Drilling
Arne Lislerud
Agenda for drilling operations

- well planned operations and correctly selected rigs yield low cost drilling
- technically good drilling (good drill settings) and correctly selected drill steel yields low cost drilling
- straight hole drilling yields safe and low cost D&B operations
The most common drilling methods in use

- Top Hammer (hydraulic or pneumatic)
- Down-the-Hole (pneumatic)
- Rotary (roller bits)
- Rotary (drag bits)
Drilling consists of a working system of:

- **bit**
- **drill string**
- **boom or mast mounted feed**
- **TH or DTH - hammer**
  - **Rotary - thrust**
- **drill string rotation and stabilising systems**
- **powerpack**
- **automation package**
- **drilling control system(s)**
- **collaring position and feed alignment systems**
- **flushing (air, water or foam)**
- **dedusting equipment**
- **sampling device(s)**
How rock breaks by indentation

- Energy used for rock breakage
- Energy lost as elastic rock deformation
- Volume of cuttings

\[ F_{\text{button}} \]
\[ u_{\text{button}} \]
\[ A_{\text{button footprint}} \]
\[ u_{\text{bit}} \]
Chipping – as the button is off-loaded

Chipping around the button footprint area

Off-loading fractures at (2) which create cuttings by chip spalling

On-loading fractures created at (1)

5 mm

$F_{bit}$

$u_{button}$

$k_1$
Chip formation by bit indentation and button indexing

- Direction of bit rotation
- Ø76mm/3"
- Spray paint applied between bit impacts
- Button footprint
- Chipping around button footprint
Selecting drilling tools

- bit face and skirt design
- button shape, size and carbide grade
- shanks, rods, tubes, …
- grinding equipment and its location
Guidelines for selecting cemented carbide grades

- Avoid excessive button wear (rapid wearflat development)
  => select a more wear resistant carbide grade or drop RPM

- Avoid button failures (due to snakeskin development or too aggressive button shapes)
  => select a less wear resistant or tougher carbide grade or spherical buttons
  => use shorter regrind intervals
Selecting button shapes and cemented carbide grades

- Spherical buttons
  - DP65
  - S65

- Robust ballistic buttons
  - 48
  - R48
Optimum bit / rod diameter relationship for TH

<table>
<thead>
<tr>
<th>Thread</th>
<th>Diameter coupling</th>
<th>Diameter</th>
<th>Optimum bit size</th>
</tr>
</thead>
<tbody>
<tr>
<td>R32</td>
<td>Ø44mm</td>
<td>Ø32mm</td>
<td>Ø51-2”</td>
</tr>
<tr>
<td>T35</td>
<td>Ø48</td>
<td>Ø39</td>
<td>Ø57-2½”</td>
</tr>
<tr>
<td>T38</td>
<td>Ø55</td>
<td>Ø39</td>
<td>Ø64-2½”</td>
</tr>
<tr>
<td>T45</td>
<td>Ø63</td>
<td>Ø46</td>
<td>Ø76-3”</td>
</tr>
<tr>
<td>T51</td>
<td>Ø71</td>
<td>Ø52</td>
<td>Ø89-3½”</td>
</tr>
<tr>
<td>GT60</td>
<td>Ø82</td>
<td>Ø60</td>
<td>Ø92-3.62”</td>
</tr>
<tr>
<td>GT60</td>
<td>Ø85</td>
<td>Ø60/64</td>
<td>Ø102-4”</td>
</tr>
</tbody>
</table>
Optimum bit / guide or pilot (lead) tube relationship for TH

<table>
<thead>
<tr>
<th>Thread</th>
<th>Diameter coupling</th>
<th>Diameter</th>
<th>Optimum bit size</th>
</tr>
</thead>
<tbody>
<tr>
<td>T38</td>
<td>ø55mm</td>
<td>ø56mm</td>
<td>ø64-2½”</td>
</tr>
<tr>
<td>T45</td>
<td>ø63</td>
<td>ø65</td>
<td>ø76-3”</td>
</tr>
<tr>
<td>T51</td>
<td>ø71</td>
<td>ø76</td>
<td>ø89-3½”</td>
</tr>
<tr>
<td>GT60</td>
<td>ø85</td>
<td>ø87</td>
<td>ø102-4”</td>
</tr>
<tr>
<td>GT60</td>
<td>ø85</td>
<td>ø102</td>
<td>ø115-4½”</td>
</tr>
</tbody>
</table>

(QUARRY ACADEMY)

Improving Processes. Instilling Expertise.
Trendlines for bit service life

- Rotary Drilling - Ø12½” / Std.
- DTH *
- Tophammer *

* Bit service life highly dependent on regrind intervals – regard curve as toplimit

Siever’s J Value, SJ

Limestone
Dolomite
Granite
Quartzite
Relationship between SJ and VHNR

- rock surface hardness, VHNR
- rock surface hardness, SJ

![Diagram showing a graph with Vickers Hardness Number (VHNR) on the y-axis and Stevers J Value (SJ) on the x-axis. The graph includes data points for different types of rock conditions, such as non-weathered rock, weathered rock, and rock with "zero" grain bonding.](image-url)
Bit regind intervals, bit service life and over-drilling

Bit service life (dr-ft)

Bit regind intervals (dr-ft)

Premature button failures
Example of drill steel followup for MF-T51

<table>
<thead>
<tr>
<th>Bit service life (dr-ft)</th>
<th>Rod and shank service life (dr-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>165</td>
<td>33,000</td>
</tr>
<tr>
<td>330</td>
<td>1,320</td>
</tr>
<tr>
<td>660</td>
<td>660</td>
</tr>
<tr>
<td>13,200</td>
<td>1,980</td>
</tr>
<tr>
<td>33,000</td>
<td>19,800</td>
</tr>
<tr>
<td>66,000</td>
<td>52,800</td>
</tr>
</tbody>
</table>

- Short holes
- Long holes

- Shanks
- MF-T51 rods
KPI’s for drill steel followup work

- **drilling capacity drm/ph**
- **drill-hole straightness**
- **avg. percussion pressure**
- **geological conditions**

- **drill steel component life**
- **bit regrind intervals**
- **bit replacement diameter**
- **component discard analysis**
- **cost € per drm or m³**
Flushing of drill-cuttings

**Insufficient air < 50 ft/s**
- low bit penetration rates
- poor percussion dynamics
- interrupt drilling to clean holes
- plugged bit flushing holes
- stuck drill steel
- "circulating" big chip wear

**Too much air > 100 m/s**
- excessive drill steel wear
- erosion of hole collaring point
- extra dust emissions
- increased fuel consumption

**Correction factors**
- high density rock
- badly fractured rock (air lost in fractures - use water or foam to mud up hole walls)
- high altitude (low density air)
- large chips
Predicting bit penetration rates - TH

- **rock mass drillability, DRI**
- **percussion power level in rod(s)**
- **bit diameter** ✓ hole wall confinement of gauge buttons
- **goodness of hole-bottom chipping** ✓ bit face design and insert types ✓ drilling parameter settings (RPM, feed)
- **flushing medium and return flow velocity**

![Graph showing bit penetration rate vs. rock drillability, DRI](image)

| HL510/HLX5T  | 51 mm | 2” |
| HL600        | 64 mm | 2.5” |
| HL710/800T   | 76 mm | 3” |
| HL1500/1560T | 102 mm | 4” |

| HL510/HLX5T  | 64 mm | 2.5” |
| HL600        | 76 mm | 3” |
| HL710/800T   | 89 mm | 3.5” |
| HL1000       | 89 mm | 3.5” |
| HL1500/1560T | 115 mm | 4.5” |

| HL510/HLX5T  | 76 mm | 3” |
| HL600        | 89 mm | 3.5” |
| HL710/800T   | 102 mm | 4” |
| HL1000       | 115 mm | 4.5” |
| HL1500/1560T | 127 mm | 5” |
Predicting bit penetration rates - DTH

- rock mass drillability, DRI
- percussion power of hammer
- bit diameter
  ✓ hole wall confinement of gauge buttons
- goodness of hole-bottom chipping
  ✓ bit face design and insert types
  ✓ drilling parameter settings (RPM, feed)
- flushing and return flow velocity

![Graph showing bit penetration rate vs. rock drillability, DRI with data points for different bit sizes and diameters.]

<table>
<thead>
<tr>
<th>Bit Size</th>
<th>Diameter (mm)</th>
<th>Diameter (”)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M50 / M55</td>
<td>140 mm</td>
<td>5.5”</td>
</tr>
<tr>
<td>M60 / M65</td>
<td>165 mm</td>
<td>6.5”</td>
</tr>
<tr>
<td>M30</td>
<td>89 mm</td>
<td>3.5”</td>
</tr>
<tr>
<td>M40</td>
<td>115 mm</td>
<td>4.5”</td>
</tr>
<tr>
<td>M60 / M65</td>
<td>203 mm</td>
<td>8”</td>
</tr>
<tr>
<td>M85</td>
<td>251 mm</td>
<td>9 7/8”</td>
</tr>
</tbody>
</table>
Gross drilling capacities (dr-ft/h)

- **rig setup and feed alignment time per drill-hole**
- **collaring time through overburden or sub-drill zone**
- **drill-hole wall stabilisation time (if required)**
- **rod handling times (unit time and rod count)**
- **bit penetration rate loss percentage i.e.**
  - ✔ rods and couplings 6.1 % per rod
  - ✔ MF rods 3.6 % per rod
  - ✔ tubes 2.6 % per tube
- **effect of percussion power levels on:**
  - ✔ bit penetration rates
  - ✔ drill steel service life
  - ✔ drill-hole straightness
- **rig tramming times between benches, refueling, etc.**
- **effect of operator work environment on effective work hours per shift**
- **rig availability, service availability, service and maintenance intervals**

![Graph showing the relationship between bit penetration rate and gross drilling capacity](image)
Typical breakdown of longterm rig usage and capacities

- **Shift time, 100 %**: shift hours
- **Mechanical availability, 80 - 90 %**: engine hours
- **Machine utilisation, 60 - 80 %**: net drilling hours
- **Net drilling time, 40 – 60 %**: percussion hours (30 - 60 % of engine hours)

**Daily service**
- Scheduled maintenance
- Breakdowns

**Shift change**
- Lunch
- Blast downtime
- Set out pattern

**Set out TIM**
- Tramming
- Refueling
- New set rods

**Bit penetration time**
- Rod handling
- Hole stabilisation
- Reposition rig and feed
- Bit change
Mechanics of percussive drilling

**Percussive drilling**

*Down-the-hole, DTH*
Stress waves transmitted directly through bit into rock

*Tophammer*
Stress wave energy transmitted through shank, rods, bit, and then into rock

**Basic functions**

- **percussion** - reciprocating piston used to produce stress waves to power rock indentation
- **feed** - provide bit-rock contact at impact
- **rotation** - provide bit impact indexing
- **flushing** - cuttings removal from hole bottom
- **foam flushing** - drill-hole wall stabilisation
Percussive impact cycle in TH drilling

1. Piston accelerates forwards and strikes shank
2. Incident stress wave travels down drill string to bit. Rod compression $u_i$
3. Incident stress wave powers bit indentation $u_{bit}$ – and reflections travel back to shank-end
4. Re-reflected stress waves travel to bit again – etc. Piston accelerates backwards - starting a new cycle
5. Rock drill now moved forwards by $u_{bit}$ – and drill string ready for next piston strike
Energy transfer efficiency in TH drilling

\[ \eta / (1 - \gamma) \]

\( k_1 = \text{indentation resistance of bit (kN/mm)} \)
Energy transfer chain
- video clip cases

cavity

“perfect” bit / rock match

bit / rock gap – i.e. underfeed

bit face bottoming – caused by:

- drilling with too high impact energy
- drilling with worn bits i.e. buttons with too low protrusion
Feed force requirements

From a drilling point of view
- to provide bit-rock contact
- to provide rotation resistance so as to keep threads tight

From a mechanical point of view
- compensate piston motion
- compensate linear momentum of stress waves in rods
Energy transmission efficiencies are divided into:

- **energy transmission through the drill string**
  - optimum when the cross section throughout the drill string is constant
  - length of stress wave
  - weight of bit

- **energy transmission to rock**
  - bit indentation resistance – $k_1$
  - bit-rock contact

The most critical issue in controlling stress waves is to avoid high tensile reflection waves.

Tensile stresses are transmitted through couplings by the thread surfaces - not through the bottom or shoulder contact as in the case for compressive waves.

High surface stresses combined with micro-sliding result in high coupling temperatures and heavy wear of threads.
Matching drill settings to site conditions

- **BPR ratio**
- **η_{single pass}**
- **Feed ratio** $(p_{feed} / p_{perc.})$

**Rock hardness**

**Chipping during bit indentation**

- **$k_{1\text{-soft}}$**
- **$k_{1\text{-good rock}}$**

**Same bit in 2 different rock types or quarries**
Drilling in variable rock mass

- $k_1$-void $\approx 0$
- $k_1$-good rock
- $k_1$-joint $< k_1$-good rock
- $k_1$-good rock
- $k_1$-hard layer $> k_1$-good rock

BPR ratio

Total overfeed (feed speed control)
- OK (ratio set here)
- Overfeed
- Underfeed

Feed ratio ($\frac{p_{feed}}{p_{perc}}$)

Situation =>

Actual feed conditions
Ranger DX700 and 800 / Pantera DP1500

$$v_{gauge} = \pi d \cdot \frac{RPM}{(60 \cdot 1000)}$$

<table>
<thead>
<tr>
<th>RPM</th>
<th>for Ø76mm – 3”</th>
<th>RPM</th>
<th>for Ø89mm – 3½”</th>
<th>RPM</th>
<th>for Ø102mm – 4”</th>
<th>RPM</th>
<th>for Ø127mm – 5”</th>
<th>RPM</th>
<th>for Ø152mm – 6”</th>
</tr>
</thead>
<tbody>
<tr>
<td>66</td>
<td>79</td>
<td>92</td>
<td>105</td>
<td>118</td>
<td>132</td>
<td>145</td>
<td>158</td>
<td>56</td>
<td>67</td>
</tr>
<tr>
<td>49</td>
<td>59</td>
<td>69</td>
<td>78</td>
<td>88</td>
<td>98</td>
<td>108</td>
<td>118</td>
<td>39</td>
<td>47</td>
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<tr>
<td>33</td>
<td>39</td>
<td>46</td>
<td>53</td>
<td>59</td>
<td>66</td>
<td>72</td>
<td>79</td>
<td>33</td>
<td>39</td>
</tr>
</tbody>
</table>
Summary of drill settings - TH

- **higher percussion pressure** => penetration rates increase proportionally with percussion power
  => more drill steel breakage if …
  => deviation increases with percussion energy

- **feed ratio (Pfeed / Ppercussion)**
  => ratio controls average feed levels
  => UF reduces drill steel life (heats up threads)
  => OF increases deviation (especially bending)

- **higher rotation pressure**
  => tightens threads (open threads reduce drill steel life)
  => increases with OF
  => increases with drill string bending

- **higher bit RPM**
  => increases gauge button wear (especially in abrasive rocks)
  => increases indexing of button footprints on drill hole bottom
  => straighter holes
  => higher thread temperatures

- **bits**
  => select bits with regard to penetration rates, hole straightness, stable drilling (percussion dynamics), price, …
  => bit condition / regrind intervals / damage to rock drill
How do we go about drilling straighter holes?

- understand the many issues leading to drill-hole deviation
- technically good drill string
- technically good drill rig, instrumentation, ...
- motivate the drillers!
Can we drill straight holes?

Ventilation Shaft, Olkiluoto Nuclear Power Plant

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaft diameter, Section I</td>
<td>Ø21.3’</td>
</tr>
<tr>
<td>Shaft length</td>
<td>49.2’</td>
</tr>
<tr>
<td>Rock type</td>
<td>Quartz Diorite</td>
</tr>
<tr>
<td>Contour hole size</td>
<td>Ø60mm – 2.36”</td>
</tr>
<tr>
<td>Contour hole charging</td>
<td>80 g/m cord</td>
</tr>
<tr>
<td>Contour hole spacing</td>
<td>1.3’</td>
</tr>
<tr>
<td>Contour row burden</td>
<td>2.3’</td>
</tr>
</tbody>
</table>
What happens when we shoot holes that look like spaghetti?

- **floor humps** => poor loading conditions, uneven floors
- **poor walls** => unstable walls => difficult 1st row drilling
- **flyrock** => safety
- **blowout of stemming** => safety, dust, toes, ...
- **blast direction** => quality of floors and walls
- **shothole deflagration / misfires** => safety => locally choked muckpiles (poor diggability)
- **good practice** => max. drill-hole deviation up to 2 – 3% for production drilling
Accurate drilling gives effective blasting

**Sources of drilling error**

1. Collar position
2. Hole inclination and direction
3. Deflection
4. Hole depth
5. Omitted or lost holes
6. Shothole diameter (worn out bits)
Shothole diameter error control

- bits loose diameter due to gauge button wear
- typical diameter loss for worn out bits is ~ 10%
- diameter loss effect on drill patterns

Diameter new bit: Ø102mm – 4"
Diameter worn out: Ø89mm – 3½"
Diameter loss: (4 – 3½) / 4 = 12.8%
=> Drill pattern too big: (4 / 3½)¹.⁶ = 24%

![Graph showing the relationship between drill-hole diameter and blastability/fragmentation]

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Improving Processes. Instilling Expertise.
Collar position error control

- Use tape, optical squares or alignment lasers for measuring in collar positions.
- Use GPS or total stations to measure in collar positions.
- Collar positions should be marked using painted lines – not movable objects such as rocks etc.
- Completed drillholes should be protected by shothole plugs etc. to prevent holes from caving in (and filling up).
- Use GPS guided collar positioning devices e.g. TIM-3D.
Examples of drill-hole deviation

Directional error for Ø3½” retrac bit / T45 in granite

Drill string deflection caused by gravitational pull or sagging of drill steel in inclined holes in syenite
Examples of drill-hole deviation

Deflection with and without pilot tube for Ø3½" DC retrac bit / T51 in mica schist

Floor hump due to explosives malfunction – caused by drill string deflection
# Lafarge Bath Operations, Ontario

**Annual production** | 1.6 mill. tons  
**Rock type** | Limestone

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bench height</td>
<td>105’</td>
</tr>
<tr>
<td>Bit</td>
<td>Ø115mm - 4½” guide XDC</td>
</tr>
<tr>
<td>Drill steel</td>
<td>Sandvik 60 + pilot tube</td>
</tr>
<tr>
<td>Hole-bottom deflection</td>
<td>&lt; 1.5 %</td>
</tr>
<tr>
<td>Gross drilling capacity</td>
<td>220 dr-ft/h</td>
</tr>
<tr>
<td>Drill pattern</td>
<td>14⅞’ x 15⅜’ (staggered)</td>
</tr>
<tr>
<td>Sub-drill</td>
<td>0’ (blast to fault line)</td>
</tr>
<tr>
<td>Stemming</td>
<td>9⅞’</td>
</tr>
<tr>
<td>No. of decks</td>
<td>3</td>
</tr>
<tr>
<td>Stem between decks</td>
<td>5.9’</td>
</tr>
<tr>
<td>Deck delays</td>
<td>25 milliseconds</td>
</tr>
<tr>
<td>Charge per shothole</td>
<td>520 lbs</td>
</tr>
<tr>
<td>Explosives</td>
<td>ANFO (0.95 &amp; 0.85 g/cm³)</td>
</tr>
<tr>
<td>Powder factor</td>
<td>0.34 kg/bm³</td>
</tr>
</tbody>
</table>
Hole depth error control

Remaining drill length \(= c - a\) (at 1st laser level reading)

Total drill hole length \(= c - a + b\)

Set-point values for TIM 2305

Laser level

Bench top level

Laser height

Quarry floor level

Sub-drill level

Inclination
Inclination and directional error control

Set-point values for TIM 2305
✓ inclination
✓ blast direction projection
✓ distant aiming point direction
(new aiming point reading required when tracks are moved)
How bit face designs enhance drill-hole straightness

When the bit first starts to penetrate through the joint surface on the hole bottom, the gauge buttons tend to skid off this surface and thus deflect the bit. More aggressively shaped gauge inserts (ballistic / chisel inserts) and bit face gauge profiles (drop center) reduce this skidding effect by enabling the gauge buttons to "cut" through the joint surface quickly - thus resulting in less overall bit deflection.
How bit skirt designs enhance drill-hole straightness

As the bit cuts through the joint surface - an uneven bit face loading condition arises; resulting in bit and drill string axial rotation - which is proportional to bit impact force imbalance.

A rear bit skirt support (retrac type bits) reduces bit and string axial rotation by “centralizing” the bit.

Other counter measures:
- longer bit body
- add pilot tube behind bit
- lower impact energy
- rapid drilling control system reacting to varying torque and feed conditions
Drill-hole deflection error control

- select **bits** less influenced by rock mass discontinuities
- reduce drill string deflection by using **guide tubes**, etc.
- reduce drill string bending by using less **feed force**
- reduce **feed foot slippage** while drilling - since this will cause a misalignment of the feed and lead to excessive drill string bending
- avoid **gravitational** effects which lead to drill string sagging when drilling inclined shot-holes (> 15°)
- avoid inpit operations with **excessive bench heights**

\[ \Delta L = f(L^3) \text{ for } \delta \neq 0 \]
\[ \Delta L = f(L^2) \text{ for } \delta = 0 \]
Drill-hole deflection trendlines in schistose rock

Fissures along schistosity or bedding planes

Stabile drilling direction perpendicular to fissures along schistosity or bedding planes

Relatively stabile drilling direction parallel to fissures along schistosity
Selecting straight-hole drilling tools - TH

- optimum bit / rod diameter relationship
- insert types / bit face and skirt
  - spherical / ballistic / chisel inserts
  - normal bits
  - retrac bits
  - drop center bits
  - guide bits
- additional drill string components
  - guide tubes / pilot (lead) tubes
Drill pattern at quarry floor

**Bench height** 108 ft

**Hole inclination** 14°

**Drill steel** Ø3” retrac bit / T45

**Drill pattern** 8.2’ x 9’

**Rock type** Granitic gneiss

**Clustered shothole areas / Risk of dead pressing**

**Vacant shothole areas / Risk of toe problems**

**Small burden areas / Risk of flyrock**

**Bench toe**

**Bench crest**

- **Drill-hole collar positions**
- **Drill-hole positions at quarry floor**
Vertical projection of Row #1
Prediction of deviation errors

- **direction of deviation can not be “predicted”**
- **magnitude of deviation can be predicted**

**Rock mass factor, \( k_{\text{rock}} \)**
- **massive rock mass** 0.33
- **moderately fractured** 1.0
- **fractured** 2.0
- **mixed strata conditions** 3.0

**Bit design and button factor, \( k_{\text{bit}} \)**
- **normal bits & sph. buttons** 1.0
- **normal bits & ball. buttons** 0.70
- **normal X-bits** 0.70
- **retrac bits & sph. buttons** 0.88
- **retrac bits & ball. buttons** 0.62
- **retrac X-bits** 0.62
- **guide bits** 0.38

**Drill-hole Deviation Prediction**

<table>
<thead>
<tr>
<th>Location</th>
<th>Bench H = 33m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock type</td>
<td>Granitic gneiss</td>
</tr>
<tr>
<td>Bit type</td>
<td>Retrac bit</td>
</tr>
</tbody>
</table>

| Bit diameter (mm) | \( d_{\text{bit}} \) | 76 |
| Rod diameter (mm) | \( d_{\text{string}} \) | 45 |
| Guide tube diameter (mm) | \( d_{\text{guide}} \) / No | No |

| Total deflection factor | \( k_{\text{def}} \) | 1.34 |
| rock mass               | \( k_{\text{rock}} \) | 1.30 |
| drill-string stiffness  | \( k_{\text{stiffness}} \) | 0.138 |
| bit wobbling            | \( k_{\text{wobbling}} \) | 0.592 |
| guide tubes for rods    | \( k_{\text{guide}} \) | 1.000 |
| bit design and button factor | \( k_{\text{bit}} \) | 0.88 |
| constant                | \( k_{\text{rod}} \) | 0.096 |

| Inclination and direction error factor | \( k_{\text{I + D}} \) | 47.8 |

**Drill-hole deviation prediction**

<table>
<thead>
<tr>
<th>Drill-hole Length (m)</th>
<th>( \Delta L )</th>
<th>( \Delta L_{\text{def}} )</th>
<th>( \Delta L_{\text{total}} )</th>
<th>( \Delta L_{\text{total}} / L )</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.3</td>
<td>444</td>
<td>116</td>
<td>459</td>
<td>4.9</td>
</tr>
<tr>
<td>13.4</td>
<td>640</td>
<td>241</td>
<td>684</td>
<td>5.1</td>
</tr>
<tr>
<td>17.6</td>
<td>840</td>
<td>415</td>
<td>937</td>
<td>5.3</td>
</tr>
<tr>
<td>21.7</td>
<td>1036</td>
<td>631</td>
<td>1213</td>
<td>5.6</td>
</tr>
<tr>
<td>34.1</td>
<td>1628</td>
<td>1559</td>
<td>2254</td>
<td>6.6</td>
</tr>
</tbody>
</table>
Factors affecting drill-hole deviation

- **drill string startup alignment**
- **bit will follow a joint if at sharp angle to bit path**
- **drill string stiffness and “tube” steering behind bit**
- **deviation increases with impact energy**
- **button shape, bit face and bit body design**
- **drilling with dull buttons (worn bits)**
- **bit diameter checks when regrinding**
- **feed foot slippage while drilling**
- **removal or controlled drilling through prior sub-drill zone**
- **drilling control systems, i.e.**
  - applied feed, torque and percussion dynamics
- **operator motivation!**
Mina Alumbrera -
Double bench presplitting
Mina Alumbrera - Pitwall scanlines
Wall control drilling - Macon Quarry, GA

DP1500 - Ø87/3½” Tubes - 80’
Bench - Ø140/5½” Presplit

Excessive deviation due to feed foot slippage
Wall control drilling - Macon Quarry, GA

<table>
<thead>
<tr>
<th></th>
<th>( \Delta L )</th>
<th>%</th>
<th>( \Delta x = \Delta y )</th>
<th>( \alpha )</th>
<th>( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max error</td>
<td>1.48 ft</td>
<td>1.8</td>
<td>1.05 ft (( \approx 2d ))</td>
<td>0.75(^\circ)</td>
<td>12.0(^\circ)</td>
</tr>
<tr>
<td>Median error</td>
<td>0.49 ft</td>
<td>0.6</td>
<td>0.36 ft (( \approx d ))</td>
<td>0.25(^\circ)</td>
<td>4.2(^\circ)</td>
</tr>
</tbody>
</table>

\[ \Delta L = (\Delta x^2 + \Delta y^2)^{1/2} \]

\( \Delta y = \text{error perpendicular to wall is of greater importance to extent of blast damage in backwalls} \)

\[ \beta = \tan \frac{\Delta y}{S} \]

\( \Delta x = \text{error parallel to wall - lesser importance} \)

\[ \alpha = \tan \frac{\Delta x}{H} \]
Thank You
Workshop ?
Optimisation of quarrying => overview of operations, technology and markets

- end-product volumes
- costs
- prices
- stockpiling

=> right mix of parameters?
Key Performance Indicators, KPI’s

- **key financial performance in period**
  - overall quarry profitability
  - capital employed (especially unscheduled stockpiling)

- **key production performance in period**
  - end-product tonnages, costs and margins
  - productivity and cost per machine
  - safety in operations
  - public relations
Occupational health and safety

- work related accidents for:
  - mobile equipment
  - hazardous work areas
- emissions control
- noise control
- dust control
- fly rock / charging / straight-hole drilling
- falling rocks / wall control

⇒ safety is linked as much to equipment as it is to attitudes
⇒ health, safety and environmental issues are everyone’s concern
⇒ the ultimate safety target is zero harm – not just a minimum occurrence of accidents
Assessment of some work related health risks

Risk


Silicosis
Oil mist
Radon
Vibrations
Noise
Musculoskeletal disorders
Stress/mental workload
Diesel
Safety of inpit operations

- unwanted incidences do not just happen – they have root causes
- actions can be taken so as to reduce frequency and consequences of unwanted occurrences
- the relationship between complexity and knowledge in the workforce is often unbalanced - e.g. operator hazard training is a must!

Premature ignition of electric detonators and blast due to lightning

Pit wall failure burying 3 drill rigs in rubble
Safety of inpit operations

- *new equipment requirements for the future?*

**Rock fall source area**

**Mandatory 65’ personnel exclusion zone from highwall?**

**Rollover from terrain bench - 35m drop**
How drilling and blasting affect downstream operations

- Drilling
  - sizing drill patterns
  - drilling accuracy

- Blasting
  - field performance of explosives
  - shotrock fragmentation
  - boulders
  - floor humps
  - fines and fragment microfractures
  - muckpile profiles & swell

- Loading
  - loadability and loading capacities
  - selectivity in mining & industrial mineral operations

- Crushing
  - boulder downtime
  - crushing capacities
  - power consumption
  - production of fines and waste
Quality feed – handling boulders

- boulder count dependent on primary crusher opening (and to a lesser extent primary crusher capacity)
- sort boulders from muck pile
- down-size boulders before entering primary crusher
- minimize boulder count using reduced uncharged height and/or tighter drill patterns
Quality feed – effect of micro-fracturing

- **Rock type**: Anorthosite
- **Explosive**: Slurrit 50-10
- **Test blasts**: 4 x 50,000 tons
- **Bench height**: 36’

---

**Graph**: Percentage of 0 – 1¼” vs. Hole diameter, d (mm)

- 0 – 1¼”
- Ø3½”
- Ø4”
- Ø4½”
- Large SUB’ from prior bench level

---

**Diagram**: Feed and belt weights

- 0 – 37¼”
- 0 – 11¾”
- 0 – 2¾”
- 0 – 1¼”
- 1¼” – 2½”
Criteria for selecting drills

- **annual production requirements in bm³ or t** => number of drills
- **critical diameter of explosive** => hole size big enough?
- **flexibility in usage** => different types of work?
- **application costing** => D&B costs per t
- **level of automation**
- **operator training and support**
- **operator comfort and safety**
- **ease of transport between pits**

![Graph showing D&B costs vs. drill-hole diameter](image)

- Better blastability
- Finer fragmentation

![Drill pattern, SB (m²)](image)
Wall control D&B – Chadormalu Iron Mine

Case Study #10 – Presplitting
Chadormalu Iron Mine

<table>
<thead>
<tr>
<th>Diameter, mm</th>
<th>165</th>
<th>185</th>
<th>185</th>
<th>201</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drill Pattern</td>
<td>3.5 x 3.5</td>
<td>3 x 3.2</td>
<td>4.5 x 5.2</td>
<td></td>
</tr>
<tr>
<td>Charge, kg</td>
<td>Ø36mm PVC</td>
<td>ANFO + NTN</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sandvik Mining and Construction
Thank You
www.quarryacademy.com