Facts About Axial Initiation
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Role of a Cast Primer

1. **Initiates commercial explosives at full velocity within a few microseconds after a short run-up distance**
2. **Always a run-up distance to steady-state conditions for water-based commercial explosives**
3. **Primers must have a high detonation pressure and should be detonator and/or cord sensitive**
4. **Best to use molecular explosive cast primers**
   a. **Pentolite – 50/50 mixture of PETN and TNT**
   b. **Cast boosters – Pentolite core encased in cast TNT**
   c. **Detonation pressures > 250 KBar**
5. **Dynamites, packaged emulsions and watergels are sometimes used – not recommended for extreme environmental conditions like water-saturated ground especially when ground is seamy and full of cracks**

Initiating a detonator sensitive explosive from a detonating cord, placed along the longitudinal axis of an explosive loaded into a blasthole shown in Figure 1, frame 2 produces a complete change in geometry with respect to the orientation of the traveling shock front. The obliquely traveling detonation head driven laterally in the explosive column may be the recipe for deflagrations and outright failure of a detonator sensitive explosive product to detonate at its characteristic detonation velocity. The orientation of the oblique shock front is angled across the explosive column and is subject to run-up conditions. There is a misconception that since det cords (primacord) have high detonation velocities, an equivalent detonation velocity would be induced in the explosive column. In fact, axial priming practice could lead to deflagration of the explosive. There are cases where axial priming destroyed the matrix of emulsions – especially those using glass micro-balloons as a means of sensitizing an explosive product (After B. Mohanty, D. Joyce - 1993).
Normal priming involves primer placement in the explosive column so that the resulting shock front runs perpendicular to the central axis of the explosive column. Figure 1, frame 1 shows a normal priming configuration along with the concept of axial initiation represented in frame 2.

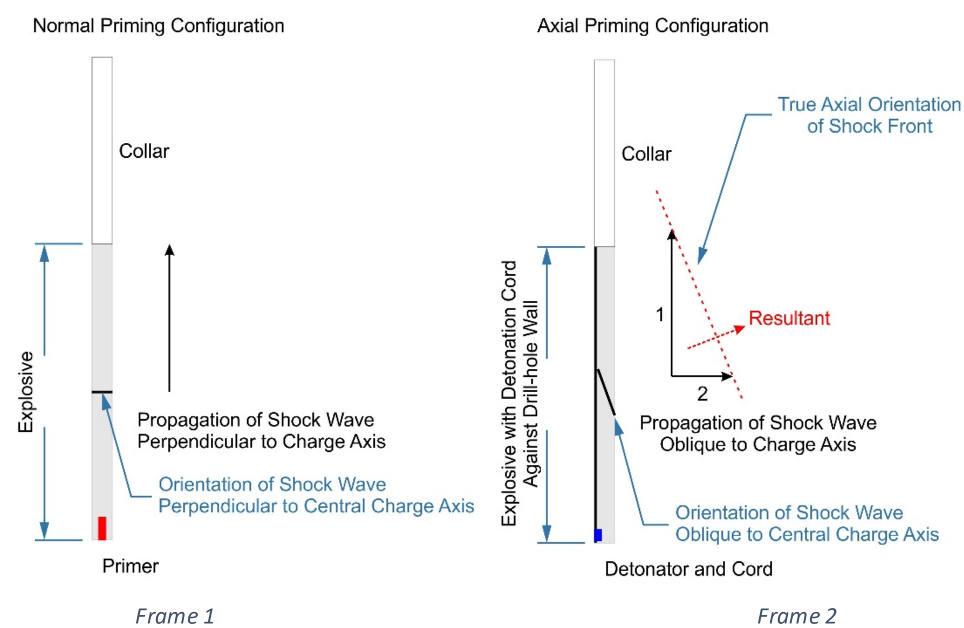


Figure 1 - Normal method of priming an explosive column (Frame 1) vs the axial method of tracing an explosive column (Frame 2).

For det cord types available, it should be noted that one grain (gr) count of an explosive is equal to 0.065 gm of that same explosive. A 150 gr/ft cord (492 gr/m) translates to 9.72 grams/ft of the same explosive. A standard #8 detonator contains about 1-gram of PETN/RDX as a base charge. This 1-gram element converts to 15 grains of explosive. Using a

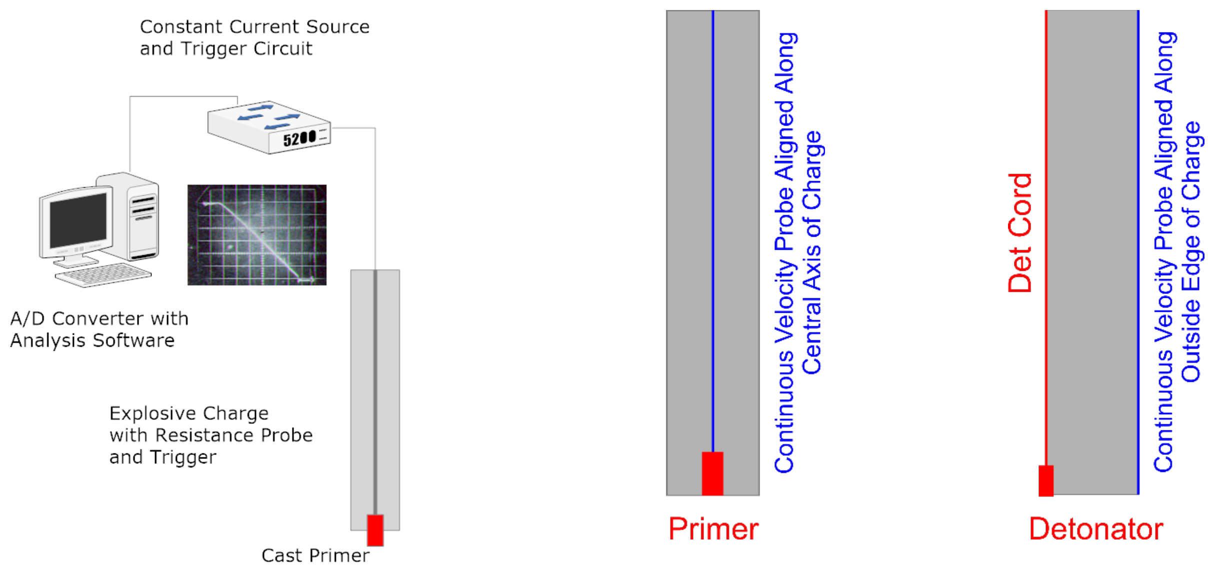
150 gr/ft cord translates to 12.5 gr/in which may be questionable as a good primer. Table 1 presents some commercially available det cords up to 400 gr/ft.

Table 1 - Core Loads of Popular Detonating Cords in gm/m

Trade Name	Nominal Diameter (mm)	Nominal Core Load (gm/m, gr/ft)	
Cordtex	4.0	5.0	24
Primacord 10	4.7	10.6	50
Primaline 21	5.84	21.3	100
Primaline 32	7.1	31.9	150
Primaline 42	7.62	42.5	200
Primaline 85	10.3	85.0	400

Measurement of Continuous Velocity Using Resistance Wire and a Constant Current Source

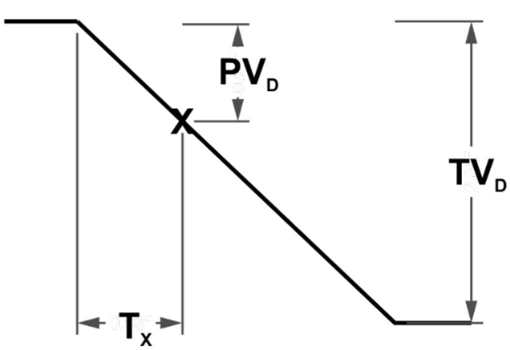
The methodology is not difficult to understand and top of the line instruments use either portable equipment such as the MREL MicroTRAP multichannel recorder and the very simple HandiTRAP single channel recorder. The typical setup that was used by this author is shown in Figure 2, frame 1.



Frame 1 *Frame 2* *Frame 3*

Figure 2 - Method of capturing VoD from an explosive product shown in Frame 1. Normal priming consists of a primer and probe oriented along the central axis of the explosive whereas the position for monitoring the VoD for an axially traced charge is shown in frame 3. The shock wave generated would be oblique.

Determining the VoD for any explosive product is shown below in Figure 3.



$$Velocity\ at\ Point\ X = \frac{\frac{PV_D}{TV_D}}{T_X} \times PL$$

Where:

PV_D = Partial Voltage Drop
TV_D = Total Voltage Drop
T_X = Time to Point X
PL = Probe Length

Figure 3 - Translating results of velocity traces using constant current sources and resistance wire probes.

Axial priming produces low velocities of a cord sensitive explosive due to the oblique nature of the shock wave that is formed which inevitably includes run-up effects. In cases where there is a fear of ore structure getting in the way of continuous longitudinal velocity propagation, it would be important to insure that multiple primers are used instead of det cord as a means of providing the security factor needed dealing with incompetent or fractured ore/rock. The use of cord as a priming mechanism in production blasting will result in low energy detonations not suitable for generating good fragmentation. For the drawing below, a radial velocity of 5000 m/s for an emulsion product is overly optimistic since run-up distance is not considered. In most cases close to a priming element the radial velocity near the priming point would probably be one-half this value or 2500 m/s. Two cases are analyzed with the characteristic velocity at 5000 m/s and the second with the radial velocity at one-half the 5000 m/s value or 2500 m/s – probably the most realistic run-up scenario.

Axial Priming – Det Cord Tracing Along the Longitudinal Axis and Observations

Axial Initiation is a change in the geometry of the propagating detonation front resulting from a continuous det cord as shown in Figure 4.

1. Heavy primacord is placed along the side of an explosive column
2. Produces an oblique shock front
3. Called an "alternate velocity technique" that been proposed in order to obtain better performance from ANFO and other commercial explosives
4. Long thought to be a 'wonder' method in that claims were made that the velocity of an explosive column could be doubled

What has been found is that axial priming produces lower velocities for most commercial explosive cord sensitive products and should not be used in production blasting operations. Caution should be exercised with ANFO since prills can be crushed (ANFO is very insensitive) – performance can be degraded.

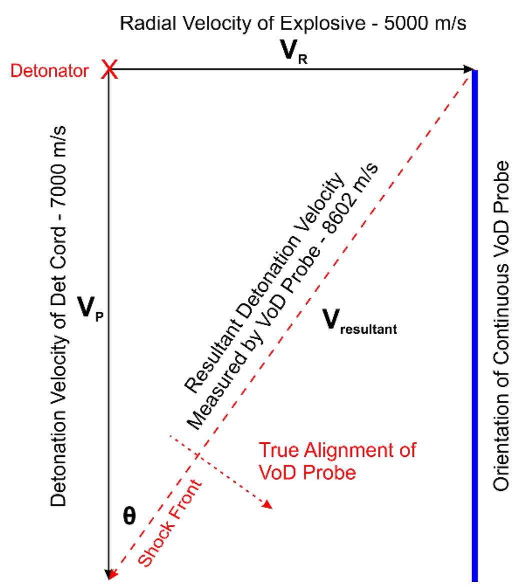
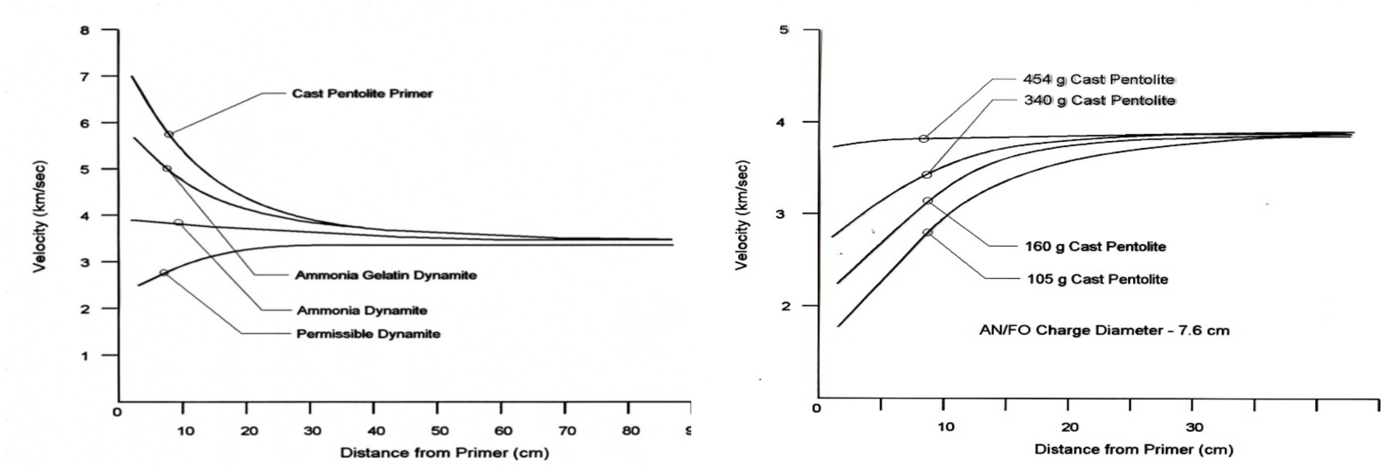


Figure 4 - Shows velocity vectors for the axial orientation of detonating cord and with reference to the radial velocity of a typical emulsion explosive. These are drawn to scale (cord velocity – 7000 m/s with 5000 m/s for explosive velocity with no run-up). It can be shown that the continuous velocity probe will read 8602 m/s because of the probe's alignment. More probe will be reacted per unit time in the configuration shown than a probe aligned perpendicular to the shock front.

Run-Up Distance and Run-Up Detonation Velocity

When an explosive is initiated by detonator or det cord, there will be a small run-up distance that is required for the explosive to reach the detonation velocity of the explosive in the diameter of charge used. Non-ideal explosives refer to a class of commercial explosives such as emulsions, watergels and ANFO products that do not detonate at the ideal velocity of the explosive. A non-ideal detonation implies that not all the explosive constituent ingredients are consumed in the detonation head. Some ingredients will react outside of the detonation head in the gas expansion region immediately following the reaction zone resulting in a value of detonation velocity below the ideal. The chemistry of the explosive and its density will dictate what the maximum ideal velocity will be as well as the diameter of the explosive charge.

Figure 5 shows the effects of overpriming and underpriming on run-up distance. The rule of thumb for run-up distance is that for small diameter explosives that are detonator sensitive, the run-up distance can be as high as 6 charge diameters (particularly in ANFO, watergels and some small diameter emulsions). In most cases the detonation velocity close to the priming point can be one-half the true detonation velocity in a specific diameter of charge (After Neill, Torrance 1988)



Frame 1 *Frame 2*

Figure 5 - Overpriming (Frame 1) and underpriming (Frame 2)) can cause transient effects at several diameters of charge away from the primer. Overpriming does not contribute to any long-lasting effects since the ideal detonation velocity is dependent on the chemistry of the explosive formulation along with the charge diameter and explosive density. (After Bauer, Katsabanis)

Cord traced explosives have found use as splitting charges such that a continuous length of decoupled explosive charge is used as a pre-split or post-split charge for perimeter control in underground mining or wall control in open cast mining. Decoupling limits borehole pressures along a line of drill-holes to values that are below the dynamic compressive strength of rock/ore types in which the split action takes place. The cord must be strong enough to initiate the explosive that it is paired with (always a detonator sensitive explosive).

Measurement of Detonation Velocity of an Axially Primed Explosive

A sketch of the geometry associated with axial initiation of linear charges in drill-holes is given in Figure 6. This shows the detonation velocity vector of the explosive charge along with the orientation of det cord shock wave progression with respect to the longitudinal axis of the explosive charge when used as an axial primer.

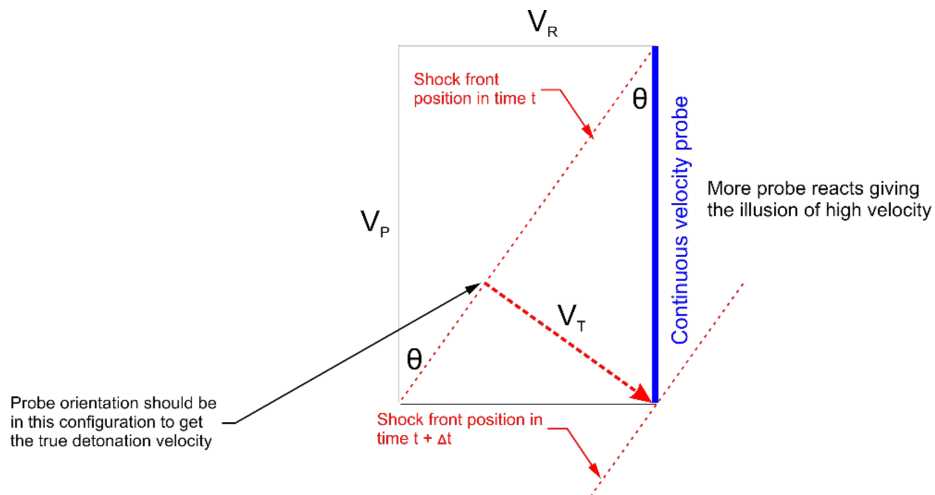


Figure 6 - Priming shock wave orientation diagram showing the orientation of the shock wave (red) with respect to the VoD probe (blue). This unit charge is based on velocity vectors for both primacord and an emulsion. It is easily seen that the continuous velocity probe is oriented in the wrong direction and will always give higher VoD readings.

A continuous velocity probe configuration shown in Figures 6 and 7 shows cutaway views and close-ups of the incorrect VoD measurement probe orientation (blue) with respect to the orientation (red) that should be used for determining the VoD of the primacord and explosive axial priming configuration.

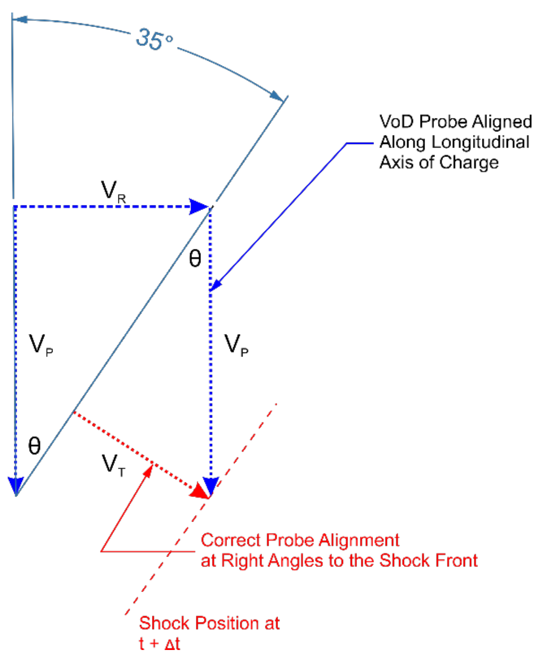


Figure 7 - Velocity vectors associated with axial Initiation showing the resultant shock front. It should be noted that the detonation velocity should be measured perpendicular to the resultant. V_R is the radial velocity of the cord sensitive explosive charge and V_P is the detonation velocity of the detonating cord.

To get an accurate reading of the true velocity of detonation of an explosive using axial priming, the measurement probe must be placed perpendicular to the shock front. In the above case of Figures 6 and 7, the velocity probe should be at right angles to the resultant illustrated by the shock wave direction arrow (red) above. Note that the velocity vector for the axially primed explosive is 90 degrees to the resultant during the time interval t, t + Δt.

Using Figures 6 and 7 to visualize the roles of det cord and emulsion explosive, it would be interesting to determine the true detonation velocity with a velocity vector that is perpendicular to the shock front generated by the det cord and emulsion explosive combination. There would be two cases – case 1 for the emulsion explosive detonating with the velocity normal to its package diameter and case 2 – with a run-up velocity considered to be one-half the velocity normal to its package diameter.

Case 1 - Axial Initiation Solutioin Using the Detonation Velocity of an Emulsion with a Velocity of 5000 m/s

$V_R := 5000 \cdot \frac{m}{s}$ $\qquad V_P := 7000 \cdot \frac{m}{s}$

$$tan(\theta) := \frac{V_R}{V_P} = 0.714$$

Angle formed by these two vectors

$$\theta := \text{atan}\left(\frac{V_R}{V_P}\right) = 0.62$$

$$\theta = 35.538\ deg$$

The true detonation velocity obtained with a VoD probe perpendicular to the resultant shock front is;
Probe placed at the side of the blasthole wall will read **VX - 8602 m/s**

$V_T := \sin(\theta) \cdot V_P = (4.069 \cdot 10^3)\ \frac{m}{s}$ $\qquad V_X := \sqrt[2]{7000^2 + 5000^2}$ $\qquad V_X = 8.602 \cdot 10^3$

Case 2 - Axial Initiation Solutioin Using the Detonation Velocity of an Emulsion with a Run-Up Velocity of 2500 m/s

$V_R := 2500 \cdot \frac{m}{s}$ $\qquad V_P := 7000 \cdot \frac{m}{s}$

$$tan(\theta) := \frac{V_R}{V_P} = 0.357$$

Angle formed by these two vectors

$$\theta := \text{atan}\left(\frac{V_R}{V_P}\right) = 0.343$$

$$\theta = 19.654\ deg$$

The true detonation velocity obtained with a VoD probe perpendicular to the resultant shock front is;
Probe placed at the side of the blasthole wall will read **VY - 7433 m/s**

$V_T := \sin(\theta) \cdot V_P = (2.354 \cdot 10^3)\ \frac{m}{s}$ $\qquad V_Y := \sqrt[2]{7000^2 + 2500^2}$ $\qquad V_Y = 7.433 \cdot 10^3$

As the velocity of detonation of the emulsion decreases, the oblique shock front velocity will also decrease. The result is that the corresponding borehole pressure will also be lower.

Synopsis for Using Axial Priming Methodology or Tracing Explosive Loaded Blastholes:

1. **For the examples used in this article with a det cord detonating at 7000 m/s and used to initiate a traced explosive small diameter detonator sensitive emulsion charge that has no run-up and detonates at 5000 m/s, the detonation velocity of the resulting oblique shock wave will be 4069 m/s. Borehole pressure will be decreased.**
2. **Similarly, for the case in which the run-up velocity is 2500 m/s, the detonation velocity of the oblique shock wave will be reduced to 2354 m/s along with a much-reduced borehole pressure.**
3. **Obviously, this priming arrangement should not be used in production blast holes.**

Notes:

1. **Axial priming produces a shock wave front that is oblique to the longitudinal axis of a blasthole loaded with explosives**
2. **The detonation velocity of the oblique shock front will always be less than the detonation velocity measured along the longitudinal axis of a blasthole**
3. **Borehole pressures will be lower when axial priming is used in a blasthole**
4. **Axial priming that generates lower borehole pressures will have application in pre and post splitting, as well as reducing potential damage to perimeters next to hanging walls**
5. **Using axial priming in production blasting operations generates coarser muck material and should not be used in this manner.**

Some General Rules for Priming Explosive Columns

1. **Place primers at locations that are farthest away from any free face so that an explosive can perform the most work**
2. **Direction of blast motion should be at maximum burden distance, normal to the slot and away from any path of least resistance**
3. **Avoid priming near the collar region since cracks will grow from this position to the nearest free face – gasses will naturally follow this path of least resistance**
4. **An example – never prime drift rounds in the collar since cratering and bootlegs will result – in SLC, resist the temptation to pre-load since primers cannot be pushed far into the explosive column from the collar**
5. **If loading conditions are poor, additional primers provide cheap insurance when there are gaps in an explosive column – the use of a cheap borehole camera mounted on a sidewinder may provide a means to locate bad structures**
6. **If cord downlines are used - ensure that the cord strength will initiate primers without destroying them first**
7. **Some primers have designs that include special tunnels that allow multiple primers to be loaded on a single downline – make sure that the correct strength downline is used**
8. **Do not use axial initiation in production blastholes since the resultant velocity of the traced explosive will be lower than the velocities produced by normal column priming practices**