NOTES ON

MINE DEVELOPMENT

Drilling

INTRODUCTION

In virtually all forms of mining, rock is broken by drilling and blasting. Except in dimension stone quarrying, drilling and blasting are required in most surface mining. Only the weakest rock, if loosely consolidated or weathered, can be broken without explosives, using mechanical excavators (rippers, wheel excavators, shovels, etc.) or occasionally a more novel device, such as a hydraulic jet.

In the mining cycle, drilling performed for the placement of explosives (both OB and mineral)is termed **production drilling**. Drilling is also used in surface mining for purposes other than providing blastholes.

It finds application in (non production drilling),

1)during exploration for obtaining drill hole samples and

2)during development for drainage, slope stability, and foundation-testing purpose.

CLASSIFICATION OF METHODS

A classification of drilling methods can be made on several bases. These include size of hole, method of mounting, and type of power.

The scheme that seems the most logical to employ, a generic one, is based on the form of rock attack or mode of energy application leading to penetration.

The application of mechanical energy to rock can be performed basically in only two ways: by **Percussive** or by **Rotary** action. Combining the two results in a hybrid method termed **Rotary-Percussive.**

THEORY OF PENETRATION

Since the vast majority of rock penetration in surface mining is carried out by mechanical attack systems, the remainder of this section is devoted almost entirely to drilling.

Operating Components of System

There are four main functional components of a drilling system (and of most other penetration systems):

(1) drill (energy source);

(2) rod (energy transmitter);

(3) bit (energy applicator);

(4) circulation fluid.

These components are related to the utilization of energy by the drilling system in attacking rock in the following ways:

1. The **drill** is the prime mover, converting energy from its original form (fluid, electrical, pneumatic, or combustion-engine drive) into mechanical energy to actuate the system.
2. The **rod** (or drill steel, stem or pipe) transmits energy from the prime mover or source to the bit or applicator.
3. The **bit** is the applier of energy in the system, attacking rock mechanically to achieve penetration.
4. The **fluid** cleans the hole, controls dust, cools the bit, and at times stabilizes the hole.

Bailing velocity:

The velocity atwhich the air is passed through the blasthole for flush out drill cuttings.

In commercial drilling machines, attention has focused to some extent on reduction of energy losses in transmission. This has led to the introduction of down-hole (in-the-hole) drills, both of the large percussion variety and the roller-bit rotary (electro- and turbodrill) type, although the latter has found application mainly in oil well boring. They replace mechanical energy transmission with fluid or electrical transmission, which usually results in more energy reaching the bit and faster drilling.

Functions of Rock Drilling

A drilling (or any penetration) system must perform two separate functions in order to achieve advance into rock:

(1) fracture and break material from the solid,
(2) eject the debris formed.

The first phase is, of course, actual penetration, while the second is cuttings removal. Both affect drilling and drill performance but are distinct and separate functions of the process.

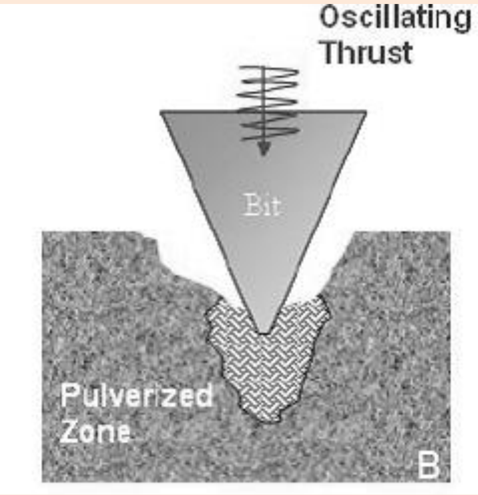
Mechanics of Penetration

As indicated earlier, there are only two basic ways to attack rock mechanically—by percussion and by rotation—and the four classes(percussion,rotary drag bit,rotary roller bit,rotary percussion) of commercial drilling methods to be discussed utilize these principles or combinations of them.

It is the **bit/rock interaction that governs the efficiency of energy transfer** and the nature of the breakage process.

Causing rock to break during drilling is a matter of *applying sufficient force with a tool to exceed the strength of the rock*. This resistance to penetration of rock is termed its **drilling strength**; it is not equivalent to any of the well-known strength parameters. Further, the stress field created by the tool must be so directed as to produce penetration in the form of a hole of the desired shape and size. These **stresses are quasi-static in nature, because forces are applied slowly in the drilling process.(quasi=seemingly/seems to be).**

Percussion Drilling:



The **applicator** in a percussion drill is a chisel-shaped or button-studded tool that impacts the rock with a hammer-like blow. The stress effective in breaking the rock acts essentially in an *axial direction and in a pulsating manner*. Rotation enables the bit to strike the rock in a different spot on consecutive blows, a mechanism called **blow indexing**, which forms contiguous craters and ultimately a directed hole in the rock. The rotational torque applied, however, is usually not responsible for any penetration of the rock, since it is small in magnitude and, with rifle-bar rotation, is operative between blows only. Likewise, the sole function of the applied thrust is to keep the bit in contact with the rock.

The sequence in crater formation is as follows:

(1) the rock is inelastically deformed, with crushing of surface irregularities;

(2) subsurface microcracks form from stress concentrations and confinement at the bit/rock interface enclosing a wedge of material, which is crushed;

(3) secondary cracks propagate along shear trajectories to the surface, forming large fragments or chips;(trajectory=the path followed by an object moving through the air).

(4) broken particles are ejected by the rebound of the bit and the cleaning action of any circulation fluid, resulting in the formation of a crater.

The sequence is repeated with succeeding blows, except that indexing tends to provide additional "free faces" that may aid rock breakage and increase crater size. Indexing(**bounding index/blow index=blows/unit time)** is not a sensitive variable, however, nor does it lend itself to precise control in drilling machines .

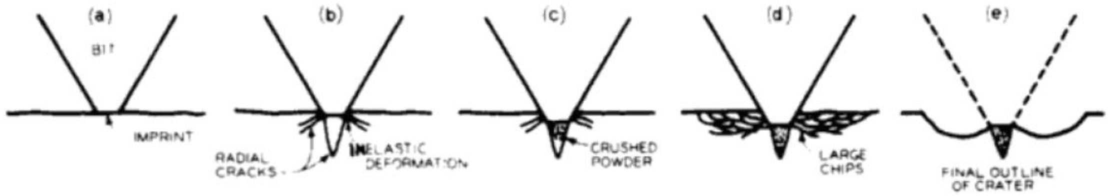


Fig. 2. Cutting sequence of a percussion drill bit (after Hartman, 1959).

In essence, insofar as rock fracture is concerned, the two predominant mechanisms in percussion drilling are crushing and chipping.

THEORY OF ROTARY DRILLING-

Rock breakage takes place due to-

- *Axial thrust*
- *Compressive shear*
- *Impact on rotation*

1)Axial thrust/ pull-down pressure, is exerted on the drill rod to which bit is attached, its amount varying directly, as the compressive strength of the rock and bit diameter. The rotary motion is also imparted to the rod and this varies, again on the rock properties-**harder the rock, lower the RPM**.

2)The pull down force exerts axial thrust on the bit (cutting edge), causing crushing of the rock at the tips of the cutting edge, at every fresh point of contact as rotation continues, producing finer powder. The combined action of rotation under pull down exerts horizontal compressive stress, on the edge of rock, being cut and it breaks under compressive shear.

The lenticular shape of the broken chips will depend upon the angle of internal friction of the rock. Due to sudden release of accumulated elastic strain on rotation under axial thrust, cutting edge causes impact on the rock, causing its crushing into fine chips. The above three actions repeat in cyclic order for every rotation. The RPM varies, from 20 for very hard rock to 150 for soft rock. In summary-

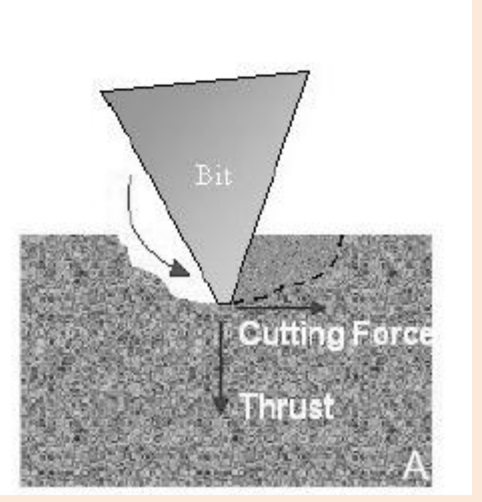
- Hard rock- high axial thrust with low rotational speed
- Soft rock- low axial thrust with high rotational speed.

Operative practice-

- Pull down force, should be sufficient to overcome the compressive strength of the rock. Excessive force will lead to bit failure. It is a joint function of the bit diameter (which determine the bearing size) and rock type.

Rotation speed (RPM)- soft: 75-160, medium: 60-80, hard: 35-70

Rotary Drag-Bit Drilling:



The planing or plowing action of a drag-type rotary drill bit is performed by a variety of tools, including blade and diamond drills as well as rope, chain, and rotary saws.

Regardless of the geometry of the device, drag action at the cutting surface is supplied by two forces:

1)thrust, a static load acting normally,

2) torque, the tangential force component of a rotational moment acting on the rock surface.

The mechanism of penetration in drag-bit drilling is as follows:

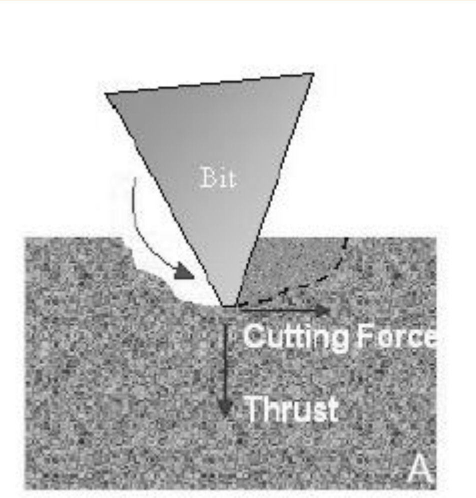
(1) as the cutting edge of the bit comes in contact with the rock, elastic deformation occurs;

(2) the rock is crushed(microcracks forms) in the high-stress zone adjacent to the bit;

(3) cracks propagate along shear trajectories to the surface, forming chips;

(4) the bit moves forward to contact solid rock again, displacing the broken fragments. One may conceive of the thrust as being responsible for indentation and the tangential force for plowing.

The similarity in cutting action of these two basic drilling systems is striking. One concludes that, under mechanical attack, rock fails alternatively by crushing and chipping, whether the energy is applied by percussion or rotation.



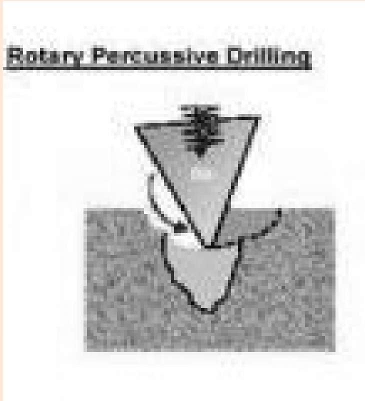
Rotary Roller-Bit Drilling:

Essentially, the same form of drill rig may be used with rolling-cutter bits as with drag bits, employing the same forces to achieve penetration (*although higher levels of thrust and torque are utilized, and heavier machines are customary*).

However, **the geometry of the roller bit is such that a hybrid cutting action**, a combination of percussion and rotary, results .

As the bit turns, cutting teeth mounted on each rotating cone alternately engage the rock, impacting, indenting, and (with "soft-rock" bits) planing it . The same crushing and chipping occur, however, as in the two basic systems; only the proportions differ.

Rotary-Percussion Drilling:



This is also a hybrid form of drilling, **combining independent percussive and rotational actions** .

Generally, percussion bits (with buttons or asymmetric wings) or sometimes roller bits are used

. In percussion drills of a down-hole design, independent rotation is utilized, and the cutting action can be adjusted from straight percussion to rotary percussion.

The superimposing of percussion on a rotary system means that higher impact forces are realized than in straight rotary drilling, but thrust and torque-induced forces are still operative.

In rotary-percussion drilling, rock failure occurs by crushing and chipping, the proportion being a function of the drilling action.

Rotary- percussive drilling depends upon the combination of the following *actions*:

- **Percussion**-the piston energy is transmitted to the bit directly in DTH drilling and through drill rod in top hammer drilling. Energy transfer is less efficient in case of the latter than the former, due to losses at rod joints and generation of heat by the reflected shock waves. Impact weakens the rock, by developing micro cracks in it.
- **Rotation**-it is necessary for the bit to strike the fresh ground. The rotational speed will depend upon rock type. Rotary axial thrust on the bit causes shear failure of rock.
- **Thrust load/feed**-it helps to keep the bit in permanent contact with the ground for better energy transfer from the hammer to the ground through the bit. Insufficient thrust will lead to lower penetration rate, greater wear of rods & sleeves, loosening & heating of rod threads. However, excessive *thrust results in lower penetration rate, rod jamming due to increased rotational resistance, more bit wear and hole deviation.*
- **Flushing**-it is necessary to removing the cuttings as soon as generated, keep the bottom of the hole clean to avoid regrinding of the same, minimize wear of bit, hammer casing and drill rod. It is done with used air alone and sometimes supplemented with water and foam. The velocity of airflow for efficient hole cleaning with air range from 15 to 30m/s, depending upon rock type. Adequate air quantity and annular space are the pre requisites for achievement of this.

Factors Influencing Drilling

A number of factors affect rock penetration or cuttings removal in the drilling process. These in turn largely determine the performance of a given drilling machine.

The various factors may be grouped in six categories:

(1) drill,

(2) rod,

(3) bit,

(4) circulation fluid,

(5) drill hole, and

(6) rock.

1)operating variables/components

Those design factors in categories 1 to 4, components of the drilling system itself, are referred to as **operating variables/components**.

Wear of the bit:

When steel tooth roller triccones are used, the drilling rate goes down considerably as the wear on the bit increases.

Feed or thrust load on the bit:

The feed force applied to the bit should be sufficient to overcome the compressive strength of the rock, but not excessive to avoid premature or abnormal failure of the tricone bit.

The drilling rate increase proportionately with the feed, up to the point where the bit becomes locked against the rock as the teeth or inserts bury into the material, or because of the high drilling rate and the large volume of cuttings produced the blasthole is not adequately cleaned.

ROTATION SPEED:

Penetration rate increases with rotation speed in a proportion that is slightly lower than the unit, up to a limit imposed by the bailing out of drill cuttings.

They are controllable within limits, interrelated in some instances, and must be selected to match the environmental conditions reflected by rock type.

2)drill hole factors

The **drill hole factors** , size, depth, and inclination, are dictated primarily by outside requirements and are independent variables in the drilling process.

The drilling rate obtained with constant feed force and rotation speed is proportional to the inverse of the squared drilling diameter.

3)rock factors

The **rock factors** are environmentally derived. They are also independent variables in the drilling process and include the following ,

1. Material properties (resistance to penetration, porosity, moisture content, density, Shore hardness, compressive strength, coefficient of rock strength, etc.)
2. Geologic conditions (petrologic and structural-bedding, fractures, folds, faults, joints, etc.)
3. State of stress (in situ pressure and pore pressure—unimportant in shallow holes).

4)job or **service factors**

Another group of factors is external to the drilling process itself and may be referred to as **job** or **service factors**. These include operational variables related to labor, supervision, job site, scale of operations, power availability, and weather. While job factors are not involved in the mechanics of rock penetration, they may exert considerable influence on drill performance.

Table 2. Operating Variables in Drilling and Their Effects on Different Methods

	Percussion	Rotary	Rotary-Percussion
1. Drill			
Drill power	x	x	x
Drill thrust	x	x	x
Drill torque		x	x
Drill rotary speed		x	x
Blow energy	x		x
Blow frequency	x		x
2. Rod			
Rod dimensions	x	x	x
Rod geometry	x	x	x
Material properties	x	x	x
3. Bit			
Bit diameter	x	x	x
Bit geometry	x	x	x
Material properties	x	x	x
4. Circulation Fluid			
Fluid flow rate	x	x	x
Fluid properties	x	x	x

ANALYZING DRILL PERFORMANCE

For the operating details of application with a particular drilling method, the reader is referred to the latter part of this section. The discussion here is restricted to the basic aspects of drilling applications.

Performance Parameters

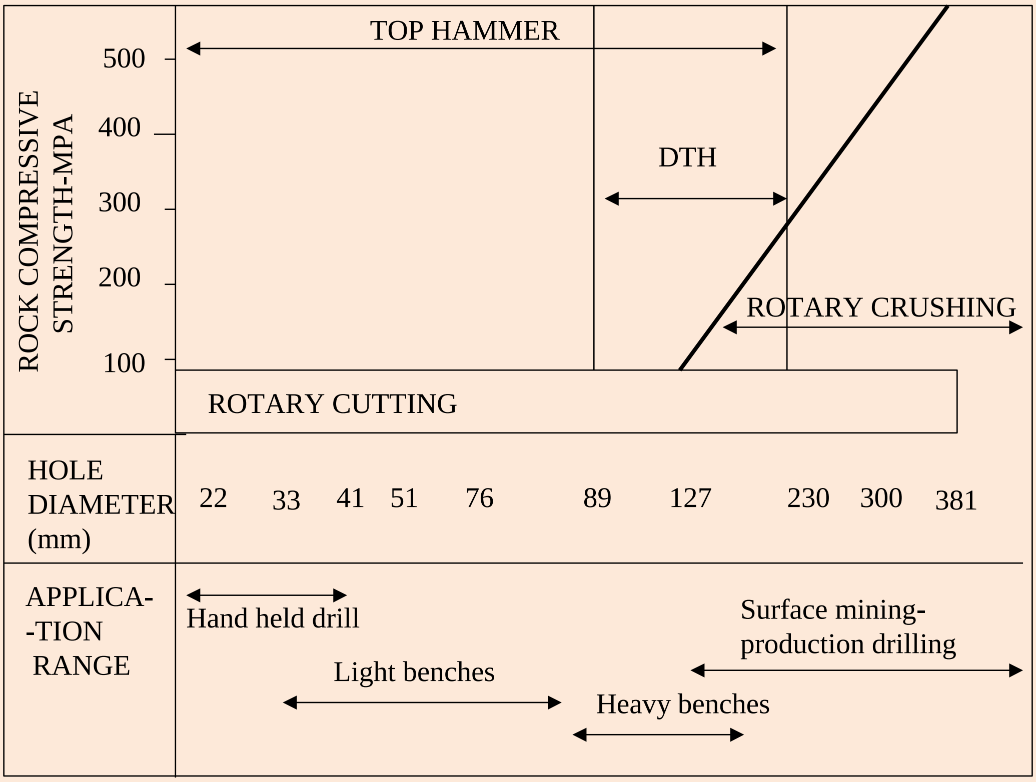
While more sophisticated criteria have been proposed, the following are adequate and employed almost exclusively in evaluating the performance of a given drilling system or in comparing different systems:

1. Energy or power
2. Rate of penetration
3. Bit wear
4. Cost

Under particular field circumstances, any one of these parameters may govern. In surface mining, energy or power consumption is becoming of increasing concern; but energies or powers, if compared, are generally of more concern because of their effect on penetration rate. Both penetration rate and bit wear are popular criteria, with rate more general in usage and wear more common for deep drilling where bit changes must be minimized.

But preeminent as a yardstick in any drilling situation is cost, for it collectively reflects all the other factors and is the ultimate measure of feasibility. A drill can have high availability and be novel, fast, and environmentally acceptable; but if it is not cost-effective, then an alternative system should be sought. (It is well to remember, however, that the goal in mining is the minimization of **all** rock breakage costs, and that drilling cannot be analyzed independently of blasting and comminution.) Nevertheless, the first three parameters (energy, rate, and wear) enter into determination of the cost and largely control it. For this reason, it is desirable to know the quantitative, individual effect of pertinent operating variables on energy, penetration rate, and bit wear, because they in turn determine the drilling cost

Selection of drilling method:



FIELDS OF APPLICATION OF DRILLING METHODS