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IIT(BHU) VARANASI

STUDENTS' NOTES

MINING MACHINERY

TOPIC-DRILLING TECHNIQUES

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Drilling Techniques

02/1/14

Methods of Drilling :

Factors influencing drilling / drillability :

① Weight on drill machine

② Thrust (rotation of drill bit)
other type of forces.

③ Rock and its ore properties :

→ hardness , abrasiveness of the rock.
Mohs's scale,
Abrasiveness — how blunt it becomes after applying blade or steel or diamond after how much time.
Diamond makes it even sharper.

→ Texture of the grains (shape & size of grains & how the inter-locking is done).

→ Interlocking & texture , also known as fabric of rock.

Texture coefficient was developed,

$$\text{Texture coefficient} \propto \frac{1}{\text{Drillability}}$$

→ strength properties of the rock.
(compressive , Tensile & shear strength. (all effect rate of penetration)

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Factors affecting drilling:

1. Bit type and their geometry
2. Applied thrust and rotational speed.
3. Flushing media and flushing rate
4. Rock Properties

1, 2 & 3 They are controllable parameters

4 is uncontrollable parameter.

Drillability index is considered a relative indication of this property for different drilling system such as rotary, percussive and rotary percussive.

Influence of hardness and abrasiveness on drillability of rocks.

Hardness is a function of hard mineral composition and the competency, strength and the bonding capacity of the matrix material.
Micro-hardness can be determined using knoop and vickers hardness testing method. This method is based on the principle of measuring the indentation depth on a polished

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surface of a diamond indenter, & NCB cone indenter is also another method. The commonly known indenters are ① Schmidt hammer

② Shore - scleroscope and shelograph

These are some of the commonly known indenters based on the principle of rebound numbers. It is generally assumed that harder the rock, more difficult it is to drill, but many hard-rocks have been drilled more easily compared to soft rocks. So in fact drillability is related to the manner in which hard crystals are bound together than to the hardness of the minerals.

It is

Higher penetration rates are achieved in Cuddalore sandstones of Neyveli in Chennai with a high percentage of quartz.

Abrasivity is not the fundamental property of the mineral. Therefore there is no single index about it but rate of wear of the cutting tool is taken as an index for abrasivity. 2 tests are defined

① Cerchar abrasiveness index test

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(2) Micro-bit drilling test:
Have been widely adopted to assess the relative abrasiveness of the mineral

The loss of weight of micro-bit made of mild steel under constant thrust and rotational speed during drilling for a specific time has been taken as the relative abrasiveness of the rock.

Abrasiveness dependents on the amount of quartz, texture & other grain characteristics.

Higher abrasiveness of rock such as sandstone sharpens the impregnated diamond bits by exposing fresh diamond grids by abrading the matrix.

Influence of rock texture on drillability of rocks:

$$\text{Texture coefficient} \propto \frac{1}{\text{Penetration rate}}$$

The method of quantitative assessment of rock texture consists of 4 components

(1) Measurement circularity
(2) Measurement elongation
(3) Measurement grain
(4) Weight of grain

Texture with data

Infl drill This

$\delta =$
$T =$
$\mu =$
$F_V =$
$S =$
$A =$

Penetration per revolution (inch)

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1. Measurement and analysis of grain circularity.
2. Measurement and analysis of grain elongation
3. Measurement and quantification of grain orientation.
4. Weighting the result based on degree of grain packing.

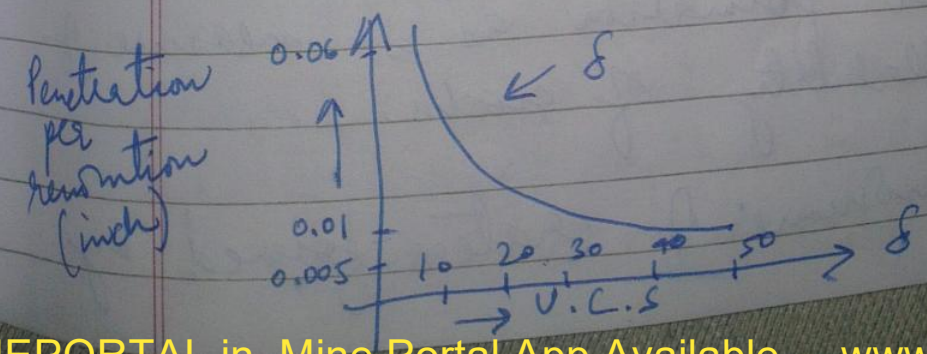
Texture coefficient is highly significant with rock strength and drillability data

Influence of strength properties on drillability of rocks:

This formula

$$\delta = \frac{2\pi (T - \mu F_v Y)}{S.A - F_v}$$

δ = Depth of penetration per revolution
T = Applied Torque (N-m)
μ = coefficient of frictional resistance
F_v = Applied thrust on bit (N)
S = Resistance of rock drilling or U.C.S.
A = Cross sectional area.



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Percussive drilling: Percussive drilling shows correlation with DRI (drilling rate index) and DRI expresses the rock properties that are important in drilling such as hardness, strength, brittleness and abrasiveness. This index is a relative drillability value given to various rocks and was determined from the data obtained from the Swedish drop hammer brittleness and Siever's miniature drill test. Higher the DRI value, greater will be the drillability.

Rabia and Brook proposed an empirical relation for percussive drilling. It relates penetration rate to drill operating pressure (DOP), SH (~~Sole~~ Shore hardness), RIHN (Rock Impact hardness number).

$$PR = C\left[\frac{(DP)^a}{(RIHN \times SH)^b}\right]$$

Crater formation as a measure of drillability of rocks:

The volume of crater formed by

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different types of impact testers can be used for determination of drillability of rocks with respect to percussive drilling.

$$R = \frac{2.4(P - P_t)}{d^2 S}$$

S = drilling strength

P is the mechanical power input to the rock in (lb/min)

P_t is threshold power in (lb/min)

d is the threshold diameter

Specific Energy as a criterion for drillability:

This idea was proposed by Teale & he defined SE as the energy required to remove a unit volume of rock.

However Surface SE is defined by others as the SA created by the amount of energy.

$SE_V = C_0 \times 10^{-9}$ — mellor

C_0 is the compressive strength

$$SE_V = \frac{2.35\, WN}{d(PR)}$$

Tricone roller bit rotary drilling.

W = weight on bit in kg

N (rev/min)

d = diameter of bit

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PR = penetration rate (m/min)

9/1/15 Percussive Drilling: is done broadly by 3 methods:

1. Churn drilling.
2. Rock drilling
3. Down-the-hole drilling

~~Churn~~ Percussive drills reproduce mechanically the action of hand held drill and hammer. A reciprocating piston usually actuated by compressed air but sometimes by hydraulic fluid provides the necessary source of impact and this energy is transmitted to the rock through various modular elements. They include compressed air, piston, anvil, drill rod and bit rock interface

Churn drilling: is also known as cable tool drillings, spudding and so forth. In this type of drilling the entire piston rod bit combination is actuated by a reciprocating mechanism using gravity impact. Vertical holes of 150-300mm diameter can be drilled in the

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rocks of all hardness. These drills are usually self propelled crawler mounted and provided with hydraulic jacks on which they are lifted up and levelled during drilling. They may be electric or diesel operated but diesel operated drills are preffered in areas where access routes are not readily available. The drilling tool comprises of a rope socket, drilling jars, drill stem and chisel drill bit. They are connected to each other by tool joints. The 4 basic components together form the tool string whose combined weight provides the force needed to drill the rock-mass.

Bailing is the process of removing drill cuttings from the hole. For this a bailer also called a sludger or a vacuum sand pump is used, the sludger consists of a pipe 3.5 m long having a diameter equal to 0.3 times of the hole diameter. It has a non-return valve at the bottom and which opens when the sludger rests at the bottom of the

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hole. Thus ~~down~~ allowing the sludge to enter. The valve is closed when sludge is raised. a sand-pump is used in sand and gravel as sludger cannot pick-up the material. It consists of a tube with hinged flap valve and a plunger that rocks inside the barrel. The sand line is attached to the top of the plunger rod.

The work done below the tool

$$A_1 = \frac{m v_0^2}{2}$$

$$= \frac{w\sqrt{(2ah)^2}}{2g} = \frac{wha}{g} \text{ (kg.m)}$$

$A = A_1 n$ (m/min) work done per minute

$V = \frac{\pi d^2}{4} PR$ cm²/min volume of rock broken per minute.

w = weight of the tool

V_0 = velocity of tool at the moment of impact.

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a = acceleration of tool inside hole partly filled with sludge. (m/s^2)

h = height of fall of tool

g = acc^n due to gravity.

V = volume of rock broken

PR = Rate of penetration

d = diameter.

The specific work done

$$S.E. = \frac{A}{V} \quad kg.m/cm^3$$

$$P.R = \frac{4.w.h.a.n}{\pi g d^2.SE}$$

SE = specific work of breaking in churn drilling and it varies from 5 to 100 $kg.m/cm^3$ for soft to hard rocks.

Disadvantages of this method:

(1) This is limited to vertical drilling only (2) Production output is very low per shift.

(3) Drill line failure is very frequent

Incompatibility for deep holes especially for hard formations.

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Rock drills or hammer drills:
Rock drills are manufactured in various sizes and may be classified as jack hammers, drifters, stops, jumbos and wagon drills.

Jack hammers are relatively small weighing around 30 kg and used to drill small holes 25 to 40mm in diameter and can be used vertical as well as horizontal position. The other types of rock drills are heavy machines and requires a suitable supporting system for easy mobility. These drill machines supported on a compressed air piston air bag are commonly termed drifters or stops. Jumbo's have a self propelled undercarriage system with booms on which drills are mounted. They may be crawler mounted or track mounted and can be propelled by air, electric, hydralic or diesel motor. Thrust is applied mechanically usually by screw feed mechanism. Tyre mounted drills in this range are known as wagon drills

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and are used for U/G stope drilling & for O/C bench drilling.

Operating principle of rock drills:
The essential component in rock drill is in delivering blows against the bottom of the rock and lifting the rock cuttings. The rock drill basically consists of

(1) Hard steel piston which delivers impacts to the shank of the drill rod. The piston comprises a head which slides in the cylinder and is smaller in its diameter. The shaft is cut externally by straight splines which fit inside the similar grooves on the chuck by means of which the hexagonal shaped drill rod is attached to the drill. The ratchet and pawl mechanism restrict the rotation of the riffle bar in 1 dir^n only.

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Indexing: For efficient drilling the single or multiple type cutting wedges, the bit must rotate as each blow is applied to the drill rod. This phenomena is called indexing. This rotation should be optimum.

Rotating of the bit presents a new surface to the bit for each blow causing chipping, crushing and consequent penetration.
For angular indexing in percussive & rotary percussive drilling, there is no critical angle. The rotating mechanism provides for a relatively constant resolution of the steel for each blow and there are many factors which can cause indexing angle to vary such as resistance to rotation, effects of reflected stress waves in the rock, inertia of rotating parts, rock defects and the like.

Energy Generation and Transmission in Percussive Drilling:
In percussive drilling, a piston is caused to accelerate along a cylinder by the application of compressed air along one side of the piston. The

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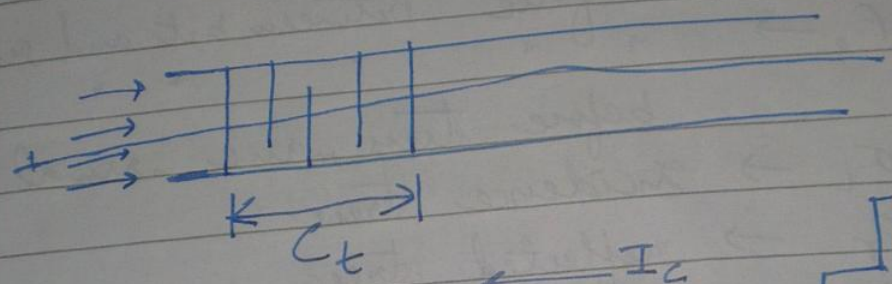
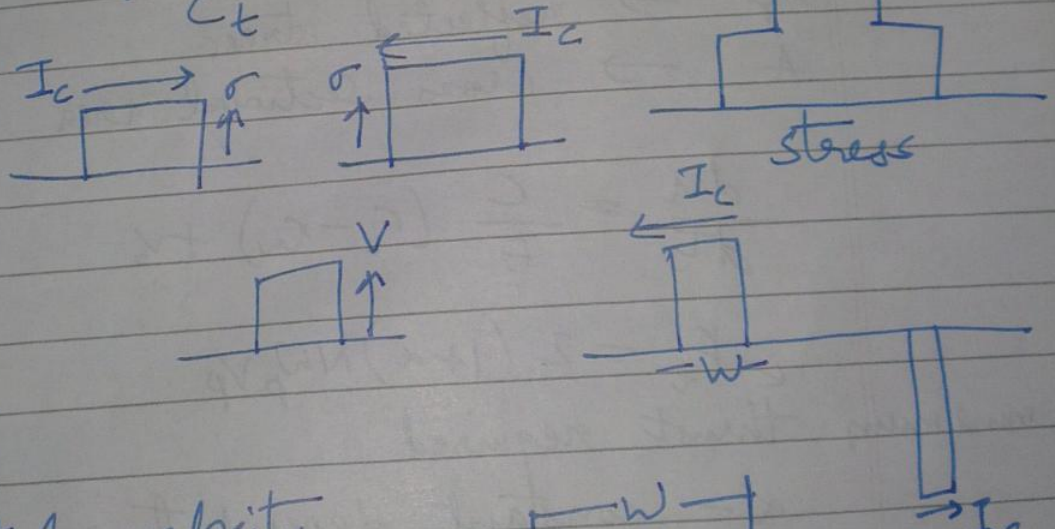
piston then impacts a drill steel transferring its momentum and energy to the steel in the form of a stress wave. The wave is then transmitted along the drill steel to the bit rock interface where the stress level is raised sufficiently by the wedge shape of the bit to cause rock failure and bit penetration.



$$V = \frac{\varepsilon C_t}{t} = \frac{\sigma C t}{E t}$$



$$V = \frac{\sigma C}{E}$$

V = particle velocity

C = wave velocity

E = modulus of elasticity

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Requirement of Thrust in Drills:

The stress wave generated by the piston in the drill steel travels to the bit rock interface part of the energy in the wave goes into rock breaking and part is reflected. Some energy is elastically transmitted. Simon has given a relation

$$F = (\sigma_i + \sigma_r)A + F_0$$

$F \rightarrow$ total force between bit and rock

$F_0 \rightarrow$ " " " " " " before stress wave arrival

$\sigma_i \rightarrow$ incidence stress

$\sigma_r \rightarrow$ reflected stress

$A \rightarrow$ cross sectional area.

$$\frac{du}{dt} = \frac{C}{E}(\sigma_i - \sigma_r) + v_0$$

$$F_t = 2(1+\alpha) N W_p V_p$$

minimum thrust required

α – constant dependent on piston geometry and wave reflected

$n \rightarrow$ no. of blows/min

W_p – piston weight

V_p – piston impact velocity.

At lower thrust, force energy is not properly transmitted to the rock, much of the energy gets dissipated & concentrated

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in machine and drill rod. This results in shorter life of drill steel due to metal fatigue. However there is an optimum level of thrust below which penetration suffers due to inefficient energy transmission and above which penetration falls off due to problem of indexing and flushing. Ultimately if thrust continues to be increased at a given operating air pressure, a point will be reached at which drill will stall.

The bit takes the essential form of a diametral wedge shape as in a chisel bit or cross bit, the wedge angle is an important factor. If it is broad and produce obtuse angle to the rock, a small depth of penetration will be obtained due to larger area of contact. On the other hand a sharp bit which effects an acute angle to wedge penetration generates higher contact stresses with max. compressional component at a smaller angle to the surface of the rock.

Rotary percussive drilling:

① Down the hole drilling: In conventional percussive drilling, the energy transmitted from the piston to the cutting edge of the drill bit diminishes as the depth of hole increases. This is due to partly friction

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damping and flexural energy losses in the drill rod but mainly to energy transmission losses at their connecting joints

* Due to these disadvantages and damage to the bit, therefore another alternative drill is required that is rotary rock drills.

The advantage of rotary percussive rock drilling is that it is able to penetrate hard rocks with continuous cutting process. Therefore these machines consist essentially a rotary air motor to drive the drill combined with a pneumatic motor which delivers impact directly on a drill rod. The rotational drive is through gears with a speed of 100, 200 & 300 rev. per minute. In this machine, hydraulic motor replaces compressed air unit of rotation & thrust and only percussive motor is actuated by compressed air & thrust is supplied by

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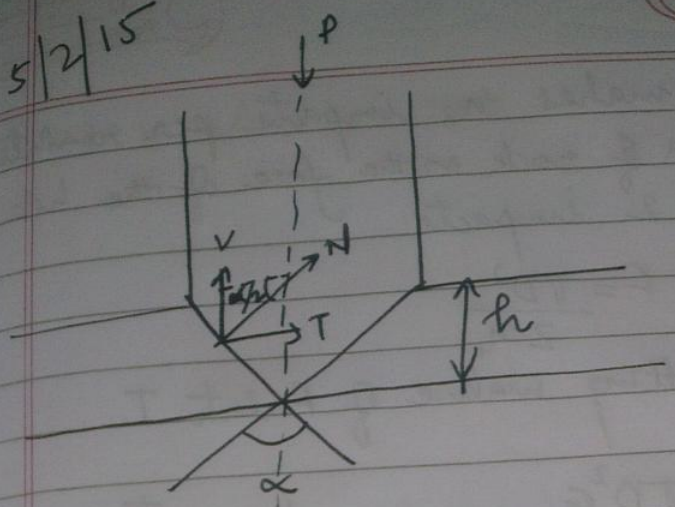

Resisting forces on wedge shaped bit

$$T = N\cos\frac{\alpha}{2} = \frac{P}{2}\left\{\tan\frac{\alpha}{2} + \mu\right\}$$

$$F = \pi D^2 / 2\mu_0$$

$$P = 2V + 2W\cos\frac{\alpha}{2}$$

$$V = N\sin\frac{\alpha}{2}$$

$W = N\mu$ = force of friction between bit & rock.

μ = coeff. of friction

$$N = \frac{\sigma_c . D . h}{\cos\frac{\alpha}{2}}$$

D = diameter of bit

σ_c = compressive strength

$$P = 2N\left\{\sin\frac{\alpha}{2} + \mu\cos\frac{\alpha}{2}\right\}$$

$$= 2Dh\sigma_c\left\{\tan\frac{\alpha}{2} + \mu\right\}$$

$$h = \frac{P . h}{2D\sigma_c\left\{\tan\frac{\alpha}{2} + \mu\right\}}$$

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If bit makes n_0 impacts per revolution, the area of rock on the face of the hole between 2 impacts

$$F = \frac{\pi D^2}{2 n_0}$$

Now putting value of F into T.

$$T = \frac{\pi D^2 \sigma_s}{2 n_0} \qquad \sigma_s \text{ shear strength}$$

$$n_0 = \frac{\pi D^2 \{\tan \frac{\alpha}{2} + \mu\} \sigma_s}{P}$$

$$n = n'/n_0$$

n' = No. of impacts per second

~~Combin~~ $V = 2hn = 2hn'/n_0$

$$V = \frac{2Phn'}{\pi D^2 (\tan \frac{\alpha}{2} + \mu) \sigma_s}$$

Combining eqn, we have required no. of impacts per revolution

During the process of penetration, the value of P increases from 0 to max when depth reaches to h.

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acts per revolution,
face of the hole

f into T.

shear strength

τ_s

second

n_0

quired no. of

It is also seen that

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