Technical Area: 2 Drilling Tools and Equipment

Item: 2-1 Selection of drilling bit and drilling method

1: Objectives
To be able to explain and advise for differences between drilling methods and how to select them according to geological conditions.

2. Contents
- Principles of DTH method and mud rotary method and cable tool method
- Selection of drilling methods and bits according to geological conditions

3. Teaching Methods
(1) Explain principles of DTH, mud and cable and tool drilling using manual.
(2) Explain how to select drilling method according to geological conditions using manual.
(3) Explain how to select bit among blade bit, rotary bit and tricone rotary bit for mud drilling.

4. Materials
2-1M1 DDCA's Manual for Drilling Works

2 DRILLING TOOLS AND EQUIPMENT (TA CODE 2)

2.1 SELECTION OF DRILLING BIT AND DRILLING METHOD (TA CODE 2-1)

2.1.1 PRICIPLES OF DTH, MUD AND CABLE AND TOOL DRILLING

(1) Types of Drilling Rig

Hydrogeology/ Drilling as an option has a major activities namely as;

1. Prospecting for groundwater
2. Drilling and well construction

Prospecting for groundwater deals with the investigation of groundwater existing at certain areas. The aim of this task is to allocate well sites to produce water for human consumption. But a geologist after this prediction is yet to prove weather his work is successful unless the water is exploited.

The task of exploitation is given to the drillers. The driller sinks the well through the earth to strike water from underground and takes it out to the surface to accomplish the task of drilling and well construction. This work is done by the aid of drilling machine called a rig.

What is a Rig

A rig is a device , which is used to penetrate through the earth to a certain depth underground to exploit minerals for human consumption.

Types of Rigs

1. Cable and tool percussive drilling (percussion)
2. Rotary drill rig (schramn, xu 600 , pilcon, Romanian, Diamond)
3. Percussive rotary drill rig (schramn, aquadrll etc)
4. Core rotary drill rigs(, xu 600, pilcon, diamond)
5. Reverse circulation rotary drill rigs (Romanian)

EXPLANATION OF DRILLING RIGS

a. **Rotary Rigs** ; This type of rig is designed to drill by applying rotation to the drilling head driven by hydraulic oil pressure, which eventually drives the drilling string to rotate . Bits like roller , alloyed bit and short bits are used.
b. **Percussive Rotary Rigs;** In this type of rig the rotation application is quite the same , except that the bit is connected
c. **Cable and tool Percussive Rig;** This type of drilling method is accomplished by regular lifting and dropping of a strings of tools. This phenomenon is aided by means of connecting rod crank mechanism of oscillating movement to the locker frame. The rocker frame ,the drum with a rope, which has the connection to the pulley and drilling string.
d. **Core Rotary Rigs** ; In this type of rig the drilling method is to drill and take out cores instead of rocks dust (rock cuttings) Hollow bit and core barrel are used drilling tools
e. **Reverse Circulation Method;** In this method of drilling, setting of the circulation system is reversible, that means the fluid flows hydraulically in the well, and then the cuttings are uplifted inside the drill pipe up to the swivel where the sucktion hose is connected to let out cuttings to the pump which eventually pumps the cuttings out to the mud pit.

(2) Drilling Methods

There are various drilling methods, because of geological conditions range from completely unconsolidated sediments such as alluvial sand and gravel to hard rock such as basalt and granite. It is obviously then , that no single drilling methods is best for all geological conditions and well installations successfully drilling in both , an art developed from long experience and application of good engineering practices.

Well construction usually comprises five distinct operations

a. Drilling operations
b. Installing the casing
c. Placing a screen and filter pack
d. Developing well to ensure sand free operation at maximum yield(pumping test)
e. Well completion

The term well drilling method is being used here to include all methods used in creating holes in the era and for well construction purposes. It includes methods like boring and driving which are not drilling methods in a pure sense.

Three drilling methods which are employed in DDCA are 1) DTH drilling method, 2) Mud rotary drilling method and 3) Cable and tool drilling method. Mud rotary drilling methods and Cable and tool drilling method are regarded as the types of Mud drilling methods. Cable and tool drilling rigs are used for cable and tool drilling method, while rotary cum drilling rigs are used for both Mud rotary drilling method and DTH drilling method. In this manual, drilling techniques of DTH drilling and Mud rotary drilling are described as the drilling equipment to be hired to the private drilling companies are of the type of DTH cum rotary. Principles of each drilling methods are described below.

1) DTH Drilling Method

The (DTH) down the hole hammer is rotary percussive tool, which operates at the bottom of the end of the hole being drilled. It is attached at the end of the drill string and powered by compressed air flowing down the center of the drill string into the hammer. The air operates a piston within the hammer, which strikes the rear end of the drill bit providing a percussive action. The pneumatic drill can be used on any standard rotary rig with an air compressor of sufficient capacity. It is used for fast and economical drilling of medium to extremely hard formation. Fast penetration results from the air piston blows are transmitted directly to the bit without losing energy through the string. Figure 1 show the mechanism of DTH drilling method.

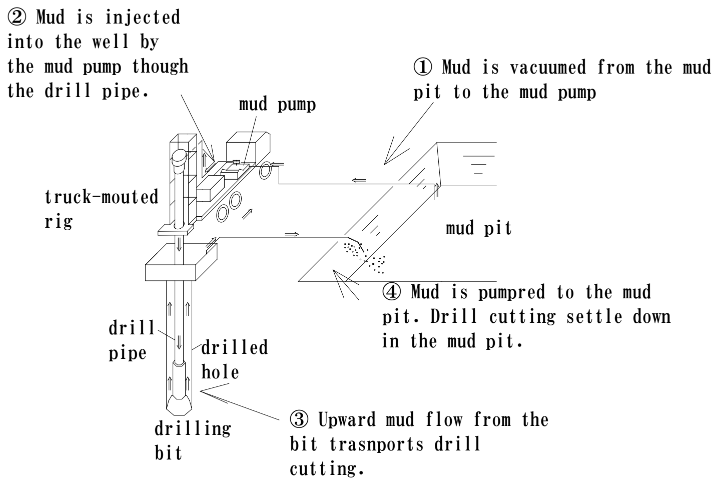


Figure 1 Mechanism of DTH Drilling Method

Performance varies with different makes of DHH but as an example a particular hammer provided with 8 BARS (116Psi) air pressure will deliver 15.5 blows per second at the piston striking the bit and with 14 BARS (250Psi) air pressure will deliver 23 blows per second.

In water well drilling particularly air pressure must also overcome ground water pressure when encountered. When drilling under the head of water, a back pressure is exerted against the air pressure of the hammer and as the air pressure is less the back pressure approaches the minimum operating pressure of the hammer penetration rates will gradually fall to zero, and in the fact the hammer will cease to operate.

2) Mud Rotary Drilling Method

In this method, action is accomplished by rotating a drill pipe by means of a power driven rotary table or top-head type swivel, with a bit cuts and breaks up the material as it penetrates the formation. Drilling fluid for mud is pumped through the rotating drill pipe and through the hole picking up material broken by the bit. Then flow upwards in the space outside the drill pipe, carrying the cutting to the ground surface, and clearing the hole. The greater fluid flow the faster the drilling. The drill pipe and bit move downward deepening the hole as the operation proceeds. At the surface, drilling mud flows into a ditch to a settling pit where the cuttings settle to the bottom. From the settling pit the fluid overflows into another pit from which it is picked up through the suction hose of the mud pump and re-circulated through the drill pipe. In thr mud rotary drilling method the casing pipe is not introduced until the drilling operations are completed. The walls of the hole are held in place by the pressure of the mud against the sides of the hole. ***Figure 2*** shows the mechanism of mud rotary drilling method.

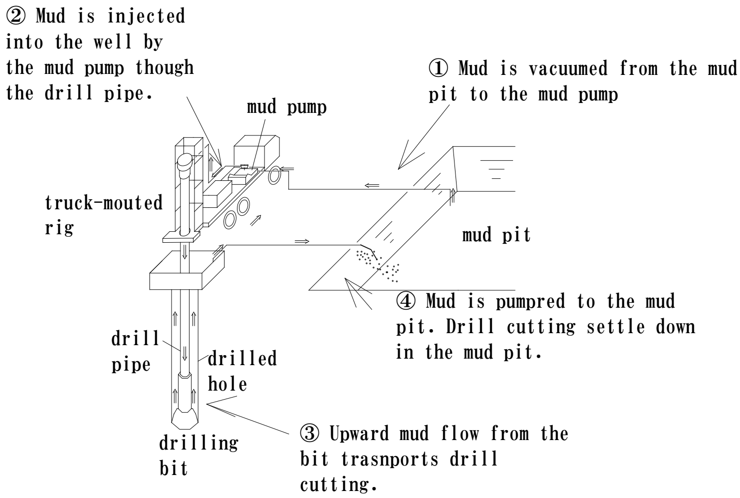


Figure 2 Mechanism of Mud Rotary Drilling Method

3) Cable Tool Method

The cable tool drills which drills by means of lifting and dropping as many as 60 times a minute, a drill bit to break-up and loose the material in well crushing and breaking the formation material

The cable tool method has survived for thousands of years because it is reliable for a wide variety of geological conditions. ***Figure 3***

The tool method offer the following advantages

1. Drilling are relatively inexpensive
2. Rig have low energy requirements
3. Rig are simple in design and require little sophisticated maintenance
4. Well are stabilized during the entire operation
5. Taking samples is possible from every depth
6. Well can be constructed with little chance of contamination
7. Only 2 person are needed to operate rig

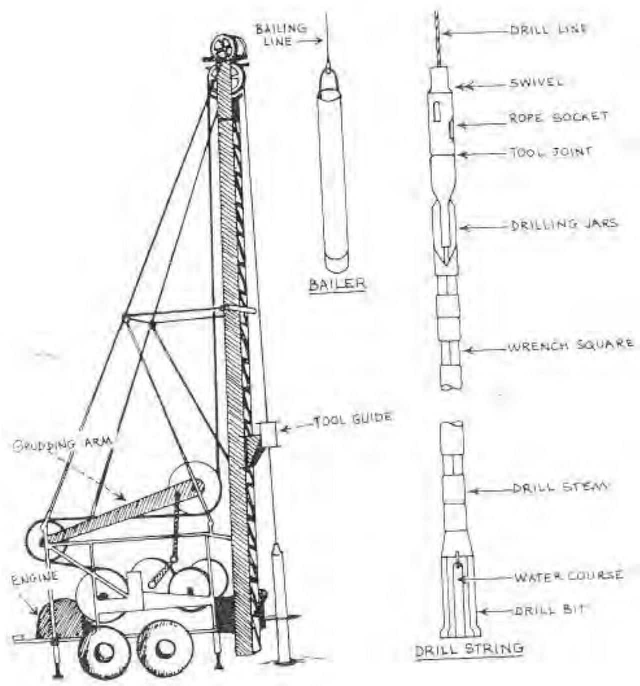


Figure 3 Structure of Cable and Tool Drilling Machine

8. Well can be drilled in area where little water exist
9. Rig can be operated in all temperature regions
10. Well can be drilled in formation where loosen circulation is a problem
11. Well can be bailed at any time to determine the approximately field

DISADVNTAGES OF CABLE TOOL METHOD / METHOD ARE

1. Productive output measured in hole produced per day is low
2. In hard rock's where penetration rate may be very low
3. When casing is required , deep drilling presents problems in keeping the casing free
4. The heavy hammering action causes disturbance and damage in same formation

2.1.2 SELECTION OF DRILLING METHODS AND BITS ACCORDING TO GEOLOGICAL CONDITIONS

A drilling method is to be selected principally based on their performance for types of geological formations, as shown in ***Table 3***.

Table 1 Drilling Performance of Drilling Methods for Type of Formation

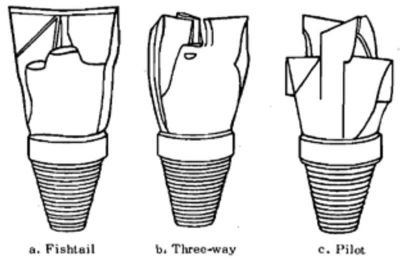
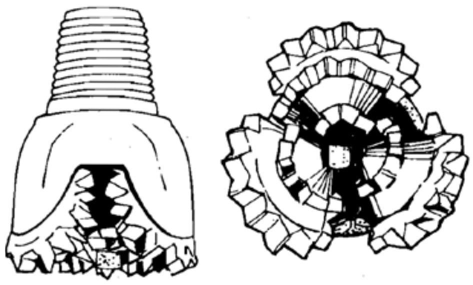
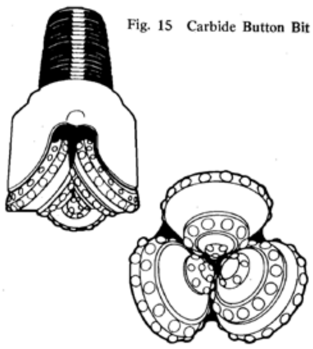
Type of Formation	Cable and Tool	Mud Rotary	DTH
Dune sand	Difficult	Rapid	Not recommended
Loose sand and gravel	Difficult	Rapid	Not recommended
Quicksand	Difficult, except in thin streaks. Requires a string of drive pipe.	Rapid	Not recommended
Loose boulders in alluvial fans or glacial drift	Difficult – slow but generally can be handled by driving pipe.	Difficult, Frequently impossible	Not recommended
Clay and silt	Slow	Rapid	Not recommended
Firm shale	Rapid	Rapid	Not recommended
Sticky shale	Slow	Rapid	Not recommended
Brittle shale	Rapid	Rapid	Not recommended
Sandstone – poorly cemented	Rapid	Rapid	Not recommended
Sandstone – well cemented	Fair	Slow	Not recommended
Chert nodules	Slow	Slow	Not recommended
Limestone	Slow	Rapid	Very Rapid
Limestone with chert nodules	Very Slow	Slow	Very Rapid
Limestone with small cracks or fractures	Very Slow	Slow	Very Rapid
Limestone cavernous	Very Slow	Slow to impossible	Difficult
Dolomite	Very Slow	Rapid	Very Rapid
Basalts, thin layers in sedimentary rocks	Slow	Slow	Very Rapid
Basalts – thick layers	Slow	Slow	Rapid
Metamorphic rocks	Slow	Slow	Rapid
Granite	Slow	Slow	Rapid

Source: Drillers Training and Reference Manual

Though the cable and tool method is effective for the collapsible and/or large size gravel layer, the mud rotary cum DTH method can cover larger range of geological conditions. Therefore, the major drilling methods which are used in DDCA are the mud rotary and the DTH methods.

Rotary cum DTH drilling rigs correspond to both DTH methods and mud rotary method. Therefore, suitable drilling method and bits are selected basically according to the hardness and collapsibility of the formations.

Table 2 Selection of Bit for Rotary Cum DTH Drilling

Formation	Drilling Method	Bit
Soft Formation	Mud Rotary	 Drag Bits are used used for very soft and unconsolidated formations such as clay and sand.
Medium Formation	Mud Rotary	 Tri-cone tooth bits are used for soft to hard formations. The tooth of cone is long for soft formation and short for hard formation.
Hard Formation	Mud Rotary	Fig. 15 Carbide Button Bit  Carbide Button Bit is used for hard formation. This type of bits needs the certain weight on bit in order to obtain the proper drilling progress (more than 3 tons). Therefore it is not suitable for small capacity drilling rigs.
Very Hard Formation	DTH	 The down the hole hammer (DTH) is suitable for very hard and consolidated formations. They are used for waterwell drilling in most of the areas of the mainland of Tanzania.

Technical Area: 2 Drilling Tools and Equipment

Item: 2-2 Rotary Bits

1: Objectives
To be able to explain and advise for type, structure and use of rotary bits for mud drilling.

2. Contents
- Type of Rotary Bits
- Structure of Rotary Bits

3. Teaching Methods
(1) Explain type of rotary bits and their structure, using manual and catalogs.

4. Materials
2-2M1 DDCA's Manual for Drilling Works
2-2M2 Drilling Chap. 3. P263-269

2.2 ROTARY BITS (TA CODE 2-2)

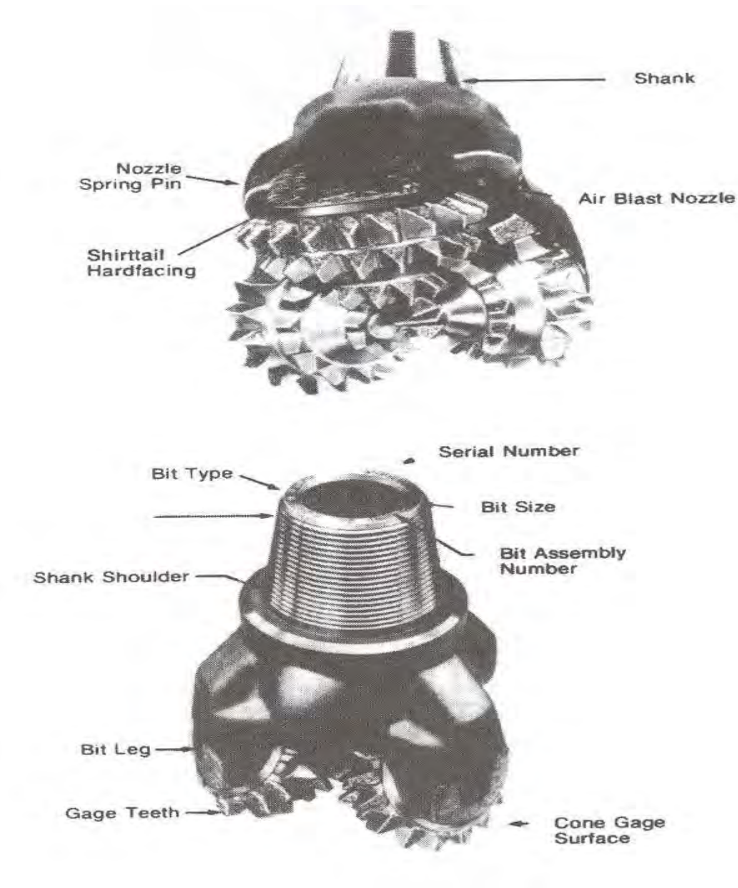
As shown in ***Table 4***, DDCA uses the three types of rotary bit i.e. drag bit, tri-cone tooth bit and carbide button bit. Commonly to each type of rotary bit, a bit has a pin connection of API Regular (Reg.) standard. The ***Table 5*** shows the connections of each size of the rotary bits.

Table 5 Connection of Rotary Bit

Bit Size	Connection
3-1/2" – 4-1/2"	2-3/8" Reg. Pin
4-3/2-4" – 5-1/8"	2-7/8" Reg. Pin
5-3/8" – 7-3/8"	3-1/2" Reg. Pn
7-7/8" – 9"	4-1/2" Reg. Pin
9-5/8" – 15"	6-5/8" Reg. Pin

Figure 4 shows the structure of tri-cone tooth bit. The drillers shall execute the following bit control to realize the proper drilling operation:

- Prompt checking of wearing and cleaning of bit after pulling-out from the hole,
- Checking of diameter to prevent from the decrease of hole diameter. In case of drag bits, standard diameter shall be kept by welding,
- Record of bit operation hours with necessary information such as rotation speed, weight on bit, pump pressure etc.



Source: Australian Drilling Industry Training Committee Limited

Figure 4 Structure of Tri-cone Tooth Bit

Recognising what's happening

Torque and feel are important indicators of downhole conditions. Increased torque is an indication of extra power required downhole, as in hard drilling. Slow penetration and "chatter" or "bounce" are also indications that boulders or hard zones are encountered. The driller then determines by feel and experimentation how to proceed.

When a hard zone or object is encountered, the driller can increase bit thrust and observe the result. If the bit cuts without deviation, penetration can proceed.

If torque builds, a sideways force is building which can cause deviation. The driller should attempt to clear the hole and then recheck the torque.

Auger drilling is frequently used for site investigation drilling. When operated with careful feeling for thrust and torque applied, the driller's record becomes a reliable statement of variations in subsurface conditions.

Changes in degree of saturation of the formation can cause large differences in the drilling forces. The driller's record must include information on moisture content.

Auger drilling functions and uses are further described in Chapter 11, particularly in Environmental Drilling and Sampling and in the context of sampling in Chapter 8.

Section 5 Rotary bits and tools

- The rotary bit drive
- Rotary blade bits
- Rotary roller bit design
- Chip clearing with roller bits
- Bits for soft formations
- Bits for medium formations
- Roller bits for hard formations
- Maintenance for tricone bits
- Hammer bits
- Caring for hammer bits
- Straight and crooked holes
- Control over deviation
- Rotary undercutters and hole openers

The rotary bit drive

Bits used when drilling by one of the rotary methods operate using combinations of four forces:

1. thrust force.
2. rotary force.
3. percussive force.
4. hydraulic or fluid force.

Provision and transmission of these forces have been discussed in earlier chapters. In this chapter, we examine the many types of bits, the mixture of forces necessary to achieve the cutting action and the way that the forces are delivered at the bottom of the hole.

Other forces (often undesirable) enter the drill string.

These forces may come from:

- gravity effects,
- inertia (either rotary or in line with the hole),
- vibration (from bit or rod movements),
- formation factors.

A driller using one of the rotary methods must select the most suitable bit (1) to make best use of the useful drilling forces and (2) to tolerate or counteract the forces not wanted.

The type of bit used will depend on the mode of the drilling and the formation(s) to be drilled. The bit must make chips and contribute to the clearing of the chips. Since chip making and clearing depends on the relationship of the bit to the rock drillability, there should be a good match. The control which the driller has over the bit while it is in the hole is not sufficient to make an unsuitable bit operate correctly.

The correct bit must be used along with suitable down hole tools such as collars or stabilisers to control its action and contribute to its performance. A bit program should be prepared. It will show the numbers of bits required in each type. Bit sizes chosen depend on the ultimate intentions for the borehole.

Chapter 5 provides more guidance in making bit decisions based on rock drillability.

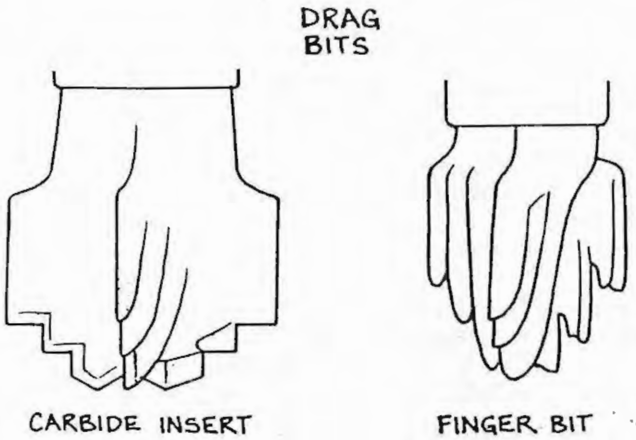
Rotary blade bits

Rotary fluid flush drilling in soft formations such as clays and weathered shales makes use of **blade bits for stirring** as well as for **cutting** and **shearing** actions. These bits make maximum use of rotary forces and hydraulic forces.

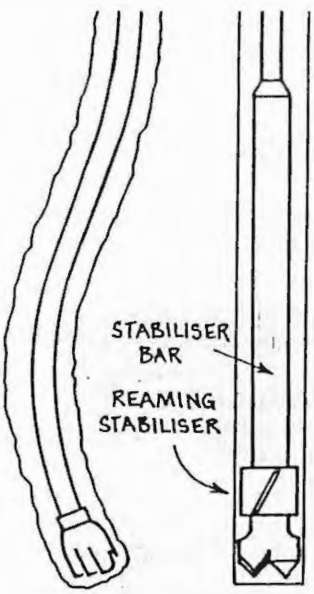
The rotary energy makes the chips. The hydraulic energy contributes to chip making and clears the chips.

Unconsolidated formations: These formations are cut with bits having a forged or hard faced edge suited to **stirring.** Circulated fluid is directed on the bottom of the hole through the bit nozzle.

In contrast, hard clays and **consolidated formations** are cut better if a sharp cutting edge is provided. The edge is usually hard faced or fitted with carbide inserts to resist wear. Some formations form better chips if a plowing action is provided using a finger type drag bit.



Unstabilized blade bits are prone to drill crooked holes. The large rotary forces cause the bit to move away when it strikes an obstacle. Any thrust force will buckle the pipe.



Reaming stabilisers and **drill collars** or **large diameter stabiliser bars** reduce the tendency to run off.

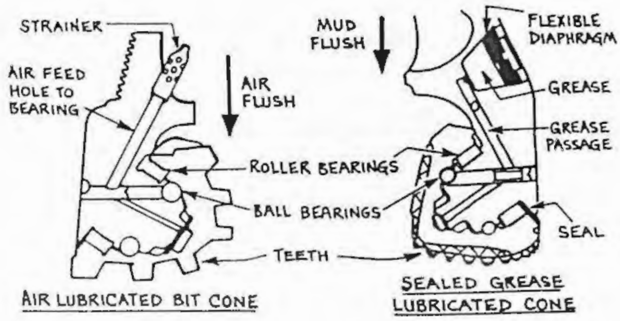
Rotary roller bit design

A drilling program should be planned to make best use of modern bit designs. Roller bits offer many variations in design:

1. different tooth material, shape, height and spacing.
2. different cone rolling patterns resulting from changes in shape of the cone and in alignment of the cone axes.
3. different placement, size and direction of the openings or nozzles directing flow of the circulation fluid.
4. different types of bearings with differing provision for bearing lubrication.

Drillers using roller bits on water well, mineral investigation, and similar projects that call for light, or medium weight rigs, will not be able to load their bits sufficiently to take full advantage of the high performance bits designed for oil-field work or for use on heavy blast-hole rotary rigs. They have to make better use of their total system to provide clean, straight holes.

Selection of bearing type: The cheapest design provides non sealed roller bearings with the circulating fluid passing through and lubricating the bearings. Such bearings have short life when used with sand laden mud but provide excellent performance when run with air, mist or foam.

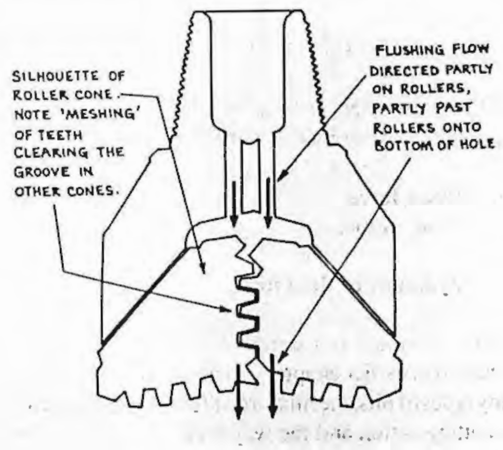


Bits for mud circulation are provided with sealed bearings. Most have a built-in reservoir of grease, but some must be replenished by fitting a grease nipple and pumping grease in.

High load bits are built with bush type friction bearings rather than the roller race shown.

Chip clearing with roller bits

A regular (nonjetting) bit provides flushing through a hole or holes drilled in the centre of the bit.



Drilling operations

In general, water and mineral drilling operations require a versatile bit design. This is the "full hole" mud circulation type, which directs the flushing flow onto the rollers as well as the hole bottom. Such bits can be used in air drilling operations without modification.

A bit designed to allow air flow throughout the bearings would need to have the air passages plugged if it is to be pressed into use for mud drilling.

The fluid flow over and past the rollers provides a turbulent flow zone at the bottom of the hole. The turbulence stirs up the cuttings as they are produced. The flow lifts the cuttings away from the bottom of the hole.

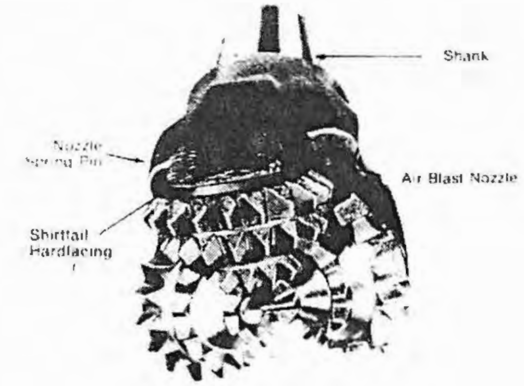
When running the bit into the hole, the pump should always be started and circulation in progress before running the bit to bottom. Forcing the bit into a mass of cuttings is likely to jam one of the cones, causing it to slide rather than roll when drilling starts.

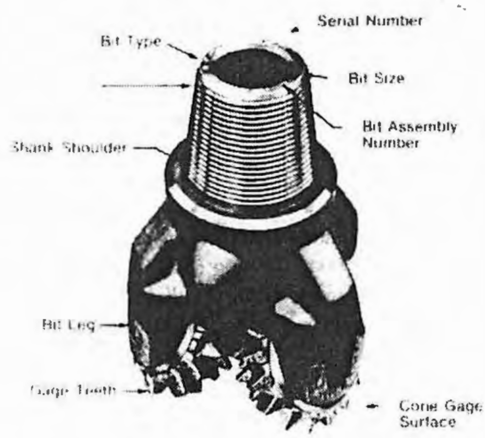
Chips may be "sluiced" from the bottom of the hole using **jet bits** (Section 1). If the full performance of a jet bit is to be gained, the bit must be supplied with fluid using a high volume, high pressure pump. These bits are more common in oilfield and other applications encountering high downhole fluid pressure.

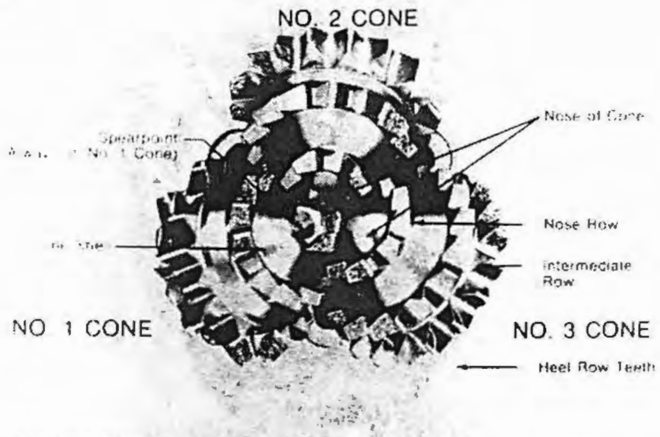
Bits for soft formations

Plastic or sticky formations require a well defined cutting action to separate the chips. With the appropriate rig and equipment, greater efficiency is obtained using correctly designed blade bits.

Roller bits: The use of roller bits allows good penetration with lower torque than is required for blade bits. In this case, more of the cutting energy is provided by the thrust force.







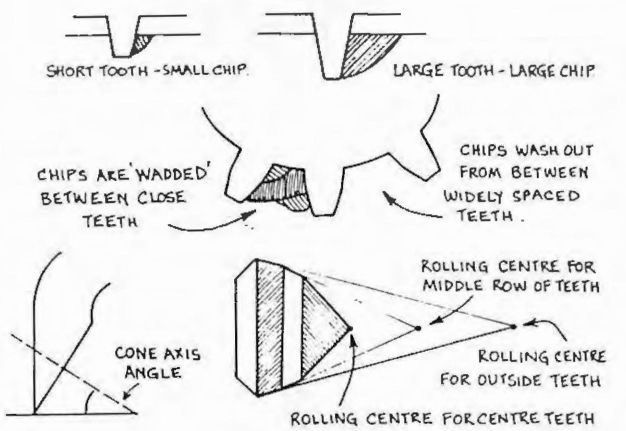
Roller Bit Terminology (Toothed Bit)

A roller bit for soft formations (low compressive strength, e.g., calcite, shale, clay) is designed with long teeth to give large penetration and large "rolling chips" (Section 1) with comparatively light weight and down pressure. Bit geometry is adjusted to give the best desirable scraping action at the hole face.

Such soft formation zones frequently contain abrasive units and layers of medium hard material. In such sandy and harder formations, hardened teeth are required.

Drilling operations

Widely spaced teeth allow for easier clearing of the "sticky" chips typical of clay and shale. The angle that the cone axes make with the bottom, the centre lines of the axes and the rolling centre for the cones are all adjusted to force a twisting-tearing-scraping action rather than a rolling action on the bottom of the hole.



Normally, soft formation bits are run with relatively low weight, ranging from 500 to 1400 kg (1,100 to 3,000 lb) per inch of bit diameter. Rotary speeds usually range from 85 to 100 rpm, depending on the application (more in Section 6). Tooth breakage may indicate that either weight or rpms are too high.

- use the bit with the longest and sharpest teeth.
- use a bit with a near true rolling action.
- increase the fluid flow to the maximum possible to improve the clearing and bit contact on the bottom.

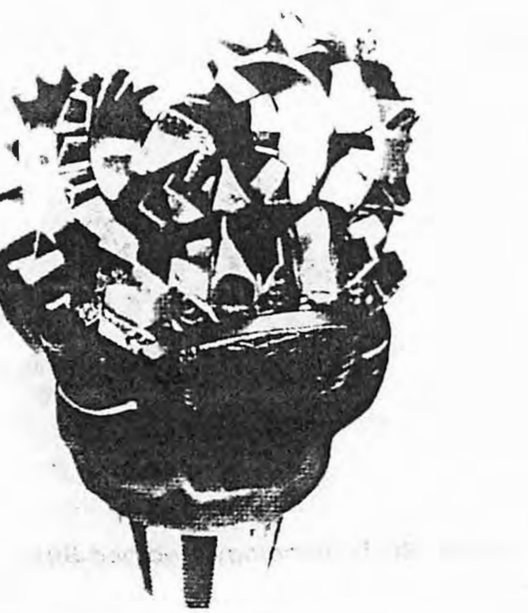
Bits for medium formations

Harder formations tend to chip more easily. Consequently, bits for medium formations will have a greater number of shorter, more closely spaced teeth. This change in design gives more chipping-crushing action.

Some cone offset to produce chipping is desirable. The offset angles of 3 to 4 degrees, used in soft formation bits, are reduced to 1 to 2 degrees in medium formations.

Higher thrust forces are necessary to give good penetration rates in medium formations. A consequence is higher bearing wear. The life of bits in harder formations is determined by a balance between tooth and bearing wear.

Sandstones and other abrasive formations require bits with hardened teeth, particularly at the gauge, and hard-faced shoulders to resist undersized holes. Bits with teeth comprising chisel-shaped tungsten carbide inserts and carbide gauge and shoulder facings are available. Hard-faced, large gauge surface bits with closely spaced teeth are a good choice for alternating shales, sandy shales, and limestones, typical of old marine basins.



MEDIUM FORMATION BITS

HARD FORMATION BITS

Note: there is a tendency for water well and exploration drillers to purchase and run refurbished oilfield bits due to their economy. Drillers operating light machines will find that an oilfield type bit, with a large "offset" between the axes of the cones, may require more bit weight than can be applied efficiently by a light machine. When the thrust force is limited:

Selection for penetration rate: Higher penetration rates are obtained with bits designed for soft formations.

When selecting a bit for a medium formation, the very large range of bits available for formations described as medium/soft, medium or medium/hard makes selection difficult.

Always prefer the bit design for softer rather than harder formations. The weakness of the longer, wider spaced teeth is offset by better chip clearing. Tooth weakness can be compensated for by hard facing.

In medium and harder formations, bits with reinforced gauge teeth or webs between the gauge teeth will give better life.

Application: Weight can be applied effectively to these types of bits due to their more rugged cutting structure and bearings. Excessive rotation speed should be avoided to reduce shock loads, particularly in broken formations, which cause rough operation. Rough operation reduces bearing and cone life. Weights generally range from 500 to 2300 kg(1,100 - 5,000 lb)/inch bit diameter and rotation from 60 to 100 rpm.

When changing a bit, particularly if a different design bit is being run, **always** allow a **break in** period. Do not "bump" the bit into the bottom, but ream it down gently to **break** the formation **in** to match the different bottom hole profile of the new bit.

Roller bits for hard formations

Hard formation bits are designed to overcome high compressive strength, using more crushing action and eliminating shearing action to the extent possible. Such bits also must withstand abrasiveness. Hard formation examples include:

- high compressive strength/low abrasiveness - dolomite.
- high compressive strength/high abrasion - granite, siliceous limestone, hard dolomite.
- medium compressive strength/high abrasion - sandstone and other quartz-containing granular rock, copper ores.

As you can see, there is also variety in "hard" formations, and bits should be chosen to meet the need.

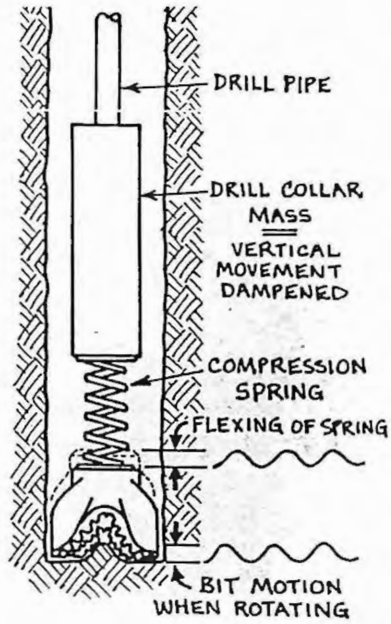
Hard rock cannot be torn or cut. It must be fractured. Any twisting, tearing action in the bit used will result in broken teeth and high wear. Hard formations must be drilled with bits having a true rolling action, that is, zero cone offset.

The hard-formation bit also requires a higher capacity bearing. High thrust loading is required (1800 to 3000 kg or 4,000 to 6,000 lb per inch bit diameter) and will cause failure of the hard facing on hard faced teeth used in soft to medium formations. The teeth in the hard formation bit are either case-hardened steel or tungsten carbide inserts with conical or hemispherical ends.

Carbide teeth hold their shape better and will drill with lower thrust forces that those required for steel toothed bits. Tungsten carbide is a brittle material, and bits with carbide teeth should not be subjected to vibration.

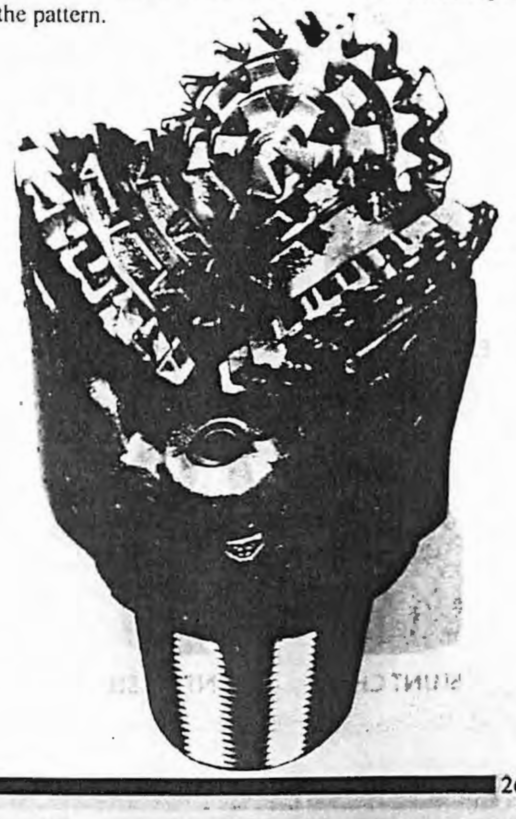
Shock absorber: Shock and vibration can be dampened downhole. In a typical case, a roller bit tends to ride up and down on an uneven formation. It develops a cyclic vibration, which may carry up the drill string to take shock loading to the rig and also may damage carbides.

The action of the shock absorber will reduce vibration damage.



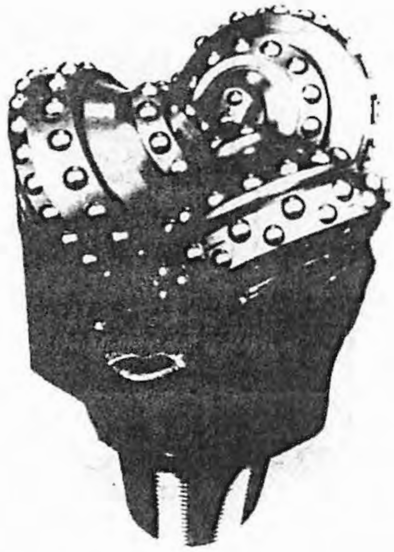
To avoid slipping or skidding on bottom, the bits are rotated at low speeds (40 to 80 rpm). They are never rotated without sufficient thrust to ensure that the cones do roll.

In the typical design, the outer row of teeth on each cone is the driving row, generating a rock gear pattern on the bottom, which is not easily broken in tough rocks. A webbed gear surface is used on the heel rows of teeth to break up rock in the pattern.



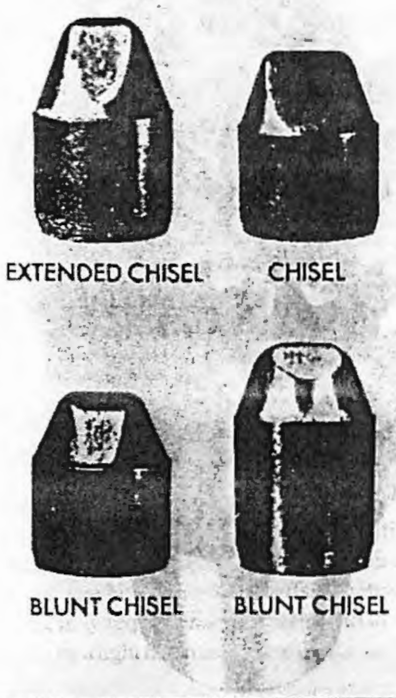
Very hard formation bits

This bit type has sintered tungsten carbide compacts for cutting edges instead of the more conventional chisel-shaped teeth.



They were introduced to drill extremely hard and abrasive rocks, such as chert, quartzite, and taconite. Modifications resulted in compact mineral drilling bits for hard abrasive copper and other hard basic metal ores.

In this type of bit, the insert design is specifically chosen for the rock type to be drilled. This selection process mirrors teeth selection on other roller bit types: more chisel shaped compacts are used on "softer" types and shorter, more rounded types on extremely hard rock.



All tungsten carbide bit designs incorporate the use of inserts in the gauge surfaces of the cones and combinations of inserts and hard facing on the shoulder and bit leg to resist loss of gauge due to abrasion.

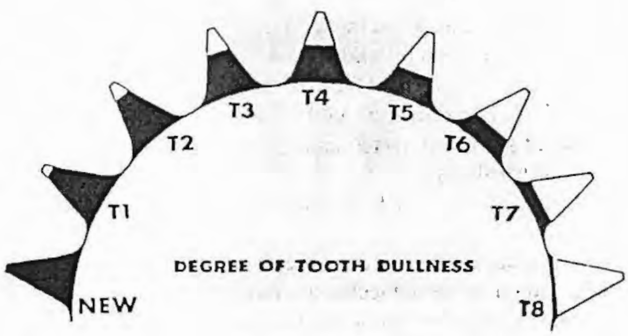
While more expensive, carbide insert bits provide better meterage per bit, typically 4 to 10 times the meterage obtained from steel-tooth bits. The penetration rate is also higher, and remains more constant through the bit life in relatively uniform drilling.

Weight and rotation are not greatly different from steel tooth hard formation bits. Weights run in the range of 1800 to 3600 kg (4,000 - 8,000 lb) per inch diameter and rotation 50 to 80 rpm.

Maintenance for tricone bits

The primary means of care for roller bits is proper selection of bit type for the drilling conditions and application of optimal pressure and rotation (next section).

Steel tooth bits cannot be retouched, but wear can be observed and records kept to build a body of experience in your drilling program. If you are keeping records, pick a system and stick with it. The International Association of Drilling Contractors adopted a system of reporting wear in "eighths" (1/8 gone = T1, 1/4 gone = T2, etc.).



Degree of undergauge can be measured using a standard gauge ring or a piece of steel casing with a known I.D. With the ring or casing touching two of the cones, measurement of undergauge is made between the third cone and the inside of the ring or casing.

Bearing condition must be checked regularly to ensure trouble free operation. Loose cones, stuck cones and bearing exposure caused by shirttail wear are all indicators of bearing wear.

Hammer bits

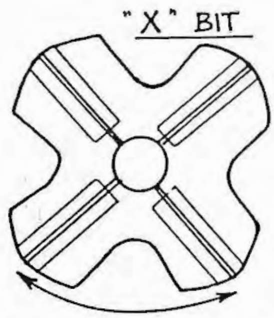
Hammers provide light rigs with the ability to drill hard rock; rock that cannot be drilled economically or quickly using any other method unless a much heavier rig is available.

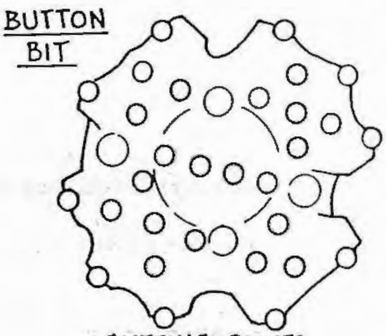
For most hammer drilling, button bits provide lower costs per metre drilled as they give:

- faster penetration and
- longer runs between grinding.

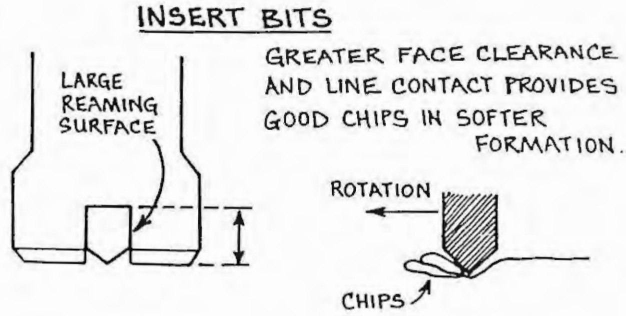
The button bit drills more efficiently because the percussive forces are distributed over the bottom of the hole.

Chisel or cross bits concentrate the energy at the centre of the hole. Most of the outer edge is without effective cutting points.





However, **cross "X"** or **insert bits** are more resistant to heavy gauge wear. In some formations, insert bits drill straighter than button bits, and in softer formations which are "scooped out" rather than shattered, insert bits can give better penetration.



Button bits are available, with buttons of varying sizes to suit different formations and to suit the energy output of the hammer. Button patterns are varied to suit the rock and the hole size. Bits with a cutting edge at the back shoulder are supplied to drill "backwards" when caving could be a problem.

Caring for hammer bits

Carbide insert breakage and loss: Carbide inserts are fragile, so handle them carefully. Bits can fail in a variety of ways due to careless use.

- **Carbide shear:** This is the most common type of carbide breakage. Although strong in compression, it is relatively weak when subjected to tensile or shearing forces.

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Torque and feel are important indicators of downhole conditions. Increased torque is an indication of extra power required downhole, as in hard drilling. Slow penetration and "chatter" or "bounce" are also indications that boulders or hard zones are encountered. The driller then determines by feel and experimentation how to proceed.

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Section 5 Rotary bits and tools

- The rotary bit drive
- Rotary blade bits
- Rotary roller bit design
- Chip clearing with roller bits
- Bits for soft formations
- Bits for medium formations
- Roller bits for hard formations
- Maintenance for tricone bits
- Hammer bits
- Caring for hammer bits
- Straight and crooked holes
- Control over deviation
- Rotary undercutters and hole openers

The rotary bit drive

Bits used when drilling by one of the rotary methods operate using combinations of four forces:

1. thrust force.
2. rotary force.
3. percussive force.
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Provision and transmission of these forces have been discussed in earlier chapters. In this chapter, we examine the many types of bits, the mixture of forces necessary to achieve the cutting action and the way that the forces are delivered at the bottom of the hole.

Other forces (often undesirable) enter the drill string.

These forces may come from:

- gravity effects,
- inertia (either rotary or in line with the hole),
- vibration (from bit or rod movements),
- formation factors.

A driller using one of the rotary methods must select the most suitable bit (1) to make best use of the useful drilling forces and (2) to tolerate or counteract the forces not wanted.

The type of bit used will depend on the mode of the drilling and the formation(s) to be drilled. The bit must make chips and contribute to the clearing of the chips. Since chip making and clearing depends on the relationship of the bit to the rock drillability, there should be a good match. The control which the driller has over the bit while it is in the hole is not sufficient to make an unsuitable bit operate correctly.

The correct bit must be used along with suitable down hole tools such as collars or stabilisers to control its action and contribute to its performance. A bit program should be prepared. It will show the numbers of bits required in each type. Bit sizes chosen depend on the ultimate intentions for the borehole.

Chapter 5 provides more guidance in making bit decisions based on rock drillability.

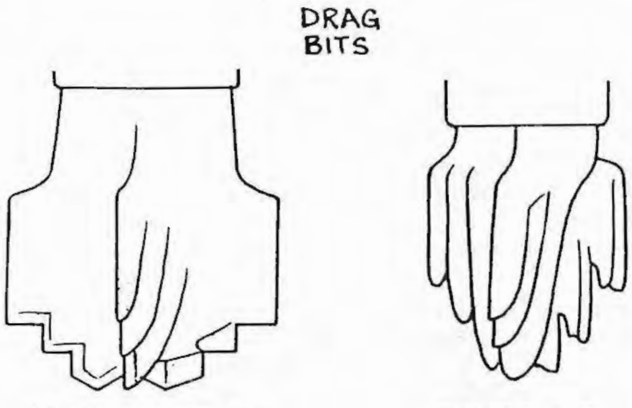
Rotary blade bits

Rotary fluid flush drilling in soft formations such as clays and weathered shales makes use of **blade bits for stirring** as well as for **cutting** and **shearing** actions. These bits make maximum use of rotary forces and hydraulic forces.

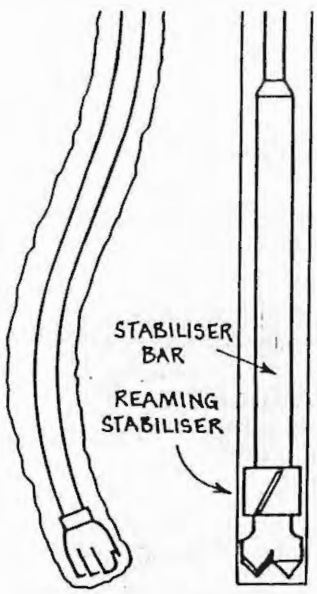
The rotary energy makes the chips. The hydraulic energy contributes to chip making and clears the chips.

Unconsolidated formations: These formations are cut with bits having a forged or hard faced edge suited to **stirring.** Circulated fluid is directed on the bottom of the hole through the bit nozzle.

In contrast, hard clays and **consolidated formations** are cut better if a sharp cutting edge is provided. The edge is usually hard faced or fitted with carbide inserts to resist wear. Some formations form better chips if a plowing action is provided using a finger type drag bit.



Unstabilized blade bits are prone to drill crooked holes. The large rotary forces cause the bit to move away when it strikes an obstacle. Any thrust force will buckle the pipe.



Reaming stabilisers and **drill collars** or **large diameter stabiliser bars** reduce the tendency to run off.

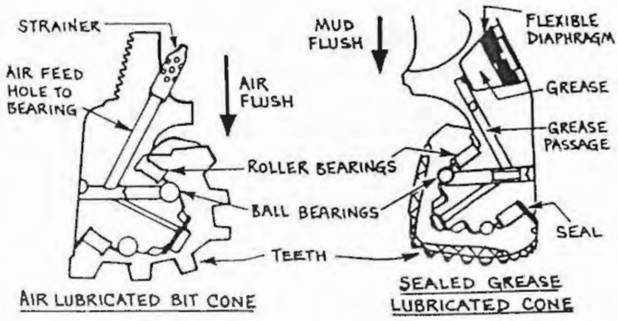
Rotary roller bit design

A drilling program should be planned to make best use of modern bit designs. Roller bits offer many variations in design:

1. different tooth material, shape, height and spacing.
2. different cone rolling patterns resulting from changes in shape of the cone and in alignment of the cone axes.
3. different placement, size and direction of the openings or nozzles directing flow of the circulation fluid.
4. different types of bearings with differing provision for bearing lubrication.

Drillers using roller bits on water well, mineral investigation, and similar projects that call for light, or medium weight rigs, will not be able to load their bits sufficiently to take full advantage of the high performance bits designed for oil-field work or for use on heavy blast-hole rotary rigs. They have to make better use of their total system to provide clean, straight holes.

Selection of bearing type: The cheapest design provides non sealed roller bearings with the circulating fluid passing through and lubricating the bearings. Such bearings have short life when used with sand laden mud but provide excellent performance when run with air, mist or foam.

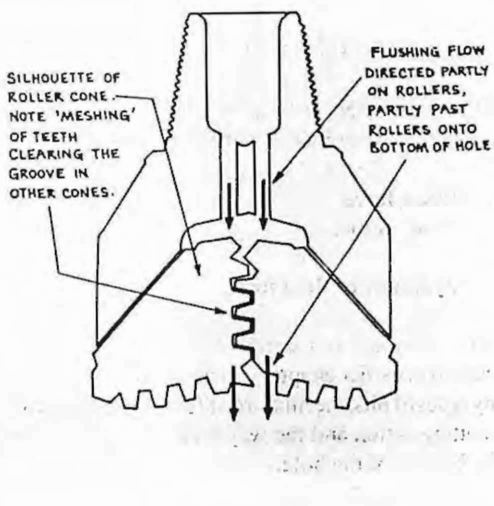


Bits for mud circulation are provided with sealed bearings. Most have a built-in reservoir of grease, but some must be replenished by fitting a grease nipple and pumping grease in.

High load bits are built with bush type friction bearings rather than the roller race shown.

Chip clearing with roller bits

A regular (nonjetting) bit provides flushing through a hole or holes drilled in the centre of the bit.



In general, water and mineral drilling operations require a versatile bit design. This is the "full hole" mud circulation type, which directs the flushing flow onto the rollers as well as the hole bottom. Such bits can be used in air drilling operations without modification.

A bit designed to allow air flow throughout the bearings would need to have the air passages plugged if it is to be pressed into use for mud drilling.

The fluid flow over and past the rollers provides a turbulent flow zone at the bottom of the hole. The turbulence stirs up the cuttings as they are produced. The flow lifts the cuttings away from the bottom of the hole.

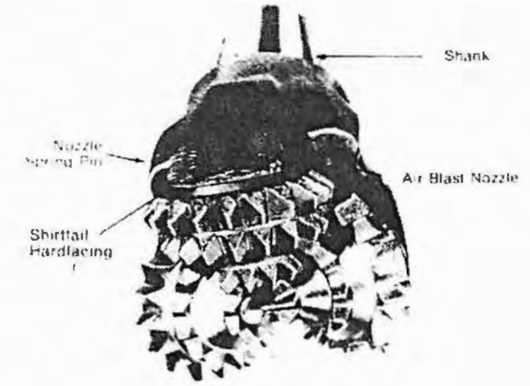
When running the bit into the hole, the pump should always be started and circulation in progress before running the bit to bottom. Forcing the bit into a mass of cuttings is likely to jam one of the cones, causing it to slide rather than roll when drilling starts.

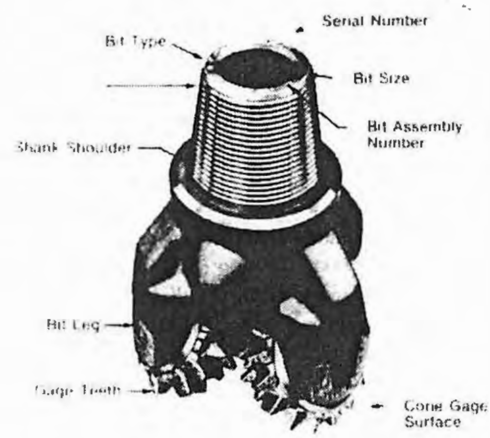
Chips may be "sluiced" from the bottom of the hole using **jet bits** (Section 1). If the full performance of a jet bit is to be gained, the bit must be supplied with fluid using a high volume, high pressure pump. These bits are more common in oilfield and other applications encountering high downhole fluid pressure.

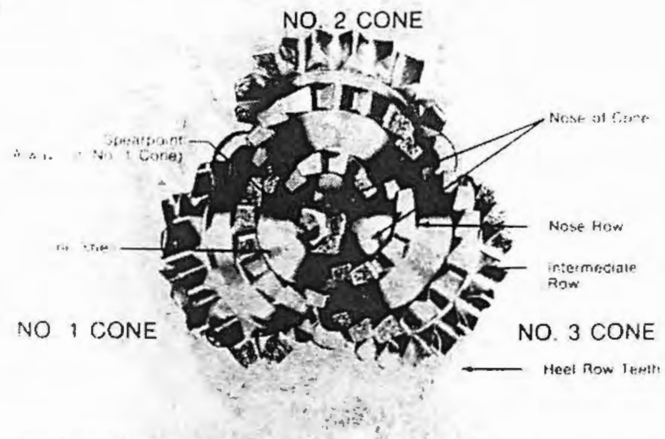
Bits for soft formations

Plastic or sticky formations require a well defined cutting action to separate the chips. With the appropriate rig and equipment, greater efficiency is obtained using correctly designed blade bits.

Roller bits: The use of roller bits allows good penetration with lower torque than is required for blade bits. In this case, more of the cutting energy is provided by the thrust force.





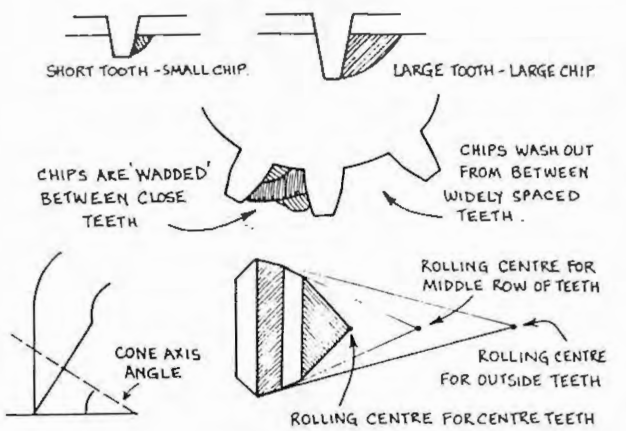


Roller Bit Terminology (Toothed Bit)

A roller bit for soft formations (low compressive strength, e.g., calcite, shale, clay) is designed with long teeth to give large penetration and large "rolling chips" (Section 1) with comparatively light weight and down pressure. Bit geometry is adjusted to give the best desirable scraping action at the hole face.

Such soft formation zones frequently contain abrasive units and layers of medium hard material. In such sandy and harder formations, hardened teeth are required.

Widely spaced teeth allow for easier clearing of the "sticky" chips typical of clay and shale. The angle that the cone axes make with the bottom, the centre lines of the axes and the rolling centre for the cones are all adjusted to force a twisting-tearing-scraping action rather than a rolling action on the bottom of the hole.



Normally, soft formation bits are run with relatively low weight, ranging from 500 to 1400 kg (1,100 to 3,000 lb) per inch of bit diameter. Rotary speeds usually range from 85 to 100 rpm, depending on the application (more in Section 6). Tooth breakage may indicate that either weight or rpms are too high.

- use the bit with the longest and sharpest teeth.
- use a bit with a near true rolling action.
- increase the fluid flow to the maximum possible to improve the clearing and bit contact on the bottom.

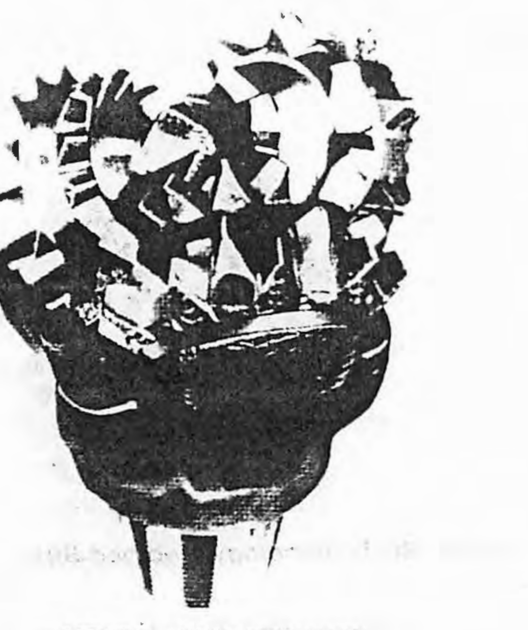
Bits for medium formations

Harder formations tend to chip more easily. Consequently, bits for medium formations will have a greater number of shorter, more closely spaced teeth. This change in design gives more chipping-crushing action.

Some cone offset to produce chipping is desirable. The offset angles of 3 to 4 degrees, used in soft formation bits, are reduced to 1 to 2 degrees in medium formations.

Higher thrust forces are necessary to give good penetration rates in medium formations. A consequence is higher bearing wear. The life of bits in harder formations is determined by a balance between tooth and bearing wear.

Sandstones and other abrasive formations require bits with hardened teeth, particularly at the gauge, and hard-faced shoulders to resist undersized holes. Bits with teeth comprising chisel-shaped tungsten carbide inserts and carbide gauge and shoulder facings are available. Hard-faced, large gauge surface bits with closely spaced teeth are a good choice for alternating shales, sandy shales, and limestones, typical of old marine basins.



MEDIUM FORMATION BITS

HARD FORMATION BITS

Note: there is a tendency for water well and exploration drillers to purchase and run refurbished oilfield bits due to their economy. Drillers operating light machines will find that an oilfield type bit, with a large "offset" between the axes of the cones, may require more bit weight than can be applied efficiently by a light machine. When the thrust force is limited:

Selection for penetration rate: Higher penetration rates are obtained with bits designed for soft formations.

When selecting a bit for a medium formation, the very large range of bits available for formations described as medium/soft, medium or medium/hard makes selection difficult.

Always prefer the bit design for softer rather than harder formations. The weakness of the longer, wider spaced teeth is offset by better chip clearing. Tooth weakness can be compensated for by hard facing.

In medium and harder formations, bits with reinforced gauge teeth or webs between the gauge teeth will give better life.

Application: Weight can be applied effectively to these types of bits due to their more rugged cutting structure and bearings. Excessive rotation speed should be avoided to reduce shock loads, particularly in broken formations, which cause rough operation. Rough operation reduces bearing and cone life. Weights generally range from 500 to 2300 kg(1,100 - 5,000 lb)/inch bit diameter and rotation from 60 to 100 rpm.

When changing a bit, particularly if a different design bit is being run, **always** allow a **break in** period. Do not "bump" the bit into the bottom, but ream it down gently to **break** the formation **in** to match the different bottom hole profile of the new bit.

Roller bits for hard formations

Hard formation bits are designed to overcome high compressive strength, using more crushing action and eliminating shearing action to the extent possible. Such bits also must withstand abrasiveness. Hard formation examples include:

- high compressive strength/low abrasiveness - dolomite.
- high compressive strength/high abrasion - granite, siliceous limestone, hard dolomite.
- medium compressive strength/high abrasion - sandstone and other quartz-containing granular rock, copper ores.

As you can see, there is also variety in "hard" formations, and bits should be chosen to meet the need.

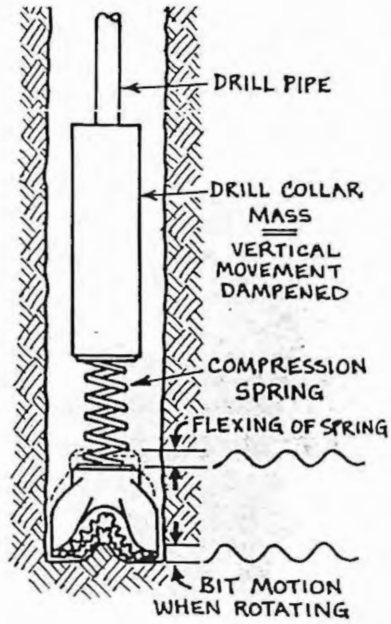
Hard rock cannot be torn or cut. It must be fractured. Any twisting, tearing action in the bit used will result in broken teeth and high wear. Hard formations must be drilled with bits having a true rolling action, that is, zero cone offset.

The hard-formation bit also requires a higher capacity bearing. High thrust loading is required (1800 to 3000 kg or 4,000 to 6,000 lb per inch bit diameter) and will cause failure of the hard facing on hard faced teeth used in soft to medium formations. The teeth in the hard formation bit are either case-hardened steel or tungsten carbide inserts with conical or hemispherical ends.

Carbide teeth hold their shape better and will drill with lower thrust forces that those required for steel toothed bits. Tungsten carbide is a brittle material, and bits with carbide teeth should not be subjected to vibration.

Shock absorber: Shock and vibration can be dampened downhole. In a typical case, a roller bit tends to ride up and down on an uneven formation. It develops a cyclic vibration, which may carry up the drill string to take shock loading to the rig and also may damage carbides.

The action of the shock absorber will reduce vibration damage.



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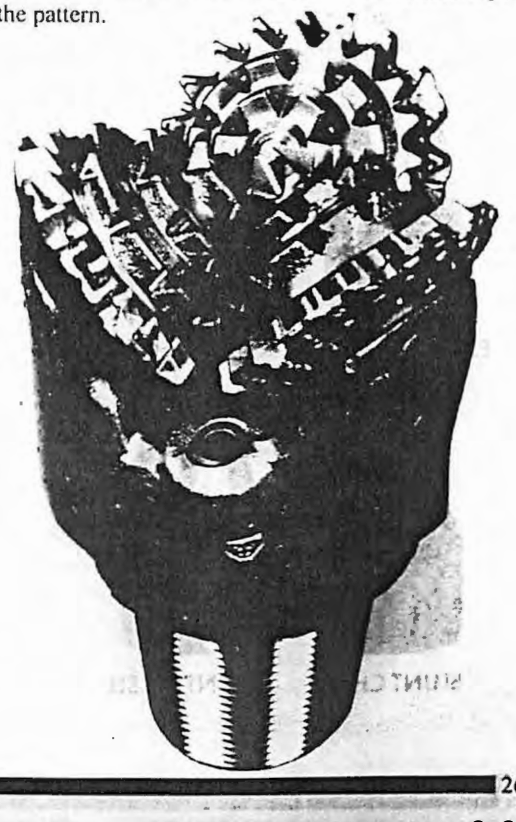

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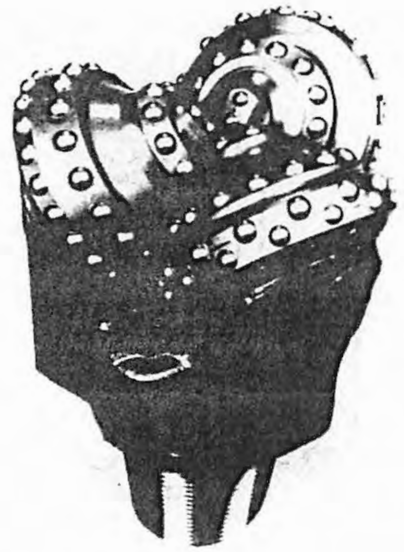

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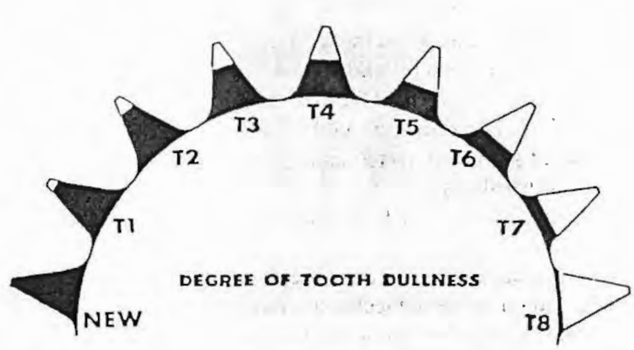

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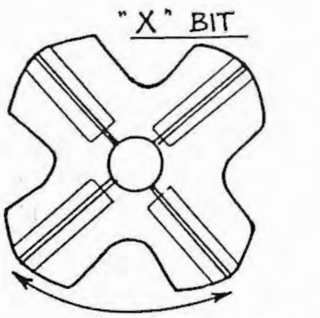

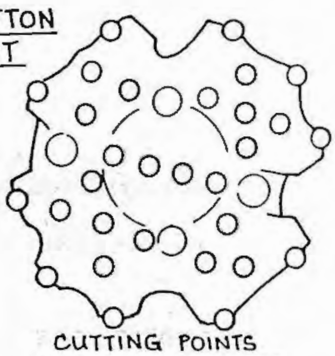

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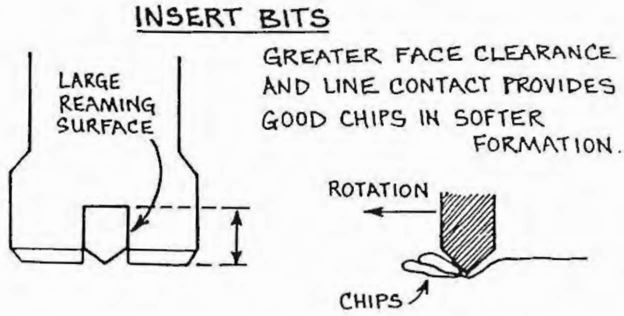

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A driller using one of the rotary methods must select the most suitable bit (1) to make best use of the useful drilling forces and (2) to tolerate or counteract the forces not wanted.

The type of bit used will depend on the mode of the drilling and the formation(s) to be drilled. The bit must make chips and contribute to the clearing of the chips. Since chip making and clearing depends on the relationship of the bit to the rock drillability, there should be a good match. The control which the driller has over the bit while it is in the hole is not sufficient to make an unsuitable bit operate correctly.

The correct bit must be used along with suitable down hole tools such as collars or stabilisers to control its action and contribute to its performance. A bit program should be prepared. It will show the numbers of bits required in each type. Bit sizes chosen depend on the ultimate intentions for the borehole.

Chapter 5 provides more guidance in making bit decisions based on rock drillability.

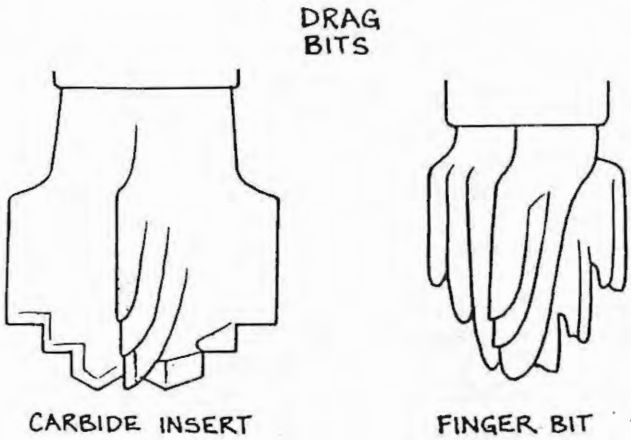
Rotary blade bits

Rotary fluid flush drilling in soft formations such as clays and weathered shales makes use of **blade bits for stirring** as well as for **cutting** and **shearing** actions. These bits make maximum use of rotary forces and hydraulic forces.

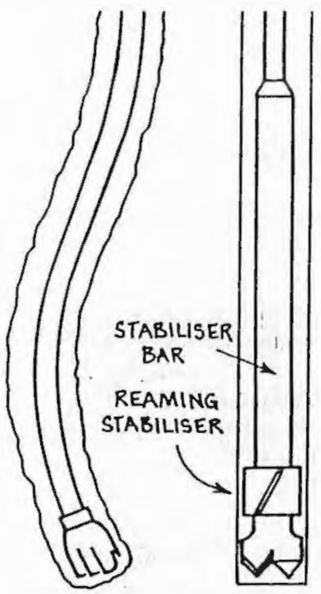
The rotary energy makes the chips. The hydraulic energy contributes to chip making and clears the chips.

Unconsolidated formations: These formations are cut with bits having a forged or hard faced edge suited to **stirring.** Circulated fluid is directed on the bottom of the hole through the bit nozzle.

In contrast, hard clays and **consolidated formations** are cut better if a sharp cutting edge is provided. The edge is usually hard faced or fitted with carbide inserts to resist wear. Some formations form better chips if a plowing action is provided using a finger type drag bit.



Unstabilized blade bits are prone to drill crooked holes. The large rotary forces cause the bit to move away when it strikes an obstacle. Any thrust force will buckle the pipe.



Reaming stabilisers and **drill collars** or **large diameter stabiliser bars** reduce the tendency to run off.

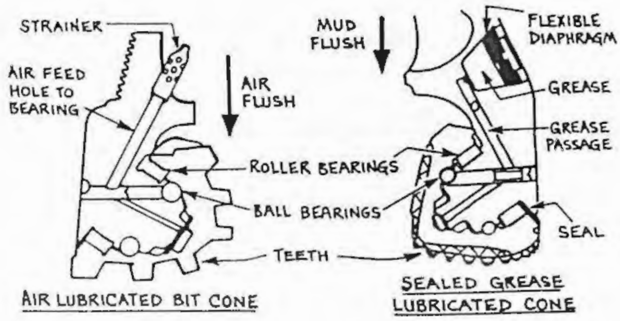
Rotary roller bit design

A drilling program should be planned to make best use of modern bit designs. Roller bits offer many variations in design:

1. different tooth material, shape, height and spacing.
2. different cone rolling patterns resulting from changes in shape of the cone and in alignment of the cone axes.
3. different placement, size and direction of the openings or nozzles directing flow of the circulation fluid.
4. different types of bearings with differing provision for bearing lubrication.

Drillers using roller bits on water well, mineral investigation, and similar projects that call for light, or medium weight rigs, will not be able to load their bits sufficiently to take full advantage of the high performance bits designed for oil-field work or for use on heavy blast-hole rotary rigs. They have to make better use of their total system to provide clean, straight holes.

Selection of bearing type: The cheapest design provides non sealed roller bearings with the circulating fluid passing through and lubricating the bearings. Such bearings have short life when used with sand laden mud but provide excellent performance when run with air, mist or foam.

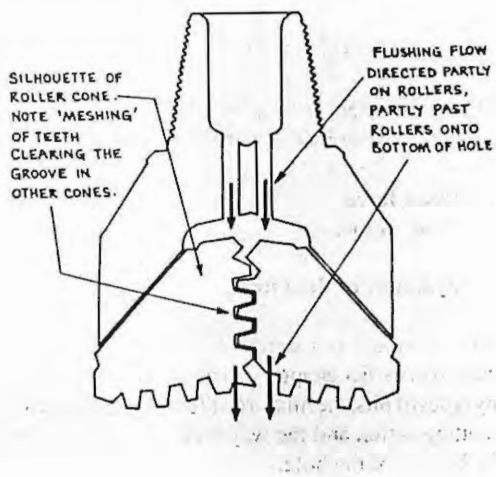


Bits for mud circulation are provided with sealed bearings. Most have a built-in reservoir of grease, but some must be replenished by fitting a grease nipple and pumping grease in.

High load bits are built with bush type friction bearings rather than the roller race shown.

Chip clearing with roller bits

A regular (nonjetting) bit provides flushing through a hole or holes drilled in the centre of the bit.



In general, water and mineral drilling operations require a versatile bit design. This is the "full hole" mud circulation type, which directs the flushing flow onto the rollers as well as the hole bottom. Such bits can be used in air drilling operations without modification.

A bit designed to allow air flow throughout the bearings would need to have the air passages plugged if it is to be pressed into use for mud drilling.

The fluid flow over and past the rollers provides a turbulent flow zone at the bottom of the hole. The turbulence stirs up the cuttings as they are produced. The flow lifts the cuttings away from the bottom of the hole.

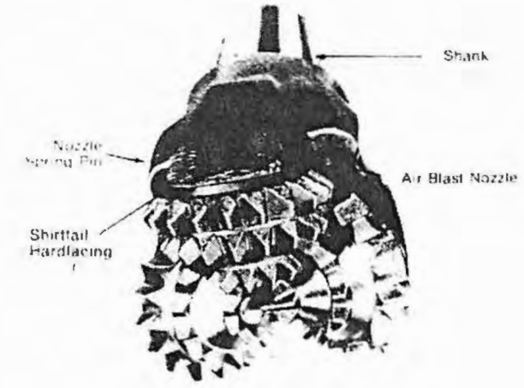
When running the bit into the hole, the pump should always be started and circulation in progress before running the bit to bottom. Forcing the bit into a mass of cuttings is likely to jam one of the cones, causing it to slide rather than roll when drilling starts.

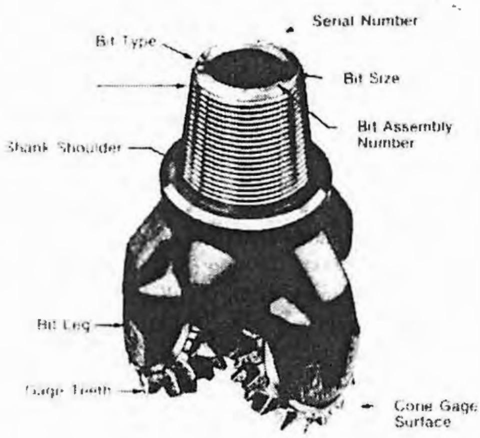
Chips may be "sluiced" from the bottom of the hole using **jet bits** (Section 1). If the full performance of a jet bit is to be gained, the bit must be supplied with fluid using a high volume, high pressure pump. These bits are more common in oilfield and other applications encountering high downhole fluid pressure.

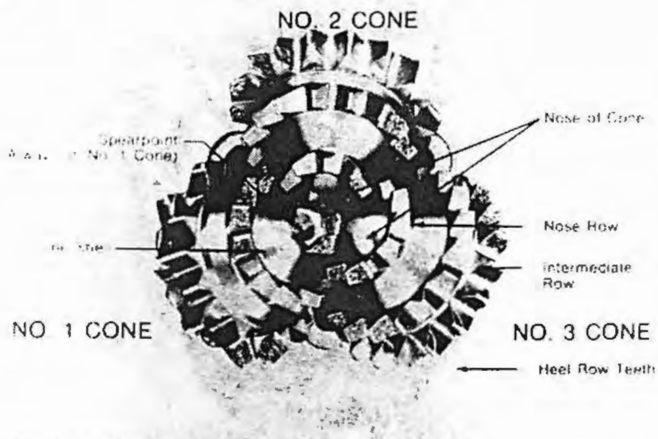
Bits for soft formations

Plastic or sticky formations require a well defined cutting action to separate the chips. With the appropriate rig and equipment, greater efficiency is obtained using correctly designed blade bits.

Roller bits: The use of roller bits allows good penetration with lower torque than is required for blade bits. In this case, more of the cutting energy is provided by the thrust force.





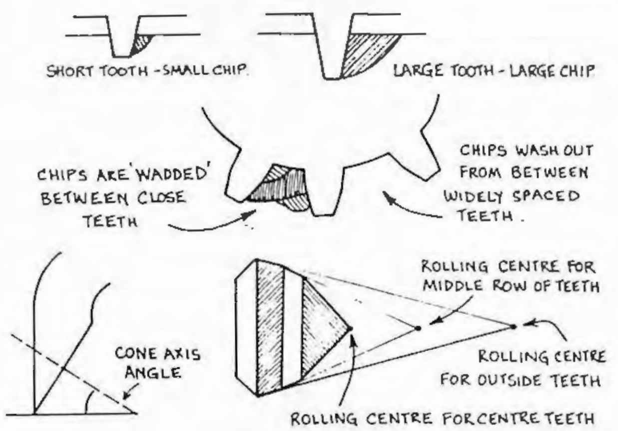


Roller Bit Terminology (Toothed Bit)

A roller bit for soft formations (low compressive strength, e.g., calcite, shale, clay) is designed with long teeth to give large penetration and large "rolling chips" (Section 1) with comparatively light weight and down pressure. Bit geometry is adjusted to give the best desirable scraping action at the hole face.

Such soft formation zones frequently contain abrasive units and layers of medium hard material. In such sandy and harder formations, hardened teeth are required.

Widely spaced teeth allow for easier clearing of the "sticky" chips typical of clay and shale. The angle that the cone axes make with the bottom, the centre lines of the axes and the rolling centre for the cones are all adjusted to force a twisting-tearing-scraping action rather than a rolling action on the bottom of the hole.



Normally, soft formation bits are run with relatively low weight, ranging from 500 to 1400 kg (1,100 to 3,000 lb) per inch of bit diameter. Rotary speeds usually range from 85 to 100 rpm, depending on the application (more in Section 6). Tooth breakage may indicate that either weight or rpms are too high.

- use the bit with the longest and sharpest teeth.
- use a bit with a near true rolling action.
- increase the fluid flow to the maximum possible to improve the clearing and bit contact on the bottom.

Bits for medium formations

Harder formations tend to chip more easily. Consequently, bits for medium formations will have a greater number of shorter, more closely spaced teeth. This change in design gives more chipping-crushing action.

Some cone offset to produce chipping is desirable. The offset angles of 3 to 4 degrees, used in soft formation bits, are reduced to 1 to 2 degrees in medium formations.

Higher thrust forces are necessary to give good penetration rates in medium formations. A consequence is higher bearing wear. The life of bits in harder formations is determined by a balance between tooth and bearing wear.

Sandstones and other abrasive formations require bits with hardened teeth, particularly at the gauge, and hard-faced shoulders to resist undersized holes. Bits with teeth comprising chisel-shaped tungsten carbide inserts and carbide gauge and shoulder facings are available. Hard-faced, large gauge surface bits with closely spaced teeth are a good choice for alternating shales, sandy shales, and limestones, typical of old marine basins.

MEDIUM FORMATION BITS

HARD FORMATION BITS

Note: there is a tendency for water well and exploration drillers to purchase and run refurbished oilfield bits due to their economy. Drillers operating light machines will find that an oilfield type bit, with a large "offset" between the axes of the cones, may require more bit weight than can be applied efficiently by a light machine. When the thrust force is limited:

Selection for penetration rate: Higher penetration rates are obtained with bits designed for soft formations.

When selecting a bit for a medium formation, the very large range of bits available for formations described as medium/soft, medium or medium/hard makes selection difficult.

Always prefer the bit design for softer rather than harder formations. The weakness of the longer, wider spaced teeth is offset by better chip clearing. Tooth weakness can be compensated for by hard facing.

In medium and harder formations, bits with reinforced gauge teeth or webs between the gauge teeth will give better life.

Application: Weight can be applied effectively to these types of bits due to their more rugged cutting structure and bearings. Excessive rotation speed should be avoided to reduce shock loads, particularly in broken formations, which cause rough operation. Rough operation reduces bearing and cone life. Weights generally range from 500 to 2300 kg(1,100 - 5,000 lb)/inch bit diameter and rotation from 60 to 100 rpm.

When changing a bit, particularly if a different design bit is being run, **always** allow a **break in** period. Do not "bump" the bit into the bottom, but ream it down gently to **break** the formation **in** to match the different bottom hole profile of the new bit.

Roller bits for hard formations

Hard formation bits are designed to overcome high compressive strength, using more crushing action and eliminating shearing action to the extent possible. Such bits also must withstand abrasiveness. Hard formation examples include:

- high compressive strength/low abrasiveness - dolomite.
- high compressive strength/high abrasion - granite, siliceous limestone, hard dolomite.
- medium compressive strength/high abrasion - sandstone and other quartz-containing granular rock, copper ores.

As you can see, there is also variety in "hard" formations, and bits should be chosen to meet the need.

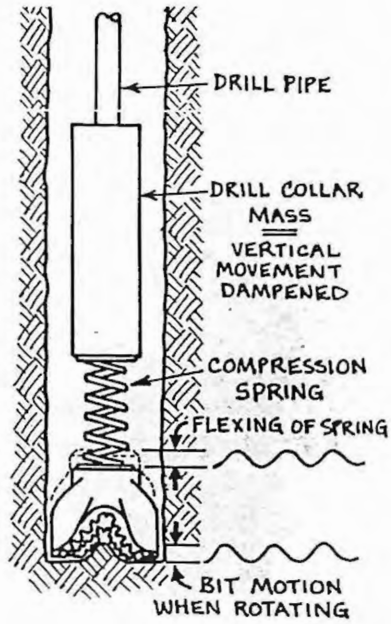
Hard rock cannot be torn or cut. It must be fractured. Any twisting, tearing action in the bit used will result in broken teeth and high wear. Hard formations must be drilled with bits having a true rolling action, that is, zero cone offset.

The hard-formation bit also requires a higher capacity bearing. High thrust loading is required (1800 to 3000 kg or 4,000 to 6,000 lb per inch bit diameter) and will cause failure of the hard facing on hard faced teeth used in soft to medium formations. The teeth in the hard formation bit are either case-hardened steel or tungsten carbide inserts with conical or hemispherical ends.

Carbide teeth hold their shape better and will drill with lower thrust forces that those required for steel toothed bits. Tungsten carbide is a brittle material, and bits with carbide teeth should not be subjected to vibration.

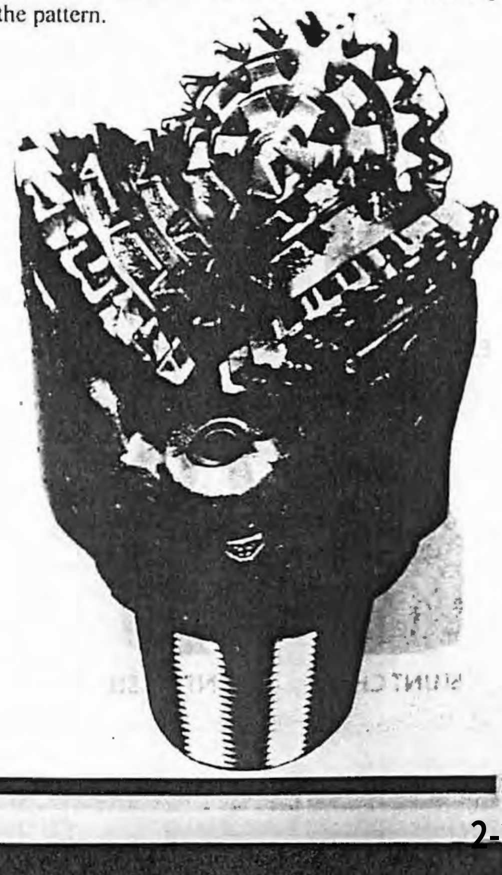
Shock absorber: Shock and vibration can be dampened downhole. In a typical case, a roller bit tends to ride up and down on an uneven formation. It develops a cyclic vibration, which may carry up the drill string to take shock loading to the rig and also may damage carbides.

The action of the shock absorber will reduce vibration damage.



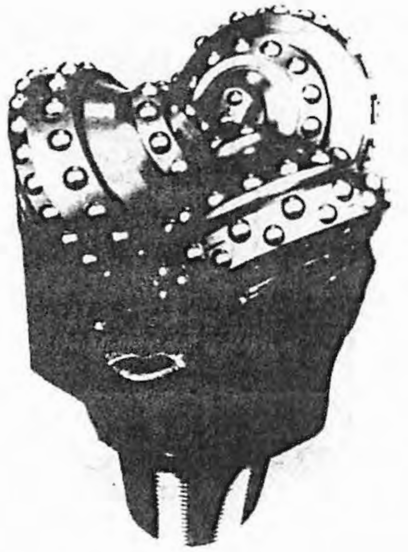
To avoid slipping or skidding on bottom, the bits are rotated at low speeds (40 to 80 rpm). They are never rotated without sufficient thrust to ensure that the cones do roll.

In the typical design, the outer row of teeth on each cone is the driving row, generating a rock gear pattern on the bottom, which is not easily broken in tough rocks. A webbed gear surface is used on the heel rows of teeth to break up rock in the pattern.

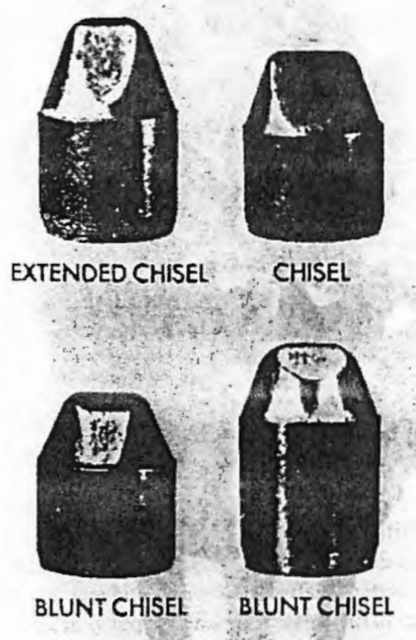


Very hard formation bits

This bit type has sintered tungsten carbide compacts for cutting edges instead of the more conventional chisel-shaped teeth.



They were introduced to drill extremely hard and abrasive rocks, such as chert, quartzite, and taconite. Modifications resulted in compact mineral drilling bits for hard abrasive copper and other hard basic metal ores.
In this type of bit, the insert design is specifically chosen for the rock type to be drilled. This selection process mirrors teeth selection on other roller bit types: more chisel shaped compacts are used on "softer" types and shorter, more rounded types on extremely hard rock.



All tungsten carbide bit designs incorporate the use of inserts in the gauge surfaces of the cones and combinations of inserts and hard facing on the shoulder and bit leg to resist loss of gauge due to abrasion.

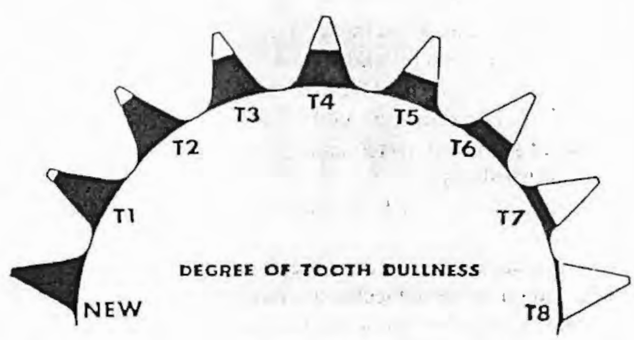
While more expensive, carbide insert bits provide better meterage per bit, typically 4 to 10 times the meterage obtained from steel-tooth bits. The penetration rate is also higher, and remains more constant through the bit life in relatively uniform drilling.

Weight and rotation are not greatly different from steel tooth hard formation bits. Weights run in the range of 1800 to 3600 kg(4,000 - 8,000 lb) per inch diameter and rotation 50 to 80 rpm.

Maintenance for tricone bits

The primary means of care for roller bits is proper selection of bit type for the drilling conditions and application of optimal pressure and rotation (next section).

Steel tooth bits cannot be retouched, but wear can be observed and records kept to build a body of experience in your drilling program. If you are keeping records, pick a system and stick with it. The International Association of Drilling Contractors adopted a system of reporting wear in "eighths" (1/8 gone = T1, 1/4 gone = T2, etc.).



Degree of undergauge can be measured using a standard gauge ring or a piece of steel casing with a known I.D. With the ring or casing touching two of the cones, measurement of undergauge is made between the third cone and the inside of the ring or casing.

Bearing condition must be checked regularly to ensure trouble free operation. Loose cones, stuck cones and bearing exposure caused by shirttail wear are all indicators of bearing wear.

Hammer bits

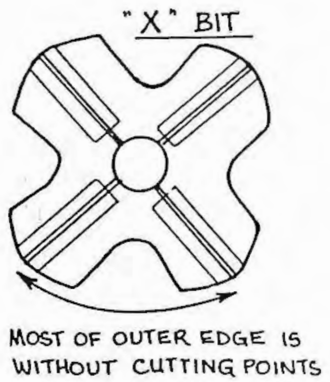
Hammers provide light rigs with the ability to drill hard rock; rock that cannot be drilled economically or quickly using any other method unless a much heavier rig is available.

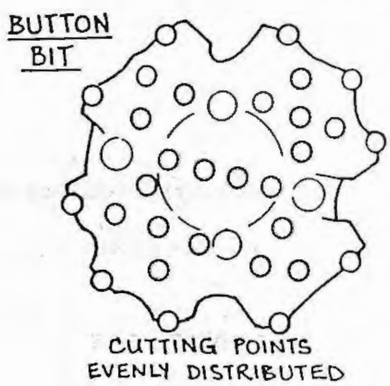
For most hammer drilling, button bits provide lower costs per metre drilled as they give:

- faster penetration and
- longer runs between grinding.

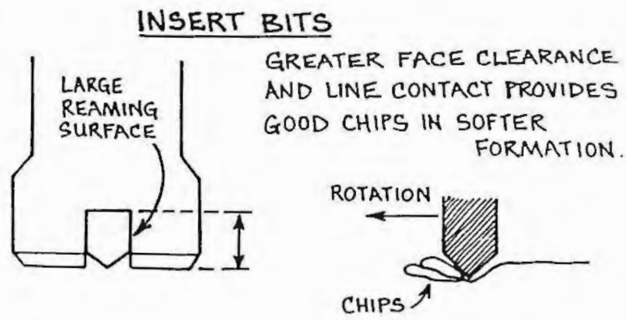
The button bit drills more efficiently because the percussive forces are distributed over the bottom of the hole.

Chisel or cross bits concentrate the energy at the centre of the hole. Most of the outer edge is without effective cutting points.





However, **cross "X"** or **insert bits** are more resistant to heavy gauge wear. In some formations, insert bits drill straighter than button bits, and in softer formations which are "scooped out" rather than shattered, insert bits can give better penetration.



Button bits are available, with buttons of varying sizes to suit different formations and to suit the energy output of the hammer. Button patterns are varied to suit the rock and the hole size. Bits with a cutting edge at the back shoulder are supplied to drill "backwards" when caving could be a problem.

Caring for hammer bits

Carbide insert breakage and loss: Carbide inserts are fragile, so handle them carefully. Bits can fail in a variety of ways due to careless use.

- **Carbide shear:** This is the most common type of carbide breakage. Although strong in compression, it is relatively weak when subjected to tensile or shearing forces.

1. As the button wears, it develops flat spots and loading on the button shifts from the intended vertical to a horizontal, shear direction.
2. The result is typically gauge button breakage.

Technical Area: 2 Drilling Tools and Equipment

Item: 2-3 DTH and DTH Bit

1: Objectives
To be able to explain and advise for type, structure and use of DTH and DTH bits for DTH drilling.

2. Contents
- Type of DTH
- Structure of DTH

3. Teaching Methods
(1) Explain specification of DTH using DDCA's manual.
(2) Explain structure of DTH using DDCA's manual.

4. Materials
2-3M1 DDCA's Manual for Drilling Works
2-3M2 Drillers Training and Reference Manual Section Chapter 2 Section 2 P25 - 32
2-3M3 Operation Manual of DTH (Atlas COPCO)

2.3 DTH AND DTH BIT (TA CODE 2-3)

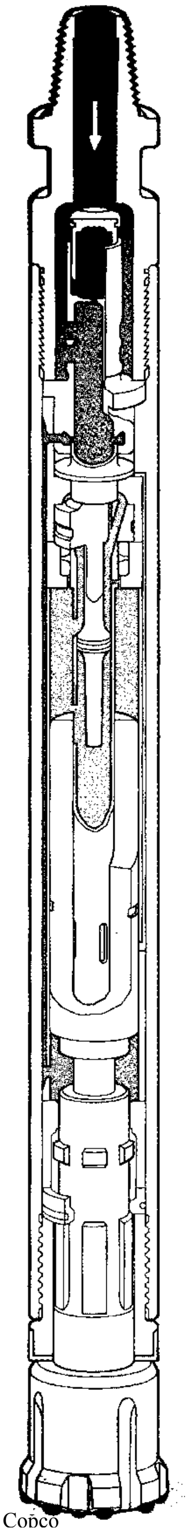
Figure 5 shows the structure of DTH. The DTH is a rotary percussive tool which operates at the bottom of the hole being drilled. It is attached at the end of the drill string, and powered by compressed air flowing down the centre of the drill string into the hammer. The air operates a piston within the hammer which strikes the rear end of the drill bit providing a percussive action. Porting, and in some cases valves within the hammer cause the piston to return to the upward position and then strike again in a continuous sequence. The hammer and drill string is rotated by the drilling machine on the surface which also provides necessary feed force, or, in a deep hole feed hold back force. Air exhausted from the hammer operation and additional air by-passed through the hammer is then used to cool the drill bit and evacuate drill cuttings from the hole. The DTH is very effective in drilling hard rock and the essential difference to rotary drilling is that the percussive rock breaking effort is being conducted on the hole bottom. Feed forces are only required to keep to bit on the bottom of the hole and any further effort (feed force) will not increase penetration but damage the hammer tool. Experienced rotary drillers shold guard againt a natural tendency to overfeed.

Figure 6 shows the structure of DTH bits. Hammers provide light rigs with the ability to drill hard rodk; rock that cannot be drilled economically or quickly using any other method unless a much heavier rig is available.

For most hammer drilling, button bits provide lower costs per meter drilled as they give:

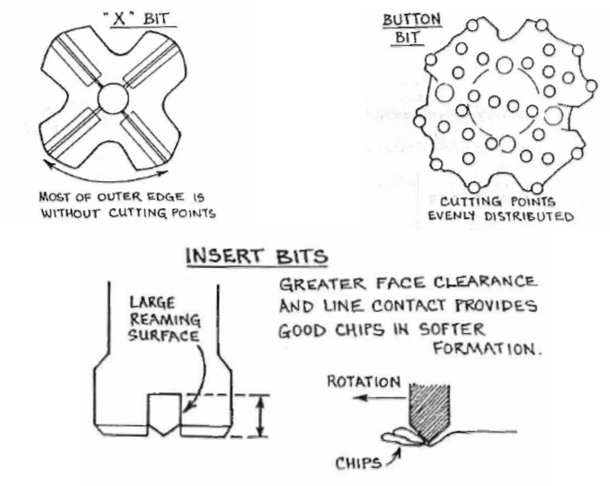
- Faster penetration and
- Longer runs between grinding.

The button bit drills more efficiently because the percussive forces are distributed over the bottom of the hole. Chisel or cross bits concentrate the energy at the centre of the hole. Most of the outer edge is without effective cutting points.



Source: Atlas Copco

Figure 5 Structure of DTH



Source: Australian Drilling Industry Training Committee

Figure 6 Structure of DTH Bits

However, cross “X” or insert bits are more resistant to heavy gauge wear. In some formations, insert bits drill straighter than button bits, and in softer formations which are “scooped out” rather than shattered, insert bits can give better penetration. Button bits are available, with buttons of varying sizes to suit different formations and to suit the energy output of the hammer. Button patterns are varied to suit the rock and the hole size. Bits with a cutting edge at the back shoulder are supplied to drill “backwards” when caving could be a problem.

In order to keep the good drilling progress, buttons of bit shall be kept being sharped. The drillers are required to execute the proper bit sharpening by referring the manufacturer’s manual of DTH.

to the drill bit as well as its RPM. Again the drill string should always be kept in tension and not run in compression. It should be remembered that while drilling with air, there is no buoyancy or flotation factor so more weight can be applied to the bit with a lighter drill string than when using mud.

Again as with mud drilling each hole will drill different. Generally speaking however, with air faster penetration and more footage per bit can be expected. A good rule is that while using air and the same weight on the bit as with mud, three times faster penetration rate will be obtained.

It should also be remembered that while air drilling, the bit has a tendency to run longer and will continue to drill even after it becomes dull and the cones become loose. Therefore, until an area is well known the bit should be inspected often even though it appears at the surface to be running fine.

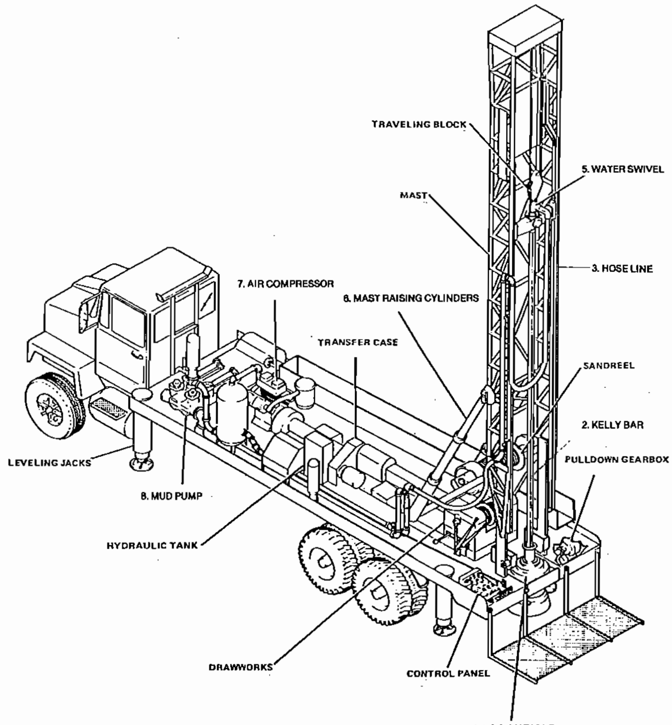


Figure 18
Rotary Table Drive Rig

The simplest form of air rotary drilling is where nothing but dry air is used as a circulating medium. However, this rarely occurs for very long in any hole. Usually water is encountered, when this happens especially in small quantities the hole will become sticky and the cutting will start to stick to the drill string, causing "mud rings" to form. At this point water must be injected with the air from surface to ensure the hole is kept clean. A normal practice is to add a foaming agent or detergent to the water being injected. This foaming agent should be added to a degree that circulation is as steady as possible and all heading or surging is eliminated. There is no set rule for all holes, but under most conditions if approximately one quart of foam mixed with 200 gallons (900L.) of water is pumped in the hole per hour, it should remain clean.

When drilling with air remember that when the air supply is turned off, there is nothing in the hole to suspend the cutting like when drilling with mud. Therefore, it is a good idea to circulate the hole clean before making a connection or adding another drill rod.

If hole conditions become such that normal air or air and foam drilling become difficult or impossible there are other methods that can be used. One method is the use of stiff foam (which looks and acts much like shaving cream). Stiff foam is made by mixing 12 lbs bentonite, ¾ lb soda ash, ¾ lb ccm, ½ gallon of foaming agent with 40 gallons of water. This mixture is added to the air stream. A ratio of air to stiff foam should be maintained to achieve a steady column of foam in the hole at all times. It is not necessary to unload the hole to obtain a clean hole, just maintain injection of foam and allow the hole to circulate clean. This method can also be used for drilling larger diameter hole, where a shortage of air volume is a problem.

One last thought on air rotary drilling. Air is just another tool that is available to drillers. It cannot be used in all holes, but can make cheaper faster holes than mud drilling if conditions are right.

SECTION 2
Air Hammer Drilling

Allan Greenough, Mole Engineering Pty. Ltd.

The Down Hole Hammer (DHH) is a rotary percussive tool which operates at the bottom of the hole being drilled. It is attached at the end of the drill string, and powered by compressed air flowing down the centre of the drill string into the hammer. The air operates a piston within the hammer which strikes the rear end of the drill bit providing a percussive action. Porting, and in some cases valves within the hammer cause the piston to return to the upward position and then strike again in a continuing sequence. The hammer and drill string is rotated by the drilling machine on the surface which also provides necessary feed force, or, in a deep hole feed hold back force. Air exhausted from the hammer operation and additional air by-passed through the hammer is then used to cool the drill bit and evacuate drill cuttings from the hole.

The Down Hole Hammer is very effective in drilling hard rock and the essential difference to rotary drilling is that the percussive rock breaking effort is being conducted on the hole bottom. Feed forces are only required to keep to bit on the bottom of the hole and any further effort (feed force) will not increase penetration but damage the Hammer Tool. Experienced rotary drillers should guard against a natural tendency to overfeed.

2.1 Effect of Air Pressure

The Down Hole Hammer is powered by compressed air and consequently, within the design restrictions of the tool itself, the more air pressure, the faster and harder the tool will work.

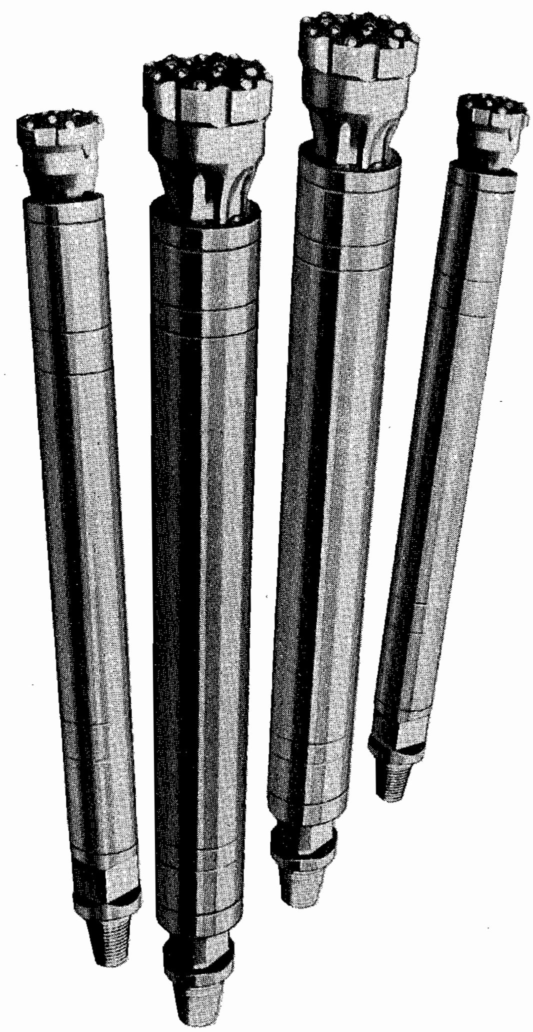
Figure 19 shows typical performance improvement on a hammer's drilling speed in hard granite at varying air pressures.

Performance varies with different makes of DHH but as an example a particular hammer provided with 7 bar (100 p.s.i.) air pressure will deliver 15 blows per second of the piston striking the bit and with 14 bar (250 p.s.i.) air pressure will deliver 23 blows per second. In this instance where the piston weighs 5 kg and has a stroke of 50 cm before striking the bit, some idea of the power of a Down Hole Hammer can be appreciated.

In water well drilling particularly, air pressure must also overcome ground water pressure when encountered. When drilling under a head of water, back pressure is exerted against the air pressure at the hammer and as the air pressure less the back pressure approaches the minimum operating pressure of the hammer, penetration rates will gradually fall to zero, and in fact the hammer will cease to operate.

A 10 metre head of water exerts a back pressure of approximately 1 bar (14.5 p.s.i.) and as examples, if a hammer with a minimum working pressure of 6 bars (87 p.s.i.) was used with a compressor providing 14 bar (250 p.s.i.) it would be possible for the hammer to work down to 80 m below the head of water (water table).

However, if it was used with a compressor providing 7 bar (100 p.s.i.) it would only be



Typical Down Hole Hammers

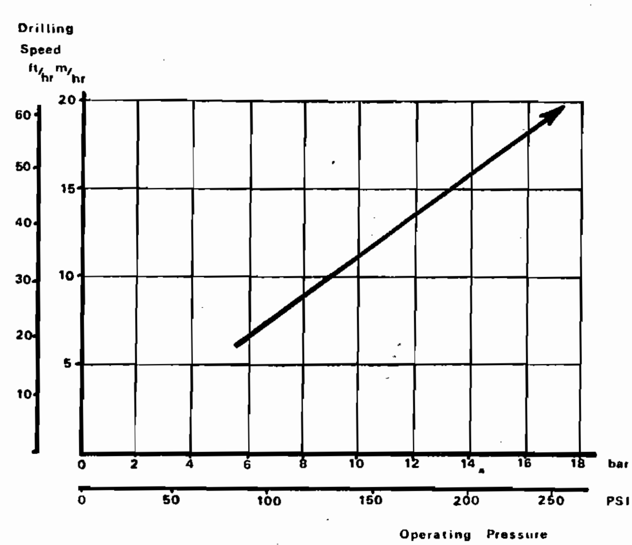


Figure 19

possible to drill 10 metres below the head of water.

To summarise this section air pressure is critical in Down Hole Hammer operation. Air volume requirements will depend to a certain extent on specific hammer and hole size requirements. In embarking on a hammer drilling operation careful consideration should be given to compressor selection, when considering pentetration/labour costs, and target depths in the pressure of ground water.

2.2 Up Hole Velocity

This is the major factor in deciding the amount of air needed to be passed through the hammer. The speed with which the air travels up the hole between the drill pipe and the side of the hole is critical in carrying chips and cuttings from the drill bit to the surface. The optimum speed or air velocity is 1220 m/min (4000 ft/min). Air velocities below 850 m/min (2800 ft/min) should definitely be avoided. At this speed the air will not have the capability to lift heavier chips. Higher air velocities particularly in dry drilling are acceptable and in fact may be desirable up to 2290 m/min (7500 ft/min).

However, when substantial quantities of ground water (500 galls. + /hour) is present in deep holes, air velocities over 1830 m/min (6000 ft/min) should be avoided. Under these conditions high air velocities can cause a suction effect actually increasing ground water back pressures.

In considering up hole velocity remember the cardinal rules:—

1. INCREASING BIT SIZE OR DECREASING ROD SIZE WILL LOWER Up Hole Velocity.
2. DECREASING BIT SIZE or INCREASING DRILL ROD SIZE WILL INCREASE Up Hole Velocity.
3. When considering up hole velocity consider gauge wear on the bit. As an example a 114 mm (4-1/2") new bit properly used and sharpended in abrasive conditions may well finish its effective life at 105 mm (4-1/8"). This change in bit diameter will substantially change the Up Hole Velocity produced.

Down Hole Hammer manufacturers have available tables presenting hole velocities for typical bit/drill rod sizes and air available.

However the formulas for calculating Up Hole Velocity are as follows:—

$$\text{Annular Air Velocity metres/min} = \frac{\text{free air consumed m}^3\text{/min x 106}}{\text{* annular area in mm}^2}$$

$$\text{Annular Air Velocity feet/min} = \frac{\text{free air consumed cfm x 144}}{\text{* annular area in sq. in.}}$$

where

* Annular area = Cross section of hole minus cross section area of drill pipe.

Cross Section area of hole = .785 x $(\text{hole dia})^2$
Cross Section area of drill pipe = .785 x $(\text{drill pipe dia.})^2$

2.3 Hammer Lubrication

The Down Hole Hammer is a sophisticated tool using high technology metals and works very hard indeed. As has been stated, at high air pressures a hammer is completing an operational cycle in excess of 23 times a second. Because of this and hole restriction factors it operates to very fine tolerances and MUST BE CORRECTLY LUBRICATED.

A special rock drill oil is injected into the air stream by an air line lubricator. Check the hammer specifications for the quantity of oil lubrication required.

Check daily or more frequently if required the lubricator oil reservoir.

Check daily that oil is coming through the drill head by holding a clean shiny surface into the air stream about 30 cm (12") below the head. Within seconds a thin oil film should appear.

When commissioning a new hammer with new drill pipe it is advisable to add 1/4 pint of additional oil with each drill rod added. This ensures a well lubricated drill string avoiding future rusting and sealing which can cause down hole hammer stoppage.

Too much oil or the incorrect oil can cause inefficient hammer action resulting in low penetration rates.

At times when stopped in the hole, oil from the inside of the drill string can drain into the hammer and prevent operation. In this instance pull off bottom and air flush continuously to displace the excess oil from the hammer.

2.4 Drilling Techniques

When operating a Down Hole Hammer for the first time, strip and reassemble according to the manufacturer's manual checking for condition of parts and observation of the way the hammer operates.

Plan your hole with regard to bit sizes necessary and expected to allow you to reach target depth and hole diameter at target depth. Influencing factors will be:—

1. Pump size
2. Screen size
3. Casing size
4. Expected water head

5. Drill String and bits available
6. Air available.

2.5 Housekeeping

Because of the very fine tolerances required all Down Hole Hammers are prone to foreign bodies interfering with penetration rates or, in fact stopping the hammer operating altogether. Very small quantities of rust scale, dirt or chippings, metal filings on new drill rods/machine will effectively stop a hammer.

Always keep drill rods off the ground on a clean drill board or preferably on a drill rod rack.

When adding drill rods to a string, cap the top rod in the ground and positively air flush the added rod before making up.

When adding drill rods, drill past the breaking position, then pull off hole bottom and air flush before breaking the rods. After making up the new rod air flush while lowering back to hole bottom.

Never leave a non operating hammer on hole bottom. If leaving the string in hole for any period e.g. meal break or overnight, pull string at least one rod back from hole bottom.

For wet drilling a Down Hole Hammer is fitted with a Non Return Valve preventing water and, more importantly, drill cuttings, slime, etc. from entering the hammer. When servicing, always ensure that the Non Return Valve is seating perfectly and that the spring is in good condition and of the correct tension.

Consider the action of a Down Hole Hammer on drill pipe and hammer joints whilst drilling. It is similar to tightening up the joints with spanners and then continuing to tighten the joint with a 5 kg sledge hammer hitting 23 times a second. The joints get very much tighter than with conventional rotary drilling. Thread grease using at least 40% finely powdered metallic zinc, lead or copper must be used at all times on drill pipe and hammer joints, if easy effective joint breaking is to be achieved.

Some hammers are available with a shock absorber unit which considerably eases this problem.

When replacing a drill bit, thoroughly clean the bit splines and centre tube counterbore, and coat with thread grease or rock drill oil.

Check for wear on drill rods. It is better to discard a drill rod than risk losing a drill string and hammer down the hole.

Rotate the sequence of drill rods down the hole to obtain even drill rod wear.

2.6 Drill Set Up and Hole Collaring

When setting up the drill ensure that a stable platform is obtained and that the drill will not move whilst the drilling is in progress. Ensure that the mast is aligned straight and true to the hole angle required. Check that lubrication is present in the air stream. Install the hammer on the drill head and test it on a block of wood prior to commencing the hole.

When collaring the hole ensure that the correct diameter half collar bushes are used in the drill table to match the diameter of the hammer. Feed the hammer into the ground gently with only partial air supply and low revs. Mast sway must not be permitted if an accurate collar is to be obtained. Unless a very shallow hole is required, it is best to drill 50 cm with a large diameter bit and install a stand pipe, reduce to a smaller bit and carry on drilling. Once the hammer has passed through the drill table, replace half collar bushes with the correct size for the drill rods being used. This is essential if a straight hole is to be achieved.

2.7 Feed Pressure and Rotation

In rotary drilling feed pressure and rotation combine to cut the rock and drill the hole.

In Down Hole Hammer drilling feed pressure and rotation are used essentially only to assist the operation of the hammer.

With DHH operation the feed pressure required is that which will keep the drill bit firmly in contact with the bottom of the hole, allowing maximum effectiveness of the piston blows within the hammer striking the bit. Typically, the desired weight on a hammer bit, depending on ground conditions can range between 250 and 500 kg for optimum drilling performance. (For a 4" [90 mm] hammer).

A drill hole does not have to be particularly deep before the weight of the drill string exceed 500 kg, e.g. with 6 m x 2-3/8 AP/IF rods @ 120 kg per length from the fifth rod, feed hold back must be employed to keep feed pressures within required limits.

Excessive feed force will cause premature bit and hammer component failure. It will not improve penetration rates. Feed force is not doing the drilling, the Down Hole Hammer is doing the work.

Insufficient feed force will result in the bit not being kept on the hole bottom and will cause shattering of the drill bit tungsten carbides. With button bits it can shake the inserts out of the bit. It can be noticed by a high pitched "ringing" noise in the sound of the hammer operation.

The essential function of rotation in DHH drilling is to regulate the number of times the hammer strikes a given piece of rock. Rotation speeds are varied according to the hardness of the ground to give the optimum cutting performance, generally evidenced by chip size. Too low rotation can cause the rock to pulverise to dust before being evacuated. Too high rotation can have the same effect as the same rock is hit several times round.

Remember that with higher air pressures a hammer is working faster and harder and generally the optimum rotation will be higher. As with feed force, high rotation will not increase penetration by itself. The optimum rotation speed is that which will match the hammer's cutting ability with the air's evacuation of the drill cuttings.

In abrasive rocks a major consideration becomes premature bit gauge wear. This must be compensated for by lower rotation speeds than would normally be used. The object is to balance bit gauge wear with face wear. maximising bit life between sharpenings and thus minimising lost time tripping out of the hole to change bits.

As a general guide to abrasive conditions, rotation speeds should be kept in the order of 12-20 RPM and in other formations from 20-40 RPM maximum.

An indication of the feel of a Down Hole Hammer is shown in Figure 19. The sound of the hammer is also valuable. A high pitched ring indicates too low feed pressure, a flat muffled hammering too high a feed pressure.

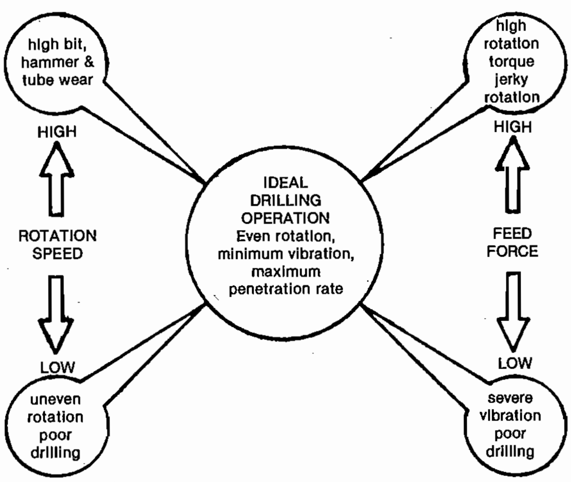


Figure 20

Rotation speed and feed force must be set **together** by careful attention to the **feel** of the drilling operation, because both affect the characteristics of the drilling operation.

Note: When approaching the bottom of the hole to resume drilling, use low rotation speed and feed carefully until hammer starts operating. Then set optimum feed force and rotation speed.

2.8 Bit Changing

The time to change a bit whilst drilling a hole is arguably the most important decision a driller makes whilst drilling a hole. A drill bit whilst drilling will gradually, or in hard abrasive conditions, quickly wear to a point where the carbide is flattened, penetration falls off, stresses are built up, and finally carbides shatter and the bit is destroyed. If carbides are lost and not successfully "fished" with a magnet they may well destroy the following bit and indeed cause the loss of the hole, apart from lost production time and the cost of the failed bits. As a bit wears to the "overdrilled" situation, penetration falls off dramatically and the driller must evaluate the cost in slow production rate versus the time and effort required to trip the rods and change the bit. When one considers the potential cost of bit failure down the hole, apart from lost time in slow penetration, it is always best to trip the rods and replace with a sharp bit of smaller diameter.

2.9 Drilling Through Overburden

Down Hole Hammers work very efficiently in hard rock but considerable care must be taken when drilling overburden, particularly when the ground is too soft to activate the hammer cycle.

The key is to proceed slowly and at all times keep the hole clean. Large volumes of debris are created in the hole, there is a tendency for the hole to collapse, and there is a potential for the bit to jam in fractured rock. It is recommended that the bit is pulled off the bottom of the hole frequently, allowing the full volume of air available to flush the hole.

At times water injection into the air stream will help stabilise the hole. In bad conditions water/foam injection is recommended.

Additionally, a straight slug of foam poured straight down the drill rods will assist in getting out of "stuck" or tight hole conditions.

When using foam ensure there is good oil lubrication as some foam formulas can be very corrosive.

2.10 Drilling in Hard Rock

A DHH will thrive in these conditions and with correct up hole velocity and air pressure, effective drilling becomes purely a balance between feed and rotation pressures.

However as the water table is entered, a small quantity of water in the hole can develop a problem which if unchecked will lead to a stuck drill string.

A small quantity of water in the hole will gradually turn the drill cutting fines into a sticky sludge which tend to build a collar behind the hammer and/or behind the spanner flats on the drill rods. There will be noticed a gradual decrease of cuttings returns, and tightness of hole. As drilling advances and more ground water is encountered the collars will generally clear themselves, but break up may be assisted by water or water/foam injection into air line, or pouring a slug of water or water/foam down the drill rods.

2.11 Water/Foam Drilling

The following table shows use of water and additives for particular problems.

Technique	Flushing Mixture	Method of Addition	Injection Quantity
Dust suppression and prevention of 'balling' of cuttings in damp formations.	1% volume mixture 1 gall. foaming agent in 100 gall. of water. (1 litre in 100 litres of water.	Pump mixture directly into air stream through metering valve.	15-30 galls. per hour (70-140 lts. per hour)
Mist drilling where where moderate amounts of water intrusion or sticky formations.	3lbs. of Polymer powder in 100 galls. of water (.6 kg in 200 litres of water). Use jet mixer.	Pump mixture directly into air stream through metering valve.	30-40 galls. per hour. (140-180 lts. per hour).
Reduction of lost air due to extremely porous and fractured conditions.	3 lbs. of Polymer powder in 100 gall. of water. (.6 kg in 200 litres of water) together with 1% volume foaming agent, i.e. add further 1 gall. (4.5 litres) of foaming agent. Use jet mixer. Mix powder before adding foaming agent.	Pump mixture directly into air stream through metering valve.	30-60 galls. per hour. (140-280 lts. per hour). Depending on severity of problem.
Slug drilling to remove well developed obstruction in hole annulus, clay or mud collars etc.	1/8 - ¼ pint. (.1 - .15 litre) of full strength foaming agent followed by a slug of 2-3 gall. (9-14 litre) of water.	Pour directly into drill tubes and use air to blow through	

2.12 Bit Sharpening

Resharpening bits correctly before they reach the "over-drilled" stage, particularly in hard abrasive ground, is the most important feature in gaining maximum penetration and shortest time for hole drilled, together with lowest cost for hole drilled with Down Hole Hammer operations.

In this section the sharpening of button bits will be covered because as a general rule button bits are much preferred today over Cross or 'X' types.

In most cases a button bit will fail because of either:-

1. Flattening of the guage buttons to the point where the wedging effect of jamming into a tight hole will crack and shatter the button.
2. Incorrect sharpening of the steel body to allow guage buttons to work effectively.
3. Incorrect button sharpening.
4. Failure when re-sharpening to re-shape and open out the flushing grooves.
5. Returning a bit down the hole when it is worn to the stage where there is not enough metal left in the bit to adequately retain the buttons when subjecting to drilling stresses.
6. Overfeeding/Overrotation.

Overfeeding can be confirmed by bruising or chipping of the bit striking faces, chuck and/or piston striking faces.

Overrotation is evidenced by a reduced footage penetration per sharpening and is common in abrasive ground.

7. Returning a bit down the hole which is greater in diameter than the guage the previous bit finished at down the hole (almost certainly not the gauge at which it went into the hole).

8. Faulty bit manufacture.

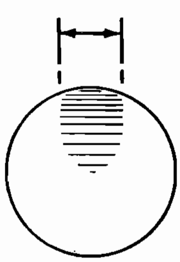
The correct re-sharpening of button bits should be as follows:-

Equipment:

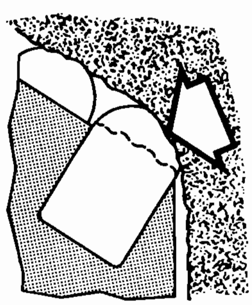
Use a small hand grinder (die grinder) running at 20,000 - 25,000 rpm and a cylindrical shaped silicon carbide wheel of 50-80 grit and J to P hardness, 25mm (1") diameter and 12.5mm (1/2") - 25mm (1") width. For cutting the steel body a suitable hand held or bench mounted steel grinder should be used. A simple grinding stand holding the bit vertically is recommended.

2.13 Button Sharpening.

The need for button sharpening is determined by the width of the flats on the outer heel row buttons. In formations that can be drilled over 12.2 m/hr, sharpen the buttons when the flats become ¼ inch wide; in formations that can be drilled at 7.6 to 12.2 m/hr, sharpen when the flats become 3/16 inch wide; and in formations that can be drilled at less than 7.6 m/hr, sharpen when the flats become 1/8 inch wide. See Illustration 1.



Ill. 1



Ill. 2

If the buttons are allowed to wear beyond these widths, bit wear will be greatly accelerated, and the outer heel row buttons will be subjected to a wedging effect during drilling that will break them off. See Illustration 2.

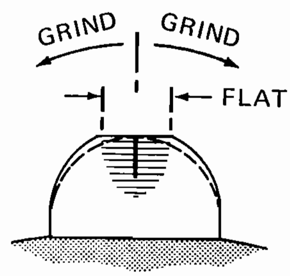
Although the face buttons will not wear as rapidly as the heel row buttons, they should be sharpened to restore their original shape when the heel row buttons are sharpened.

The aim of button sharpening is to reproduce the original spherical shape removing the wear flat. When re-sharpened the button will be spherical as new, but slightly smaller.

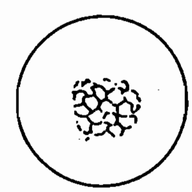
To aid in reproducing the original shape of the button, mark a pencil line across the flat as shown in Figure 3. The line should divide the flat into symmetrical halves. Grind on one side of the line until the shape is restored before grinding on the other side. Blend in the pencil line later. Remove as little of the carbide as possible to produce the spherical shape, especially when blending in the pencil line.

Chipped buttons will continue to function if the sharp edges are ground smooth to prevent further breakage. Broken buttons should be ground flush with the bit head to prevent the remainder of the button from breaking off in the hole and causing further damage.

When inspecting a bit to determine if sharpening is necessary, be alert for the presence of areas on the buttons which resemble alligator skin. See Ill. 4. These areas are actually fine networks of



Ill. 3



Ill. 4

very shallow cracks caused by excessive local heating. If this condition is not corrected, continued drilling will cause the cracks to deepen until small pieces of carbide begin to flake off the surface of the button. The button will eventually be destroyed. This type of button failure may be prevented by grinding the buttons just enough to remove the cracks, usually only a few thousandths of an inch, when they are first detected. Shiny areas on the buttons should be examined under slight magnification for the possible presence of "alligator skin"

2.14 Gauge Relief Taper Restoration.

The bit head diameter is slightly less than the gauge diameter (measured across the outer heel row buttons) and is tapered back toward the shank. This gauge relief taper must be maintained to prevent the bit from binding in the hole. Grind an approximately 3/16 inch wide cylindrical area on the bit head beginning at the base of the outer heel row buttons. The diameter of the cylindrical area must be approximately 1/32 inch less than the gauge diameter. Grind a smooth taper from the edge of the cylindrical area back toward the shank. The taper must not run into the driving splines or into the preload surface, whichever area is critical for the shank type of the bit being reconditioned. See Ill. 5.

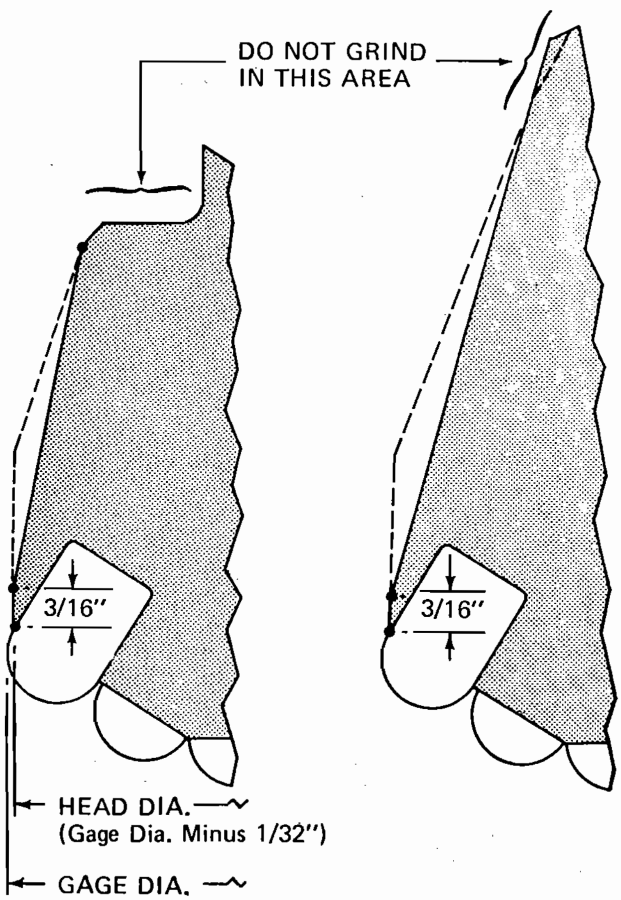
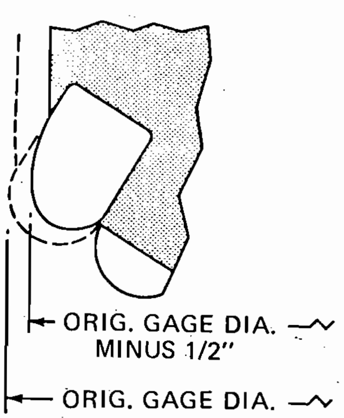
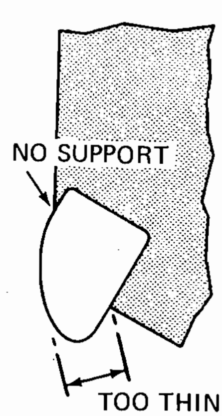


Illustration 5



Ill. 6



Ill. 7

2.15 Limits of Bit Reconditioning.

"Most" bits can be repeatedly reconditioned until the gauge diameter has been reduced ½ inch. See Ill. 6. Further reconditioning will reduce the thickness of the outer heel row buttons below that required to resist breakage and will reduce the thickness of the metal at the circumference of the bit below that required to resist outer heel row button. See Ill. 7.

A bit having several broken buttons can be successfully reused; however, it will generally require more frequent reconditioning.

SECTION 3

Specialised Rotary Drilling Methods

by Richard Lauman, Vice President
The Lauman Co. Bethpage, L.I., N.Y.

Reverse circulation drilling is really a form of excavating. The equipment cleans out a hole in the ground as it rotates. The drill cuttings are sucked up into the machine similar to dust being sucked into a vacuum cleaner. It is through this method that large diameter, high capacity wells have become more feasible for municipalities, industry, irrigation and other large water users.

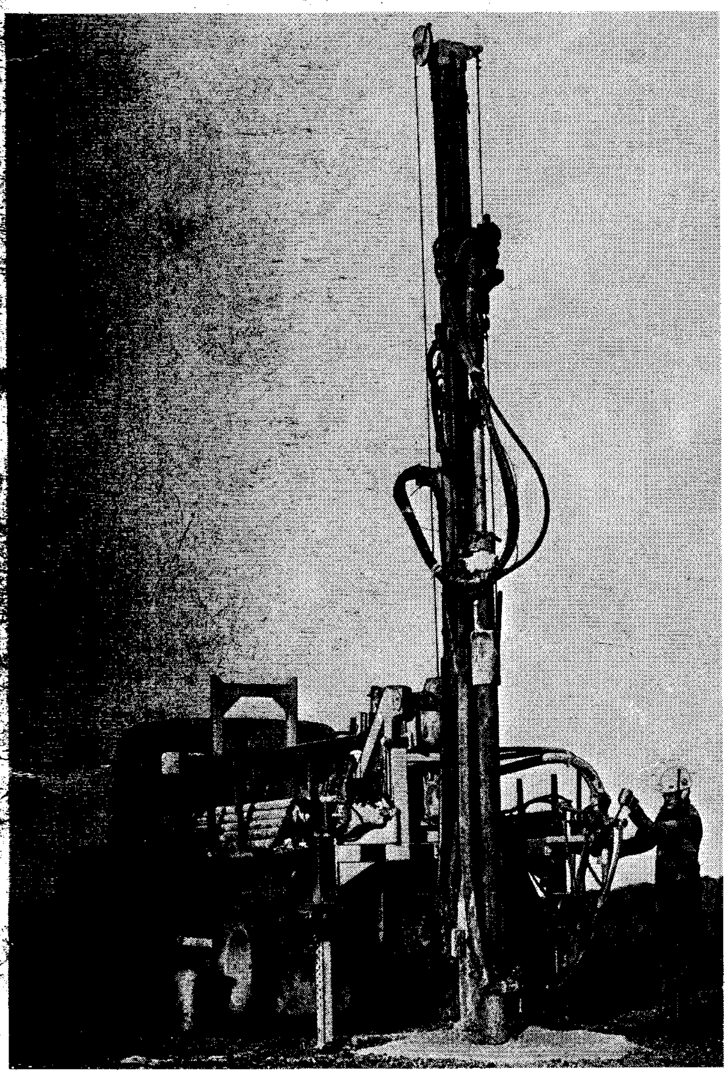
The reverse circulation procedure has been best proven in areas containing deep sand and gravel formations. It is capable of developing a well which will produce more water per cubic foot of usable formation than any other method of well construction now available to the industry. Reverse rotary is not, however, a rock well drill rig; at least not in hard rock areas. It can and has been used in soft prolific rock structures with some success. Its greatest performance is in "sand country" where large capacity wells are more prevalent.

Usually, you will find reverse rotary equipment being employed for drilling wells for high capacity projects. In some instances, reverse rotary has been instrumental in drilling large diameter entrance and feed holes for underground storage caverns for gas and water reserves.

3.1 Reverse Circulation Equipment

The equipment consists of a rotary table, an engine to run the rotary table, plus an engine to handle the pump. In some instances a single engine can be installed to handle both the pump and rotary table. Gasoline or diesel power is determined by preference of the drilling contractor. A pump with enough capability and stamina is necessary to handle 2250 lph and drill cuttings

Down-the-Hole Drilling with COP Drills



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Down-the-Hole Drilling with
COP Drills

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1. INTRODUCTION

Ever increasing demands for rising productivity in bench drilling have led to the more and more common occurrence of large hole sizes. While conventional percussive drilling is limited for practical reasons to sizes of about 4" (max. 5"), down-the-hole hammers are being used for considerably larger sizes. Even for hole sizes around 4" down-the-hole drilling is often to be preferred because of better flushing characteristics and the low air consumption in relation to output. A down-the-hole drill also drills a straighter hole than a surface drill, even in fissured or fractured rock. This makes the holes easier to charge and they can be drilled with less risk for the wrong direction.

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Down-the-hole hammers are also used for water well **drilling, drilling ventilation** and drainage holes both above **and below ground,** connecting holes for various kinds of **lines and other large,** long holes where accuracy in direction **is called for.** While ordinary percussive rock drills **already show an** often uneconomical decrease in output **at depths of** 20–30 m (65–100 ft), output is largely **unchanged** for a down-the-hole hammer because the impact energy is always developed adjacent to the bit. For the same reason noise is reduced appreciably, a factor of great importance in contracting work in populated areas.

Down-the-hole drills are furthermore often a valuable complement when drilling through hard sections of rock with rotary drilling units, which in most cases can be directly equipped with a down-the-hole hammer. Underground down-the-hole drilling is used for benching, for large holes in drifting, for drainage, connection and ventilation holes. The cuttings are then bound by metering water into the operating air or collected in dust collectors.

Mechanized down-the-hole drilling equipment is often an economical alternative in production drilling or rationalized construction work. COP 4 and COP 6 operate at air pressures between 4 and 18 bar (400–1800 kPa; 60–250 psi) and the output is then a product of the capacity of the compressed air source. A high air pressure gives a proportionally higher net rate of penetration, which in addition to a pure increase in production also leads to better bit economy.

2. APPLICATIONS

2.1 Applications of Atlas Copco standard units (see also 16.2 "Standard drilling units")

	BVB 25 light three-wheeled wagon drill	**Aquadrill** drill rigs for mounting on truck	**ROC 301-00** light crawler	**ROC 306** mini crawler for underground drilling with DTH-drills	**ROC 601** medium heavy crawler, normally used with BBE 57-01 and COP 130EB	**ROC 606** crawler modified for 6" DTH drilling	**Mobile Drill® B 30L** light auger rig for mounting on truck or tractor	**Mobile Drill® B 40L** medium heavy auger rig for mounting on truck or tractor	**Mobile Drill® B 80** medium heavy drill rig for mounting on truck or tractor	Rigs of other makes for percussive or rotary drilling
Benching, production drilling and construction work	COP 4		COP 4		COP 4	COP 4 COP 6				COP 4 COP 6
Water well drilling, prospecting and other deep holes	COP 4	COP 4 COP 6	COP 4		COP 4	COP 4 COP 6	COP 4	COP 4	COP 6	COP 4 COP 6
Construction work Long-hole drilling and large diameter holes for e.g. drainage operatons, water conduits, sewage, ventilation, and holes for cables	COP 4	COP 4 COP 6	COP 4		COP 4	COP 4 COP 6	COP 4	COP 4	COP 6	COP 4 COP 6
Anchoring, holes for grouting	COP 4		COP 4		COP 4	COP 4 COP 6	COP 4	COP 4		COP 4 COP 6
Post hole drilling (short holes in fill or soil)		COP 6			COP 6	COP 6	COP 6	COP 6	COP 6	COP 6
Underground mining Holes for drainage, ventilation, large holes in drifting, raise driving and blast holes in production drilling. etc.			COP 4	COP 4 COP 6	COP 4	COP 4 COP 6				COP 4 COP 6
Rotary drilling Complement for drilling in hard rock										COP 4 COP 6

2.2 Hole range

In normal benching COP 4 and COP 6 are used for hole diameters around 105 and 165 mm (4 1/8" and 6 1/2") respectively, while there are larger diameter bits for special types of drilling and reaming bits for a total hole range of 105 – 304 mm (4 1/8" to 12").

	COP 4	COP 6
Bench drilling (production drilling)	105–115 mm (4 1/8"–4 1/2")	152–165 mm (6"–6 1/2")
Special drilling Direct drilling	105–127 mm (4 1/8"–5")	152–216 mm (6"–8 1/2")
– under favorable conditions	105–152 mm (5 1/2"–6")	254 mm (10")
Reaming	–	254 mm (10") with pilot hole 165 mm (6 1/2")
– under favorable conditions	–	304 mm (12") with pilot hole 216 mm (8 1/2")

3. PREPARATIONS

3.1 Choice of operating pressure

COP 4 and COP 6 have been developed for operating pressures from 4 to 18 bar*). The difference in output (the relationship between metres drilled and air consumption) varies with the rock conditions, but the actual rate of penetration is directly proportional to the operating pressure (Fig. 1). A higher operating pressure (greater through-flow of air) also results in better flushing, which reduces the risk for getting stuck. This is valuable when drilling deep holes in rock with heavy cuttings (ores) and in fissured and otherwise difficultly-drilled rock.

The wear on the drill bit is primarily dependent upon total metres drilled, and upon grinding intervals (also measured in drill metres). As costs for drill bits make up a large share of drilling costs, a higher operating pressure also means a reduction of the total costs.

Raising the operating pressure for example from 6 to 10.5 bar*) raises the shift capacity by 60 to 70%, at the same time as the total costs drop in part due to lower direct costs and in part due to a better exploitation of the machine plant. In production drilling and in rationalized construction work a high operating pressure is then very advantageous.

*) 1 bar = 100 kPa = 1.02 kg/cm^2 = 14.5 psi

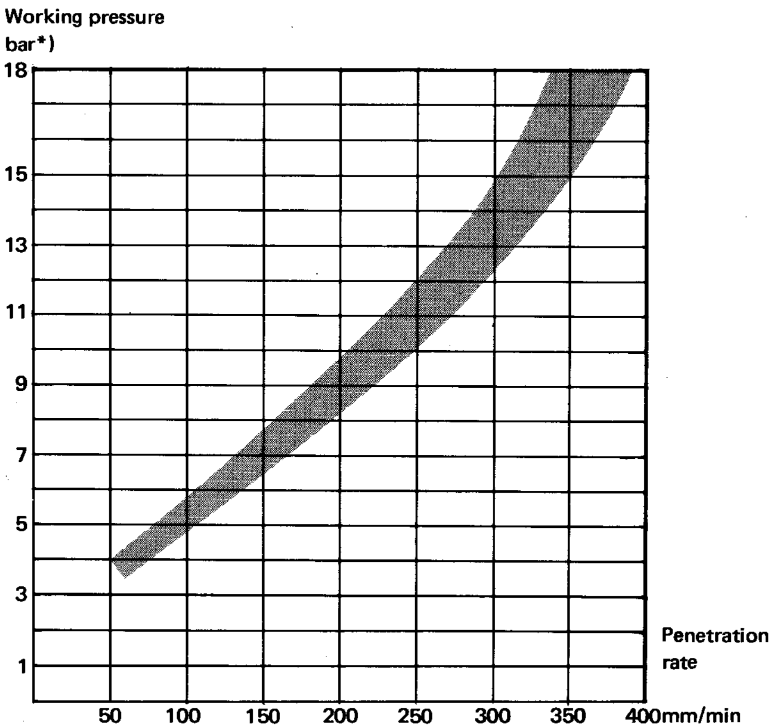


Fig. 1. Net rate of penetration with COP 4 and COP 6 at varying working pressures when drilling in granite with a compressive strength of approx. 24.5 kN = 2500 kg/cm^2 (35500 psi).
Drill bit diameter: COP 4 = 105 mm (4 1/8 in), COP 6 = 152 mm (6 in).

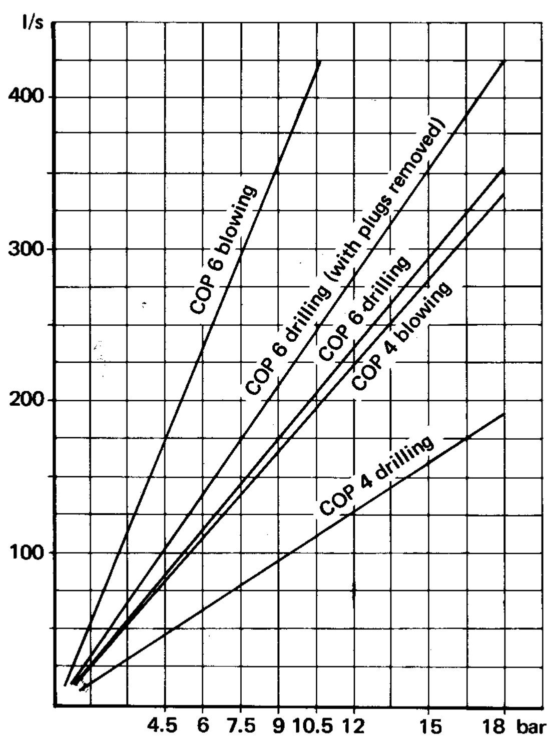
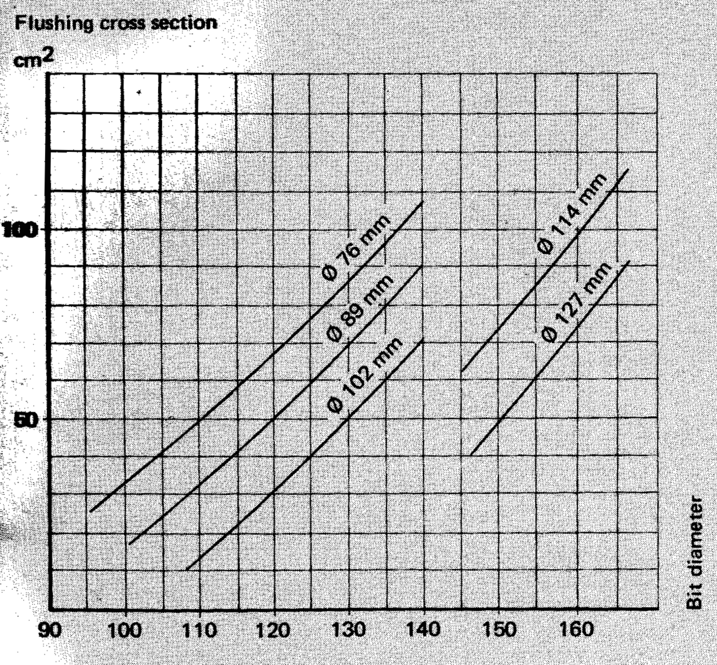


Fig. 2. Air consumption of COP 4 and COP 6 down-the-hole drills during drilling and when blowing clean the drill hole



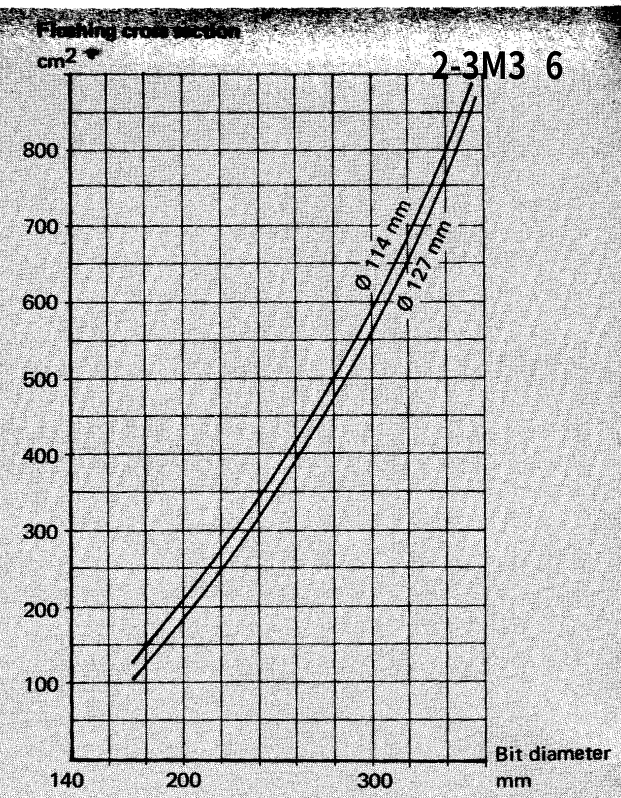


Fig. 3–4. Flushing cross section with varying **bit diameters** and **drill tube diameters**

In figures 2-6 and in the following, three types of flushing are mentioned, defined as follows:

Flushing – flushing in general, the exhaust air from the down-the-hole hammer during drilling.

Extra flushing during drilling – additional flushing from a flushing adapter on the back head of the hammer.

Blowing – a substantially increased volume of flushing air in order to blow clean the hole, obtained by lifting the hammer, so that the impact mechanism stops.

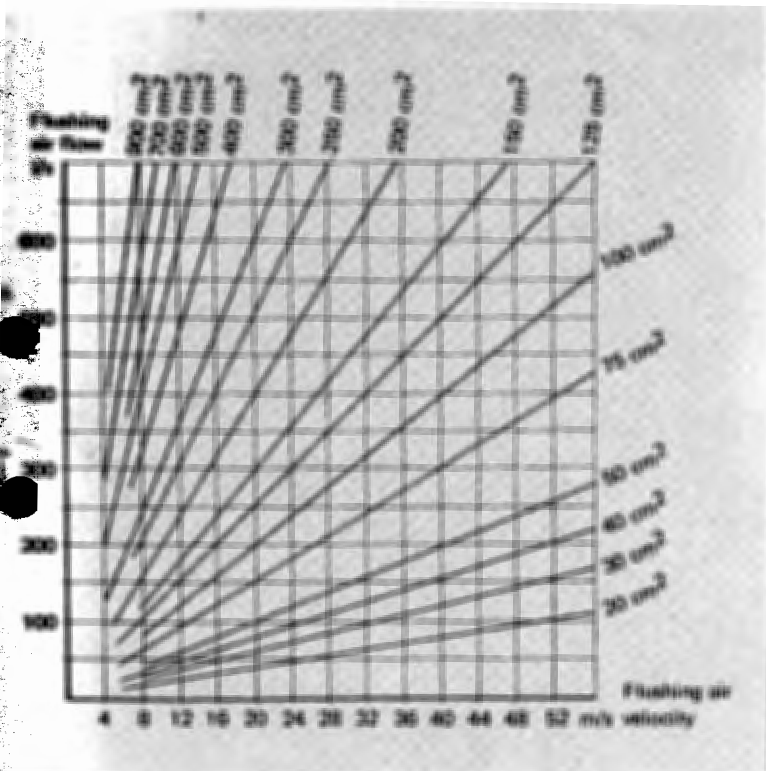


Fig. 5. Flushing air velocity at the surface with varying **flushing cross section** and **air flow.** The flushing cross section is obtained in Figs. 3–4

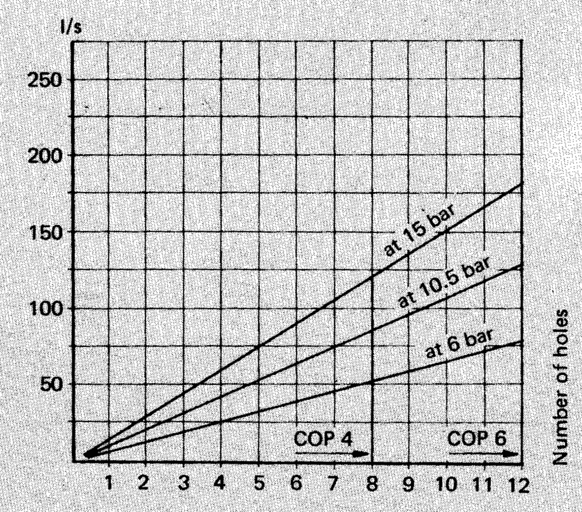


Fig. 6. Capacity of the flushing adapters for extra flushing. The holes of the adapters (eight and twelve, respectively) can be plugged to an optional degree in order to match the volume of air

Note. 1 bar = 100 kPa = 1.02 kg/cm^2 = 14.5 psi
1 l/s = 0.06 m^3/min = 2.12 cfm
1 cm^2 = 0.155 sq.in
10 mm = 0.394 in

Using the diagrams in Figs. 3-5

Task: To determine the flushing air velocity with a given bit diameter, drill tube diameter and flushing air flow (air consumption).

Solution: First determine the flushing cross section from Fig. 3 or 4, and then the flushing air velocity from Fig. 5.

The diagrams can also be used to determine compressor size and working pressure, i.e. flushing air flow, with the desired flushing air velocity as point of departure.

Example 1: Determine the flushing air velocity with a bit diameter of 115 mm (COP 4) and drill tube diameter of 76 mm with an air consumption of 110 and 200 l/s (drilling and blowing at 10.5 bar, respectively, compare the air consumption diagram, Fig. 2).

Solution: From Fig. 3 (bit diameter 100-165 mm) is obtained the flushing cross section **58 cm^2.** Then move to Fig. 5 and find the line for 58 cm^2 (located between 50 and 75 cm^2), which gives a value of **19 m/s** for a flow of 110 l/s and 33 m/s for a flow of 200 l/s.

Example 2: Determine the flushing air velocity with a bit diameter of 216 mm (COP 6) and drill tube diameter of 114 mm, with an air consumption of 240 and 330 l/s.

Solution: From Fig. 4 (bit diameter 165-355 mm) is obtained the flushing cross section **250 cm^2.** Then move to Fig. 5 and find the line for 250 cm^2. This gives a value of **10 m/s** for a flow of 240 l/s and **13.5 m/s** for a flow of 330 l/s.

3.2 Choice of compressor

In addition to the choice of operating pressure the following factors affect the choice of compressor (see Tables 1 and 2):

1. Air consumption of the down-the-hole drill during drilling (fig. 2)
2. Capacity for blowing clean the drill hole (Fig. 2)
3. Requirements for flushing during drilling (Figs. 3-6)
4. Air consumption of the feed and rotation motors during drilling (Tables 1 and 2)
5. Air consumption for other equipment, e.g. grinder and dust collector.

Table 1. Recommended compressors for COP 4

Working pressure bar*)	Air consumption during drilling			Max. air consumption when blowing drill hole			Compressor		Available blowing capacity B)
	COP 4	BBR 4 A)	BMM 35K 855 BMM 35K 859 A)	COP 4	BBR 4 A)	BMM 35K 855 BMM 35K 859 A)	Type	Capacity l/s **)	l/s **)
6.0	60	–	–	113	–	–	ST 71 XA 120 ST 95 XA 160 PR 425	117 118 155 158 200	113 113 113 113 113
	60	40	10	113	40	40	ST 95 XA 160 PR 425 PR 600 PR 700	155 158 200 284 330	75 C) 78 C) 113 113 113
10.5	110	–	–	200	–	–	PRH 425 PRH 700	193 320	193 200
	110	40	10	200	40	40	PRH 425 PRH 700 PRH 900	193 320 412	113 200 200
18.0	195	–	–	333	–	–	ER 518 D) ER 618 D)	252 322	252 322
	195	40	10	333	40	40	PNS 1200 ER 518 D) ER 618 D) ER 718 D)	566 252 318 440	333 172 238 360

*) 1 bar = 100 kPa = 1.02 kp/cm^2 = 14.5 psi
**) 1 l/s = 0.06 m^3/min = 2.12 cfm

A. Working pressure 6 bar. A dash in the table indicates the use of a **non**-air-powered feed motor or rotation motor.
B. With a high working pressure (10.5–18 bar) there is generally no longer a blowing capacity requirement beyond the air consumption during drilling.
C. Reduced blowing capacity. Acceptable under favourable circumstances.
D. Stationary compressor

Table 2. Recommended compressors for COP 6

Working pressure bar *)	Air consumption during drilling			Max. air consumption when blowing drill hole			Compressor		Available blowing capacity B) l/s **)
	COP 6	BBR 6 A)	BMM 36K 658 A)	COP 6	BBR 6 A)	BMM 36K 658 A)	Type	Capacity l/s **)	
6.0	112	–	–	250	–	–	PR 425 PR 600 PR 700	200 284 330	200 C) 250 250
	112	75	20	250	75	100	PR 700 PT 900 PT 1050 PT 1200	330 425 500 567	155 C) 250 250 250
	212	–	–	425	–	–	PRH 700 PTH 900	320 412	320 412
10.5	212	75	20	425	75	100	PRH 700 PTH 900 PTH 1200	320 412 553	135 C) 237 378
18.0	350	–	–	683	–	–	PNS 1200 ER 518D)F) ER 618E)F) ER 718F)	566 252 318 440	566 252 318 440
	350	75	20	683	75	100	PNS 1200 ER 718 F)	566 440	391 265

*) 1 bar = 100 kPa = 1.02 kp/cm^2 = 14.5 psi
**) 1 l/s = 0.06 m^3/min = 2.12 cfm

A. Working pressure 6 bar. A dash in the table indicates the use of a **non**-air-powered feed motor or rotation motor.
B. With a high working pressure (10.5–18 bar) there is generally no longer a blowing capacity requirement beyond the air consumption during drilling.
C. Reduced blowing capacity. Acceptable under favourable circumstances.
D. Supplies 12.5 bar during drilling.
E. Supplies 16.0 bar during drilling.
F. Stationary compressor.

3.3 Choice of down-the-hole bit

The choice of bit is of great importance for drilling results. The special operating method of down-the-hole drills and the wide range of application mean that a variety of different questions must be considered. The choice of both the type of bit and diameter must often be made on the basis of experience, but the instructions below and the summary 5. "Table of typical situations" will provide general guide lines.

The correct choice of bit is also the basic condition for the best drilling economy. In general this is synonymous with the best bit economy, but special circumstances may require that such questions as purchase price, penetration rate, grinding costs and durability are given priorities which vary from case to case. The following are to be included among the basic considerations for the choice of bit: the drilling characteristics of the bit under various conditions, grinding costs, purchase price and at times factors of a local nature such as the organization of the work site and established praxis.

A matter of very great importance is grinding. An over-drilled bit (especially in the case of anti-taper) is difficult to reestablish and in addition to the drilling output being lowered, there is also a great risk for breakdown. In the case of bench drilling, for example, a weighing of hole depth against regrinding interval may call for careful reflection (see 13. "Maintenance and grinding of the down-the-hole bit").

Choice of drill bit type (Fig. 7)

There are two types of drill bit for COP 4 and COP 6, button bits and full head bits. Both types are manufactured in a number of standard diameters. Reaming bits are also manufactured for COP 6 for holes 254 and 304 mm in diameter.

The cemented carbide in the button bits is of a grade which is characterized by high resistance to wear and excellent toughness.

The cemented carbide in the full head bits for COP 6 is manufactured in two grades. The more wear-resistant should be chosen for hard kinds of rock, while the less wear-resistant but tougher grade is recommended for less abrasive rock and for certain types of ores.

Full head bits are manufactured for COP 4, intended for non-consolidated, fissured or lightly abrasive rock.

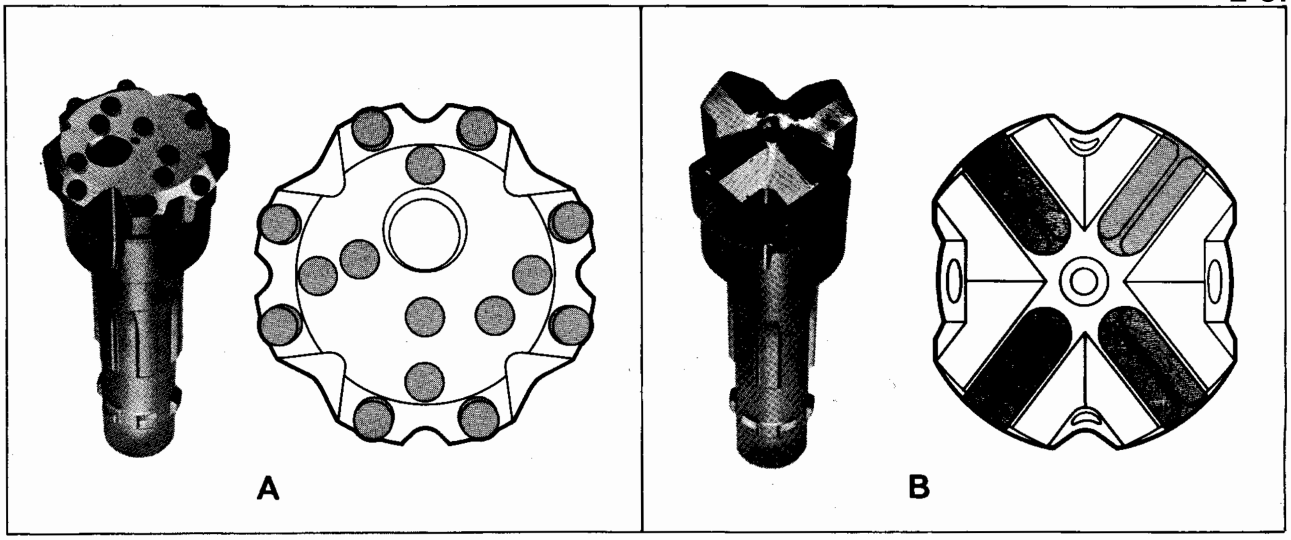


Fig. 7. Bit types

A. Button bit
B. Full head bit

Button bits (fig. 7a)

This is the type of bit which should principally be selected. It is characterized by a number of buttons pressed into the bit head. Their protruding part has a hemispherical or half-round shape. Thanks to the method of fitting them in the steel, considerably more wear-resistant cemented carbide can be used than in conventional insert bits, where the insert is attached by brazing.

Like insert bits, button bits should be ground regularly, if one wishes to obtain as long a service life as possible. However, a button bit does not need to be ground as often as an insert bit. See further under "Number of possible regrindings per drill bit".

Button bits can in general be used in all kinds of rock. As a result of the long redressing interval it is in most cases not necessary to withdraw the drilling equipment from the drill hole to grind the bit, until the hole has been completely drilled. This saves time and the drilling economy is improved.

Full head bits (Fig. 7b)

Full head bits can be used in all types of rock. Because of the higher regrinding costs and longer down-time connected with regrinding, full head bits should, however, be employed only if button bits for some reason are not suitable.

Choice of bit diameter

As in the case of bit type the choice of bit diameter is affected by considerations of drilling technology and economy. Bench drilling of blast holes is the most difficult to judge, while the hole diameters for, e.g., water well drilling and precision drilling are often determined beforehand by the pump diameter, casing tubes and other equipment. When drilling blast holes, other aspects of blasting technology influence the choice of diameter. For example, a large hole diameter often means less drilling per ton blasted rock.

Otherwise the choice of diameter is based on a consideration of:

1. Penetration rate
2. Flushing effect
3. Abrasive wear on the outside of the down-the-hole drill
4. Number of possible regrindings of the bit

See also 5. "Table of typical situations".

Penetration rate

A small bit diameter may appear attractive, as it favours the rate of penetration and is as well economically advantageous considering the purchase price and regrinding costs. Considerations of blasting technology and the drilling conditions such as flushing effect, wear on the drill and number of possible regrindings, may however direct the choice of a larger diameter.

Flushing effect

The flushing effect is generally dependent on the hole diameter and operating pressure. A smaller bit diameter and higher operating pressure raise the velocity of the flushing air, and this should be taken into consideration when this velocity is critically low for any reason. It is most critical then around the drill tubes as the velocity there, because of the smaller diameter, is always less than around the drill itself (see also Figs. 3-5).

In certain cases however it is the flushing around the drill which must be attended to. The space between the rock wall and the drill casing must be sufficiently great to permit the passage of the cuttings. Otherwise stagnation occurs and the operation of the equipment is made more difficult. If difficulties in flushing, occur, due to coarse cuttings or material loosening from the hole walls, it is advisable to increase the bit diameter.

Abrasive wear on the outside of the down-the-hole drill

When drilling in quartzite, quartz sandstone and other abrasive kinds of rocks, the flow of cuttings has a strong, wearing effect on the casing and driver chuck of the down-the-hole drill. The wear is dependent to a great degree on the annular space around the DTH-drill, which calls for a larger bit diameter, especially at high operating pressures. Maintenance costs may then well motivate a larger bit diameter even if the flushing otherwise permits the use of a smaller diameter. This is the general situation in highly abrasive rock. (See 4.2 "Mounting the drill bit with driver chuck – wear on the driver chuck and casing").

Number of possible regrindings of the bit

In rock which causes heavy gauge wear it may occur that the diameter of the bit wears down more quickly than the height of the cutting inserts or the buttons. The bit then reaches the minimum diameter too soon if too small a diameter was selected from the beginning. Economic reasons then support the idea of not choosing the smallest bit diameter, even if it otherwise is suited to the drilling case at hand.

From the point of view of grinding button bits are to be preferred over insert bits. The regrinding interval is normally 3-5 times longer for a button bit than for a full head bit, while the regrinding time is considerably shorter. This is of great importance, especially in drilling long holes and in benching, since the regrinding occasion can often be made to coincide with the start of a new hole. In this way the down-time can be reduced appreciably.

Fig. 8. By loading the feed spike with a portion of the weight of the wagon drill a solid set-up can be obtained (ROC 301 with COP 4)

4. DRILLING

4.1. Setting up

Each drilling operation with a down-the-hole drill should begin with a careful installation of the carrier. Stability should be as great as possible. The effect of the torque and the feed force may otherwise create swaying. This swaying affects the drilling operation unfavourably, especially when deep, straight holes are being drilled.

When setting up a wagon drill or a crawler unit it is then important that the points of support against the ground are as far to the rear as possible. By putting the feed in contact with the ground a solid three-point set-up is obtained, where the weight of the wagon drill is to a great extent exerted on the point of the feed (Fig. 8).

When drilling in drill dirt or other loose material the feed should not be supported on the ground near the opening of the hole as this may easily cause collapse. Instead the feed should be supported at a point some distance from the hole. A suitable arrangement is a sturdy steel channel under the point of the feed, laid out on a couple of planks or steel channels. A plank should be placed in the channel in order that the point of the feed is not damaged and to prevent annoying noise (Fig. 9).

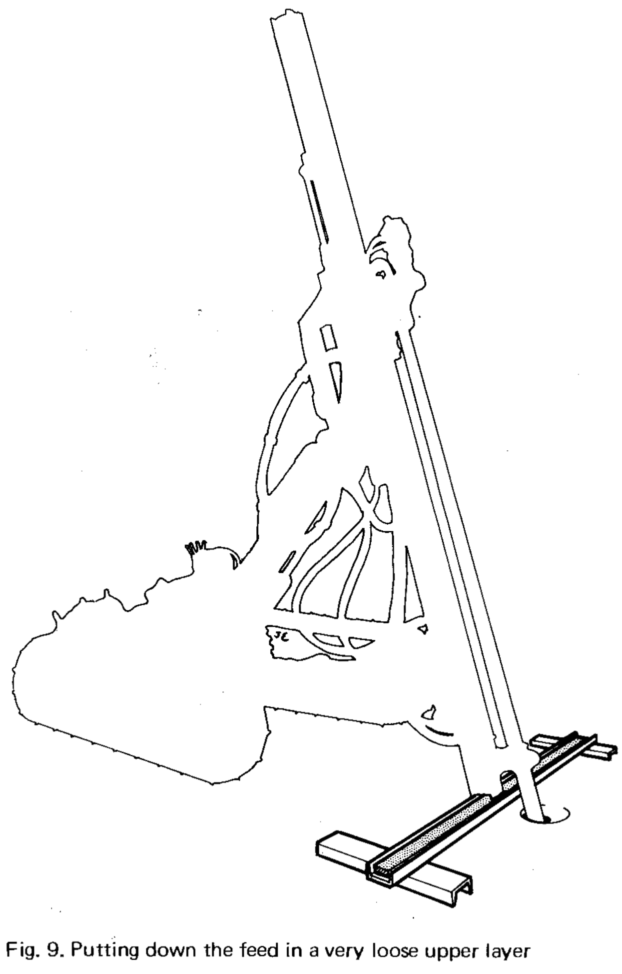


Fig. 9. Putting down the feed in a very loose upper layer

4.2 Mounting the drill bit with driver chuck

The drill bit is mounted with a driver chuck and two-part stop ring (Fig. 10). The driver chuck holds the bit and transfers rotation. It has a right-hand thread and is threaded to the casing. Rotation the the right (clockwise) is then always employed during drilling, the opposite situation to drilling with top hammers (Fig. 11).

Mounting and tightening the driver chuck

The driver chuck with drill bit for COP 4 can be screwed to the casing by hand. The heavier bit for COP 6 should be placed on a plank or other flat base, at right angles to the drill and be carefully screwed on with the rotation unit in order to prevent damage to the connection threads (Fig. 10).

The driver chuck should then be tightened properly before drilling begins. Tightening is to be carried out with the special tool (Fig. 13) (also used for loosening the bit) and consists of pressing the bit firmly against the tool, starting the impact mechanism carefully and turning the drill (clockwise) very slowly for a few seconds. The impact mechanism plus the contact of the bit with the tool creates a torque which tightens the driver chuck.

At high operating pressure and in abrasive rock the wear on the casing is great. It is then important to choose a drill bit with a large diameter, which reduces the velocity of the flushing air so that the abrasive effect of the cuttings is lessened.

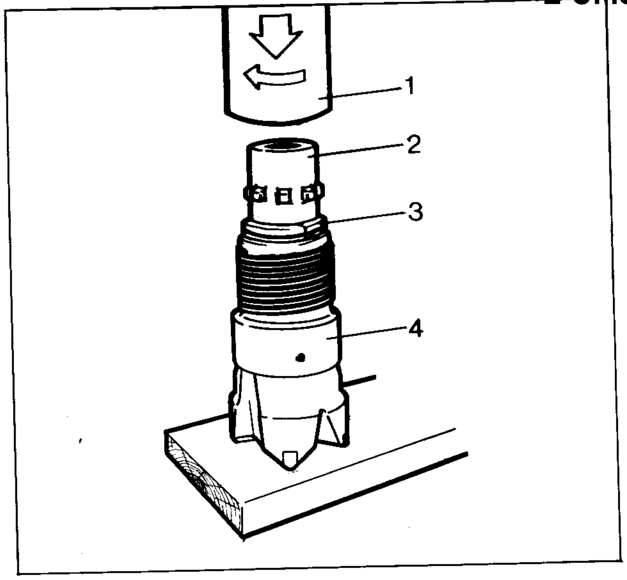
When the driver chuck is fitted after changing the bit or regrinding one should also note the uneven wear on the driver chuck which occurs by the cuttings grooves of the bit (Fig. 12). By turning the driver chuck one spline graduation each time it is fitted, the effect of this wear can be evenly distributed.

Safety precautions during drilling (Fig. 11)

Rotation to the right should always be kept on as long as the impact mechanism is working. The opposite direction of rotation or no rotation can lead to the thread loosening, with a risk of the drill bit coming unscrewed because of vibrations from the impact mechanism.

Rotation to the right may be kept on without the impact mechanism working, however, and this is the general practise when cleaning out the drill hole and when taking up the tube string. In summary it can be said that rotation should always be kept on as long as other operations are being carried out with the drill in the drill hole.

Attention should also be paid to the risk of unintentional unfastening of the drill bit during the operation of unfastening the drill tubes, and the drill string should not be turned backwards more than necessary to adjust the breaking wrenches (only about 1/4 turn).



1. Casing of the drill
2. Drill bit
3. Two part stop ring with O-ring
4. Driver chuck

Fig. 10. Mounting the bit

Wear on the driver chuck and casing

The casing of the drill and the driver chuck are exposed to the grinding and "sand-blasting" flow of cuttings and wear down with time. To prevent unnecessary wear on the casing the driver chuck should not be permitted to wear to a lesser diameter than the casing. By circulating worn driver chucks and always choosing one which is greater than the diameter of the casing, the service life of the casing can be considerably lengthened. When the casing has to be replaced (a wear template is supplied with the drill), the driver chuck should also be replaced by a new one.

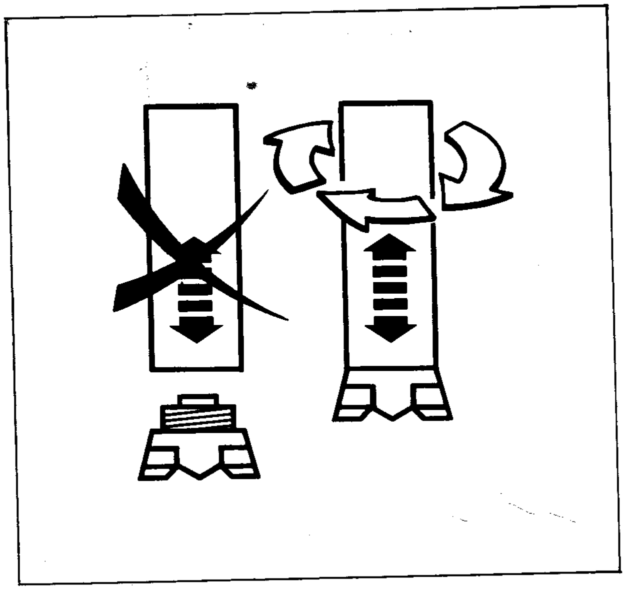


Fig. 11. Rotation to the right must be continued during all operations in the drill hole

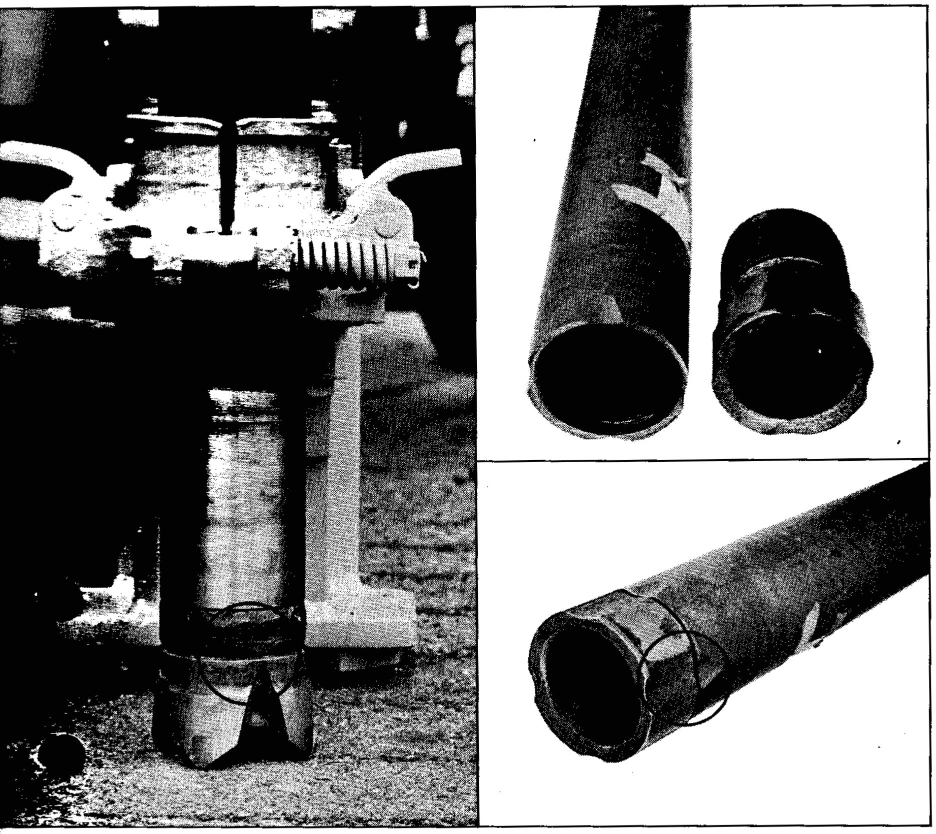


Fig. 12. Unfavourable wear on the driver chuck and casing which is caused by the cutting grooves of the bit coming against the same section of the driver chuck each time the bit is mounted

Fig. 13a. Correct positioning of a button bit in the recess of the tool

Fig. 13b. Put the breaking wrench in the wrench recess and apply force by hand turning to the left

4.3. Removing the drill bit

The driver chuck may be tightened relatively hard during drilling and the special tools which are supplied to loosen the chuck should be used to the greatest extent possible. Sledge hammers damage bits and should not be used.

Bit for COP 4 (Fig. 13)

In the case of COP 4 a simple knock-off tool is used. On the lower side is a round lug which serves as a guide in the drill tube support of the unit. The tool can also be placed with the lug in the drill hole. The shaft is used as a dolly during the loosening operation. As well, the relatively great weight of the tool helps to keep it in place during loosening. (Fig. 13b).

The tools (two sizes) are designed both for fullhead bits and button bits.

The following procedure is recommended when changing the bit:

1. Place the tool on the drill support and run the drill bit down into the tool. The lugs of the tool fit the large grooves of the drill bit (see Fig. 13a).
2. Apply a light feed force.
3. Put the breaking wrench in the wrench recess of the drill and apply force by hand turning to the left (counter-clockwise) (Fig. 13b.)
4. Start the impact mechanism of the drill slowly and stop as soon as the bit comes loose. It is important to stop the impact mechanism immediately when the threads in the driver chuck come loose.
5. Screw out the drill bit.

Bit for COP 6 (Fig. 14)

The drill bit is loosened with the aid of a bit holder (1) and tube tongs (2), which are attached to the casing of the drill. The tube tongs are connected to a hydraulic cylinder (3), which twists loose the casing from the driver chuck:

1. Run down the drill so that the bit takes up the correct position in the jaws of the bit holder (1).
2. Fit the hydraulic cylinder (3) in the bit holder.
3. Attach the tube tongs (2) to the casing of the drill and tighten with the tension screw. Connect the tube tongs to the piston rod of the hydraulic cylinder.
4. Start the hydraulic pump of the drilling unit and open the valve to the hydraulic cylinder so that the casing is turned with rotation to the left until the casing and driver chuck are loosened.
5. Disassemble the tube tongs and unscrew the driver chuck with the aid of the rotation unit.

4.4. Collaring

Collaring is a sensitive moment for the right hole inclination. The bit should not "walk " or wobble on the surface of the rock.

Collaring is then to be carried out at a low operating pressure with reduced feed and rotation. When the drill bit has worked its way down into the rock the operating pressure and the feed and rotation are adjusted to normal.

An uneven collaring surface must be worked over before the actual drilling begins. Run with light blows and low rotation speed until the surface is flat. Check that the driver chuck is properly tightened before drilling is begun.

4.5. Feed force and rotation speed (Fig. 15)

Setting the feed and rotation are in normal cases simple matters as the down-the-hole drill is relatively insensitive to variations. The setting can ordinarily be considered correct and will give the optimal drilling output, when the rotation works smoothly without jerking and catching.

Feed force

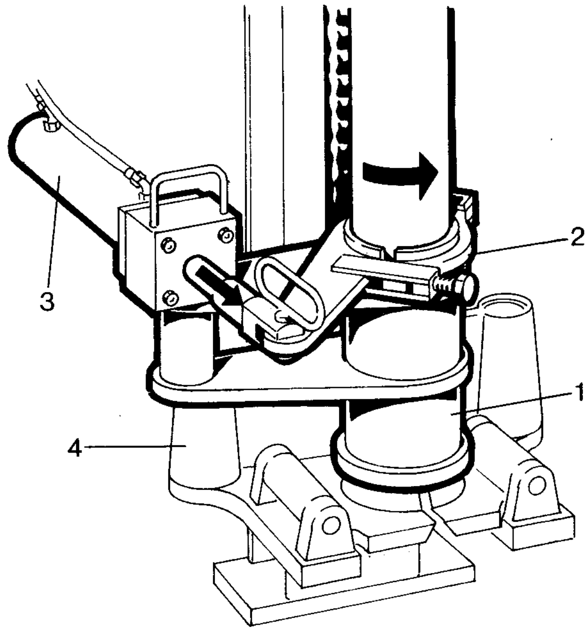
	COP 4		COP 6	
	Feed force range	**Normal feed force**	**Feed force range**	**Normal feed force**
kN	3–8	6	4–12	8
kg	300–800	600	400–1200	800
lb	650–1750	1300	900–2650	1750

Normal feed forces stated in the above table are reference values for normal drilling conditions in homogeneous rock. The optimal feed force must be set according to the rock conditions of each individual case.

Too high a feed force can be recognized by the rotation becoming jerky and catching from time to time. Because of the increased friction in the splines of the bit and driver chuck the drilling effect may deteriorate at the same time as wear is increased. The tightening in the joints of the drill tubes will also be unnecessarily great.

Too low a feed force causes the drill to begin to shake because of recoil forces. The drilling effect deteriorates and the feed and rotation unit are exposed to increased stresses.

It is important to match the feed force to the weight of the drill string. This requires a lever with a responsive setting capacity and the possibility of "negative feeding" or hold-back function.



1. Bit holder 3. Hydraulic cylinder
2. Tube tongs 4. Drill tube support

Fig. 14. Tools for loosening the drill bit on COP 6

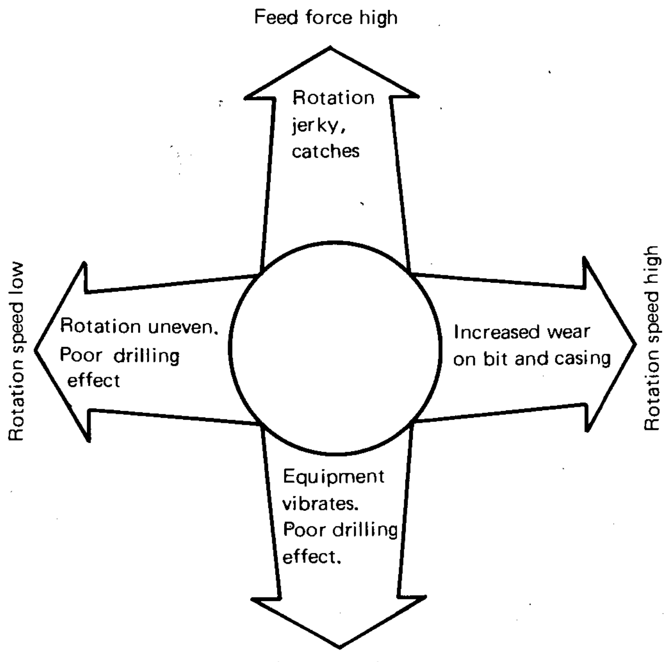


Fig. 15. When the equipment runs evenly and smoothly the feed force and rotation speed are correctly set

Rotation speed

Normally the speed for COP 4 lies between 0.33 and 0.67 r/s and for COP 6 between 0.25 and 0.50 r/s. The upper limit generally results in the best rate of penetration but in highly abrasive rock the speed must be lowered to prevent too great wear (especially gauge wear on the bit).

Too high a rotation speed contributes to increased wear on the bit and even on the drill and drill tubes. Stresses on the feed and rotation unit also increase.

Too low a rotation speed gives a poorer drilling effect and uneven running as the bit works with too small a turn per blow.

4.6. Impurities and counter-measures

Functional disruptions caused by impurities occur with all machines and down-the-hole drills are no exception. A down-the-hole drill is not more sensitive than a conventional top hammer in this respect, rather the opposite, but the particular working method entails completely different and much greater risks of contamination. In unfavourable cases this leads to disruptions in operation or more rapid wear. It is important to be familiar with this situation if the drilling work is to proceed without trouble.

The risk of contamination and the corresponding degree of caution should be viewed as part of the actual drilling situation. The type of drill hole, kind of rock and hole depth affect an assessment of the situation to a great extent. For example, shallow holes in non-abrasive rock are associated with a relatively harmless type of functional disruption, which only requires that the drill be cleaned. Such a disruption is easily dealt with when it occurs by putting in a spare machine. In this type of drilling it may be possible to permit a lesser degree of caution. A deep rock well in granite, on the other hand, requires great care. Not only does a stop in operations at great depth cause a time-consuming withdrawal of equipment, but damage may also occur to the impact mechanism.

Drilling in extremely aggressive rock, e.g. quartzite, requires special attention. Thorough cleaning of the drill and the drill tubes from time to time as a preventive measure gives good results in the form of longer wearing periods. Effective dust elimination is also worthwhile.

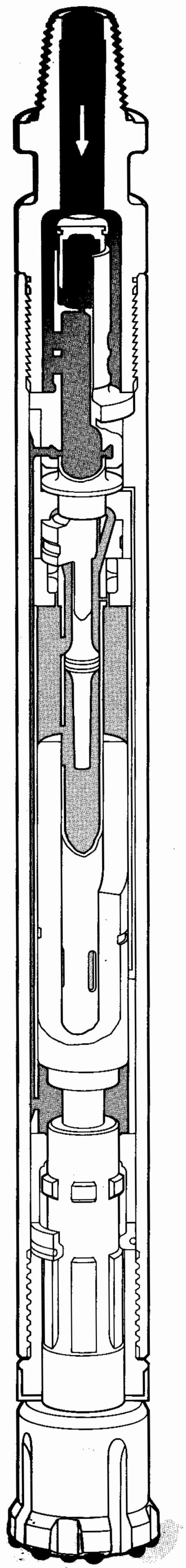


Fig. 16. Down-the-hole drill. Shaded areas indicate the path of the air

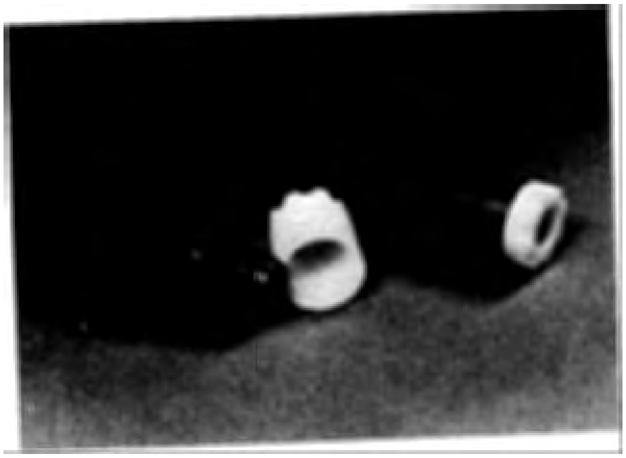


Fig. 17. Thread guard

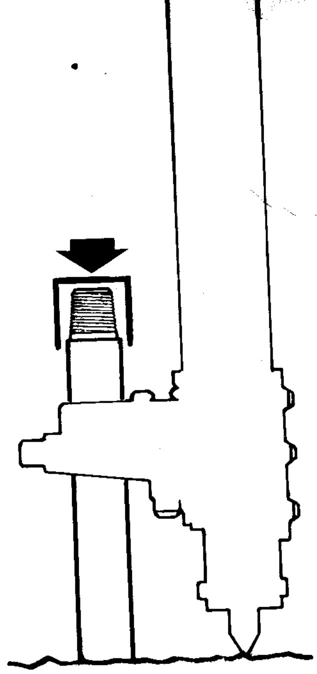


Fig. 18. A simple protection over the end of the tube prevents impurities from falling into the tube string

Impurities

Dust, cuttings and scrap in general have a natural tendency to spread and be distributed, either by a direct transfer or by precipitation from the air. Impurities which enter the air system, mostly via the drill tubes, sooner or later find their way to the drill. In most cases nothing particularly noticeable happens – the particles pass quickly through the machine and it cleans itself. In other cases disruptions may occur due to the nature and quantity of the particles. The drill can become clogged and the impact mechanism may cease to function because of friction. Usually the disruptions find expression as wear and excessively short service lives. These are treacherous chains of events which can be difficult to trace. The conditions at drilling sites are always such that active counter-measures are required to limit contamination. The following general counter-measures are recommended:

1. Use thread guards (Fig. 17) on all threaded joint ends including the down-the-hole drill. (Thread guards may be impractical to use when tubes are stored vertically in the magazine, but some corresponding protection must be arranged.)
2. Put a cover or a hood over the upper end of the drill tube when shifting tubes (Fig. 18), so that clumps of cuttings, which come loose from the rotation unit, do not fall down into the tube string.
3. Avoid placing the end of the tube on the ground when moving tubes to or from the magazine (Fig. 19). With vertical storage, stand the tubes on a checker-plate floor or something similar and arrange a roof.

Storing drill tubes

The drill tubes should always be stored in such a way that drilling dust or other impurities cannot be deposited on the inside. This reduces the need for cleaning and also avoids long-term machine disruptions.

Always store the drill tubes with the thread guards in place, regardless of whether it is a matter of short-term storage in a tube magazine or long-term storage in a spares stockpile. Put on the thread guards as soon as the tube is disconnected from the drill string.

In long-term storage care should be given to the problem of corrosion. You must always count on moisture, condensate, occuring on the inside of the tubes and the film of oil not giving adequate protection. If the tubes are to be stored for a long period, excessive fluid (oil, oil emulsion) should be emptied out and a lesser quantity of anti-corrosion oil should be poured in and spread over the walls of the tube. Prior to this the tubes should be cleaned. It is always easier to remove impurities before sedimentation and drying out occur.

The outside of the tubes with the connection threads should also be inspected before long-term storage. A badly worn tube or a tube displaying cracks should possibly be scrapped. Clean the threads, remove burrs and upsetting on the connecting parts and brush the threads with grease before putting on the thread guards.

Cleaning drill tubes

If the storage procedure has been incorrect, the inside of the tubes may gather large quantities of impurities, which then during drilling are slowly transported down to the drill. A single contaminated drill tube can foul an entire tube string and cause disruptions in operations over a long period.

If a tube is fouled and requires cleaning very resolute efforts must be made. It is, for example, practically meaningless to "blow out" the drill tube when it is already mounted in the rotation unit. The air velocity along the walls of the tube is far too low to have any appreciable cleaning effect.

A suitable procedure for cleaning is to lay the tube horizontal and then pour in water mixed with a solvent. Roll the tube and rinse out loose particles. Note that sedimented drilling dust can form hard "cakes" which are difficult to rinse away. Some form of scraping or brushing may be required. This also applies to zones of corrosion where the rust sits more or less well attached.

Finally, blow out the inside with compressed air with a nozzle which can be passed along the full length of the drill tube.

5. TABLE OF TYPICAL SITUATIONS

Table 3 on page 14 lists a number of general rules of thumb for the choice of down-the-hole bit and auxiliary equipment, which are required under different drilling conditions. It is the purpose of the recommendations to offer a first choice for test drilling in a given formation, the choice of equipment can then be modified on the basis of this experience.

Fig. 19. ROC 301-00 with tube rack

6. MEASURES TO PREVENT GETTING STUCK DURING DRILLING

A loss of the ability to manoeuvre because of some obstacle down the drill hole is in most cases the result of insufficient flushing or the absence of flushing but other causes are also possible, e.g. collapsing hole walls, slips due to poor rock, clay strata, etc.

A bad case of getting stuck means that neither the impact mechanism nor the rotation can be kept working, upwards and downwards movement is prevented. Continued efforts to work free the drill only worsen the situaton, the annular space around the drill and bit fills with cuttings and matter falls down from the mouth of the hole. In such a situation it is a choice of abandoning the drill and tubes or trying the method for freeing the equipment which is described in the section 7. "Taking up stuck or lost equipment".

6.1. Flushing and blowing clean the drill hole (Fig. 20)

As stated above flushing is an important factor in causing the situation of a stuck drill. One should note that flushing demands vary greatly. Hard-to-drill, homogeneous rock places fewer demands on the flushing, as a result of the small production of cuttings and the small risk of collapse. On the other hand flushing demands increase when the rock is easily drilled and the cuttings production is high, as in drilling in ore with heavy cuttings. Moisture in the hole is a complicating factor which causes lumps to form and the equipment to stick to the walls of the hole.

Insufficient flushing means that the stream of air is not capable of lifting the cuttings out of the hole. At the point of passage from drill to drill tube, where the velocity of the air is sharply reduced, cuttings may pile up (Fig. 20a). This leads to a stagnation of the flow of cuttings and the formation of a plug. Coarser matter falling from the mouth of the hole or a collapse of the walls of the hole may also be circumstances causing such a plug.

At the first sign of poorer flushing the hole should be cleaned by shifting the down-the-hole drill to the blowing position: the drill is lifted from the bottom of the hole with rotation to the right retained or increased and is run back and forth with the feed until the obstacles are removed (Fig. 20b).

Reduced flushing will not correct itself; some form of cleaning is always required and this should be done as a preventive measure, e.g. in connection with jointing the tubes. A similar preventive measure is to keep the edges of the hole clean. It is inadvisable to permit cuttings to gather in a large pile by the mouth of the hole. The velocity of the air in this funnel-shaped opening will be so low that a certain portion of the matter will finally always fall back into the hole and can then cause a plug.

Use of DCT dust collectors reduces the risk of cuttings falling back into the drill hole.

When drilling in poor rock the flushing air may suddenly disappear into cracks and cavities (Fig. 20c). As previously one must stop drilling (and the creation of cuttings) and direct efforts toward cleaning out the hole. One can then carefully pass through the critical zone.

The choice of drill bit and operating pressure also affect the flushing conditions and the risk of getting stuck. A higher operating pressure gives a better flushing effect despite the fact that the rate of penetration increases.

Choosing drill tubes with a larger outer diameter than standard reduces the annular space between the hole wall and the drill tube. This results in a higher velocity for the flushing air and improves cuttings removal. Thus, larger drill tube diameters are recommended when drilling long holes or holes with a large diameter and when drilling in heavy ores or other fissured or difficultly drilled rock formations where flushing problems may occur.

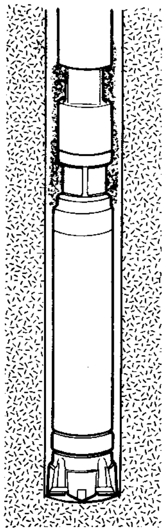


Fig. 20a. Cuttings can gather by the transition between the drill and drill tubes, if the flushing is insufficient

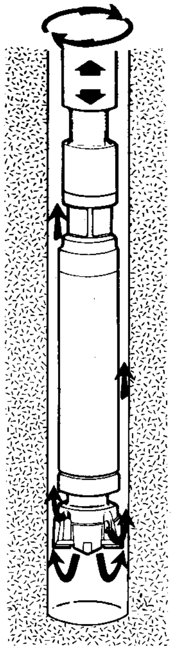


Fig. 20b. During the blowing (cleaning) of the drill hole, almost the double volume of flushing air flows through the drill

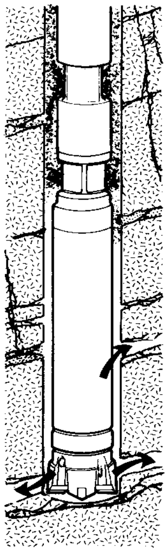


Fig. 20c. If the flushing air disappears into fissured rock, the column of cuttings falls back and can clog the drill

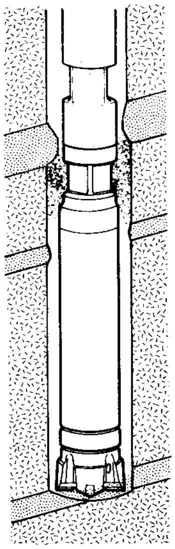


Fig. 20d. Clay strata may be forced out into the drill hole and impede drilling. Clay may even clog the flushing holes of the bit

Table 3. Typical cases

Drilling conditions: Type of rock	Drilling conditions: Nature	Drilling conditions: Working pressure bar 1)	Operating air requirements (down-the-hole drill only) 3) l/s 2): COP 4	Operating air requirements (down-the-hole drill only) 3) l/s 2): COP 6	Choice of DTH-bits 4): Type of bit B = button bit F = full head bit	Choice of DTH-bits 4): Diameter, mm: COP 4	Choice of DTH-bits 4): Diameter, mm: COP 6	Recommended extra equipment	Notes
Hard rock (over 6) 200 N/mm^2) **Abrasive** (quarzite, taconite)	Homogeneous	6	65–120	120–250		110 (115)	165 (156)		
		10.5	115–150	220–310	B	110 (115)	165 (156)		
		18	195	350		115	165		
Hard rock **non-abrasive** (diabase)	Homogeneous	6	65–120	120–250		105 (110, 115)	152, 156 (165)		Remove plugs in valve housing of COP 6 when drilling at depths below 30 m (100 ft)
		10.5	115–150	220–310	B	105, 110 (115)	152, 156 (165)		
		18	195	350		110, 115	165		
Medium hard rock (100–200 N/mm^2) 6) **abrasive** (quartz/ sand stone)	Homogeneous	6	85–135	150–285		110 (115)	165 (156)		Remove plugs in valve housing of COP 6 when drilling at depths below 30 m (100 ft)
		10.5	135–170	250–350	B	110, 115	165 (156)		
		18	195	350		115	165		
Medium hard rock **non-abrasive** (limestone)	Homogeneous	6	85–135	150–285		105 (110, 115)	152, 156 (165)		
		10.5	135–170	250–350	B	105, 110 (115)	152, 156 (165)		
		18	195	350		110, 115	156, 165		
Hard to soft rock **abrasive**	Fissured	6	110–170	250–300		110, 115	165	Flushing adapter, retrac sub	Flushing requirements high
		10.5	110–200	250–350	B (F)	110, 115	165	Flushing adapter, retrac sub	
		18	200–230	350–450		115	165	Retrac sub	
Hard to soft rock **non-abrasive**	Fissured	6	110–170	250–300		105, 110 (115)	152, 156 (165)	Flushing adapter, retrac sub	Flushing requirements high
		10.5	110–200	250–350	B (F)	105, 110, 115	152, 156, 165	Flushing adapter, retrac sub	
		18	200–230	350–450		115	165	Retrac sub	
Heavy rock (ore)	Fissured, loose	6	170–230	350		105, 110	152, 156, 165	Flushing adapter, retrac sub, flushing agent	Flushing requirements high
		10.5	230	450	B (F)	105, 110	152, 156, 165	Flushing adapter, retrac sub	
		18	230	450		110, 115	165	Retrac sub	
Very loose rock	Hole walls cave in	6	135–170	250–350				Flushing adapter, flushing agent	Flushing requirements high
		10.5	135–230	250–350	B (F) 5)	110, 115	165		
		18	230	350				Flushing agent	
All types of rock	Fissured, clay zones	6	135–170	250–350				Retrac sub, flushing agent	Flushing requirements high. Careful feeding and frequent clean-out
		10.5	135–230	250–350	B (F)	115	165		
		18	230	350					
Soil, overburden (Water well drilling)		6	170–230	350				Flushing adapter, flushing agent, casing tubes	Flushing requirements high
		10.5	230	450	B (F) 5)	152	216		
		18	230	450					

1) 85, 150 and 260 psi. 1 bar = 100 kPa = 1.02 kg/cm^2 = 14,5 psi

4) Second choice in parentheses

6.2. Extra flushing during drilling (Fig. 21)

The normal flushing capacity of down-the-hole drills, that is, the exhaust air from the impact mechanism, must often be increased when drilling in ores with heavy cuttings, in easily drilled rock with a high cuttings production and in badly broken rock. Deep holes and holes with a large diameter in relation to the drill tubes may also call for additional flushing. The need for extra flushing is greater at low operating pressures. The supplementary flushing means a higher air consumption, so that the availability of compressed air must also be checked.

To provide extra flushing COP 4 can be equipped with an adapter with holes which is fitted between the top sub and first drill tube, in extreme cases also in the joints of the tube string at different levels. COP 6 can be equipped with a special top sub with flushing holes and cemented carbide inserts directed to the rear (retrac sub, see below). By providing an addition to the flushing air by the top sub, the flushing effect is increased where it is required, that is, at the point where the diameter becomes smaller, between the drill and the tubes (see Fig. 20a). The flushing holes are angled upwards and therefore do not damage the hole walls.

The capacity of the flushing air can be varied within wide limits by plugging the flushing holes. If one selects a capacity as great as the air consumption of the down-the-hole drill, one obtains the same average flushing air velocity along the entire tube string as by the drill (see Figs. 3–6).

Fig. 21. Subs with flushing holes and retrac inserts for COP 4 and COP 6

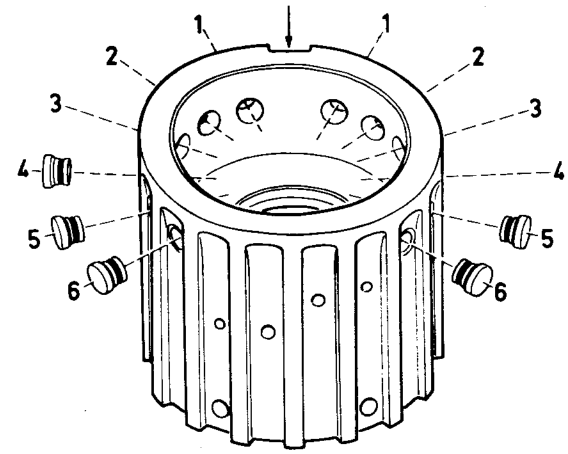


Fig. 22. The valve casing in COP 6 is, as standard, equipped with five plugs which can be removed if extra flushing through the drill and bit is required

In general extra flushing is required when the column of cuttings in the hole has such a high density that drilling cannot continue without frequent blowing out and cleaning. Turbulence and the accumulation of coarser material above the top sub of the drill lead to a gradual reduction of flushing where there is an imminent risk of clogging. If the flushing from the bit obviously disappears into a crack or if the flushing holes for some reason, e.g. clay bands, get plugged, the situation may easily develop into a bad case of stuck equipment. With the aid of a flushing adapter one both has an effective addition and keeps the flushing effect even if it is no longer provided from the bit.

Extra flushing through COP 6

The volume of flushing air can also be increased through COP 6, by removing the plugs in the valve casing (see Figs. 22 and 2). If this extra flushing air is not required and the compressor capacity is limited, the plugs should be kept in the valve housing.

On delivery the drill has plugs in five holes as shown in Fig. 22. An optional number of these plugs may be removed. When the plugs are to be refitted, the same holes as previously should be blocked. The duct (1), nearest the key groove, controls the automatic restarting of the drill after blowing and should not be plugged.

6.3. Retrac sub (Figs. 21 and 23)

In bench drilling, e.g. in a quarry, it is not uncommon that the upper layer of the ground consists of badly blasted rock. When withdrawing the drill, material can fall down and fasten between the rock walls and the top sub of the drill. For this reason the latter can be equipped with a retrac sub. The reardirected cemented carbide inserts of the adapter or sub facilitate withdrawal by breaking up the material that has fallen as they rotate. A retrac sub has however a marginal effect and the precautions earlier named in connection with flushing and blowing should not be neglected. In rock which is fissured throughout one should count on disruptions localized around the bit part of the drill and extra flushing may be required.

The retrac sub is also used in clay strata (Fig. 20d) to ream up the congestion which may arise. On COP 4 a special adapter is used, fastened to the top sub of the machine (Fig. 23) while COP 6 is equipped with a special top sub with rear-directed cemented carbide inserts (Fig. 21). The top sub has a number of holes which make extra flushing possible (see above). The holes can be plugged if the additional flushing air is not desired.

6.4. Stabilizing the hole walls with clay

(Figs. 24–26)

In rock with a very shattered upper layer collaring may result in a hole opening which continually collapses (Fig. 24), and which gradually becomes very large. This greatly reduces the flushing velocity, already reduced by leakage through cracks. Drilling becomes impossible because of the constant risk of collapse and by the fact that the cuttings can no longer be transported out of the hole.

A means of remedying this drilling problem is to stabilize the mouth of the hole with clay. Its purpose is to pack the hole walls and the surface of the ground nearest the hole with clay and thus bind the loose stones which would otherwise fall into hte hole. One should choose a clay with a relatively smooth yet still solid and tough consistency. If there is no clay at the site, bought clay of the bentonite type can be used. Lining with clay is to be done as follows:

Fig. 23. Adapter with retrac inserts for COP 4 (Retrac sub)

Fig. 24. An unstable surface layer collapses easily and may make drilling impossible

Collaring is to be done carefully, preferably at a reduced operating pressure, to a depth of about 0.5 m (20"). The drill hole is then filled with clay (Fig. 25) which is packed into the walls of the hole by running the drill down into the hole several times with reduced impact and slow rotation. Filling and packing are to be repeated until solid rock is reached and the tendency of the hole walls to collapse has stopped. Th e clay can also be reinforced with gravel and small stones.

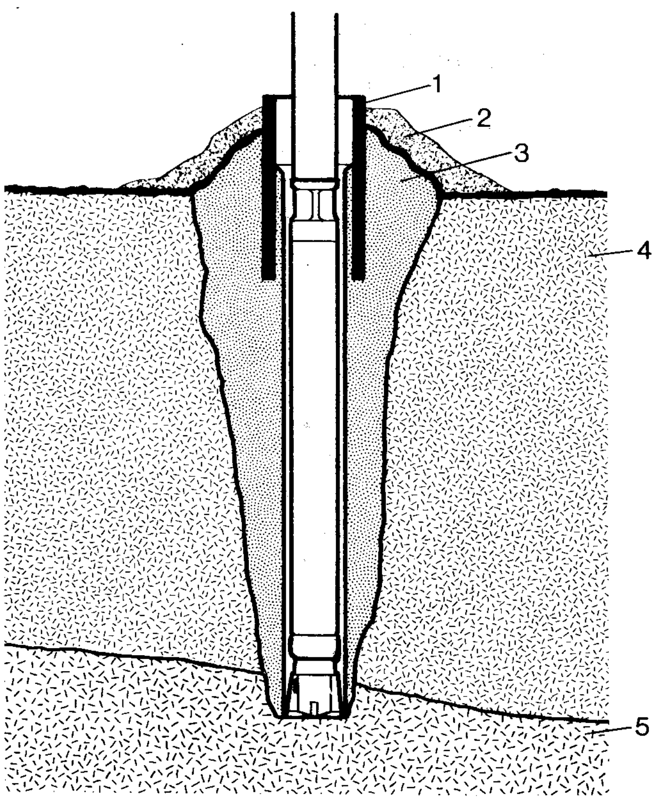
Lining is concluded by a bank around the mouth of the hole to prevent the cuttings from running back down in it. A piece of tubing with a suitable diameter can also be placed over the mouth (Fig. 26).

A great deal of care is required and all efforts should be made to do a careful job. A successful treatment with clay provides an acceptable hole mouth and permits drilling to continue without disruption.

6.5. Casing tubes

Another method of mastering the difficulties of poor surface rock, blasted muck or gravel and soil is to employ short casing tubes. The loose layer of rock is first drilled through with a large bit. The hole is then lined with a metal or plastic tube whose inner diameter is somewhat greater than the final hole diameter, and drilling may then continue.

Fig. 25. Filling the upper part of the drill hole with clay



1. Tube
2. Cuttings
3. Clay
4. Loose rock
5. Solid rock

Fig. 26. Principle drawing of clay treatment

6.6. Stabilizing the hole walls with foam

(see also printed matter No. 20200)

In rock which is loose or fissured throughout or in gravel and soil strata there also exists the possibility of stabilizing the walls of the hole by means of a special liquid foaming mixture, which is metered into the compressed air (Fig. 27). The liquid foaming mixture is mixed with the air to a mist which forms a foam in the drill hole and along with the cuttings penetrates cracks and cavities, binding the loose material. (Fig. 28).

The liquid foaming mixture consists of water with a foaming concentrate, DFA 51, which contains no dangerous elements. When the foam enters natural surroundings it is rapidly broken down biologically so that ground water and watersources are unaffected.

The liquid foaming mixture also has a dust-binding effect. It moistens the cuttings as the mixture is carried out of the drill hole in the form of foam. The dust is still bound after the water has evaporated so that the risk of dust being stirred up by the wind or machines is small.

The liquid foaming mixture provides a satisfactory lubrication of the drill during drilling. After the use of the flushing additive, however, an extra amount of lubricating oil must be supplied to the drill. Pour the oil directly into the drill or through the drill tubes.

The equipment consists of a tank with a compressed air powered pump (Fig. 29). The liquid foaming mixture is transported through a hose to a metering valve with a shut-off cock, which is connected to the control for the impact mechanism.

Mixing ratio

Foaming concentrate DFA 51 should be mixed with water **according to the** table below. At temperatures lower **than ±0°C)+32°F)** the liquid foaming mixture must be **warmed up or an** anti-freeze agent added.

Drilling conditions	Part by weight DFA 51 to 100 parts water
Thick strata of clay or clay slate	0.5–1
Solid kinds of rock	1–2
Unconsolidated kinds of soil	2–4
Unconsolidated kinds of rock	2–4
Water-bearing kinds of rock	4–[illegible]

Under difficult drilling conditions foam stabilizer C is to be added according to the following table:

Drilling conditions	Parts by weight (DFA 51 + Stabilizer C) to 100 parts water	
	DFA 51	Stabilizer C
Soil drilling with difficult ground conditions	2	1
Drilling in very unconsolidated or fissured rock	2–4	2
Soil drilling under very difficult conditions in layers of porous sand and gravel	3–4	3
Drilling in formations sensitive to water	1–3	3
Drilling in rock with large intrusion of water	4–6	2–3

Fig. 27. Metering the liquid foaming mixture into the compressed air

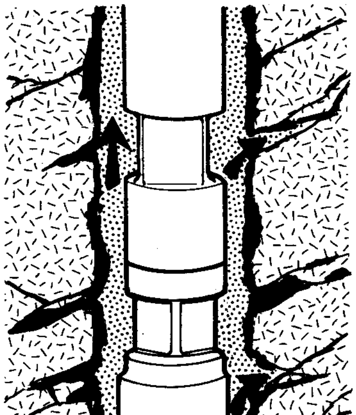


Fig. 28. The liquid foaming mixture is mixed with cuttings and stabilizes the loose walls of the hole

6.7. Drilling wet holes

The drilling of water wells is naturally associated with the presence of water in greater or lesser quantities, but one can expect water on other drilling occasions as well. In normal cases the inflow of water creates no drilling problems.

The presence of water can however pose a problem for drilling when the inflow reaches a certain volume as the water gives the cuttings a paste-like, difficultly moved consistency. This paste sticks to the hole walls and "collars" or plugs are easily formed. The difficulties are lessened by adding water to the operating air, thus increasing the fluidity of the cuttings. Regardless of the use of water a continuously blowing and cleaning of the hole are necessary. The drilling operation is facilitated by generous flushing during drilling (flushing adapter).

To meter water into the compressed air it is suitable to use the foam flushing equipment (Fig. 29). The water should be clean and it should be possible to control the volume. The amount of water added should be as little as possible in order to get a satisfactory flow of cuttings. 0.5 l per m^3 free air (0.3 Imp.gal per 100 cu.ft) may be considered a reference value. In many cases the inflow will increase as the hole gets deeper and water metering needs to be employed only temporarily. Water metering lowers the rate of penetration somewhat and should consequently be used only when there is a real need.

A certain care and attentiveness to the drill should always be observed as concerns lubrication. Doubling the oil quantity is recommended. When the water metering is stopped, the drill should be blown and then given an extra quantity of lubricating oil, which is to be poured directly into the machine or through the drill tubes.

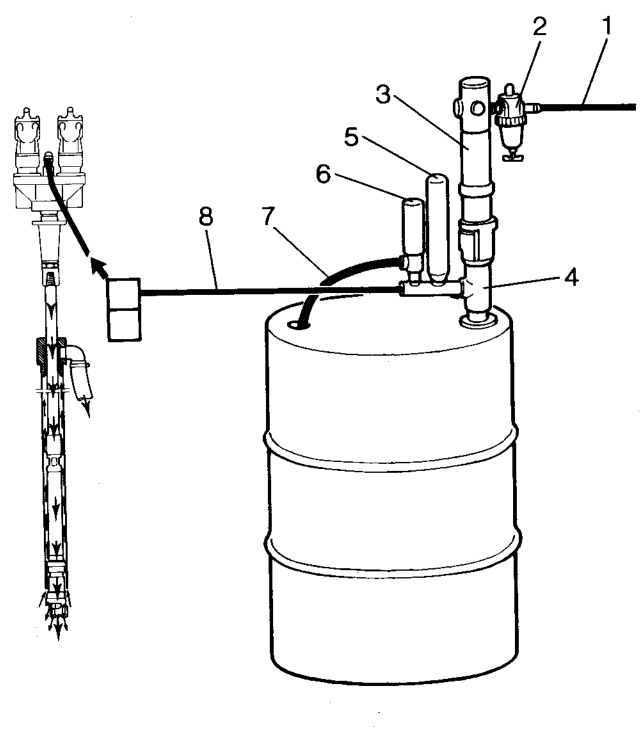
7. TAKING UP STUCK OR LOST EQUIPMENT

7.1. Cleaning out cuttings with ring drilling equipment (Figs. 30–32)

If the drill, despite preventive measures, gets stuck because of cave or poor cuttings removal, the matter which locks the drill can be cleaned out with the aid of casing tubes with a ring bit (Atlas Copco Craelius CMS tubes with tungsten carbide tipped casing shoe bit). The principle is shown in Fig. 32. The ring drilling equipment is introduced between the drill tubes and the hole walls with full rotation and full blowing, and breaks up and blows up the cuttings.

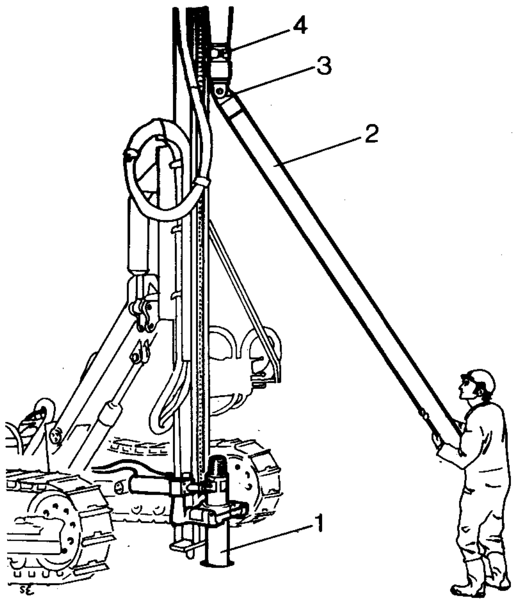
The casing tubes are to be connected in the following way (Figs. 30–32).

1. Unscrew the drill string from the rotation adapter.
2. Calculate the hole depth to the top sub of the down-the-hole drill and lower a corresponding number of casing tubes, fitted with a casing shoe bit. The light tubes for COP 4 can be handled manually, while a special hinged adapter (3, Fig. 30) is used mounted to the rotation unit (4) to lift the tubes (2) for COP 6 when lowering and taking up. The tubes are held in the drill tube support during the jointing operation by tube tongs, which are locked with a ring over the legs.
3. Connect the adapter (2, Fig. 31) to the rotation device, connect the string of casing tubes (3) and drill down with the air for the impact mechanism turned on (blowing) until the bit reaches the top sub of the drill (Fig. 32).
4. Break up the pile of cuttings by using full rotation and full blowing.



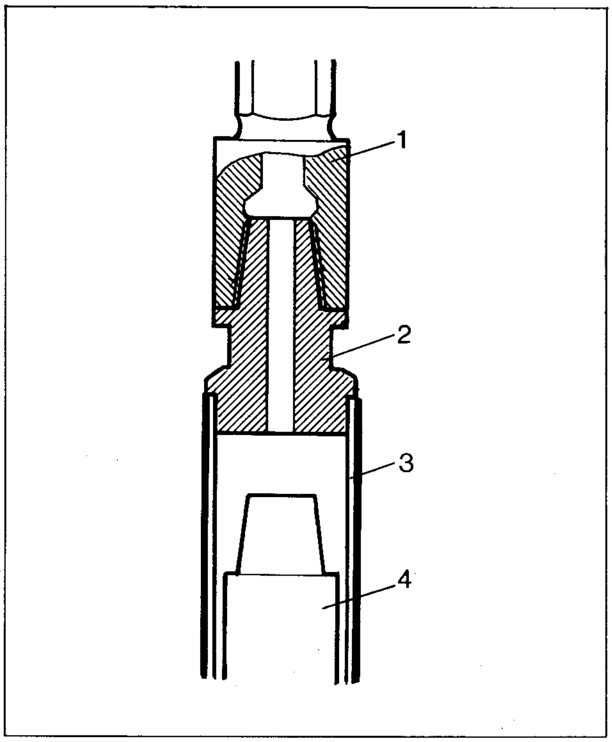
1. Compressed air hose
2. Oil fog lubricator
3. Air motor
4. Pump part
5. Pressure balancer
6. Pressure limiting valve
7. Drainage hose
8. Pressure hose for liquid foaming mixture

Fig. 29. Foam flushing equipment



1. Stuck drill string
2. Casing tube
3. Hinged adapter
4. Rotation unit

Fig. 30. Introducing (or withdrawing) cuttings cleaning equipment for COP 6. The tubes (2) are connected to a jointed adapter (3) and lifted with the aid of the feed



1. Rotation adapter
2. Tube adapter
3. Casing tube
4. Stuck drill string

Fig. 31. Connecting the set of casing tubes

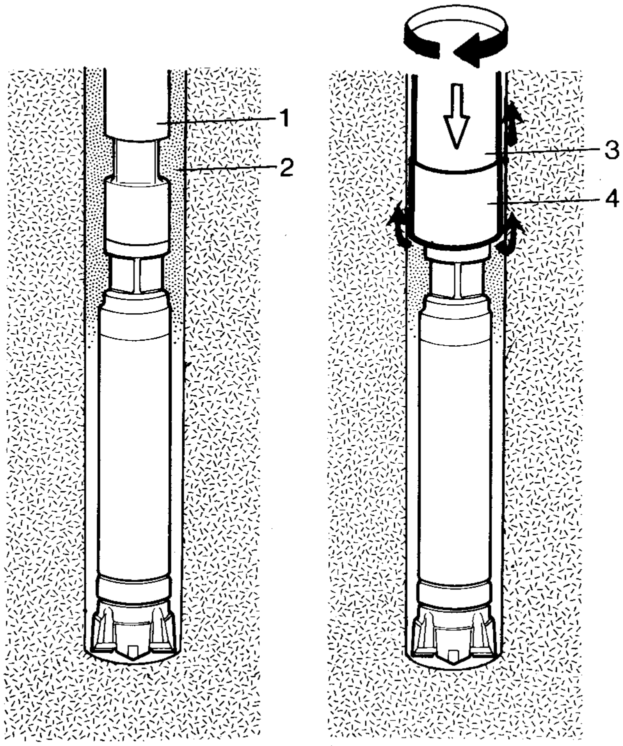
5. Take up the casing tubes and connect the rotation unit to the drill string again. Pull free the drill with the rotation and feed and clean the hole thoroughly.
6. If possible, continue drilling carefully. Pay attention to the cuttings removal and blow the hole clean at regular intervals.

For every set of tubes (see "Drilling equipment"), one should select at least one tube 0.5 m (20") and one 1.5 m (5 ft) long in order to easily match the length of the tube set. The other tubes are of normal length, 3 m (10 ft).

8. DRILLING STRAIGHT HOLES AND LARGE DIAMETER HOLES

8.1. Precision drilling — Pilot hole drilling

One special type of drill hole is characterized by rigorous demands for straightness and direction. They may be long, large diameter holes, horizontal or vertical. It is usually a matter of connection holes for ventilation or drainage in connection with civil engineering work. This type of drill hole can also in certain cases replace trenching operations. By equipping the down-the-hole drill with special guides very high precision can be achieved as concerns straightness and direction (Fig. 33). The direction requirement naturally presupposes careful alignment and a very stable set-up of the feed-carrier. The cradle is adjusted to have the least possible clearance.



1. Drill tube
2. Cuttings
3. Casing tube
4. Casing shoe bit

Fig. 32. Cleaning out cuttings, principal drawing

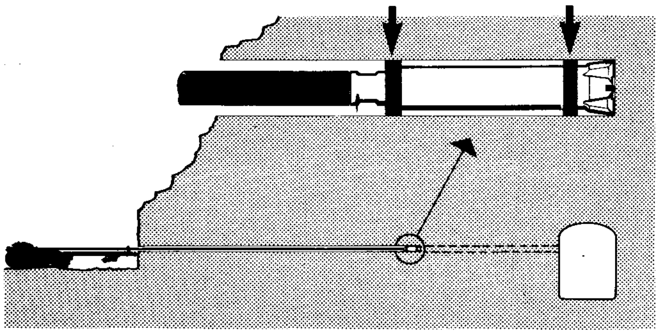


Fig. 33. ROC 606 and COP 6 with guides for precision drilling

If conditions permit, the front part of the feed should be attached to the rock with bolts. Another possibility is to drill a guide hole for the feed spike. The collaring surface should be sufficiently flat with clean rock and also at right angles to the direction of drilling. Some type of preparatory work is generally called for: scaling, levelling or cementing. Collaring is effected within a carefully drawn hole circle.

For reaming to larger diameters, see the following section.

Aligning the feed and drill tube

After the rough positioning, blocking up of the drill wagon and possible bolting of the front end of the feed to the rock, the horizontal and vertical angles of the feed beam must be carefully set.

The drilling work is very dependent on the stable set-up of the feed. The greater the requirement for hole direction and guidance, the greater the requirement that the feed not change position in the course of drilling. Another important requirement is that the drill string is parallel to the feed beam during collaring. Otherwise there occur bending stresses and misalignments which may greatly worsen the results. If required, equip the drill steel support lugs with guides which tightly grip the down-the-hole drill and check the parallelity before collaring the hole.

Another method to assure good collaring is to use a special bit guide which is bolted to the rock. The bit guide consists of a 20 mm thick plate with holes for rock bolts, positioning holes for the feed and a guide hole for the drill bit, see Fig. 34.

The bit guide prevents the bit from pulling in any direction during collaring, but here too accurate parallelity between the tube string and the feed beam is necessary.

If the hole is to be reamed to a larger diameter, the upper part of the bit guide must be cut away. The lower part with the four rock bolts remains fixed to the rock.

Collaring

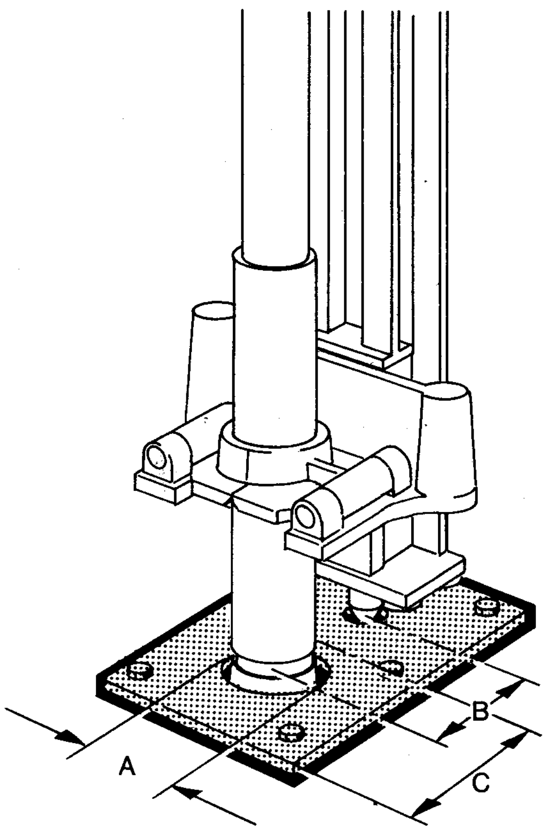
Handle the control levers with great care. Put the drill bit in contact with the rock with slow rotation and start up the impact mechanism with reduced pressure. When the rock has been levelled off, and the bit begins to work its way into the rock, the pressure can be increased carefully. Check that the collaring point lies within the circle which is marked out. Collaring is completed when the front guide has entered the hole.

If the collaring operation is unsuccessful and the bit pulls to one side, you must choose between adjusting the alignment of the feed to the real direction of drilling, and starting again from the beginning.

Continuation of drilling

Use the feeding force with care until both guides have entered the hole. It should be possible to regulate the feeding force with the reducing valve.

During the drilling which follows, special attention must be paid to the removal of cuttings. A flushing adapter may be required, especially when drilling horizontal holes, in ore, or with large bit diameters.



A = Drill bit diameter + 2 mm
B = Distance between drill bit centre and feed spike centre (264 mm for BMM 36K 658)
C = Part to be cut away when reaming the hole

Fig. 34. Principal drawing of precision drilling with the aid of bit guide, bolted to the face of the rock

Hole deflection

A certain hole deflection is unavoidable. The degree depends to a great extent on the condition of the guides and how well they are matched to the drilled hole diameter. The gauge wear of the guides should not be greater than the gauge wear on the bit, plus 0.5–1% of the bit diameter. When the bit is taken up for regrinding, control measurements should be made of the diameters and when required the guide surfaces should be built up with hard welding. Check the concentricity and roundness and adjust as required.

Hole deflection is of two kinds: en error in height or in the vertical plane because of the effect of mass on hole directions which are not vertical, and lateral error which is due to the rotation and feeding force combined. With the aid of guides, deflection can be kept to very low values. Vertical holes often have less deflection.

Special difficulties

The circumstances which normally aggravate drilling work are also to be met in this type of drilling. Fissures and poor rock create a greater risk for getting stuck than normally, in addition to the hole direction being negatively affected. Matching the bit diameter to hole conditions when changing bits requires more attention than in normal cases.

Fig. 35. ROC 606 and COP 6 with a 254 mm reaming bit. To visualize the reaming bit, the dust collector device has been opened

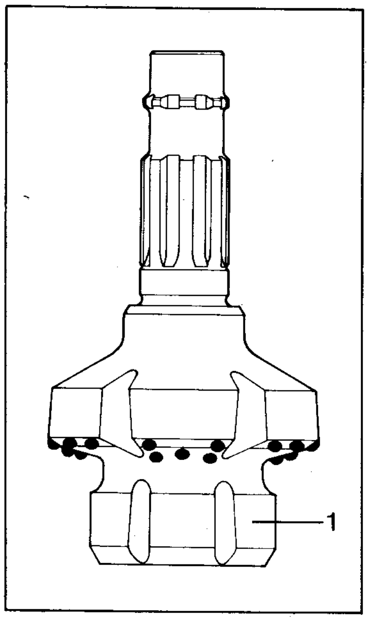
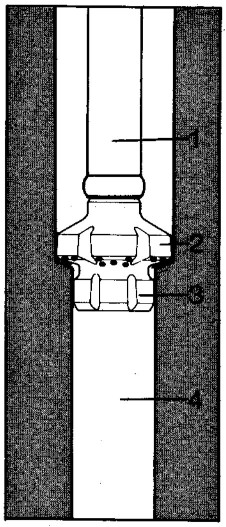


Fig. 36. Reaming bit with pilot (1)



1. Down-the-hole drill
2. Reaming bit
3. Pilot adapter
4. Pilot hole

Fig. 37. Reaming drilling

8.2. Drilling large diameter holes

Drilling without reaming should be practised if possible. COP 4 is employed for direct drilling of holes 105 mm (4 1/8") to 140 mm (5 1/2"). Furthermore there is a 152 mm bit which is recommended only for drilling through overburden in connection with casing of the holes.

For holes 152 mm (6") and larger the following methods have been developed with COP 6:

Hole diameter		Drilling method
mm	in	
152–165	6–6 1/2"	Direct drilling
216	8 1/2	Direct drilling
254	10	Reaming from 165 mm pilot hole
304	12	Reaming from 216 mm pilot hole

Reaming holes to larger diameters (Figs. 35–37)

Pilot holes are drilled in the normal way following the demands for precision (see the foregoing section). A reaming bit with pilot (Figs. 35 and 36) is used in reaming. The pilot hole and the large hole are drilled from the same set-up of the feed and drill wagon, as the requirements for the coincidence of direction and centering are very great.

The feed force must be used with great care, so that the drill string is not bent, causing uneven loading on the bit. Cuttings removal must be observed. Frequent cleaning may be called for. Access to generous amounts of air is required.

When drilling towards a breakthrough, flushing problems are few. In certain cases with horizontal holes it may however be suitable to plug the pilot hole to facilitate the cleaning out of cuttings behind the drill. This in turn makes it easier to remove the drill. Water flushing with a separate flushing hose may be employed.

If drilling is not towards a breakthrough, the pilot hole should be drilled somewhat longer than necessary in order to create a space for coarser cuttings to collect in as they may not be blown out of the hole. During reaming it may be necessary to clean the pilot hole with water by lowering a hose (about 25 mm, 1") into the drill hole.

Fig. 38. Water well drilling through soil with Aquadrill 461, incl. feed BMM 36K 855, rotation unit BBR 6 and down-the-hole drill COP 4

9. WATER WELL DRILLING (Fig. 38)

9.1. Choice of equipment

In water well drilling the choice of compressor is of special importance, since the drilling of holes at times very deep, through overburden and in water-bearing rock, places high demands for flushing and blowing clean. A compressor which provides a good blowing capacity (see 3.2. "Choice of compressor") and a high pressure should therefore be selected. The setting up of the equipment is also of great importance when drilling deep holes.

The feed force and the torque from the rotation unit should receive special attention in the case of deep holes. The choice of feed is determined by the force which is required to pull up the drill string, plus a certain margin to deal with any obstacle which may occur in the drill hole. A feed with a low feed force can if necessary be complemented by a winch arrangement for use with deep holes.

Deep holes and fissured or difficult-to-drill rock also require high torque. In this respect rotation unit BBR 6 can be used with COP 4 along with a standard thread adapter.

Drilling units with hydraulic feeds and hydraulic rotation units can generally be employed for hole depths in current use.

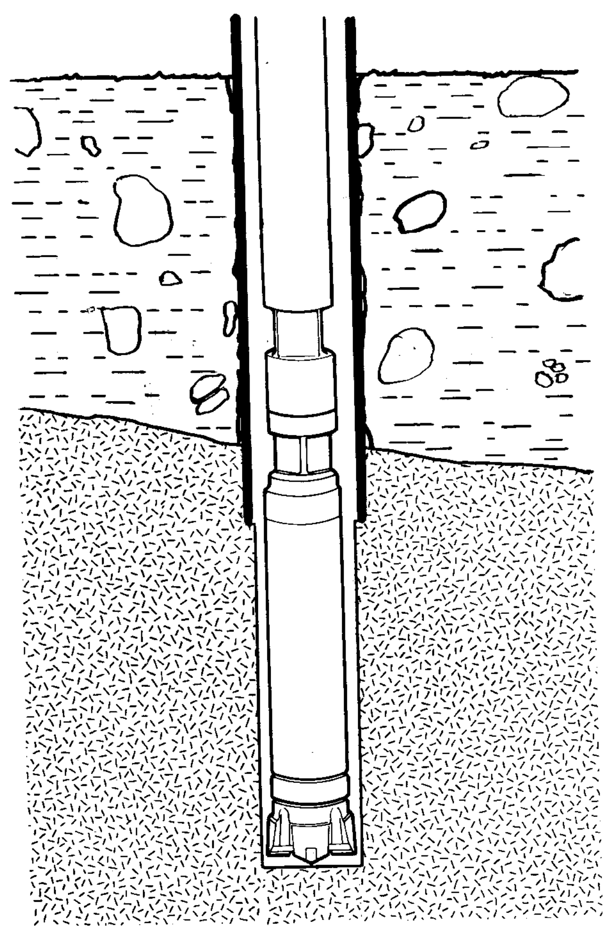
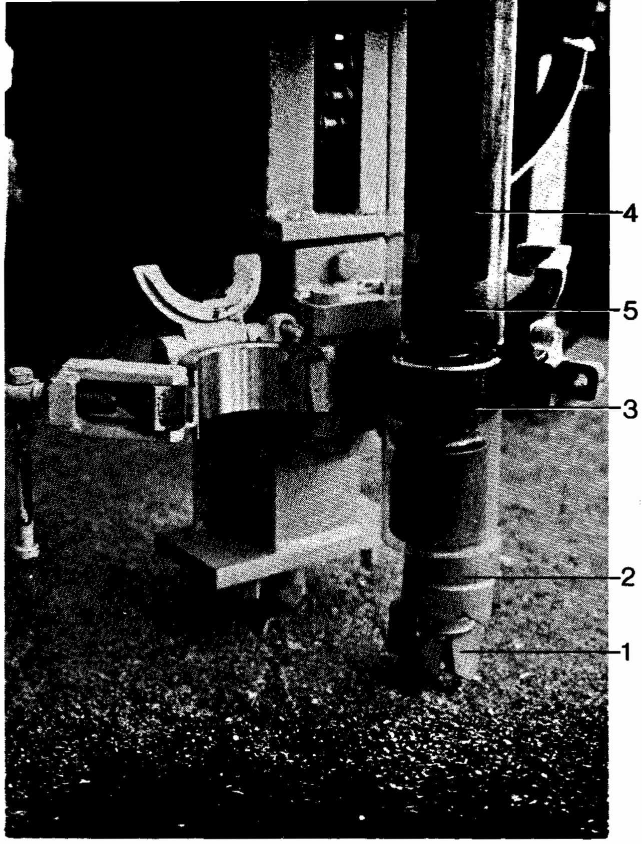


Fig. 39. Principle for drilling with casing tubes with an oversized bit through the overburden



1. Pilot bit, 110 mm (4 1/4") 4. Down-the-hole drill COP 4
2. Reamer, 152 mm (6") 5. Extended rotation chuck
3. Guide

Fig. 40. COP 4 with ODEX eccentric equipment (with a plastic tube representing the 140 mm (5 1/2") casing tube

9.2. Drilling in soil (Fig. 39)

Thin soil strata can often be passed with a larger bit diameter (152 mm for COP 4 and 216 mm for COP 6), after which casing tubes can be put down through the soil strata. If necessary the tubes can be driven down with the down-the-hole drill and a driving shoe attached to the tube. Drilling can then continue with a smaller bit. In connection with this type of drilling a flushing additive is most often used in the operating air in order to stabilize the walls of the hole (see 6.6. "Stabilizing hole walls with foam"). The liquid foaming mixture is broken down after a short time and will not pollute the well. See also 9.3 "Drilling through overburden".

9.3. Drilling through overburden

with ODEX eccentric equipment
(See also printed matter No. 15490.)

Description

The equipment for drilling through overburden, loose formations containing boulders, gravel and other obstacles consists of COP 4 with extended chuck and a reamer assembly complemented with wing coupling, drilling tubes and a discharge head assembled inside a casing tube with a bit tube welded in the lower end (Fig. 40–41).

The casing tube is prolonged by welding and does not rotate. It follows the reamer by its own weight – if needed it is driven down by the guide and the bit tube shoe. Most of the drill's capacity is therefore utilized for the actual drilling, resulting in a high rate of penetration even at great depths.

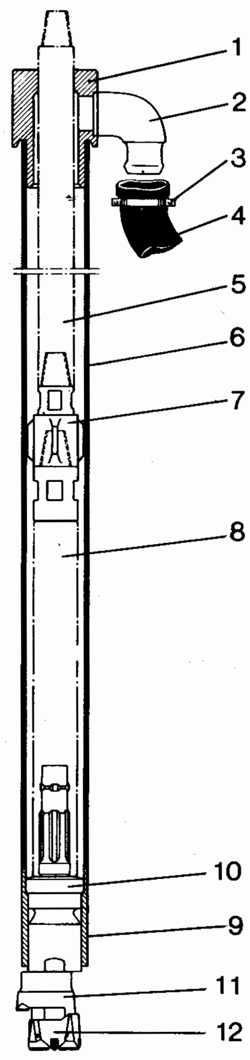
The reamer drills a 152 mm (6") hole for the casing tube when rotated clockwise. When solid rock or proper depth has been reached the reamer can be retracted by rotating the string half a turn counter-clockwise.

The reamer assembly is substituted by an 105–115 mm (4 1/8"–4 1/2") full head bit or button bit for drilling in solid rock to greater depths.

The cuttings are lifted by a liquid foaming mixture in between the drilling tubes and the casing and can be sampled at the discharge head.

The casing tubes used are seamless pressure tubes with an inner diameter of 128–130 mm (5"–5 1/8") and an outer diameter of 138–142 mm (5 3/8"–5 1/2"), corresponding to a wall thickness of 5–6 mm (13/64"–15/64"). Suitable steel quality is SIS 1300 (Swedish standard), DIN 2441 (German standard) or similar. The tubes must be round and easy to weld.

Length is 3000 mm.



1. Discharge head
2. Elbow
3. Clamp
4. Hose
5. Drill tube
6. Casing tube
7. Wing coupling
8. Down-the-hole drill with extended driver chuck
9. Bit tube
10. Guide
11. Reamer
12. Pilot bit

Fig. 41. Cut-through of assembled eccentric equipment ODEX 115 mm (4 1/2")

Application

The ODEX equipment can be used for a number of projects which require drilling through overburden such as

- Well drilling
- Drilling of holes for grouting
- Anchoring
- Drilling through embankments for conduit tubing under roads and railways
- Drilling for supporting structures
- Finding the water table
- Drilling for soil sampling

Suitable drilling rigs are ROC 606, Aquadrill 461 and Mobile Drill® 50 R, which also can be equipped with hoisting, retaining and foam-mixing accessories which are necessary when drilling with ODEX equipment.

Drilling

A casing tube having the same length as the drilling tube is first welded to the bit tube in order to obtain proper positioning. The various parts are then placed inside the tube hoisted up to and joined with the rotation unit. When the first tube has been drilled down, detach the rotation unit and discharge head. Then place a new casing tube — of the same length as the drilling tubes used — in the hoisting device. Insert an additional drilling tube, put on the discharge head, lift and rejoin the drill tube threads and weld the casing tubes together.

Welding (Figs. 42—45)

The casing tubes must be properly cut, aligned and welded. A chamfer grinder is used to make the chamfer shown in Fig. 44. Use a welding fixture for aligning the tubes and be careful not to get any welding material inside the casing tubes so that the inner equipment can be retracted when needed. Grind off external surplus welding material by moving the grinder in the direction of the tubes.

Fig. 42. Semi-automatic, pneumatic tube cutter ensuring a perfect 90° cut, a prerequisite for easy and safe welding

Fig. 43. Semi-automatic, pneumatic bevelling machine

Flushing

It is of great importance that the liquid foaming mixture is properly made and adjusted so that the cuttings are removed from the bottom of the hole. For safe and reliable drilling use a mixture of air and water mixed with foaming concentrate DFA 51.

9.4. Drilling in dry rock formations

As long as the drilling is in normal rock without an inflow of water, it can proceed in normal fashion with regular blowing of the drill hole. At greater hole depths a flushing adapter can be introduced (see 6.2. "Extra flushing with flushing adapter"). On COP 6 the flushing capacity can also be increased by removing the plastic plugs fitted in the inlet holes of the valve system.

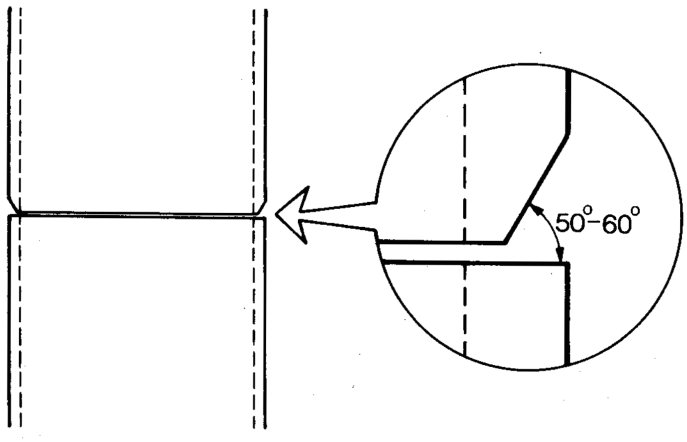


Fig. 44. Bevelling smooth casing tubes. Principal drawing

Fig. 45. Welding smooth casing tubes with the welding fixture Electric welding, employing a small, portable petrol-driven welding set as power aggregate, is much easier to perform than gas welding

9.5. Drilling in water-bearing rock formations

Drilling wet holes covers a range of cases from slightly moist holes to flowing wells. The entire scale is common and is even desirable in water well drilling. It is distinguished from ordinary dry hole drilling as concerns technique, which must be given due attention, or more or less difficult drilling problems will occur. Wet hole drilling entails appreciably greater risks as concerns impurities than dry hole drilling.

This is naturally connected with the great ability of water to carry cuttings and its tendency to fill all cavities when pressure conditions so permit.

Since hardrock wells are generally deep holes which entail great cost, an equally careful and well thought-out drilling technique is an undeniable requirement.

If we consider a typical case of water well drilling in rock, it begins as dry hole drilling. With time water appears, to begin with in small quantities. In this situation the removal of cuttings may be very difficult since the cuttings form clumps which coat the walls of the hole and the drill tubes. Particular care must then be given to cleaning the hole by blowing and by running the tube string up and down in the drill hole. The removal of cuttings can be facilitated by adding extra water. This is best done in the form of pump metering into the working air.

Gradually the inflow of water increases and the cuttings begin to float. As long as the drill is working or blowing, drilling can continue without disruption. The rate of penetration will however be lower because of the slow removal of cuttings from the bit and bottom of the hole.

When drilling is interrupted, for tube jointing or a pause, the water rises more or less quickly. The outer water table, above the drill, can quickly become unexpectedly high. This requires particular attention.

When running down the tube string, e.g. after changing the bit, the hole must be blown clean at tight intervals, preferably after each jointed tube. The jointing operation must be carried out at a pace which takes into consideration the rising speed of the water level.

This circumstance underlines the importance of keeping the tube jointing time as short as possible and of keeping the drill blowing in the event that there is an interruption in drilling.

Tube joints

You should count on the tube joints being more or less "leaky", if no special sealing measures have been taken. If you leave the drill and tube string submersed in a water-filled hole without pressure, there is a risk that considerable amounts will leak in. The water in the drill hole contains a great deal of suspended cuttings which also enter. Since all water which is trapped must be expelled through the drill, it is apparent that solid particles can cause disruptions in operations.

Coating the threads generously with thread grease with a solid consistency increases the tightness of the seal.

Check valve (1, Fig. 46)

The check valve is designed as a flat seat valve placed in the top sub with a spiral spring as initial load. The sealing force is primarily from the counter-pressure from the external column of water.

The check valve only partially prevents water from penetrating into the drill. Since it encloses a compressible cushion of air, the inner water level will be adapted to the pressure in the external column of water. The drill will not, however, completely fill with water, which is important, and in addition the rate of the inflow will be so low that only fine material can be carried in by it.

A leaky check valve means that the entire system of drill and drill tubes can be filled with suspended cuttings and water. It will be impossible to continue drilling and the equipment will have to be pulled up for cleaning.

The great importance of the sealing of the check valve then justifies a careful supervision of its functioning. Check the check valve at the following points:

- That the cone and its guide are free of cuttings or other impurities. Too great a friction in the guide may prevent the movement of the valve.
- That the spring has sufficient closing force. It may be fatigued and the closing power may be too low.
- That the rubber seal is correctly fitted.
- Finally, check the sealing of the check valve. Fill the top sub with air tool oil and watch the oil level. If it drops, rapidly or slowly, it means that the sealing is not sufficient for water well drilling.

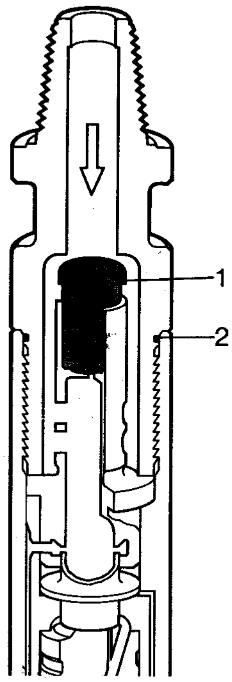


Fig. 46. The check valve (1) and O-ring (2) must be without defect when drilling in water-bearing formations

Sealing of the O-ring (2, Fig. 46)

The sealing of the O-ring between the top sub and the casing has the same important function as the check valve in containing a cushion of air.

Inspect the seal and try to judge its ability to function correctly. The casing may be deformed because of external effects or may be damaged internally. The O-ring should be changed frequently. It becomes deformed and looses its elasticity after a certain time.

If the sealing ability is judged doubtful, it can be improved by a sealing agent.

Measures to counteract disruptions in operation in wet hole drilling

1. Check the sealing ability of the check valve.
2. Coat the tube threads with thread grease with a solid consistency.
3. When recollaring a water-filled hole, blow often in order to resist the counter-pressure.
4. Use a working pressure which has a sufficient margin in relation to the pressure of the column of water.
5. If possible, withdraw the drill from a water-filled hole at the end of the shift or lift it above the level of the water.
6. Keep the drill blowing during pauses in drilling. If there is a tendency to icing, meter ethyl alcohol into the system.
7. Use drill tubes clean on the inside.
8. Check that the O-ring seal on the top sub of the drill is without defect.

10. POST HOLE DRILLING (Fig. 47)

Holes for posts required for road guard rails, lighting, highway signs, etc can be drilled in rational fashion with COP 6 and ROC 606. The method can be used in both solid rock and in fill and overburden. A certain extra equipment is required, viz. a shorter drill tube, a fixed drill tube support and a casing tube, permanently fitted with a cramp iron to the rotation unit (see Fig. 47b). Full head bits are used. The casing tube has a diameter just less than that of the drill bit. The cuttings are then packed against the hole walls which has a stabilizing effect in such loose material. The casing tube supports and shapes the hole walls during drilling. In stone fill an operating pressure of 6 bar (600 kPa, 87 psi) is sufficient. In dense fill a higher pressure generally gives a better result. The equipment is available in sizes 165 and 216 mm (6 1/2" and 8 1/2").

The drilling proceeds in the following way:

1. If the surface is loose, place a platform under the flange on the tube of the drill tube support.
2. Drive the bit down a few decimetres (0.5–1 ft) without rotation if possible. If the surface is hard use the levelling off technique described under "Drilling: collaring".
3. Drill carefully with slow rotation, 5–15 rpm.
4. If the hole walls are very unstable and cave in, the drill can be taken up and the hole filled with clay to stabilize it (see 6.4. "Stabilizing the hole walls with clay"). Repeat the clay treatment as required.
5. Continue to the desired depth (1–2.5 m, 3–8 ft). Employ blowing and rotation with great care when taking up the string, so that the hole walls are not damaged.

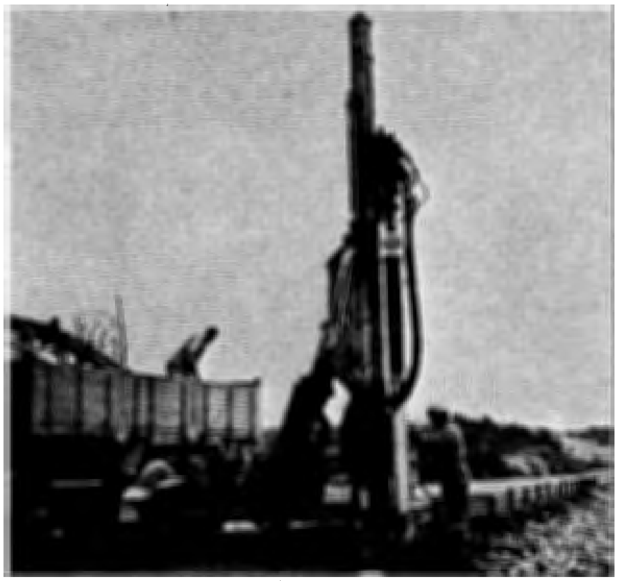


Fig. 47a. Drilling post-holes

11. DRILLING UNDERGROUND

A down-the-hole drill can be chosen to good advantage for drilling drainage and ventilation holes, and cut holes in drifting and tunnelling, as well as in driving raises. Holes with lengths of up to 100 metres are common in this respect. The fact that the rate of penetration is relatively independent of the length of the hole is of great importance here, as is the precision in the direction of the drill hole since through holes are often drilled in these cases.

The precision can be further improved with the use of special guides (see 8. "Drilling straight holes and large diameter holes"). The guides should always be used when precision requirements are high.

Setting up and the drilling of long drainage and ventilation holes proceed as described under 8.1. "Precision drilling".

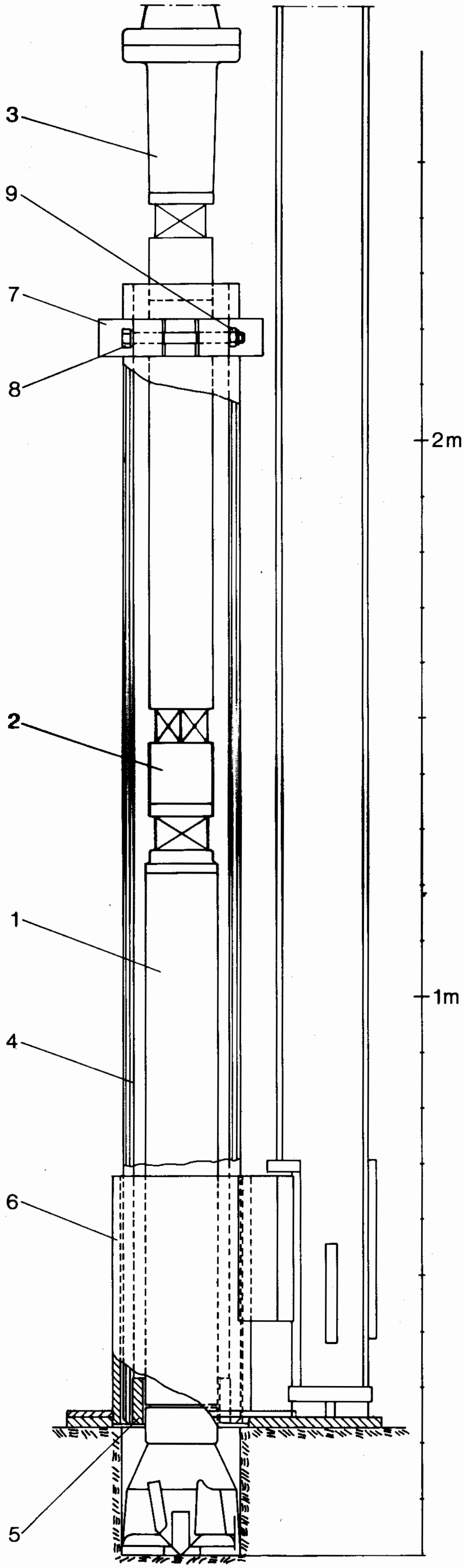
Reduced direct drilling costs, low sound level and reduced jointing frequency are other important factors which have led to the increasing use of down-the-hole drills in production drilling underground. The possibility of drilling long holes with little deviation means that even the cost for mine development can be reduced since the number of drifts can be cut down.

11.1. Dust suppression

To bind dust underground you must either use water – the wet method – or use a dust collector – the dry method.

The wet method means that water is mixed with the compressed air to the down-the-hole drill so that the cuttings are drenched and are bound during transport up through the drill hole. Flushing water is injected into the working air in such cases by a high pressure pump by way of a valve arrangement with the possibility of setting a suitable amount of water. The high pressure pump with valve arrangement is included as standard on Atlas Copco ROC 306 (Fig. 48a), which is intended for drilling with COP 4 or COP 6 underground.

When there is access to a water main with a pressure which is greater than the air pressure to the drill, the water from the main can be brought in to the impact mechanism air without an intermediate high pressure pump, but still with the valve arrangement for setting a suitable amount of water.



1. COP 6
2. Drill tube
3. Rotation motor
4. Casing tube
5. Bushing (for 8 1/2" only)
6. Drill tube support
7. Cramp iron
8. Screw
9. Lock nut

Fig. 47b. Post hole drilling equipment for COP 6 is available in sizes 165 and 216 mm (6 1/2" and 8 1/2")

12. LUBRICATION

The drill is lubricated by oil mixed in the compressed air and carried with it to the parts to be lubricated. The oil is added to the compressed air by a lubricating valve. The admixture of oil should be 1–2 cm^3 of oil per m^3 free air (0.17–0.34 cu.in. per 100 cu.ft).

The supply of lubricating oil is very important for the reliability of the drill, and for this reason the matter should receive great care. As well as regular checks of the oil level in the lubricating oil tank, all suitable occasions should be used to check for the presence of oil in the compressed air. Take the opportunity when the drill is accessible, e.g. when changing bits. Blow operating air against a suitable object placed on the drill tube support in front of the drill. The surface should become oily after a while. Similar tests can be carried out during a jointing operation, when the air can blow from the adapter of the rotation unit against the test surface.

The sooner deficient or arrested lubrication is discovered, the greater the chance of preventing stoppage by a simple measure.

12.1. Choice of lubricating oil (Fig. 49)

The lubricating properties of the oil as well as the possibility of atomizing it in the lubricating valves are dependent to a great extent on its viscosity (ability to flow), which varies with the temperature (Fig. 49). A suitable oil should, with reference to the lubricator, not have a higher viscosity than 700 cSt, and, with reference to its lubricating properties, not lower than about 50 cSt in the drill. In the table "Recommended lubricants" are given the most suitable pneumatic tool oils of mineral oil types from the major oil companies within the various temperature ranges. Equivalent grades of other well known makes can also be used. In addition to a suitable viscosity the oils should have good adhesion properties, high film strength and should prevent corrosion. From the viewpoint of hygiene they should be non-toxic.

In general it is suitable to choose an oil with a high SAE value, but keep in mind the higher viscosity limit of 700 cSt.

The temperature limits given in the table refer to the temperature of the oil in the tank, that is the ambient temperature. In cases where the drill is powered by warm compressed air, e.g. when connected to a nearby portable compressor and at high operating pressure, one must take into consideration the temperature of the operating air. It may at times be suitable to choose a thicker oil than that recommended by the table. (See also "Measures under special temperature conditions"):

A thick oil has advantageous characteristics which can be exploited under stable temperature conditions, e.g. underground. In general, a thick oil has a better film strength and better adhesion and thus leads to lower oil consumption and less oil mist in the exhaust air.

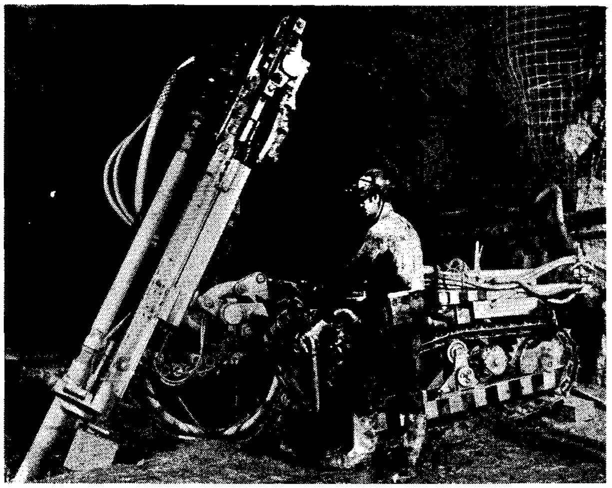


Fig. 48a. Underground blast hole drilling with ROC 306 and COP 6

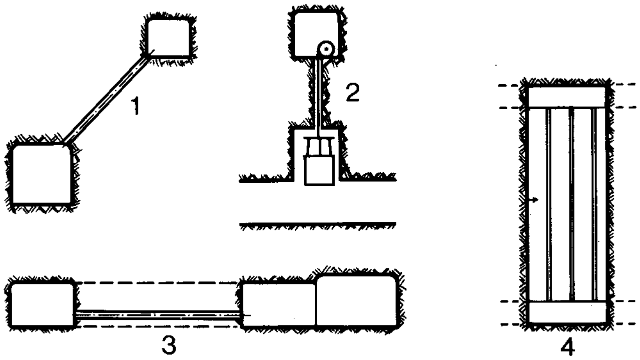


Fig. 48b. Examples of large diameter holes underground:
1. Drainage hole
2. Big hole for the Jora raise lift
3. Ventilation and cut hole for drifting (e.g. sub-level caving)
4. Sub-level benching

12.2. Measures under special temperature conditions

The temperature in the down-the-hole drill is often considerably higher than in the lubricator, especially under winter conditions with great differences in temperature.

In such cases the problem must be remedied by choosing an oil with a higher viscosity index, that is, a wider temperature range. Another solution is to use a normal oil with high viscosity and install a heating device by the lubricating oil tank to facilitate distribution from the valves.

Icing

May occur in connection with blowing deep holes when the compressed air is moist and the hole wet. The drill and tubes are chilled greatly and since condensate and humidity are present, icing becomes a tangible risk.

Table 5. Recommended lubricants

Temperature by the oil tank °C (°F)	SAE viscosity number*)	Make of oil								
		BP	Castrol	Esso Exxon	Gulf	Mobil	Shell	Texaco Caltex	Total	Valvoline
−20 to ±0 (−4 to +32)		—	—	Arox EP 38	Gulfstone 10	Almo Oil 1	Torcula Oil 25	Rock Drill Lube X5W	Ruscus 10	ATO Nr 0
±0 to +15 (+32 to +60)	SAE 10W	Energol RD-E80	Magna SPX	Arox EP 45	Gulfstone 20	Almo Oil 1	Torcula Oil 25	Rock Drill Lube X5W	Ruscus 30	ATO Nr 1
+15 to +40 (+60 to +104)	SAE 30	Energol RD-E150	RD Oil Light	Arox EP 65	Gulfstone 30	Almo Oil 3	Torcula Oil 41	Rock Drill Lube XL	Ruscus 50	ATO Nr 3
+40 to +60 (+104 to +140)	SAE 40	Energol RD-E220	RD Oil No. 3	Arox EP 65	Gulfstone 30	Almo Oil 5	Torcula Oil 41	Rock Drill Lube XM	Ruscus 50	ATO Nr 3

*) Approximate equivalent

During drilling the risk of icing is less because of the more favorable heat balance, but it cannot be excluded. The best way to deal with icing in difficult cases is to meter an amount of industrial alcohol into the tube string. In milder cases mineral oil as listed in the table can be employed with an Anti Ice Additive.

When the lines are long between the compressor and the drill rig or with permanent lines of steel piping the risk of freezing can be appreciably cut down by using a water separator.

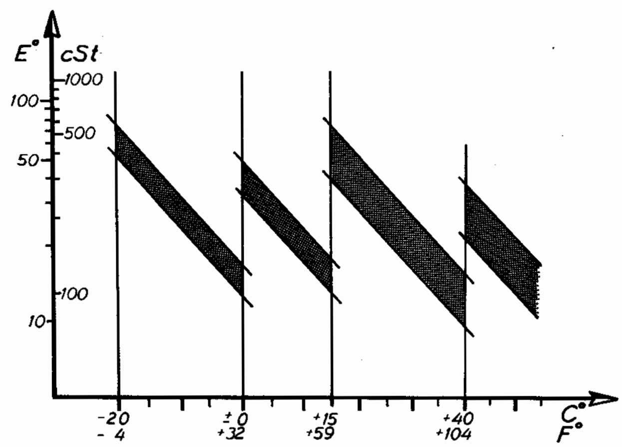


Fig. 49. Changes in viscosity of the recommended groups of lubricating oil with rising temperatures

13. HANDLING AND GRINDING OF DTH-BITS

(Figs. 50—59)

13.1. Handling

The carbide inserts are the most costly and vulnerable part of the bit. Careless handling can result in cracking or chipping, leading in due course to insert failure. Always observe the following rules:

- Check the bit for damage during transport — especially if the packaging appears to be damaged.
- Leave the bit in its packaging as long as possible.
- Avoid knocks and bumps against hard objects and take care during transportation.
- Never strike the bit with a hammer or sledge during assembly or dismantling!
- Engage the feed and impact mechanism carefully when collaring.

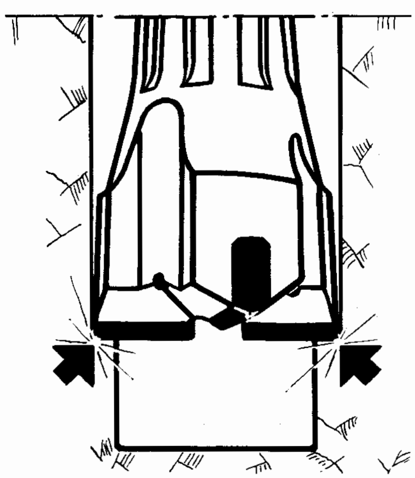


Fig. 50. Measure the drill bit carefully and always begin with the largest gauge in order to avoid "reaming"

Some common causes of damage

DRILLING WITH AN OVERWORN BIT

Heavily worn inserts entail increased stresses, from which it is only a short step to insert damage.

"REAMING" (Fig. 50)

Drilling with a bit of larger diameter than the one that was last withdrawn from the drill hole sets up extreme stresses on the insert corners. Check the bit diameters before drilling and mark every bit with its size. Always begin drilling with the largest bit and work downwards in size.

FRAGMENTS OF CARBIDE IN THE DRILL HOLE

The presence of carbide chips in the drillhole can easily lead to insert damage. For this reason, check the bit carefully for any chipping and make sure that any particles of carbide are fished up with a suitable magnet.

FAULTY ROTATION

Correct speed of rotation must be set by experience at each individual working site. It should be noted, however, that unduly fast rotation results in quicker wear of the carbide without any corresponding increase in penetration rate. In gauge-wearing rock it is often possible to reduce gauge wear and corner rounding by reducing the speed of rotation.

INCORRECT BIT SHAPE, e.g., incorrect edge angle or corner radius, failure to bevel sharp edges and corners, unequal insert heights or the edges being at an angle across the inserts.

OVERHEATING OF THE CARBIDE INSERTS, due to protracted grinding at the same point, incorrect choice of grinding wheel or incorrect grinding pressure.

BENT DRILL TUBES, resulting in uneven wear of the edges. Change the faulty drill tube to avoid breakage and unnecessary grinding.

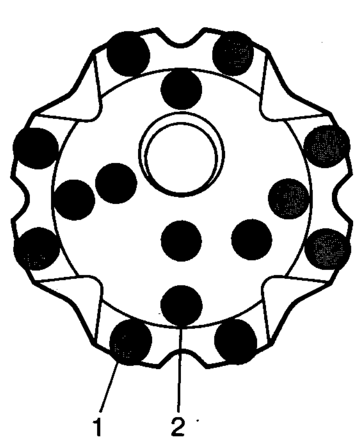


Fig. 51. Button bits carry both peripheral buttons (1) and centre buttons (2)

13.2. Redressing button bits (Figs. 51–57)

Wear on button bits

Experience with button bits has shown that both the rate of penetration and the service life of the bit are better if the original, spherical shape of the buttons is restored at regular intervals. These intervals are, however, 3–4 times longer than for bits with conventional cutting inserts.

The buttons are of two types, **peripheral buttons,** which are placed on the peripnery of the bit and maintain the correct diameter, and **centre buttons** (Fig. 51). The buttons are placed so that the impact energy is equally distributed over all the buttons.

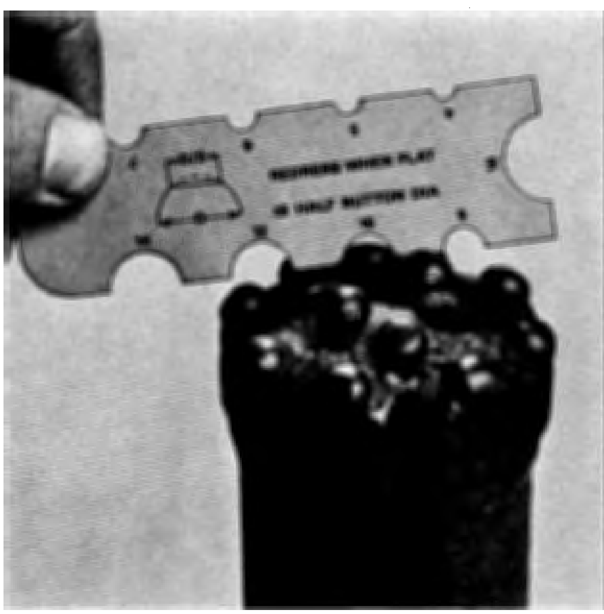


Fig. 52a. Determine the button diameter by means of the recesses in the template

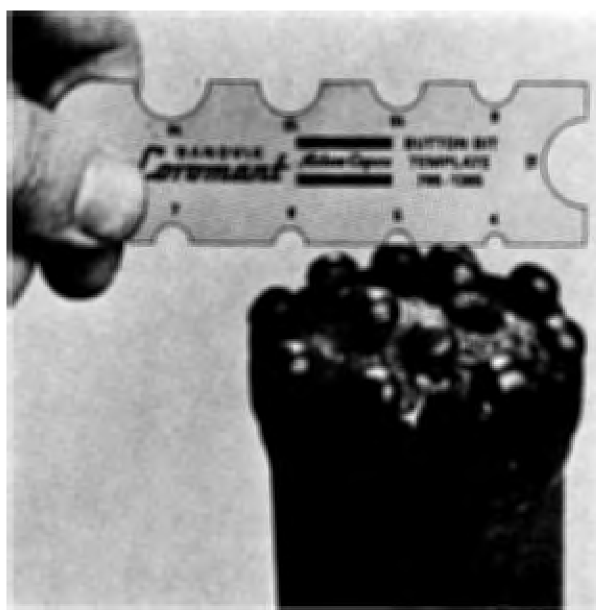


Fig. 52b. The other recess on the template is half the button diameter and represents the maximum permissible flat diameter before redressing

The centre buttons are directed straight forwards and are subjected to pure frontal wear. The peripheral buttons are directed obliquely forwards and outwards and are then subjected to both frontal and diametral wear. The buttons on the periphery are also exposed to greater abrasion since during each rotation of the bit they move a greater distance than the centre buttons and at a higher speed. The wear is more pronounced with larger diameter bits and depends to a great extent on rotation speed and flushing. With a low rotation rate and/or high flushing pressure the hole is cleaned out better, each blow strikes a clean hole bottom and wear on the peripheral buttons is reduced.

Routine

As a general rule it can be said that bits should be redressed when the rate of penetration decreases appreciably and when this cannot be attributed to harder rock, reduced air pressure or similar factors. The best way to dress bits is according to a fixed routine. Investigate to find out which of the following points determines the intervals at the work site in question and then set up a routine which is simple to keep to, e.g. redressing after a certain number of holes or after each shift.

It is more economical to redress too soon than to run the risk of damage by redressing too late.

In drilling in abrasive rock there occurs a characteristic frontal wear bevel on the tops of the cemented carbide buttons. If this bevel is permitted to become too great, the buttons can easily be damaged by the excessive stresses which are created. The buttons should then be redressed so that they recover their original spherical form. Wear is greatest on the peripheral buttons, and it is their wear bevel which determines when the bit should be redressed. **Redress when the width of the wear bevel is half the diameter of the button (Fig. 52).** The size of the button is also of importance; the smaller the diameter of the button, the greater the wear bevel which can be permitted. Use the template.

Redress independently of the width of the wear bevel if there occur small concavities or cracks on the border between the wear bevel and the unworn part of the button.

Redress all the buttons at the same time – including the centre buttons – even if they have not reached the wear limit.

Certain non-consolidated kinds of rock do not wear down cemented carbide buttons. The cemented carbide surface, however, gradually becomes fatigued and this appears in the form of a shiny surface, which on closer examination can be seen to be crisscrossed by a network of fine fatigue cracks, called "snake skin".

Grind off the outer layer of cemented carbide as soon as "snake skin" is observed.

The cemented carbide becomes fatigued even if no wear bevel, concavities or "snake skin" are visible.

Redress the buttons lightly at the very latest every 300 metres drilled (1000').

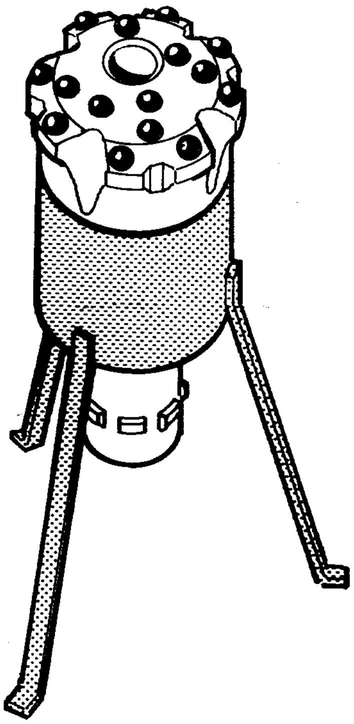


Fig. 53. Place the drill bit in a solid clamp for redressing

Equipment

The drill bit should be stably mounted during redressing (Fig. 53). The machine should be a light, hand-held machine such as:

– **Atlas Copco LSR 33S 120**

– Grinding wheel for **cemented carbide 50 x 13 x 10** Naxos Sicto 15C60 J6VT

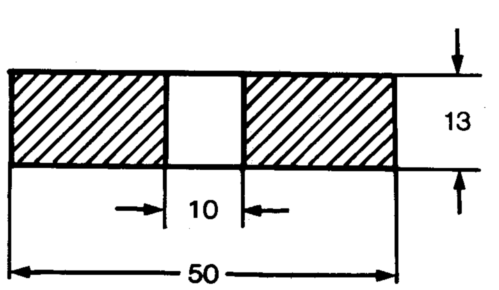


Fig. 54a. Grinding wheel for **steel** Naxos Sicto 43A 60K8VA

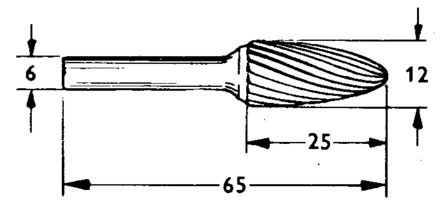


Fig. 54b. Rotary file for **cleaning flushing holes** and cuttings grooves
Sandvik Coromant 695-6912

Grinding template 795—1365

Use protective goggles. Do not exceed the highest permissible peripheral speed if other types of machines, pins or wheels are used.

Redressing centre buttons (Fig. 55)

Dress around the button in towards the centre so that the original, ballike shape is restored. Remove the worn surface on the top of the button. Avoid as much as possible reducing the height of the button.

If the button has been badly worn, the projecting part can be extended by a careful grinding down of the steel around the button.

For an inexperienced operator it may prove easier if he draws lines on the button over the flat wear bevel. Then dress the button to a round shape on both sides of the lines without touching them. Finish by smoothing off uneven points on the button.

Redressing peripheral buttons (Fig. 56)

Dress the button on a third of its circumference until it has about same shape as a new button.

Turn the bit a third of a turn and dress the next third of the button.

Turn the bit another third of a turn and dress the third of the button which lies along the periphery of the bit. This part of the button should be redressed as little as possible, just enough to take off the "anti-taper" without reducing the diameter too much.

When the drill bit is used in rock which wears extensively on the diameter of the bit, it may at times be necessary to regrind the flushing grooves. For this purpose use a grinding wheel intended for steel. Check the steel under the buttons and see that there is sufficient clearance. There should be no diametral grinding as with bits with cutting inserts. Avoid excessive grinding!

Damaged buttons (Fig. 57)

Button bits can be used as long as they still have enough peripheral buttons to maintain the correct diameter.

To protect whole buttons from damage by chips of cemented carbide damaged buttons should be ground down and levelled off.

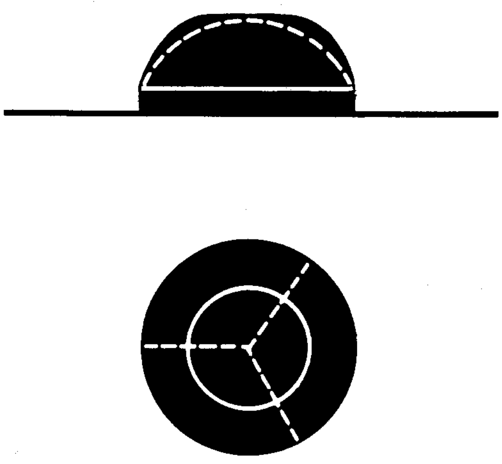


Fig. 55.

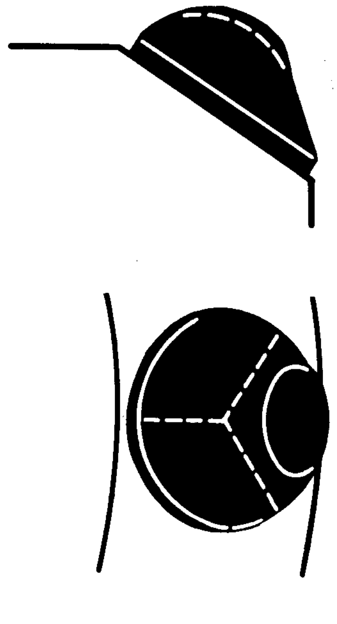


Fig. 56.

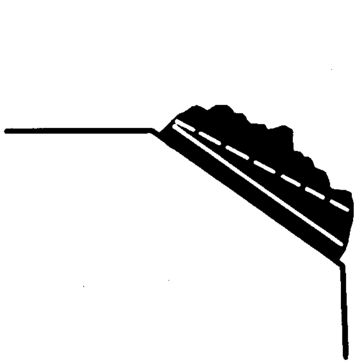


Fig. 57.

13.3. Grinding full head bits (Fig. 58)

Regrinding in due time is important to obtain optimum **bit life and penetration** rate. Overdrilled inserts subject **the bit to abnormally** high stresses that can easily result **in damaged** inserts and tubes. Abnormal wear also involves an unnecessarily time-consuming job of grinding.

The carbide inserts suffer wear on the cutting edges and on the periphery – known as frontal wear and gauge wear, respectively. The easiest way to check wear in order to determine when the bit should be reground is to use a Sandvik Coromant grinding template as shown in the figures. (See also 17.1. "Standard equipment").

Wear limits, frontal wear (Fig. 58a)

- on drill bits with a gauge of 4 1/8–5 1/2" when the width of the cutting edge is 3.2 mm, measured at a point 12 mm from the periphery.
- on drill bits with a gauge of 6"–9 1/2" when the width of the cutting edge is 4.8 mm, measured at a point 12 mm from the periphery.

Wear limits, gauge wear

- when the anti-taper reaches a height of 6.4 mm (Fig. 58b), or
- when the insert corners are rounded to a radius of 4.8 mm (Fig. 58c)

Snake skin

In certain kinds of rock, wear takes place very slowly. In such cases the bit may instead develop a network of small fatigue cracks in the carbide, a phenomenon known as "snakeskin". When this occurs, it is often necessary to carry out regrinding earlier than is recommended for normal cases. Grinding should be concluded with heavy honing of the cutting edges and all corners.

Even if no snakeskin wear is descernible, the bits should be reground after about 150 metres (500') of drilling. Grit size of grinding wheel should be about 80.

Some general rules for grinding

Avoid overheating the carbide:

Work with the correct grinding pressure and maintain continuous movement. There must be no "spot" grinding. Do not try to complete the regrinding of one insert at a time. Work over all the inserts in rotation.

Should one insert be damaged, the bit can still be used with three inserts. But it is important to grind down the affected insert so that the damage comes lower than the other three inserts and the damaged insert takes no part in drilling.

Avoid rapid cooling of the inserts. Whenever possible, grinding should be accompanied by copious water cooling.

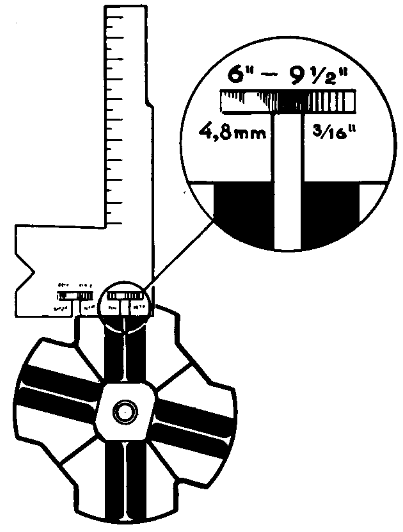


Fig. 58a. Measuring frontal wear

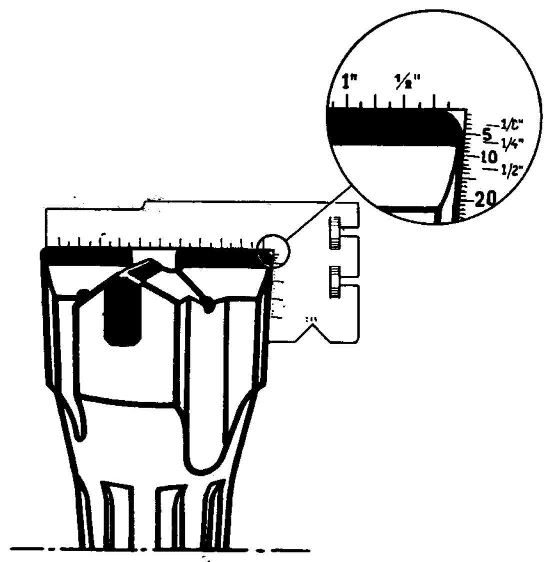


Fig. 58b. Height of anti-taper

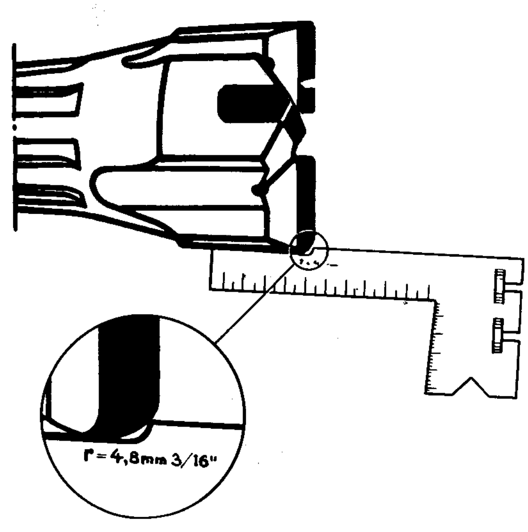


Fig. 58c. Radius of insert corners

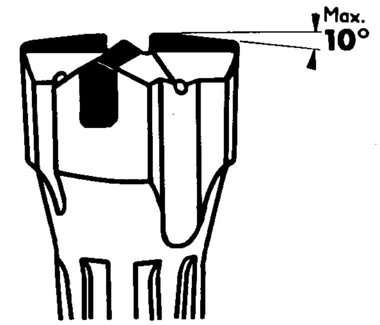


Fig. 59a. Grind down the inserts to the same height. Max. 10° angle (in very hard rock)

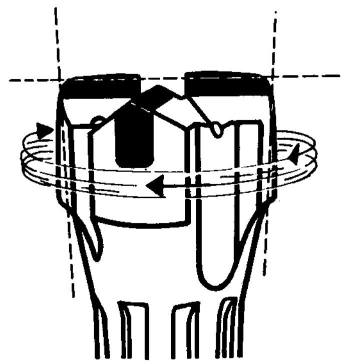


Fig. 59b. Grind down the anti-taper

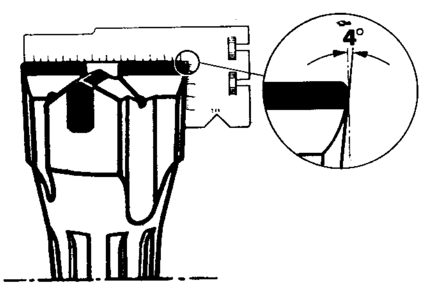


Fig. 59c. Check the angle

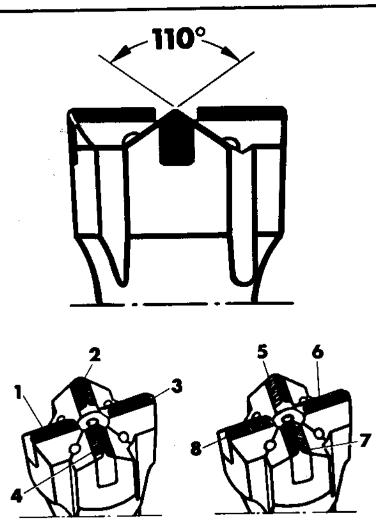


Fig. 59d. Grind the inserts in turn to a cutting angle of 110°

Use ceramic grinding wheels with the right hardness and grain size. Shiny, "burnt" inserts and "loaded" grinding wheels are a sign that the wheel is too hard or too fine-grained. Pronounced scratches in the insert are produced by an excessively coarse-grained wheel. Grit size should be about 60 for a straight wheel. Note also that different grinding wheels should be used for dry and wet grinding. Stick to the safety regulations! Use the safety devices on the grinder, and wear safety goggles. Make sure that the grinding wheel is whole by tapping it and listening to the sound. Do not exceed the highest permitted speed of rotation.

Grinding procedure (Fig. 59)

A. Grind all inserts down to the same height so that the drilling stresses will be evenly distributed.

   When drilling very hard rock, crowning up to 10° is permissible. But bear in mind the risk of insert damage if bits with different degrees of crowning are used.

B. Reduce any anti-taper or corner rounding by grinding the bit all around the circumference or by carrying frontal grinding further than normal. A combination of frontal and gauge grinding is often the most economical approach. Make sure that gauge grinding is equal on all inserts. The bit must be correctly centred after regrinding.

C. Check the clearance angle. The correct angle of 4° will be found on the grinding template.

D. Grind the inserts a little at a time. Grind first on one side of one insert and then continue with the corresponding side of the other inserts. Then grind the opposite of all four inserts and continue working in this way from insert to insert until you reach the correct edge engle of 110° and dull width of approx. 0.8 mm.

   Grind to the same extent on both sides of the inserts so that the resulting cutting edge is straight and runs along the centre of the insert.

Checking measurements

After grinding, check the following measurements:

edge angle	= 110°
dull width	= approx. 0.8 mm (1/32")
anti-taper	= max. 3.2 mm (1/8")
clearance angle	= 4°

Make sure also that the cutting edges are straight and are central on the inserts.

A reground bit should have pretty much the same appearance as a new bit. Bevel the outer and inner corners of the inserts on the grinding wheel. Hone down all sharp edges by hand with a silicon carbide whetstone or on old grinding wheel.

Measure the gauge of the bit after grinding and mark it accordingly.

14. HANDLING DRILL TUBES

14.1. Circulating the drill tubes (Fig. 60)

Tube and rod fracture are problems especially in bench **drilling** because of the downwards direction of drilling. **In** the case of down-the-hole drilling tube fracture can also mean the loss of the drill. Even if it can be recovered, it is often filled with cuttings and must be cleaned.

The risk for unexpected tube fracture can be considerably reduced by circulating the tubes, so that each tube is used for the same number of drill metres, that is, is exposed to the same degree of wear. When one of the tubes shows signs of impending fracture, the other tubes should be checked carefully and it may be required to replace the entire tube string at the same time.

The principle of tube circulation is simple (Fig. 60):

When the tube string is taken up, the tubes are placed in the rack as they are disconnected, with exception of the tube (1) which was nearest the down-the-hole drill. It is placed last in the tube rack (b) so that tube (2) will be the first in the new hole. This procedure is repeated each time the string is taken up (C, D) and after five holes, in this case (as many holes as tubes), all the tubes have occupied all the positions in the string and will have worked the same number of drill metres.

14.2. Wear on drill tubes

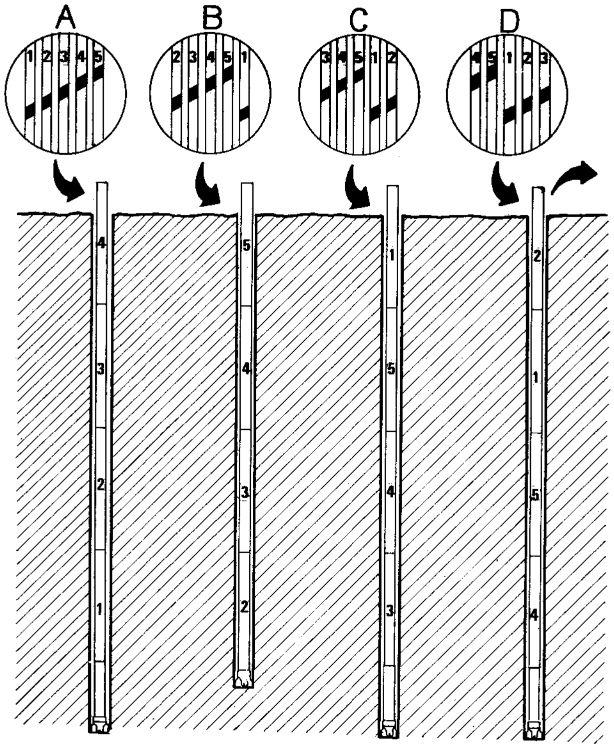
In addition to pure diametric wear the drill tubes after a long period of use may show signs of cracks forming. This is evident by the compressed air leaking out and leaving stains of lubricating oil. If such a fracture sign is noted, all the tubes should be checked carefully. It may be advisable to replace all tubes used for the same number of drill metres in order to prevent fracture. Damaged or deformed drill tubes should be removed from use. Crooked tubes may cause damage to threads and the spindle of the rotation motor, increase hole deflection, and reduce the rate of penetration.

A dent on the casing surface of tube may lead to increased local wear due to the turbulence in the cuttings around the depression. Particular attention should then be paid to such damage.

15. MOUNTING COP 4 AND COP 6 ON DRILLING UNITS

Thanks to their simple design COP 4 and COP 6 can very easily be mounted on carriers. Carriers other than standard, intended for both conventional percussive drilling and down-the-hole drilling as well as rotary drilling or auger drilling, can often easily be fitted with COP 4 and COP 6.

When mounting COP 4 and COP 6 on non-standard units the following general points should be observed:



A. Tubes before the 1st hole
B. Tubes before the 2nd hole
C. Tubes befors the 3rd hole
D. Tubes before the 4th hole

Fig. 60. Circulation of the drill tubes

15. 1. Mounting

COP 4

- the carrier should be equipped with a rotation motor, whose speed can be set variably from 0—0.7 r/s. A torque of at least 750—1000 Nm (75—100 kgm; 550—750 lb.ft) is most often sufficient within this speed range
- it should be possible to set the feed force between 3 and 8 kN (300—800 kg; 650—1750 lbs.) in short holes and further reduce it in deeper holes, due to the weight of the drill string. When drilling very deep holes the feed must be sufficiently strong to lift the drill string out of the drill hole (approx. 8 kg per metre, 6 lbs per ft).
- there must be an air inlet for the compressed air to the impact mechanism of the down-the-hole drill, placed in either the rotation motor or in an adapter above the drill string
- the guide in the drill tube support should be matched to the outer diameter of the down-the-hole drill (95 mm, 3.74")
- rotation units and drill tubes of other makes are often equipped with other types of threads so that transition

adapters must be used, either between the rotation unit and standard drill tubes or between drill tubes of other makes and COP 4

- smaller equipment for down-the-hole drilling may be equipped with a rotation unit, whose design is sensitive to the recoil from the impact mechanism on COP 4. Such rotation units can be used if a shock-absorber is fitted between the down-the-hole drill and the first drill tube (see "Drilling equipments").
- the air system should contain the required control and lubricating functions. In the case of COP 4 an admixture of lubricating oil to the compressed air of normally 1–3 cm^3 per m^3 free air (0.17–0.51 cu.in per 100 cu.ft) is recommended.

COP 6

- the carrier should be equipped with a rotation motor, whose speed can be set variably from 0–0.5 r/s. A torque of 1500 to 2000 Nm (150–200 kgm; 1100–1500 ft.lbs) is most often sufficient within this speed range.
- it should be possible to set the feed force between 4 and 12 kN (400–1200 kg; 900–2650 lbs) in short holes and further reduce it in deeper holes, due to the weight of the drill string. Precision in regulating the feed force should be good. When drilling very deep holes the feed must be sufficiently strong to lift the drill string out of the hole (approx. 20 kg per metre, 14 lbs per ft).
- there should be an air intake, correctly dimensioned, for compressed air to the impact mechanism of the down-the-hole drill, placed in either the rotation motor or in an adapter above the drill string
- the guide in the drill tube support should be matched to the outer diameter of the down-the-hole drill (136 mm)
- rotation units and drill tubes of other makes are often equipped with other types of threads so that transition adapters must be used, either between the rotation unit and standard drill tubes or between drill tubes of other makes and COP 6
- smaller equipment for down-the-hole drilling may be equipped with a rotation unit, whose design is sensitive to the recoil from the impact mechanism on COP 6. Such rotation units can be used if a shock-absorber is fitted between the down-the-hole drill and the first drill tube (see "Drilling equipments").
- the air system should contain the required control and lubricating functions. In the case of COP 6 an admixture of lubricating oil to the compressed air of 1–3 cm^3 per m^3 free air (0.17–0.51 cu.in. per 100 cu.ft.) is recommended.
- there must be equipment for loosening the bit. When loosening the bit or tube joints the middle part (cylinder) of the down-the-hole bit should not be gripped with tongs or other tools. Only the wrench recess and the parts (approx. 200 mm, 8") by the top sub and driver chuck should take up tightening forces.

15.2. BBE 53 and BBE 57-01 as rotation units for COP 4

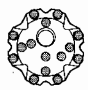
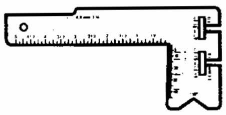
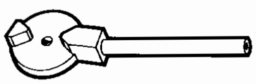
Rock drills BBE 53 and BBE 57-01 can be equipped with a special shank adapter which makes it possible to use them as rotation units with COP 4. With this possibility equipment for conventional drilling can be used for occasional hole opening, operations better suited to down-the-hole drills. Examples: drilling very long or very deep holes, drilling in very hard-to-drill rock or other types of rock formations which require large quantities of flushing air. The torque with BBE 57-01 is 750 Nm (75 kgm; 550 lb.ft) and with BBE 53 1200 Nm (120 kgm; 890 lb.ft) by comparison the torque with BBR 4 is 900 Nm (90 kgm; 650 lb.ft).

Conversion of a rig equipped with BBE 53 or BBE 57-01 requires the following modifications:

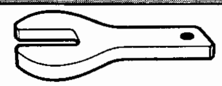
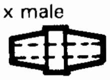
1. The air to the impact mechanism of the rock drills is blocked.
2. A special shank adapter which fits the drill tubes for COP 4 is mounted on the rock drill.
3. The operating air for COP 4 is led into the impact mechanism by way of the flushing head of the shank adapter. The air is taken after the lubricator so that it will be mixed with oil and will lubricate the impact mechanism of COP 4.
4. Drilling with high pressure requires that reducing valves are fitted in the air system to reduce the air pressure to normal pressure for all the functions which require compressed air with the exception of the impact mechanism. (See also "Preparations: Safety considerations").
5. The inserts of the drill steel support are to be changed to standard inserts for COP 4 (3162 1414).
6. The direction of rotation must be reversed for COP 4 (rotation to the right), which means that the lubricating hose to the intermediate part of the rock drill must be switched by the inlet to the rotation motor.

16. DRILLING EQUIPMENT

16.1. Table 6. Standard equipment

	COP 4				COP 6			
		Diameter mm	in	Catalogue No.		Diameter mm	in	Catalogue No.
Button bits 		105 110 115	4 1/8 4 5/16 4 1/2	7745-2605-40 7745-2610-40 7745-2615-40		152 156 165 216 254	6 6 1/8 6 1/2 8 1/2 10	7745-7652-40 7745-7656-40 7745-7665-40 7745-7616-40 7745-7655-40*)
Full head bits 		105 110 115 127 140 152	4 1/8 4 3/8 4 1/2 5 5 1/2 6	7745-4105-11, -42 7745-4110-11 7745-4115-11 7745-4127-11 7745-4140-11*) 7745-4152-11**)		152 165 216	6 6 1/2 8 1/2	7745-8152-11 7745-8165-11
Reaming bits						254 305	10 12	7745-9654*) 7745-9605*)
[illegible]		Bit diameter mm	in	Catalogue No.		Bit diameter mm	in	Catalogue No.
Grinding template for insert bits 		105-115 ≧ 116	4 1/8-4 1/2 ≧ 4 3/4	795-1346 795-1337		≧152	≧6"	795-1337
Grinding template for button bits				795-1365				795-1365
Bit loosening [illegible]	For bit type	Bit diameter mm	in	Catalogue No.	Bit type	Bit diameter mm	in	Catalogue No.
Bit wrench 	Full head bits Button bits Full head bits Button bits	105-140 105-127 127-152 127-140	4 1/8-5 1/2 4 1/8-5 5-6 5-5 1/2	795-2402 795-2402 795 2406 795 2406				
Bit loosening tool (used with hydraulic loosening tool)					Full head bits Button bits	152-165 216 254	6-6 1/2 8 1/2 10	3162 1532 3162 1631 3162 1632
Hydraulic loosening tool								Catalogue No.
Hydraulic cylinder-compl. Rod tongs, compl. Breaking wrench								3176 3639-80 3162 1531-80 3162 1450

*) On special order.
**) Recommended only when drilling through soil overburden in conjunction with lined drill holes.

	COP 4		COP 6	
Spanners for tube jointing	Width across flats mm in	Catalogue No.	Width across flats mm in	Catalogue No.
	65 2 9/16	795 1495	95 3 3/4	3162 1454
Drill tube length	Outer diameter mm in / Thread	Catalogue No.	Outer diameter mm in / Thread	Catalogue No.
1500 mm (4' 11")	76 3 API 2 3/8" REG	8393 0702-09	114 4 1/2 API 3 1/2" REG	8393 0709-02
1500 mm (4' 11")	— — —		114 4 1/2 API 3 1/2" REG	8393 0711-08***)
3000 mm (9' 10")	76 3 API 2 3/8" REG	8393 0701-00	114 4 1/2 API 3 1/2" REG	8393 0708-03
3000 mm (9' 10")	89 3 1/2 API 2 3/8" REG	8393 0703-08	114 4 1/2 API 3 1/2" REG	8393 0710-09***)
Threaded adapters	Thread a–b	Catalogue No.	Thread a–b	Catalogue No.
female x female 	**API 2 3/8" REG/–** –/RD 50-6 –/API 2 3/8" IF –/Gg 2" –/ Wirth –/Rd 70-4 –/Holman –/API 2 3/8" REG –/Rd 70-6	 3862-6396 7002-3841 7002-2841 7002-1841 3862-6403 3862-6404 3862-6406 3862-6411*)	**API 3 1/2" REG/–** – API 3 1/2" REG – API 2 3/8" IF	 7002-6861 7002-3861
female x male 	API 2 3/8" REG/ RD 50-6 RD 50-6/ API 2 3/8" REG API 2 3/8" REG/ API 3 1/2" REG (COP 4/ BBR 6)	3862 6394 3862 6395*) 3862-6402	API 3 1/2" REG/API 4" FH	7850-6801*)
male x male 	API 2 3/8" REG/ RD 70-6 API 2 3/8" REG/ RD 70-4	3862 6397 3862 6408		
Adapter blanks	Thread	Catalogue No.		
female x male	API 2 3/8" REG/ ID 26 mm (blank)	3862 6394-70*)		
female x female	API 2 3/8" REG/ ID 42 mm (blank)	3862 6406-70*)		
female x female/male			API 3 1/2" REG/ ID 47 mm	3862 6412-70*)
Adapter BBE 57-01/ COP 4	Shank adapter Flushing head	7850-9000 7850-9001		
Retrac adapter and flushing adapters		Catalogue No.		Catalogue No.
Retrac adapter		7745-0195		
Flushing adapter		3161 0923-80		
Flushing adapter with retrac inserts				3161 0922-80
Shock absorber		8092 0115-20		8092 0115-38

*) On special order
**) Without spanner flats
***) For B-80

	COP 4			COP 6		
				Diameter mm	in	Catalogue No.
				165	6 1/2	8092 0115-46*)
				216	8 1/2	8092 0115-04*)

ODEX equipment	Dimensions mm	in	Catalogue No.	
Pilot bit	Ø 110	4 5/16	7588-1610	
Reamer	Ø 152	6	7588-1652	
Guide	Ø 126	4 31/32	7989-1615	
Wing coupling	Ø 127	5	7989-1627	
Bit tube	Ø 142	5 1/2	7985-1607	
Extended chuck			3162 0992	
Casing tube	See description section 6.8			
Discharge head				
– complete			7989-1680	
– outlet only			7982-0001	
Wrench for tubes and coupling			795-1495	
Wrench for guide			795-1430	

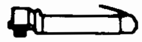
	COP 4 COP 6
...pment	Catalogue No.
Equipment compl. with hoses, valves and transfer pump	3176 7265-90
Transfer pump, compl.	3176 7265-80
DFA 51, 25 kg	3176 5697
– 200 kg	3176 5698
Stabilizer C, 25 kg	3176 7001
– 200 kg	3176 7002

	COP 4		COP 6	
Equipment for taking up stuck drill	Dimensions	Catalogue No.	Dimensions	Catalogue No.
Casing tubes (CMS)				
– OD/ID, mm	98/89		128/119	
– length, m	0.50	8393 8121-05	0.50	8393 8129-07
– length, m	1.5	8393 8122-04	1.5	8393 8130-04
– length, m	3.0	8393 8123-03	3.0	8393 8131-03
Casing shoe bit, cemented carbide tipped, mm	101/86.5	8372 0806-09	131/116.5	8372 0808-07
Tube adapter, for connection to rotation unit		3862 6400		3862 6899
Adapter, jointed		–		3862 6398

Equipment for precision drilling	Diameter mm	in	Catalogue No.	Diameter mm	in	Catalogue No.
Top sub with guide surfaces	115	4 1/2	3163 0926	165	6 1/2	3161 0928
	140	5 1/2	3161 0927	216	8 1/2	3161 0929
Driver chuck with guide surfaces	115	4 1/2	3161 0930	165	6 1/2	3161 0924
	140	5 1/2	3161 0931	216	8 1/2	3161 0925

Fishing tools		Catalogue No.		Catalogue No.
Magnet, 150 m wire and drum		8092 0115-12		8092 0115-12

*) On special order

Hand-held grinder	COP 4 Type		COP 6 Type
Full head bits	LSR 62S041		
Button bits	LSR 33S120		

Grinding wheels for	Diameter (COP 4 / COP 6) mm	in	Width mm	in	Hole mm	in	Type
– LSR 62S041	152	6	25	1	32	1 1/4	Naxos Sicto 15C60J6VT (for cemented carbide)
– LSR 33S120	50	2	13	33/64	10	3/8	Naxos Sicto 43A60K8VA (for steel)

16.2. Table 7. Drilling units

	BVB 25			
	-00	-01	-00	-0
Standard rock drill	–	–	COP 4	BE 57
COP 4	o	o	●	o
COP 6				
BBR 4	o	o	●	o
BBR 6				
Torque Nm*)	900	900	900	90
Adapter 3862 6402				
Shock absorber 8092 0115-20				
Shock absorber 8092 0115-38				
BMM 35K 130				
BMM 35K 157				
BMM 35K 257				●
BMM 35K 855				
BMM 35K 859	o	o	●	
BMM 36K 130				
BMM 36K 255				
BMM 36K 258				
BMM 36K 655				
BMM 36K 659				
BMM 36K 855				
BMM 36K 658				
Feed force kN**)	12,5	12,5	12,5	7,
Cradle 3161 1431-80				o
Cradle 3162 1578-80				
Cradle 3162 1460-80				
Base plate 3162 1430				o
Base plate 3162 1630				
Drill tube support halves (2 pcs) 3162 1414				o
Drill tube support 3162 1110-85				
Drill tube support 3162 1110-89				
Spacer sleeve 3162 0984				
Screw (2 pcs) 147 1569				
Screw (3 pcs) 147 1570				o
Screw (3 pcs) 147 1572				
Nut (5 pcs) 291 1116				
Air system normal pressure				
Air system high pressure	●	●	●	●
Tube rack 8092 0114-21			●	(o
Tube handling equipment 8092 0105-14				
Tube handling equipment				
Equipment for foam or water flushing 1)				
Equipment for drilling with ODEX 115				
Alignment instrument DIT 70	(o)	(o)	(o)	(o
Dust collectors – DCT 95-04	(o)	(o)		
– DCT 91-04			(o)	(o
– DCT 160				

o Available on drilling unit
o Components required for conversion for drilling wit
(o) Optional equipment for i.e. ODEX drilling, dust col
*) 1 Nm = 0,102 kgm = 0,738 ft.lb
**) 1 kN = 102 kg = 225 lb

1) With exception for ROC 306 use order no. 8092 0106-

ROC 301				ROC 306		ROC 601				ROC 606		Aquadrill						Mobile Drill®			
1	-02	-03	-04			-00		-02				441	461	661		571		B 30L	B 40L	B 80	
3E -01	BBC 120F	BBC 100F	COP 130EB	COP 6		BBE 57-01		COP 130EB		COP 6		COP 4	COP 4	COP 6		BBE 57-01		–	–	–	–
	o	o	o		o	o	o	o	o		o	●	●		o	o	o	o	o	o	
				●						●				●							o
	o	o	o			o		o				●				o					
				●	●		o		o	●	●		●	●	●		o				
·0	900	900	900	2000	2000	900	900	900	2000	2000	2000	900	2000	2000	2000	900	2000	3000	4800	8500	8500
					o		o		o		o		●		o		o			o	
																		o	o	o	
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			●																		
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35	7.85	7.85	7.85	34.5	34.5	17.7	17.7	17.7	17.7	34.5	34.5	12.5	34.5	34.5	34.5	17.7	17.7	27.5	41.5	62	62
	o	o	o																		
						o		o								o					
							o		o								o				
	o	o	o		o	o	o	o	o		o				o	o	o				
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	o	o	o			o	o	o	o							o	o				
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	●	●	●	●	●					●	●	●	●	●	●	●	●			●	●
)	(o)	(o)	(o)																		
										●	●										
														●	●					●	●
				●	●	(o)	(o)	(o)	(o)	(o)	(o)	●	●	●	●	●	●			(o)	(o)
							(o)		(o)		(o)		●								
)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)
)	(o)	(o)	(o)		(o)	(o)	(o)	(o)	(o)		(o)									(o)	
				(o)						(o)										(o)	(o)

h COP 4 or COP 6
lecting, tube handling etc.

21. 8092 0106-21 also included in equipment for drilling with ODEX 115.

Technical Area: 2 Drilling Tools and Equipment

Item: 2-4 Rig Accessory

1: Objectives To be able to explain and advise for necessary contents and specifications of rig accessory such as drill pipe, drill collar etc.
2. Contents - Specifications of drill pipe, drill collar, handling tools, thread types
3. Teaching Methods (1) Explain contents of rig accessory using manual. (2) Explain specification of following drill tool using specification list: drill pipe, drill collar, sub, DTH, bits. (3) Explain type of thread and their identification, (API IF and REG threads).
4. Materials 2-4M1 DDCA's Manual for Drilling Works

2.4 RIG ACCESSORY (TA CODE 2-4)

2.4.1 CONTENTS OF RIG ACCESORY

The rig accessory shall consist of drilling string elements and handling tools. They are major tools for the drilling works to be attached to each drilling rig. ***Table 6*** shows the contents of rig accessories for a set of DDCA's new rotary cum DTH drilling rig of 150 m in capacity which are currently under procurement. Total of 6 rigs are to be procured and they are planed to be hired to the private drilling companies. The major components of rig accessory are drill pipes, drill collars, subs, DTHs, DTH bits, rotary bits etc. The quantities of each element in ***Table 6*** were calculated for the drilling of wells of 150 m in depth by using DTH drilling method and mud drilling method. This section describes the use and the specifications of each element for the purpose of proper use and selection by the drillers.

Table 6 Rig Accessories DDCA's New Drilling Rig of 150 m Capacity

No.	Description	Unit	Qty
1	Drill pipes 41/2" 0.D flush type with API 31 1/2"IF BOX and pin joints furnished with wrech squares and steel made protectors,6m long/pc	Pcs	30
2	Drilling collars 5"0.D,2"IF BOX and pin joints,furnished with wretch squares and steel protectors,6m long/pc	Pcs	3
3	Hoisting swivel API 1/2" IF Pin joint	Pcs	3
4	Hoisting plug API 1/2" IF Pin joint	Pcs	3
5	Drill pipes collar hanger	Pcs	3
6	Cross over sub API 3 1/2 IF BOX and pin	Pcs	3
7	DTH Hammer assembly for 6 1/4"(150mm) hole drilling API 3 1/2 Regular pin and 8" to 10" hole drillling	Assy	3
8	DTH Hammer assembly for 12"(300mm) hole drilling API 3 1/2 Regular pin	Assy	3
9	DTH Button Bit for 12"(300mm) hole drilling	Pcs	5
10	Bit sub for drill pipes/collar to 6 1/4" DTH Hammer API 3 1/2" Regular box and API 3 1/2" IF Box joint	Pcs	3
11	Bit sub for drill pipes/collar to 6 1/4" DTH Hammer API 3 1/2" Regular box and API 3 1/2" IF Box joint	Pcs	3
12	DTH Button bit for 6 1/4"(159mm) hole drilling	Pcs	10
13	DTH Button bit for 8 1/4"(216mm) hole drilling	Pcs	10
14	DTH Button bit for 10"(254mm) hole drilling	Pcs	5
16	Bit grindeer for button bit and body dressing,furnished with 15 m long high pressure air hose	Pcs	1
17	Tricone roller bits 6 1/2" dia	Pcs	4
18	Tricone roller bits 8 1/2" dia	Pcs	4
19	Tricone roller bits 10 1/2" dia	Pcs	4
20	Tricone roller bits 12 1/2" dia	Pcs	4
21	Roller bits 8 1/2" dia	Pcs	4
22	Roller bits 10 1/2" dia	Pcs	4
23	Roller bits 12 1/2" dia	Pcs	4
24	Roller bits 14 1/2" dia	Pcs	4
25	Drag bits three winged 8 1/2" dia	Pcs	4
26	Drag bits three winged 10 1/2" dia	Pcs	4
27	Drag bits three winged 12 1/2" dia	Pcs	4
28	Drag bits three winged 16 1/2" dia	Pcs	0
29	Roller bit 16" dia for soft formation	Pcs	0
30	Stabilizer for 6 1/4" hole body dia,1.5m long API 3 1/2 IF BOX and pin joints furnished with wretch squares and steel made thread protectors on both ends	Pcs	3
31	Stabilizer for 8 1/2" hole 5" body dia,1.5m long API 3 1/2 IF BOX and pin joints furnished with wretch squares and steel made thread protectors on both ends	Pcs	3
32	Stabilizer for 10" hole 5" body dia,1.5 long API 3 1/2 IF BOX and pin joints furnished with wretch squares and steel made thread protectors on both ends	Pcs	3

No.	Description	Unit	Qty
33	Stabilizer for 12" hole 5" body dia,1.5m long API 3 1/2 IF BOX and pin joints furnished with wretch squares and steel made thread protectors on both ends	Pcs	3

2.4.2 DRILL STRING ELEMENTS

The composition of different tools and elements as rotary subs, drill rods, stabilizers, drill collars, reamers, down the hole hammers with various bits, as well as tricone roller bit and drag bits, starting from the pin of the rotation head and ending with the bit on the bottom of the hole, is called “DRILL STRING”. The three major functions to be performed by the drill string are:

a. To transmit rotation from the drill unit to the drill bit
b. To transmit feed pressure (bit weight) from the drill unit to the drill bit
c. To provide passage for air or drill fluid to the bottom of the hole to operate the down the hole hammer, to cool the drill bit, to flush the cuttings and to lift them up to the surface.

Resulting from these three major functions, the drill string is subject to various kinds of stress such as torsion, tension bending, buckling and compression depending upon borehole depth, hole diameter directions etc.

Because of some fact, that almost the total length of the drill string is placed below the ground level, that all elements of the string are connected through threads and that of the above mentioned various kinds of stress are caused considerable wear on the whole drill string, care has to be taken that all elements but in particular threads are in good working condition in order to avoid any breaking in the string. Therefore it is the responsibility of the Driller in charge and of the Shift Operators to check various elements of the drill string carefully before being lowered in the borehole. It is once more emphasized that only equipment in proper working condition should be used in the borehole. But also drill string handling tools as bit brakers, clamps, chain wrenches, lifting caps, etc have to be checked before use and should also be in proper working condition.
The strongly requested checking and controls by the personnel concerned are considered as preventive measures at the drill sites in order to avoid difficult time and money consuming fishing work hindering drilling crews from good performance. ***Figure 7*** shows the standard assembly of drill string.

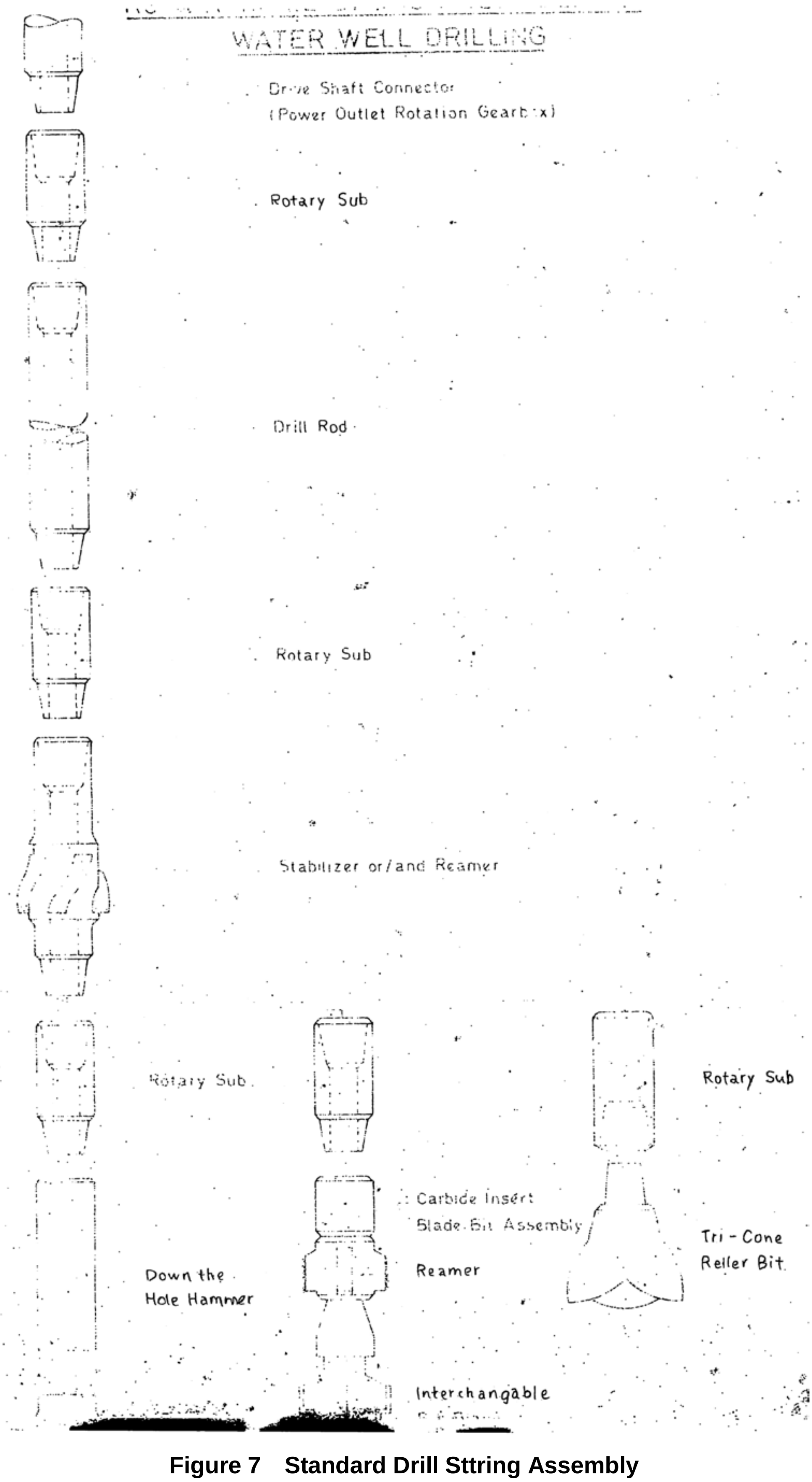


Figure 7 Standard Drill Sttring Assembly

- **Drive shaft**

The drive shaft pin of the rotation gear box is threaded with 31/2" API Reg. Pin and is the connector from the drill unit to the drill string.

- **Rotary Substitutes "SUBS"**

Rotary substitutes commonly known as "SUBS" are elements of the drill string and are used where threads of one size or type must be completed together with threads of another size or type. These subs are called "Cross Over subs". Other subs are used as wear prevention at connection points that are frequently made up and broken out. These subs are called "Saver Subs." Casing driver subs are to connect steel surface/conductor casing to the top drive head of the rig. This enables the drilling by the casing or the mud/air circulation to remove the sediment which disturbs the casing installation to the desired depth. DDCA has casing driver subs for 65/8", 85/8", 103/4", 123/4" and14" O.D casings with API 5L line pipe thread; the connector is 31/2 API IF Box.

Elements of the drill string which are used with our rotary rigs and which have to be coupled in the drill string with the help of subs are as follows:

- **Drill Pipes and Drill Collars**

Drill pipe is a type of piping used on a drilling rig. It helps with wellbore drilling, which is the process of digging a hole in the ground in order to access a particular natural resource, such as oil or water. The pipe pumps drilling fluid, which generates pressure to keep unwanted fluids out of the liquid pumped, removes drill cuttings, and helps to cool and clean the drill bit. It is one of the most significant member of the drill string. It is available in different diameters according to requirements, as FLUSH JOINT DRILL ROD AND UPSET DRILL ROD, (here the tool joint is larger in diameter than the pipe itself). Tool joints are threaded with male and female threads for connecting in the drill string. The material of drill pipes is considered of having the best physical properties and to provide a combination of hardness, strength and ductility.

DDCA has various size of drilling pipes such as:

- 51/2" O.D Fitted with 31/2" API IF Box Pin
- 51/4" O.D fitted with 31/2" API Reg. Box Pin
- 41/2" O.D fitted with 31/2" API Reg. Box Pin
- 31/2" O.D fitted with 23/8" API IF Box Pin
- 31/2" O.D fitted with 27/8" API IF Box Pin.

The drillers are required to correctly grasp the specifications of drill pipes which they use, i.e. nominal diameter, connection (API Reg. or IF), outside and inside diameters, unit weight. ***Table 7*** show the general capacity of API drill pipes

Table 7 Capacity of API Drill Pipe

Nominal Diameter	OD (mm)	ID (mm)	Threads / inch	Unit Weight (kg / m)
2-3/8”	60	47	4	11.0
2-7/8”	73	54.6	4	17.0
3-1/2”	88.9	70.3	4	21.0
4-1/2”	114.3	97.1	4	27.0
5-1/2”	139.7	121.4		32.7

Drill collar is heavy weight pipe which shall be connected between rotary bit and drill pipes. In water well drilling, one to three tons of drill collars is used and the weight on bit shall be within the total weight of drill collars. ***Table 8*** shows the general capacity of API drill collars.

Table 8 Capacity of API Drill Collar

Connection	OD (inch)	ID (inch)	Unit Weight (kg/m)
NC23-31	3-1/8"	1-1/4"	
NC26-35 (2-3/8 IF)	3-1/2	1-1/2"	39.7
NC31-41 (2-7/8 IF)	4-1/8"	2"	51.6
NC35-47	4-3/4"	2"	73.8
NC38-50(3-1/2 IF)	5"	2-1/4"	79.3
NC44-60	6"	2-1/4"	122.9
NC44-60	6"	2-13/16"	113.0
NC44-62	6-1/4"	2-1/4"	134.7
NC46-62(4IF)	6-1/4"	2-13/16"	124.7
NC46-65(4IF)	6-1/2"	2-1/4"	148.0
NC46-65(4IF)	6-1/2"	2-1/4"	138.1
NC46-67 (4 IF)	6-3/4"	2-13/16"	160.7
NC50-70 (4 1/2 IF)	7"	2-13/16"	174.1
NC50-70 (4 1/2 IF)	7"	2-13/16"	165.2
NC50-72 (4 1/2 IF)	7-1/4"	2-13/16"	178.6
NC56-77	7-3/4"	2-13/16"	208.3
NC 56-80	8"	2-13/16"	224.7
6-5/8REG	8-1/4"	2-13/16"	241.1
NC61-90	9"	2-13/16"	291.7
7-5/8R E G	9-1/2"	3"	322.9
NC70-97	9-3/4"	3"	342.3
NC70-100	10"	3"	361.6
NC77-110	11"	3"	445.0

- **Stabilizer or/and Reamer**

There are a number of stabilizers and reamers manufactured of different type and use in drilling boreholes. There is the rubber stabilizer used almost only in deep oil well or water well drilling. More common is the welded blade type stabilizer or reamer in shallow water well drilling. It is especially effective in soft formation where "balling up" of mud and cuttings on the drill string may be a problem. These stabilizers are generally used for the following purpose:

- To avoid crocked hole drilling
- To center the part of the drill string under weight (mostly drill collars) and to make the drill string more stiff although using more weight.
- To prevent the bit from wandering.

But there are also special reamers or hole openers known, placed immediately above the bit in order to stabilize the bit but also to enlarge the borehole immediately after the pilot bit. (e.g. Carbide Insert Blade Bit Assy.). DDCA has some kinds of stabilizer sucy as 6 5/8" O.D fitted with 4 1/2" API Reg. Box Pin.

- **Down the Hole Hammer (DTH), Bits, Drag Bits, Roller Bits**

These tools as members of the drill string are doing the actual drilling work on the lower end of the drill string on the bottom of the borehole. These tools are designed and manufactured in a wide variety in order to meet the demand originating from the property of the underground to be penetrated.

DTH

In order to overcome these problems which may result from lack of experience or proper knowledge of the matter by the rig operators in addition to the above given hints each driller shall refer to the operation and maintenance manual of the manufacturer of DTH. One copy will have to be with a driller incharge for the purpose of training his crew and the other copy always to be available at the drill site for the shift operators disposal in order to have information required when on duty. The operation and Maintenance Manual shall contain all necessary general information on:

- Preparation for Drilling

- Drilling Operation
- Maintenance(sharpening bit) which have to be studied and followed thoroughly by the rig operators and considered as a working guide in order to improve performance of this very expensive equipment. Emphasis has especially to be put on the “CAUTIONS” mentioned in the Operation and Maintenance Manual indicating the most decisive actions for proper operation service and maintenance of the equipment.
- In addition to the instructions and guidelines given above general cleanliness at the site proper handling of drill string as well as use of proper drill oil has to be put on the “CAUTIONS” mentioned in the Operation and Maintenance Manual indicating the most decisive actions for proper operation service and maintenance of the equipment.
- In addition to the instructions and guideline given above general cleanliness at the site proper handling of drill string as well as use of proper drill oil has to be maintained. Proper drill sting handling tools have to be used in order to avoid damages of Megadrills and Megabits and to avoid general failure. Consultation of Senior Inspector Drilling or Drilling Superintendent should get more common in future in case of problems with equipment or low penetration rate in order to seek advices for improving performance of tools.

DDCA has DTH such asMission Mega and Hammer drills as follows:

- Model A 53-15 fitted with 31/2" API Reg. Box
- Model A 63-15 fitted with 41/2" API Reg. Pin
- Model A 100-10 fitted with 65/8" API Reg. Pin
- Model A 51-20 fitted with 31/2" API Reg. Box
- Model A 43-15 fitted with 25/8" API Reg. Box

Drag Bits, Tri-cone Bits and Tri-cone Roller Bits

These three types of rotary bits are major types for DDCA’s drilling works. Please refer to section 2-1 and 2-2 of this manual for the further explanation.

2.4.3 IDENTIFICATION OF SIZE AND TYPE OF THREADS

Operational trouble may sometimes be caused by not having the right tool-at the right place at the right time. But the Driller incharge as well as the stores staff must be able to identify threads of drill rods, bits, stabilizers and other tools of the drill string as well as threads of subs which are required to assemble the drill string. Identification of threads manufactured according to API-Standard is possible by measuring the PIN BASE DIAMETER and COUNTER BORE DIAMETER at box mouth as well as by determination of threads per inch. Table 9 shows an identification chart and instructions giving how to identify properly threads and how to determine on the subs required at drill sites for the drilling operation.

Table 9 Identification of API Threads

Thread Type		Thread per inch	Thread Angle	Pin diameter at base	Box diameter at counterbore
2-3/8	REG	5	60°	66.68	68.26
	FH	-	-	-	-
	IF	4	60°	73.05	74.61
2-7/8	REG	5	60°	76.20	77.79
	FH	-	-	-	-
	IF	4	60°	86.13	87.71
3-1/2	REG	5	60°	88.90	90.49
	FH	5	60°	101.45	102.79
	IF	4	60°	102.01	103.58
4-1/2	REG	5	60°	117.48	119.06
	FH	5	60°	121.72	123.83
	IF	4	60°	133.35	134.94
6-5/8	REG	4	60°	152.20	153.99

Technical Area: 2 Drilling Tools and Equipment
Item: 2-5 Casing Tools

1: Objectives
To be able to explain and advise for specifications of steel casing pipes to be used as surface and conductor casing.

2. Contents
- Specifications of Surface and Conductor Casing, thread types

3. Teaching Methods
(1) Explain size and type of steel casing pipes which are generally used as surface, conductor and production holes.
(2) Explain the casing handling tools.

4. Materials
2-5M1 DDCA's Manual for Drilling Works

2.5 CASING TOOLS (TA CODE 2-5)

2.5.1 SIZE AND TYPE OF STEEL CASING PIPE

(1) Steel Casing Pipes

The steel casing pipes are used as the surface casing and/or the conductor casing. DDCA has various types and standards of steel casing pipes. Normally, casing pipes are used as temporary casings. Therefore they are pulled out from the borehole after the completion. In this reason casing pipes are with threaded flush for the easiness of the handling. Stadards of API 5L-B, JIS STPG Sch-40, JIS SGP, DIN Medium are popularly used for the steel casing. Their sizes are shown in ***Table 10***, ***Table 11***, ***Table 12*** and ***Table 13***.

Table 10 Size of API 5L-B Steel Pipes

ND (mm)	ND (inch)	OD(mm)	ID(mm)	Thickness (mm)	Unit Weight (kg/m)
	3-1/2"	88.9	80.9	4	8.37
	3-1/2"	88.9	79.3	4.8	9.95
	3-1/2"	88.9	77.9	5.5	11.31
	4-1/2"	114.3	104.7	4.8	12.96
	4-1/2"	114.3	103.9	5.2	13.99
	4-1/2"	114.3	103.1	5.6	15.01
	4-1/2"	114.3	102.3	6	16.02
	6-5/8"	168.3	158.7	4.8	19.35
	6-5/8"	168.3	157.1	5.6	22.47
	6-5/8"	168.3	154.1	7.1	28.22
	6-5/8"	168.3	152.5	7.9	31.25
	8-5/8"	219.1	207.9	5.6	29.48
	8-5/8"	219.1	206.3	6.4	33.57
	8-5/8"	219.1	205.1	7	36.61
	8-5/8"	219.1	203.3	7.9	41.14
	8-5/8"	219.1	202.7	8.2	42.65
	8-5/8"	219.1	201.7	8.7	45.14
	8-5/8"	219.1	200.1	9.5	49.1
	10-3/4"	273	260.2	6.4	42.09
	10-3/4"	273	258.8	7.1	46.57
	10-3/4"	273	257.4	7.8	51.03
	10-3/4"	273	255.6	8.7	56.72
	10-3/4"	273	254.4	9.3	60.5
	12-3/4"	323.8	311	6.4	50.11
	12-3/4"	323.8	309.6	7.1	55.47
	12-3/4"	323.8	308	7.9	61.56
	12-3/4"	323.8	307	8.4	65.35
	12-3/4"	323.8	306.4	8.7	67.62
	12-3/4"	323.8	304.8	9.5	73.65
	12-3/4"	323.8	303.2	10.3	79.65
	14"	355.6	342.8	6.4	55.11
	14"	355.6	341.4	7.1	61.2
	14"	355.6	339.8	7.9	67.74
	14"	355.6	338.2	8.7	74.42
	14"	355.6	336.6	9.5	81.08
	14"	355.6	335	10.3	87.71
	16"	406	393.2	6.4	63.13
	16"	406	391.8	7.1	69.91
	16"	406	390.2	7.9	77.63
	16"	406	388.6	8.7	85.32
	16"	406	387	9.5	92.98
	18"	457	442.8	7.1	78.77
	18"	457	441.2	7.9	87.49
	18"	457	439.6	8.7	96.18

ND (mm)	ND (inch)	OD(mm)	ID(mm)	Thickness (mm)	Unit Weight (kg/m)
	18"	457	438	9.5	104.84
	18"	457	436.4	10.3	113.46

Table 11 Size of JIS STPG Sch-40 Steel Pipes

ND (mm)	ND (inch)	OD(mm)	ID(mm)	Thickness (mm)	Unit Weight (kg/m)
80	3	89.1	78.1	5.5	11.3
90	3-1/2	101.6	90.2	5.7	13.5
100	4	114.3	102.3	6	16
125	5	139.8	126.6	6.6	21.7
150	6	165.2	151	7.1	27.7
200	8	216.3	199.9	8.2	42.1
250	10	267.4	248.8	9.3	59.2
300	12	318.5	297.9	10.3	78.3
350	14	355.6	333.4	11.1	94.3
400	16	406.4	381	12.7	123
450	18	457.2	428.6	14.3	156

Table 12 Size of JIS SGP Steel Pipes

ND (mm)	ND (inch)	OD(mm)	ID(mm)	Thickness (mm)	Unit Weight (kg/m)
80	3	89.1	80.7	4.2	8.794
90	3-1/2	101.6	93.2	4.2	10.089
100	4	114.3	105.3	4.5	12.186
125	5	139.8	130.8	4.5	15.015
150	6	165.2	155.2	5	19.754
175	7	190.7	180.1	5.3	24.2
200	8	216.3	204.7	5.8	30.1
225	9	241.8	229.4	6.2	36
250	10	267.4	254.2	6.6	42.4
300	12	318.5	304.7	6.9	53
350	14	355.6	339.8	7.9	67.7
400	16	406.4	390.6	7.9	77.6
450	18	457.2	441.4	7.9	87.5

Table 13 Size of BS Heavy Steel Pipes

ND (mm)	ND (inch)	OD(mm)	ID(mm)	Thickness (mm)	Unit Weight (kg/m)
80	3"	88.75	79.05	4.85	10.0
100	4"	114.05	103.25	5.4	14.4
125	5"	139.65	128.85	5.4	17.8
150	6"	165.2	154.4	5.4	21.1

Figure 8 shows the specifications chart giving indication on what tools and casings have to be used at drill sites in order to complete boreholes of the required final diameters as requested by the hydrogeologist. It will help the driller in charge to check at he site whether he has got the proper tools or to enable him to arrange for the required tools and casings respectively. It should be considered as general guideline when this type of casings is used for water well drilling.

Each of the columns is giving particulars on casings, couplings, drill bit as well as clearance in annular spaces required to allow the drill bit to pass, to allow proper running of casing and to insert gravel pack envelope around screens.

In column 2, 3, 4 and 7 are particulars of casings as O.D. Wall thickness and O.D of couplings listed. Column 5 is indicating the max. Diameter of drill bit which may be run in the casings with a clearance as shown in column 6. This clearance is a result from J.D casing column 4 and bit size column 5. It is important for the Drillers incharge and the Shift Operator to know as what is the bit clearance in order to avoid jamming of the drill string in the casings. In column 7 it is the O.D. of the casing coupling listed important for th be determination of the bit size required to run casings without problems. Now in columns 8 and 9 the required bit sizes are listed depending from the O.D of casings columns 2 and the O.D. of couplings column 9 in order to have the required clearance for running casings and inserting gravel pack.

The annular space listed in column 10 is the minimum clearance required which will enable the Driller incharge or Shift Operator to run casings without trouble provided he has not drilled a crooked borehole and the borehole has got throughout the same required diameter.

The annular space listed in column II between casing O.D. and borehole wall refers to artificially gravel packed boreholes drilled in unconsolidated soft soil formation where an effective gravel envelop around the screens is required in order to get sand free water out. As already mentioned above this chart is only giving general indication while in some instances special arrangements or combinations of bit size and casing diameter may be necessary. But even in this respect the listed diameter of casings and drill bits may help to find the correct decision.

SPECIFICATIONS OF STEEL CASTIN_S ON ORDER (T6/75) AND _A OF DRILL BITS TO BE USED

	CASINGS			DRILL BIT		CASINGS	DRILL BIT		ANNULAR SPACE		
1	2	3	4	5	6	7	8	9	10	11	12
DIMENSIONS	O.D.	WALL THICKNESS	J.D.	MAX DIAMETER	ANNULAR SPACE 4 to 5	O.D. COLLAR	MIN. DIA WITHOUT GRAVEL PACK	MIN DIA WITH GRAVEL PACK	WITHOUT GRAVEL PACK 7 to 8	WITH GRAVEL PACK 2 to 9	REM
INCH	6 5/8	7/32	63/16	5 7/8	5/32	7 11/32	8 1/2	9 7/8	35/64	15/8	
INCH DECIMALS	6.625	.215	6.187	8.875	.156	7.405	8.500	9.875	.546	1.625	
mm.	168.3	5.5	157.2	149.2	4	188.0	215.9	250.8	13.9	41.3	
INCH	8 5/8	1/4	8 1/8	7 7/8	1/8	9 11/32	11	13	51/64	9 3/16	
INCH DECIMALS	8.625	.250	8.125	7.875	.125	9.405	11.00	13.00	.796	2.187	
mm.	219.1	6.4	206.3	200.0	3.15	238.9	279.4	330.2	20.3	55.5	
INCH	10 3/4	9/32	103/16	9 7/8	5/32	11 17/32	13	15	47/64	21/8	
INCH DECIMALS	10.750	.279	10.192	9.875	.156	11.530	13.000	15.000	.734	2.125	
mm.	273.0	7.1	258.0	250.8	4	292.9	330.2	381.0	18.6	54.0	
INCH	12 3/4	5/16	12 1/8	11 1/8	1/2	13 17/32	15	17 1/2	47/64	2 3/8	
INCH DECIMALS	12.750	.312	12.125	11.125	.492	13.530	15.000	17.500	.734	2.375	
mm.	323.9	7.9	308.1	282.6	12.5	343.7	381.0	444.5	18.6	60.3	
INCH	14"	5/16	13 3/8	13	3/16	14 25/32	17 1/2	18 1/2	23/64	2 1/4	
INCH DECIMALS	14.000	.312	13.376	13.000	.139	14.780	17.500	18.500	1.359	2.250	
mm.	355.6	7.9	339.8	330.2	4.8	375.4	444.5	469.9	34.6	57.2	
							*Minimum dia. to be used	++Gravel pack should be not less than 2" around the screens.			

Figure 8 Specifications of Steel Casings and Drill Bits

(2) PVC Casing and Screen Pipes

Most of the case in Tanzania, PVC pipes are used as the production casing and screen pipes. DDCA mainly use the product of the PVC manufacturer, PLASCO, of which the sizes are shown in ***Table 14.*** The products with the remarks of 4”, 5”, 6”, 8” and 10” casing are the standard casing types. 5” casings are standard type for handpump wells and 6” casings are for wells for piped water supply schemes, respectively.

Table 14 Size of uPVC Pipes

Description	OD (mm)	ID	Thickness (mm)	Unit Weight (kg/m)	Remarks
FLUSH FITTING DIN4925 CASE	113	99	7	3.9	
FLUSH FITTING DIN4925 CASE	125	110	7.5	4.3	4" Casing
FLUSH FITTING DIN4925 CASE	140	124	8	5.2	5" Casing
FLUSH FITTING DIN4925 CASE	165	146	9.5	7.3	
FLUSH FITTING PLASCO CASE	165	150	7.5	5.9	6" Casing
FLUSH FITTING DIN4925 CASE	200	177	11.5	10.8	
FLUSH FITTING PLASCO CASE	200	182	9	8.6	
FLUSH FITTING DIN4925 CASE	225	199	13	13.7	
FLUSH FITTING PLASCO CASE	225	205	10	10.7	8" Casing
FLUSH FITTING PLASCO CASE	250	225	12.5	15	
FLUSH FITTING DIN4925 CASE	280	248	16	21.3	
FLUSH FITTING PLASCO CASE	280	255	12.5	16.9	10" Casing
FLUSH FITTING PLASCO CASE	315	285.4	14.8	22.4	

Source: Catalog of PLASCO

2.5.2 Casing Handling Tools

Steel or wooden clampes, or casing elevators (See ***Figure 9***) are usually used to install and/or pull out the casing string. In addition, wire slings and shackles shall be prepared on site according to the total weight of the casing string.

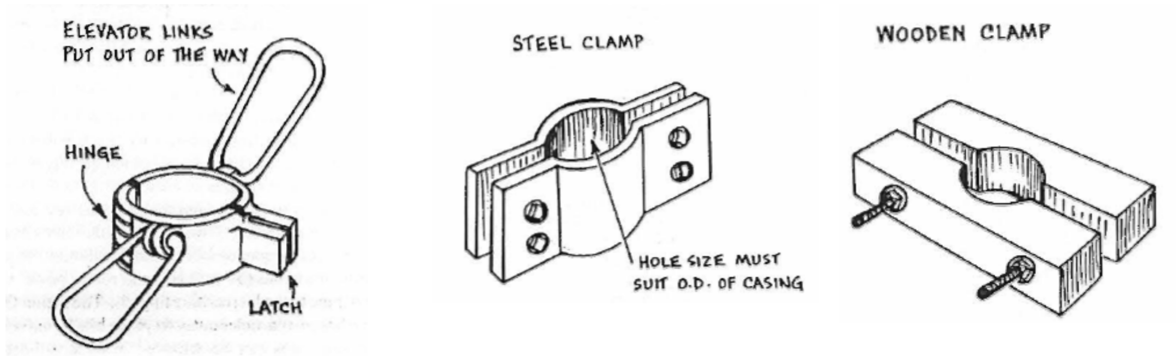


Figure 9 Casing Lifting Tools

Technical Area: 2 Drilling Tools and Equipment

Item: 2-6 Drilling Equipment

1: Objectives
To be able to explain and advise for specifications of major drilling equipment such as drilling rig, mud pump, compressor, supporting truck etc.

2. Contents
- Specifications of Drilling Rig, Mud Pump, Air Compressor, Water Tank Truck, Supporting Truck

3. Teaching Methods
(1) Explain of representative speicifications of the following major drilling equipment:
- Drilling Rig: Lifting Capacity (ton)
- Mud Pump:
  Discharge Rate (L/min)
  Pressure (MPa)
- Air Compressor:
  Delivery (m3/h, cfm)
  Pressure (MPa)
- Water Tank Truck:
  GVW (ton), Capacity (m3)
- Supporting Truck:

4. Materials
2-6M1 DDCA's Manual for Drilling Works
2-6M2 Drilling Chapter 4 P145-P151

2.6 DRILLING EQUIPMENT (TA CODE 2-6)

This section describes the major equipment for drilling works by rotary cum DTH drilling. It consists of drilling rig, mud pump, air-compressor, cargo truck and water tank truck. DDCA is currently procuring new drilling equipment including two drilling rigs of 300 m depth, six drilling rigs of 150 m depth and supporting equipment and trucks.

Drillers are required to evaluate the capacity of each equipment whether or not capable to drill a borehole of various depth, diameter and drilling method. The representative capacity of each equipment is described below.

2.6.1 SPECIFICATION OF DRILLING RIG

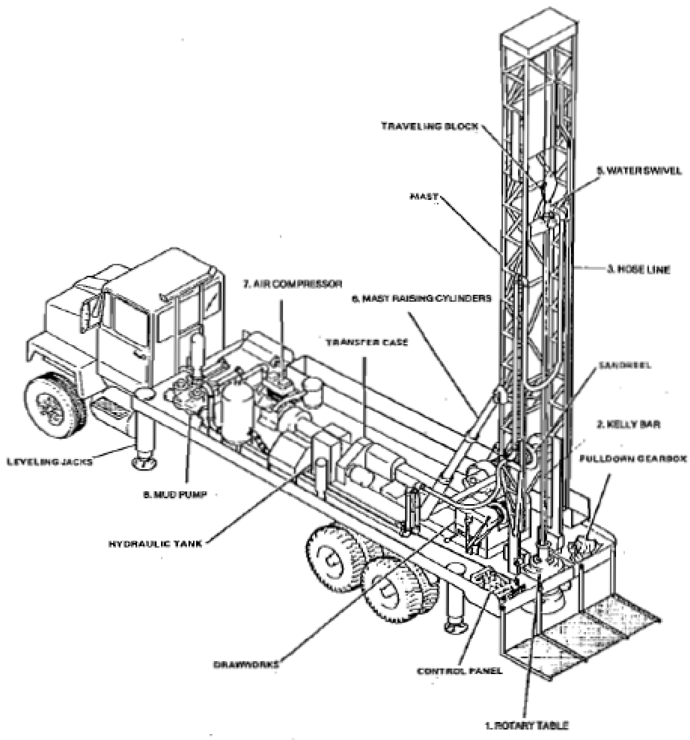
Figure 10 shows the structure of standard truck-mounted drilling rig. Besides rig plan, generally either a mud pump or an air-compressor is equipped on the truck.

The representative capacity of a drilling rig is lifting capacity (ton). This capacity expresses the maximum length of drill string which can be hold and lifted up by the drilling rig. It is directly related to the maximum drilling depth.

If the drilling is to be executed by DTH down to 200 m with 4-1/2” drill pipes without drill collar, total weight of the drill string is:

97 kg /m x 200 m = 10 tons

With consideration of stucking of drill string, 10 to 15 % of surplus shall be considered as a safety factor. 10 % of safety factor is taken, necessary lifting capacity comes to be 11 tons.



Source: National Waterwell & Drilling Association of Australia

Figure 10 Structure of Truck-mounted Drilling Rig

Prior to the selection and preparation of the drilling equipment, drillers shall determine the necessary drilling tools such as drilling pipes, drill collars, bits, DTH etc. The total weight of the drill string is calculated and shall be evaluated whether or not within the capacity of the drilling rig.

2.6.2 CAPACITY OF MUD PUMP

Most of DDCA’s truck-mounted rigs are equipped with duplex mud pump, as shown in ***Figure 11***. The representative capacities of mud pump are the discharge rate and the pressure.

- **Discharge Rate**

Necessary discharge rate shall be calculated from the necessary annular velocity between drill pipe and hole diameter. In general, at least 10 m/min of annular

Figure 11 Structure of Mud Pump

velocity is necessary for the proper removal of drilled cuttings.

In case of drilling by 8” bit and 4-1/2” drill pipe:

Necessary Disharge Rate (L/min)

= Annular Volume 22 L/m x Annular Velocity 10 m/min =220 L/min

In case of drilling by 12” bit and 4-1/2” drill pipe:

Necessary Disharge Rate (L/min)

= Annular Volume 63 L/m x Annular Velocity 10 m/min =630 L/min

Therefore, approximately 600 L/min is necessary if 12” bit drilling is used.

- **Pressure**

Each pump has its maximum pressure according to the discharge rate. The maximum pressure of mud pump equipped on the DDCA’s new drilling rig of 150 m depth is 25 bar for 600 L/min of discharge rate. ***Figure 12*** shows an example of separated type duplex mud pump made by TONE and its specifications are shown in ***Table 15***. Discharge rate of a duplex pump is decided by piston (liner) diameter, stroke length and stroke speed (See ***Figure 13***). Drillers shall liner and piston of suitable diameter for the drilling diameter and depth.

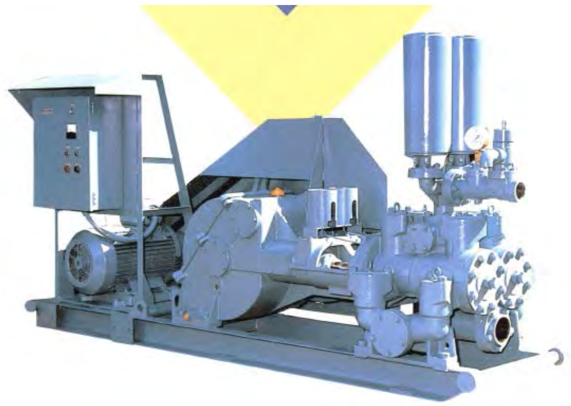
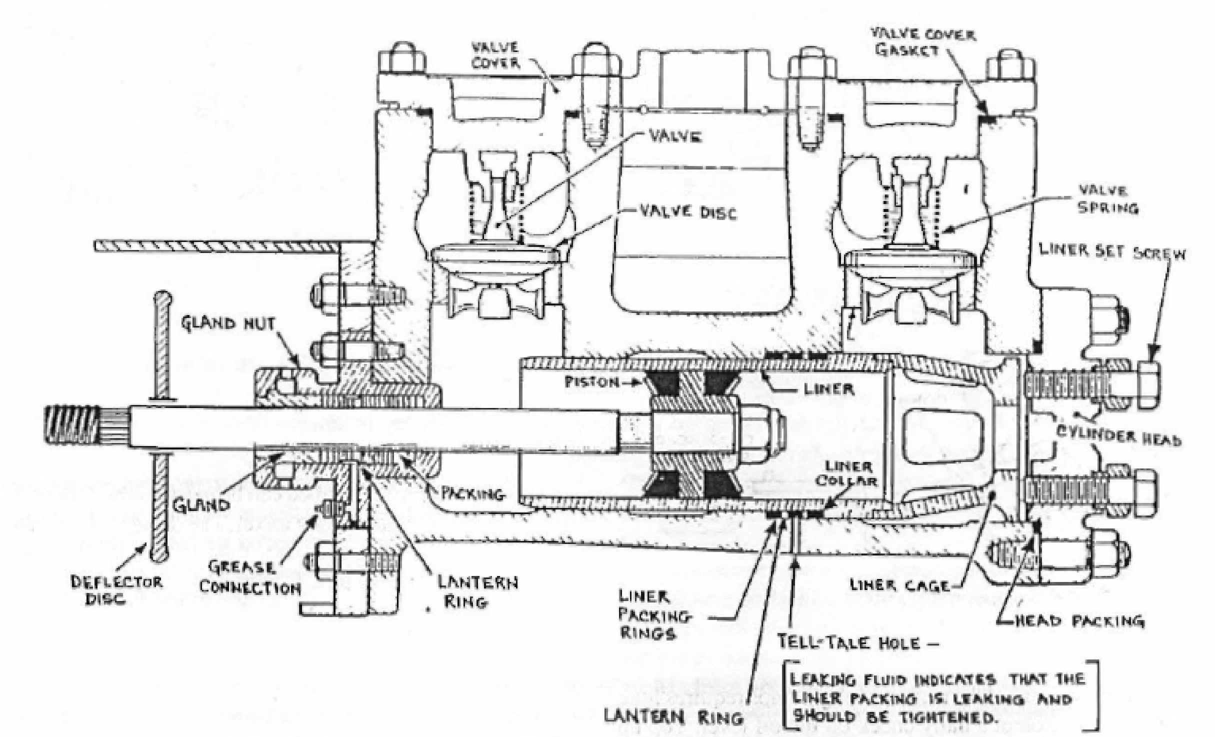


Figure 12 Duplex Mud Pump NP-700 (TONE)



Source: Australian Drilling Industry Training Cmmittee

Figure 13 Internal Structure of Mud Pump

Table 15 Specifications of NP-700 Mud Pump

Cylinder Dia. (mm)	140 (5-1/2")	127 (5")	114 (4-1/2")	102 (4")	89 (3 一 1/2")
Discharge Rate (L/min)	615	505	405	315	235
Max. Pressure (bar)	22	27	34	43	58
Stroke r.p.m	80	80	80	80	80
Drive Shart r.p.m	395	395	395	395	395
Stroke Length (mm)	130				
Valve Type	Ball or Conical				
Suction Hose Dia. (mm)	100 or 75				
Delivery Hose Dia. (mm)	65 or 50				
Power (kw)	30-4P				
Total Weight (kg)	1600				
Dimension (mm)	3,040 (L) x 830 (W) x 1,575 (H)				

Discharge pressure is mainly caused by the friction loss of the inside of drill pipes. Therefore, the discharge pressure is effected by the discharge rate and inside diameter and length of drill pipes as the following:

- Disharge pressure increases, if the discharge rate is increases,
- Disharge pressure increases, if the pipe inside diameter becomes smaller,
- Discharge pressure increases proportionally to the length of the pipe for the constant discharge rate and pipe inside diameter.

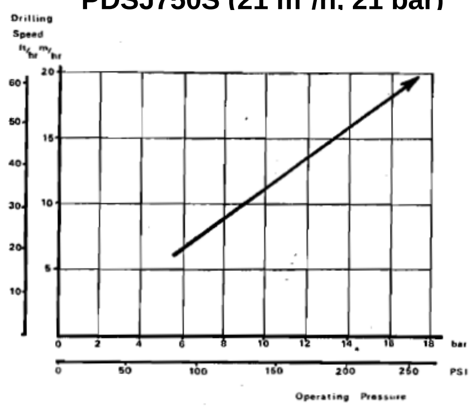
Standard type of mud pump has the capacity of 600 L/min and 25 bar. They are sufficient for the drilling of medium scale borehole down to 150 m with 8" to 12". However, for large bore and/or deep borehole drilling more than 150 m, discharge rate not less than 1,000 L/min will be necessary. In this case, large pressure will occur if the small diameter drill pipes such as 3-1/2" are used. Drillers are required to always check the relationship between pipe size, depth, discharge rate and pressure to utilize such information for the proper selection of drill pipes and rig capacities.

2.6.3 Capacity of Air Compressor

Air-compressors for DTH drilling are of type of either reciprocating or rotary screw. Nowadays, rotary screw type air-compressors are mainly used. Representative capacities of the air-compressor are air delivery and maximum pressure. DDCA's new compressor for the drilling down to 150 m has the capacities of 18.4 m^3/min (650 CFM) and 17 bar (246 psi). ***Figure 14*** show another type of PDSJ750 air-compressor, of which air delivery is 21 m3/min and the maximum pressure is 21 bar.

Figure 14 Rotary Screw Air-Compressor PDSJ750S (21 m^3/h, 21 bar)

Air delivery shall be determined from the necessary annular velocity for the proper removal of cuttings. The optimum annular velocity is thought to be 1,220 m/min. The maximum pressure shall be not less than the hydro static pressure of water in borehole. If the borehole depth is 150 m, the compressor of not less than 15 bar is preferable to be selected. However, if the water level is deep, hydro static pressure becomes lower. The pressure to drive the DTH shall be considered as well. More



Source: National Waterwell & Drilling Association of Australia

Figure 15 Change of Drilling Speed by Operating Pressure of DTH

pressure will give the better progress of the drilling. ***Figure 15*** shows typical performance improvement on a hammer's speed in hard granite at varying air pressures. Performance varies with different makes of DTH but as an example a particular hammer provided with 7 bar air pressure will deliver 15 blows per second of the piston striking the bit and with 14 bar air pressure will deliver 23 blows per second. In this instance where the piston weighs 5 kg and has a stroke of 50 cm before striking the bit, some idea of the power of a DTH can be appreciated.

2.6.4 CAPACITY OF WATER TANK TRUCK

In general, capacity of tank of water tank truck for water well drilling is 5,000 to 6,000 L. Necessary water volume for the drilling work is though to be three times of bore volume. The estimation examples are shown below:

8” x 150 m

Unit bore volme: 8 x 4 = 32 L/m

Total bore volume: 32 L/m x 100 = 3,200 L

Total necessary water: 3,200 L x 3 = 9,600 L

(2 times of transportation)

12” x 150 m

Unit bore volme: 12 x 6 = 72 L/m

Total bore volume: 72 L/m x 100 = 7,200 L

Total necessary water: 7,200 L x 3 = 21,600 L

(4 to 5 times of transportation)

2.6.5 CAPACITY OF CARGO TRUCK

The representative capacities of cargo truck are gross vehicle weight and payload. The payload is the maximum load acceptable to the truk. The gross vehicle weight is the total of truck weight and the payload. DDCA's new cargo truck has a capacity of 10 tons of payload (See ***Figure 16***). This can load approximately 370 m of 4-1/2” drill pipe (unit weight 27 kg/m).

Figure 16 DDCA's New Cargo Truck

Helical screw pumps require adjustment of the gland and, at longer intervals, replacement of the rotor and its drive linkage parts.

High pressures (deeper holes): Most drilling situations are best suited to piston or plunger pumps. These provide the positive displacement characteristics of:

- high pressure capability,
- rapid pressure change in response to changed conditions,
- an ability to handle fluids of a range of viscosities and solids contents.

Although piston pumps require considerable maintenance, this can be carried out under field conditions.

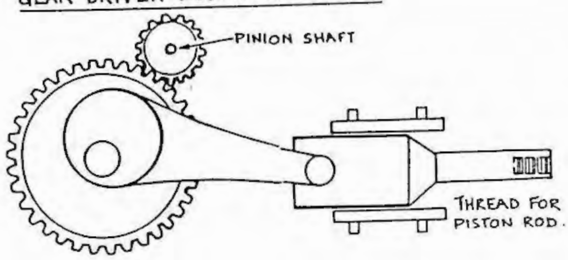
Pump drives – the power end

Drilling pumps are commonly referred to as having a power end and a fluid end. The power end of the pump incorporates the gears and linkages necessary to provide the pumping motion for the fluid end.

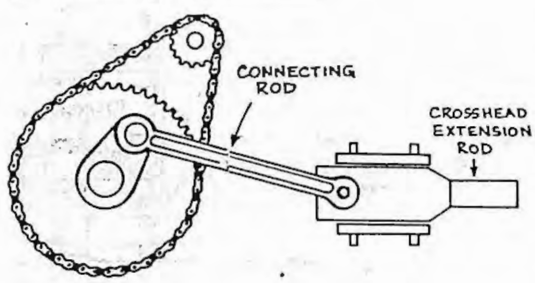
Helical pumps require a "rotary" action that allows the rotor to move from side to side as it rotates. This "free-sideways movement" is made possible by a short, flexible or universal shaft between the pump bearings and the rotor.

Reciprocating pumps incorporate a **crank** or an **eccentric** to generate the reciprocating action. The power end includes speed reduction gearing or chain sprockets.

GEAR DRIVEN ECCENTRIC ACTION



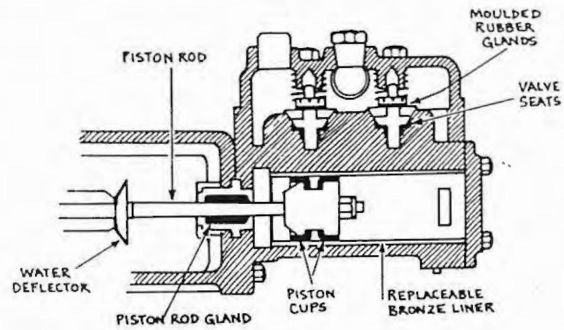
CHAIN DRIVEN CRANKSHAFT



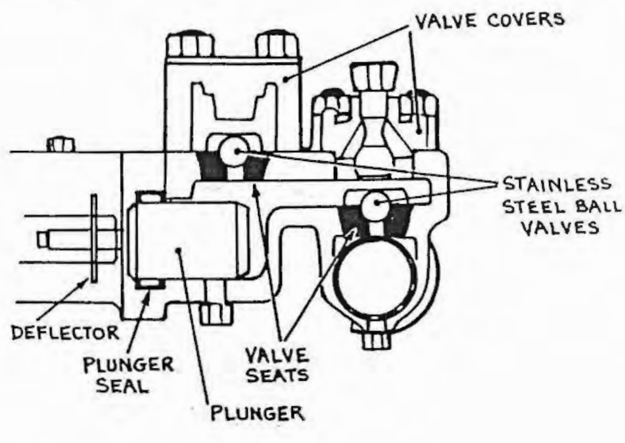
The power end of the reciprocating pumps requires little maintenance except a daily check on the oil level. Top up with the correct oil when necessary. The oil must be changed if it becomes contaminated with drilling fluid.

Low capacity fluid ends

The pumps in use on light and medium rigs have capacities in the range 0.5 to 15 L/s (8-240 U.S. gpm). Many of these are small single-cylinder pumps. Wearing parts that require replacement include piston cups, valve rubbers, gland packings, piston rods, and liners.



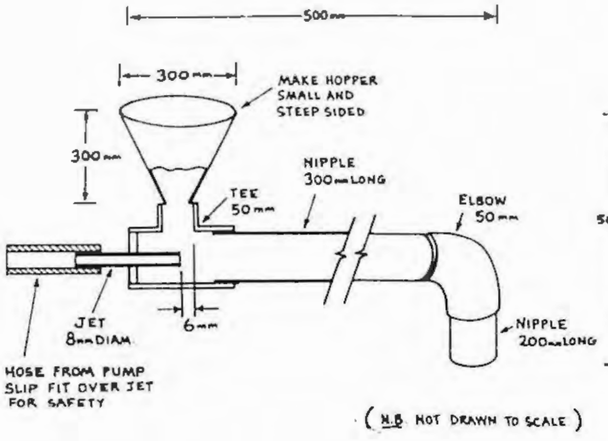
Light plunger pumps provide circulation on diamond drill rigs. They are used as injection pumps on larger rotary-air rigs. These small pumps require little maintenance. Valves, seats, plungers and plunger seals should be checked for wear.

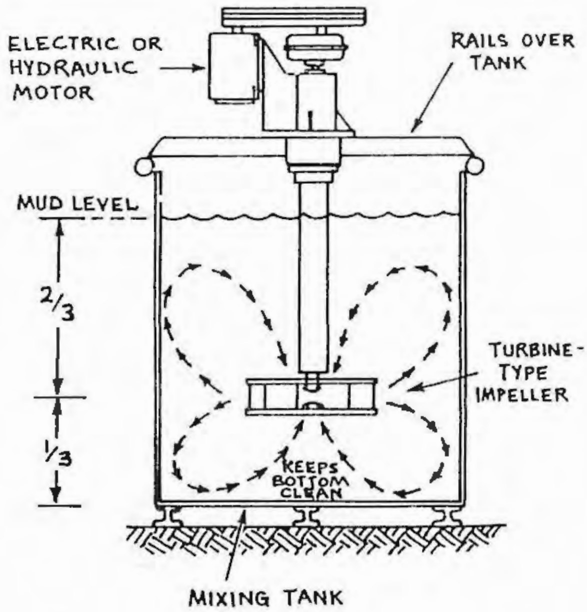


Mud mixing equipment

Hopper mixer

The small pumps described can be used for mud mixing using a simple jet/hopper mud mixer. The design advocated by NL Baroid is reproduced on the following page. It can be made up from standard pipe fittings.





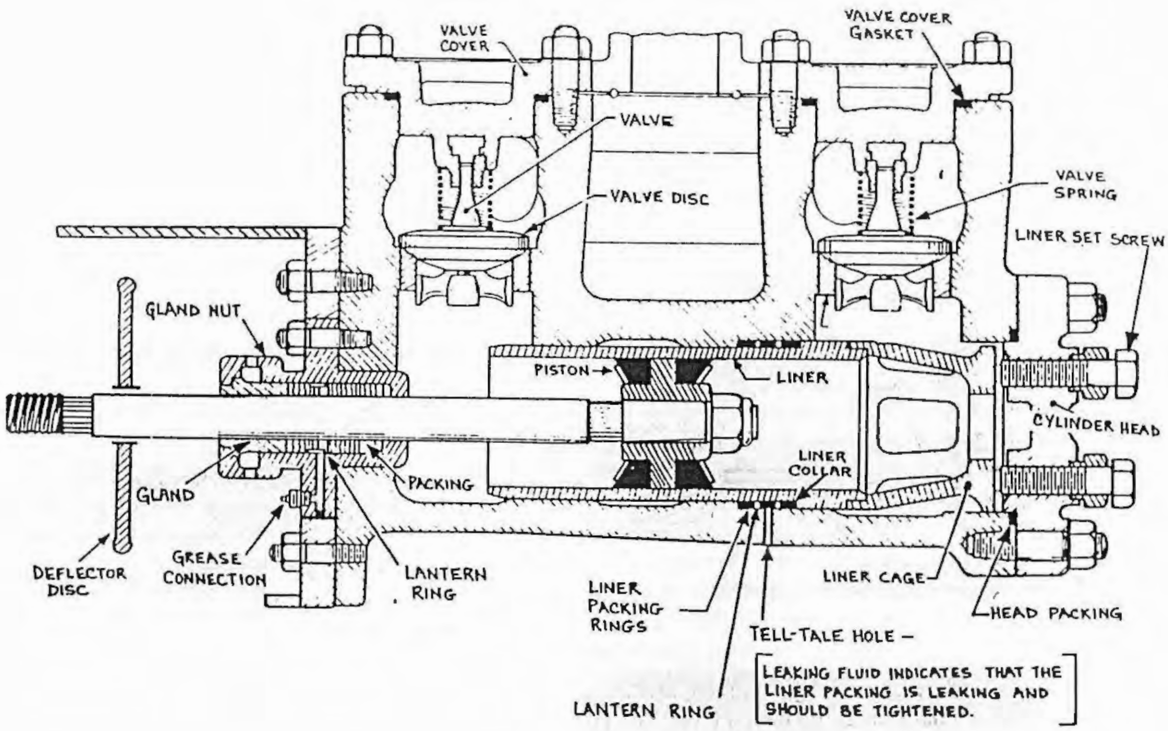
Propeller type mixers

Simple propeller mixers may be driven by vertical spindle petrol engines (lawnmower motors) or by hydraulic or electric motors, which require much less maintenance.

Mud pump fluid ends

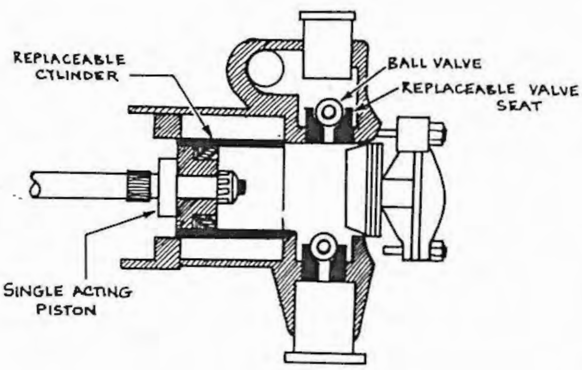
Single acting triplex pump

The most common pumps on light to medium rotary rigs are the medium capacity single-acting triplex pump and the double-acting duplex pump.



2-6M2 - 2

TRIPLEX PUMPS
(2 L/s at 70 bars pressure)



To handle abrasive mud fluids, larger triplex pumps are equipped with conical valves with replacement inserts. They handle volumes of 60 L/s (950 U.S. gpm) and pressures of 35,000 kPa (5,000 psi).

Double-acting duplex pumps

These pumps are of medium capacity (15 L/s)(240 U.S. gpm) up to 7,000 kPa (1,000 psi). These pumps are used on most medium rotary rigs. The driller is usually responsible for all maintenance of the fluid end.

Maintenance of fluid end components

Pistons: Abrasive drilling fluids cause rapid wear of the pistons. A gradual decrease in pressure indicates valve or piston wear. To replace the pistons, the piston rod must be unscrewed from the crosshead extension. The piston rod assembly is removed after taking off the liner cover and withdrawing the liner cage. Usually piston rubbers can be renewed without taking the piston body off the rod. A new piston may have to be driven into the liner.

Before reconnecting the piston rod, fit the deflector disc. Replace the disc if it has become torn or soft.

Liners: Liners are worn rapidly if pistons are allowed to run when worn. Liners are removed using a **liner puller** inserted through the cylinder head.

Valves: Sticks and stones in the circulating fluid can jam in the valve ports and hold the valves open. A pressure drop and an increase in the jumping of the kelly hose indicate a stuck valve.

Worn valve inserts (or the whole valve) must be replaced when the valves fail to seal. When the seats become worn, the seat must be removed using a **puller.** (Screw or hydraulic types are available). The new set should be driven firmly into place.

New liners should be greased and fitted with packing rings separated by a "lantern ring" before being slid into the pump body. After fitting the piston and reinstalling the liner cage and the cylinder head, the liner packings are compressed by tightening the **liner set screws.**

Stuffing box (gland): The gland must be tightened just sufficiently to stop it leaking. When the gland becomes worn, the nut is removed and the packing withdrawn. New packing is fitted around the piston rod and the nut replaced and adjusted.

Some stuffing boxes make a provision for greasing. These should be greased daily.

Pump fittings for protection

Relief valves

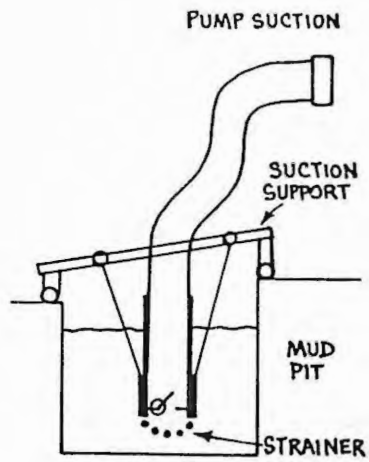
Every reciprocating pump, including the mud pumps described in preceding pages, must be fitted with a pressure relief valve.

Foot valves (and strainers)

Mud pumps should be set up so that they have a **flooded suction.** When a flooded suction cannot be arranged, the suction line can be kept full by providing a nonreturn valve at the end of the suction line.

A strainer is added to prevent solids from jamming the foot valve.

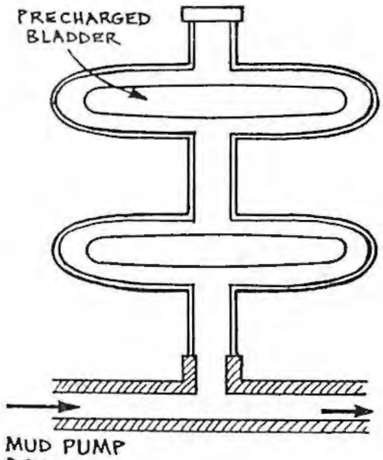
FOOT VALVE



Pulsation dampener

Dampeners may be simple air-chambers or special high response units incorporating precharged inflated bladders. The air chamber units require daily draining to replace air dissolved in the circulating fluid.

2-6M2 - 3



Delivery strainer

Pumps feeding a drill string that incorporates low clearance tools like core barrels or down hole turbines are fitted with delivery strainers. When fitted, these strainers should be cleaned weekly.

Kelly hoses and swivels

Like hydraulic hoses, kelly hoses will be damaged if bent around sharp corners or subjected to tension loading. Kelly hoses must always have secure safety chains at each end. The chains and the hose should be inspected daily for damage and loose connections.

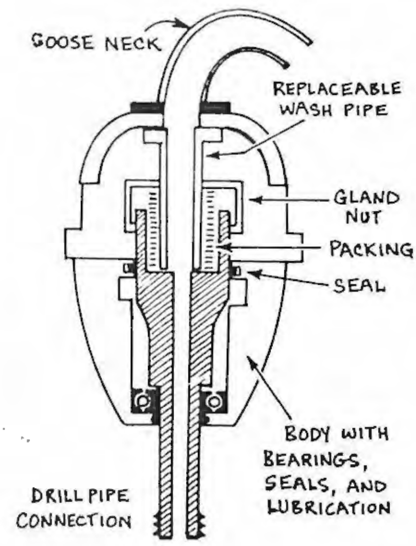
The manufacturers state a working pressure for the hose. This pressure must not be exceeded.

Swivels

Swivels vary in detail according to the weights they have to carry and the fluids they will conduct. Special swivels provide for dual-pipe drilling and reverse circulation. Swivel maintenance can be very expensive, so it must be done correctly. **Read maker's recommendations first.**

All swivels have similar basic parts:

- a threaded connection to the drill rod.
- a body carrying bearings and provision for lubrication. In some designs, these bearings carry the weight of the drill string.
- a replaceable "wash-pipe" or spindle which runs in the packing.
- a packing gland.



Swivel maintenance

- Grease each shift.
- Tighten gland just enough to stop leaks.
- Replace gland packing and wash pipe when worn.

Section 8 Compressors and air systems

- Compressors for drilling
- Reciprocating compressors
- Rotary screw compressors
- Operation and maintenance of air compressors
- Air motors and rig controls

Compressors for drilling

Air compressors provide:

- air circulation which clears the bottom of the hole more efficiently.
- air power to operate down-hole hammers giving vastly superior rock penetration rates on light and medium rigs.
- air power for hand tools.

Selection for air volume and pressure

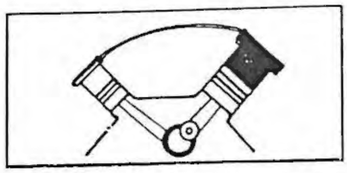
Low pressure air (Less than 1,000 kPa)(150 psi): For drilling in shallow dry holes, low pressure air may be provided by **reciprocating compressors,** but in recent years single stage **rotary screw compressors** are more common.

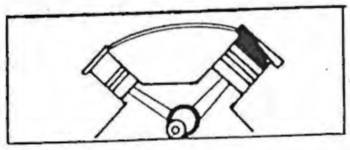
Medium pressure high volume air is most efficiently provided by **two stage compressors** using rotary screw units in both stages, while **high pressure air** is provided by **two stage rotary compressors, compressor plus booster.** (Pressures exceeding 1,500 kPa (220 psi) are classified as high pressure).

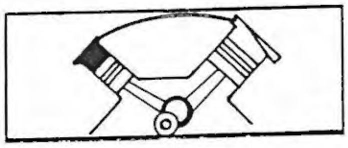
Air hazards

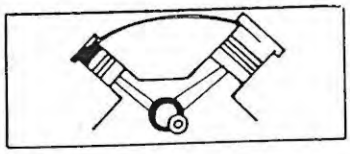
Compressed air is dangerous: Liquid pressure is quickly released, but air changes volume as its pressure is released. The air takes time to expand through the valve and retains enough pressure to be dangerous for some time after the valve is opened.

All air hoses must have **safety chains at both ends.** Always remember to **"Take care with pressure air".**









Reciprocating compressors

A tyre pump is a simple reciprocating compressor. A tyre is an air tank.

A single acting piston compressor is identical to the tyre pump except that hoth the inlet and exhaust valves are in the head of the compressor. The valves are operated by the air pressure.

Most reciprocating compressors use flat plate valves with thin metal strips or circles forming the actual valve. These valves are very sensitive parts and require expert attention.

Reciprocating compressors are often double-acting, compressing air on both strokes.

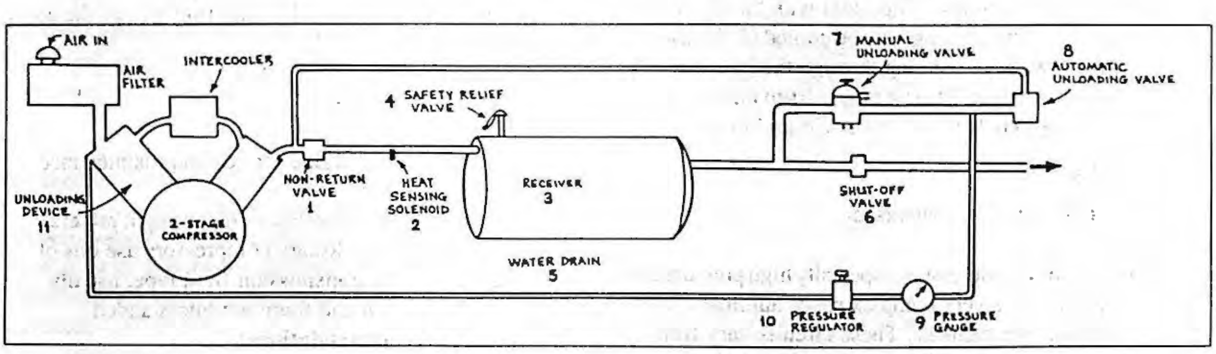
Lubrication is usually similar to that in a piston engine, but oil is also delivered to the cylinder walls.

Two stage compression

Pressures above 600 kPa (90 psi) are achieved more efficiently by compressing the air in two stages. Two-stage compressors have a large low pressure cylinder and a small high pressure cylinder. (1) Air is taken into the low pressure cylinder. (2) It is compressed. (3) Then it is pushed into the high pressure cylinder. This is where final compression takes place.

Air circuit of a piston compressor

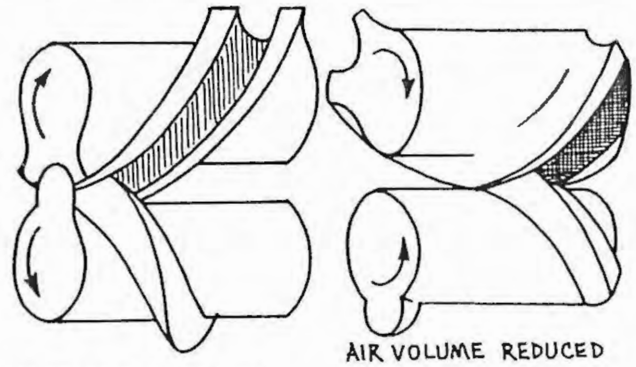
1. **nonreturn valve** prevents reverse rotation on shut-down.
2. **heat sensing solenoid** shuts down the engine if the temperature rises above the set limit.
3. **air receiver:**
   - smoothes out pressure variations.
   - prevents short cycle unloading.
   - separates oil and water.
   - stores air for heavy demands.



4. **Safety relief valve** blows off if the pressure in the system becomes excessive.
5. **Water drain** drains water condensate.
6. **Service outlet valve** controls output.
7. **Manual unloading valve** allows the receiver to be emptied of air under pressure.
8. **Automatic unloading valve** releases the compressed air when the engine is shut down so that the engine can be restarted without load.
9. **Pressure gauge** shows receiver pressure.
10. **Pressure regulator** permits selection of desired air pressure.
11. **Unloading device** permits the compressor to run free when the system is at maximum pressure and air is not being used. This type holds the inlet valve open.

Rotary screw compressors

The rotary screw compressor is, in fact, a gear pump with helical gears. "Pumping" air is complicated by the volume change as the pressure increases. The helical "gears" push the air along the grooves, compressing it as it goes.



AIR TRAPPED IN GROOVE

AIR VOLUME REDUCED AS ROTORS TURN

The rotors do not actually touch. Dust in the air will cause wear. Wear increases the clearances and destroys efficiency.

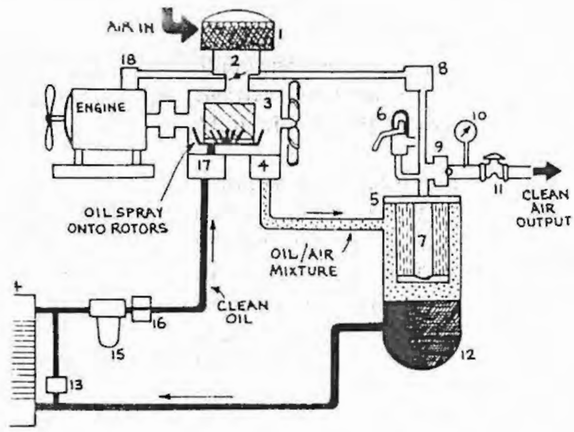
Most screw compressors spray oil into the compression space. The oil (1) seals and lubricates the surfaces and (2) carries away the heat of compression. Two stage compression is achieved by connecting the output of the large low pressure screws to the intake of smaller high pressure screws.

Cooling becomes more important with the higher compression ratios. The housing may be cooled (1) by using air fins or (2) by water circulating through the housing.

The air may be cooled, as it passes from one stage to the other, by an **intercooler**. Intercoolers improve compression efficiency.

Air circuit of a rotary compressor

Rotary screw compressors, especially high pressure units, are equipped with a very complex set of automatic control and protection mechanisms. These circuits vary from one manufacturer to another. The simplified circuit shows the oil injection, air and oil separation processes.



1. Air intake filter
2. Air inlet throttle (controls output)
3. Rotary screw compressor
4. Check valve
5. Air receiver/separator
6. Safety valve
7. Oil separating filter
8. Automatic unloading valve operates air intake and engine speed controls
9. Non-return valve
10. Pressure gauge
11. Service outlet valve
12. Oil sump in bottom of receiver
13. Thermostatic valve controls oil flow through the cooler
14. Oil cooler
15. Oil filter
16. Cut-off valve operates on engine shut down
17. Oil nonreturn valve
18. Engine control unit

Operation and maintenance of air compressors

A noisy compressor is better located away from the rig. Position the rig so that drilling dust is not carried into the compressor air intake.

Compressors are complex pieces of plant. The **manufacturer's manual** must be studied carefully before the unit is started.

As a general rule:

- follow normal engine service and maintenance requirements.
- reciprocating compressors use straight mineral lubricating oils. Rotary compressors use oils of the automatic transmission fluid type, usually with corrosion and foam inhibitors added **(check recommendations).**

Air filter: Clean dust dish (if fitted) twice a shift. Service the filter at recommended intervals.

Oil level: Check each shift and top-up when required.

Moisture traps: Drain these each shift.

Unloading cycle: Observe each shift that the unit loads and unloads properly. Report any irregularity.

Oil filter: Change every 1000 hours. Change oil every 2000 hours, or more frequently in dirty conditions.

Monitor pressure and temperature gauges and report any changes from normal.

When connecting hoses to the compressor, always connect the safety chain.

Air cleaners

The following fact illustrates the importance of air cleaner maintenance. Almost one-half kilogram of impurities per hour is taken in by a 34,000L/min (1200 c.f.m.) compressor working in an industrial area. An equal amount is also taken in by the engine. Dusty sites rapidly increase these amounts.

The correct method of servicing an air cleaner is just as important as the regularity with which it is serviced. Ensure that all gaskets, clamps and connections are airtight.

Compressors should never be operated with clogged filter elements or a poorly functioning air cleaner, as serious damage can result in only a few minutes.

Lubrication

Clean oil is as important as clean air - both are vital. Dust or dirt passing through an air filter or cleaner will rapidly contaminate the oil - which means rapid wear, more frequent oil changes and increased costs.

When changing oil, either in the compressor or engine, the utmost care must be taken to ensure that no dirt is allowed to enter the system. Be sure to provide clean oil of the correct grade and that your oil storage and changing equipment is always clean. Grease and lubricate the compressor in accordance with the instructions.

The cooling system

Always use clean, soft water and a high quality rust inhibitor in the cooling system. This will help prevent scale deposits, retard rust, and lubricate the water pump.

Periodically, flush out the system, using a radiator cleaner, following the recommended instructions. The radiator core should also be flushed clean regularly by forcing water in the reverse direction (opposite to the normal air flow) through the core.

Check that the radiator cap is sealing up to its designed pressure rating; replace it when faulty.

Fan belts should be checked for correct tension and replaced when worn or when cracks develop on the inside of the belts.

Fuel system

On portable compressors, you have to be concerned with fuel as well. Keep your fuel storage clean, especially any funnels, pumps, and tools used to transfer fuel. Periodically, drain fuel tanks to remove any moisture, silt, etc. Replace primary and secondary fuel filters as specified by the manufacturer and use only recommended filters.

As a general rule:

- Check that all gauges, dials, and controls are functioning properly.
- Never operate the compressor if you are not positive that these instruments are correct.
- Repair, or preferably, replace any faulty units.
- Follow normal engine service and maintenance requirements.

Reciprocating compressors use straight mineral lubricating oils. Rotary compressors use oils of the automatic transmission fluid type or special synthetic oils with corrosion and foam inhibitors added.

Air motors and rig controls

Some rigs use air control systems rather than mechanical or hydraulic linkages. Air motors may be used for operating most drilling functions including drill head rotation and pump drive.

Air motors

Low power but high speed drives use vane type air motors. Most drilling applications are better served by piston motors, which may be:

- single or v-twin cylinder.
- radial motors.
- direct coupled piston.

Piston type air motors have the advantage that they can exert full output torque when stalled.

Air brakes and clutches

Air operation permits very fast operation of the brake or clutch while retaining precise control. Clutches are usually of the multiple disc type with an air bladder pushing the plates together. Brakes are the expanding drum-type, which have quick release valves in the air lines.

Technical Area: 2 Drilling Tools and Equipment

Item: 2-7 Drilling Calculation

1: Objectives
To be able to explain and advise for necessary calculation for drilling work such as unit conversion, calculation of discharge rate, annular volume etc.

2. Contents
- Unit conversion
- Weight
- Pressure
- Discharge Rate
- Annular Volume

3. Teaching Methods
(1) Explain meaning of weight, pressure, dicharge rate, annular volume.
(2) Explain conversion tables.
(3) Explain the calculation of annular volume and annular velocity

4. Materials
2-7M1 DDCA's Manual for Drilling Works
2-7M2 Drilling Chapter 2 P7-P25

2.7 DRILLING CALCULATION (TA CODE 2-7)

2.7.1 UNIT CONVERSION

During the drilling works, drillers are required to observe and calculate the various values from materials and equipment actions such as weight, pressure, discharge rate etc. These values are expressed in different unit system such as metric, imperial etc. Therefore, drillers shall acquire the knowledge of the conversion between different unit systems. This section describes the major units to be used for the drilling works and gives the reference for the unit conversion. Examples of unit conversion using conversion tables are given below:

Length

100	inch	=	2.54	mm
100	mm	=	3.937	inch
10	ft	=	3.048	m
50	m	=	164.05	ft

Discharge

1000	gal/hr	=	3.785	m3/hr
1	m3/hr	=	264.2	gal/hr
1	m3/day	=	0.04167	m3/hr
25	m3/hr	=	600	m3/day
200	l/min	=	12	m3/hr
48	m3/hr	=	800	l/min
100	m3/hr	=	27.78	l/s
100	l/s	=	360	m3/hr

Pressure

1,000	Kgf/cm2	=	98.1	MPa
5	MPa	=	51	Kgf/cm2

Conversion Table

Length

	m	ft	in
m	1	3.281	39.37
ft	0.3048	1	12
in	0.0254	0.0833	1

Volume

	m3	gal
m3	1	264.17
gal	0.003785	1

Pressure

	kgf/cm2	bar	kN/m2 (kPa)	lbf/in2(psi)
kgf/cm2	1	0.981	98.1	14.223
bar	1.02	1	100	14.504
kN/m2 (kPa)	0.0102	0.0098	1	0.145
lbf/in2(psi)	0.0703	0.0689	6.89	1

In the following pages, useful conversion factors and conversion tables are provided.

Table 16 Conversion Factors – Imperial to Metric

CONVERSION FACTORS - IMPERIAL TO METRIC

	Metric Unit and Symbol	Value	Conversion Factor
			NOTE: Exact conversions underlined. Others given to three significant figures.
LINEAR MEASUREMENT	metre (m)	base unit	yd x 0.9144 = m
			ft x 0.3048 = m
	micrometre (μm)	0.000 001 m	in x 25.4 x 10^3 = μm
	millimetre (mm)	0.001 m	in x 25.4 = mm
	kilometre (km)	1 000 m	mile x 1.61 = km
AREA	square metre (m^2)	SI unit	yd^2 x 0.836 = m^2
			ft^2 x 92.9 x 10^{-3} = m^2
	square millimetre (mm^2)	0.000 001 m^2	in^2 x 645.16 = mm^2
	hectare (ha)	10 000 m^2	acre x 0.405 = ha
	square kilometre (km^2)	1 000 000 m^2	sq mile x 2.59 = km^2
VOLUME	cubic metre (m^3)	SI unit	yd^3 x 0.765 = m^3
			ft^3 x 28.3 x 10^{-3} = m^3
	cubic millimetre (mm^3)	1 x $10^{-9} m^3$	in^3 x 16.4 x 10^{-3} = mm^3
(Fluids only)	litre (l)	0.001 m^3	pt x 0.568 = l
			gal x 4.55 = l
	millilitre (ml)	1 x $10^{-6} m^3$	pt x 568 = ml
	kilolitre (kl)	1 m^3	gal x 4.55 x 10^{-3} = kl
	megalitre (Ml)	1 x $10^3 m^3$	gal x 4.55 x 10^{-6} = Ml
MASS	kilogram (kg)	base unit	lb x 0.454 = kg
	microgram (μg)	1 x 10^{-9} kg	oz x 28.3 x 10^6 = μg
	milligram (mg)	1 x 10^{-6} kg	oz x 28.3 x 10^3 = mg
	gram (g)	0.001 kg	oz x 28.3 = g
	tonne (t)	1 000 kg	ton (2240 lb) x 1.02 = t
PRESSURE	pascal (Pa)	SI unit	lbf/in^2 x 6.89 x 10^3 = Pa
	kilopascal (kPa)	1 000 Pa	lbf/in^2 x 6.89 = kPa
	megapascal (MPa)	1 000 000 Pa	lbf/in^2 x 6.89 x 10^{-3} = MPa
			$tonf/in^2$ x 15.4 = MPa
TIME	second (s)	base unit	
	minute (min)	60 s	
	hour (h)	60 min	
	day (d)	24 h	
TEMPERATURE	kelvin (K)	base unit	
	degrees Celsius (°C)	K – 273.15	$\frac{5}{9}$ (°F – 32) = °C
WORK, ENERGY QUANTITY OF HEAT	joule (J)	SI unit	Btu x 1.06 x 10^3 = J
	kilojoule (kJ)	1 000 J	Btu x 1.06 = kJ
	megajoule (MJ)	1 000 000 J	therm x 106 = MJ
POWER	watt (W)	SI unit	hp x 0.746 x 10^3 = W
	kilowatt (kW)	1 000 watts	hp x 0.746 = kW
	megawatt (MW)	1 000 000 watt	hp x 0.746 x 10^{-3} = MW

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Source: National Waterwell & Drilling Association of Australia

CONVERSION FACTORS — Metric to Imperial

	Metric Unit and Symbol	Value	Conversion Factor
LINEAR MEASUREMENT	metre (m)	base unit	x 1.09 = yd
			x 3.28 = ft
	micrometre (μm)	1×10^{-6} m	x 3.94×10^{-5} = in
	millimetre (mm)	1×10^{-3} m	x 3.94×10^{-2} = in
	kilometre (km)	1 000 m	x 0.621 = mile
AREA	square metre (m^2)	SI unit	x 1.20 = yd^2
			x 10.8 = ft^2
	square millimetre (mm^2)	1×10^{-6} m^2	x 1.55×10^{-3} = in^2
	hectare (ha)	10×10^3 m^2	x 2.47 = ac
	square kilometre (km^2)	1×10^6 m^2	x 0.386 = sq mile
VOLUME	cubic metre (m^3)	SI unit	x 1.3 = yd^3
			x 35.3 = ft^3
	cubic millimetre (mm^3)	1×10^{-9} m^3	x 61.0×10^{-6} = in^3
(Fluids only)	litre (l)	1×10^{-3} m^3	x 1.76 = pt
			x 0.220 = gal
	millilitre (ml)	1×10^{-6} m^3	x 1.76×10^{-3} = pt
	kilolitre (kl)	1 m^3	x 220 = gal
	megalitre (Ml)	1×10^3 m^3	x 220 000 = gal
MASS	kilogram (kg)	base unit	x 2.20 = lb
	microgram (μg)	1×10^{-9} kg	x 35.3×10^{-9} = oz
	milligram (mg)	1×10^{-6} kg	x 35.3×10^{-6} = oz
	gram (g)	1×10^{-3} kg	x 35.3×10^{-3} = oz
	tonne (t)	1×10^3 kg	x 0.984 = ton (2240 lb)
FORCE	newton (N)	SI unit	x 0.225 = lbf
	kilonewton (kN)	1 000 N	x 0.225 = kip
	meganewton (MN)	1×10^6 N	x 100 = tonf
PRESSURE	pascal (Pa)	SI unit	x 0.145×10^{-3} = lbf/in^2
	kilopascal (kPa)	1 000 Pa	x 0.145 = lbf/in^2
	megapascal (MPa)	1×10^6 Pa	x 0.145×10^3 = lbf/in^2
			x 64.8×10^{-3} = tonf/in^2
TIME	second (s)	base unit	
	minute (min)	60 s	
	hour (h)	60 min	
	day (d)	24 h	
TEMPERATURE	kelvin (K)	base unit	$\frac{9 \times {}^oC}{5} + 32 = {}^oF$
	degrees Celsius (°C)	K – 273.15	
WORK, ENERGY QUANTITY OF HEAT	joule (J)	SI unit	x 0.948×10^{-3} = Btu
	kilojoule (kJ)	1 000 J	x 0.948 = Btu
	megajoule (MJ)	1 000 000 J	x 9.48×10^{-3} = therm
	kilowatt hour (kW.h)	3.6 MJ	
POWER	watt (W)	SI unit	x 1.34×10^{-3} = hp
	kilowatt (kW)	1 000 watt	x 1.34 = hp
	megawatt (MW)	1 000 000 watt	x 1.34×10^3 = hp

Source: National Waterwell & Drilling Association of Australia

Table 17 Conversion Tables – Length and Area

UNIT	EQUIVALENT							
	Centimeters	Inches	Feet	Yards	Meters	Rods	Kilometers	Miles
1 Centimeter =	ONE	.3937	.0328	.01093	.01	.00199	.00001	.00000621
1 Inch =	2.54	ONE	.08333	.0278	.02540	.00505	.0000254	.0000158
1 Foot =	30.48	12	ONE	.33333	.30480	.0606	.000305	.000189
1 Yard =	91.44	36	3	ONE	.91440	.18181	.000915	.000568
1 Meter =	100	39.37	3.2808	1.0936	ONE	.1988	.001	.000621
1 Rod =	502.9	198	16.5	5.5	5.0292	ONE	.00503	.00312
1 Kilometer =	100,000	39,370	3280.8	1093.6	1000	198.83	ONE	.62137
1 Mile =	160,935	63,360	5280	1760	1609.3	320	1.6093	ONE

LENGTH

UNIT	EQUIVALENT							
	Square Centimeters	Square Inches	Square Feet	Square Yards	Square Meters	Square Rods	Acres	Square Miles
1 Sq. Centimeter =	ONE	.155	.001076	.0001196	.0001	.000003953	—	—
1 Sq. Inch =	6.452	ONE	.00694	.0007716	.0006452	.00002551	—	—
1 Sq. Foot =	929	144	ONE	.1111	.0929	.003673	.00002296	—
1 Sq. Yard =	8361	1296	9	ONE	.8361	.03306	.0002066	—
1 Sq. Meter =	10,000	1550	10.76	1.196	ONE	.0395	.0002471	—
1 Sq. Rod =	252,908	39,204	272.25	30.25	25.29	ONE	.00625	.000009766
1 Acre =	40,465,284	6,272,640	43,560	4840	4047	160	ONE	.001563
1 Sq. Mile =	—	—	27,878,400	3,097,600	2,589,998	102,400	640	ONE

AREA

Source: National Waterwell & Drilling Association of Australia

Table 18 Conversion Tables – Velocity and Flow

UNIT	EQUIVALENT							
	Centimeters	Inches	Feet	Yards	Meters	Rods	Kilometers	Miles
1 Centimeter =	ONE	.3937	.0328	.01093	.01	.00199	.00001	.00000621
1 Inch =	2.54	ONE	.08333	.0278	.02540	.00505	.0000254	.0000158
1 Foot =	30.48	12	ONE	.33333	.30480	.0606	.000305	.000189
1 Yard =	91.44	36	3	ONE	.91440	.18181	.000915	.000568
1 Meter =	100	39.37	3.2808	1.0936	ONE	.1988	.001	.000621
1 Rod =	502.9	198	16.5	5.5	5.0292	ONE	.00503	.00312
1 Kilometer =	100,000	39,370	3280.8	1093.6	1000	198.83	ONE	.62137
1 Mile =	160,935	63,360	5280	1760	1609.3	320	1.6093	ONE

LENGTH

UNIT	EQUIVALENT							
	Square Centimeters	Square Inches	Square Feet	Square Yards	Square Meters	Square Rods	Acres	Square Miles
1 Sq. Centimeter =	ONE	.155	.001076	.0001196	.0001	.000003953	—	—
1 Sq. Inch =	6.452	ONE	.00694	.0007716	.0006452	.00002551	—	—
1 Sq. Foot =	929	144	ONE	.1111	.0929	.003673	.00002296	—
1 Sq. Yard =	8361	1296	9	ONE	.8361	.03306	.0002066	—
1 Sq. Meter =	10,000	1550	10.76	1.196	ONE	.0395	.0002471	—
1 Sq. Rod =	252,908	39,204	272.25	30.25	25.29	ONE	.00625	.000009766
1 Acre =	40,465,284	6,272,640	43,560	4840	4047	160	ONE	.001563
1 Sq. Mile =	—	—	27,878,400	3,097,600	2,589,998	102,400	640	ONE

AREA

Source: National Waterwell & Drilling Association of Australia

Table 19 Conversion Tables – Imperial Gallons to Litres

Basis: 1 gallon = 4.54609 **Imperial Gallons to Litres**

Imp. Gals.	0	1	2	3	4	5	6	7	8	9
0	-	4.546	9.092	13.638	18.184	22.731	27.277	31.823	36.369	40.915
10	45.461	50.007	54.553	59.099	63.645	68.191	72.737	77.284	81.830	86.376
20	90.922	95.468	100.014	104.560	109.106	113.652	118.198	122.744	127.291	131.837
30	136.383	140.929	145.475	150.021	154.567	159.113	163.659	168.205	172.751	177.298
40	181.844	186.390	190.936	195.482	200.028	204.574	209.120	213.666	218.212	222.758
50	227.305	231.851	236.397	240.943	245.489	250.035	254.581	259.127	263.673	268.219
60	272.765	277.311	281.858	286.404	290.950	295.496	300.042	304.588	309.134	313.680
70	318.226	322.772	327.318	331.865	336.411	340.957	345.503	350.049	354.595	359.141
80	363.687	368.233	372.779	377.325	381.872	386.418	390.964	395.510	400.056	404.602
90	409.148	413.694	418.240	422.786	427.332	431.879	436.425	440.971	445.517	450.063
	-	10	20	30	40	50	60	70	80	90
100	454.609	500.070	545.531	590.992	636.453	681.914	727.374	772.853	818.296	863.757
200	909.218	954.679	1000.140	1045.601	1091.062	1136.523	1181.983	1227.444	1272.905	1318.366
300	1363.827	1409.288	1454.749	1500.210	1545.671	1591.132	1636.592	1682.053	1727.514	1772.975
400	1818.436	1863.897	1909.358	1954.819	2000.280	2045.741	2091.201	2136.662	2182.123	2227.584
500	2273.045	2318.506	2363.967	2409.428	2454.889	2500.350	2545.810	2591.271	2636.732	2682.193
600	2727.654	2773.115	2818.576	2864.037	2909.498	2954.959	3000.419	3045.880	3091.341	3136.802
700	3182.263	3227.723	3273.185	3318.646	3364.107	3409.568	3455.028	3500.489	3545.950	3591.411
800	3636.872	3682.333	3727.793	3773.255	3818.716	3864.177	3909.637	3955.098	4000.559	4046.020
900	4091.481	4136.942	4182.403	4227.864	4273.325	4318.786	4364.246	4409.707	4455.168	4500.629
1000	4546.090									

Example 25 Litres = 5.499 gal. (5½ gal)
200 Litres = 43.994 gal. (44 gal)

Source: National Waterwell & Drilling Association of Australia

Table 20 Conversion Tables – Litres to Imperial Gallons

Basis: 1 litre = 0.219969 **Litres to Imperial Gallons**

	0	1	2	3	4	5	6	7	8	9
	GALLONS									
0		0.220	0.440	0.660	0.880	1.100	1.320	1.540	1.760	1.980
10	2.200	2.420	2.640	2.860	3.080	3.300	3.520	3.739	3.959	4.179
20	4.399	4.619	4.839	5.059	5.279	5.499	5.719	5.939	6.159	6.379
30	6.599	6.819	7.039	7.259	7.479	7.699	7.191	8.139	8.359	8.579
40	8.799	9.019	9.239	9.459	9.679	9.899	10.119	10.339	10.559	10.778
50	10.998	11.218	11.438	11.658	11.878	12.098	12.318	12.538	12.758	12.978
60	13.198	13.418	13.638	13.858	14.078	14.298	14.518	14.738	14.958	15.178
70	15.398	15.618	15.838	16.058	16.278	16.498	16.718	16.938	17.158	17.378
80	17.598	17.817	18.037	18.257	18.477	18.697	18.917	19.137	19.357	19.577
90	19.797	20.017	20.237	20.457	20.677	20.897	21.117	21.337	21.557	21.777
		10	20	30	40	50	60	70	80	90
100	21.997	24.197	26.396	28.596	30.796	32.995	35.195	37.395	39.594	41.794
200	43.994	46.193	48.393	50.593	52.793	54.992	57.192	59.392	61.591	63.791
300	65.991	68.190	70.390	72.590	74.789	76.989	79.189	81.388	83.588	85.788
400	87.989	90.187	92.387	94.587	96.786	98.986	101.186	103.385	105.585	107.785
500	109.985	112.184	114.384	116.584	118.783	120.983	123.183	125.382	127.582	129.782
600	131.981	134.181	136.381	138.580	140.780	142.980	145.180	147.379	149.579	151.779
700	153.978	156.178	158.378	160.577	162.777	164.977	167.176	169.376	171.576	173.776
800	175.975	178.175	180.375	182.574	184.774	186.974	189.173	191.373	193.573	195.772
900	197.972	200.172	202.371	204.571	206.771	208.971	211.170	213.370	215.570	217.769
1000	219.969									

Source: National Waterwell & Drilling Association of Australia

Table 21 Conversion Tables – Acre-Feet to 1,000 Cubit Meters

acre-feet	0	10	20	30	40	50	60	70	80	90
	1 000 cubic metres (megalitres)									
0	0.00	12.33	24.67	37.00	49.34	61.67	74.01	86.34	98.68	111.01
100	123.35	135.68	148.02	160.35	172.69	185.02	197.36	209.69	222.03	234.36
200	246.70	259.03	271.37	283.70	296.04	308.[illegible]	320.71	333.04	345.37	357.71
300	370.04	382.38	394.71	407.05	419.38	431.72	444.05	456.39	468.72	481.06
400	493.39	505.73	518.06	530.40	542.73	555.07	567.40	579.74	592.07	604.41
500	616.74	629.08	641.41	653.75	666.08	678.42	690.75	703.08	715.42	727.75
600	740.09	752.42	764.76	777.09	789.43	801.76	814.10	826.43	838.77	851.10
700	863.44	875.77	888.11	900.44	912.78	925.11	937.45	949.78	962.12	974.45
800	986.79	999.12	1 011.46	1 023.79	1 036.12	1 048.46	1 060.79	1 073.13	1 085.46	1 097.80
900	1 110.13	1 122.47	1 134.80	1 147.14	1 159.47	1 171.81	1 184.14	1 196.48	1 208.81	1 221.15
1 000	1 233.48	1 245.82	1 258.15	1 270.49	1 282.82	1 295.16	1 307.49	1 319.83	1 332.16	1 344.50

BASIS: 1 acre = 4 840 sq yd
1 sq yd = 0.836 127 36 sq m
1 ft = 0.304 8 m
1 litre = 0.001 cubic metres
1 ac ft = 1.233 481 8[illegible]

ACRE-FEET TO 1 000 CUBIC METRES (OR MEGALITRES)

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Source: National Waterwell & Drilling Association of Australia

Table 22 Conversion Tables – Cubic Yards to Cubic Meters

cubic yards	0	1	2	3	4	5	6	7	8	9
	cubic metres									
0	0.000 0	0.764 6	1.529 1	2.293 7	3.058 2	3.822 8	4.587 3	5.351 9	6.116 4	6.881 0
10	7.645 5	8.410 1	9.174 7	9.939 2	10.703 8	11.468 3	12.232 9	12.997 4	13.762 0	14.526 5
20	15.291 1	16.055 7	16.820 2	17.584 8	18.349 3	19.113 9	19.878 4	20.643 0	21.407 5	22.172 1
30	22.936 6	23.701 2	24.465 8	25.230 3	25.994 9	26.759 4	27.524 0	28.288 5	29.053 1	29.817 6
40	30.582 2	31.346 7	32.111 3	32.875 9	33.640 4	34.405 0	35.169 5	35.934 1	36.698 6	37.463 2
50	38.227 7	38.992 3	39.756 9	40.521 4	41.286 0	42.050 5	42.815 1	43.579 6	44.344 2	45.108 7
60	45.873 3	46.637 8	47.402 4	48.167 0	48.931 5	49.696 1	50.460 6	51.225 2	51.989 7	52.754 3
70	53.518 8	54.283 4	55.047 9	55.812 5	56.577 1	57.341 6	58.106 2	58.870 7	59.635 3	60.399 8
80	61.164 4	61.928 9	62.693 5	63.458 1	64.222 6	64.987 2	65.751 7	66.516 3	67.280 8	68.045 4
90	68.809 9	69.574 5	70.339 0	71.103 6	71.868 2	72.632 7	73.397 3	74.161 8	74.926 4	75.690 9
100	76.455 5	77.220 0	77.984 6	78.749 2	79.513 7	80.278 3	81.042 8	81.807 4	82.571 9	83.336 5

AUXILIARY TABLE

cubic yards	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	cubic metres									
0	0.000 0	0.076 5	0.152 9	0.229 4	0.305 8	0.382 3	0.458 7	0.535 2	0.611 6	0.688 1

BASIS: 1 yd = 0.914 4 m

Source: National Waterwell & Drilling Association of Australia

Table 23 Conversion Tables – Imperial Gallons Per Minute to Litres Per Second

gallons/minute	0	1	2	3	4	5	6	7	8	9
	litres per second									
0	0.000 0	0.075 8	0.151 5	0.227 3	0.303 1	0.378 8	0.454 6	0.530 4	0.606 1	0.681 9
10	0.757 7	0.833 4	0.909 2	0.985 0	1.060 8	1.136 5	1.212 3	1.288 1	1.363 8	1.439 6
20	1.515 4	1.591 1	1.666 9	1.742 7	1.818 4	1.894 2	1.970 0	2.045 7	2.121 5	2.197 3
30	2.273 0	2.348 8	2.424 6	2.500 3	2.576 1	2.651 9	2.727 7	2.803 4	2.879 2	2.955 0
40	3.030 7	3.106 5	3.182 3	3.258 0	3.333 8	3.409 6	3.485 3	3.561 1	3.636 9	3.712 6
50	3.788 4	3.864 2	3.939 9	4.015 7	4.091 5	4.167 2	4.243 0	4.318 8	4.394 6	4.470 3
60	4.546 1	4.621 9	4.697 6	4.773 4	4.849 2	4.924 9	5.000 7	5.076 5	5.152 2	5.228 0
70	5.303 8	5.379 5	5.455 3	5.531 1	5.606 8	5.682 6	5.758 4	5.834 1	5.909 9	5.985 7
80	6.061 5	6.137 2	6.213 0	6.288 8	6.364 5	6.440 3	6.516 1	6.591 8	6.667 6	6.743 4
90	6.819 1	6.894 9	6.970 7	7.046 4	7.122 2	7.198 0	7.273 7	7.349 5	7.425 3	7.501 0
100	7.576 8	7.652 6	7.728 4	7.804 1	7.879 9	7.955 7	8.031 4	8.107 2	8.183 0	8.258 7

BASIS: 1 gallon = 4.546 09 litres

Source: National Waterwell & Drilling Association of Australia

Table 24 Conversion Tables – Pounds Per Square Inch to Kilo Pascals

psi	0	1	2	3	4	5	6	7	8	9
	kilopascals									
0	0.00	6.89	13.79	20.68	27.58	34.47	41.37	48.26	55.16	62.05
10	68.95	75.84	82.74	89.63	96.53	103.42	110.32	117.21	124.11	131.00
20	137.90	144.79	151.68	158.58	165.47	172.37	179.26	186.16	193.05	199.95
30	206.84	213.74	220.63	227.53	234.42	241.32	248.21	255.11	262.00	268.90
40	275.79	282.69	289.58	296.47	303.37	310.26	317.16	324.05	330.95	337.84
50	344.74	351.63	358.53	365.42	372.32	379.21	386.11	393.00	399.90	406.79
60	413.69	420.58	427.47	434.37	441.26	448.16	455.05	461.95	468.84	475.74
70	482.63	489.53	496.42	503.32	510.21	517.11	524.00	530.90	537.79	544.69
80	551.58	558.48	565.37	572.26	579.16	586.05	592.95	599.84	606.74	613.63
90	620.53	627.42	634.32	641.21	648.11	655.00	661.90	668.79	675.69	682.58
100	689.48	696.37	703.27	710.16	717.05	723.95	730.84	737.74	744.63	751.53
110	758.42	765.32	772.21	779.11	786.00	792.90	799.79	806.69	813.58	820.48
120	827.37	834.27	841.16	848.06	854.95	861.84	868.74	875.63	882.53	889.42
130	896.32	903.21	910.11	917.00	923.90	930.79	937.69	944.58	951.48	958.37
140	965.27	972.16	979.06	985.95	992.85	999.74	1 006.63	1 013.53	1 020.42	1 027.32
150	1 034.21	1 041.11	1 048.00	1 054.90	1 061.79	1 068.69	1 075.58	1 082.48	1 089.37	1 096.27
160	1 103.16	1 110.06	1 116.95	1 123.85	1 130.74	1 137.63	1 144.53	1 151.42	1 158.32	1 165.21
170	1 172.11	1 179.00	1 185.90	1 192.79	1 199.69	1 206.58	1 213.48	1 220.37	1 227.27	1 234.16
180	1 241.06	1 247.95	1 254.85	1 261.74	1 268.64	1 275.53	1 282.42	1 289.32	1 296.21	1 303.11
190	1 310.00	1 316.90	1 323.79	1 330.69	1 337.58	1 344.48	1 351.37	1 358.27	1 365.16	1 372.06
200	1 378.95	1 385.85	1 392.74	1 399.64	1 406.53	1 413.43	1 420.32	1 427.21	1 434.11	1 441.00

BASIS: 1 lbf = 0.453 592 37 kgf
1 kgf = 9.806 65 N
1 inch = 0.025 4 m
1 Pa = 1 N/m^2

Source: National Waterwell & Drilling Association of Australia

Table 25 Conversion Tables – Horsepower to Kilowatts

horsepower	0	10	20	30	40	50	60	70	80	90
	kilowatts									
0	0.00	7.46	14.91	22.37	29.83	37.28	44.74	52.20	59.66	67.11
100	74.57	82.03	89.48	96.94	104.40	111.85	119.31	126.77	134.23	141.68
200	149.14	156.60	164.05	171.51	178.97	186.42	193.88	201.34	208.80	216.25
300	223.71	231.17	238.62	246.08	253.54	260.99	268.45	275.91	283.37	290.82
400	298.28	305.74	313.19	320.65	328.11	335.56	343.02	350.48	357.94	365.39
500	372.85	380.31	387.76	395.22	402.68	410.13	417.59	425.05	432.51	439.96
600	447.42	454.88	462.33	469.79	477.25	484.70	492.16	499.62	507.08	514.53
700	521.99	529.45	536.90	544.36	551.82	559.27	566.73	574.19	581.65	589.10
800	596.56	604.02	611.47	618.93	626.39	633.84	641.30	648.76	656.22	663.67
900	671.13	678.59	686.04	693.50	700.96	708.41	715.87	723.33	730.79	738.24
1 000	745.70	753.16	760.61	768.07	775.53	782.98	790.44	797.90	805.36	812.81

BASIS: 1 hp = 550 ft-lbf/s
1 ft = 30.48 cm
1 lbf = 0.453 592 37 kgf
1 kgf = 980 665 dyn
1 W = 10 000 000 dyn cm/s

HORSEPOWER TO KILOWATTS

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Source: National Waterwell & Drilling Association of Australia

2.7.2 ANNULAR VOLUME AND VELOCITY

The calculation of annular volume and annular velocity is an indispensable knowledge to all drillers for the proper drilling plan and control. The follows are an example of the calculation of annular volume and annular velocity.

1) Bore Volume

<u>12" Hole x 100 m</u>

Unit Volume

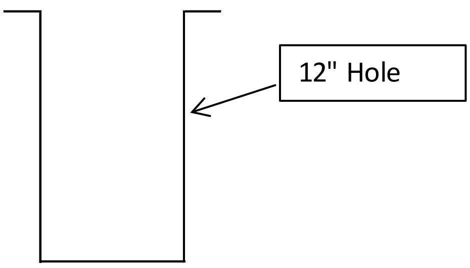
3.14 x (12 x 25.4)^2 /4,000

72.9 L/m

Total Volume

=72.93 L/m x 100 m

7293 L



2) Annular Volume

<u>12" Hole x 100 m</u>

<u>4-1/2" DP x 100 m</u>

Unit Volume

12" Hole

3.14 x (12 x 25.4)^2 /4,000

72.9 L/m

4-1/2" DP

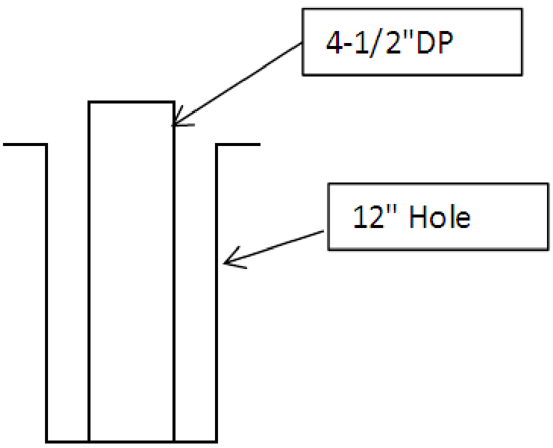
3.14 x (4.5 x 25.4)^2 /4,000

10.3 L/m

Annular Volume

72.9 L/m - 10.3 L/m

62.6 L/m



3) Annular Velocity

Discharge Rate

600 L/min

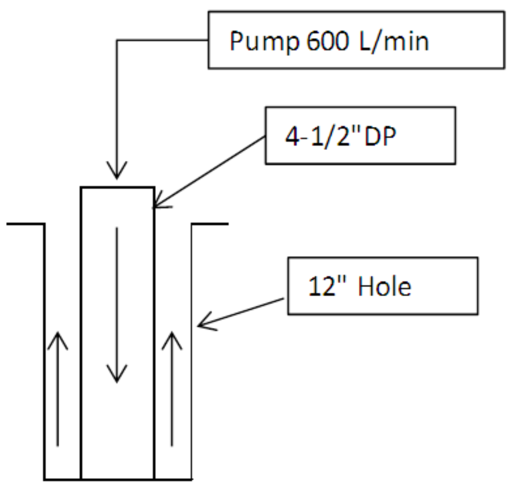
Annular Volume

62.6 L/m

Annular Velocity

(600 L/m) / (62.6 L/m)

= 9.6 m/min



Chapter 2

Drilling fundamentals

Section 1 Measurement calculations

- The metric system and its use
- Length - the metre
- Area - the square metre
- Volume - The cubic metre

Mathematics may not be a driller's first love, however, an understanding and mastery of the basic principles involved is necessary for drillers to be able to carry out their daily tasks.

This section is designed to give an understanding of the principles with the minimum of confusion or doubt. Mathematical formulae have been simplified wherever possible and examples relate to practical field conditions.

The metric system and its use

The metric system, known officially as the International System of Units (SI, System International), is the standard daily system of measure throughout most of the world, with the notable exception of the United States of America (where it is the official but not the common measure). Due to the history of U.S.and British Commonwealth influence in drilling technology, traditional "English" or SAE (USA) and "Imperial" (Commonwealth) units are frequently the basis for drilling, bore hole, and casing dimensions. However, SI is now the fundamental measurement system, and the system used frequently in this text. Below are the basic units of measurement that are part of our everyday life.

Length:	metre (m) or foot (ft) is the basic units of length or distance.
Mass:	kilogram (kg) or pound (lb) is the basic units of mass.
Time:	second(sec) is the basic unit of time.
Temperature:	degree celsius (C) or fahrenheit (F) is the basic unit of temperature.

SI units have multiples or sub-multiples of these basic units, especially when it comes to measuring things such as length (km, cm, mm), time (hr, min), area (m^2), volume (m^3), mass (kg, tonne) and speed. (kph). Throughout metric measure, the prefix of the unit tells the multiple:

- micro: 1/1,000,000
- milli: 1/1000
- centi: 1/100
- deci: 1/10
- deca: 10
- hecto: 100
- kilo: 1000
- mega: 1,000,000

Length: the metre - symbol: m

The metre (m) is the basic unit of length or distance. A long step is about a metre, and a yard is a little less than a metre. You can measure your height or the depth of a borehole, or estimate rig height in metres.

One kilometre (km) is equal to 1000 metres. Roughly, 1000 long steps would measure 1 km. Since the word "kilo" means "one thousand times", then a kilometre is equal to 1000 times 1 metre. Road or map distances are measured in kilometres (1 kilometre = 0.62 miles).

The millimetre - symbol: mm

"Milli" means 1/1000 or .001 times. Therefore 1000 millimetres (mm) = 1 metre (m). You can measure things like the size of drill rods, bits, welding rods, nuts and bolts etc. in millimetres (mm). A millimetre is approximately the width of a hacksaw blade.

The centimetre - symbol: cm

A rough estimate of 1 cm would be the width of your fingernail. Ten hacksaw blades stacked together would approximately equal 1 cm.

1 cm = 10 mm
100 cm = 1 metre

Drillers rarely use the centimetre (cm) as a unit of length. But for measuring areas and calculating pressures, the square centimetre is important. Cubic centimetres are used for volume measurement.

Common measurements

- Diamond drill rods - 3m or 10 ft long
- Rotary drill pipe - 6m or 20 ft long
- Holes sizes: **Water wells** - 200 mm or 8 in
  - 150 mm or 6 in

Drilling fundamentals

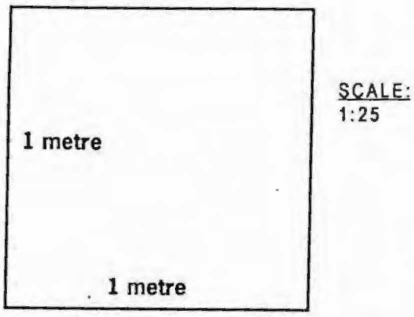
- Core holes: B - 60.0 mm ($2\frac{23}{64}$ in)
  N - 75.5 mm ($2\frac{63}{64}$ in)
  H - 96.0 mm ($3\frac{25}{32}$ in)

Area: the square metre – symbol m^2

The every day units of area are the square metre (m^2), square centimetre (cm^2), hectare (ha) or square foot (ft^2 or sq ft). For our purposes, we need only consider the m^2 (metre squared) and cm^2 (centimetre squared).

As a square metre suggests, it is a square with each side 1 metre in length:

Area of square = Side x Side
= Side ^{2}
= 1m x 1m
= 1m^2



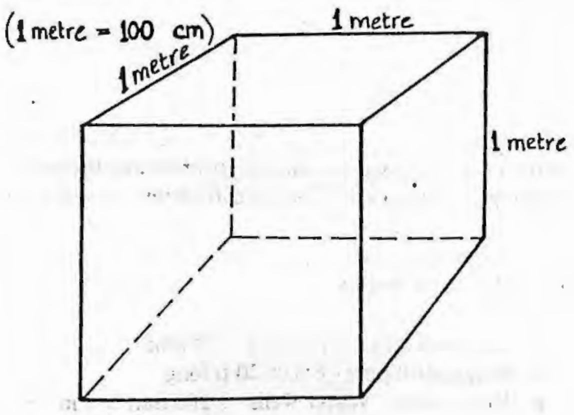
The area of a mud pit is conveniently expressed in m^2 or ft^2. It could be 5 m^2 with dimensions of 1 by 5 m.

The **square centimetre** (cm^2) or square inch (in^2) is a much smaller unit of measure. It is useful for expressing the area of objects the size of a drill bit face.

Volume: the cubic metre – symbol: m^3

The amount of space occupied by a solid object is its volume. Volume is one instance where the SI and SAE systems are sharply divided.

The units of volume used in the SI system are the cubic centimetre (cm^3) and the cubic metre (m^3). We will deal with the cubic metre first. If we welded up a water tank like the following diagram, we would have 1 m^3.



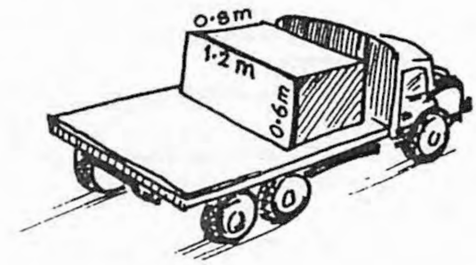
We get the volume of the tank this way:

Volume = Length x Width x Depth
= 1 m x 1 m x 1 m
= 1 m^3

Another tank, such as the one on the truck, may have these dimensions:

Length = 1.1 metres
Width = 0.8 metres
Depth = 0.4 metres

Volume = L x W x D
= 1.2 x 0.8 x 0.6
= 0.576 m^3



The basic SI measurement of volume is the cubic metre (m^3), but also frequently used is the litre.

1 m^3 = 1000 Litres (L)

In the case of the water truck tank, the volume in litres is:

Liquid Volume = 0.576 x 1000
= 576 litres

The basic SAE measurement of volume is the cubic foot (ft^3). However, when discussing the volume of a liquid, the fluid ounce (fl oz), pint (pt), quart (qt) and gallon (gal) are more common.

16 US fl oz	=	1 US pt
2 US pt	=	1 US qt
4 US qt	=	1 US gal (= 3.785 L)

Earlier in Section 1, we learned the relationship between the metre and the millimetre. That is, the millimetre is one thousandth part of a metre or 1/1000 times a metre (0.001 m).

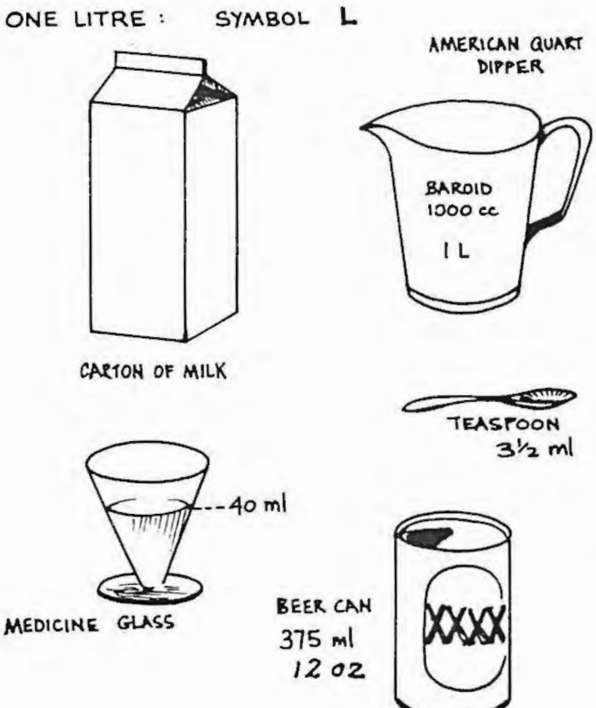
The same applies to the litre and the millilitre. The millilitre (mL) is one thousandth part of a litre. In other words, there are 1000 millilitres in 1 litre or 1 mL = 0.001 L. Millilitres are commonly used in sampling water quality. A standard bacterial sample bottle is 125 mL.

The millilitre is also conveniently equivalent to the cubic centimetre (symbol: cm^3). Example calculation: How many cm^3 would be needed to make up a 1 m^3 tank?

Volume of tank: = Length x Width x Depth
= 100 cm x 100 cm x 100 cm
= 1 000 000 cm^3

1 m^3 = 1 000 000 cm^3 since the tank has the same dimensions. (1 metre = 100 cm).
This m^3 tank has a capacity of 1000 litres, so a 1 000 000 cm^3 tank also holds 1000 litres or 1 000 000 mL.

Some volume comparisons



MEASUREMENTS DRILLERS USE

MEASUREMENTS WE NEED TO KNOW	WHY WE NEED THESE MEASUREMENTS
kilometre (km) mile	Stating distances, locations of sites
metre (m) foot (ft)	Measuring lengths Measuring depths
centimetre (cm)	Measuring lengths
millimetre (mm) inch (in)	Measuring thickness and size of pipe and casing
square metre (m^2) square foot (ft^2)	Finding areas of squares, rectangles
square centimetre (cm^2) square inch (in^2)	Area measurements
cubic metre (m^3) cubic foot (ft^3)	Calculating volumes of tanks, pits
cubic centimetre (cm^3) cubic inch (in^3)	Calculating volumes

Section 2 Volume calculations

- Making a mud pit and calculating its volume
- Mud pit with sloping sides
- Calculating volume of a circular tank
- Volume of tank or drum on its side
- Volume of partly full tank on its side
- Calculating volume of a drill hole
- Calculating volume of annulus
- Example calculations: cementing a hole and annulus

Not all volumes to be calculated are cubes. In drilling, we work with a variety of shapes and sizes of objects. The volume of other types of shapes can also be calculated geometrically, by knowing dimensions and some basic geometric formulas. Among the most important shapes in drilling and water supply are rectangular and trapezoidal volumes such as mud pits, and cylinders such as boreholes and tanks.

Units we need to use in calculating volumes of mud pits, velocities, and flow rates:

1 L = 1000 cm^3
1000 L = 1 m^3
1 ft^3 = 7.48 US gal

Keep handy a calculator and measuring tape 3 m (or 10 ft).

Making a mud pit and calculating its volume

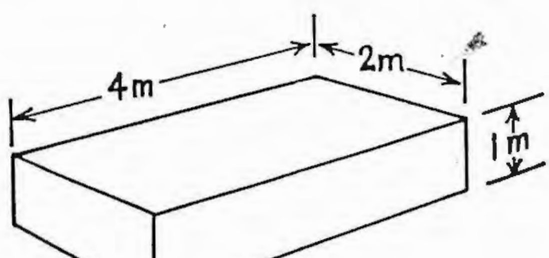
Measurements we need to make:

Length of the pit in metres or feet
Width of the pit in metres or feet
Depth of the pit in metres or feet

Volume of pit = Length x Width x Depth = m^3 or ft^3

Volume in litres = m^3 x 1000

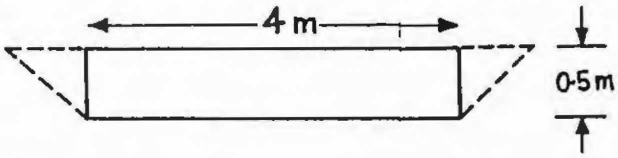
A mud pit with a volume of 8 m^3 could have these dimensions:



Length	= 4 m
Width	= 2 m
Depth	= 1 m
Volume of pit	= (4 x 2 x 1) m^3
	= 8 m^3
Volume in litres	= 8 x 1000 L
	= 8000 L

Mud pit with sloping sides

Sometimes the sides of the pit fall in when vertical sides are dug. Where this happens the best thing to do is to put a slope on the sides. Mud pit dimensions. L = 4 m, W = 2 m, Depth = 1 m.

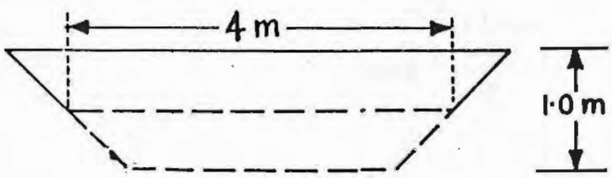


Step 1

Measure out your floor plan for the pit, that is, 4 metres long by 2 metres wide. Dig the hole to 0.5 metre depth and then increase the size of the top half, by cutting it back to a slope which is stable.

Step 2

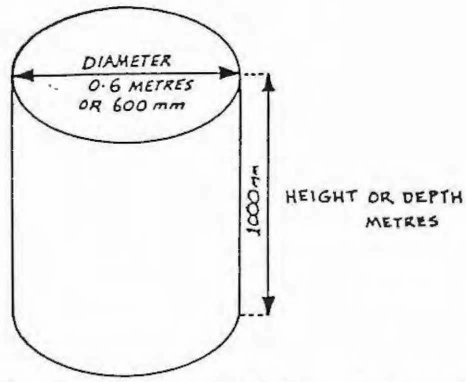
Complete the pit following down the same slope. A pit dug this way will have the same volume as the 4 x 2 x 1 rectangular pit.



Calculating volume of a circular tank

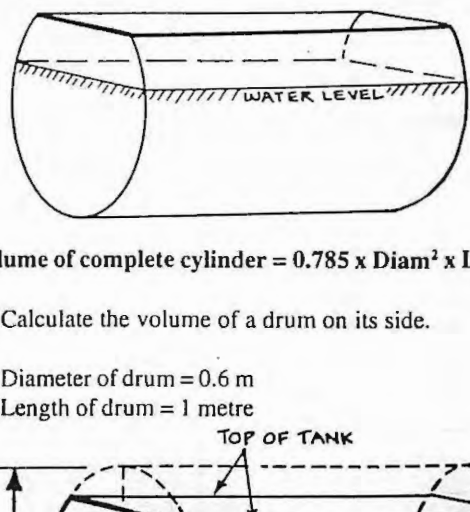
The volume of a cylindrical tank is determined as follows using SI units, (using the figure as an example):

Volume (m^3)	**= 0.785 x Diam^2 x Depth**
	= 0.785 x0.6 x 0.6 x 1.0
	= 0.283 m^3
Volume (L)	= 0.283 x 1000
	= 283 L



When the tank is only part full, calculate the volume of the liquid using the figure for depth of liquid instead of depth of tank.

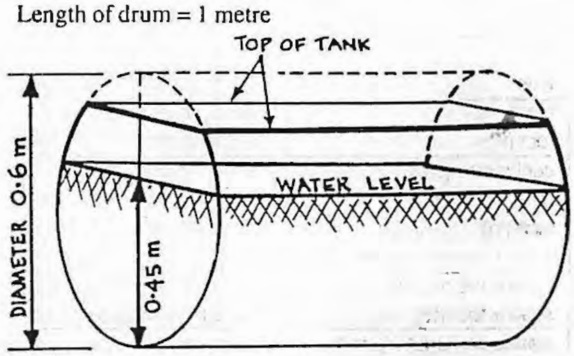
Volume of tank or drum on its side



Volume of complete cylinder = 0.785 x Diam^2 x Length

Calculate the volume of a drum on its side.

Diameter of drum = 0.6 m
Length of drum = 1 metre



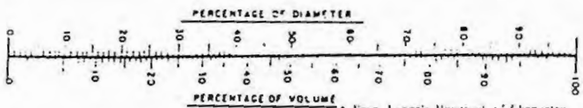
Step 1

Assume the drum is standing on end.

Volume = 0.785 x Diam^2 x Depth or Length
= (0.785 x 0.6 x 0.6 x 1)m^3
= 0.283 m^3
= 0.283 x 1000
Volume in Litres = 283 litres

Volume of partly full tank on its side

Finding the volume of the tank when full is straightforward as in the previous example. This is the same calculation as for a tank standing on end. But if the tank is only part full, the calculation of the volume of the liquid in the tank is more difficult. We use a chart to assist us in this calculation.



From Lange's Handbook of Chemistry.

In the tank shown in the example just preceding, we notice it is:

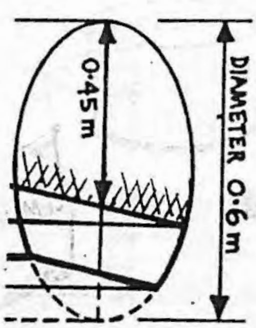
1. on its side
2. the water level is more than half way up the diameter of the drum.

We do know that the diameter of the drum is 0.6 metres. What we have to find out is:

1. How deep the water is in the drum.
2. How to calculate the volume of water in the drum.

Step 1

What we can do is to get a straight stick and stand it perpendicular to the water's surface. Take the stick out and measure with a tape, the length of stick that is wet. Suppose that the wet part of the stick measures 0.45 metres.



Step 2

Find the percentage (%) this water level is of the diameter of the drum.

$$\% = \frac{0.45}{0.6} \times \frac{100}{1}$$
$$= 75\%$$

We know that the depth of water in the tank is 75% of the diameter of the tank. What can be worked out from this?

Step 3

Simply read the nomograph (chart provided opposite).

For example:

Where the percentage of diameter is 75.
The percentage of volume is approximately 81.
Therefore the volume in tank is 81% of tank when full (283 litres).
81% of 283 litres = 229.23 litres.

Practice in reading the nomograph:

When % of diameter is 50, the % of volume is 50.
When % of diameter is 20, the % of volume is 14.
When % of diameter is 60, the % of volume is 63.
When % of diameter is 70, the % of volume is 75.

Calculating volume of a drill hole

Formula 1 (All metric)

Volume (m^3) = 0.785 x Diam^2 x Depth
Where diameter and depth is expressed in metres.

Example:

Hole diameter	= 150 mm/1000 = 0.15 m
Hole depth	= 20 m
Volume (m^3)	= 0.785 x 0.15 x 0.15 x 20
	= 0.353 m^3
Volume (L)	= 0.353 x 1000
	= 353 L

Formula 2 (Combination metric & English)

$$\textbf{Volume (Litres)} = \frac{\textbf{Diam}^2\textbf{(inches) x depth (m)}}{\textbf{2}}$$

Note that in this formula, hole diameter is expressed in inches, hole depth in metres, and the volume is given in Litres.

Example:

Hole diameter = 8 inches
Hole depth = 60 m
Volume (L) = $\frac{8 \times 8 \times 60}{2}$
= 1,920 Litres

Calculating volume of annulus

What do we mean by **annulus**? Here we have 2 circles and 2 diameters:

Diameter of large circle (D) is the hole diameter. Diameter of small circle (d) is the pipe/rod diameter. The space or region between these two circles is the **annulus** (shaded part).

We have to find the volume of a drill hole with pipe/rods in it. In other words, we have to find the volume of the annulus through which the cuttings and air or mud move. To find the Volume of the Annulus, we find the volume of the hole and take from it, the volume of the drill rods or pipes.

Formula 1 (All metric)

Volume of annulus = Volume of hole - Volume of rods

Volume (m^3) = [0.785 x (Hole Diam)^2 (m) x Depth (m)]- [0.785 x (Pipe Diam)^2 (m) x Depth (m)]

Example:

Hole diameter = 150 mm (0.15 m)
Pipe diameter = 76 mm (0.076 m)
Hole depth = 50 m

Step 1: Calculate volume of hole
Vol (m^3) = 0.785 x 0.15 x 0.15 x 50
= 0.88 m^3
= 880 Litres

Step 2: Calculate volume of pipes
Vol (m^3) = 0.785 x 0.076 x 0.076 x 50
= 0.23 m^3
= 230 Litres

Step 3: Calculate volume of annulus
Vol (annulus) = Vol (hole) - Vol (pipe)
= 880 - 230
= 650 Litres

Formula 2: (Combination metric & English)

Volume (Litres) = $\frac{[D^2 - d^2 \text{(inches)}] \times \text{depth (m)}}{2}$

Example:

Hole diameter = 6"
Pipe diameter = 4"
Hole depth = 20m

Volume (L) = $\frac{(6^2 - 4^2) \times 20}{2}$
= 200 Litres

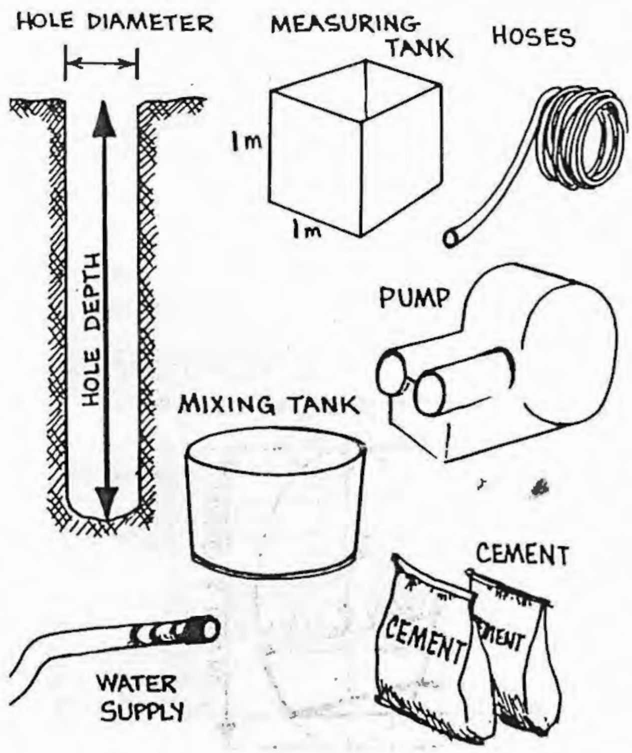
Volume (m^3) = 200 ÷ 1000
= 0.2 m^3

Example calculations: cementing a hole and annulus

Task 1: Fill a hole with cement slurry

Diameter = 185 mm
Depth = 120 metres

We need to know the volume of cement needed, the correct equipment and materials.



Formula for the volume of hole:

$V = 0.785 \times D^2 \times$ Depth of hole

Step 1: Look at the formula for finding Volume of hole.

Step 2: Convert diameter of hole into metres
Diameter of hole = 185 mm = 0.185 m

Step 3: Apply formula:
$V = (0.785 \times 0.185 \times 0.185 \times 120)\ m^3$

Step 4: Use calculator to get answer
$= 3.224\ m^3$

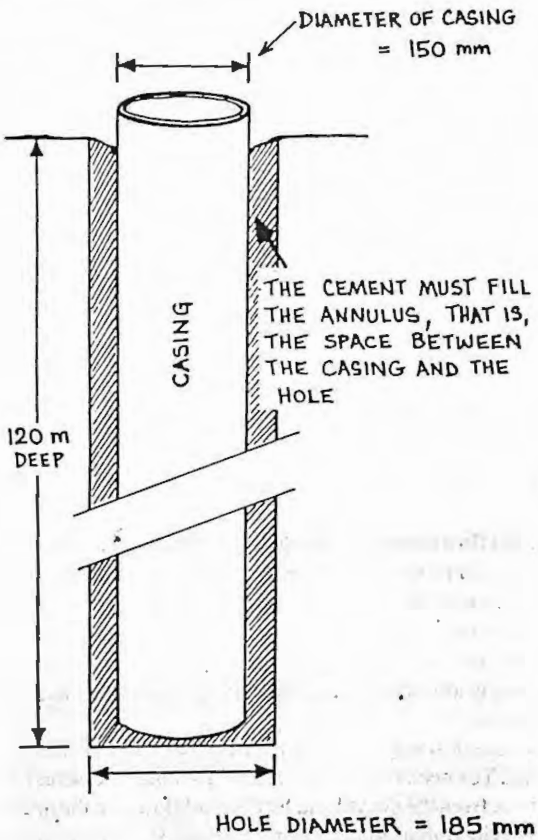
Step 5: Express m^3 in litres

$3.224\ m^3 \times 1000 = 3224$ litres

Using a kilolitre ($1 m^3$) tank, it would take roughly 3 tanks of cement slurry to do the job. (1 kL = 1000 L).

Task 2: Cementing the annulus

Let us take the last hole in **task 1**. Instead of plugging it, we are going to put in 150 mm casing and cement the casing. We need to calculate the volume of cement slurry needed to fill the annulus.



Step 1

We need to find the Volume of the hole. The formula for this is:

$V = 0.785 \times Diam^2 \times$ Depth of hole

Step 2: We need to find the volume of the casing. Formula for this is:

$V = 0.785 \times d^2 \times$ Depth
(d = smaller diameter)

Step 3: We apply the formula for volume of annulus

Volume of annulus = Volume of hole - Volume of casing

Now do Step 1

Volume of hole $= (0.785 \times 0.185 \times 0.185 \times 120)\ m^3$
$= 3.224\ m^3$
$= 3.224 \times 1000$
= 3224 litres (L)

Do Step 2

Volume of casing $= (0.785 \times 0.15 \times 0.15 \times 120)\ m^3$
$= 2.120\ m^3$
= 2120 litres (L)

Do Step 3

Volume of annulus = Volume of hole - Volume of casing
= 3224 litres - 2120 litres
= 1104 litres

Cement required for casing the hole
= 1104 litres or $1.104\ m^3$

(This is roughly 100 litres more than kilolitre tankful).

Note: The same calculation method can be used with English units to calculate gallons.

Section 3 Flow rates (velocity)

- Volume-velocity application: up-hole velocity
- Calculating flow rates
- Application: mud circulating flow
- Ways of measuring flow

Flow measurement is an essential part of drilling calculations as is volume measurement. Important reasons for making such calculations are:

1. So that we can be sure that sufficient circulation flow exists to cool and lubricate the bit.

2. To check that sufficient "uphole" velocity is available to lift cuttings from the hole.
3. To ensure that the flow velocity against the walls of the hole will not cause erosion of the hole.
4. To check for loss or gain of fluid to or from the formation, or to determine artesian flow.
5. To monitor pump output and performance.
6. To monitor cement/grout placement.

The flow rate tells us the amount in litres of fluid, liquid, gas or air that is coming out of the hole or pipe every second.

Volume-velocity application: Up-hole velocity

The velocity (speed) of air flowing up the annulus is a critical factor in lifting and clearing cuttings from a drill hole. This up-hole velocity is dependent upon the three following factors:

1. The fluid volume delivered from the air compressor, or pump
2. Hole diameter.
3. Drill rod or pipe diameter.

The size of the annulus will determine up-hole velocity (U.H.V.) when using a consistent volume of delivered fluid. This means that U.H.V. will be higher in a small annulus and lower in a large annulus for the same fluid volume.

Therefore, the diameter selection for drill rods or pipes in comparison with drill hole diameter is very important, as this decision will have a controlling influence on U.H.V. Up-hole velocity can be determined by using metric units or a combination of both metric and English.

Formula 1 (All metric)

$$\text{U.H.V. (m/min)} = \frac{1274 \times \text{L/min}}{D^2 - d^2\ \text{(mm)}}$$

Where U.H.V. is stated in metres per minute, and L/min is the pump or compressor output in Litres per minute.

D is the hole diameter expressed in millimetres

d is the pipe diameter expressed in millimetres.

Note that free air delivered from an air compressor is usually stated in cubic feet per minute (c.f.m.), or cubic metres per minute (m^3/min).

Therefore to find L/min, multiply c.f.m. by 28.3, or m^3/min by 1000.

Formula 2 (Combination Metric and English)

$$\text{UHV (m/min)} = \frac{2 \times \text{L/min}}{D^2 - d^2\ \text{(inches)}}$$

Where:

D is the hole diameter expressed in inches, and
d is the pipe diameter expressed in inches.

Example:

A drilling project requires a number of 6 inch diameter holes to a depth of 20 metres. Our available drill rig is equipped with 4 inch diameter drill pipe and a compressor which delivers 650 c.f.m. of air.

Using the formula:

$$\text{U.H.V (m/min)} = \frac{2 \times \text{L/min}}{D^2 - d^2\ \text{(ins)}}$$

$$= \frac{2 \times 650 \times 28.3}{36 - 16}$$

$$= \frac{36{,}790}{20}$$

$$= 1{,}840\ \text{m/min}$$

Compared with the recommended range of 1,500 to 2,100 m/min, our selected compressor produces the adequate volume of free air, to maintain an effective U.H.V. to remove cuttings from the drill hole without regrinding them.

Calculating flow rates

One simple way to measure flow rates involves two measurements:

1. Volume in litres of a suitable drum or container.
2. Time it takes to fill the drum or container with the liquid.

We then use these measurements to get the flow rate.

$$\text{Flow rate} = \frac{\text{Volume in litres of drum}}{\text{Time in seconds to fill it}}$$

Flow rate is expressed in Litres per second (L/sec.).

Example: A 16L container fills in 4 sec.

Flow rate = 16 litres/4 seconds
= 4 litres per second (4 L/sec.).

Application: Mud circulation flow

Mud flows down the hollow drill rods and up through the annulus. Mud flow rates are usually given in gallons per minute,(i.e. GPM) Litres per second (i.e. L/sec.) or in kilolitres per hour (i.e. kL/h). We sometimes need to calculate the rate of flow of mud up hole. For example, sometimes the velocity is too slow to keep the cuttings moving up and out of the hole.

The easiest way is to time the filling of a 20 litre drum or bucket. To check the delivery rate of your pump, disconnect the hose from the swivel and let the mud flow into the drum.

Provided that you are using a "positive displacement" pump, the flow rate will not have changed.

2-7M2 - 8

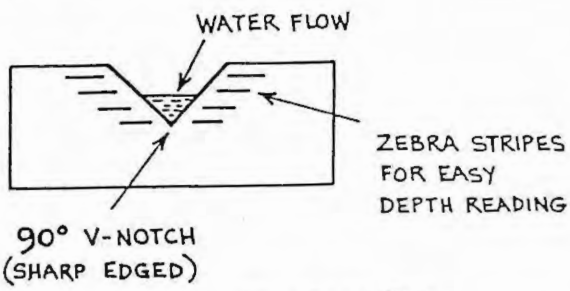
For example, you find that the 20 litre drum fills in 5 secs. Flow = 4 litres per second.

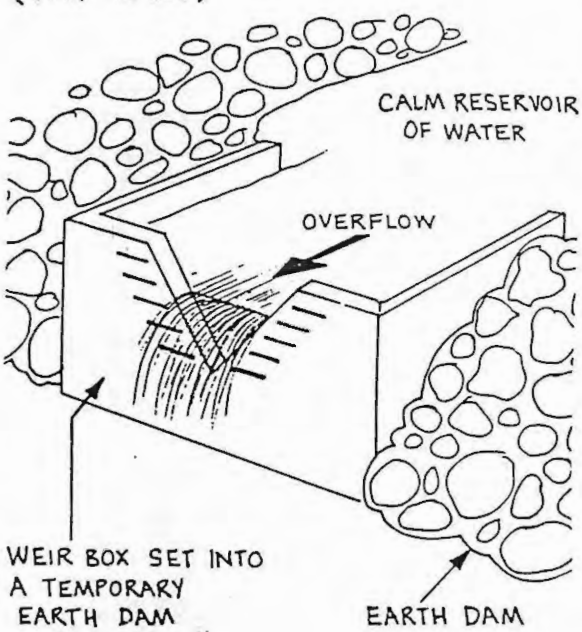
Ways of measuring flow

Sometimes we have to use other methods of measuring flow rates of pumped water. Why? It is useful where continual monitoring and flow rate adjustment is needed. Also, the drum and watch methods becomes unreliable and impractical at high flow rates.

The V-notched weir allows the driller to see what's happening without leaving the rig's controls.

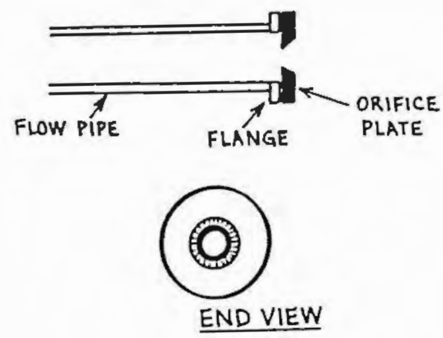
V - NOTCHED WEIR

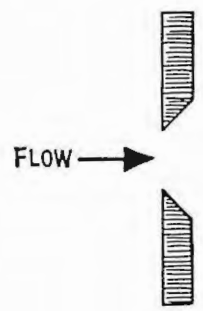




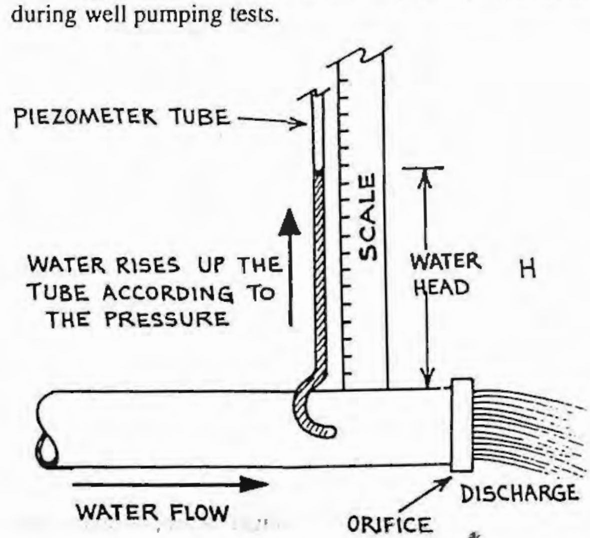
The depth of flow over the V-notch can give the flow rate in litres per second. We just look up a table of depths versus flow rates which are available from hydrological references. This device is very useful in measuring open channel flows such as mud flows through mud pit channels.

Another method is to use a sharp edged orifice instead of a notch. The sharp edge reduces drag and gives more accurate readings.





A piezometer or manometer tube can be added to the pipe and weir, providing a means of measuring pressure backed up behind the weir. This device is referred to as an **orifice weir** and is the most useful for closed pipe flows, such as during well pumping tests.



Discharge (flow rate) is read directly from a set of tables of head (mm or inches of height in the tube) versus Flow rates. The greater the flow, the greater the discharge and the greater the pressure in the pipe, and vice versa. A set of tables provides head "H" versus discharge in L/sec. or gallons per min. Discharge tables are reproduced in a number of hydrological references.

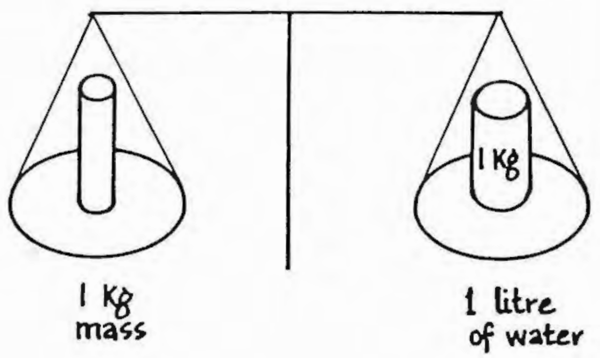
Section 4 Mass, density, pressure, force

- Mass
- Density, specific gravity(S.G.), and pressure
- Buoyancy
- Measuring force

Mass, density, pressure, and force are all interrelated measurements that define many properties of the physical world. Mass is the "heft" of an object that is the same anywhere in the universe no matter its weight. Weight depends on the **force** of gravity. The unit of **mass** in the **SI** is defined by a volume of a substance that has a certain **density**. Pressure also depends on **force** and **mass**. In drilling operations, we are concerned with all of these types of measurements.

Mass

The unit of mass is the pound (lb) or kilogram (kg), which in SI is also related to volume since 1 kg is the mass of 1000 cm^3 of water (at its maximum density – see following). The standard kilogram is a cylinder of platinum alloy kept by the International Bureau of Weights and Measures. When we weigh any object we are in fact balancing it against the standard mass unit.



We usually use the term "weight" when we really mean "mass". The weight of a substance depends on how near the earth it is. Substances have weight simply because they are affected by the force of gravity. When we say we feel the "weight" of something, it is actually the effect of gravity that we are feeling.

The mass of the body would be the same anywhere in the universe: that is, the amount of matter in the body, its mass, remains the same.

As with length and volume, the basic unit of 1 kg (kilogram) can be multiplied and divided:

1000 kg	= 1 tonne (2,200 lb)
1 m^3 of water	= 1 tonne mass
1 kL of water	= 1 tonne mass
1 L of water	= 1 kg mass

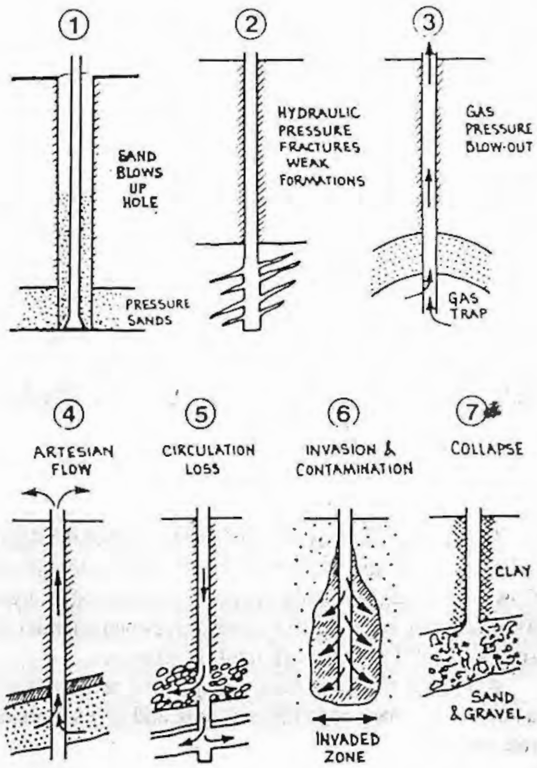
Tonnes are handy for very large mass measurements, such as gross vehicle weight or mass of a pile of rubble (SI and English are roughly equivalent).

Grams on the other hand are very small: 1 gram (g) = mass of 1 cm^3 of water. Grams are useful for expressing the mass needed in a phamaceutical mixture or of constituents in water, for example: a groundwater may contain 1 g/L of total dissolved solids.

Density, specific gravity (S.G.) and pressure

There are various drilling situations that require the driller to calculate mud density, specific gravity and pressure. The following are examples of situations where incorrect down hole pressures result in problems:

1. "Running" sands entering the hole - unstable formations.
2. Hydraulic fracturing and lost circulation – unstable formations.
3. Gas pressures, in coal seams or in petroleum traps.
4. Artesian water pressures blowing into the hole.
5. Circulation loss in gravels, fractures or cavities.
6. Drilling fluids invading/contaminating aquifers.
7. Collapse of unconsolidated formations.



In Section 3, we used units of liquid volume to calculate volume, velocity and flow rates. In this section, we will be using the Unit of mass and the Unit of Force to calculate **density, pressure and buoyancy.**

Density of water and specific gravity

The density of water (or any substance: iron, granite, polystyrene) is the mass of the substance (e.g., water) divided by the volume it occupies. Stated as a formula:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Density of water = 1 kg per litre (1000 cm^3)

The density of other substances differ from water; iron is far more dense; petrol(gasoline) is lighter. For example, if you weighed a litre of petrol (gasoline), it would weigh 0.7 kg. Its density is 0.7 kg/litre.

Specific gravity is defined by the **density** of water. **The S.G.** of water is by definition = 1. We can find out the specific gravity of a substance by taking the density of that substance and dividing it by the density of water.

$$\text{Specific gravity} = \frac{\text{Density of a substance}}{\text{Density of water}}$$

Using petrol again (at 0.7 kg/L), the specific gravity would be:

$$\text{S.G.} = \frac{0.7 \text{ kg/L}}{1 \text{ kg/L}}$$

$$= 0.7$$

When we compare the density of a substance with the density of water, we determine which of the substances will sink or float. The lower specific gravity of petrol explains why it floats on water.

In drilling, the removal of cuttings from a drill hole is made easier when the specific gravity of the drilling fluid is high. The dense fluid will tend to "float" the dense cuttings up the hole better than less-dense water.

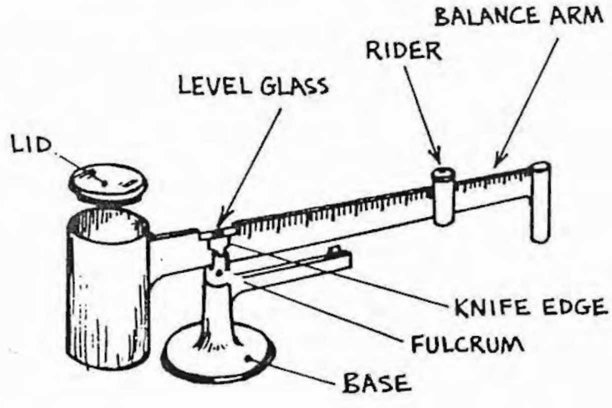
But when we try to separate the cuttings in the mud pit we find that the high specific gravity fluids slow the settling rate. The pits must be made larger to allow more time for the cuttings to separate.

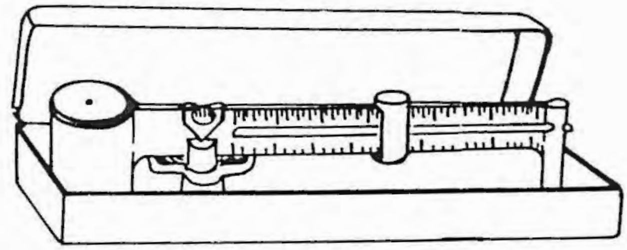
Calculating specific gravity

Specific gravity calculations are very important in mud work (see Chapter 6). The most practical instrument the driller can use to determine the specific gravity (S.G.) of his mud is the **mud balance.**

The mud balance is designed to measure the mass of a defined volume of mud. A Scale on the balance arm allows direct reading of Specific Gravity which the driller can use to:

(a) calculate required increase in mud weight
(b) determine pressure head





Example 1

How to calculate the required increase in mud weight:

You take a reading from the mud balance S.G. of 1.2 (Measured). You find you need to increase the weight of mud to S.G. 1.3 (Desired). What quantity of barytes (weighting agents, which are very dense) per litre of mud is needed?

Apply formula:

$$\textbf{Barytes in kg per litre} = \frac{\mathbf{4.2 \times [D(S.G.) - M(S.G.)]}}{\mathbf{4.2 - D(S.G.)}}$$

(Use your calculator)

Where;
D = Desired M = Measured

$$\text{Barytes in kg per litre} = \frac{4.2 \times (1.30-1.20)}{4.2 - 1.30}$$

$$= \frac{4.2 \times 0.1}{2.9}$$

$$= \frac{0.42}{2.9}$$

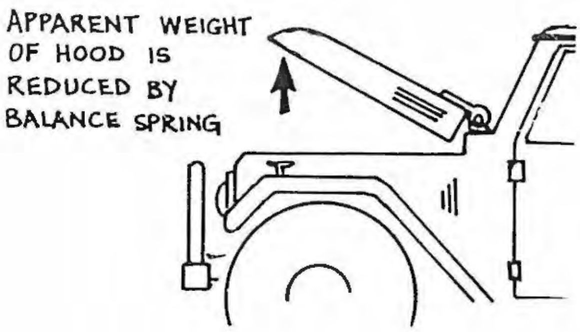
$$= 0.145 \text{ kg per litre}$$

This means that for every litre of fluid, you need 0.145 kg of barytes to increase the density the desired amount. If your mud pit or tank holds 500 litres the total amount of barytes needed

= (0.145 kg/L) x 500 L
= 72.5 kg

Buoyancy

As we discussed previously, the weight of an object is really the force exerted on it by gravity. We can lower the apparent weight of an object by balancing the force of gravity with another force. Thus we provide a "balance spring" to reduce the weight of a heavy engine hood.



When an object is immersed in a liquid, the liquid provides support for the object and thus reduces its apparent weight.

The Greek mathematician and inventor, Archimedes, who lived about 2,200 years ago, explained that an object placed in a liquid loses an amount of weight equal to the weight of the liquid it displaces or pushes aside. A floating object will displace its own weight of liquid. Such an effect is termed "buoyancy".

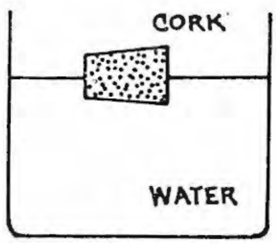
In drilling, we are primarily concerned about the buoyancies of cuttings, drill pipe and casing. The buoyancy of cuttings makes them easier to remove from the hole. The buoyancy of pipe reduces the load on the rig. The buoyancy of a light casing may make it hard to force down through dense grout.

Buoyancy of cuttings

We can measure the density or S.G. of a liquid by taking note of how far a floating object is submerged.

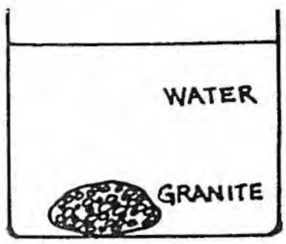
Let's look at examples 'A' and 'B'

In 'A' the density or S.G. of the cork is less than the S.G. of the water. The cork displaces only a small weight of water. The volume of the displaced water is less than the volume of the cork. So the cork floats.



Example A

In 'B' the density or S.G. of the piece of granite is greater than the S.G. of the water. The weight of the water displaced is less than the weight of the granite. Therefore the granite sinks.

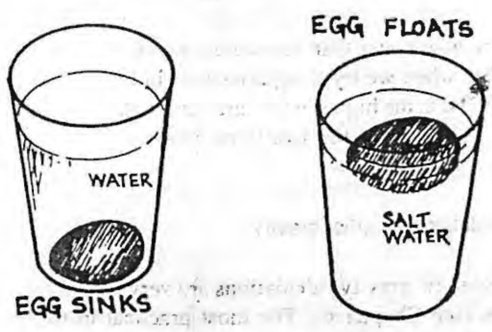


Example B

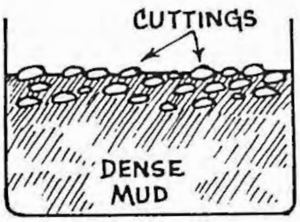
Try this:

Put a fresh egg in a glass full of water. What happens? Yes the egg sinks to the bottom. The density of the egg is greater than the density of the water. The S.G. of the egg is greater than 1, which is the S.G. of water.

Add 2 tablespoons of salt to the glassful of water. What happens? The egg floats because the density of the water is now greater than the density of the egg.



The same applies to drill cuttings. Cuttings become buoyant in more dense mud.



Really dense mud with S.G. of 2.8 would float most cuttings up and out of the hole.

Controlling buoyancy

The driller can control the buoyancy effect of his mud. As the force balancing gravity is fixed by the weight of the displaced volume of fluid, buoyancy can be increased by increasing the weight of that volume. That is by increasing the density (or specific gravity) of the fluid.

Once the Specific Gravity of the fluid is known, we can calculate the balance force (on the mud balance) it will exert.

For example, a diamond driller may desire to "float" a friable core up the barrel to improve core recovery. He knows that he can get 1.5 m runs of a type of core in water. The geologist has checked the core and says that it has a Specific Gravity of 2.1, but is so friable that it is breaking under its own weight.

Calculate the weight of the core (which is 63.5 mm in diameter).

Per metre volume $= 0.785 \times d^2 \times 1$
$= 0.785 \times 0.0635 \times 0.635 \times 1$
$= 0.0032$ cubic metres

Mass of 1.5 m of core $= 0.0032 \times 1000 \times 1.5 \times 2.1$
$= 10.08$ kg

Balancing force = Weight of displaced water
$= 0.0032 \times 1000 \times 1.5 \times 1$
$= 4.8$ kg force

Thus weight causing core to break is $10.08 - 4.8 = 5.28$ kg force.

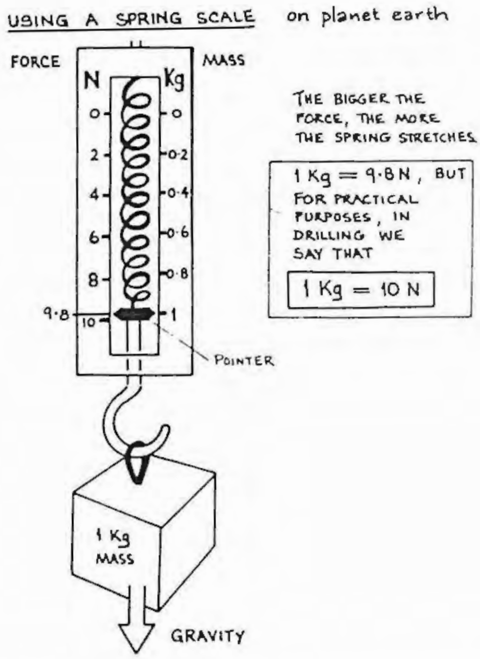
Reducing the apparent weight of a 1.5 m core to 2.5 kg will allow 3 metre runs before the weight reaches 5.28 kg force.

This will need a balancing force of $10.08 - 2.5 = 7.58$kg force. S.G. to cause this balancing forçe $= 7.58 \div 4.8 = 1.6$

By weighting his drilling fluid to 1.6 S.G., the driller will stop the core from being crushed under its own weight.

Measuring force

We have talked about the basic unit of mass as the kg. The basic unit of force is the newton and the size of the force may be stated in newtons. Every object is pulled to the earth by a force called gravity.



On earth, a 1 kg mass is pulled down by a force of approximately 10 newtons. The force of gravity on 1 kg mass is equal to 10 newtons. If a person has a mass of 75 kg, a force of 750 newtons is exerted on that mass at the surface of the earth.

Pressure

Pressure is the force exerted over an area of contact:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area of Contact}}$$

In drilling, we are concerned with a number of forms of pressure, including the pressures necessary for crushing or fracturing rock, as well as liquid and water pressures for various applications.

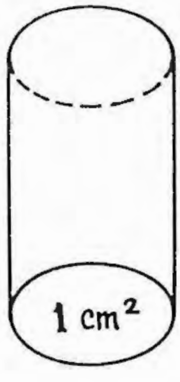
In the English system, we may use psi to describe the pressure of a fluid such as air or mud, or lb/ft^2 to describe loading on a jack-pad.

Pressure (Liquid)

Liquid pressure in drilling is important in several ways, but best illustrated by demonstrating the property of **head.** **Pressure** at any point in an open vessel or hole is directly proportional to the depth below the surface. **Pressure** depends on **depth** of a container such as a borehole and not on **size** (or diameter) of the container.

Drilling fundamentals

Refer to the diagram of a cylindrical jar below. It has a cross sectional area of 1 cm^2. If 1 kg of liquid is poured into it, the force on the bottom will be 1 kg.

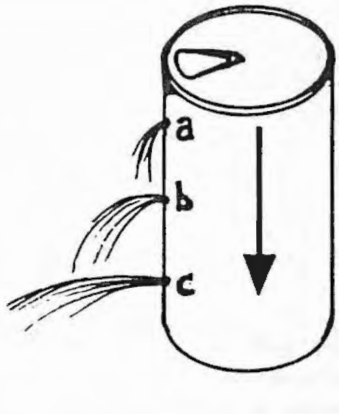


$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} = \frac{1\text{ kg (Force)}}{1\text{ cm}^2}$$

If another 1 kg is poured in, the liquid is twice as deep as before.

Pressure = 2 kg (Force) per 1 cm^2

Example: Get an empty beverage can and pierce in places indicated. Fill with water and notice the way the fluid comes out of the holes.



You will see that the bigger the pressure, the bigger the squirt. In other words, the deeper the hole, the greater the pressure. Pressure is greatest at the bottom of the hole. In the case of the can, pressure is greatest at "C".

Calculating Pressure

How can we calculate down-hole pressure? We need to know:

1. Depth of fluid in the hole.
2. Density of liquid or S.G.
3. The pressure of water per metre depth of hole.

We now need to determine what pressure is exerted by a depth of 1 m of water.

Remember that:

Pressure is force per unit of area.

$$\textbf{Pressure}\text{ in pascals} = \frac{\text{Force in newtons}}{\text{Area in m}^2}$$

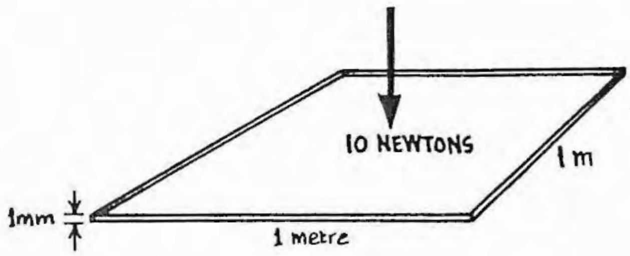
1 pascal = 1 newton per 1 m^2.

Remember that one litre of water occupies 0.001 m^3. Take 1 kg or a litre of water and put it in a tank that has a bottom area of 1 square metre. The water will be 1 mm deep.

The force on the bottom of the tank is directly proportional to the depth of the water in the tank, that is, 1 kg (force) or, we could say, 10 newtons. This force of 10 newtons is spread over one square metre.

Pressure is defined as force per unit area. A pressure of 1 pascal is a force of one newton per square metre. A force of 10 newtons over 1 square metre is a pressure of 10 pascals.

A column of water 1 mm deep has a pressure of 10 pascals.



A column of water 1000 mm deep or 1 metre deep exerts a pressure of 1000 x 10 pascals.

Since 1000 pascals = 1 kilopascal and 10 000 pascals = 10 kPa, 1 metre of water exerts a pressure of 10 kPa. For most pressure measurements the kPa is a more useful sized unit than the Pa.

Therefore, in order to determine the pressure of a column of fluid in a bore hole, we use the formula;

Pressure (kPa) = Depth (m) x 10 kPa x S.G.

Where,

- D is the depth of fluid in the hole, stated in metres.
- 10 kPa is the force exerted by a column of water 1 m deep,
- and S.G. is the specific gravity or density of the drilling fluid as determined by the mud balance (see chapter 6).

Example 1:

Determine the pressure exerted by the drilling fluid at the bottom of the hole, given;

Hole	= 60m
S.G. of mud	= 1.2
Pressure (kPa)	= 60 x 10 x 1.2
	= 720 kPa

Example 2:

Given a bore hole depth of 150m, with a standing water level (S.W.L.) of 10m in the hole, what is the minimum pressure requirement for a compressor to displace the water in the hole?

Depth of water in the hole	= 150 - 10
	= 140m
Pressure (kPa)	= 140 x 10 x 1
	= 1400 kPa
	= 200 psi (approx)

Pressure – summary

Things to remember about pressure:

Pressure is the force exerted on each unit area of a surface.

- The unit of pressure is N/m^2 = Pa (also ft.lb).
- Pressure is directly proportional to depth.
- Pressure is proportional to density.
- Pressure is expressed in bars or kPa (also psi or ft of head).

Air pressure in drilling

When drilling in water bearing formations, the air pressure requirements to clear water and cuttings from the hole will be greater than that required in a dry hole.

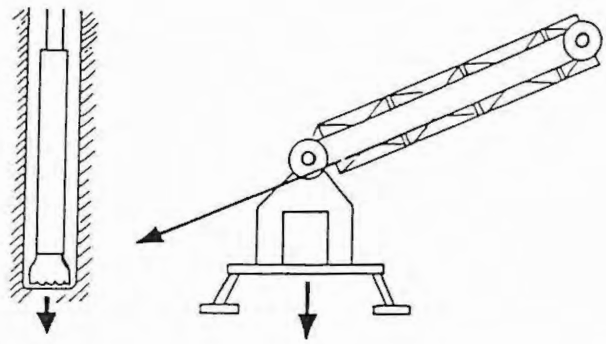
Pressure is not to be confused with up-hole velocity. Pressure can be termed as the power supplied to lift the cuttings and up-hole velocity is the speed that the cuttings travel up the hole.

Forces during drilling

Weight

A driller knows that the weight applied to the drill string is a critical factor in controlling the performance of the bit.

- Weight at the bottom of the hole (behind the bit):
- Weight in the machine helps hold it down and gives stability.
- Weight is one of the forces that the rig has to overcome when pulling rods or pipe.



Gravity force (weight) holds machine against tipping when pulling from an angle hole

Inertia and momentum

What is inertia? Inertia can be described as a tendency for any object to stay still if still; or, if moving, to keep moving. Any object has inertia.

An example: Legislation in Australia and North America made it compulsory for all car passengers to use a seat belt (or child safety seats). Why is this desirable or necessary?

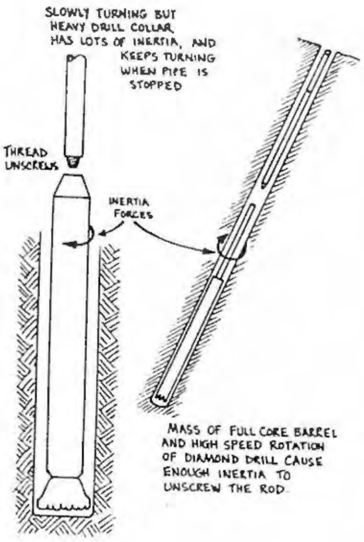
Because of inertia, car passengers in a head-on collision will fly forward over the dashboard. In other words, their bodies tend to keep moving after the car has stopped suddenly, thus causing grave injury or death. This movement of their bodies forward after the vehicle has stopped, shows the effect of their inertia.

In drilling, the inertia of a tool depends on its mass. The greater the mass, the greater its inertia; i.e. the greater the mass, the more it tends to stay still, if still, and the more it tends to keep moving, if moving.

Sometimes it is necessary to compare the forces capable of being exerted by the inertia of moving objects. These forces – called momentum – are calculated by multiplying the mass of the object by its velocity. A driller knows that it is just as hard to stop a single rod from falling quickly as it is to stop a whole string from falling slowly. They might well have the same momentum. They would both require the same amount of braking to stop them from crashing into the ground.

Inertia is a property not only of still or moving bodies, but also of rotating bodies. Rotational inertia can be a real problem for drillers. We have seen that inertia depends on mass. When the mass is rotating, it will have more inertia if its mass is concentrated at its outer edge. That is, a pipe will have more inertia than a round bar of the same mass. Drillers spend much of their time working with rotating pipes. They must appreciate that large forces can be exerted by a rotating pipe.

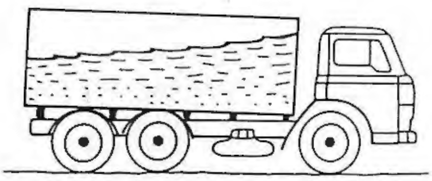
This pressure is more than enough to unscrew joints if the top end of the pipe is stopped suddenly.

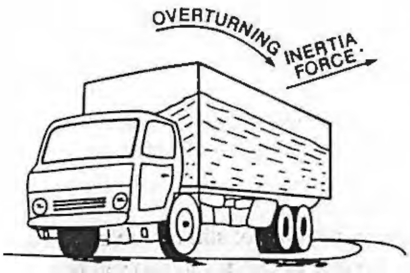


Forces in liquid

Liquids, like solids, have inertia. The inertia of water in a tank causes the liquid to mount up at the front of the tank when the truck carrying it stops, or at one side of the tank when the truck carrying it goes round a corner.

Sudden movements like this can make the vehicle uncontrollable or even cause the vehicle to turn over. Although the pressure may be low, if the side of the tank is large, the total force may be sufficient to tear the weld.

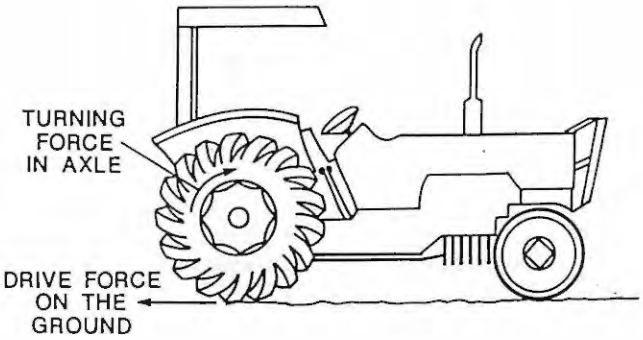




Torque

Almost everything you do around a drilling rig has to do with turning or rotating something. It is therefore important for the driller to understand what torque is.

Take, for example, the farm tractor. The force which pushes the tractor along does not depend on the power of the engine but on the turning force that the engine can put into the drive shaft.



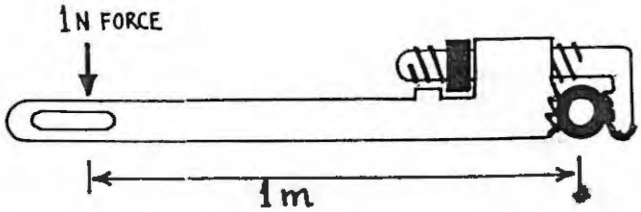
The turning force is called torque. In drilling, it is the torque of the rotary drive that turns a rotary bit or the twist of the cable that turns the cable-tool bit.

Every machine is designed to do a particular job. In other words, the machine will perform within certain specified limits.

When you purchase a piece of equipment, the manufacturer provides a book of instructions on how to operate and care for the equipment.

These may include a specification for the tightening of nuts or bolts, expressed in terms of torque necessary to properly tighten them. It is the torque or tightening force that the driller uses to make up the rod or tool joints that determines the life of the pipe or rods.

The basic unit of **torque** is the **Newton Metre** (Nm)
Torque (in Nm) = Force (in N) x Distance (in m). Torque tends to produce rotation. The torque produced by this pipe wrench is 1 Nm.



In SI, correctly speaking, torque is stated in newton metres. In some manufacturer's specifications, you may find torque expressed as kilogram metres (kg.m). 1 kg.m = 10 Nm. This is derived from the imperial expression of stating torque in foot-pounds. Make sure you check the unit of measurement if you need to calculate torque

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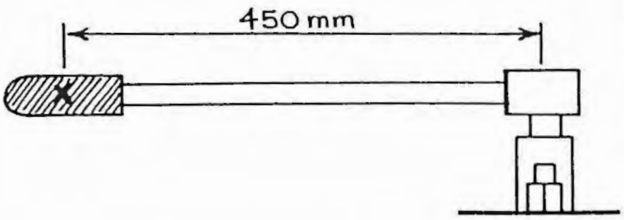
Example 1

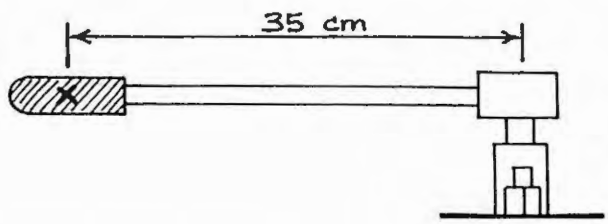
Find the torque applied to a cylinder head nut using the torque wrench as shown below. A force of 300 N is applied to the handle at point 'X':



Torque = Force x Distance (m)
= 300 N x 0.45m
= 135 Nm

Example 2

Find the torque applied to a clutch pressure plate assembly where a torque wrench, as shown, is used. A force of 500 N is applied.



Torque = Force x Distance
= 500 N x 0.35m
=175 Nm

Note: Where manufacturers express force in kg.m, change kg into newtons.

Force in newtons = kg x 10
(1 kg force = 10 N)

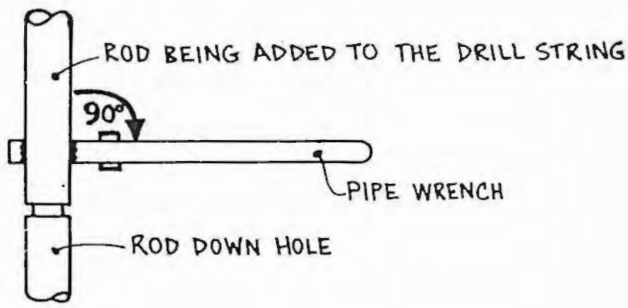
30 kg (force)	= 30 x 10 newtons
	= 300 N
50 kg (force)	= 50 x 10 newtons
	= 500 N

Recommended torque – making up a drill string

To make the shoulders of the joint butt properly, it is necessary to torque the joint according to the manufacturer's specifications. Some manufacturers recommend that joints be torqued to 20% more than the torque at which the rods will be operated. Others specify a make-up torque. This ensures that the joints perform as designed. Recommended make-up torques should be equalled but not exceeded.

Wrenching to the recommended torque

Keep pipe wrench at a 90 degree angle to the rod to avoid slipping and damaging the rods.



Calculating force required on wrench

Example 1

A manufacturer of wire line drill rods of 55.6 mm diameter, with tapered thread, recommends a pre-torque of 1250 Nm (or 125 kg.m)

If a pipe wrench with a handle 500 mm long (effective length), is used, find the force that must be applied.

Step 1: We know that:
Torque = Force x Distance (in metres)

Therefore, **force** = Torque/Distance
= 1250 N/(500/1000 m)
= 1250 N/0.5
= 2500 newtons (250 kg Force)

Example 2

In this example, the manufacturer of wire line drill rods with tapered thread, recommends pre-torque of 850 Nm for 44.5 mm diameter rods.

If a pipe wrench with a handle 750 mm long (effective length) is used, find the force that must be applied to the wrench.

Force = torque/distance
= 850 N/0.75m
= 1,133 N (113 kg force)

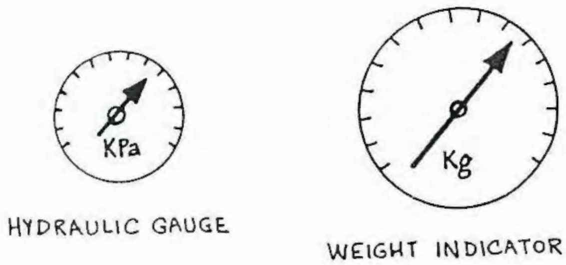
Bit pressure and torque

We can use a formula to calculate torque applied through a pipe wrench to a stationary pipe or bolt, but how do we know how much torque is being applied to a rotating drill pipe or rod?

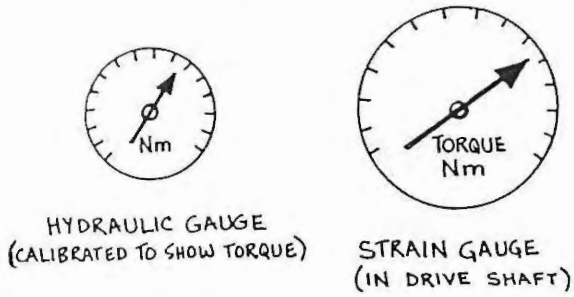
We can read a torque meter or hydraulic gauge on a rig. On some rigs we are forced to estimate torque from vibration, noise and engine tone and behaviour.

Torque in the rods or pipe is the indicator most often used by a driller on light machines to monitor changes in performance of the bit.

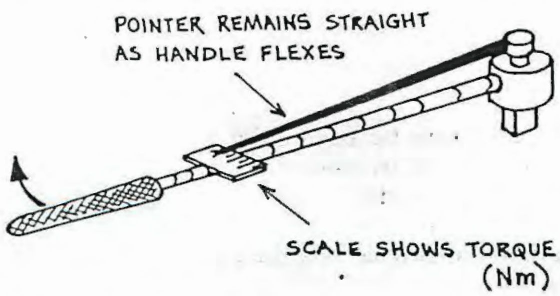
It is an advantage to be able to read a gauge, but if one is not available, the driller has to "estimate" or "judge" changes in torque by listening to the sounds from the engine.



WEIGHT (FORCE) ON BIT INDICATORS



TORQUE GAUGES



TORQUE WRENCH

Friction forces

Forces of gravity and momentum are positive forces which act to cause movement. We use these forces to assist our drilling operations. Another natural force is always acting against motion. This force is called **friction.**

We spend much of our time trying to avoid friction. Lubrication is necessary to reduce friction in all machine parts and between the rods or pipe and the hole. But often we desire to prevent or retard motion, and one way of doing this is to make use of friction.

- Friction holds the rig in place on the ground.
- Friction brakes are used in vehicles and in the winches.

Control of friction

The most undesirable aspect of friction is the galling and tearing of sliding surfaces when friction becomes very high. Friction is best controlled by keeping sliding surfaces apart. This may be done by:

- Air cushion (like a hover-craft)
- Water or mud film (between rods and hole)
- Lubricants: Oils (in high speed shafts or engines),
- Grease (in slow moving parts),
- Solid lubricants which provide strong thin films over surfaces under heavy pressures.

Deliberate friction surfaces (like brake blocks and clutch plates) are designed to provide consistent friction without high wear.

Glazing of the surface which destroys some of the friction is most undesirable. Lubricants (water and oil) must be kept away from friction surfaces.

Section 5 Conversion factors: converting between metric and English units

- What's required for conversion
- Conversion into metric units using tables

Drillers will find measurements for many purposes expressed in a combination of metric, British Imperial units or United States units. In such cases you will often need to convert such units into one consistent system of units, that is, the metric system or SI. Also, those readers (such as in the USA) who are most accustomed to other units will want to convert SI units from time to time to get a sense of proportion. Note to metric skeptics: "SI really IS easier". For calculation purposes, you may need to convert, for example:

- inches into millimetres
- feet into metres
- yards into metres
- miles into kilometres
- gallons into litres, and so on.

Use conversion only when necessary. If you have some sense of proportion, you can usually just estimate. The most difficult approach to learning anything new is to attempt to work in the "older system first" and then try "to convert".

What's required for conversion

1. A calculator.
2. A conversion table for reference when required.

Conversion into metric units using tables

Conversion tables are provided (following). These tables comprise a list of conversion factors. You will need to refer to these tables from time to time as you read through this book. Other conversion tables also exist. Find one or two that suit and keep them handy.

CONVERSION FACTORS FOR DRILLERS: TABLE 1

To Convert	into	Multiply by (x)
LENGTHS		
inches (")	millimetres (mm)	25.4
feet (ft)	metres (m)	0.3
yards (yds)	metres	0.9
miles (mls)	kilometres (km)	1.6
AREA		
inches² (sq. inch)	centimetres² (cm²)	6.5
feet² (sq. ft)	metres² (m²)	0.09
yards² (sq. yds)	metres² (m²)	0.84
VELOCITY		
feet per minute	metres per second	0.005
miles per hour	metres per second	0.45
miles per hour	kilometres per hour	1.6
VOLUME		
inches³ (cubic inches)	centimetres3 (1cm x 1cm x 1cm) 1cm³	16.4
feet³ (cubic feet) (ft. x ft. x ft.)	Litres (L)	28.3
yards³ (yd. x yd. x yd.) (yd³)	metres³	0.76
US gallons	Litres (L)	3.8
Imperial gallons	Litres (L)	4.5
MASS		
Ounces (oz)	grams	28.3
pounds (lbs)	kilograms	0.45
long tons (2 240 lbs)	tonnes	1.0

CONVERSION FACTORS FOR DRILLERS: TABLE 2

To Convert	into	Multiply by (x)
DENSITY		
Pounds per gallon (US)	Specific gravity (kg per Litre)	0.12
TEMPERATURE		
°F	°C	(°F-32) x 5/9
FORCE (WEIGHT)		
Pounds (force)	Newtons	4.4
Kilograms (force)	Newtons	9.8
PRESSURE		
Pounds/inch² (p.s.i.)	• Kilopascals	6.9
	• bars	0.07
	• metres head of water	0.7
	* (1 bar = 1 Kg/cm²)	
ENERGY		
B.Th.U.	Kilojoules	1.06
HYDRAULIC CONDUCTIVITY		
Gallons/ft²/day	m³/m²/day	0.04
POWER		
Horsepower	Kilowatts	0.746
TORQUE		
ft. lbs	kg.m	0.14
	N.m	1.4
TRANSMISSIVITY (Volume/Length/Unit of Time)		
Gallons/ft/day	m³/m/day	0.012

Section 6 Strength of materials

- Types of stress
- Stress combinations
- Factors that increase stress
- Indicators of excess stress
- Ways a driller reduces stress
- Application: Strength of wire rope
- Where can you find this information?

The driller must know something about the strength of materials. In practical terms, the strength of these materials matters in terms of:

Safety – Can the material stand up to the stress incurred?

Reliability – Can the machine do the job it is intended to do?

Forces that cause an object or structure to change shape or size are called **stresses. Strain** is the result of stress. Take the example of a drill pipe stuck in the ground. When you pull on the pipe, it stretches. The amount it stretches is the strain occurring as the result of the **tensile** stress applied to the pipe.

Technical Area: 2 Drilling Tools and Equipment

Item: 2-8 Weight of drilling tools

1: Objectives
To be able to explain and advise for unit weight and total of drilling tools weight which shall be balanced with rig capacity during drilling.

2. Contents
- Drill String Assembly
- Weight calcuation

3. Teaching Methods
(1) Explain how to determine drilling string assembly for each drilling bit.
(2) Explain how to calculate the total weight of drill string assembly.

4. Materials
2-8M1 DDCA's Manual for Drilling Works

2.8 WEIGHT OF DRILLING TOOLS (TA CODE 2-8)

The elements of the drill string is described in Section 2-4 Rig Accessory of this manual. This section explains how to express the drill string assembly and how to calculate the total weight of the drill string.

2.8.1 DRILL STRING ASSEMBLY

Prior to the decision of drill string assembly, necessary tools shall be listed up with their capacities before the determination of drill string assembly. Example of drill string assembly is shown in ***Table 26***, ***DP:*** Drill Pipe, DC: Drill Collar, ST: Stabilizer
Table 27 and ***Table 28***. These examples are for the mud drilling of 2stages. The 1st stage is drilling by 12-1/4" bit down to 30 m and the 2nd is drilling by 8-1/2" bit down to 100 m. At first, necessary drilling tools for 12-1/4" drilling and 8-1/2" drilling shall be listed up as shown in ***Table 26***. Then, the drill string assemblies are determined respectively for 12-1/4" drilling and 8-1/2" drilling as shown in ***DP:*** Drill Pipe, DC: Drill Collar, ST: Stabilizer
Table 27 and ***Table 28***.

Table 26 List of Necessary Tools for 12-1/4" and 8-1/2" Drilling

Tool	Connection		Unit Length (m)
	Top	Bottom	
4-1/2" DP	3-1/2" IF Box	3-1/2" IF Pin	6
6-1/4" ST	4" IF Box	4" IF Pin	1.2
6-1/4" DC	4" IF Box	4" IF Pin	6
8-1/4" ST	6-5/8" Reg Box	6-5/8" Reg Pin	1.2
8-1/4" DC	6-5/8" Reg Box	6-5/8" Reg Pin	6
8-1/2" Tri-Cone Bit	4-1/2" Reg Pin	-	0.6
12-1/4" Tri-Cone Bit	6-5/8" Reg Pin	-	0.8
Crossover Sub	3-1/2" IF Box	6-5/8" Reg Pin	0.6
Bit Sub	6-5/8" Reg Box	6-5/8" Reg Box	0.6

DP: Drill Pipe, DC: Drill Collar, ST: Stabilizer

Table 27 Drill String Assembly for 12-1/4" x 30 m Drilling

Tool	Connection		Unit Length (m)	Qty.	Length (m)
	Top	Bottom			
4-1/2" DP	3-1/2" IF Box	3-1/2" IF Pin	6	4	24
Crossover Sub	3-1/2" IF Box	6-5/8" Reg Pin	0.6	1	0.6
8-1/4" DC	6-5/8" Reg Box	6-5/8" Reg Pin	6	1	6
8-1/4" ST	6-5/8" Reg Box	6-5/8" Reg Pin	1.2	1	1.2
Sub	6-5/8" Reg Box	4-1/2"Reg Box	0.6	1	0.6
12-1/4" Tri-Cone Bit	6-5/8" Reg Pin	-	0.6	1	0.6
Total Length (m)					33

Table 28 Drill String Assembly for 8-1/2" x 100 m Drilling

Tool	Connection		Unit Length (m)	Qty.	Length (m)
	Top	Bottom			
4-1/2" DP	3-1/2" IF Box	3-1/2" IF Pin	6	14	84
Crossover Sub	3-1/2" IF Box	4"IF Box	0.6	1	0.6
6-1/4" DC	4" IF Box	4" IF Pin	6	3	18
6-1/4" ST	4" IF Box	4" IF Pin	1.2	1	1.2
Bit Sub	4" IF Box	6-5/8" Reg Box	0.6	1	0.6
12-1/4" Tri-Cone Bit	6-5/8" Reg Pin	-	0.6	1	0.6
Total Length (m)					105

2.8.2 WEIGHT CALCULATION

Total weight of the drill string assemblies are calculated for each. The weights of bits, subs, stabilizers can be included in those of driller pipes or drill collars, as they are not heavy comparing to the total weight.

Table 29 Weight Calculation of Drill String Assembly for 12-1/4" x 30 m Drilling

Tool	Unit Weight (kg/m)	Length (m)	Weight (kg)
4-1/2" DP	27	27	729
8-1/4" DC	241	6	1,446
Total		33	2,175

Table 301 Weight Calculation of Drill String Assembly for 8-1/2" x 100 m Drilling

Tool	Unit Weight (kg/m)	Length (m)	Weight (kg)
4-1/2" DP	27	84	2,268
6-1/4" DC	125	21	2,625
Total		105	4,893

As a result, total weight is 2.2 tons for 12-1/4" drilling and 4.9 tons for 8-1/2" drilling. Therefore, with the consideration of 10 % of the safety factor for the stucking, the lifting capacity of the drilling rig shall be not less than 5.4 tons. Furthermore, the total weight of casing pipes shall be considered as well.

Technical Area: 2 Drilling Tools and Equipment

Item: 2-9 Rotary bit rotation speed and weight on bit

1: Objectives
To be able to explain and advise for suitable bit rotation speed and weight on bit so as to use them effectively and safely during mud drilling.

2. Contents
- Rotataion speed
- weight on bit

3. Teaching Methods
(1) Explain how to control rotary bit rotation speed and weight on bit using manual.

4. Materials
2-9M1 DDCA's Manual for Drilling Works.

2.9 ROTARY BIT ROTATION SPEED AND WEGHT ON BIT (TA CODE 2-9)

2.9.1 ROTATION SPEED OF BIT

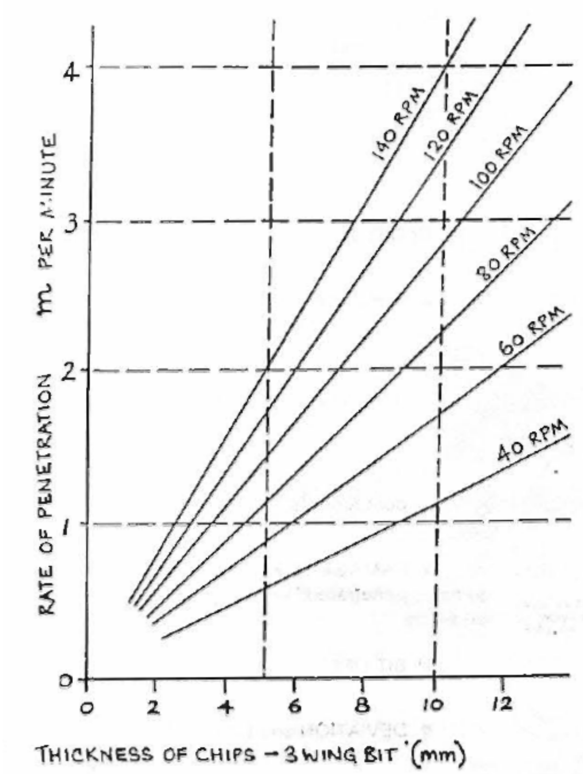
At the commencement of the hole, safe and smooth rotation and feed rates must be aimed for any consideration. When the hole is safely collared and drilling is proceeding, smooth operation continues to be the prime aim, but while maintaining smooth operation, work to achieve the desirable thrust loadings and rotational speed to give correct chip making.

The chip size produced by a rotary bit is controlled by four factors:

1. nature of the formation
2. the way that the bit makes the chip (crushing, cutting, tearing etc)
3. rotary speed
4. penetration rate

Large chips measn better samples and less energy required to penetrate. Larger chips also make chip clearing more difficult.:

1. the formation
2. the drill string
3. the interaction between these and the drilling rig



Source: Australian Drilling Industry Training Committee Ltd

Figure 17 Bit Penetration and Rotary Speed

The penetration rate improves as we increase thrust and rotation speed. But this holds true only while the bit operates correctly. If the bit is overloaded or runs too fast, the bearings break down, the gauge cutters wear rapidly and the chip clearing operation bogs down. For all bits, there is a maximum thrust and speed. For most bits, there is a minimum thrust to make them penetrate correctly.

Figure 17 shows the relationship between bit penetration and rotary speed. However, in DDCA, the range of 30 to 100 r.p.m is employed for the rotation speed of rotary bits.

2.9.2 WEIGHT ON BIT

The weight required on any rock roller bit for effective and Maximum Efficient Rate of Penetration (MERP) varies directly as the compressive strength of material being cut. This is a broad statement which is bascally true but within which there are many variations and exceptions. The heavy weights necessary to drill hard formations are required to give effective crushing force to the bit tooh and probably to keep the tool more or less flat running bottom.

The weight shall be loaded to to the bit when drilling the hard formations. In general, maximum weight on bit (WOB) is thought to be 1 to 1.5 tons per inch of bit diameter. If a bit is of 8 inches, maximum WOB is estimated to be eight to 12 tons. However, for the drilling of the level of 150 m boreholes, WOB is

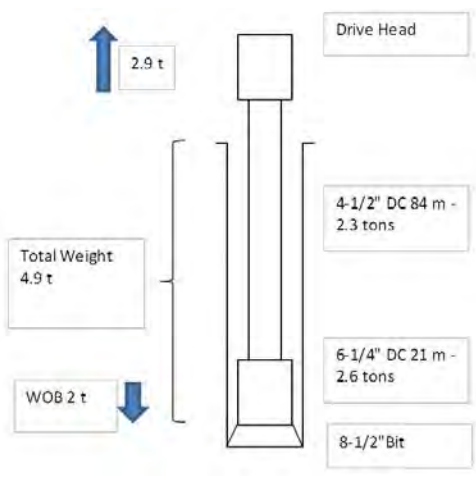


Figure 18 Example of the Calculation of WOB

between the range of 1 to 3 tons. So as not to cause the damage of the drilling tools and the deviation of the hole, the WOB shall be within the weight of drill collar. During drilling, WOB shall be regulated by the lifting force by drive head.

Figure 18 shows an example of the calculation of the WOB for the drilling by 8-1/2" bit with 84 m of 4-1/2" DPs and 21 m of 6-1/4" DCs. The WOB is calculated as the following:

Maximum Weight on Bit (WOB)

2.6 x 0.8 = 2.08 ton

Total Weight of Drill String

4.9 ton

Target WOB 2 ton

Lifting Load by Drive Head

4.9 - 2 = 2.9 ton

The maximum WOB shall be not more than 80 % of the weitght of DCs (2.6 tons), with the consideration of the safety factor. Therefore, the target WOB was decided to be 2.0 tons. Total weight of the drill string is 4.9 ton. In order to regulate the WOB to 2.0 tons, the drill string shall be lifted up by the drive head. Then remaing weight of 2.9 tons are loaded on the bit as the WOB.

Technical Area: 2 Drilling Tools and Equipment

Item: 2-10 DTH Bit rotation speed and weight on bit

1: Objectives
To be able to explain and advise for suitable DTH bit rotation speed and weight on bit so as to use them effectively and safely during DTH drilling.

2. Contents
- Rotataion speed
- weight on bit

3. Teaching Methods
(1) Explain how to control DTH bit rotation speed and weight on bit using manual.

4. Materials
2-10M1 DDCA's Manual for Drilling Works.

2.10 DTH BIT ROTATION SPEED AND WEGHT ON BIT (TA CODE 2-10)

2.10.1 ROTATION SPEED

To start drilling, turn on air rotary slowly. Then feed down slowly until the piston starts operating. Add just enough pulldown pressure to start breaking rock. Make sure the bit does not drift when it first strikes the formation because this can damage the bit buttons. Always check the operation of a DTH tool before running it into a hole. Try it out first on a solid piece of timber at the surface. As the tool approaches the bottom of the hole, proceed and start rotation before putting weight on the bit. The presence of water in the hole when drilling is resumed will not prevent tool operation. Lowering the tool into the hole with the air turned on will force the water out of the hole.

Proper rotation speed is important for long bit life and optimum penetration. The recommended speed ranges from 12 to 40 r.p.m. A slower rotation is used in hard, abrasive formations. A faster rotation is acceptable when drilling in soft, nonabrasive formations. Ideally, the bit should penetrate about 10 mm (3/8 in) per drill pipe revolution. "Rule of thumb" is penetration rate in metres-per-hour x 1.6 to obtain r.p.m about one-half of the penetration rate in feet-per-hour (Adjust up or down several r.p.m to match formation).

2.10.2 WEIGHT ON BIT

When the bit first cotacts the formation, apply minimal weight on the bit. After a few minutes, increase the thrust pressure to allow the tool to run smoothly. The correct optimum weight should be monitored and maintained throughout the drilling operation. As the hole gets deeper and drill pipe is added, the thrust pressure must be reduced to compensate for the added weight of the drill pipe. Hydraulic pressure required to keep the optimum weight on the bit varies from rig to rig.

Principally, whole totoal weight of the drill string shall be balanced by the drill head and WOB shall be less than one ton, so as not to cause the hole deviation. However, WOB and drilling speed shall be carefully regulated by the driller, so that the DTH can catch up the drilling down speed.