The drilling pattern should be planned to produce rock sizes that are small enough to permit most of them to be handled by the excavator, such as a loader or shovel, or to pass into the crusher opening without secondary blasting.
In analyzing a job for drilling and blasting operations, there are four factors to be considered:

1. The cubic yards of rock per linear foot of hole.
2. The number of pounds of explosive per cubic yard of rock.
3. The number of pounds of explosive per linear foot of hole.
4. Will the resulting breakage meet the job requirements?

Note: The value of each of the first three factors may be estimated in advance of drilling and blasting operations, but after experimental drilling operations are conducted, it probably will be desirable to modify the values to give better results.

The fourth factor is more subjective, but the relationship between hole size and spacing gives some indication of expected results.
The relationships between the first three factors are illustrated in Table 1.

The volumes of rock per linear foot of hole are based on the net depth of holes and do not include sub-drilling, which usually will be necessary.

The pounds of explosive per linear foot of hole are based on filling the holes completely with 60% dynamite.
The pounds of explosive per cubic yard of rock are based on filling each hole to 100, 75, and 50% of its total capacity with dynamite.

When a hole is not filled completely with dynamite, the surplus volume is filled with stemming.

The rates of drilling rock will vary with a number of factors such as:

- The type of drill and bit size,
- Hardness of the rock,
- Depth of holes,
- Drilling pattern,
- Terrain, and
- Time lost waiting for other operations.
If pneumatic drills are used, the rate of drilling will vary with the pressure of the air.

The portion of time that a drill is operative is defined as the *availability factor*, which is usually expressed as a percent of the total time that the drill is expected to be working.

Historical drill penetration rates based on very general rock-type classification is shown in Table 2 (Table 12-5, Text)

These rates should be used as a guide

Actual project estimates need to be based on drilling tests of specified rock which will be encountered.
Table 2. Drilling Production Rates (Table 12-5, Text)

<table>
<thead>
<tr>
<th>Bit size</th>
<th>Drill type</th>
<th>Compressed air</th>
<th>Effective penetration rate</th>
<th>Estimated production rate good conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Granite (f/ft/hr)</td>
<td>Dolerite (f/ft/hr)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Granite (f/ft/hr)</td>
</tr>
<tr>
<td>1½</td>
<td>Rotary</td>
<td>65</td>
<td>35</td>
<td>55</td>
</tr>
<tr>
<td>3½</td>
<td>Percussion</td>
<td>85</td>
<td>40</td>
<td>65</td>
</tr>
<tr>
<td>4½</td>
<td>Dohrshale</td>
<td>70</td>
<td>45</td>
<td>75</td>
</tr>
<tr>
<td>6¼</td>
<td>Drilling</td>
<td>100</td>
<td>65</td>
<td>90</td>
</tr>
<tr>
<td>6½</td>
<td>Rotary</td>
<td>NR</td>
<td>NR</td>
<td>65</td>
</tr>
<tr>
<td>7½</td>
<td>30,000 poly</td>
<td>95</td>
<td>45</td>
<td>85</td>
</tr>
</tbody>
</table>
CHAPTER 12b: DRILLING ROCK AND EARTH

CHAPTER 12b: DRILLING ROCK AND EARTH

RATES OF DRILLING ROCK

Table 3 (Table 12-6b, Text)

<table>
<thead>
<tr>
<th>Drill bits Type</th>
<th>High silica</th>
<th>Medium silica</th>
<th>Low silica</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low mica</td>
<td>High mica</td>
<td>Low mica</td>
</tr>
<tr>
<td>B</td>
<td>1.289</td>
<td>1.176</td>
<td>1.200</td>
</tr>
<tr>
<td>STD</td>
<td>1.800</td>
<td>1.800</td>
<td>1.800</td>
</tr>
<tr>
<td>3/4 B</td>
<td>3.000</td>
<td>3.000</td>
<td>3.000</td>
</tr>
<tr>
<td>4 B</td>
<td>3.300</td>
<td>3.300</td>
<td>3.300</td>
</tr>
<tr>
<td>Rotary bits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>ST</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>ST</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>CO</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>BS</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
</tr>
</tbody>
</table>

OPTIMUM AIR PRESSURE FOR DRILLING

- Figure 1 (Fig 11-15 Text) shows the relationship between the average rate of penetration and the operating pressure for each group of drills.
- Figure 2 (Fig 11-16, Text) is a nomogram based on the information appearing in Fig. 13-15 which indicates the percent increase in penetration resulting from an increase in air pressure.

Example:
If the pressure is increased from 90 to 100 psi, the increase in penetration will be 38%.
ECONOMY OF INCREASING AIR PRESSURE

The decision to increase the air pressure at the drills should not be determined solely on the basis of the anticipated increase in production and the increase in the cost of compressed air and drilling equipment.

Drilling is only one item in a chain of operations, which includes drilling, blasting, loading, and hauling.

Figure 3 presents a curve that establishes the lowest total cost of producing the end product of a drilling operation. The curve is plotted to indicate this cost for varying air pressures.

FIGURE 13-17
Variation in the total cost of rock product with air pressure.
To begin a drilling production estimate it is first necessary to make an assumption about the type of equipment that will be used. Tables 12-5 & 12-6 provide information to guide that first decision.

The final equipment decision should only be made after test drilling the formation. Test drilling should help to quantify:

- Penetration rate
- Drilling method
- Bit size / Bit type
Penetration Rate is a function of:

- The rock
- The drilling method
- The size & type of bit

The rock properties which effect penetration rate are:

- Hardness
- Texture
- Breaking characteristic
- Formation
Hardness is the resistance of a smooth surface to abrasion.

It is measured by the MOH scale (Friedrich Mohs).

Hardness is measured by the MOH scale.

The scale is from 1 to 10, with

- Diamond rated as 10
- Talc rated as 1
HARDNESS

Scratch Test

Diamond  10.0
Schist    5.0    Knife
Granite  4.0    Knife
Limestone 3.0   Copper coin
Potash  2.0    Fingernail
Gypsum  1.5    Fingernail

Hardness affects drilling speed.

<table>
<thead>
<tr>
<th>HARDNESS</th>
<th>DRILLING SPEED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>FAST</td>
</tr>
<tr>
<td>3-4</td>
<td>FAST - MEDIUM</td>
</tr>
<tr>
<td>5</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>6-7</td>
<td>SLOW - MEDIUM</td>
</tr>
<tr>
<td>8-9</td>
<td>SLOW</td>
</tr>
</tbody>
</table>
Texture is the **grain structure** of the rock.

- A loose grained structure (porous, cavities) drills fast.
- Grains large enough to be seen individually (granite) will drill medium.
- Fine-grained rocks drill slow.

**Breaking Characteristic**

Describes how the rock breaks when struck.
• **Shatters** - into small pieces from a light blow
• **Brittle** - breaks easily with a light blow
• **Shaving** - when shaved off in pieces they break easily
• **Strong** - resists breaking when hit hard
• **Malleable** - flattens instead of breaking

---

• **Shatters** - drills fast
• **Brittle** - drills fast to medium
• **Shaving** - drills medium
• **Strong** - drills slow to medium
• **Malleable** - drills slow
ROTARY-PERCUSION

The piston provides striking energy to the rock through the drill steel. There is rotation so the bit strikes fresh rock with each blow.
PERCUSSION DRILLING

Hardness

- Quartzite: 7.0
- Trap Rock: 6.0
- Schist: 5.0
- Granite: 4.0
- Dolomite: 3.5
- Limestone: 3.0
- Galena: 2.5

ESTIMATING DRILLING PRODUCTION

The first step in estimating drilling production is to make an assumption about the type of equipment which will be used. That first assumption will be guided by the type of rock to be drilled.
CHAPTER 12b. DRILLING ROCK AND EARTH

ESTIMATING DRILLING PRODUCTION

Both Tables 2 and 3 give information that is useful in making such a decision.

Once a drill type and bit is selected, the format given in the following figure (Figure 4) can be used to estimate the hourly production.

It must again be emphasized, the final decision on the type of equipment should only be made after test drilling the specific formation.

The drilling test should yield data on the penetration rate based on bit size and type.
## ESTIMATING DRILLING PRODUCTION

### Figure 4. Format for Estimating Drilling Production

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th>(1) Depth of hole: (a) _____ ft pull, (b) _____ ft drill</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(2) Penetration rate: _____ ft/min</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(3) Drilling time: _____ min (1b)/(2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(4) Change setup: _____ min</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(5) Blow hole: _____ min</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(6) Move to next hole: _____ min</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(7) Align setup: _____ min</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(8) Change bit: _____ min</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(9) Total time: _____ min</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(10) Operating Rate: _____ ft/min (1b)/(9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(11) Production efficiency: _____ min/hr</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(12) Hourly production: _____ ft/hr (11) x (10)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## GUIDELINES FOR ESTIMATING DRILLING PRODUCTION

### (1) Depth of Hole:

Usually, when drilling for loading explosives and blasting, it is necessary to subdrill below the desired final bottom or floor elevation. This extra depth is dependent on the blasting design. Normally, 2 or 3 ft of extra depth is required. Therefore, if the depth to the finish grade is 25 ft (pull depth), it may be necessary to actually drill 28 ft.

\[
\text{Drill (ft)} = \text{Pull} + 2 \text{ or } 3 \text{ ft}
\]
(2) Penetration Rate:

The penetration rate will be an average rate developed from test drilling program based on specific bit size and type.

If no information given for a particular drill, Table 2 (Table 13) can be used for estimating the penetration rate.

Example: If a 4 1/2" drill is used @ 250 psi to penetrate dolomite, the penetration rate in minutes will be

Penetration Rate = \( \frac{110}{60} = 1.83 \) ft/min

---

Table 2. Drilling Production Rates (Table 12-5, Text)

<table>
<thead>
<tr>
<th>Bit size</th>
<th>Drill type</th>
<th>Compressed air</th>
<th>Direct penetration rate</th>
<th>Estimated production rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Granite (ft/hr)</td>
<td>Dolomite (ft/hr)</td>
</tr>
<tr>
<td>1 1/2</td>
<td>Rotary-drill 790 cfm @ 100 psi</td>
<td>15</td>
<td>45</td>
<td>35</td>
</tr>
<tr>
<td>3 1/2</td>
<td>Rotary-drill 900 cfm @ 100 psi</td>
<td>15</td>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>Downtilt drill 400 cfm @ 250 psi</td>
<td>50</td>
<td>100</td>
<td>45</td>
</tr>
<tr>
<td>6</td>
<td>Downtilt drill 600 cfm @ 350 psi</td>
<td>100</td>
<td>185</td>
<td>65</td>
</tr>
<tr>
<td>8</td>
<td>Rotary drill 30,000 fpm</td>
<td>100</td>
<td>180</td>
<td>NR</td>
</tr>
<tr>
<td>10</td>
<td>Rotary drill 40,000 fpm</td>
<td>120</td>
<td>180</td>
<td>NR</td>
</tr>
<tr>
<td>12</td>
<td>Rotary drill 50,000 fpm</td>
<td>150</td>
<td>180</td>
<td>45</td>
</tr>
</tbody>
</table>

NR: Not recommended. Estimated production rate for ideal conditions, but does not account for drilling efficiency. Including fringe.
GUIDELINES FOR ESTIMATING DRILLING PRODUCTION

(3) Drilling Time:
The drilling time shall be calculated from

\[
\text{Drilling Time} = \frac{\text{Drill Penetration Rate}}{\text{Drill}}
\]

(4) Change Steel:
If drilling depth is greater than the steel length, it will be necessary to add steel during the drilling and to remove steel when coming out of the hole.
For track-mounted rotary-percussion drills, standard steel lengths are 10 or 12 ft. They require about 0.5 min or less to add or remove a length.
STEP 4
CHANGE STEEL

Shank (Striking Bar)

Steel

Coupling

Bit

GUIDELINES FOR ESTIMATING DRILLING PRODUCTION

(4) Change Steel (Cont’d):

It is recommended by the author to use

1.1 min to add 20-ft length of steel, and

1.5 min to remove the same length of steel

NOTE: if the steel length is less than 20 ft, the time required to change steel can be taken as 0 min, unless otherwise specified.
Steel, approximate weights:

<table>
<thead>
<tr>
<th>SIZE INCHES</th>
<th>LENGTH FEET</th>
<th>WEIGHT POUNDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>10</td>
<td>53</td>
</tr>
<tr>
<td>1.5</td>
<td>12</td>
<td>64</td>
</tr>
<tr>
<td>1.75</td>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td>1.75</td>
<td>12</td>
<td>71</td>
</tr>
</tbody>
</table>

Steel
(5) **Blow Hole:**

After the actual drilling is completed, it is good practice to blow out the hole to ensure that all cuttings are removed. Some drillers prefer to drill an extra foot and to pull the drill out without blowing the hole clean.

**NOTE:** It is customary to use 0.1 min for the blow hole time, unless otherwise specified for a particular site conditions and drill type.

(6) **Move to Next Hole:**

The time required to move between drill hole locations is a function of the distance (blasting pattern) and the terrain. Track-mounted rotary-percussion drills have travel speeds of from 1 to 3 mph. However, because the hole spacing is often less than 20 ft and the operator is maneuvering to place the drill over an exact spot, the travel speed is so low.

A speed of 0.25 mph can be used.
STEP 6
MOVE

May have to lower the mast

GUIDELINES FOR ESTIMATING DRILLING PRODUCTION

(6) Move to Next Hole (cont’d):

**Example:**
If the blasting pattern is a 6 X 8 ft grid, then the time required (in minutes) to the next hole will be

\[
\text{Time required (min)} = \frac{\text{distance}}{\text{speed}} = \frac{8 (\frac{60}{5280})}{0.25} = 0.36 \text{ min}
\]

(7) Align Steel:

Once over the drilling location, the mast or steel must be aligned. In the case of rotary drills the entire machine is leveled by the use of hydraulic jacks. This usually takes about **0.5 to 1.0 min**.
CHAPTER 12b. DRILLING ROCK AND EARTH

STEP 6
MOVE TO NEXT HOLE

If drilling for blasting operations distance will be set by the blasting pattern. An 8 X 10 pattern means 8 ft between rows and a 10 ft spacing between holes. Therefore, the travel distance moving along the row is 10 ft.

STEP 7 ALIGN STEEL

Time to align is discussed on page 360. Outrigger for leveling
GUIDELINES FOR ESTIMATING DRILLING PRODUCTION

(8) Change Bit:

A time allowance must be considered for changing bits, shanks, couplings, and steel. Table 3 (Table 13-6, Text) provides information for determining the frequency of such changes.

On the average, the normal time is about 4 min.

Unless otherwise specified.

Example: A 6 1/2 in. downhole drill @ 350 psi to be used for drilling medium silica granite. What is the time required to change bit? Assume 23’ drill length.

\[
\text{Time (min)} = \text{normal time} \times \frac{\text{drill (ft)}}{\text{life (ft)}} = 4 \times \frac{23}{1800} = 0.05 \text{ min}
\]

STEP 8 CHANGE BIT

Bits, shanks, couplings and steel are all high wear items that must be replaced frequently.
STEP 8 CHANGE BIT

The time allowance for replacement is a factor of both the actual time to remove and replace, and the frequency of such changes. Table 12-6 provides frequency information.

GUIDELINES FOR ESTIMATING DRILLING PRODUCTION

Table 4 (Table 12-6a, Text)
GUIDELINES FOR ESTIMATING DRILLING PRODUCTION

(9) Total Time:

Total Time = (3) + (4) + (5) + (6) + (7) + (8)

(10) Operating Rate:

Operating Rate (ft/min) = \frac{Drill (ft)}{Total Time (min)}

(11) Production Efficiency:

With experienced drillers working on a large project, a 50-min production hour should be achievable. Sometimes, a 40-min production hour might be more appropriate.

(12) Hourly Production

Hourly Production (ft/hr) = Production Efficiency \times Operating Rate
Example 1

A project utilizing experienced drillers will require the drilling and blasting of high silica, fine-grained sandstone rock. From field drilling tests it was determined that a direct drilling rate of 120 ft per hour could be achieved with a 3 1/2 HD bit on a rotary percussion drill @ 100 psi. The drills to be used take 10-ft steel. The blasting pattern will be a 10 X 10-ft grid with 2 ft of sub-drilling required. On the average the specified finish grade is 16 ft below the existing ground surface. Determine the drilling production.

Example 1 (cont’d)

Using the format of Figure 4:
(1) Depth of hole (a) 16-ft pull (b) 18-ft drill (16 + 2)
(2) Penetration 2.00 ft/min (120 ft ÷ 60)
(3) Drilling Time: 9.00 min (18 ft ÷ 2 ft/min)
(4) Change Steel: 0.00 min (d<20 ft)
(5) Blow Hole: 0.10 min
(6) Move to Next Hole 0.45 min (10 ft ÷ 0.25 mph)
(7) Align Steel: 1.00 min
(8) Change Bit: 0.08 min (4 X 18/850 )
(9) Total Time 10.63 min

Note: 850 was obtained from Table 5
Example 1 (cont’d)

Table 5 (Table 12-6c, Text)

<table>
<thead>
<tr>
<th>Drill bits type</th>
<th>High alaska (frosted)</th>
<th>Medium alaska (frosted)</th>
<th>Low alaska (frosted)</th>
<th>Low alaska (concrete)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>900</td>
<td>1,200</td>
<td>1,600</td>
<td>2,000</td>
</tr>
<tr>
<td>STD</td>
<td>NR</td>
<td>500</td>
<td>700</td>
<td>900</td>
</tr>
<tr>
<td>STD</td>
<td>NR</td>
<td>1,000</td>
<td>1,600</td>
<td>2,200</td>
</tr>
<tr>
<td>JD</td>
<td>950</td>
<td>3,000</td>
<td>3,200</td>
<td>3,500</td>
</tr>
<tr>
<td>B</td>
<td>2,000</td>
<td>3,100</td>
<td>3,200</td>
<td>4,000</td>
</tr>
<tr>
<td>B</td>
<td>2,500</td>
<td>3,200</td>
<td>5,000</td>
<td>4,800</td>
</tr>
<tr>
<td>Heavy bits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>NR</td>
<td>1,000</td>
<td>NR</td>
<td>8,000</td>
</tr>
<tr>
<td>ST</td>
<td>NR</td>
<td>2,500</td>
<td>NR</td>
<td>15,000</td>
</tr>
<tr>
<td>ST</td>
<td>NR</td>
<td>4,000</td>
<td>4,000</td>
<td>15,000</td>
</tr>
<tr>
<td>ST</td>
<td>NR</td>
<td>6,000</td>
<td>6,000</td>
<td>20,000</td>
</tr>
<tr>
<td>CB</td>
<td>2,000</td>
<td>8,000</td>
<td>10,000</td>
<td>20,000</td>
</tr>
<tr>
<td>CB</td>
<td>3,000</td>
<td>10,000</td>
<td>15,000</td>
<td>20,000</td>
</tr>
<tr>
<td>Dowel bits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>2,500</td>
<td>3,500</td>
<td>5,000</td>
<td>7,000</td>
</tr>
</tbody>
</table>

Example 1 (cont’d)

10) Operating Rate: 1.69 ft/min $\left( 18 \div 10.63 \right)$

11) Production Efficiency: 50 min/hr

12) Hourly Production: 84.5 ft/hr $\left( 50 \times 1.55 \right)$
Example 2

The drilling production of Example 1 must match that of hauling and loading for the project, which is 500 cu yd per hour. How many drill units will be required?

\[
\text{Hole Production} = \frac{10 \times 10 \times 16}{27} = 59.26 \text{ cu yd/hole}
\]

\[
\frac{84.5 \text{ ft/hr}}{18 \text{ ft/hole}} = 4.69 \frac{\text{hole}}{\text{hr}} \text{ per drill}
\]

\[
4.69 \frac{\text{hole}}{\text{hr}} \times 59.26 \text{ cu yd/hole} = 278 \text{ cu yd}
\]

\[
2 \times 278 = 556 \text{ cu yd} > 500 \text{ cu yd}
\]

\[
\therefore \text{ Two drills will be required}
\]

DRILLING EARTH

Purposes for drilling holes in earth.

In the construction and mining industries, holes are drilled into the earth for many purposes, including, but not limited to:

1. Obtaining samples of soil for test purposes.
2. Locating and evaluating deposits of aggregate suitable for mining.
3. Locating and evaluating deposits of minerals.
4. Permitting the installation of cast-in-place piles or shafts to support structures.
DRILLING EARTH

5. Enabling the driving of load-bearing piles into hard and tough formations.
6. Providing wells for supplies of water or for deep drainage purposes.
7. Providing shafts for ventilating mines, tunnels, and other underground facilities.
8. Providing horizontal holes through embankments, such as those for the installation of utility conduits.