2005 National Quarry Academy

Golden, Colorado

October 31 to November 3, 2005

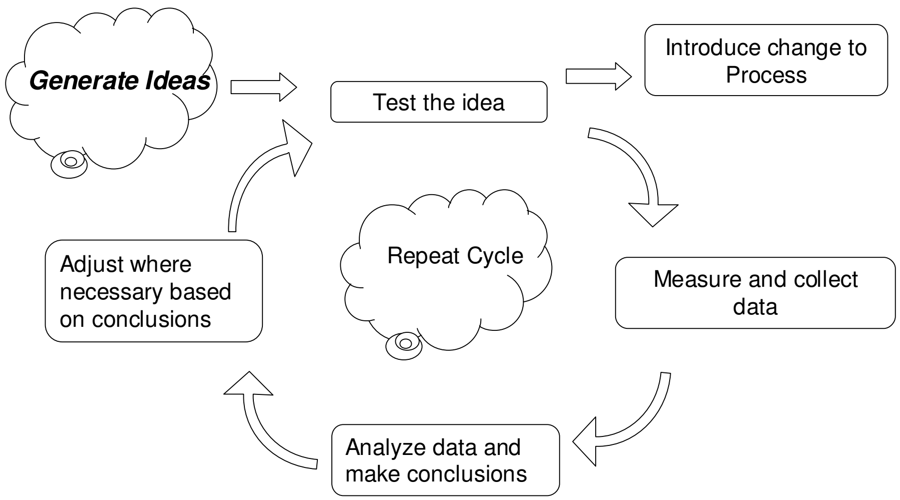
Blast Management

L. Mirabelli
Senior Technical Consultant
DynoConsult
A Service Division of Dyno Nobel Inc.

Blast Management

Continuous Improvement makes successful change!

- **Process**



- **Attitude**
  - ✓ **Proactive**
  - ✓ **“Do it right today.”**
  - ✓ **“Do it better tomorrow.” and**
  - ✓ **“Whatever you do. Track metrics and pay attention to details.”**

Blast Management

Details of Blast Design

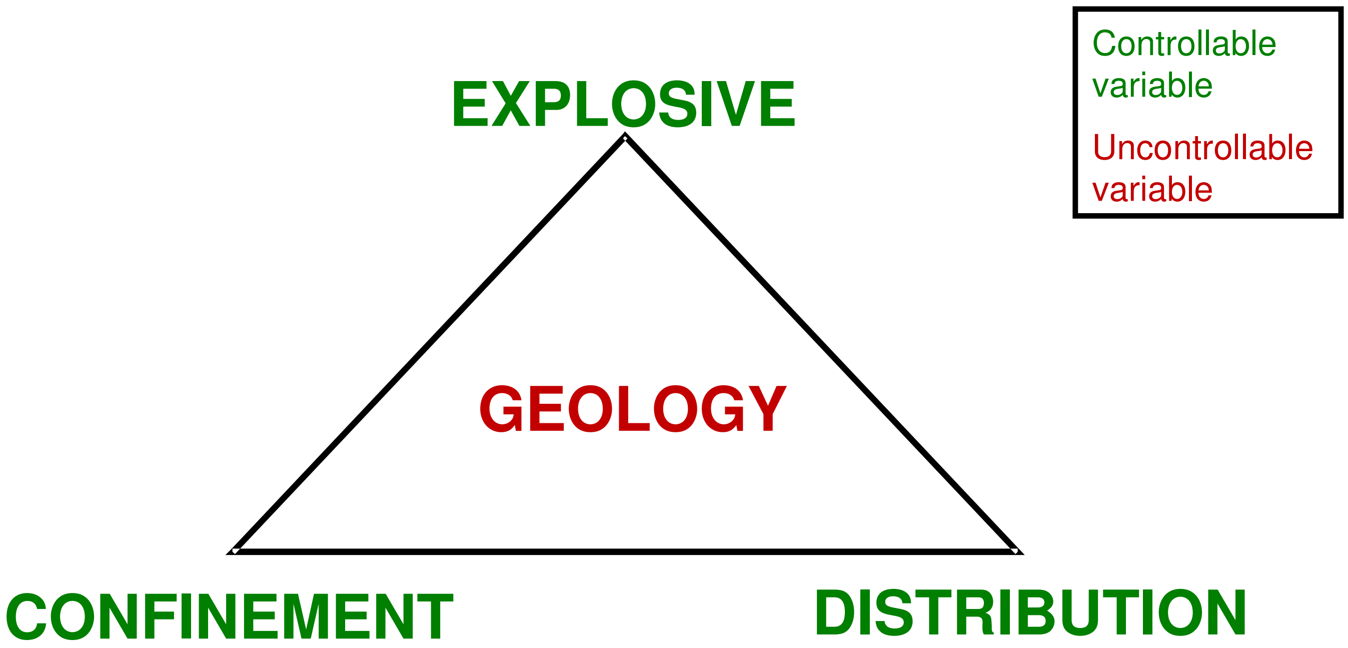
- Geology
- Explosive
- Hole diameter
- Burden
- Spacing
- Bench height
- Hole depth & inclination
- Subdrill
- Drill pattern
- Stemming & Inert decking
- Powder Factor
- Energy Factor
- Initiation sequencing
- Hole timing
- Environmental effects
  - ✓ Vibration and Air Overpressure
  - ✓ Fumes & Dust

Blast Management

Blast Design Variables

Blast Management

Blast Design Variables



Blast Management

Explosive – A controllable variable in blast design

- **What explosive is chosen to be used.**
  - ✓ **Density**
  - ✓ **Velocity of Detonation**
  - ✓ **Energy**
  - ✓ **Water Resistance**
  - ✓ **Form**
    - Package
    - Bulk
      - Dry Blend/Free Flowing
      - Wet Blend/Augerable
      - Pumpable Blend

Blast Management

Confinement – A controllable variable in blast design

- **How the explosive energy is confined so that it can do work.**
  - ✓ **Amount of material surrounding the explosive in the drill hole**
    - Material between the drill hole and any dynamic or static free space.
  - ✓ **Distance of the drill hole from an open face.**
    - Burden
  - ✓ **Distance of drill holes relative to one another.**
    - Burden
    - Spacing
  - ✓ **Type and amount of stemming**

Blast Management

Distribution – A controllable variable in blast design

- **How the explosive energy is distributed throughout the rock mass – vertically and horizontally.**
  - ✓ **Diameter of the drill hole.**
    - Limiting the diameter of explosive.
  - ✓ **Diameter of the explosive.**
    - In the case of package explosives.
  - ✓ **Depth of the drill hole and the amount loaded.**
  - ✓ **Spacing of the drill holes**

Blast Management

Geology - uncontrollable variable in blast design

- Properties of blasted rock mass can change: between pits; within a pit; between bench levels; even within a bench.
  - ✓ Density
  - ✓ Hardness
  - ✓ Jointing
  - ✓ Bedding
  - ✓ Mean Block Size
  - ✓ Voids & Caves

Blast Management

The Explosive Energy Balance

- In blasting work explosives are detonated releasing their chemical energy. Energy must go somewhere.
  - ✓ Energy – Fragmentation
  - ✓ Energy – Moving and Heaving the rock
  - ✓ Energy – Ground Vibration
  - ✓ Energy – Air Overpressure

Blast Management

Best Practice starting points for basic Blast Design

Quarrying	*Units*	*Rules of Thumb*	*Best practices*
Burden (B)	ft	(range 25 to 35) x D_e /12	([P_e x 2 / P_r]+1.8) x D_e
Spacing (S)	ft	(range 1 to 1.8) x B	1.15 x B
Bench Height (H)	ft	10 x D_e	3 x B (or greater)
Minimum Bench Height (H_m)	ft	2 x B	2 x B
Subdrill (J)	ft	(range 0.2 to 0.5) x B	0.2 x B
Stemming (T)	ft	(range 0.7 to 1.3) x B	24 x D_e / 12
Inert Decking (T_{dd})	ft	6 x D_e / 12 (dry hole)	8 x D_e / 12
Inert Decking (T_{dw})	ft	12 x D_e / 12 (wet hole)	16 x D_e / 12
Bottom Charge (E_b)	ft	[(range 0.3 to 0.5) x B] + J	
Charge Length (C_l)	ft	H + J - T	[(H + J) / cosine A_b] – [J + T]
Powder Factor (PF)	tons / lb.	2.5 to 1.25	2.2
Where:			
Diameter of charge (D_e)	in		
Density of rock (P_r)	g/cc		
Density of explosive (P_e)	g/cc		
Borehole Angle (A_b)	° off vertical		

Blast Management

Keys to Optimizing Explosive Performance

- **Choose Optimum Explosive Type.**
- **Optimize the distribution of the explosive's energy.**
- **Optimize confinement of the explosive's energy.**

Blast Management

Keys to Optimizing Explosive Performance

- **Choose Optimum Explosive Type**
  - ✓ **For Primer make-up and/or Main Explosive Charge**
    - Critical diameter
    - Density
    - Sensitivity
    - Sensitiveness
    - Water resistance
    - Detonation velocity
    - Detonation pressure
    - Energy
    - Storage, Transportation and Loading/Handling.
  - ✓ **Initiation System**
    - Type signal
    - Timing options
      - Fixed
        - » Number of delay periods
      - Programmability
    - Accuracy/Precision
    - Storage, Transportation and Loading/Handling

Blast Management

Keys to Optimizing Explosive Performance

- **Explosive Energy Distribution Optimization**
  - ✓ Increased distribution reduces overall rock fragment size.
  - ✓ Decreased distribution increases overall rock fragment size.
  - ✓ Even distribution achieves uniform fragmentation.
  - ✓ Important to maintain even distribution from top to bottom of bench.
  - ✓ Widely spaced jointed rock mass requires reduced patterns

Blast Management

Keys to Optimizing Explosive Performance

Explosive Distribution

Hole Diameter (in)	4	6	7	9
Bench height (ft) [H]	40	40	40	40
Burden (ft) [B]	10	15	17	21
Spacing (ft)	12	17	20	26
Stemming (ft) [T]	7	10.5	12	15
Subdrill (ft)	3	4.5	5	6.5
Explosive	ANFO	ANFO	ANFO	ANFO
Powder Factor (tons/lb.)	2.02	2.02	2.03	2.07
Bench Stiffness (H/B)	4	2.7	2.4	1.9
Explosive Distribution (1-T/H)x100	83%	74%	70%	63%
Energy Factor (kcal/ton)	200	200	199	195
Fragmentation F80*	25 inch	29 inch	29.5 inch	31 inch

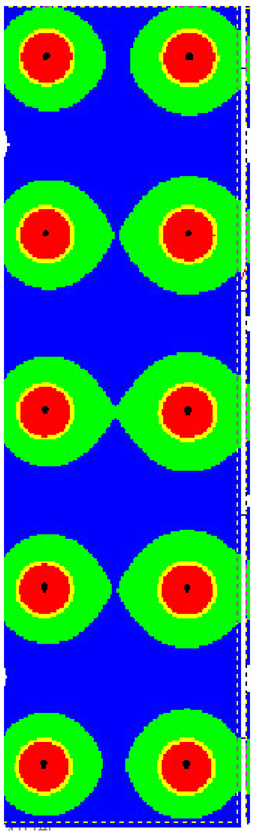
Equivalent Powder Factor or Energy Factors ≠ Equivalent Explosive Distribution

*more dramatic change in uniformity.

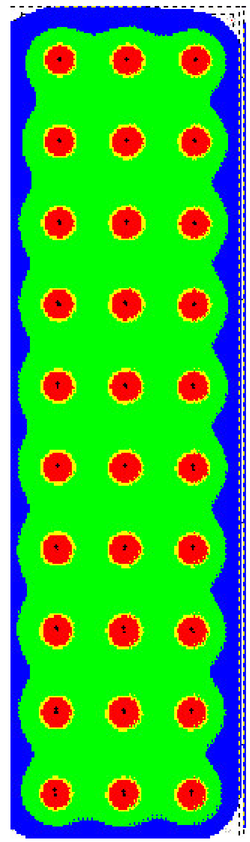
Blast Management

Energy Distribution Comparison – Planar

9 inch, 21ft x 26 ft

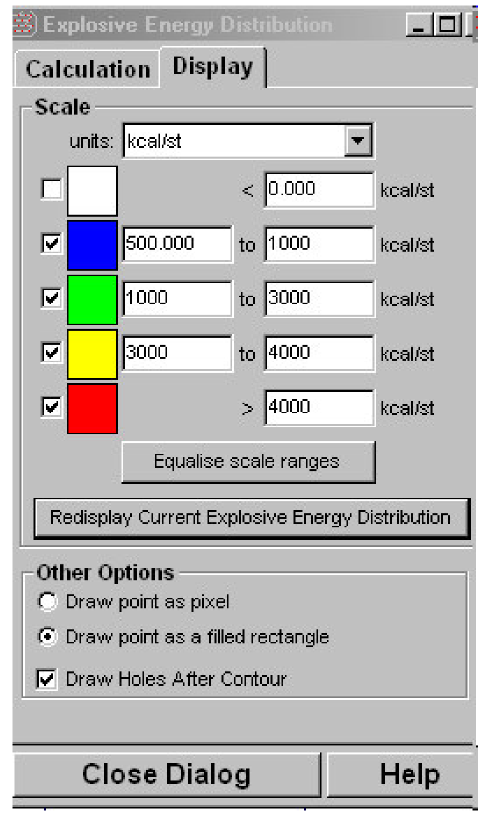


4 inch, 10 ft x 12 ft



Horizontal slices of bench @ 32 ft down from surface

Equivalent overall powder factors



Blast Management

Keys to Optimizing Explosive Performance

- **Explosive Energy Confinement Optimization**
  - ✓ **Explosive Energy must be confined long enough after detonation to establish fractures and displace rock.**
    - Design timing to provide adequate relief without loss of confinement.
  - ✓ **Control paths of least resistance for explosive energy**
    - load according to geology and face conditions
    - use adequate and proper stemming materials
  - ✓ **Accurately layout and drill the blast pattern**
  - ✓ **Remember:**
    - over confinement = excessive vibration
    - under confinement = excessive air blast

Blast Management

Explosive Types – Main Explosive Charge

- **Bulk Explosive**
  - ✓ **Blasting Agent, 1.5 D (not detonator sensitive)**
    - ANFO
    - Heavy ANFO Blend
      - Water gel
      - Emulsion
    - Repumpable ANFO Blend
      - Water gel
      - Emulsion (available with field density adjustment)
    - Repumpable
      - Water gel
      - Emulsion (available with field density adjustment and/or homogenization)

Blast Management

Explosive Types – Main Explosive Charge

- **Package Explosive**
  - ✓ **Explosive, 1.1 D (detonator sensitive)**
    - Dynamite
    - Emulsion
  - ✓ **Blasting Agent, 1.5 D (not detonator sensitive)**
    - ANFO, ANFO WR
    - Water gel
    - Emulsion

Blast Management

Explosive Types – For use in primer make-up

- **Package Explosive**
  - ✓ **Explosive, 1.1 D (detonator sensitive)**
    - Dynamite
    - Emulsion
    - Cast Boosters

Blast Management

Explosive Types – Initiation System

- **Electric**
  - ✓ **Copper leg wires**
  - ✓ **Millisecond delay period detonators**
  - ✓ **Blasting Equipment**
    - Standard Capacitor Discharge Blasting Machine
    - Sequential Capacitor Discharge Blasting Machine
- **Nonelectric**
  - ✓ **NONEL**
    - Shock tube lead
    - Millisecond delay period detonators – surface and in-hole
  - ✓ **Miniaturized Detonating Cord/Nonel**
    - Low core load detonating cord
    - Millisecond delay period detonators – surface and in-hole

Blast Management

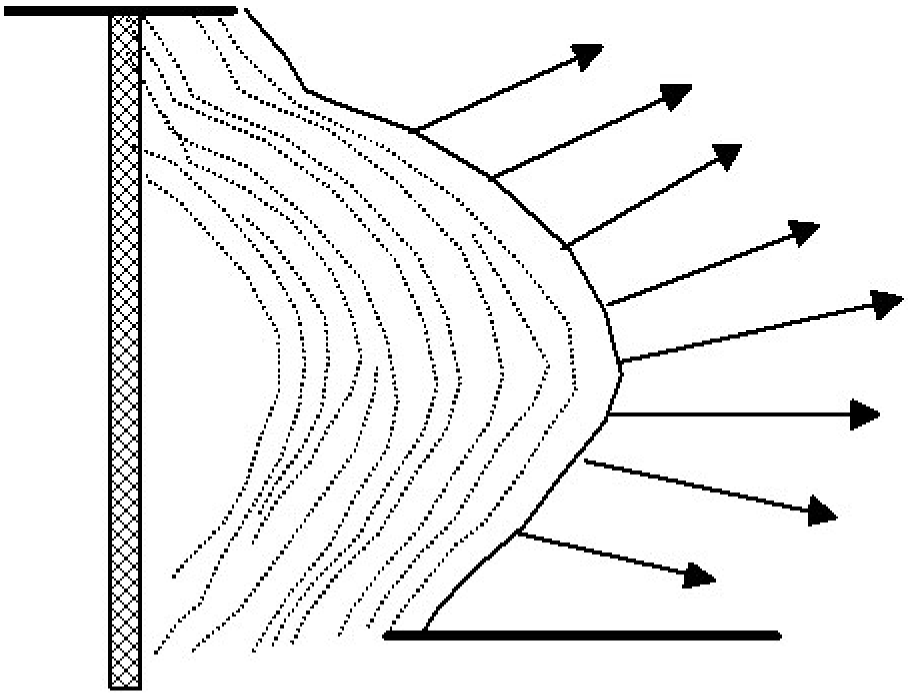
Explosive Types – Initiation System (continued)

- **Electronic**
  - ✓ **Copper leg wires**
  - ✓ **Field programmable precision delay detonators**
  - ✓ **Nonexplosive accessories**
    - Wire, connectors, controllers etc
  - ✓ **Computer testing, programming and blasting equipment.**
- **Nonelectric Electronic**
  - ✓ **Shock tube lead**
  - ✓ **Factory programmed precision delay detonators**
    - In-hole
    - Surface Delay

Blast Management

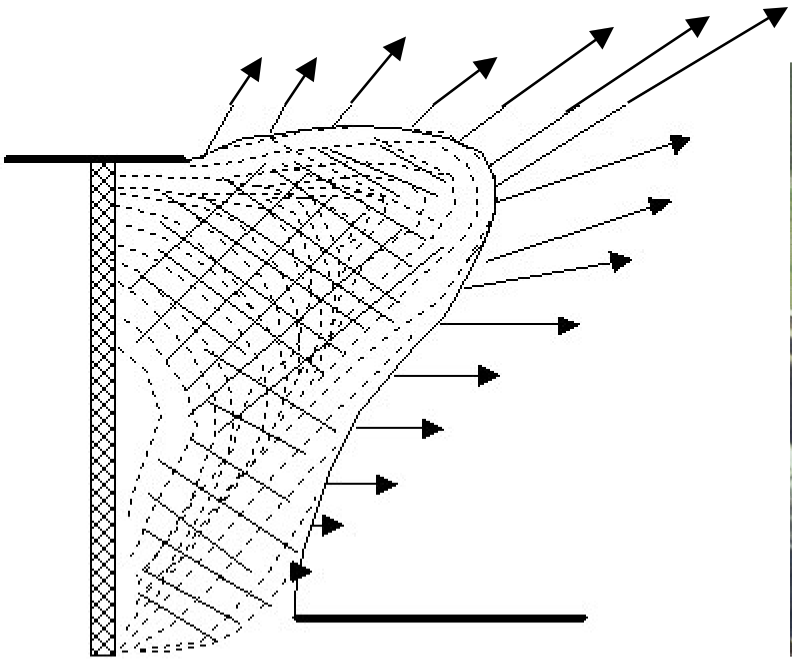
Optimizing Explosive Energy Confinement

Adequate Confinement
Proper Face Movement



Blast Management

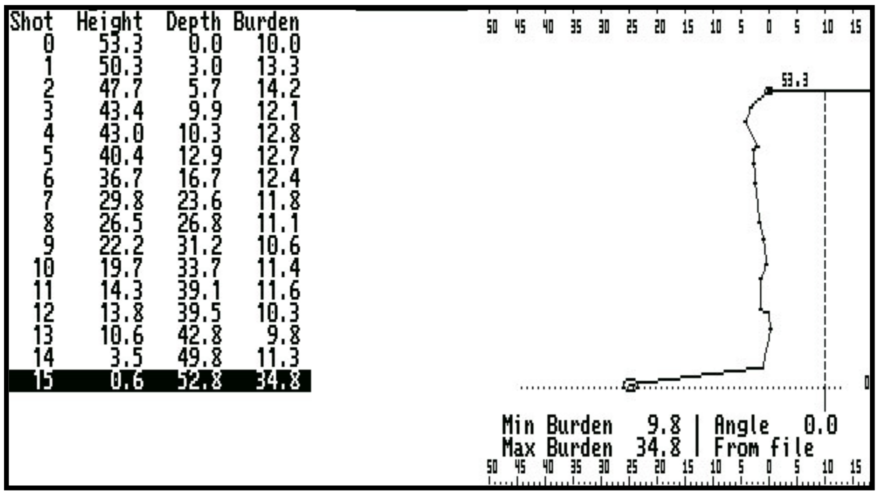
Optimizing Explosive Energy Confinement



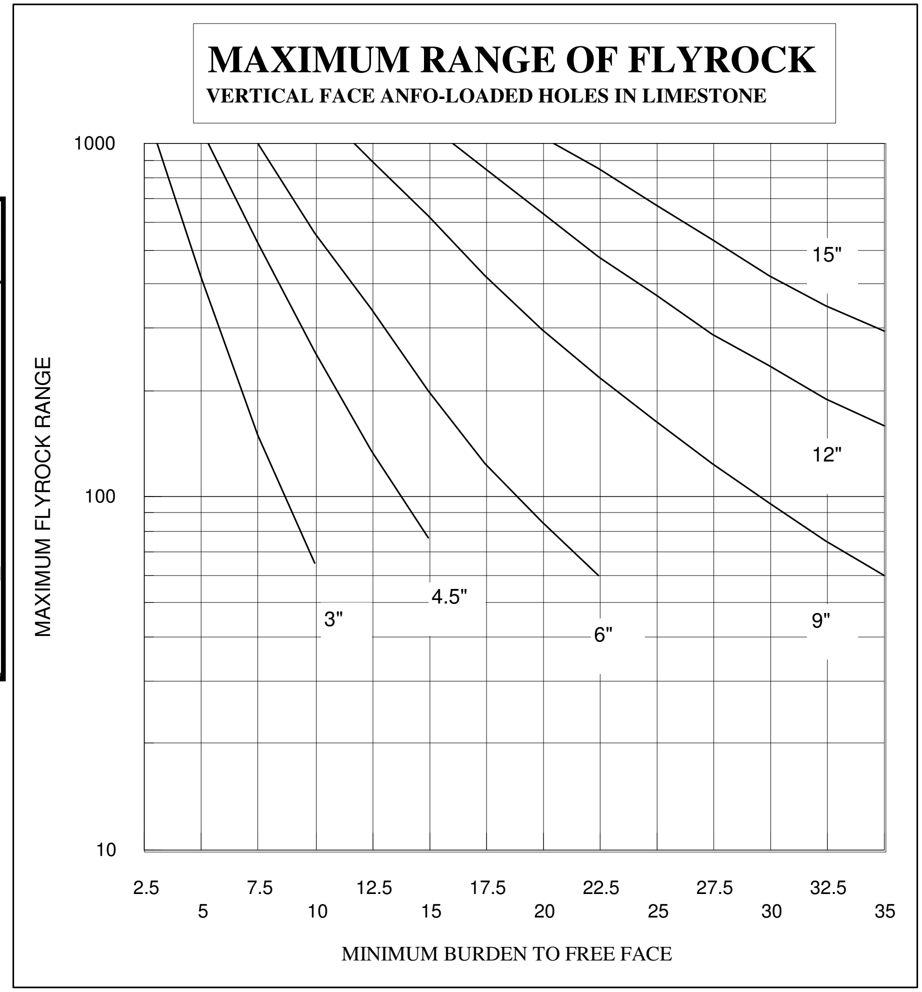
Inadequate Confinement
Improper Face Movement

Blast Management

Flyrock Nomograph
Limestone



Shot	Height	Depth	Burden
0	53.3	0.0	10.0
1	50.3	3.0	13.3
2	47.7	5.7	14.2
3	43.4	9.9	12.1
4	43.0	10.3	12.8
5	40.4	12.9	12.7
6	36.7	16.7	12.4
7	29.8	23.6	11.8
8	26.5	26.8	11.1
9	22.2	31.2	10.6
10	19.7	33.7	11.4
11	14.3	39.1	11.6
12	13.8	39.5	10.3
13	10.6	42.8	9.8
14	3.5	49.8	11.3
15	0.6	52.8	34.8



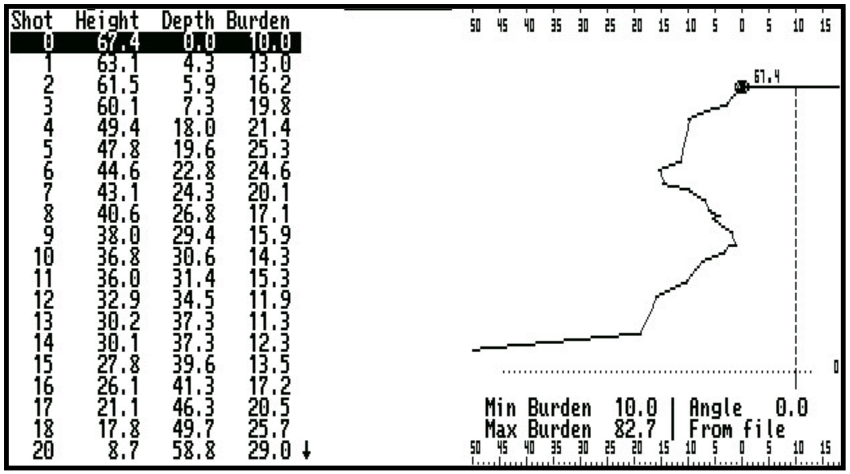
Example:

5.5” diameter hole planned for 13 ft burden

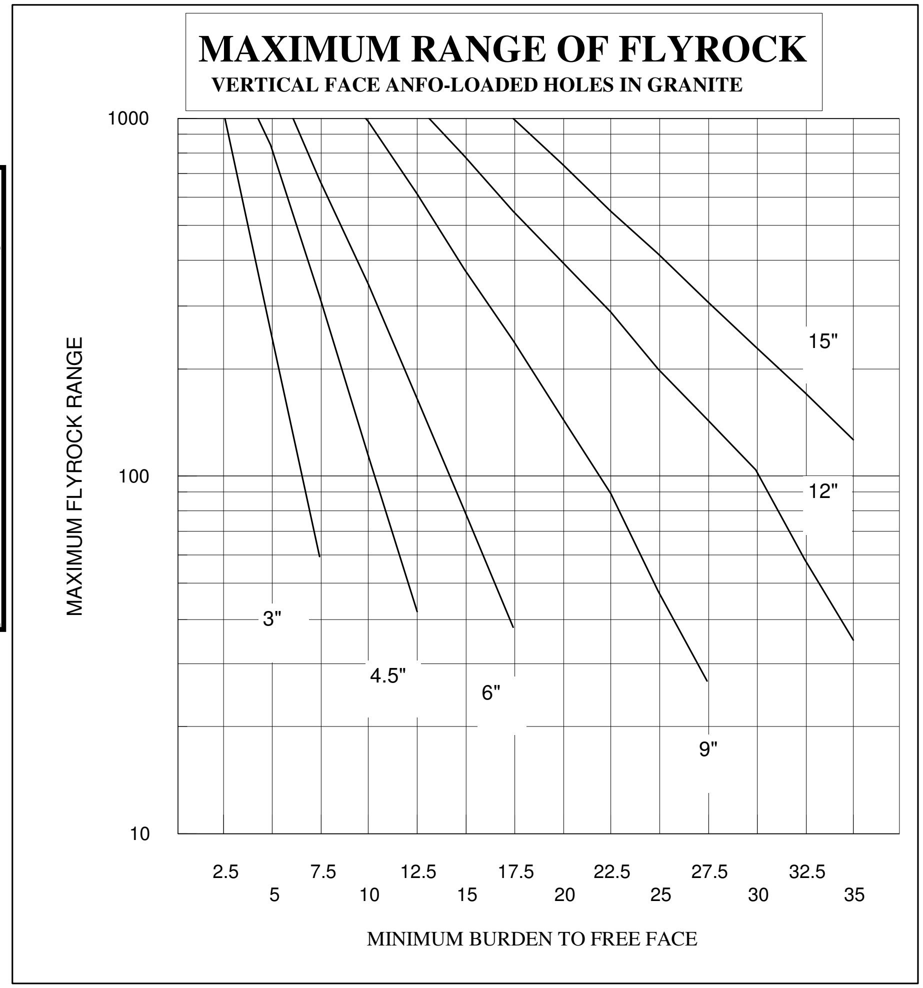
@ 43 ft depth likelihood of ~450 ft flyrock distance.

Blast Management

Flyrock Nomograph
Granite



Shot	Height	Depth	Burden
0	67.4	0.0	10.0
1	63.1	4.3	13.0
2	61.5	5.9	16.2
3	60.1	7.3	19.8
4	49.4	18.0	21.4
5	47.8	19.6	25.3
6	44.6	22.8	24.6
7	43.1	24.3	20.1
8	40.6	26.8	17.1
9	38.0	29.4	15.9
10	36.8	30.6	14.3
11	36.0	31.4	15.3
12	32.9	34.5	11.9
13	30.2	37.3	11.3
14	30.1	37.3	12.3
15	27.8	39.6	13.5
16	26.1	41.3	17.2
17	21.1	46.3	20.5
18	17.8	49.7	25.7
20	8.7	58.8	29.0



Example:

6.5” diameter hole planned for 16 ft burden

@ 37 ft depth likelihood of ~400 ft flyrock distance.

Blast Management

Stemming

Inert material loaded on top of an explosives column in a blasthole. Stemming provides for explosives energy confinement and best blasting results.

For stemming use angular stone with mean size 12.5 % of diameter of the drill hole.

- **70% of the Burden**
  - ✓ **When using the same delay for the top and bottom primer in a hole or when initiating from the top of the column**
- **50% of the Burden**
  - ✓ **When using a later delay in the top of the column.**

Blast Management

Stemming

The amount of broken material in the bench top needs to be accounted for to maintain confinement and control flyrock

STEMMING CONVERSION CHART

NORMAL STEMMING HEIGHT

DEPTH OF BROKEN, LOOSE, OR ANY UNCONSOLIDATED MATERIAL	4	5	6	7	8	9	10	11	12	13	14	15
1	5	6	7	8	9	10	11	12	13	14	15	16
2	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5
3	6	7	8	9	10	11	12	13	14	15	16	17
4	7	8	9	10	11	12	13	14	15	16	17	18
5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5
6	8	9	10	11	12	13	14	15	16	17	18	19
7	9	10	11	12	13	14	15	16	17	18	19	20
8	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5
9	10	11	12	13	14	15	16	17	18	19	20	21
10	11	12	13	14	15	16	17	18	19	20	21	22
11	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	21.5	22.5
12	12	13	14	15	16	17	18	19	20	21	22	23
13	13	14	15	16	17	18	19	20	21	22	23	24
14	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5	24.5
15	14	15	16	17	18	19	20	21	22	23	24	25
16	15	16	17	18	19	20	21	22	23	24	25	26
17	15.5	16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5	24.5	25.5	26.5
18	16	17	18	19	20	21	22	23	24	25	26	27
19	17	18	19	20	21	22	23	24	25	26	27	28
20	17.5	18.5	19.5	20.5	21.5	22.5	23.5	24.5	25.5	26.5	27.5	28.5

NOTE: STEM HEIGHTS FOR END HOLES SHOULD BE INCREASED TO 100% OF THE BURDEN.

Blast Management

Blast Vibration and Overpressure Control

- Monitor, Monitor, Monitor…Analyze, Analyze, Analyze
- Develop & maintain site constants for use in estimating blast vibration.
- In vibration sensitive areas limit pounds per delay
  - ✓ Reduce borehole size
  - ✓ Use multiple explosive decks in blast holes. (adjust pattern)
  - ✓ Limit number of rows.
- Use quality stemming material, proper amounts and stemming plugs to control overpressure.
- Avoid blasting in overcast, during temperature inversion or other weather conditions that can increase overpressure.

Blast Management

Blast Vibration and Overpressure Control

- Limit total blast duration to less than 750ms.
- Map resultant vibrations in areas around perimeter of property to identify anomalies.
- Use wave superposition models to develop and evaluate alternative blast initiation sequences that will shift wave frequencies and limit Peak Particle Velocity (PPV)
  - ✓ Consider electronic detonators to apply non conventional blast design delays.

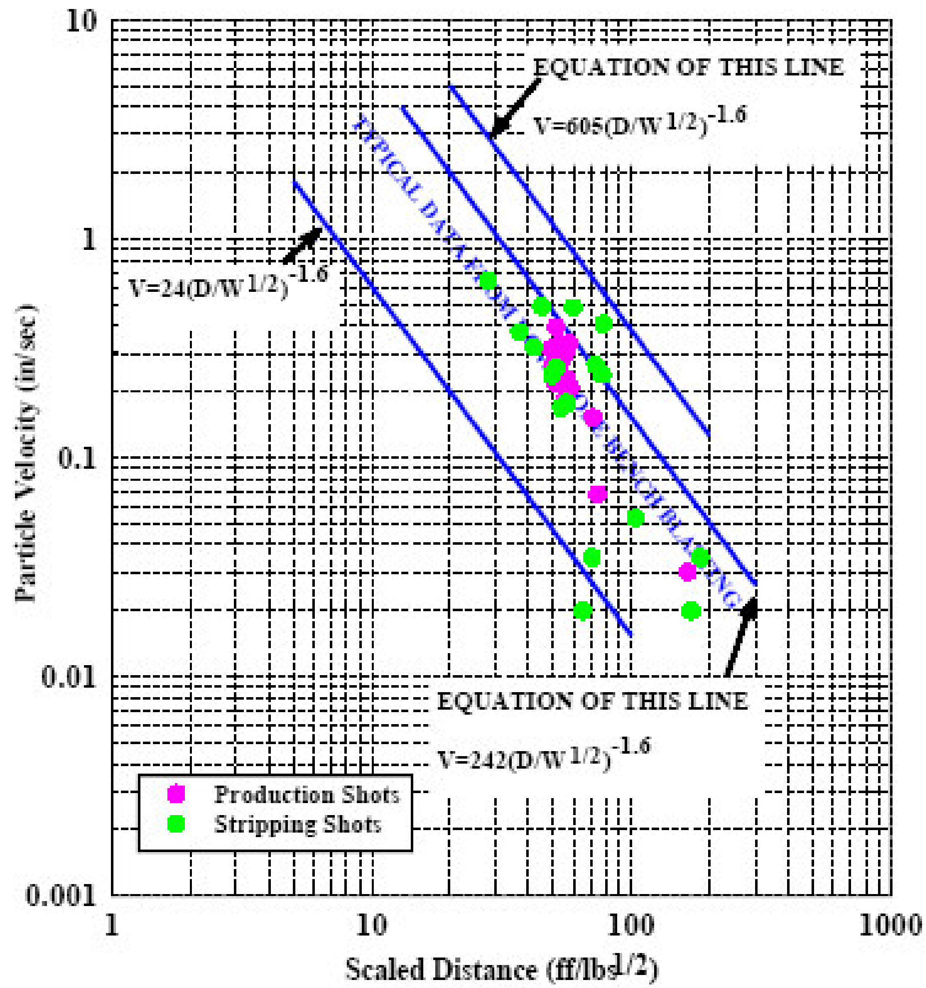
Blast Management

Blast Vibration

Oriard's equations for estimating ground vibrations (PPV) from typical blasting operations using square root scale distance.

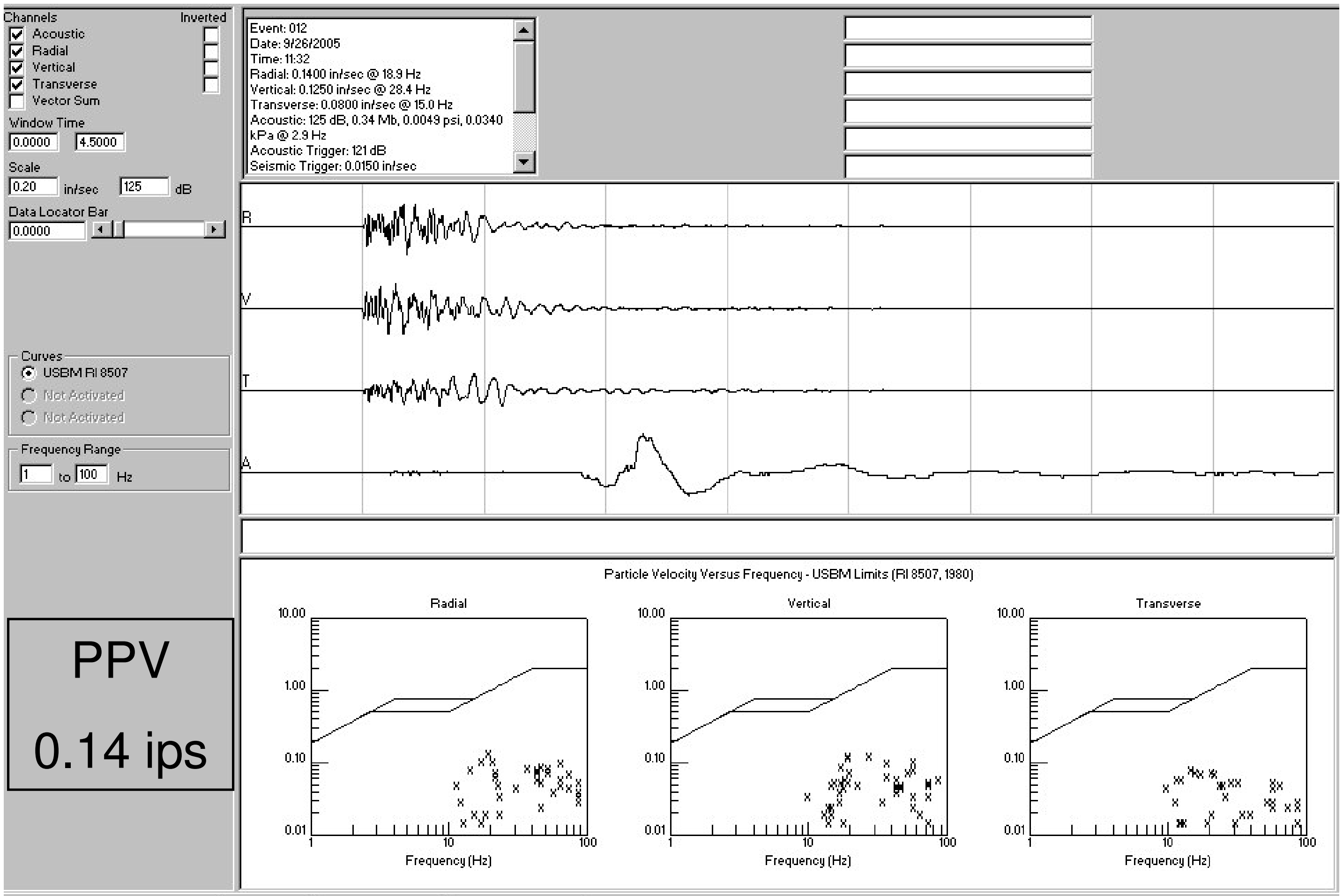
Scale Distance:

$$\frac{\text{Distance in feet to seismograph}}{\sqrt{\text{Pounds of explosive per 8 ms delay increment.}}}$$



Blast Management

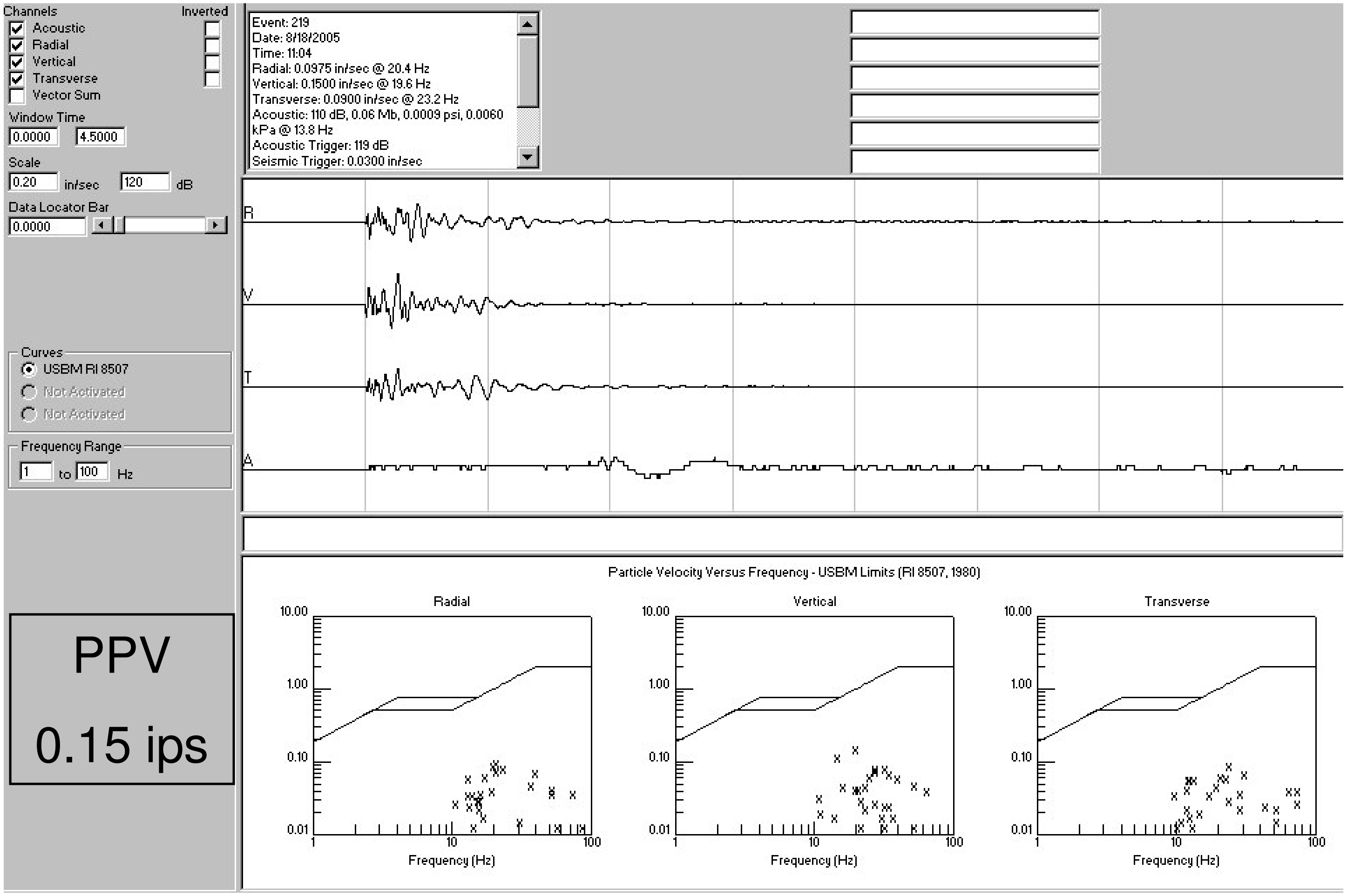
Seismograph Record – Production Blast



Quarry Academy 2005

Blast Management

Seismograph Record – Single Blasthole



Blast Management

Synthesized Seismograph Records – Model Outputs