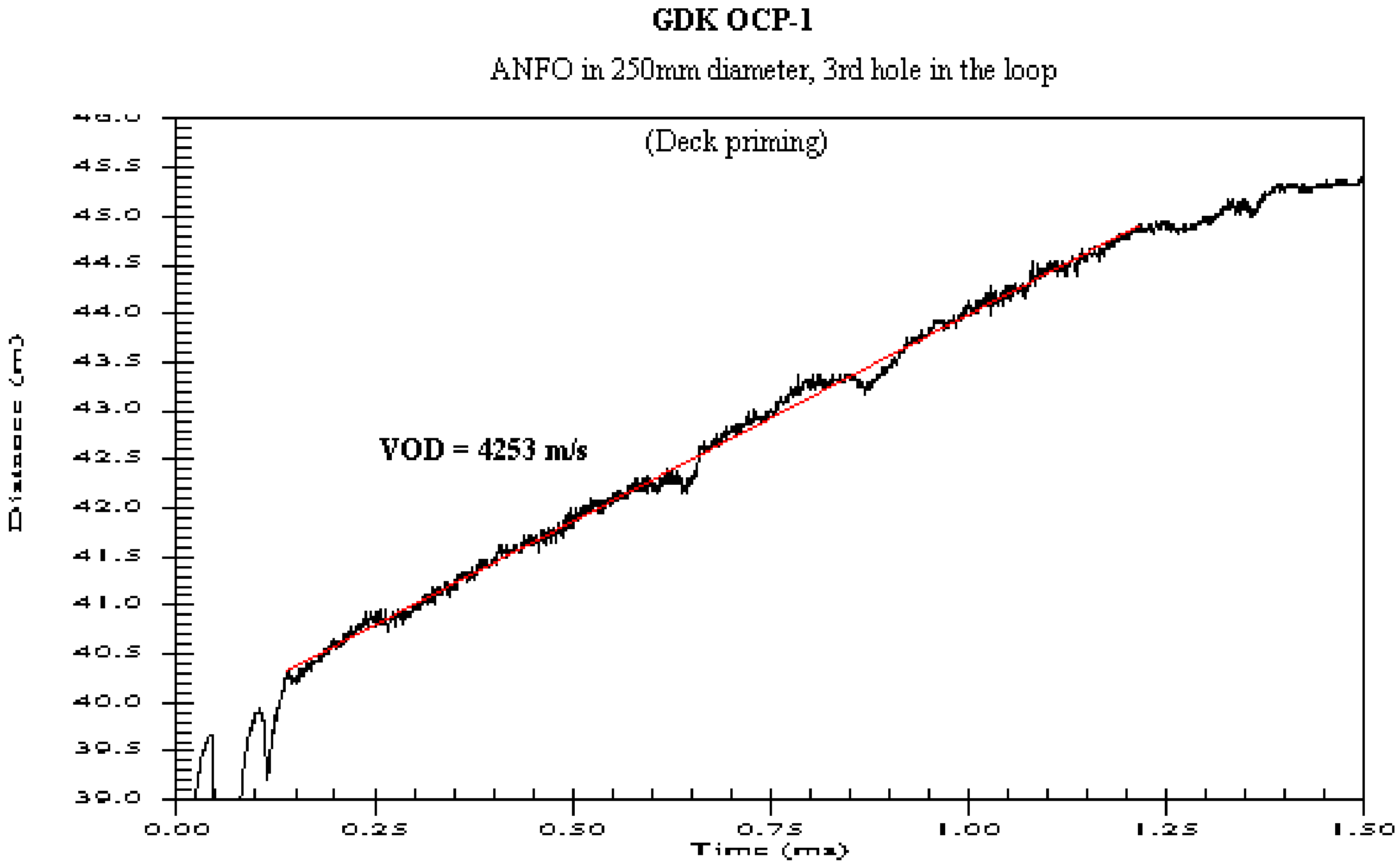


Figure 4. 79 VOD results for blast No.14 at OCP-1

Five holes were charged with SMS 634 and 654 series in 150mm diameter holes at OCP 3. Out of which 3 holes connected to MicroTrap did not trigger. Two holes were recorded in a loop with VODMate. The details of the blasthole pattern are given in Figure 4.80. The records of Blast No. 16 are shown in Figures 4.81 to 4.82. The 1st hole was partly watery and the VOD of SMS 654 series was found to be 6455m/s which is unusually high. The 2nd hole was completely watery. The recorded signal does not show stable detonation through the explosive column and the VOD of SMS 634 loaded in this hole is only 2116 m/s. The lower VOD may be due to the effect of the water in the blasthole as discussed in section 4.6.

Since the VOD records for SMS in 150 mm were not satisfactory, the experiment was repeated on 6/7/2001. In all, four holes were selected in DM7 area of OCP - 3. Two holes in a loop were connected to MicroTrap and two holes were connected to VODMate. The details of blast holes connected to MicroTrap are shown in Figure 4.83. Out of two holes, the 2nd hole was successfully monitored. The recorded VOD for SMS 654 is 4018m/s (Figure 4.84). The details of experimental holes connected to VODMate are given in Figure 4.85. The VOD signals for the 1st and 2nd hole are given in Figures 4.86 to 4.87. A summary of measured VODs are given in Table 4.10.

Table 4.10 Summary of VOD values for 150mm diameter with SMS 654

Date	Blast No.	Explosive used	VOD m/s	Instrument used
02/05/01	16	SMS 654	6455	VODMate
02/05/01	16	SMS 654	2116	VODMate
06/07/01	18	SMS 654	4018	MicroTrap
06/07/01	18	SMS 654	4335	VODMate

4.9 INFLUENCE OF STEMMING LENGTH ON VOD

The main purpose of stemming is to provide confinement to explosive charges. The stemming length at Ramagundam area varied from 5 to 7 m. In this study, the recorded VODs of explosives at different stemming length was analysed. The minimum stemming length was 3.5 m because of

Blast # 16 on 2/5/01), Location: OCP-3
(150 mm diameter holes)

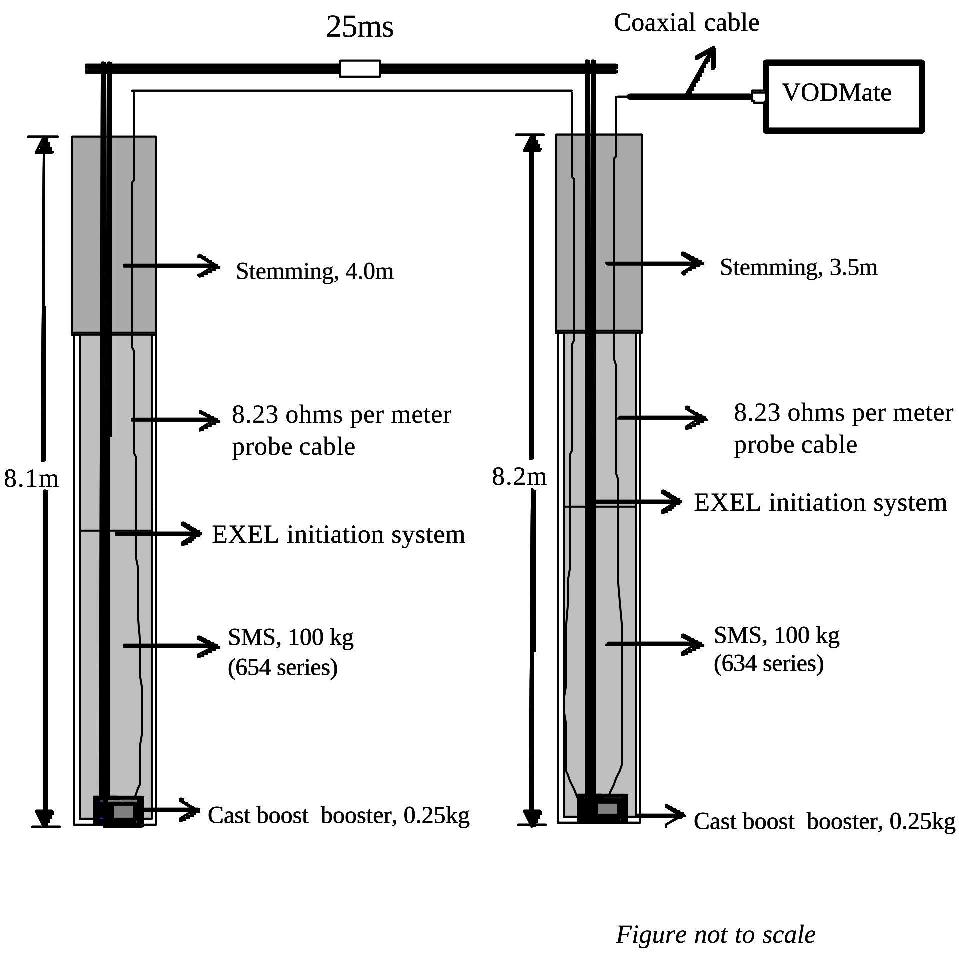
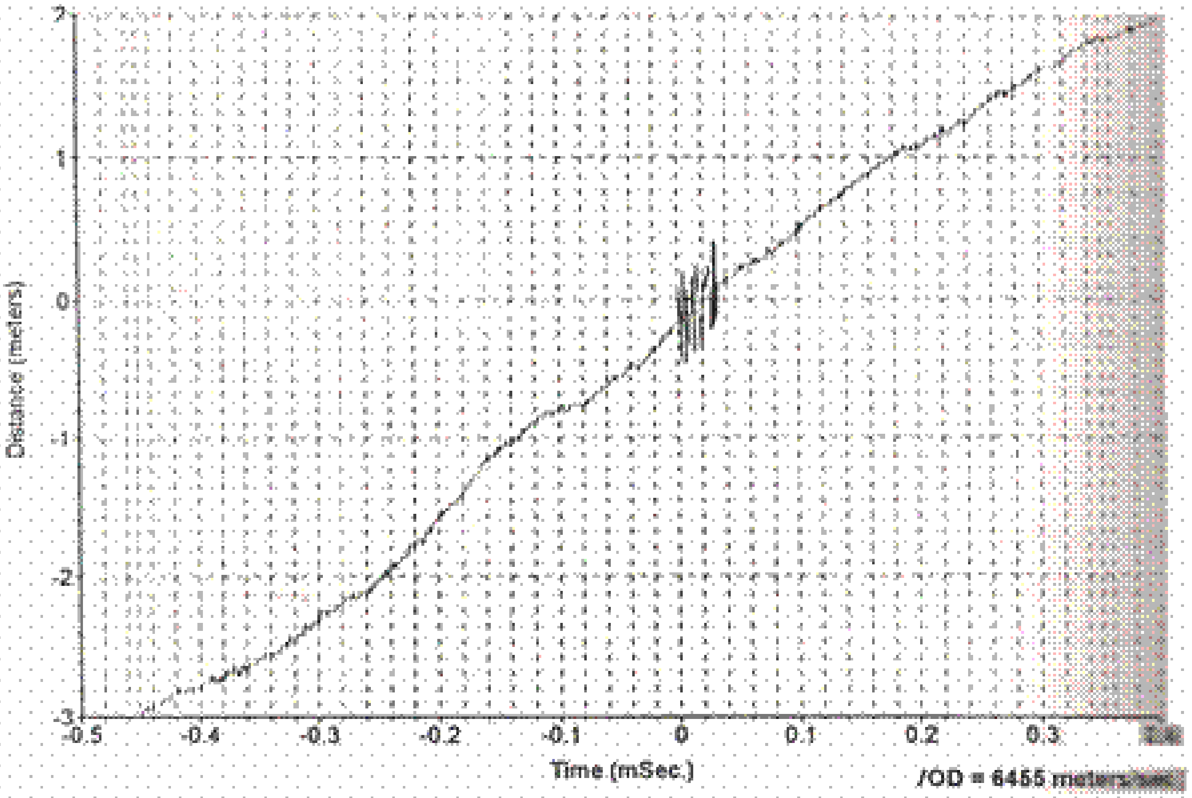


Figure 4.80 Details of the experimental holes (150 mm diameter) at OCP-3



GDK OCP 3 Blast No 16 dated 2 May 2001
Hole 1 (150 mm) SMS 654 series Average VOD 6455 m/s
Experiment on influence of hole diameter on VOD

Figure 4.81 VOD result for 150mm diameter holes (Hole 1 in the loop) at OCP-3

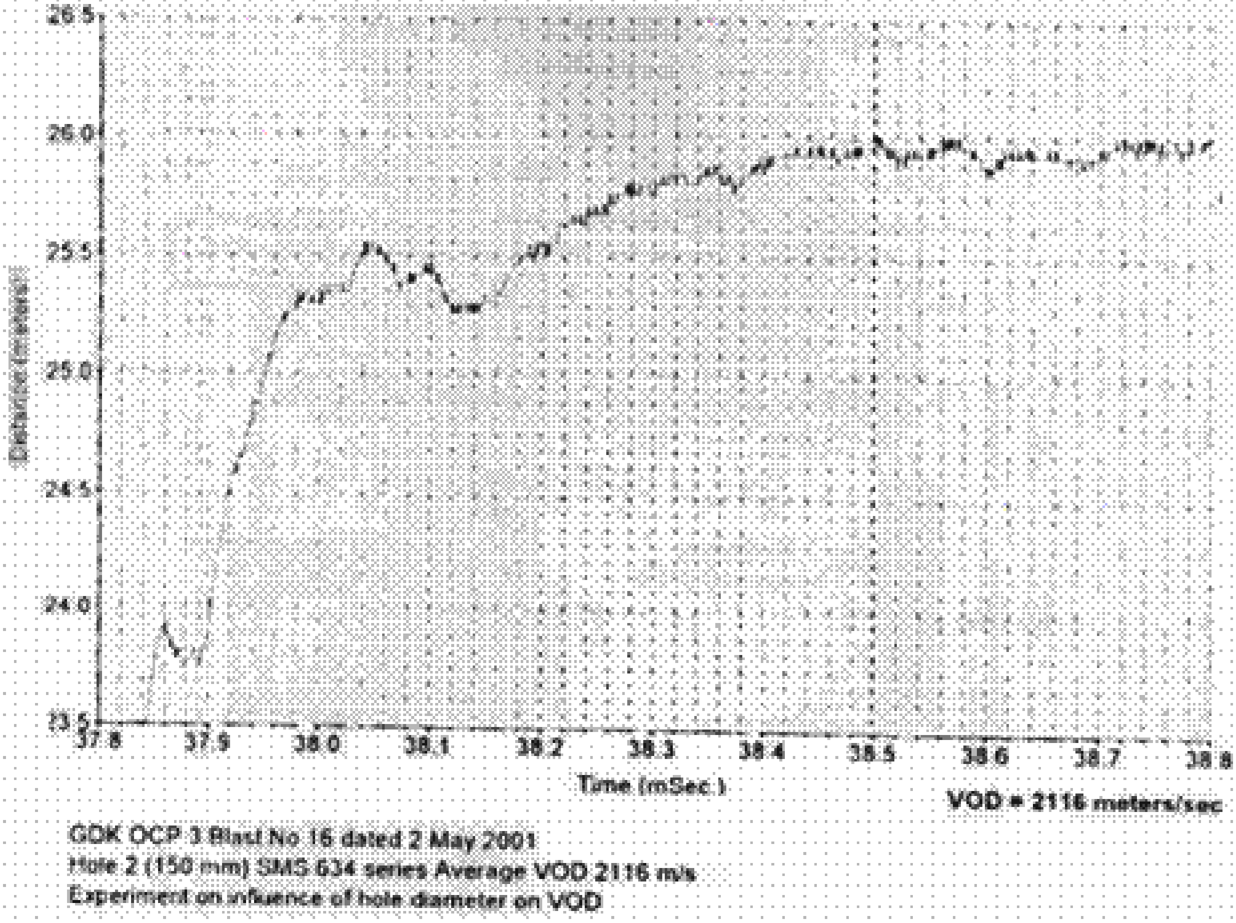


Figure 4.82 VOD result for 150mm diameter holes (Hole 2 in the loop) at OCP-3

Blast on 6.7.01, Location: OCP3, DM 7 area
(150 mm diameter holes)

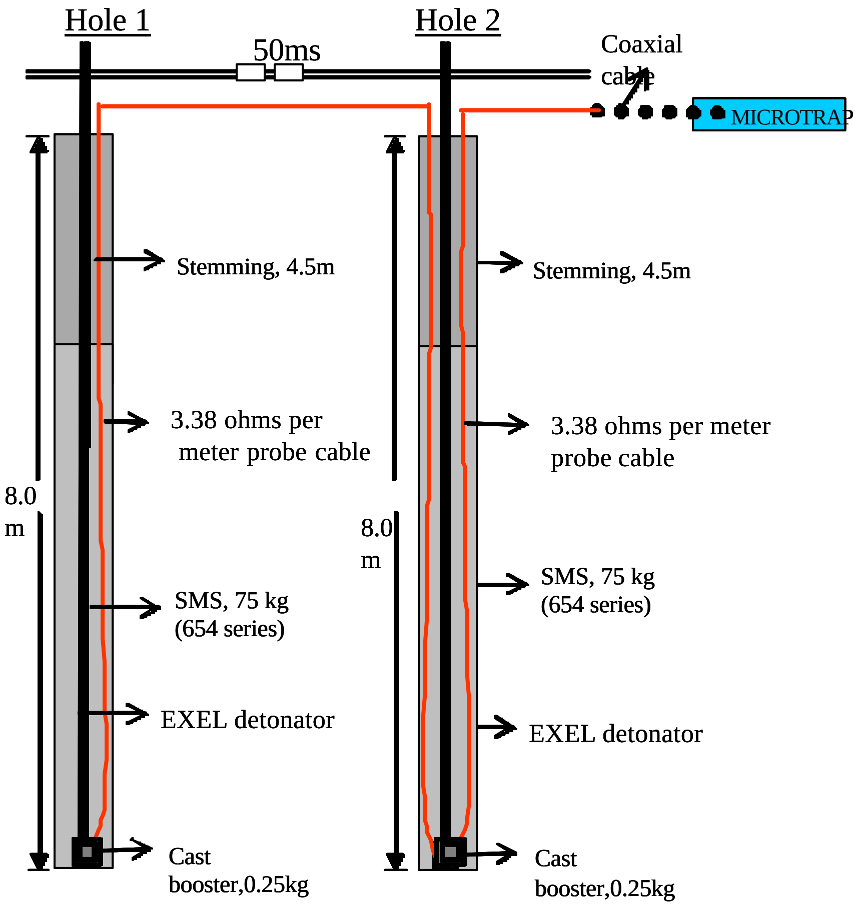


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Figure 4.83 Details of the experimental holes (150mm diameter) at OCP-3

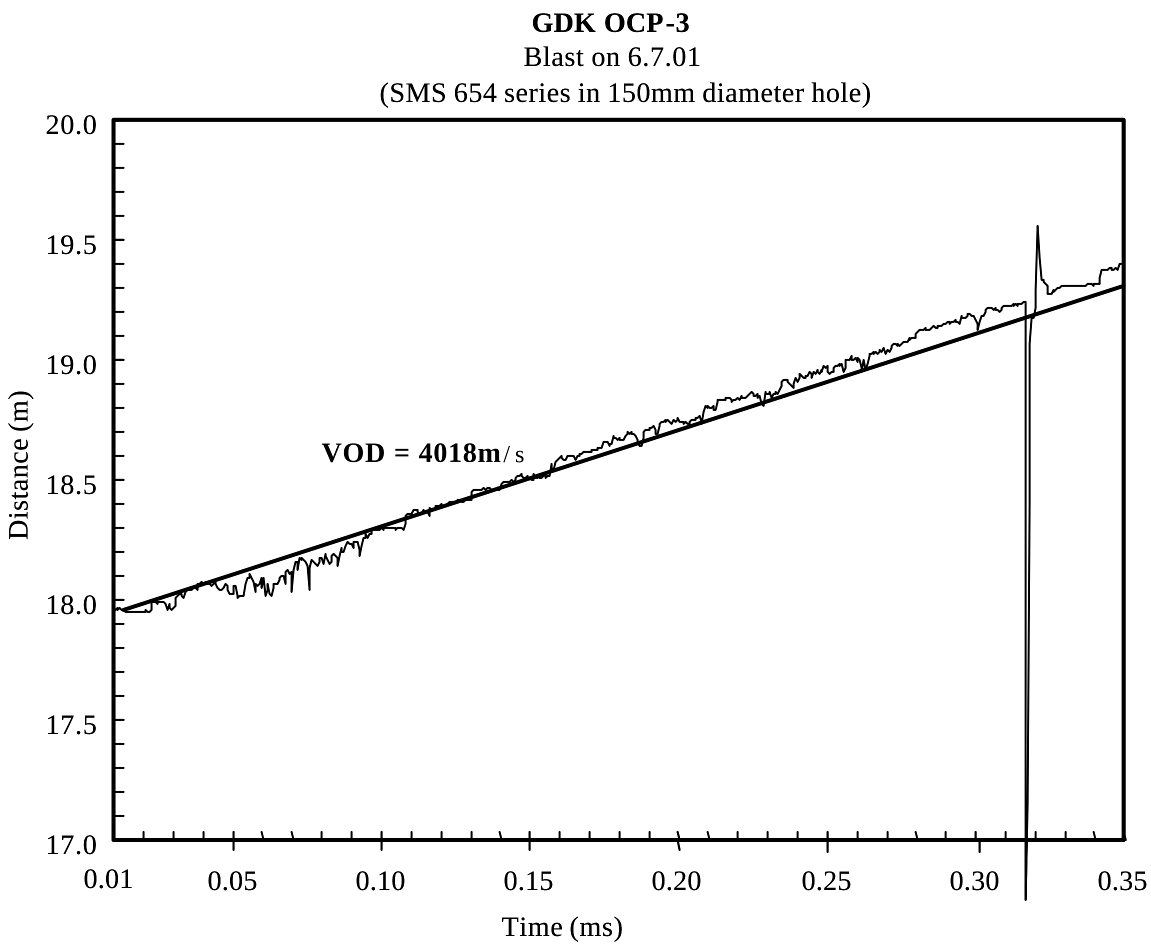

Figure 4.84 VOD trace for experimental hole (150mm diameter) at OCP-3

Blast on 6.7.01
Location: OCP-3, DM 7 area
(150 mm diameter holes)

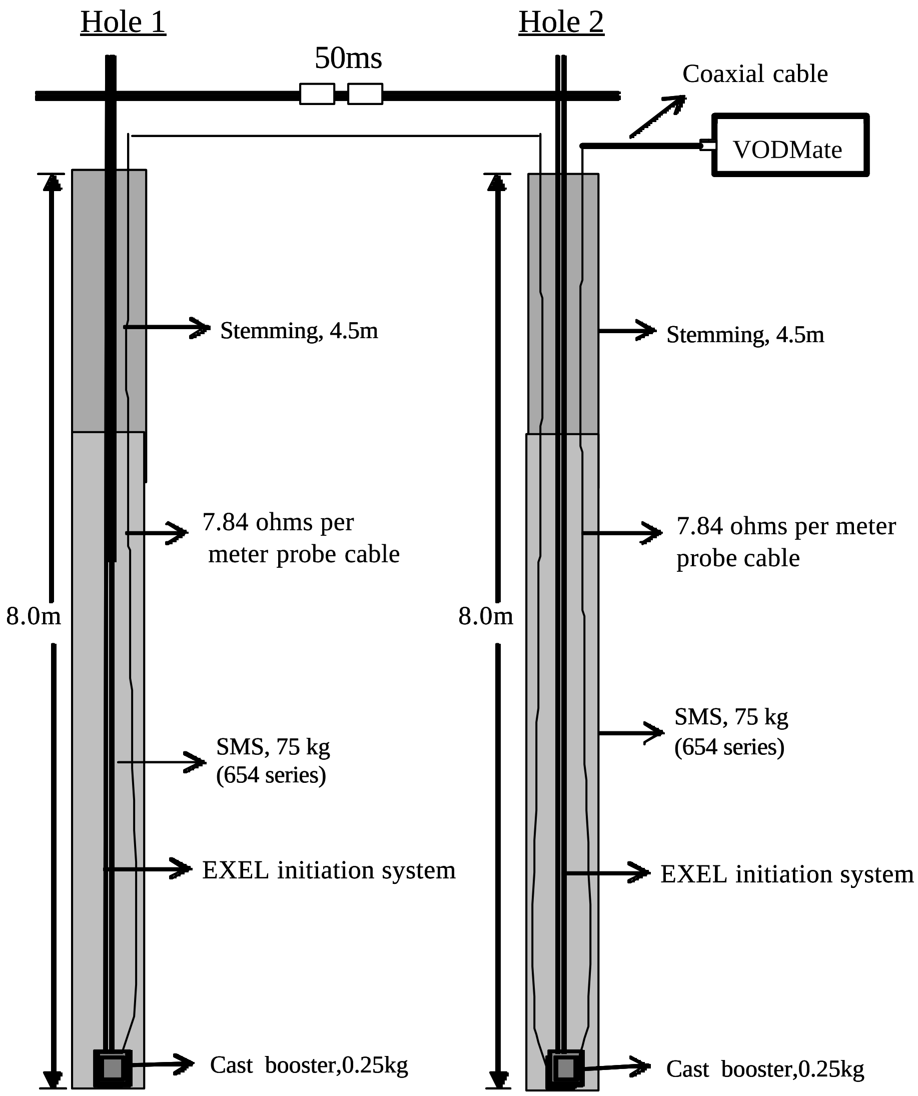

Figure not to scale

Figure 4.85 Details of the experimental holes (150mm diameter) at OCP-3

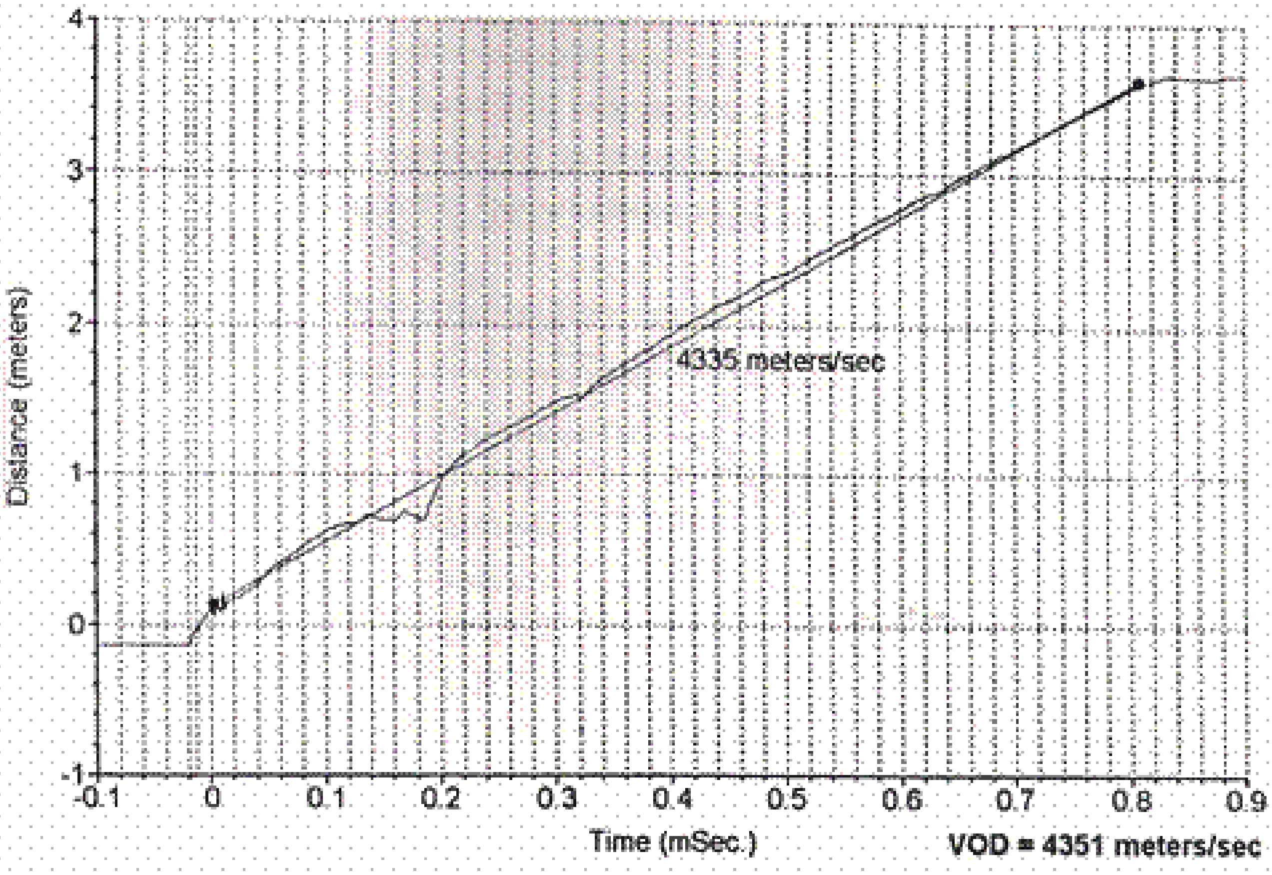

Figure 4.86 VOD result for 150mm diameter holes (Hole 1 in the loop) at OCP-3

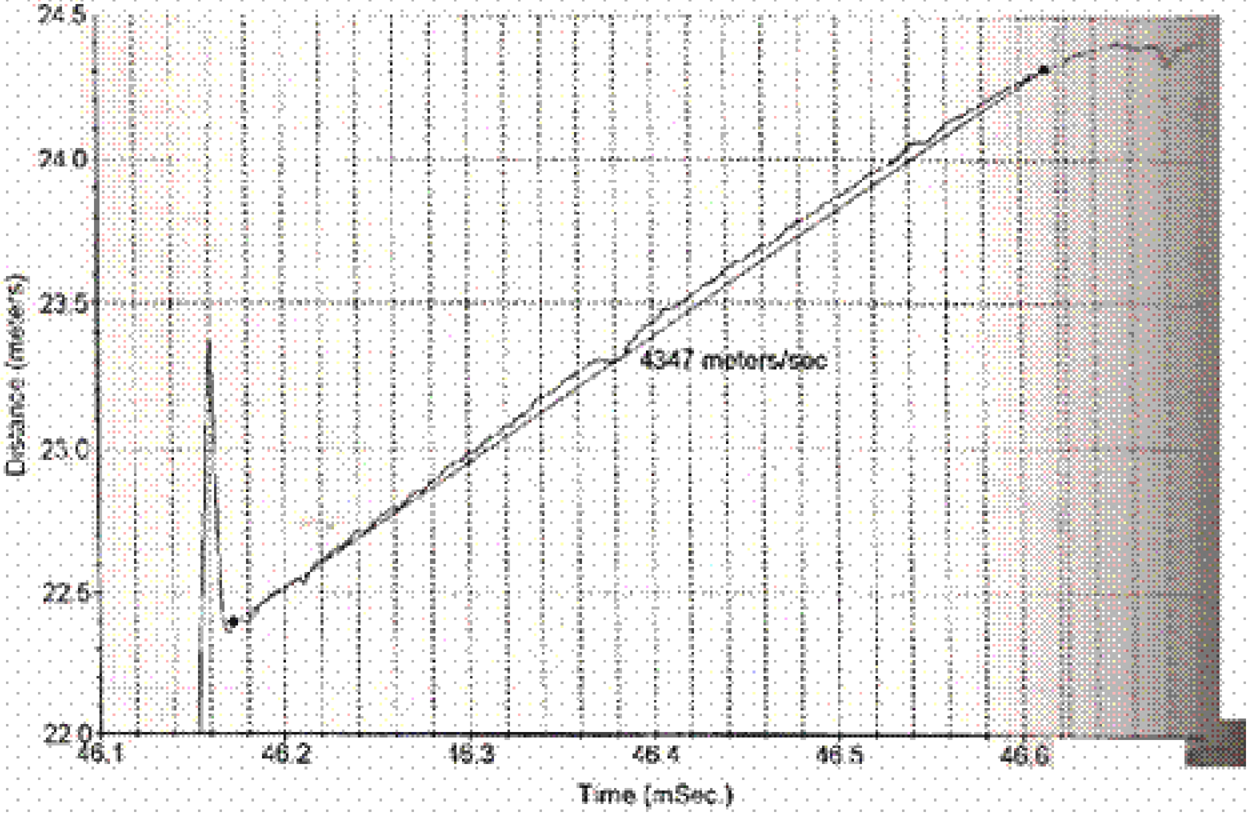

Figure 4.87 VOD result for 150mm diameter holes (Hole 2 in the loop) at OCP

the risk of the flyrock and the maximum was 7 m because of fragmentation problem from the stemming region. The measured VOD values of SMS explosives at different stemming length are shown in Table 4.11. Provided that the explosive charge is adequately confined, the VOD of explosives are not expected by increasing the stemming length.

Table 4.11 VOD of SMS explosives depending on the stemming length

Date	Blast No.	Explosives tested	Stemming length, m	VOD, mm/s
28/04/01	Blast No 4	SMS 674	5.0	4440
28/04/01	Blast No 4	SMS 614	3.5	4696
30/03/01	Blast No. 5	SMS 654	5.5	4668
27/04/01	Blast No. 13	SMS 614	7.0	4218
02/04/01	Blast No 7	SMS 634	6.5	3933
27/03/01	Blast No 3	SMS 654 & SMS 634	5.0	4302

4.10 SURFACE TESTS FOR UNCONFINED VOD

Surface tests were conducted on 31/01/1998 for cartridged explosives of IBP Company Limited at OCP using VODSYS-4 using PROBE ROD supplied by MREL. The layout of the tests is shown in Figure 4.88

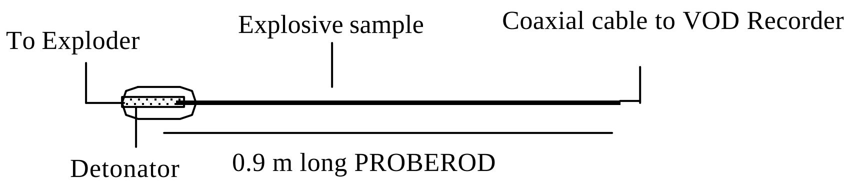

Figure 4.88 Experimental set-up for surface testing of explosive samples

The instrument (VODSYS-4) picked up only three signals and these signals were also not satisfactory (Figures 4.89 to 4.91). The VOD tests on samples of explosives were again conducted on 30/04/2001 with MicroTrap using PROBEROD supplied by MREL. The probe rod is rigid probe consisting of a high resistance insulated wire placed within a small diameter, metal tube that acts as the return lead of the circuit. The standard Probe rods as supplied by MREL are of 0.9 m in length and have a resistance of about 297 ohm/m. The resistance per meter of the PROBEROD is very much higher than that of the PROBE CABLE so that even for a very small change in probe length, associated with testing samples of explosives, there is a relatively high change in resistance.

As the critical diameter of the SMS explosives is 83 mm and the recommended diameter for bulk loading is 150 mm, samples of 150 mm diameter and 1 m long cartridges were prepared for testing. Three different series of SMS explosives were collected from the blast site while pouring into the holes and were tested one after another. For Maruti booster and Maruti column, cartridges of 125 mm diameter were picked up from the blasting site for testing purpose. For initiation of non-cap sensitive explosives, 0.25 kg booster charges were used along with the detonator.

In all, seven tests were carried out successfully. The recorded VOD traces were analysed and VOD values for the explosives tested are shown from Figures 4.92 to 4.98 and the summary of the results is presented in Table 4.12. It is found that confined VODs are 1.2 to 1.4 times greater than the corresponding unconfined VODs.

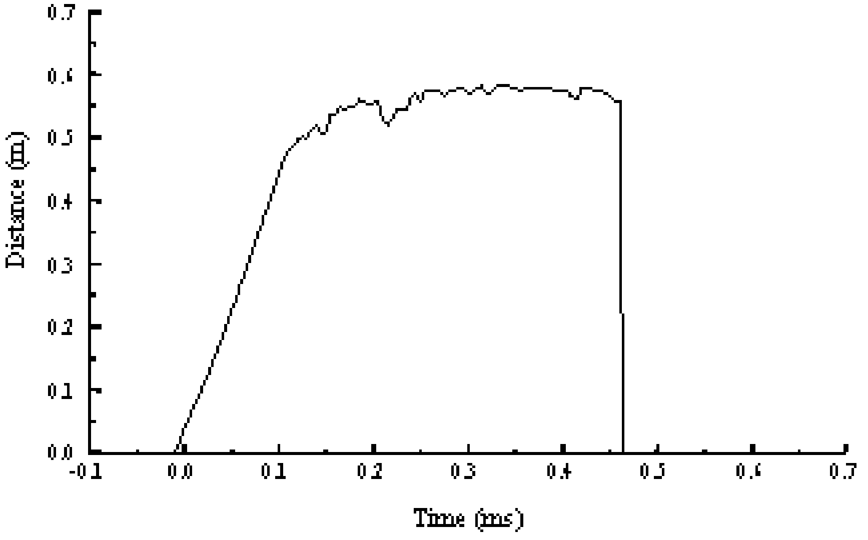

Figure 4.89 Unconfined VOD trace for IBP cartridges

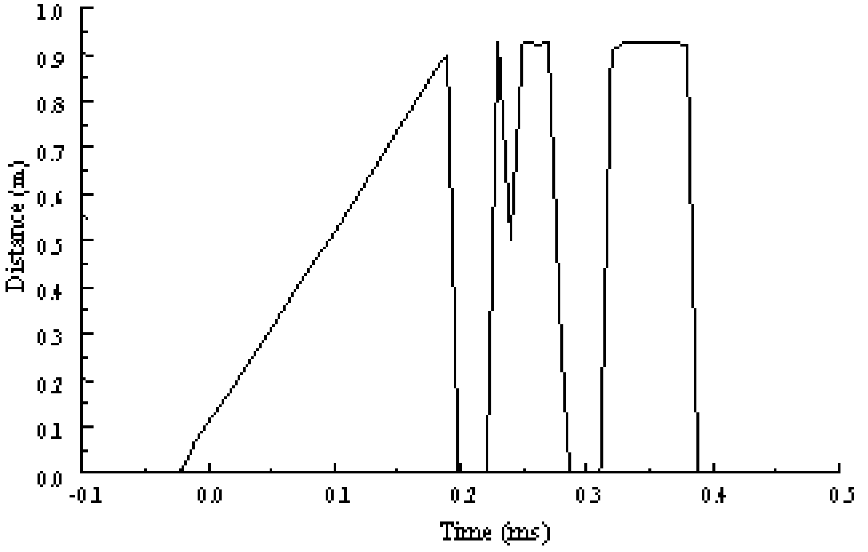

Figure 4.90 Unconfined VOD trace for IBP cartridges

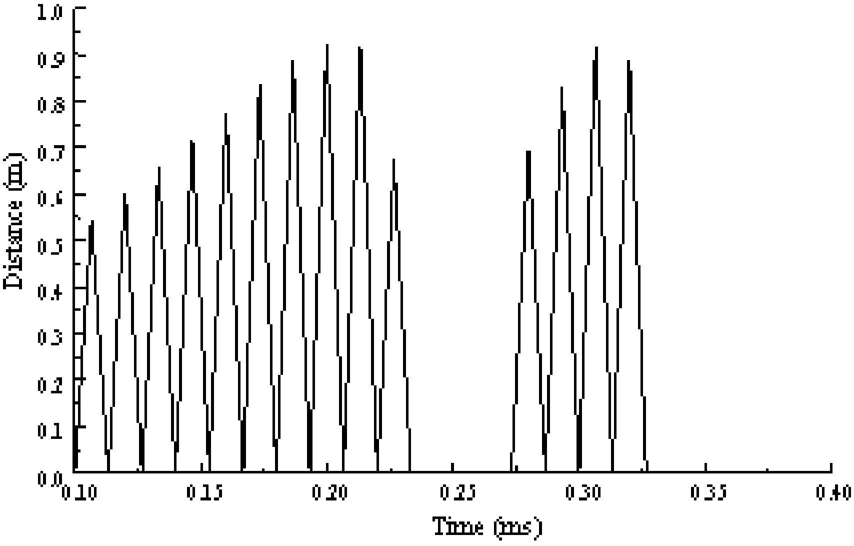

Figure 4.91 Unconfined VOD trace for IBP cartridges

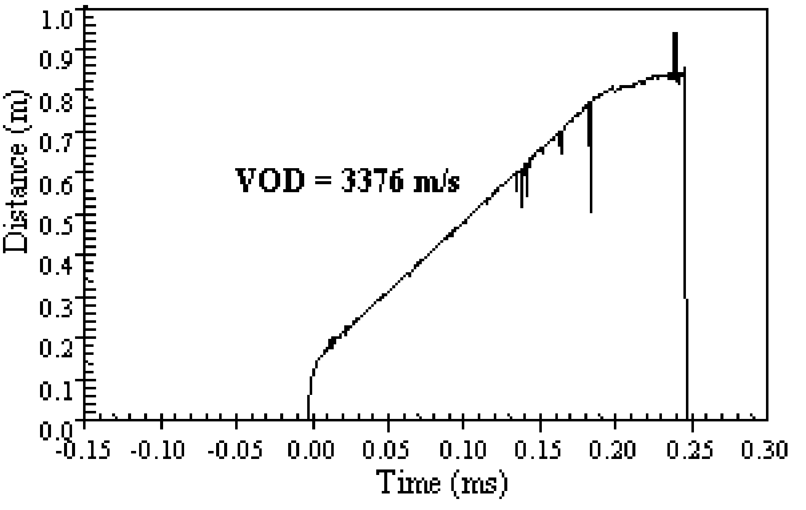

Figure 4.92 Unconfined VOD results for IBP SMS 654

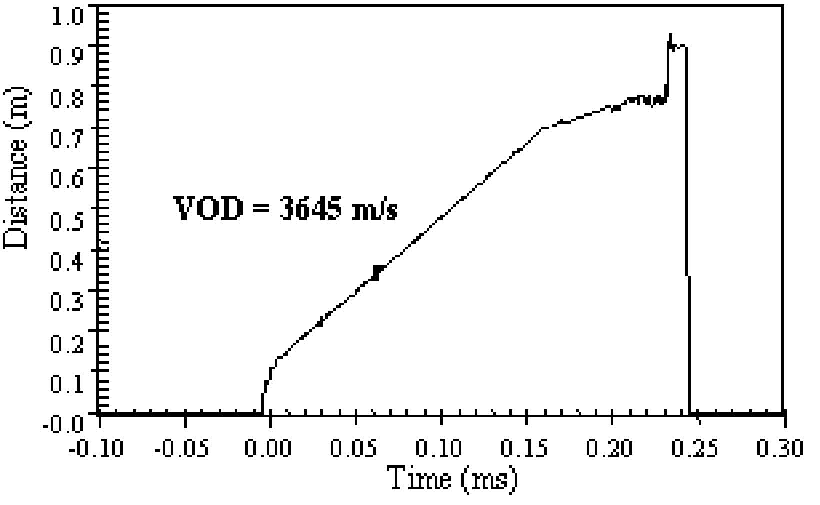

Figure 4.93 Unconfined VOD results for IBP SMS 634

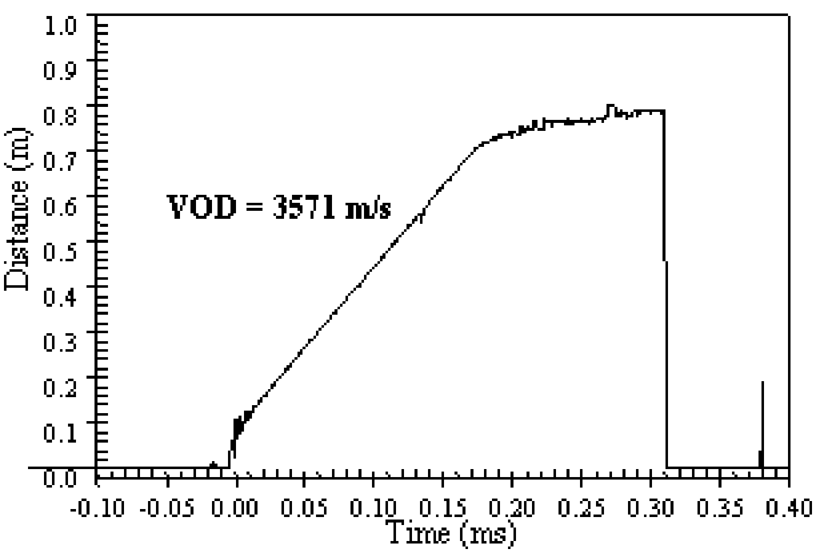

Figure 4.94 Unconfined VOD results for IBP SMS 614

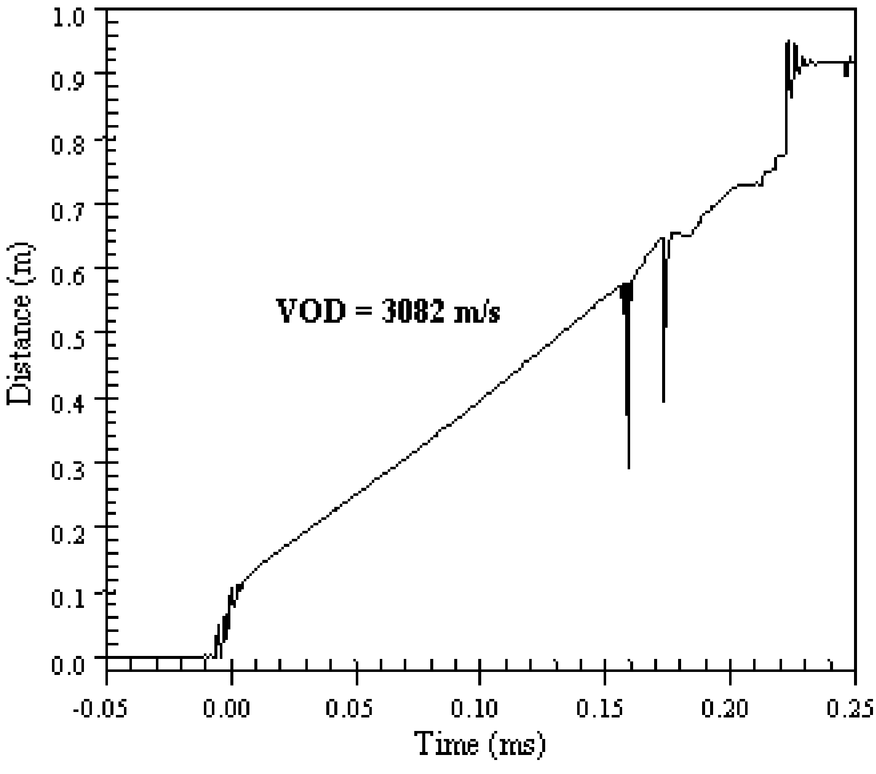

Figure 4.95 Unconfined VOD results for ANFO (150mm diameter)

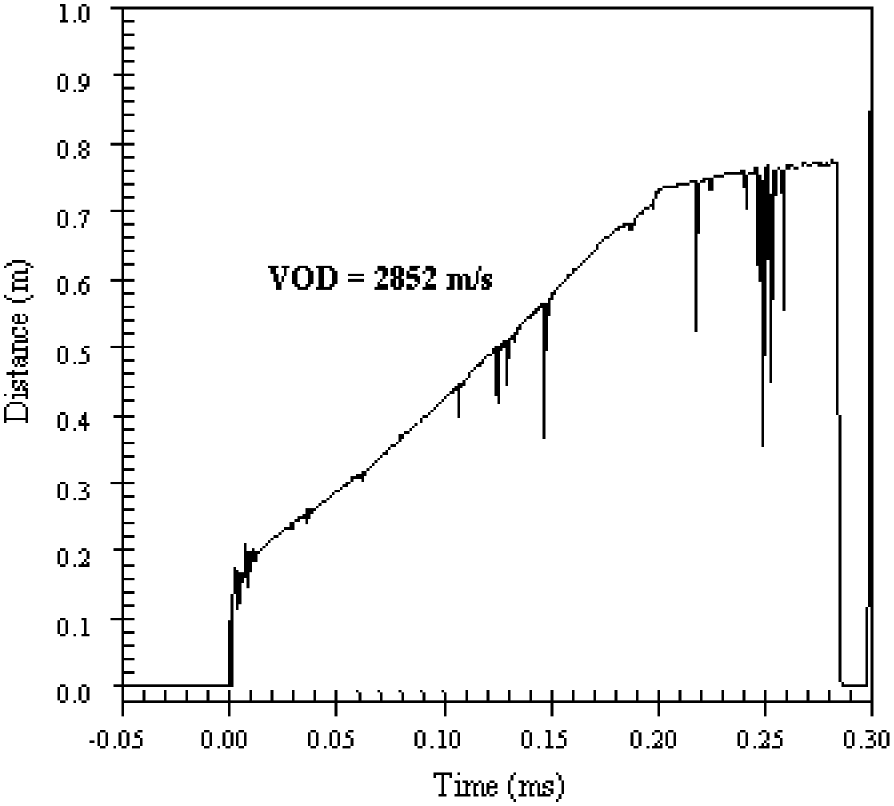

Figure 4.96 Unconfined VOD results for ANFO (150mm diameter)

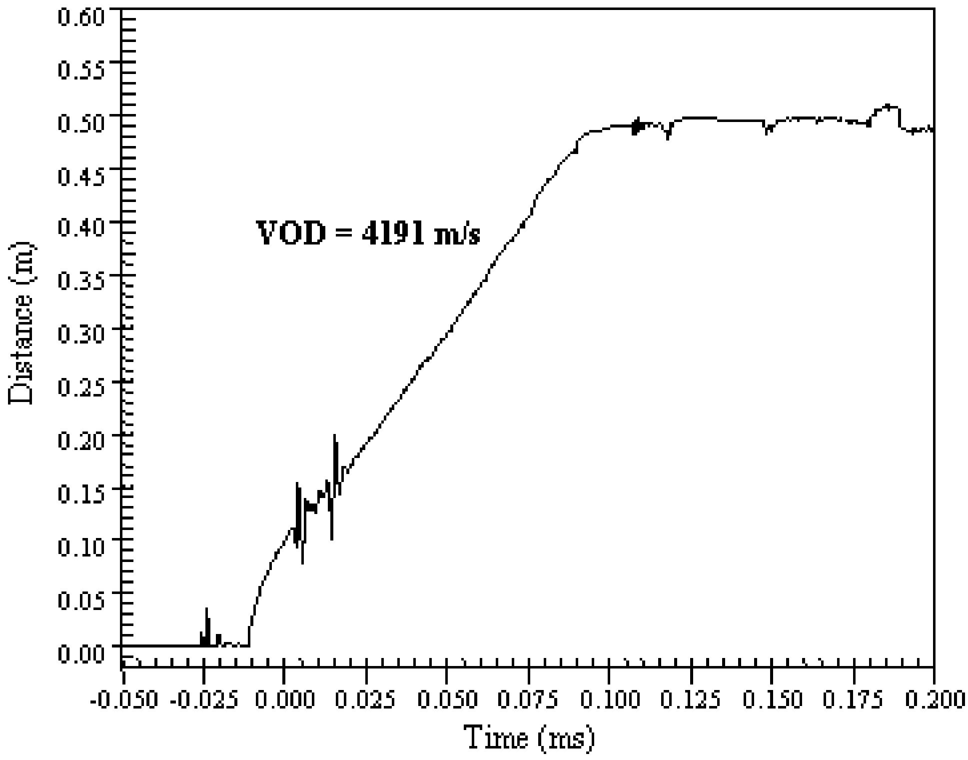

Figure 4.97 Unconfined VOD results for Marutiboost explosive (cartridge of 125mm and 6.25kg)

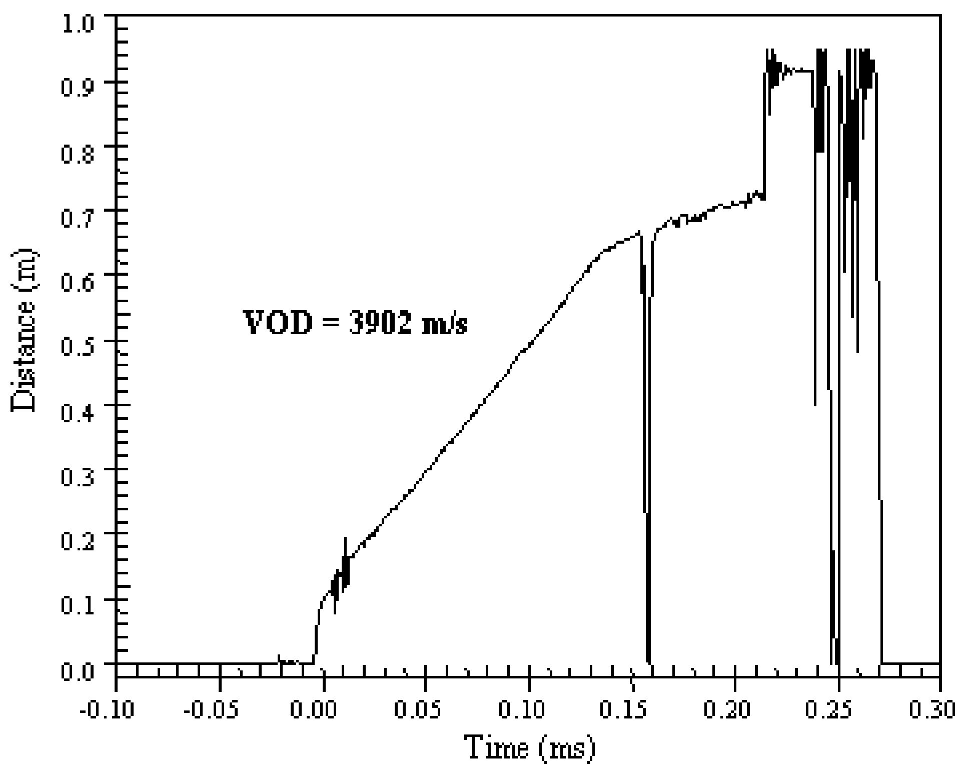

Figure 4.98 Unconfined VOD results for Maruticolumn explosive (cartridge of 125mm and 6.25kg)

Table 4.12 Unconfined VOD for the explosives tested at OCP 1

Date	Test No.	Name of the explosives	Unconfined VOD, mm/s	Confined VOD, mm/s
30/04/2001	1	SMS 654	3376	4400-4700
30/04/2001	2	SMS 634	3645	3900-4300
30/04/2001	3	SMS 614	3571	4200-4700
30/04/2001	4a	ANFO	3032	3300-4200
30/04/2001	4b	ANFO	2852	3300-4200
30/04/2001	5	Maruti boost	4191	-
30/04/2001	6	Maruti column	3902	-

From the graphs, it is noted that the detonation was complete and uniform except at the ends of the samples, particularly the end opposite to the initiation point. Such a behaviour of explosives tested on samples for unconfined VOD were also noted earlier (Refer MicroTrap manual). When the explosives were confined in a blasthole, the VOD traces show complete detonation of the charge column up to the stemming. Thus, the confinement is one of the important conditions for complete detonation of the explosive charge.

The rates of all chemical reactions are strongly dependent on the temperature and the reaction rates are higher the higher the temperature. The detonation velocity of a given explosive therefore depends on how fast the chemical reaction is completed close to detonation front, which is in turn depends on how fast the pressure and temperature decrease within the reaction zone. Both confinement and charge diameter influence the rate of decrease of pressure and pressure behind the detonation front (Persson et al, 1994).

As the stiffness of the confinement increases, lateral expansion near the primary zone is inhibited. This maintains the pressure and temperature at greater levels, and so increases the extent of combustion in the primary zone. This explains why mining explosives can detonate with a significantly higher VOD in rock than in air.

The comparison of VODs under confined and unconfined conditions makes it clear that confinement is extremely important condition for better utilisation of explosives energy. The confinement is provided in blasting through stemming and burden. It is also known that under-confinement (inadequate burden or stemming length) leads to high air overpressure and flyrock whereas over-confinement results in higher ground vibration and unwanted damage to the adjacent rock.

The surface VOD tests can be performed to check the consistency of the explosives supplied and to determine and compare VOD of different explosives. Based on VOD values, the expected performance of different explosives in terms of shock energy may be ranked. However, this method may be misleading as most of the rock breakage takes place due to gas energy of the explosives. Other parameters such as strength and density of explosives should also be considered for selection of explosives.

CHAPTER 5

A FRAMEWORK FOR EXPLOSIVE SELECTION

5.1 EXISTING PRACTICE FOR EXPLOSIVE SELECTION

Mining companies invite tenders for the supply of explosives and evaluate the bids on the basis of the 'lowest quotation', where major share is given to the supplier who quotes the least. Other suppliers are called for negotiations to bring down their prices to the lowest quoted price. Minor shares for the supply of explosives are given to one or more companies to preclude the dependence on only one supplier.

For the purpose of simplicity in the procedures for tender evaluation, a list of equivalent products for large diameter explosives has been prepared from the descriptions, specifications and the quoted prices by different explosive manufacturers. This list has been accorded acceptance by some public sector undertakings, which offer a fixed price to all manufacturers for the equivalent products. The performance of explosives, however, is yet to be ascertained in the field, as there seems to be wide variations. There is no list of equivalent products at present for bulk explosives. The system of pricing is therefore conservative. The best way of pricing should be based on in-situ tests of explosives which may include VOD, detonation pressure and fragmentation as important parameters.

Cartridged explosives are grouped into cap sensitive and non-cap sensitive. A combination of cap sensitive and non-cap sensitive explosives makes an explosive system. The mines prefer either two or three products system. Booster to column ratio is normally maintained at 20:80 in two products system and 30:35:35 (for example, Indoboost:Indogel 230:Indogel 210) in three products system The ratio is arbitrary and varies from mine to mine and even within the mine. For bulk explosives, cast boosters of about 0.2 % are used. The landed cost of the explosive system is the basis for negotiation with different suppliers. Some consideration is given, within the same system, to the performance of explosives, which is established through trial blasts. Trial orders are, sometimes, placed to assess the performance and its success may be followed by final orders.

One of the major mining companies goes by the "guaranteed powder factor", leaving the choice about the type and quantity of explosives to the manufacturer. This method also considers nothing but the price of explosives in terms of powder factor. This system does not account for the loading and hauling cost due to boulder generation.

The most serious drawback with the existing system is that it gives too much importance to the cost of explosives alone which is against the basic definition of optimum blasting. The concept of equivalent products is inadequate for the selection of explosives. In selecting one explosive as a substitute of another, equivalent products are used without considering the energy per metre of blasthole and the way in which the energy is partitioned between shock and heave energies. The simple substitution is not always effective as the fragmentation and throw will be different depending on the energy partition. Very little attempts are made to evaluate the performance of explosives for a given condition. Cartridged explosives are still widely used in large operations where bulk explosives should be the choice.

5.2 VOD AS A TOOL FOR SELECTION OF EXPLOSIVES

1. Detonation velocity of the explosive can be used to calculate the impedance of an explosive which is defied as the product of the density and the detonation velocity of the explosive. For good blasts, it is reported that the impedance of the explosive should match with that of the rock. Berta (1990) mentions that the transfer of energy to the rock is a function of both the characteristics of the explosive and the rock. According to him, the energy transferred is influenced by impedance factor (η_1)

$$h_1 = 1 - \frac{(I_e - I_r)^2}{(I_e + I_r)^2} \qquad (5.1)$$

where

I_e = impedance of explosive = density of explosive x detonation velocity (kg/m^2.s)

I_r = impedance of rock = density of rock x seismic wave velocity (kg/m^2.s)

Equation 5.1 indicates that the energy transfer is maximum when $I_e = I_r$.

2. The VOD of the explosive may be used to calculate the detonation pressure as follows:

$$P = 2.5 * \rho * (VOD)^2 * 10^{-6}$$

where P = detonation pressure (kilobars)

ρ = density of explosive (g/cc)

VOD = velocity of detonation (m/s)

3. The VOD of an explosive can be used to calculate Explosive Performance Term (Bergmann,1983), which is an empirical expression, based on extensive model blast

studies, to rate the performance of different explosives vis-à-vis fragmentation. The Explosives Performance Term (EPT) is given by

$$\mathrm{EPT} \approx (0.36 + \rho_e)\frac{D_e^2}{\left(1 + \frac{D_e^2}{V_r^2} - \frac{D_e}{V_r}\right)^{1.33}} \cdot R_V^{-1} \cdot E \cdot \rho_e \qquad (5.\ 1)$$

where ρ_e = density of explosive (g/cc)

D_e = detonation velocity of explosive (km/s)

V_r = sonic velocity of the rock to be blasted (km /s)

R_V = volume decoupling ratio (blasthole volume to explosive volume)

E = calculated maximum expansion work of explosive (kcal/g)

If the numerical value of EPT for a given explosive is higher than that of the standard, a better fragmentation performance is inferred. Likewise, a smaller number than that of the standard indicates inferior performance.

EPT provides a rational basis for rating explosives, as it brings out the interplay between rock and explosive properties, as opposed to traditional systems which have been based on explosives energy alone. It indicates that fragmentation is not controlled by a single property by a combination of properties including explosive energy, detonation velocity, density, degree of coupling between explosive and borehole wall, explosive volume to borehole volume and sonic velocity of rock.

Equation 5.1 has been tested and modified by Chiappetta (1991) for its use in the full scale environment. Sonic velocities and VODs are measured *in situ*. By substituting inert material into the original explosive composition to match measured VOD outputs, a more realistic value for the maximum expansion work of the explosive is obtained. In addition, the substitution provides a better estimate for the non-ideal behaviour of explosives when used in the field. The modified EPT is given by

$$\mathrm{EPT} \approx (0.36 + \rho_e)\frac{\mathrm{D}_e^2}{\left(1 + \frac{\mathrm{D}_e^2}{\mathrm{V}_r^2} - \frac{\mathrm{D}_e}{\mathrm{V}_r}\right)} \cdot \mathrm{R}_V^{-1} \cdot \frac{\mathrm{E}_M}{\mathrm{E}_T} \cdot \rho_e \qquad (5.2)$$

where E_M = non-ideal value (kcal/g), E_T = Theoretical value (kcal/g) and all other symbols are defined in Equation 5.1.

4. The following thumb rules should be taken into consideration while selecting explosives:

a) In massive rock, explosive is required to create a large number of new surfaces. For this, high density and high VOD explosives such as slurries and emulsion should be used. High VOD will give high shock wave, which will induce micro cracks, resulting in better fragmentation.

b) In highly jointed rock, few new cracks are needed; most of the required fragmentation is achieved when explosion gases jet into and wedge open the structural discontinuities. For this, low density and low VOD explosives such as ANFO are more efficient than high strain energy explosives as the extension of radial cracks are terminated at joints.

5.3 GUIDELINES FOR EXPLOSIVE SELECTION

The selection can be made among ANFO, Heavy ANFO, slurries and emulsions. Nitroglycerine (NG) based explosives need not be considered as they are being phased out in the world including India. In 1980, nearly 40 % of the production capacity was NG - based explosives which was reduced to around 25 % by 1990. On the other hand, the capacity based on slurry and emulsion technology multiplied five times during the same period (Datey, 1990). After the closure of manufacturing of large diameter NG-based explosives by ICI, their share has further declined to less than 10 per cent.

A step-by-step procedure is suggested for selection of explosives for a mine considering the advantages and disadvantages of the cartridged and bulk systems, the rock properties, the environmental conditions such as water in the blastholes, the performance evaluation of explosives for a given condition, and the unit cost of production.

Step 1: Select between Bulk and Cartridged Explosives

The increasing size of blasts necessitates a mechanised means of explosive charging into the blastholes. For the last 10 years there has been a trend towards the increasing use of bulk systems. Keeping in view the annual requirement of explosives for the mine, the user can select either cartridged or bulk explosives. There may be a combination of both, for instance, bulk loading in overburden benches and cartridged explosives in coal benches. It is recommended to select bulk explosives for a mine or a group of adjacent mines with annual explosives consumption over 1000 tonnes and with hole diameter of 150 mm and above. This is limited by the economic criterion for the explosive manufacturers to supply bulk explosives.

Bulk explosives offer a number of benefits: 1) cost of explosive is cheaper compared to cartridges, 2) a variety of explosive can be formulated at the site to meet the site-specific requirement, 3) better blasthole coupling allows to expand the pattern by 10-15% over cartridged explosives, 4) it reduces the investment in storage, transportation and handling of explosive, and 5) it is safer. Some problems such as loss of explosive in the existing cracks and cavities, hydrostatic pressure in deep holes and overcharging due to higher loading density were faced by the industry with bulk explosives. The technology of bulk explosives has advanced so much that these problems can be overcome easily.

***Step 2*: Consider the Blasthole Water Conditions**

If the holes are dry, explosives such as ANFO may be considered. When water is encountered in a blasthole, water resistant explosives such as slurries, Heavy ANFO, and emulsions should be used. The use of ANFO after dewatering of blastholes or by providing waterproof liner is not recommended for Indian mines because water resistant explosives are available at comparable prices.

***Step 3*: Consider the Rock Mass Properties**

Efficient and successful performance of an explosive in a rock mass requires that its properties be compatible with those of the subject rock mass. An empirical correlation of the preferred explosive type for a range of rock mass properties (Brady and Brown, 1993) indicates that ANFO is suitable for use in a wide range of rock mass conditions and the application of high energy explosives is justified only in strong and massive rock formations.

Crater tests, single hole blasting, impedance matching, and field trials (Adhikari and Ghose, 1999) are some of the approaches to matching rock and explosive properties. Some other important approaches include comparing Explosive Performance Term, explosive-rock interaction (Sarma, 1994) and computer calculations of entire process of detonation of the explosive (Persson *et al*, 1994). From these studies, it is clear that explosives should be selected by their performance for a given situation, not by its chemical efficiency. At the present level of technology, the performance of explosives has to be evaluated by field tests.

***Step 4*: Evaluate the Explosive Performance**

It is not difficult for a manufacturer to offer a product for a particular application claiming it the best. The user gets confused as various companies suggest different options. Each manufacturer claims that his products are equivalent or better than those of his competitors'.

Therefore, it is difficult to accept or reject explosives without assessing their performance in the field. Performance of the explosives can be evaluated as per the methods suggested in this report.

***Step 5*: Cost Analysis**

Until now the mine operators in India have concentrated their efforts on minimising the direct cost of explosives without fully realising the importance of blasting on overall cost of production. In most of the mines, the cost of drilling and blasting can be worked out but the costs for the subsequent operations like loading, hauling and crushing are not known, which makes the cost analysis difficult. It is, therefore, essential that the mines calculate the cost of individual operations and minimise the combined cost of production.

5.4 SIMPLIFIED FLOW-CHART FOR SELECTION OF EXPLOSIVES

Based on the information presented in the preceding sections, a simplified flow-chart (Figure 5.2) has been prepared to guide the selection of explosives.

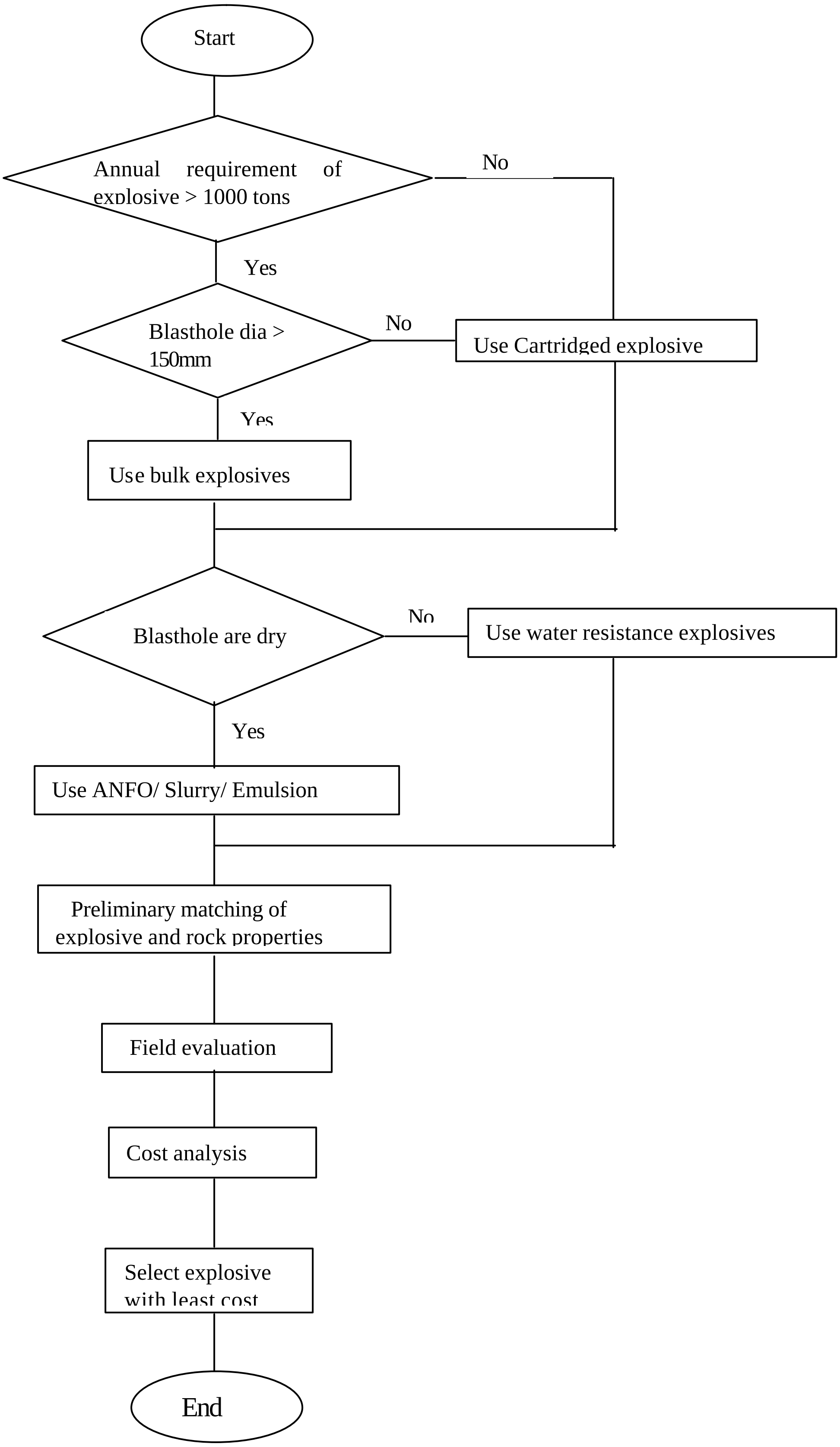

Figure 5.1 Simplified flowchart for selection of explosive

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The velocity of detonation (VOD) of explosives was tested at OCP-1 and OCP-3 of Godavarikhani area of SCCo Ltd and at two limestone mines. For this purpose, three different VOD measurement systems, namely VODSYS-4 and MicroTrap from MREL, Canada and VODMate from Instantel, Canada were used. The VOD records were analysed using software provided along with the equipment. The following conclusions are drawn from this study:

1. A total of 76 blasts were monitored of which 56 events successfully recorded were analysed. The probability of successful recording happens to be 74% which is reasonable for the field condition. The reasons for unsuccessful recordings are given in Section 3.8.2

2. The measured in-the-hole VODs of cartridge explosives were higher than the quoted values by their manufacturers as the explosives tested by them were normally under unconfined condition. In case of bulk explosives, the VOD values were nearly matching with the quoted ones. The VODs measured in the field were lower in some cases for both cartridged and bulk explosives due to unfavourble conditions such as presence of water in the blasthole.

3. Three types of primers, namely cap sensitive cartridged explosives, small diameter primers such Kelvex-P and cast boosters, used in the experiments revealed some interesting findings. The VOD of ANFO, primed with cap sensitive cartridged explosives did not vary significantly by increasing percentage of primer/booster from 14 to 49. In case of cartridged slurry explosives also, the measured VOD was in the range of 3800-3900 m/s when the percentage of primer/booster was increased from 20 to 40. Kelvex-P of about 4 per cent reliably initiated ANFO but when the primer was reduced to 2 per cent, the explosive did not attain its steady state VOD. The VOD of the SMS explosive, primed with cast boosters with 0.17 to 0.40 percentage of primer/booster was within the range of 4364-4726 m/s and did not show increasing trend with the increase of primer/booster ratio. The cast boosters about 0.2 per cent were sufficient for priming the site mixed slurry.

4. A single point priming was sufficient to reliably initiate and sustain the steady state VOD of explosives up to 10m long column without any additional booster charge. There was no obvious advantage of bottom or decked priming in respect of VOD values or the release of shock energy of the explosive. Therefore, all cap sensitive explosives can be loaded at bottom to tackle the toe problem. A method of emulating bottom initiation with detonating cord to reduce the cost has been demonstrated by NIRM at JK OCP-II, SCCo. Ltd.
5. The explosive performance deteriorated with contamination, particularly when it was contaminated more than two times that what it happens during normal course of charging.
6. The analysis of VOD records in dragline benches confirmed that SMS explosives can be loaded in blastholes up to depth of 30m without the risk of attaining dead density of the explosive due to hydrostatic pressure.
7. The experiments conducted with SMS explosives containing 0 to 9 per cent of aluminium powder indicated that the VOD values did not increase with the increasing aluminium percentage. This conclusion is in line with the fact that aluminium content in commercial explosives varies from 0 to 5 per cent by weight.
8. All explosives deteriorate progressively in wet holes. The experiments conducted in completely wet holes were not successful due to inefficient shorting of probe cable.
9. It was found that the VOD decreased by about 25 per cent when SMS 654 had a sleep time of 25 days, more than recommended limit of two weeks.
10. The VOD value of ANFO was greater in 250 mm diameter than in 115 mm diameter holes. However, the influence of blast hole diameter was not so conclusive for bulk explosives tested in 150 mm and 250 mm diameter holes.
11. Provided that the stemming length was adequate, the VOD of explosives did not vary with the stemming length.
12. It was found that confined VODs were 1.2 to 1.4 times greater than the corresponding unconfined VOD values. Since in-the-hole measurement of VOD is difficult and costly, this ratio may be useful input for blast designs. However, unconfined VOD values do not reflect the effect of hostile borehole conditions under which explosives have to function.

13. The experiments conducted with detonating cord down-the-hole initiation system were not successful due to disruption of probe cable by the detonating cord.
14. Based on VOD measurement, a framework for selection of explosives has been suggested in chapter 5.

6.2 RECOMMENDATIONS

1. It is recommended to monitor VOD of explosives periodically in the field to check the consistency and quality of explosives. The results may be compared against the quoted VODs of explosives by their manufacturers.
2. VOD monitoring can be carried to confirm whether detonation, deflagrations or failures have taken place, to study the influence of primer size on explosive performance, and to investigate the effectiveness of decking
3. The VOD of the explosive may be used to calculate the detonation pressure, Explosive Performance Term and to match impedance of rock and explosive, as discussed in Chapter 5.
4. The actual firing time of delays can be noted from VOD signals of multiple holes. This information can be used to decide maximum charge per delay and to control blast vibration.
5. It is recommended to distribute the charge column in the hole according to hard/soft bands. Explosives with high velocities of detonation are considered to have a higher shock energy component and would be most suitable for blasting hard competent rock.
6. The method of emulating bottom initiation by detonating cord may be tried, as there was no noticeable difference in the VOD values with bottom or decked priming.
7. Proper care should be taken to avoid contamination of explosive with drill cuttings.
8. Some more VOD monitoring may be conducted to determine the rate of reduction in the VOD for different explosives with varying sleep time. It is not advisable to allow sleeping of hole exceeding the time recommended.
9. Although the experiments were conducted for SMS, the same may be tried for bulk emulsions to understand whether they are having similar effects on emulsions.

ACKNOWLEDGEMENT

We have great pleasure in expressing our sincere gratitude to the Ministry of Coal, Government of India for funding the project on '**Evaluation of explosives performance through in-the hole detonation velocity measurement".** This project was closely monitored by Central Mine Planning & Design of Institute, Ranchi, and we are thankful to them. We are also thankful to Singareni Collieries Co. Ltd. (SCCo. Ltd) for collaborating with us and providing necessary facilities to carry out the field investigations. In particular we are grateful to the following personnel:

OCP-I, SCCo. Ltd

Mr. L. Bhooma Reddy, Retired GM
Mr. G. Mukunda Reddy, GM
Mr. M. Sheshkumar Reddy, S.O. to GM
Mr. Shashi Kapoor, Addl. CME
Mr. P. Umamaheshwar, Dy. CME
Mr. Y. Sreenivasa Rao, Addl. Manager
Mr. V. D. N. Lincoln, Addl. Manager
Mr. Sd. Sikander Ali, Addl. Manager
Mr. A. Narasimha Swamy, Sr. Und. Manager

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Mr. Sathyanarayana, Sr. Und. Manager
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Mr. T. P. Mishra, Blasting Incharge

We have pleasure in expressing our sincere thanks to Dr. N. M. Raju, Ex. Director, NIRM for his interest and encouragement. Our thanks are due to the officials of Administration, Technical Service and Library division of NIRM for providing necessary support and co-operation. We appreciate the co-operation extended by Mr. N. Sounder Rajan during one of our field investigations. We are also thankful to Mr. R. Balachander, SA, Excavation & Blasting Division for his help in this study.

Finally we thank all those who have directly or indirectly contributed at one time or other in successful completion of this project.

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Project Completion Report

Particulars of the Project

1. Name of the Project	Evaluation of explosives performance through in-the hole detonation velocity measurement
2. Financial Support	Funded by S&T Grant of Ministry of Coal, Government of India and SCCL
Approved Cost	Rs. 23.84 Lakhs
Details of Expenditure	Submitted separately
3. Date of Starting	1st November 1996
4. Original date of completion	October 1998
Revised date of Completion	March 31, 2001 (Completed in August 2001)
Reasons for delay	(a) in procuring zero delay (NONEL) detonators (b) problem with Notebook computer (c) problem with VODSYS-4 and software
5. Objectives	Please see page No. 2
6. Work programme	Please see Page No. 3
7. Details of Work Done	Please see Chapters 3, 4 and 5
8. Extent of object fulfillment	All the objectives have been fulfilled
9. Conclusions and Recommendations	Please see Chapter 6
10. Scope of further Work	To investigate the influence of VOD of explosives and effectiveness of deck charges on ground vibration
11. Need for further study	To control ground vibration
12. Persons Associated	Prof. R. N. Gupta, Project Advisor Dr. G. R. Adhikari, Project Coordinator cum Investigator Mr. H. S. Venkatesh, Project Leader Mr. A. I. Theresraj, Co-Investigator Mr. H. K. Verma, Research Fellow Engineers of OCP-1, SCCo Ltd. Engineers of OCP-3, SCCo Ltd. R&D Department, SCCo Ltd.
13. Expertise Developed	Measurement and analysis of VOD of explosives