

Tunnelling – Selected Topics

Tunnel Blast Design

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Joint Technical Seminar by AGS(HK), HKIE (Geotechnical Working Group on Cavern & Tunnel Engineering) & HKTS

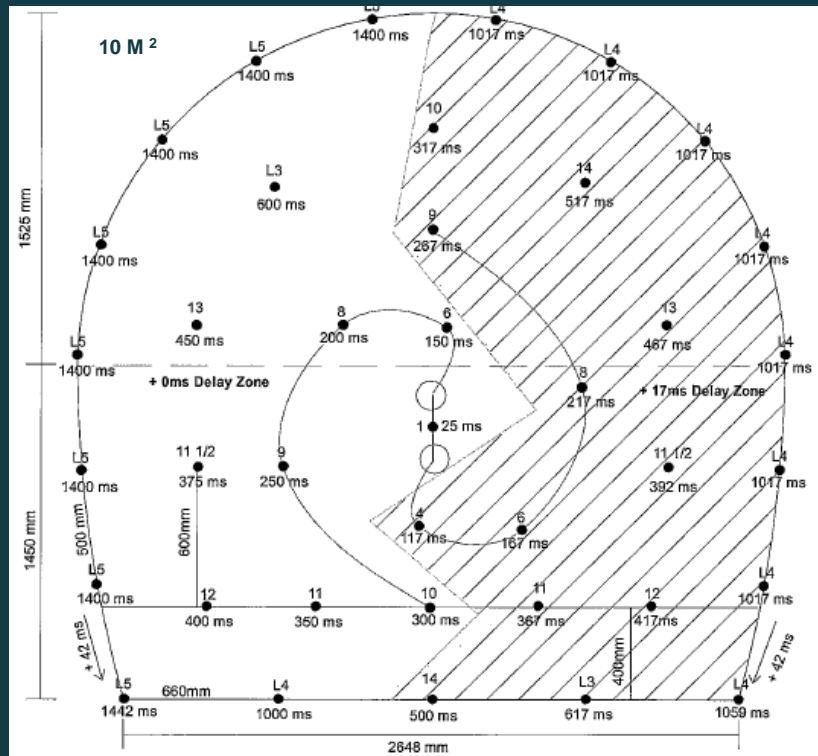
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Key Tunnel Blast Design Parameters

- **M² Face Area**
- **Tunnel Diameter**
- **Profile (Shape)**
- **Rock Type & Quality**
- **Blasthole Diameter**
- **Cut Configuration**
- **Burden & Spacing**
- **Allowable Maximum Instantaneous Charge (MIC)**
- **Available Delay Range of Non-Electric Detonators**
- **Delay Sector Initiation Sequence**

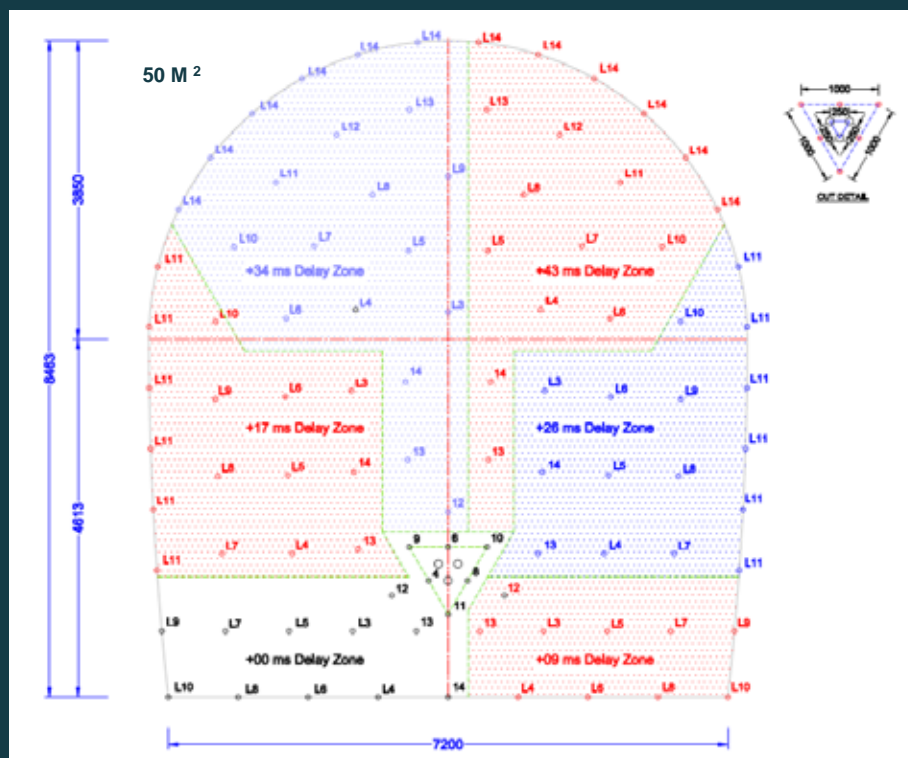
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Small Diameter Water Tunnel



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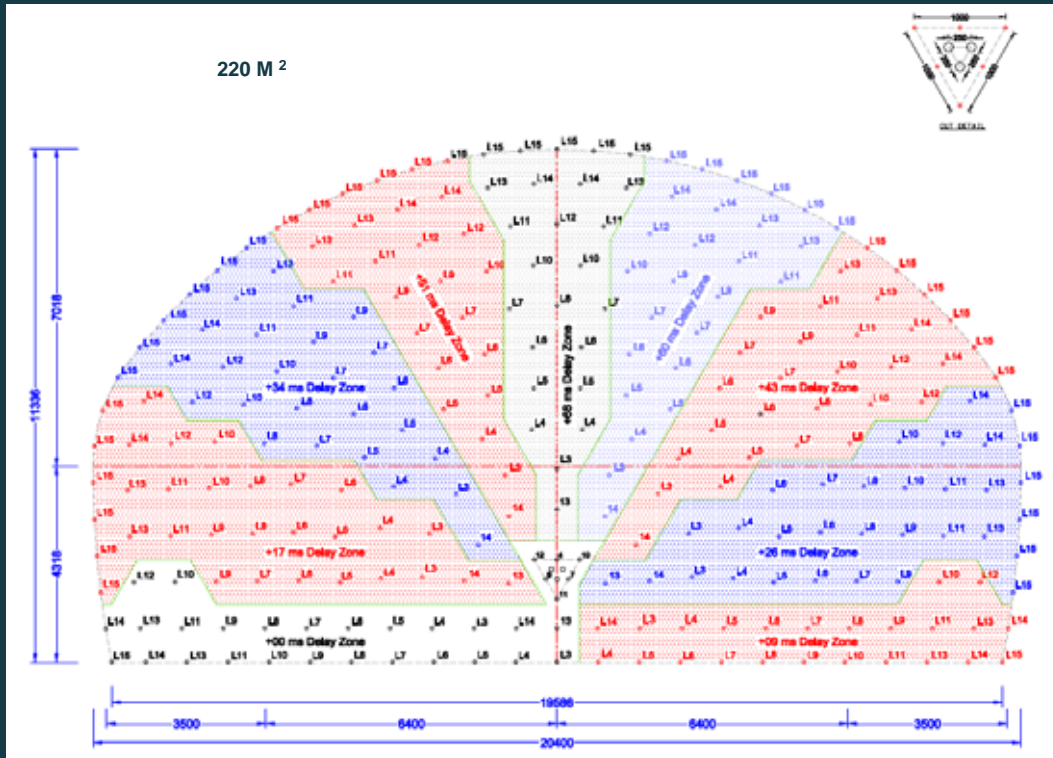
Single Track Running Tunnel With Services



Courtesy of Brandrill Engineering (HK) Limited

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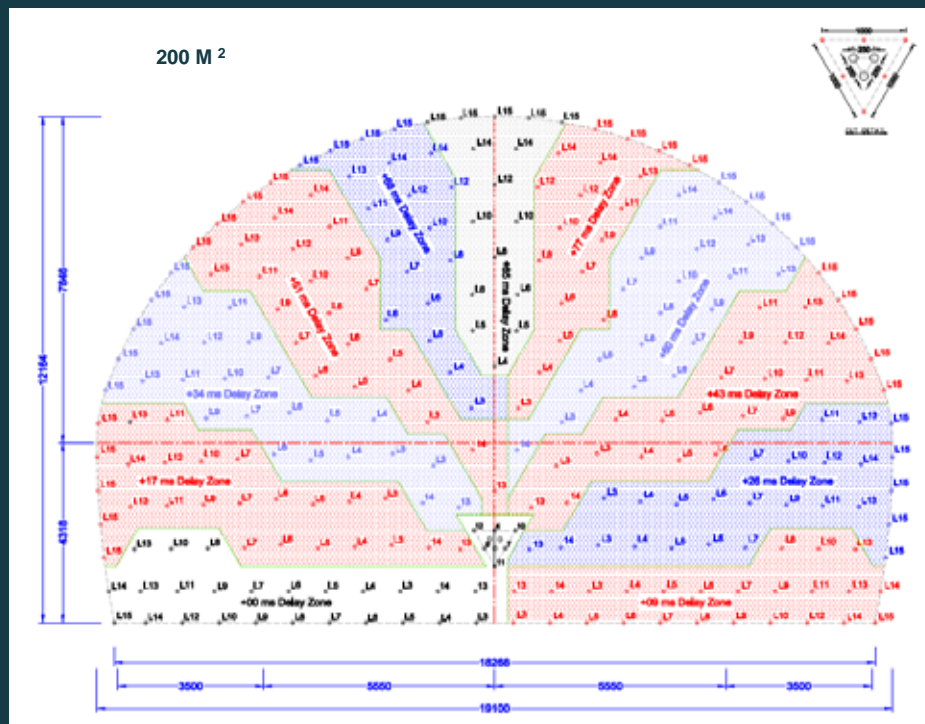
Single Tube - 3 Lane Road Tunnel



Courtesy of Brandrill Engineering (HK) Limited

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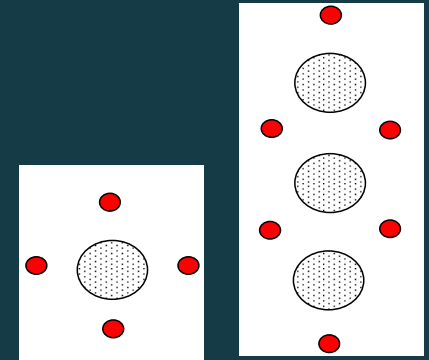
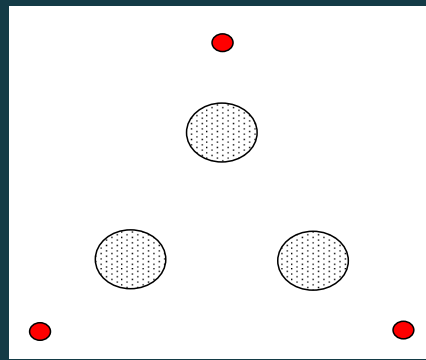
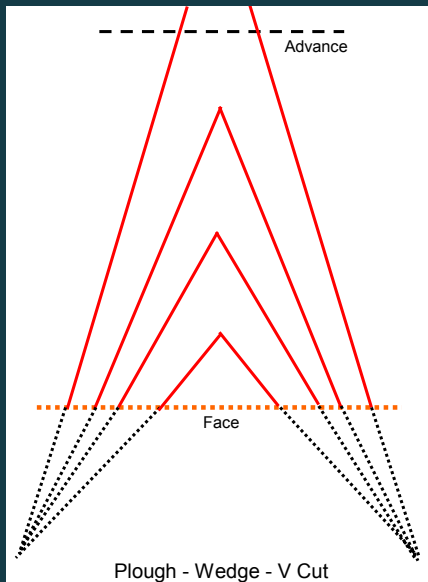
Rail Cross-Over Tunnel



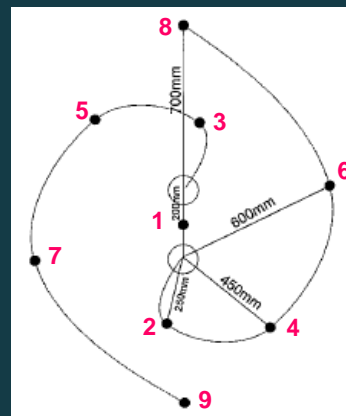
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Blast Face Cut Types



Burn Cut Types



Spiral Burn Cut

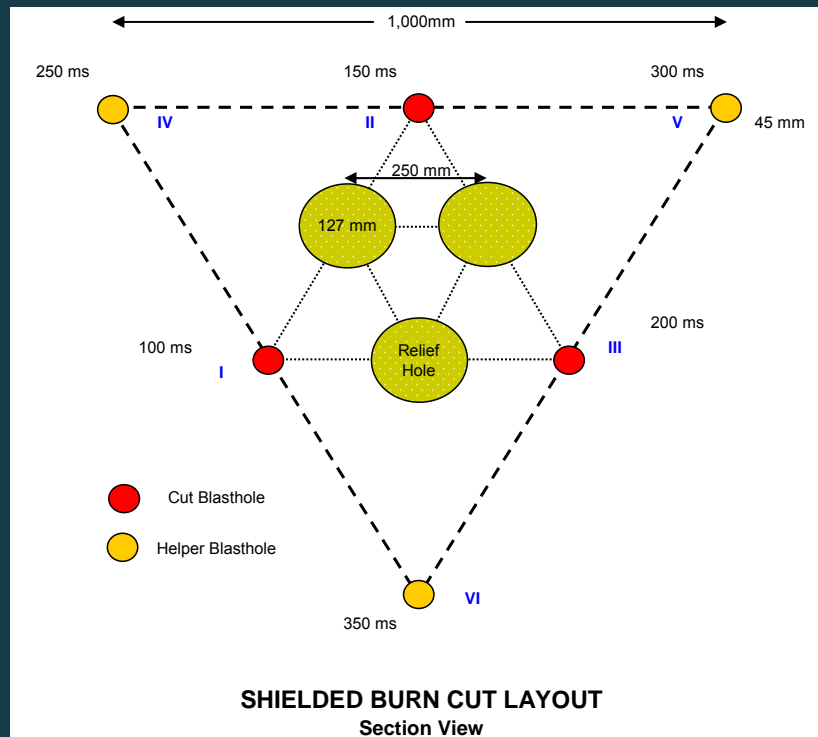
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Most Common Cut Types

- **Wedge Cuts** are largely banned in numerous operations as they eject rock violently, the rock is thrown a considerable distance resulting in services being destroyed e.g. ventilation, power, air and communications.
- **Frequently preferred cut type is the Burn Cut**
 - Numerous variations exist and this is largely a 'personal preference' of the Blasting Engineer or Shotfirer.

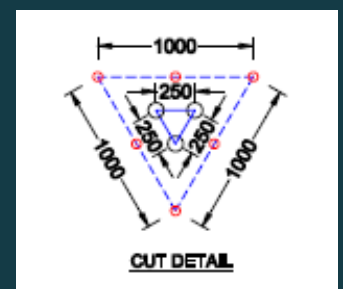
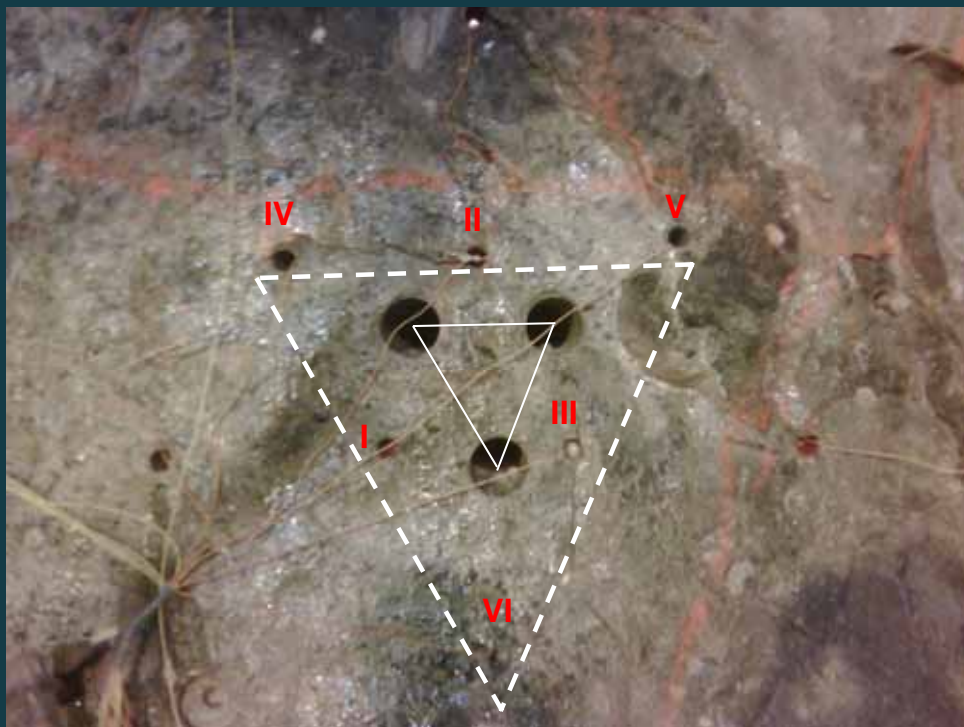
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All Purpose Cut Design – The Shielded Burn Cut



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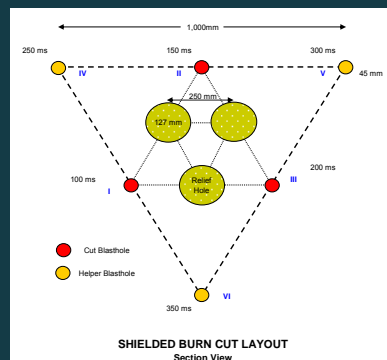
Shielded Burn Cut



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Shielded Burn Cut Key Features

- **Relief holes drilled 300mm deeper than blastholes**
- **Cut blastholes are positioned to minimize:**
 - Sympathetic detonation of adjoining blasthole
 - Dynamic pressure desensitization of explosive in adjoining blasthole
- **Each loaded cut blasthole**
 - Has two relief holes into which it can break, and
 - Is shielded (or protected) by the relief holes when other cut blastholes detonate



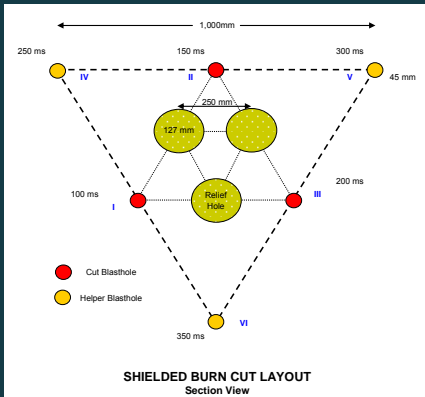
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The Cut Is Critical For A Successful Blast

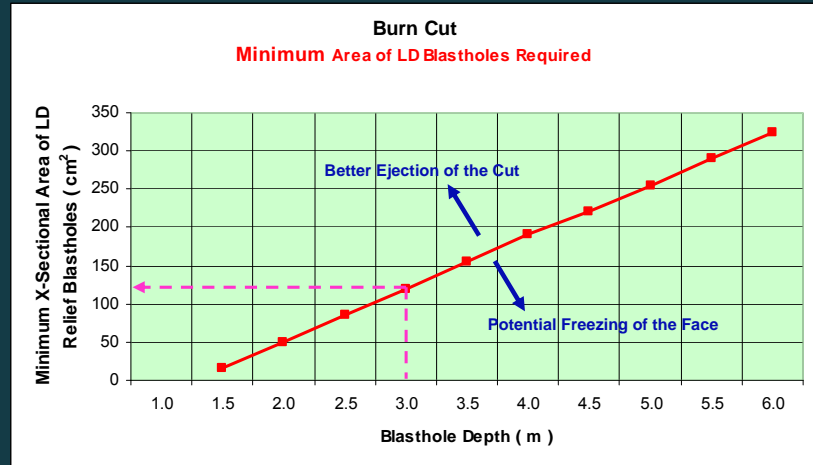
- **Design the Cut correctly**
 - Position the Cut correctly on the face
 - Drill the Cut correctly
 - Load the Cut correctly
 - Stem the Cut correctly, and
 - The Cut will ' pull ' and result in a good blast
- **If the Cut does not ' pull ' the blast advance will be poor**
 - A substantial part of the blast will ' freeze '
 - Correcting this failure costs time and money
- **The Cut can be placed centrally, or right or left of tunnel centre**
- **The Cut should be placed circa (1.5 – 1.8) m above the ' Lifters '**
 - A lower Cut position and early firing Lifter blastholes results in improved ' floors ' and maximizes the effect of ' gravity ' on the remaining blast portions

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Minimum X-Sectional Area of Burn Cut Relief Holes

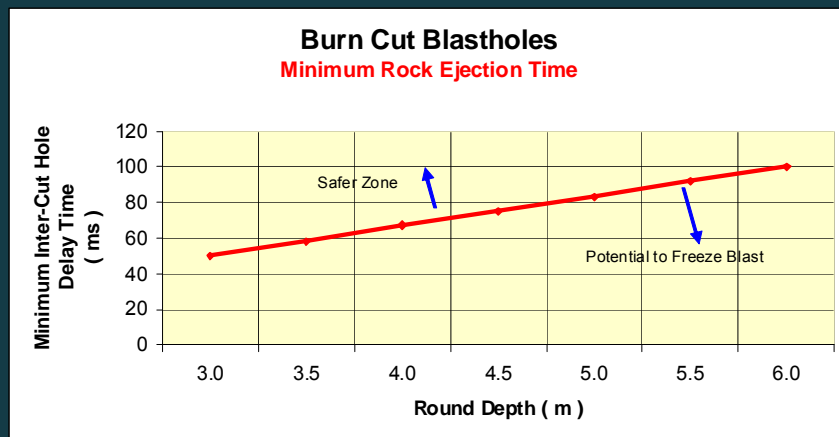


Bit OD (mm)	Area cm ²
76	45
89	62
102	82
114	102
127	127



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Minimum Rock Ejection Time For Burn Cut Blastholes



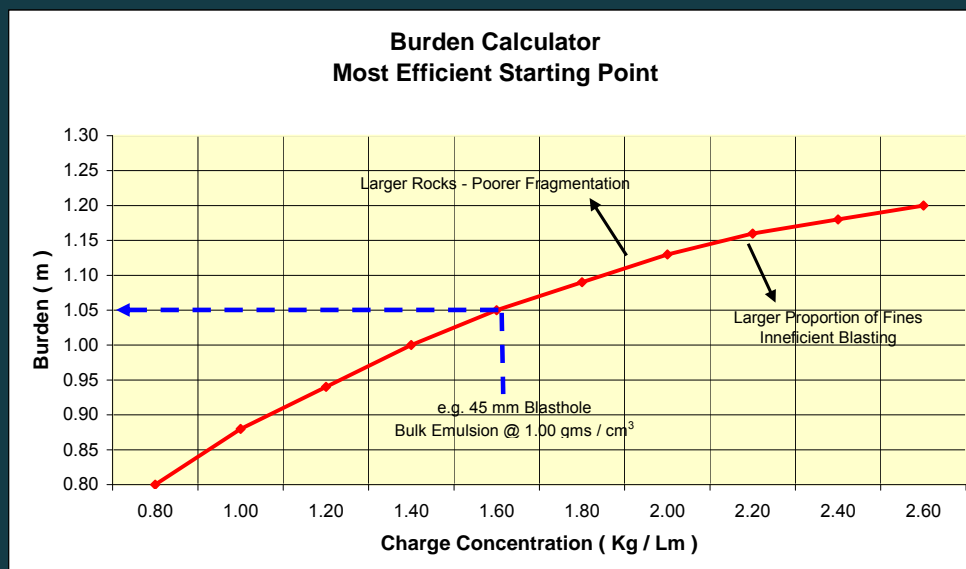
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Geological Effects On Tunnel Blast Design

- **Varying geological conditions can result in:**
 - Relocating the ' Cut ' into more competent ground
 - Expansion or reduction of burdens & spacings
 - The addition or deletion of a ' ring ' of blastholes in the face
 - Adding or deleting individual blastholes from the face
 - When a blasthole over-breaks in poor ground, the adjacent blasthole in the next outer ring will produce higher Air Overpressure (AOP) due to its thin burden when it detonates
 - Higher or lower bulk emulsion explosive density
 - Longer or shorter ' pull ' lengths

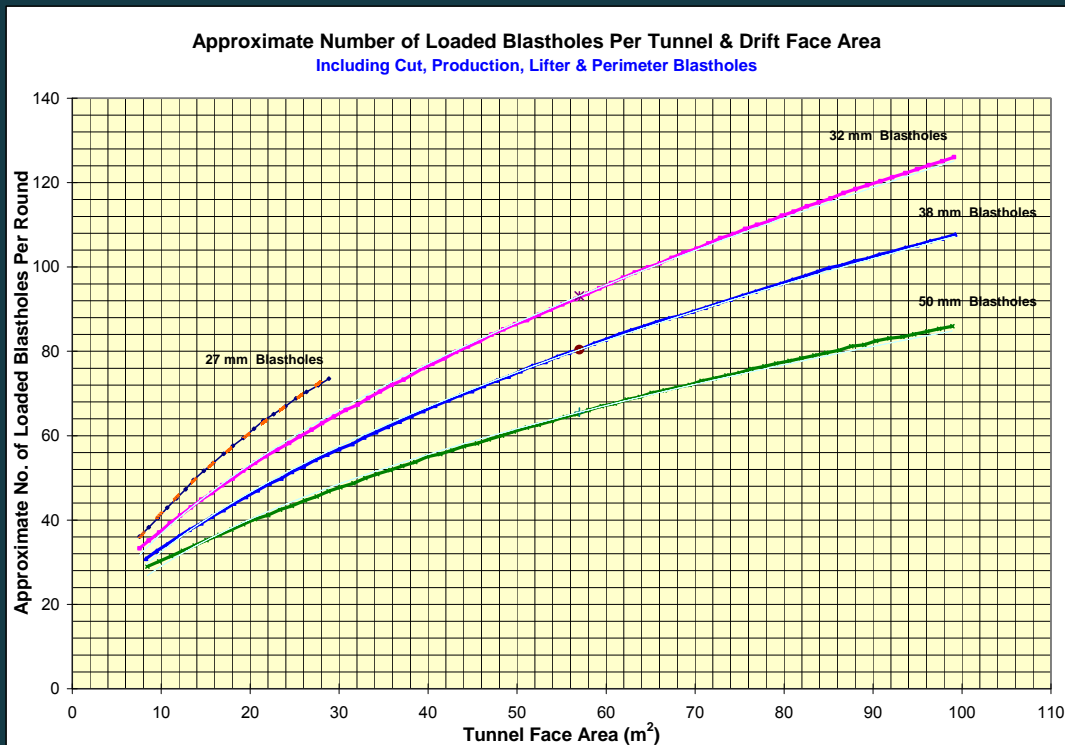
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Tunnel Blast Burden Calculator



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Approximate Number of Blastholes Per Face

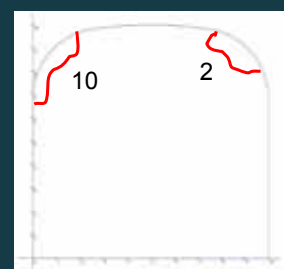


Source: Jimeno CL, Jimeno EL & Carcedo FJA, 1995 "Drilling & Blasting of Rocks "

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The Importance of Accurate Drilling

- Modern Jumbo's are computer controlled and generally place blastholes close to their design position in the face, however
- The ' power ' of modern drifters is high and if the Jumbo operator elects to drill at the highest penetration rate, blastholes can deviate within the face
- This is particularly evident at the 2 and 10 o'clock face position when drilling perimeter blastholes
 - The boom is against the tunnel wall, excessive drifter power will bend the drill rod, and
 - The blastholes will deviate left at (2 o'clock) and right at (10 o'clock)
 - This usually results in under-break at these locations



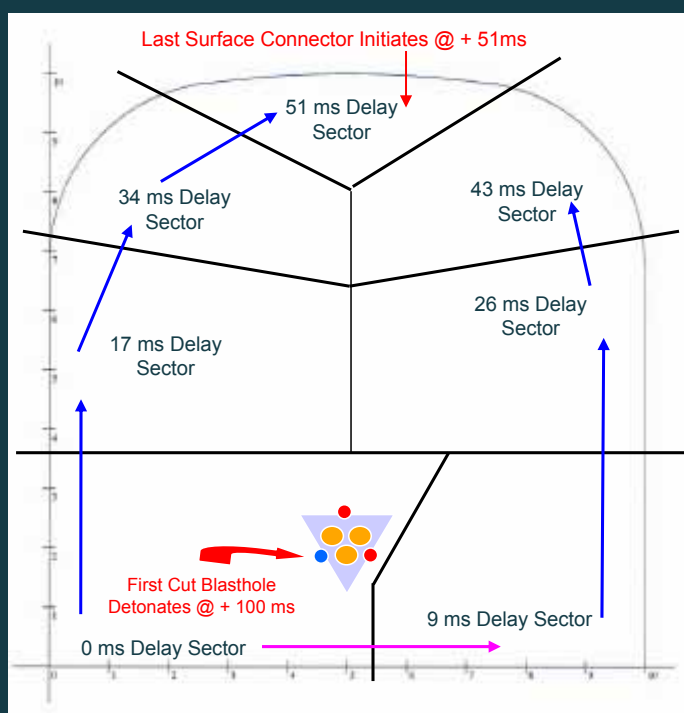
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The Importance of Stemming All Loaded Blastholes

- **Stemming blastholes retains the explosive within the blasthole so it does not eject when a nearby blasthole detonates**
- **When a stemmed blasthole detonates, the stemming momentarily retains the energy within the blasthole, only for a few milliseconds but that is sufficient**
- **Using crushed rock stemming (circa 10 mm) in thin plastic sausages will reduce Air Overpressure (AOP) by circa 6 dBL**
 - Crushed rock stemming will ' lock ' in the blasthole due to its angular shape
- **The use of traditional stemming materials are not effective, e.g.**
 - Wet cardboard
 - Wet paper
 - Hessian bags
- **Moist clay is not especially effective when compared to crushed rock stemming, as it will not ' lock ' in the blasthole**

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The Importance Of Having All Detonators Active Before The First Cut Blasthole Detonates



- All detonator delay elements are burning (alight) before the first Cut blasthole detonates at 100 ms**
- This prevents misfires from ' cut-offs ' due to projectile rocks from a detonating Cut (or other) blasthole severing a shock tube before the last Surface Connector initiates**
- As the surface area of the face and the tunnel diameter increases, then more and more sectors must be added to ensure all detonator delay elements are active (burning) before the first Cut blasthole detonates**
- The maximum number of sectors is 12 if the first Cut blasthole detonates at 100 ms. The 12th sector surface connector initiates at 94 ms.**

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The Importance of Correctly Priming Blastholes

- All primers must be placed at the back (toe) of blastholes with the primer and detonator pointing towards the free face
 - A primer should have a high Velocity of Detonation (VOD) and a high Detonation Pressure (DP)
- VOD of small diameter (SD) Bulk Emulsion : [4,800 – 5,200] m / sec
- VOD of Blow Loaded ANFO in SD blasthole : [2,800 – 2,900] m / sec
- Detonation characteristics of selected primers and bulk explosives

Primer Type	VOD (m/sec)	DP (kBar)
Cartridge Emulsion	4,200 – 4,700	62
Mini Cast Booster	7,000 – 7,800	245
Gelatin Dynamite	4,500 – 4,800	60
SD Blow Loaded ANFO	2,700 – 2,900	40
SD Bulk Emulsion	4,800 – 5,200	90

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Steady State Velocity of Explosive Column

- The distance & time taken for the explosive column to reach Steady State Velocity (SSV) is a function of the type of primer utilized
- Basic rules for priming
 - The primer should have a higher VOD than the explosive column
 - The primer should have a higher DP than the explosive column
 - This ' overdrives ' the VOD of the explosive column and the run-down distance and time to steady state velocity is shortest
 - The converse is true for primers with a VOD & DP less than the explosive column, this results in ' underdrive ', and the run-up distance & time to steady state velocity is longer when compared to ' overdriving '
 - The high strength primer diameter should be $\geq 50\%$ of the blasthole diameter which gives the fastest run-down time to steady state velocity of the explosive column (67% is the ideal)
 - Primer diameters smaller than half the blasthole diameter (e.g. $\frac{1}{3} D$) result in longer run-up times and distances to steady state velocity, even if they have a higher VOD & DP than the explosive column



Cast Mini Booster

Higher VOD & DP than Bulk Emulsions

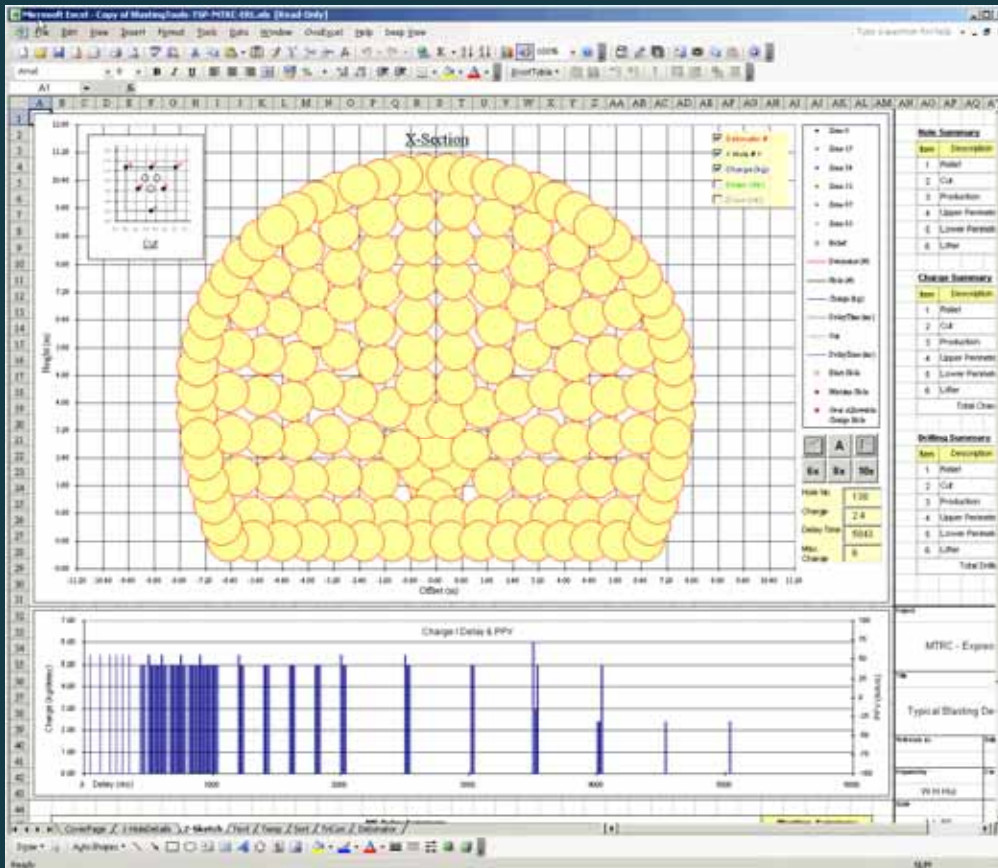


Cartridge Emulsions

Similar VOD to Bulk Emulsion but lower DP

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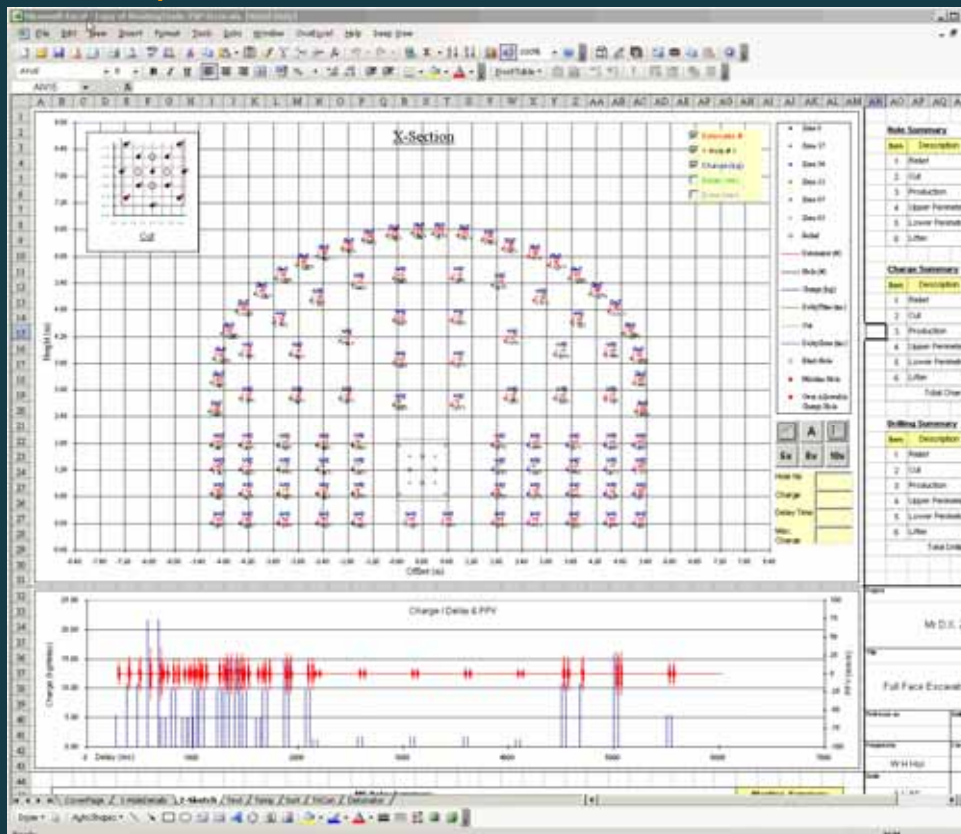
In Sequence Blast Initiation Pattern Design



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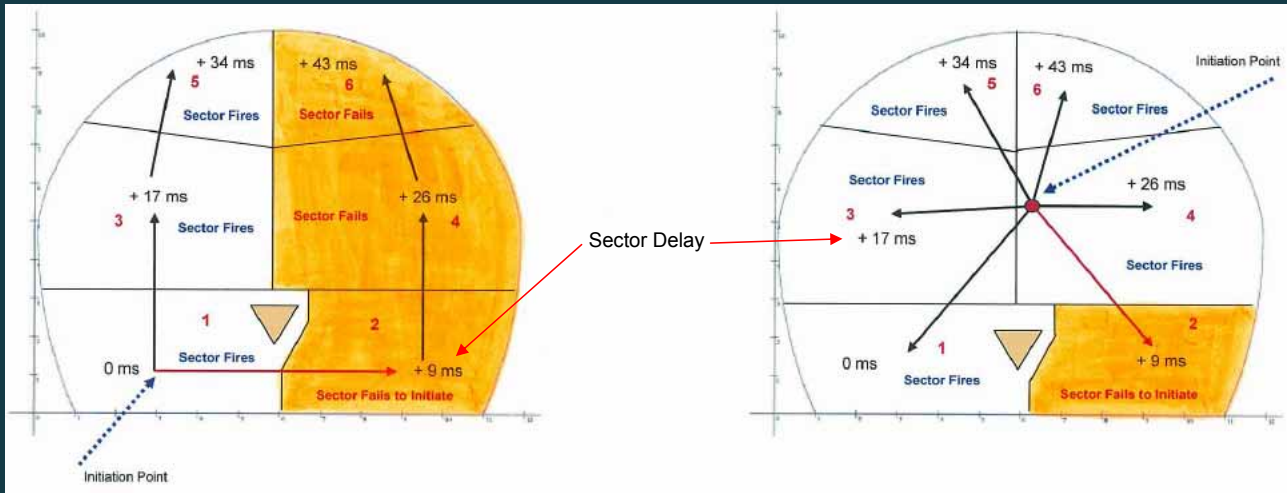
Out-Of-Sequence Blast Initiation Pattern Design



Courtesy of Brandrill Engineering (HK) Limited

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Comparative Tunnel Face Initiation Sequences

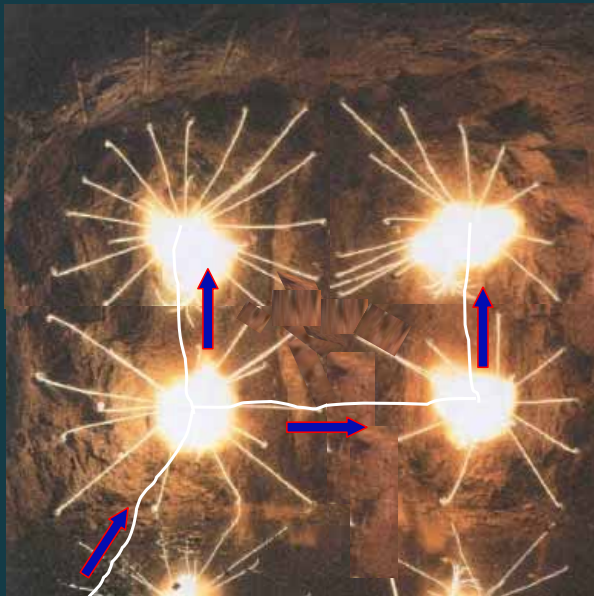


Safer – Easier to correct the ' Misfire '

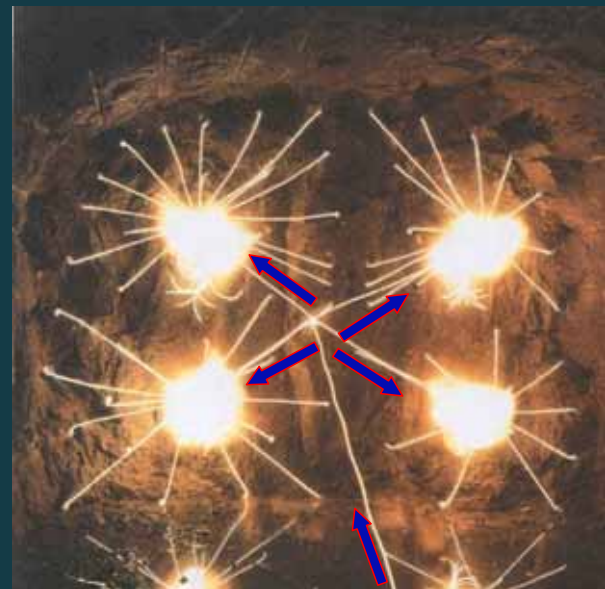
Higher Risk – Difficult to correct the ' Misfire '

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Actual Tunnel Face Initiation Sequence



Safer Method – Easier To Recover Misfired Sector(s)



Riskier Method – More Difficult To Recover Misfired Sector(s)

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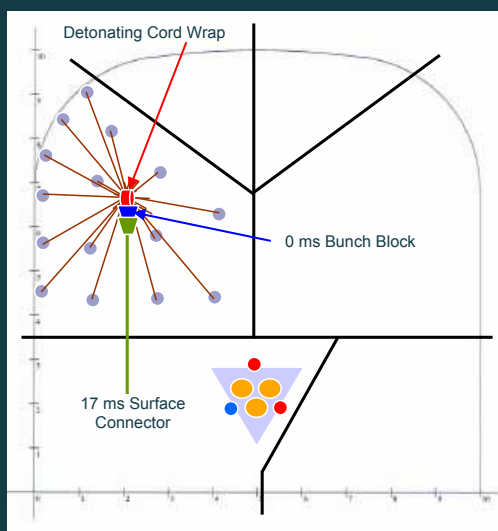
Bunch Versus Ring Firing of Sector Blastholes

- **‘ Bunch ’ firing is bunching all shock tubes in a delay sector together and securing them together with two wraps of 5 gms / m detonating cord**
 - The practical maximum number of shock tubes in a bunch is 20
 - If there are more than 20 shock tubes in a delay sector, make 2 x bunches joined by 2 strands of 5 gms / m detonating cords
 - Delay sectors are linked by the appropriate non-electric surface delay connector
 - The surface connector is attached to a 0 ms delay bunch block which initiates the detonating cord
- **‘ Ring ’ firing is when all shock tubes within a delay sector are connected to a ring (circle) of 2 x 5 gms / m strands of detonating cord**
 - The detonators have ‘ J ’ Hooks at their end which clip onto the detonating cord
 - The ‘ Ring ’ of detonating cord should be flush with the face and should not touch any other shock tube tail hanging from an adjacent delay sector
 - Delay sectors are linked by the appropriate non-electric surface delay connector
 - The surface connector is attached to a 0 ms delay bunch block which initiates the detonating cord

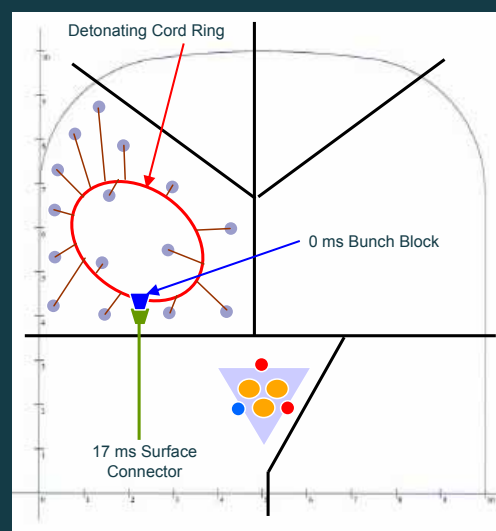
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Bunch And Ring Firing Initiation

“ Bunch ” Sector Firing



‘ Ring ’ Sector Firing



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Bulk Emulsion Explosive Parameters

- Explosive density can be lowered to give longer charge lengths in areas of reduced Maximum Instantaneous Charge (MIC's)
- Has lower 'heave' energy but high 'shock' energy
 - Generates lower gas volumes
- Contains (2.8 – 3.2) Mj / Kg of theoretical thermodynamic energy

Blasthole Diameter	Bulk Emulsion Cup Density						
	0.80	0.85	0.90	0.95	1.00	1.05	1.10
	gms / cm ³						
	Blasthole Loading Rate - Kg / Lm						
38 mm	0.91	0.96	1.02	1.08	1.13	1.19	1.25
42 mm	1.11	1.18	1.25	1.32	1.39	1.45	1.52
45 mm	1.27	1.35	1.43	1.51	1.59	1.67	1.75
48 mm	1.45	1.54	1.63	1.72	1.81	1.90	1.99
51 mm	1.63	1.74	1.84	1.94	2.04	2.14	2.25
64 mm	2.57	2.73	2.90	3.06	3.22	3.38	3.54

Blow Loaded Bulk Anfo Explosive Parameters

- Density between (0.90 – 0.95) gms / cm³
- Has lower 'Shock' energy but high 'Heave' energy
 - Generates higher gas volumes
- Contains 3.68 Mj / Kg of theoretical thermodynamic energy
- Should only be used in Dry – Damp blastholes
- Is preferred explosive option where conditions allow

Blasthole Diameter	Anfo Cup Density	
	0.90	0.95
	gms / cm ³	
	Loading Rate - Kg / Lm	
38 mm	1.02	1.08
42 mm	1.25	1.32
45 mm	1.43	1.51
48 mm	1.63	1.72
51 mm	1.84	1.94
64 mm	2.90	3.06

End

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