Determining Minimum Burdens for Quarry Blasting

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Purpose of this talk

- Determine what is an acceptable reduced burden when blasting using MEMU (mobile explosive manufacturing unit) Trucks
- Provide some guidance on blast design to address the question of reduced burdens

Key Considerations in Blast Design

- Producing good fragmentation;
- Keeping ground vibrations and air overpressure within planning limits;
- The shape of the muck pile so as to be easily loaded using the equipment that is operated at the quarry face;

Key Considerations in Blast Design

- Keeping back-break to a minimum;
- **Preventing flyrock** (flyrock is defined as rock fragments being projected beyond the predicted danger zone);
- Keeping the costs down.

Key Considerations in Blast Design

- Geometry – decide on a drill pattern (burden and spacing); shot-hole diameter; face height; sub grade drilling;
- Geology - rock type; identify geological anomalies; wet holes or dry holes.

Key Considerations in Blast Design

- Explosives & Accessories
- Initiation system (examples: nonel detonator, electric detonator, electronic detonator); primers (boosters);
- Type of explosives: ANFO; Emulsion Explosives (delivered by MEMU Truck); cartridge/ packaged materials (slurry / water gel explosives).

Prevention of Flyrock during blasting operations

- Identify what are the main causes of flyrock.
- What action should the Shotfirer take to prevent flyrock.

Potential Causes of Flyrock

- The explosives column is brought too high up the shot-hole. Resulting in the top stemming being less than the burden.
- **The Shotfirer needs to frequently (every 2 to 3 metres) check the rise of explosives in the shot-hole.**

Potential Causes of Flyrock

- Bulk explosive has filled into a cavity, fissure, joint voids or cracks all of which may have a reduced burden and will result in over-charging.
- **The Shotfirer needs to frequently (every 2 to 3 metres) check the rise of explosives in the shot-hole.**

Potential Causes of Flyrock

- Two shot-holes have deviated when being drilled and have come closer together resulting in a portion of the shot being over charged.
- **Shotfirer needs to check the azimuth of each shot-hole.**

Potential Causes of Flyrock

- The drill angle on an inclined shot-hole is increased, such that the bottom of the hole has a reduced burden, leading to over charging.
- **The Shotfirer must check the inclination of the shot-hole against the design any deviations must be carefully considered.**

Potential Causes of Flyrock

- A section of rock has fallen out of the face, after the profiling has been carried out, causing a reduced burden which has not been identified and leads to over charging. **Shotfirer must carry out pre-blast face inspection and compare with profiles. (may need to re-profile the face before continuing to charge).**

Potential Causes of Flyrock

- Poor delay sequence leading to excessive delay period between adjacent holes resulting in reduced burdens being created during the blasting operation leading to flyrock.
- **Blast design must include a delay sequence schedule so that excessive delay periods can be easily identified.**

Potential Causes of Flyrock

- The amount of explosives placed in the shot-hole is not suitable for the rock type leading to over charging.
- **Use the powder factor for the rock type to calculate the quantity of explosives (may wish to compare with previous successful blasts).**

Potential Causes of Flyrock

- A geological anomaly in the rock formation such as a dyke creates a band of weathered weaker rock in front of a charged shot-hole can lead to over charging.
- Very difficult to identify as the surface rock exposed on the quarry face will look the same as expected and the drilling could be into competent rock with the dyke located between the shot-hole and the free face.

Potential Causes of Flyrock

- Examine the other quarry faces for evidence of dykes. Check if there is any history of this in the quarry. The Shotfirer should consult with the Driller and check the Driller's Log for this and other geological anomalies such voids, clay seams, cavities, fissures, joint voids or cracks or changes in the rate of penetration of the drill string (if it increases it can be due to weaker rock).

Potential Causes of Flyrock

- Rock around the collar has been fragmented by the blasting of the previous working bench.
- **Shotfirer may need to increase the top stemming.**

Changes to Blast design following the introduction of the MEMU Truck

- The size of the shot-hole diameter increased from 95mm to 110mm.
- The drill pattern opened up from 3m x 3m (burdens & spacings) to 4m up to 6.5m.
- The overall number of shot-holes reduced when blasting the same size of rock mass.

Impact of the changes in blast design

- This change has resulted in a very significant (up to 100%) increase in the quantity of explosives in each shot-hole. When blasting with cartridge materials the burdens were approximately (in a hard rock) 3.0m.

Significant increase in Loading Rate

- The loading rate for 85mm dia. cartridge explosives was 6.25kg/m (loading rate for Energel 500 published by U.I.E. Ltd)
- The loading rate for MEMU Trucks (depends on density of the emulsion explosives) is between 11.0 to 13.5 kg/m

Minimum Burden -10% Rule

- The profiles were used to identify reduced burdens of more than10% of the planned burden (10% rule). Resulting in any sections of the shot-hole (with a 3m planned burden) which had a burden of less than 2.7m was not charged with explosives.

Minimum Burden -10% Rule

- This variation was within the range of the prescribed ‘in-hole’ Powder Factor for the given rock type.
- The ‘in-hole’ Powder Factor is calculated as the total weight of explosives divided by the rock volume calculated using the face height that is charged with explosives (Face height – depth of top stemming).

Minimum Burden -10% Rule

- When the 10% rule is applied to a 6m burden - the minimum burden is 5.4 m which is double the minimum burden when the planned burden was 3 m.
- This has resulted in the quarry industry no longer working to the 10% rule.

What is a Safe Minimum Burden

- Shotfirers now have to make a decision as to what is a safe minimum burden to fire without any rule of thumb to guide them.
- It is suspected that some Shotfirers' have adopted a minimum burden for the quarry based on the previous reduced burden when blasting with cartridge materials (minimum burden of 2.7m).

Potential Over-charging.

- Creating a situation where the minimum burden of 2.7m to a free face in front of a 110mm diameter shot-hole charged with approximately twice the weight of Emulsion Explosives when compared with the previous loading rate for cartridge materials leading to gross over-charging which is a dangerous situation.

What is a Safe Minimum Burden

- Shotfirers' do not have written criteria to establish the minimum burden.
- This does not appear to be addressed during training courses.

The use of Powder Factor in blast design

- The Powder Factor can be used to design the distribution of explosives in the rock mass that is to be blasted. The critical dimension is the burden distance which is the shortest distance to stress relieve when a shot-hole detonates. It is normally the distance to the free face.

Power Factor

- The Powder factor (PF) is the ratio of the weight of explosives (kg) divided by the volume of rock (m^3) to be blasted.

- PF = wt of explosives / volume of rock

Typical powder factors used in quarry blasts are: -

Rock type	PF (kg/m3)
Hard (Granite, Dolerite, Hard Basalt)	0.70 - 0.80
Medium (Gritstone & Hard Limestone)	0.40 - 0.50
Soft (Sandstone, Shale & Soft Limestone)	0.25 - 0.35
Very Soft (Chalk)	0.15 - 0.25

- Note: The above table is taken from Dyno Nobel publication titled 'Blasting and Explosives Quick Reference Guide 2010'

The use of Powder Factor in blast design

- When calculating the Powder factor consideration will have to be given to the density of the explosives to be used. Explosives with the same velocity of detonation can have different densities

The use of Powder Factor in blast design

- The borehole diameter is normally constant 110mm (in N.I.) but can vary depending on the age of the drill bit. The density of the explosives will be used to determine the weight of explosives. The density of Emulsion Explosives is determined on site when the MEMU truck is operating.

The use of Powder Factor in blast design

- It is not stated what explosives were used to decide on the Powder Factors set out in the Dyno Nobel table but it is normal to use ANFO as the comparator (it is either Blasting Gelatine or ANFO that was used).

The use of Powder Factor in blast design

- When considering strength by weight of Emulsion Explosives related to ANFO it is in the range 83% to 125% (taking ANFO strength by weight as 100%). Blasting Gelatine has weight strength of 133% related to ANFO.

The use of Powder Factor in blast design

- The Dyno Nobel table of Powder Factors were accepted when used with Watergel Explosives (for example Energel Explosives) which had strength by weight in the range of 115% to 125%. Therefore it would be reasonable to apply these Powder Factors for use with Emulsion Explosives

Mechanism of Rock Fragmentation

- The breaking of the rock is due to gas pressure in the shot-hole. It results in radial cracking and wedges being projected from the centre of the blast location so therefore it is reasonable to restrict the influence of the spacing to that equal to the reduced burden.

Mechanism of Rock Fragmentation

- The introduction of MEMU Trucks as stated earlier has led to an increase in the spacing. When looking at the effect of the reduced burden to keep to the ‘as planned spacings’ when applying ‘In-Hole’ Powder Factors would create an unreal situation.

The use of Powder Factor in blast design

- Explosives distribution is generally the most important factor when determining fragmentation. The use of the Powder Factor for a particular rock type is a recognised way of distributing the explosives in the rock mass.

Power Factors

- The Powder Factors quoted in the Dyno Nobel table are calculated using the total volume of rock being blasted. Geometry for a typical quarry blast is 15m face height, 1m sub-grade drill; spacing 4m, burden 4m and top stemming 4m with 2 or 3 rows of holes.

In-Hole Power Factors

- The volume of the rock located within the top stemming accounts for approximately 25% of the total volume of the rock contained in the blast. Taking this into consideration the Powder Factors for the In-Hole condition have been re-calculated and set out in the table below: -

Rock type	PF(total) kg/m³	PF(in-hole) kg/m³
Hard (Granite, Dolerite, Hard Basalt)	0.60 - 0.80	0.80 – 1.06
Medium (Gritstone & Hard Limestone)	0.40 - 0.55	0.53 – 0.73
Soft (Sandstone, Shale & Soft Limestone)	0.25 - 0.35	0.33 – 0.47
Very Soft (Chalk)	0.15 - 0.25	0.20 – 0.33

- ***Note:*** *Figures in Table 1 have been reproduced in this table for ease of comparison. The revised Powder Factors (**PF (in-hole)**) are the figures to be used to assess the blast.*

The use of Power Factor in blast design

- Using the rock type the designer can select the Powder Factor range suitable for the quarry. The face profiles will identify reduced burdens. Table below relates the explosives loading rate and the reduced burden to the expected ‘In-Hole’ Powder Factor (for a one metre section of 110mm diameter borehole)

Loading rate kg/m ___ **Reduced Burden**	**11.0 (kg/m)**	**11.5 (kg/m)**	**12.0 (kg/m)**	**12.5 (kg/m)**	**13.0 (kg/m)**	**13.5 (kg/m)**
6.00 m	0.31	0.32	0.33	0.35	0.36	0.38
5.50 m	0.36	0.46	0.40	0.41	0.43	0.45
5.00 m	0.44	0.46	0.48	0.50	0.52	0.54
4.75 m	0.49	0.51	0.53	0.55	0.58	0.60
4.50 m	0.54	0.57	0.59	0.62	0.64	0.67
4.25 m	0.61	0.64	0.66	0.69	0.72	0.75
4.00 m	0.69	0.72	0.75	0.78	0.81	0.84
3.75 m	0.78	0.82	0.85	0.89	0.92	0.96
3.50 m	0.90	0.94	0.98	1.02	1.06	1.10
3.25m	1.04	1.09	1.14	1.18	1.23	1.28
3.00 m	1.22	1.27	1.33	1.39	1.44	1.50

Action by Shotfirer

- If outside the permitted range for the rock type then the planned charging details should be re-designed.
  The Shotfirer will also take into consideration other issues with regard to the prevention of flyrock.

Practical solution to dealing with reduced burdens

- Reduced burdens mostly occur at the top section of the shot-hole. The blast designer has only one option that is to extend the depth of the top stemming and not place explosives in this section of the shot-hole.

Practical solution to dealing with reduced burdens

- The result is a large proportion of over-sized material which will require secondary breaking using an excavator with a rock hammer. In order to eliminate this costly problem the shot-hole loading rate could be reduced by placing a cylindrical void in the appropriate section of the shot-hole behind the area of reduced burden.

Practical solution

- This could be achieved by obtaining stemming bags of the appropriate diameters (50mm; 60mm; 70mm; 80mm) on rolls of say 6 to 10m in length. These stemming bags could be cut at the required length and filled with suitable stemming material and placed in the shot-hole

Practical solution

- The stemming bags could be inserted at the correct depth in the shot-hole after it has been filled with the revised charge weight of explosives and used to displace the required quantity of explosives past the section with the reduced burden.

Practical solution

- The stemming material selected must have a specific density higher than the specific density of the Emulsion Explosive being used. Generally quarry dust or sand would be heavier than the explosives.

Practical solution

- Tables have been calculated below to show the impact on the powder factor by introducing a void into the shot-hole. Tables have been prepared to cover the loading rates for MEMU trucks ranging from 11kg/m to 13.5kg/m.

Practical solution

- The tables for each loading rate include the new loading rate to be achieved in a shot-hole where a void has been placed. For example if the reduced burden is in a shot-hole being loaded with Emulsion Explosive which is normally loaded at 11 kg/m by placing a 50mm void in the shot-hole the loading rate is reduced at that section to 8.75kg/m.

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Practical solution

- Say the reduced burden is over a two metre length then the overall quantity of explosives to be placed in that shot-hole would be reduced by 4.5kg. (11 – 8.75) x 2 = 4.5 kg)

Practical solution

- ***Reduced quantity of explosives =***
- ***(original Loading Rate – new Loading Rate) x length of shot-hole***

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Practical solution

- The following Table sets out In-Hole Powder Factors (kg/m^3) for a Loading Rate of ***11kg/m*** (in 110mm dia. shot-hole) where a cylindrical void (1m length) has been created in the 110mm borehole so as to reduce the weight of explosives in sections of the shot-hole with reduced burdens

Loading rate ----------------- Reduced Burden	8.75kg/m Void diameter 50mm	7.74 kg/m Void diameter 60mm	6.56 kg/m Void diameter 70mm	5.19 kg/m Void diameter 80mm
3.5	0.71	0.63	0.54	0.42
3.4	0.76	0.67	0.57	0.45
3.3	0.80	0.71	0.60	0.48
3.2	0.85	0.76	0.64	0.51
3.1	0.91	0.81	0.68	0.54
3.0	0.97	0.86	0.72	0.58
2.9	1.04	0.92	0.78	0.62
2.8	1.12	0.99	0.84	0.66
2.7	1.20	1.06	0.90	0.71

Practical solution

- The following Table sets out in-hole Powder Factors (kg/m^3) for a Loading Rate of ***13kg/m*** (in 110mm dia. shot-hole) where a cylindrical void (1m length) has been created in the 110mm borehole so as to reduce the weight of explosives in sections of the shot-hole with reduced burdens

Loading rate ------------------ Reduced Burden	10.33 kg/m Void diameter 50mm	9.15 kg/m Void diameter 60mm	7.74 kg/m Void diameter 70mm	6.13 kg/m Void diameter 80mm
3.5	0.84	0.75	0.63	0.50
3.4	0.89	0.79	0.67	0.53
3.3	0.95	0.84	0.71	0.56
3.2	1.01	0.89	0.76	0.60
3.1	1.07	0.95	0.81	0.64
3.0	1.15	1.02	0.86	0.68
2.9	1.23	1.09	0.92	0.73
2.8	1.32	1.17	0.99	0.78
2.7	1.42	1.26	1.06	0.84

Worked Example

- Details of the geometry: -
- Burden = 5.0m
- Spacing = 5.0m
- Face Height = 15.0m
- Top Stemming = 5.0m
- No. of Holes = 14 shot-holes (two rows of 7)
- No sub drill (coming off the inter-basaltic layer)
- Hole diameter = 110mm
- Drill angles = 0^0

Worked Example

- Rock type – Basalt
- Column charge is Emulsion Explosives with a Loading Rate of 13.5 kg/m

Worked Example

- Problem: -
- Face Profile revealed a reduced burden on hole number 3 of 3.5m over a two metre length of shot-hole from 6m down from the hole collar.

Rock type	PF(total) kg/m³	PF(in-hole) kg/m³
Hard (Granite, Dolerite, Hard Basalt)	0.60 - 0.80	**0.80 – 1.06**
Medium (Gritstone & Hard Limestone)	0.40 - 0.55	0.53 – 0.73
Soft (Sandstone, Shale & Soft Limestone)	0.25 - 0.35	0.33 – 0.47
Very Soft (Chalk)	0.15 - 0.25	0.20 – 0.33

- ***Note:*** *Figures in Table 1 have been reproduced in this table for ease of comparison. The revised Powder Factors (**PF (in-hole)**) are the figures to be used to assess the blast.*

Worked Example

- Using the modified Dyno Nobel table In-Hole PF(Basalt) = 0.80 – 1.06 kg/m^3
- Reduced Burden creates a PF (in-hole) = 1.10 kg/m^3 which is outside the acceptable range. (see following Table).
- The in-hole Powder Factor can be reduced by introducing a void into this section of the shot-hole to replace a quantity of explosives.

- Table below relates the explosives loading rate and the reduced burden to the expected ‘In-Hole’ Powder Factor (for a one metre section of 110mm diameter borehole)

Loading rate kg/m Reduced Burden	11.0 (kg/m)	11.5 (kg/m)	12.0 (kg/m)	12.5 (kg/m)	13.0 (kg/m)	13.5 (kg/m)
6.00 m	0.31	0.32	0.33	0.35	0.36	0.38
5.50 m	0.36	0.46	0.40	0.41	0.43	0.45
5.00 m	0.44	0.46	0.48	0.50	0.52	0.54
4.75 m	0.49	0.51	0.53	0.55	0.58	0.60
4.50 m	0.54	0.57	0.59	0.62	0.64	0.67
4.25 m	0.61	0.64	0.66	0.69	0.72	0.75
4.00 m	0.69	0.72	0.75	0.78	0.81	0.84
3.75 m	0.78	0.82	0.85	0.89	0.92	0.96
3.50 m	0.90	0.94	0.98	1.02	1.06	**1.10 ***
3.25m	1.04	1.09	1.14	1.18	1.23	1.28
3.00 m	1.22	1.27	1.33	1.39	1.44	1.50

Worked Example

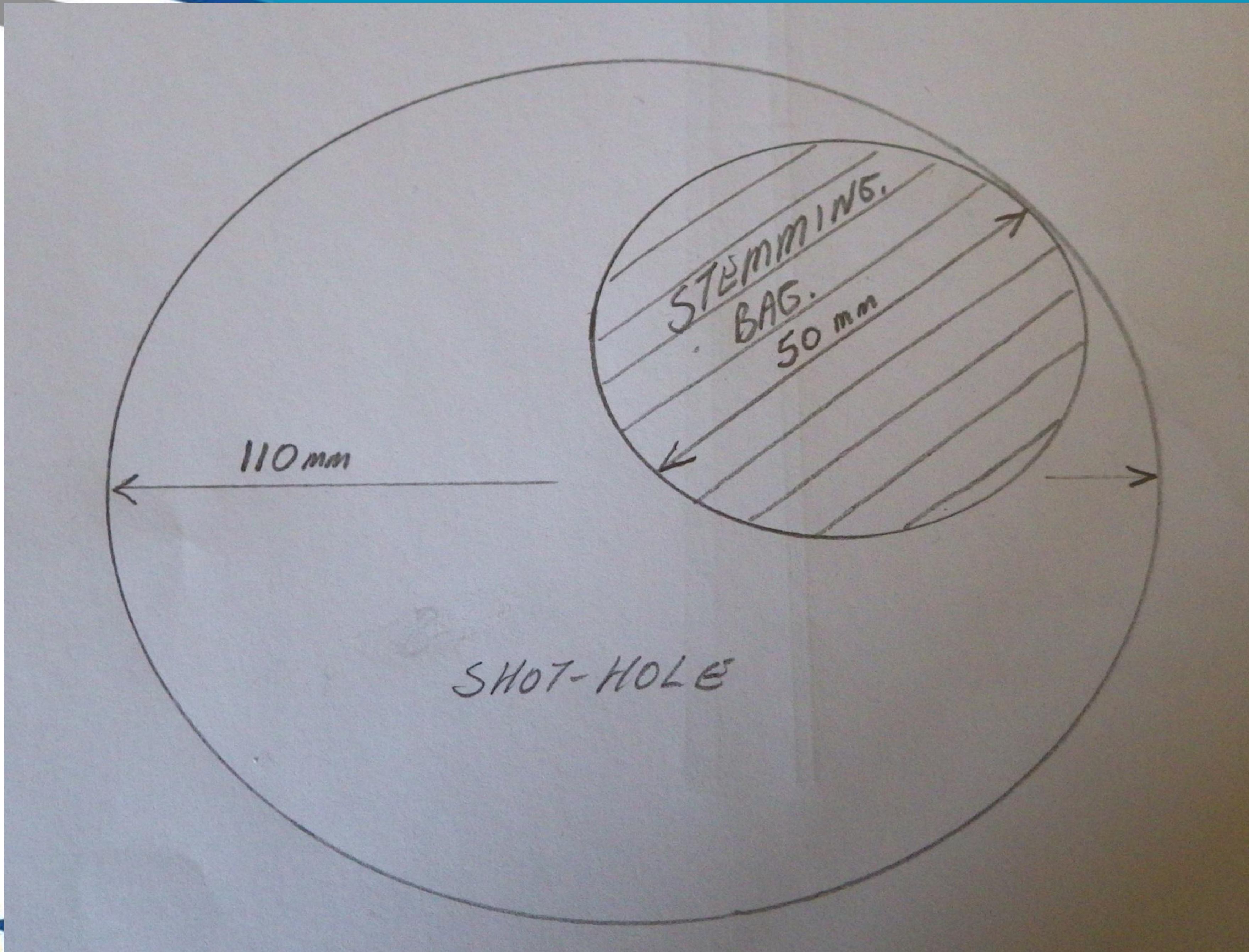
- If a 50mm diameter void (see Table for 13.5 kg/m loading rate) is placed in this section of the shot-hole it will keep the blast within an acceptable powder factor of 0.87 kg/m^3.

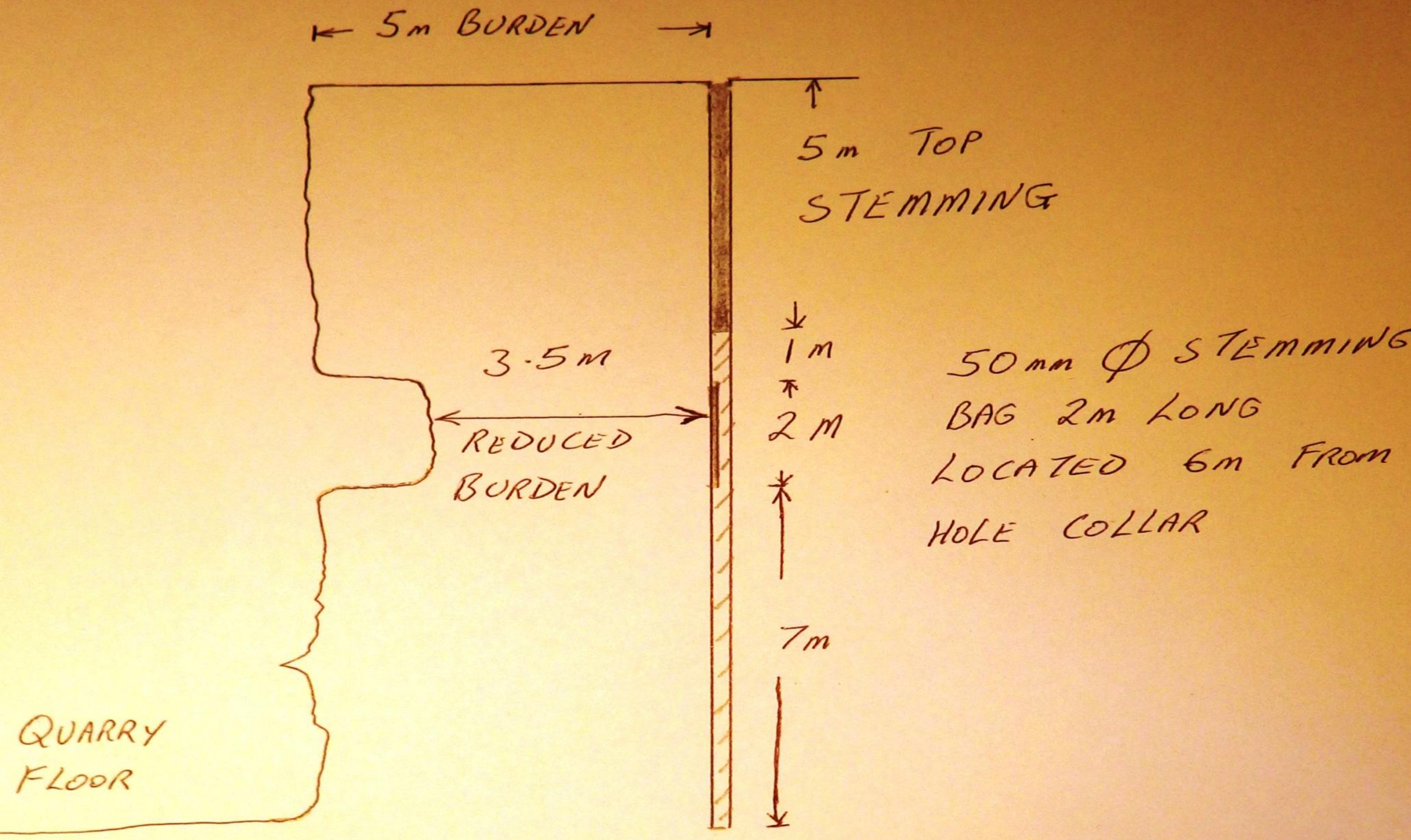
- The following Table sets out in-hole Powder Factors (kg/m^3) for a Loading Rate of ***13.5 kg/m*** (in 110mm dia. shot-hole) where a cylindrical void (1m length) has been created in the 110mm borehole so as to reduce the weight of explosives in sections of the shot-hole with reduced burdens

Loading rate ---------------- Reduced Burden	10.71 kg/m Void diameter 50mm	9.48 kg/m Void diameter 60mm	8.03 kg/m Void diameter 70mm	6.36 kg/m Void diameter 80mm
3.5	**0.87**	0.77	0.66	0.52
3.4	0.93	0.82	0.69	0.55
3.3	0.98	0.87	0.74	0.58
3.2	1.05	0.93	0.78	0.62
3.1	1.11	0.99	0.84	0.66
3.0	1.19	1.05	0.89	0.71
2.9	1.27	1.13	0.95	0.76
2.8	1.37	1.21	1.02	0.81
2.7	1.47	1.30	1.10	0.87

Worked Example

- The 50mm diameter void will result in 6.0 kg reduction in the quantity of explosives in the shot-hole.
- [(13.5 – 10.71) x2 = 5.78kg say 6.0kg].
- It is vitally important that the Shotfirer adjusts the loading rate for this shot-hole to remove the 6.0 kg of explosives.


STEMMING.
BAG.
50 mm
110mm
SHOT-HOLE



PLANNED CHARGE = 13·5 (kg/m) × 10m = 135 kgs

REVISED CHARGE = 135 − 6·0 = 129 kgs

Thank You