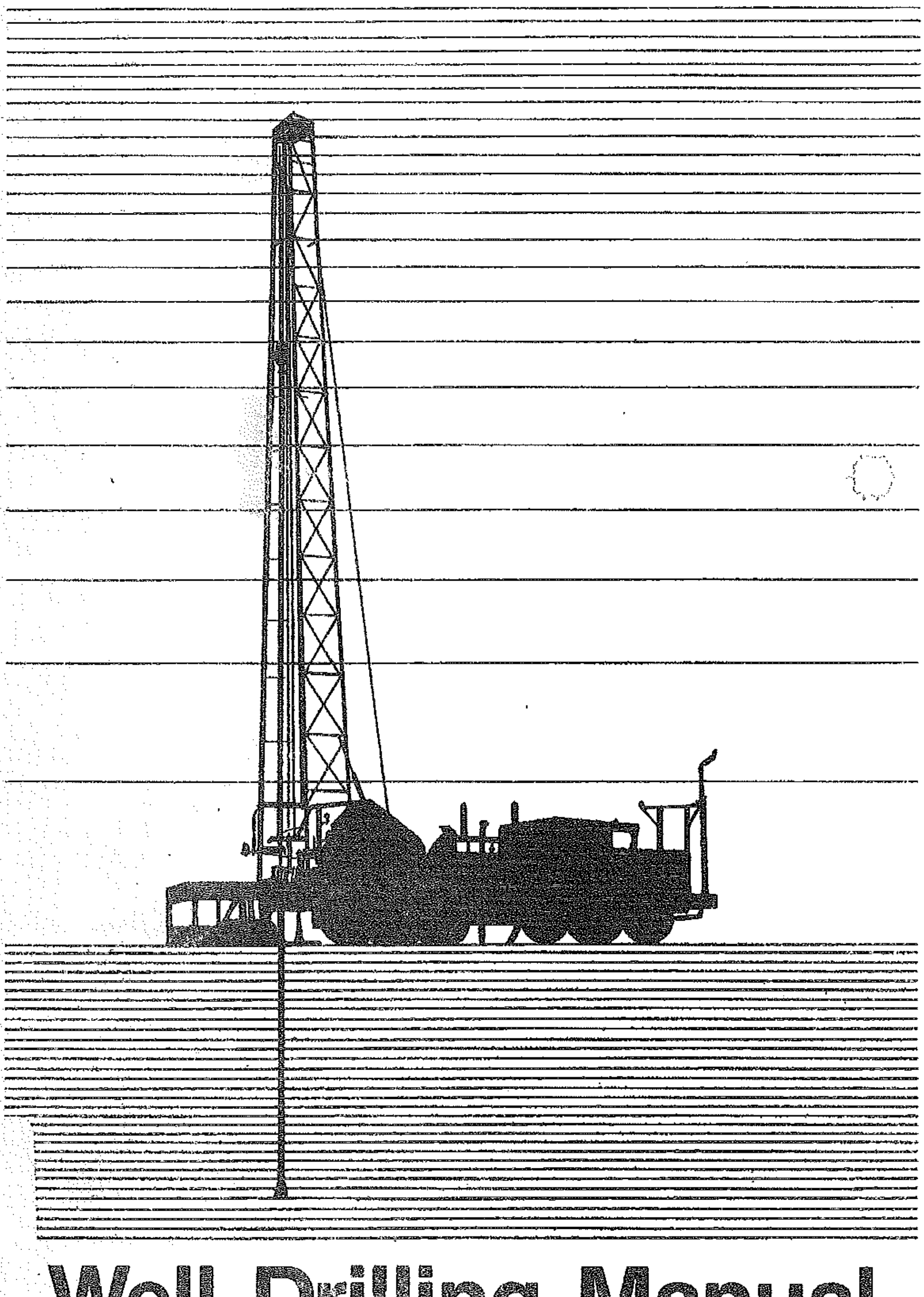

Well Drilling Manual

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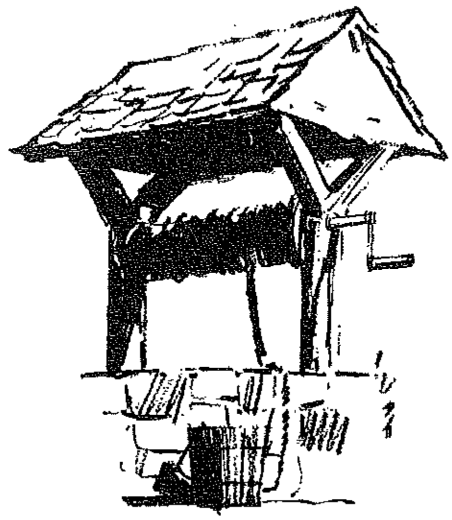
INTRODUCTION



Water is the single most important substance for sustaining life. As world population grows, the need for new sources of water to meet growing demands also increases. Because ground water is one of the major sources of supply, man through the years has devised various methods to tap this hidden reservoir. * Today, a wide variety of modern water well drilling equipment is available to probe for, and reach, ground water supplies. Each of the various types of rigs is discussed in detail in this book.

This is also a "how-to-do-it" book in the sense that it goes through a step-by-step discussion of how each of the various types of water well drills operates; and step-by-step procedures on how to drill a hole with each type of equipment. Basic fishing tools and fishing techniques for drilling tools "lost" down in the hole are also explained.

Because of varying conditions and varying needs, it is often difficult to choose the best equipment to do the job. Therefore, the Speedstar Division of the Koehring Company provides this book to aid government and private users in selection of the proper machines. As the world's only builder of a truly complete range of water well drilling equipment, Speedstar offers every type of rig. The company can be, and is, completely unbiased and objective in discussing which machines are best suited for particular drilling jobs. For answers to specific problems it is suggested that the reader communicate with the Speedstar Division of the Koehring Company.

Water well drilling is both an art and a way of life for those engaged in this occupation. To Old Time drillers nothing else can take the place of "putting down a hole." Newcomers getting into this field will find, too, that well drilling is a stimulating and rewarding occupation. So, to drillers all over the world who pursue the sometimes elusive life-giving liquid treasure buried beneath the earth, this book is respectfully dedicated.

* 97% of the world supply of fresh water is underground.

CHAPTER 1 SELECTION OF DRILLING EQUIPMENT

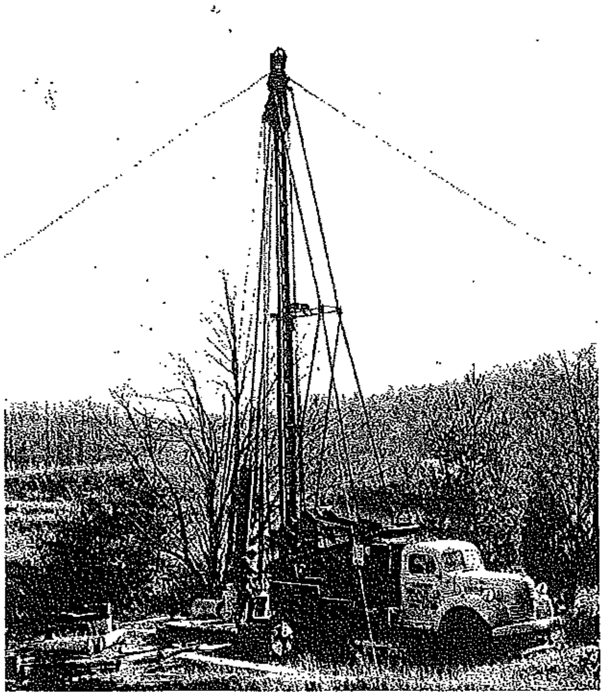


Fig. 1 Speedstar Model SS-71 Cable Tool Drill

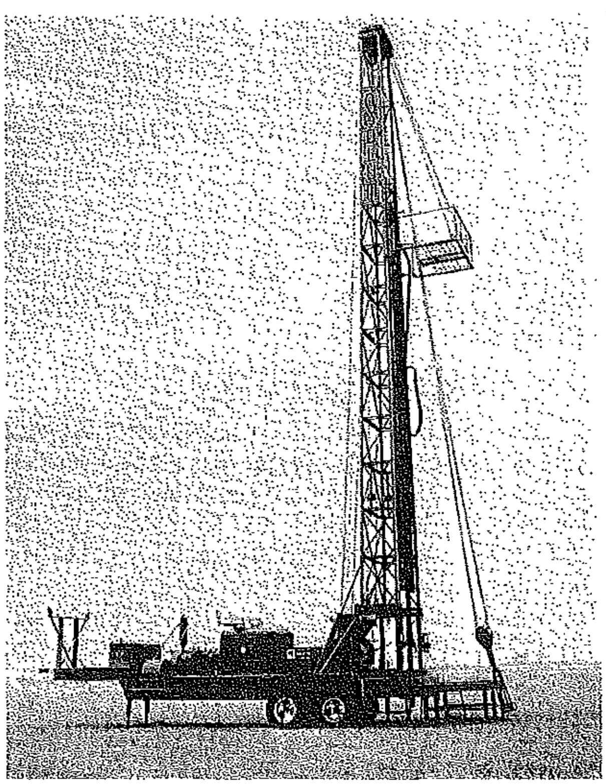


Fig. 2 Speedstar Model SS-25 Rotary Drill

There are two main types of drilling machines used to develop underground water resources from the water-bearing strata, called the aquifer, which lies beneath the surface. These two major types of equipment are percussion cable tool drills, which drill by means of lifting and dropping a drill bit to break up and loosen the material in the hole; and rotary drilling machines which use a rotating bit with mud or air to carry away the cuttings. Within each of the two major classifications of drills there are machines that have modifications or adaptations for special drilling applications.

In addition to the two major classifications, there is a third type of machine — combination rotary-percussion rig which uses both the percussion and rotary methods to drill, employing equipment common to both types of machines. All of these types of equipment are defined and explained in this chapter.

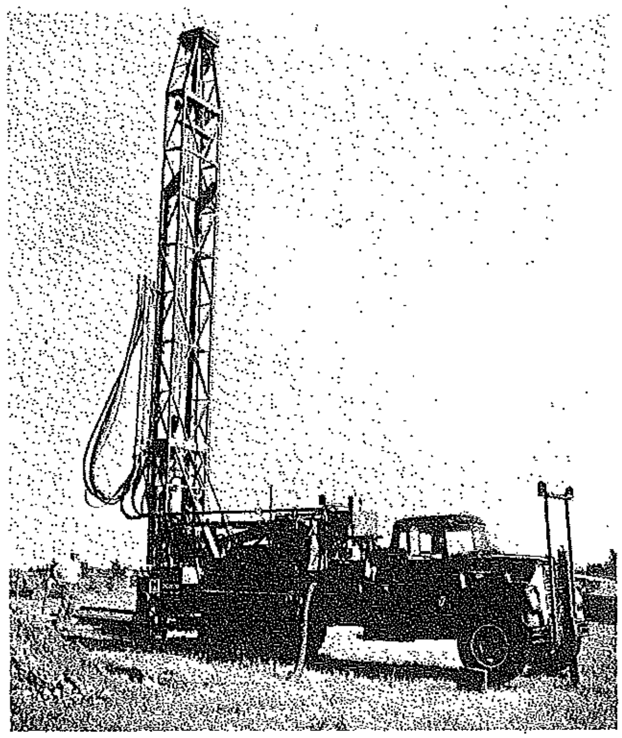


Fig. 3 Speedstar Model SS-61R Comb. Cable Tool-Rotary Drill

Because of the relatively wide choice of drilling equipment available within the two major classes of drills, it is sometimes difficult for the driller to evaluate the best equipment for his particular use. The selection and choice of equipment depends on a number of factors. These include:

1. ORIGINAL EQUIPMENT COST

The percussion or cable type drill is the least expensive of the three types to buy. A percussion machine with a hole diameter capacity range of from 5 inches to 18 inches (12.7 cm. to 46 cm.), and a maximum drilling depth range down to 1,400 feet (427 m.) will cost (depending on the truck, size of drill and auxiliary equipment) between 15,000 and 28,000 U.S. dollars. The machine has a low horsepower requirement. The mechanical drives and structure that transmit energy to the working bit can be kept to moderate size and complexity. Gravity does most of the work. The tools and bits are simple and low cost. Bits are reusable. A low cost wire cable is used to raise and drop the cutting bit as contrasted to the more expensive drill pipe used in rotary drilling.

The rotary drill with the same hole diameter range (5 to 18 inches – 12.7 cm. to 46 cm.) and a maximum depth capacity of approximately 1,500 feet (457 m.) ranges between 45,000 and 95,000 U.S. dollars depending upon the equipment included. A combination rotary and percussion machine with the above capacities would range from 30,000 to 50,000 U.S. dollars in cost. Larger or smaller machines vary above or below the prices mentioned, but in general the cost ratios would be about the same.

2. LABOR COSTS

A small percussion drill can be operated successfully by one man. In areas where time is not important, and/or skilled labor is scarce, this may be an important consideration. The rotary drill, while it can be operated by one man, needs two or three men for best efficiency and safety.

3. DRILLING SKILL

Percussion-type drills are relatively simple to master. Operators can be taught to run this machine in an efficient manner in a very short period of time. Also, because of the rugged, simple construction of the unit, careless or incorrect drilling procedure can be tolerated with less chance of major damage to the machine. Rotary drills on the other hand are more expensive and complicated, and inexperienced or careless operators could damage this machine considerably. In remote areas it could be out of operation for long periods of time. The rotary drill bit also can be damaged through improper use. These bits cost anywhere from 10 to 20 times as much as a percussion bit. Rotary bit costs can be extremely high in hard rock formations.

4. FORMATION TESTING AND WELL DEVELOPMENT

With a cable rig a more accurate sample of the formation can be obtained (unless the rotary operator uses coring tools). It also is possible for the driller to test the quantity and quality of each stratum as drilling proceeds. Bad water can be shut off by using blank casing through the contaminated formation. On the other hand, the ordinary procedure of placing a gravel envelope around the casing in a rotary drilled hole insures admittance into the well of water from all horizons.

5. GEOLOGICAL FORMATIONS

The type of formation the driller encounters such as sand, sand and gravel, clay, shale, sandstone, granite etc. and the combinations in which these materials appear at various depths, also has an effect on the choice of equipment.

Table I can be used as a general guide in determining which type of equipment to use.

In the case of wells of exceptional depth, the percussion drill method becomes relatively less efficient than the rotary method since its low cost application of energy becomes inefficient. The higher direct energy costs of the rotary, both for higher capital investment and higher direct field costs, are more than compensated for by the higher drilling production rate.

6. SPEED OF DRILLING

The speed with which a hole is drilled into the earth depends on several things. Type of equipment, kind of soil conditions and technical proficiency of the operator are all prime considerations. Generally a rotary drill will be faster than a cable rig under most conditions. But where either method is satisfactory and a driller has a choice, he should consider the greater initial cost of a rotary plus its higher operating costs. A careful study of application, local geology and costs might be necessary before a choice is made.

It is our recommendation that a decision be made with the help of an experienced driller – or with the advice of a local distributor. Consider both types – but acquire the one that offers the best balance of purchase and operating costs, simplicity of operation, and speed.

7. ACCESSIBILITY TO REPAIR PARTS

In very remote areas where accessibility to repair parts is limited or non-existent, the simplicity of the percussion drill is a distinct advantage. Breakdowns with this type of unit are rare and sometimes makeshift repairs can keep the equipment in operation until new parts arrive. Rotaries, of course, can be kept in operation in remote areas if sufficient parts and supplies are stocked. This would have to be done rather extensively, as such things as bearings, chains, gears, hydraulic pump parts, drive shafts, etc., would have to be kept on hand to assure continual operation. Also, the higher original cost of this machine and machine downtime together with added

TYPE OF FORMATION	PERCUSSION DRILL	ROTARY DRILL (with fluids)	ROTARY DRILL (bottom-hole air tool)
Dune sand	Difficult	Rapid	Not Recommended
Loose sand and gravel	Difficult	Rapid	
Quicksand	Difficult, except in thin streaks. Requires a string of drive pipe.	Rapid	
Loose boulders in alluvial fans or glacial drift	Difficult – slow but generally can be handled by driving pipe.	Difficult, frequently impossible	
Clay and silt	Slow	Rapid	
Firm shale	Rapid	Rapid	
Sticky shale	Slow	Rapid	
Brittle shale	Rapid	Rapid	
Sandstone – poorly cemented	Slow	Slow	
Sandstone – well cemented	Slow	Slow	
Chert nodules	Rapid	Slow	
Limestone	Rapid	Rapid	Very Rapid
Limestone with chert nodules	Rapid	Slow	Very Rapid
Limestone with small cracks or fractures	Rapid	Slow	Very Rapid
Limestone, cavernous	Rapid	Slow to impossible	Difficult
Dolomite	Rapid	Rapid	Very Rapid
Basalts, thin layers in sedimentary rocks	Rapid	Slow	Very Rapid
Basalts – thick layers	Slow	Slow	Rapid
Metamorphic rocks	Slow	Slow	Rapid
Granite	Slow	Slow	Rapid

TABLE 1. ROTARY AND PERCUSSION DRILL PERFORMANCE

labor costs would contribute to make the rotary relatively more expensive in remote areas.

8. DRILLING WATER REQUIREMENTS

In either case - rotary or cable - you need a ready supply of water. The percussion drill requires much less drilling water than does the rotary. In normal operation (4 or 6 inch holes - 10.16 or 15.24 cm.) it can get along with 100 to 150 gallons (378.5 to 568 liters) of water per 8-hour shift. When drilling in lost circulation zones, (openings where rotary drilling mud and water escape out of the hole) the rotary requires much greater quantities of water.

The quality of water is not critical for either machine. Fresh water makes the best rotary mud, but in an emergency almost any water can be used. Sea water has been used to drill with both rotary and percussion machines. In fact, in percussion operations in soft heaving shales, clays or bentonites, it is common practice to saturate the drilling water with salt and to pour rock salt into the hole. The salt in solution prevents the dispersion or suspension of the clay.

9. TERRAIN

Small, lightweight cable tool rigs have low move-in costs and are adaptable to extremely rough terrain. Generally, they can be used in locations which are less accessible to larger machinery. Also, the cable tools can be used in broken formations that cause the rotary method to lose mud circulation.

CHAPTER 2 TYPES OF DRILLING MACHINES

THE CABLE TOOL MACHINE

The cable tool machine drills holes by rhythmically lifting and dropping a set of drilling tools suspended on a wire cable so that the tool bit strikes the bottom of the hole. This lifting and dropping (as many as 60 times a minute) of the percussion drill develops the mechanical energy that breaks up the underground formations and bores the hole.

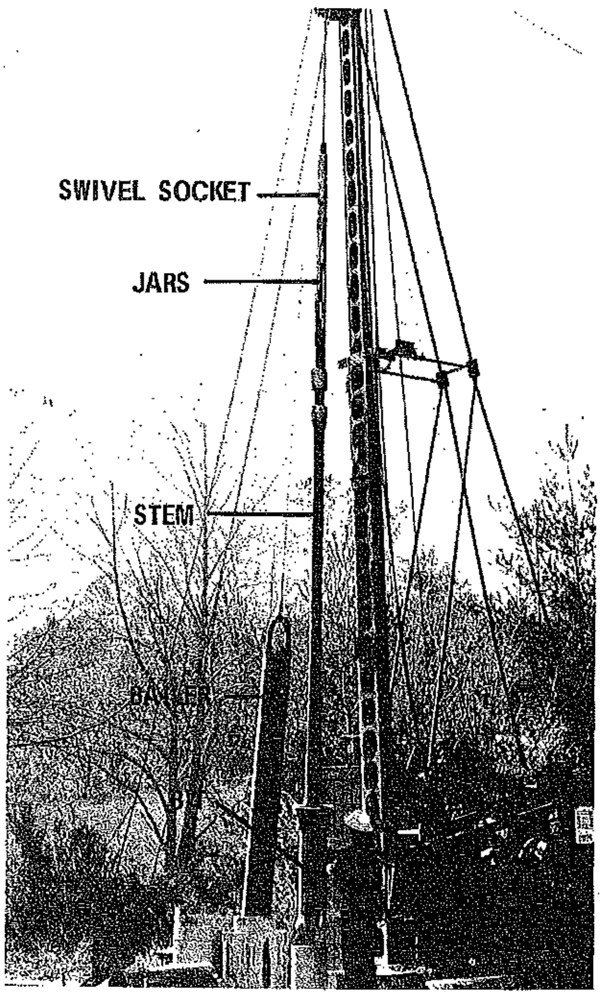


Fig. 4 Cable rig showing tool string

The loosened material, or drill cuttings, is mixed with water (either natural or added) and is removed from the hole by a bailer or sand pump. In drilling a dry hole, water must be constantly added to replace that taken out when removing the drill cuttings. Tools for drilling and bailing are carried on separate lines or cables. Each is spooled on its own drum.

JET DRILLING

The jet drill is basically a percussion unit and a pressure pump. The pressure pump is mounted on the machine together with pipe and hose connections leading from the pump to the drill pipe, with a return hose connection from the well casing to a pit or other suitable container. A suction hose returns the water from the pit or container to the pump. The drill pipe which is attached to the cable as shown in figure 5

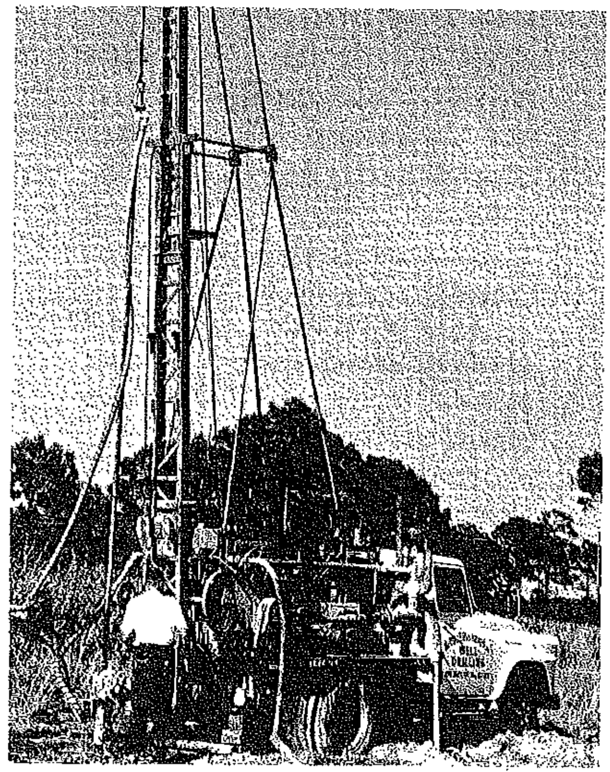


Fig. 5 Jet drilling operation.

consists of a small diameter standard pipe with a bit or chisel attached to the bottom section. Water is forced down through the drill pipe by means of the pressure pump and out through holes in the bit. This water, being under pressure, carries the cuttings to the surface through the space between the casing and the drill pipe. The lifting and dropping action of the drill pipe chops up the material in the hole and loosens it so that it may be washed to the surface. This method uses a short, fast stroke and is very effective in soft ground, sand and gravel, or other loose unconsolidated formations. This method is best suited for smaller holes from 2 to 4 inch diameter (5 to 10 cm.)

HOLLOW ROD DRILLING

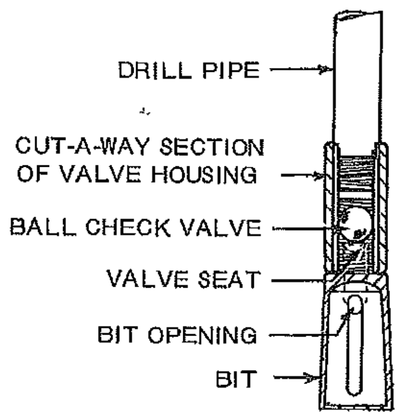


Fig. 6 Hollow Rod drilling operation.

A percussion machine is also used for drilling holes by the hollow rod method. The difference between this and the jetting method is that no pressure pump is needed. The hollow rod unit shown in figure 6 utilizes a bit with an opening at the top and a valve seat and ball check valve above it. Water is directed into the hole by gravity in the space between the drill pipe and the casing. The up and down motion of the drill pipe in this unit acts as a displacement pump. The ball check valve opens on the down stroke and draws material and fluid into the drill pipe. The valve closes on the up stroke, holding the slurry within the pipe. Eventually the pipe fills up and the mixture of fluid and cuttings are discharged at the surface. Like jetting, the hollow rod method is fast and efficient in relatively soft formations such as clay and sand. This method of drilling is best suited for hole diameters from 2 to 4 inches (5 to 10 cm.).

MUD SCOW DRILLING

Mud scow drilling utilizes a heavy bailer in place of a bit for drilling large diameter wells in areas containing heavy sand or a mixture of quicksand and clay. In mud scow drilling constant downward pressure is maintained on the casing pipe while material adjacent to and below the pipe is removed, thus forcing the pipe into the open space. As figure 7 shows, a cellar is dug which contains braces, hydraulic jack, starting pipe and anchor. Heavy planking secured by four diagonal braces leading to the center of the anchor timbers holds up the side ends of the cellar. As the hydraulic jacks pull down on the pipe, the upthrust forces are thus dissipated against the end walls. Jack and anchor positions are maintained by filling the whole pit with gravel or other material. Generally a conventional string of cable tools is used to start the hole although some operators will proceed immediately with a scow, if water is available for drilling. The scow itself consists of a heavy pipe fitted at the bottom with a plain, flat valve and a heavy shoe somewhat similar to a drive shoe. The cutting edge is tapered out slightly at the bottom to give clearance for shoe. The upper end of pipe is fitted with two reins, fastened by welding to the inside of the scow body. The reins extend above the pipe about 18 or 20 inches (45.7 or 50.8 cm.). A heavy steel pin is used to attach the reins to a scow-sub through a round hole in each member. This construction forms a knuckle joint.

The scow sub has a tongue with a round hole at its lower end to receive the pin. The upper end is fitted with a cable tool joint of a size to suit the weight of scow. The upper end of the scow sub has a tool joint that connects to the box of a set of jars.

Jars for use with a mud scow are similar to drilling jars except that a longer stroke is an important feature. A jar length or stroke of 24 to 36 inches (60.9 to 91.4 cm.) is a desirable length. An ordinary cable tool swivel socket is used to connect the drilling cable to the jars, making a practical and effective scow drilling string of tools.

The mud scow is run more slowly than a cable drill, 25 to 40 strokes per minute being an average working speed. The length of stroke depends on the

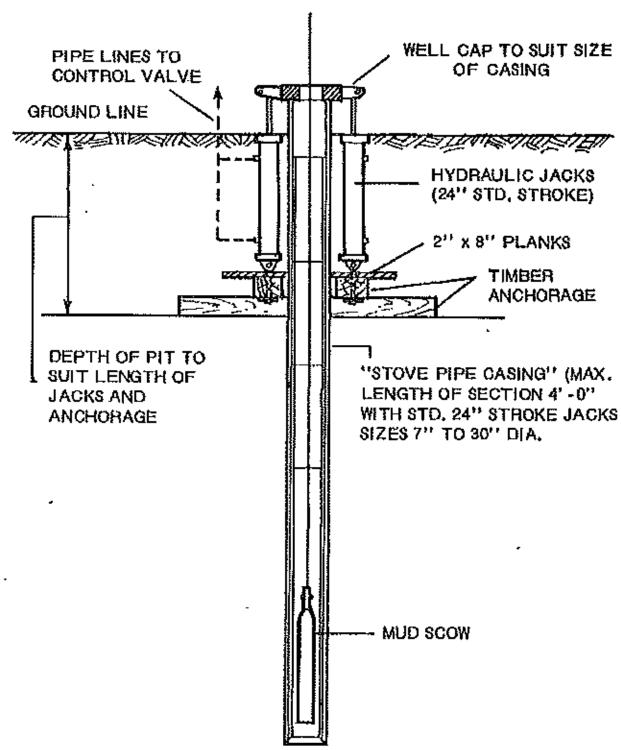


Fig. 7 Mud Scow drilling operation

formation being drilled. Sand and gravel with boulders should be drilled with a short 16 to 22 inch (40.6 to 55.8 cm.) stroke. A longer stroke could throw a boulder up through the mud scow where it may fall between the scow and pipe, thus making a very expensive fishing job necessary. Clay or sticky mud permits a longer stroke to be used to advantage. A heavy steel knife blade welded across the diameter of the cutting shoe will tend to prevent clay from balling up in the scow and may result in improved drilling speed. The pipe or casing should be down to a depth where the complete mud scow will not extend below the bottom of the pipe or casing. If the scow drills too far below pipe, a cave-in may trap the scow and require considerable work to free the drilling tools.

A hole may be cut in the mid-sectional area of the tube to drain off excess water when pulling tools from hole to dump cuttings. The scow may be upset by hand, or if too heavy, the catline can be used to up-end the tube. Some operators use the casing hook for the purpose, or when the scow is laid down, the main line can be hitched to the scow bottom.

ROTARY DRILLING WITH MUD

In the rotary method of drilling, action is accomplished by rotating a drill pipe by means of a power driven

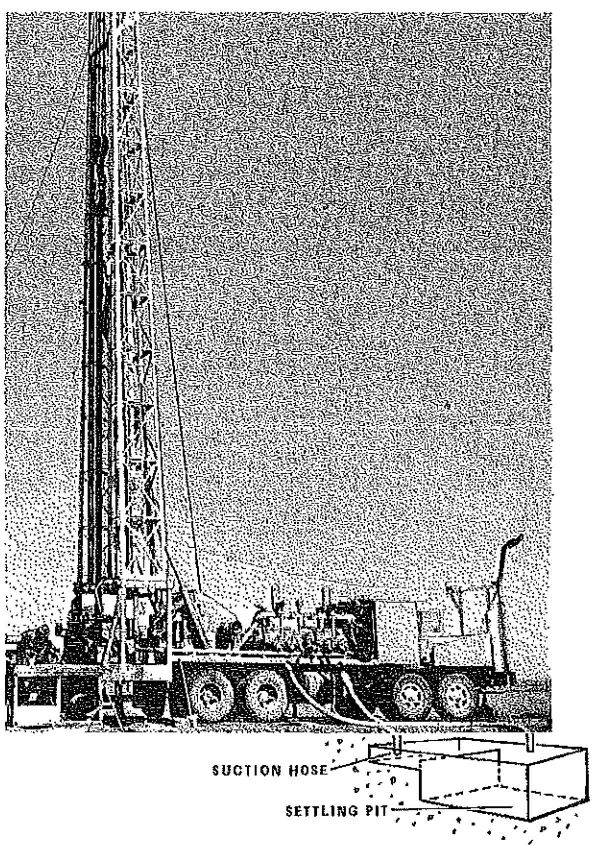


Fig. 8 Rotary drilling with mud

rotary table, with a bit attached to the bottom of the pipe. The 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 holes in the bit. This fluid swirls in the bottom of the hole picking up material broken by the bit, then flows upward in the space outside the drill pipe, carrying the cuttings to the ground surface, and clearing the hole. The greater the 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 the rotary drilling method the casing pipe is not introduced until after 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.

AIR ROTARY METHOD

The air rotary method is the same as the mud method except that compressed air is forced down the drill pipe and through the drill bit instead of mud. The particles cut by the bit are forced up through the space between the drill pipe and the outside wall of the hole by air pressure and are carried to the surface. These cuttings are collected in accumulators or are blown out away from the operator's station.

DOWN-THE-HOLE DRILLING METHOD

The down-the-hole drill is a pneumatically operated bottom-hole drill that efficiently combines the hitting action of cable tool drilling with the turning action of rotary drilling. 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 formations. Fast penetration results from the air piston blows transmitted directly to the bit. Continuous hole cleaning bares new formation to the bit, so practically no energy is wasted in chewing up cuttings. A straight hole is assured by short, rapid blows that minimize the effect of dipping and broken formations. Down-the-hole drilling is by far the fastest method of penetration in hard rock material. The bit is turned slowly (5 to 15 rpm) by the same method that rotates the drill bit in the mud or air drilling operation.

REVERSE CIRCULATION DRILLING

This drilling method was designed for rapid drilling of large diameter holes in soft formations where the hazards of cave-ins are present. As the name implies, water is allowed to travel at very low velocity down

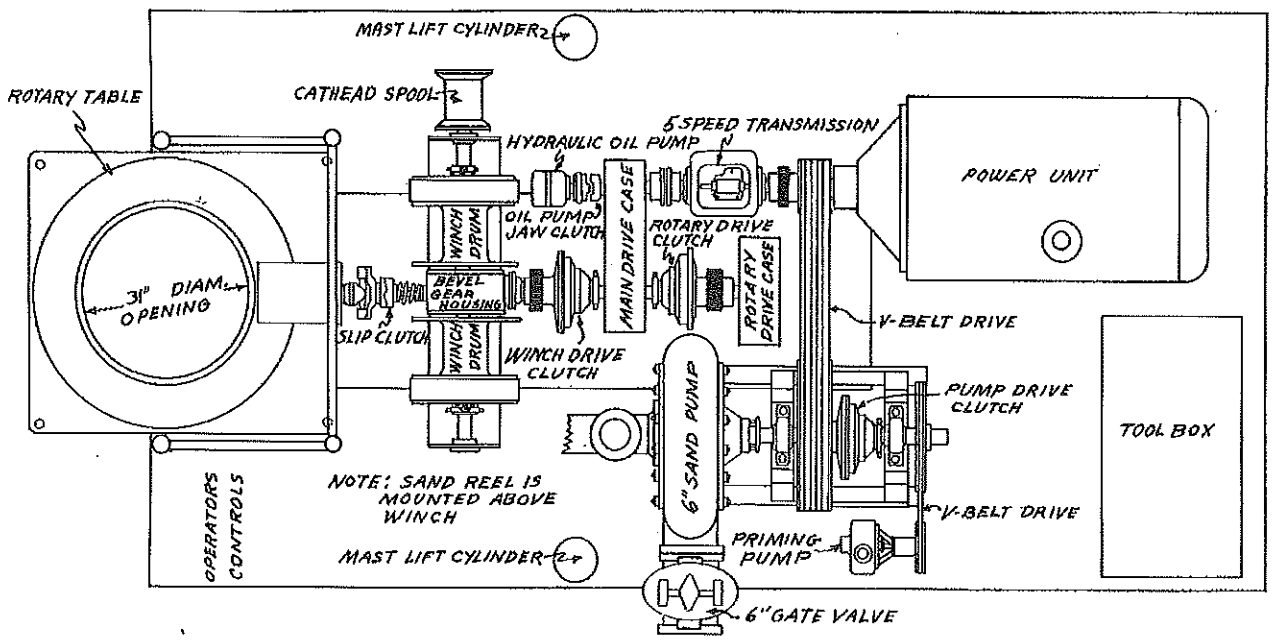


Fig 9 Layout of Reverse Circulation Rig

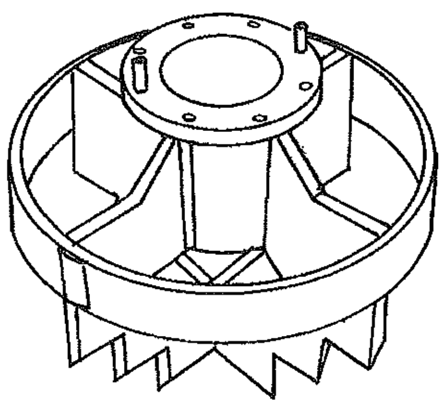


Fig. 10 Reverse Circulation Bit

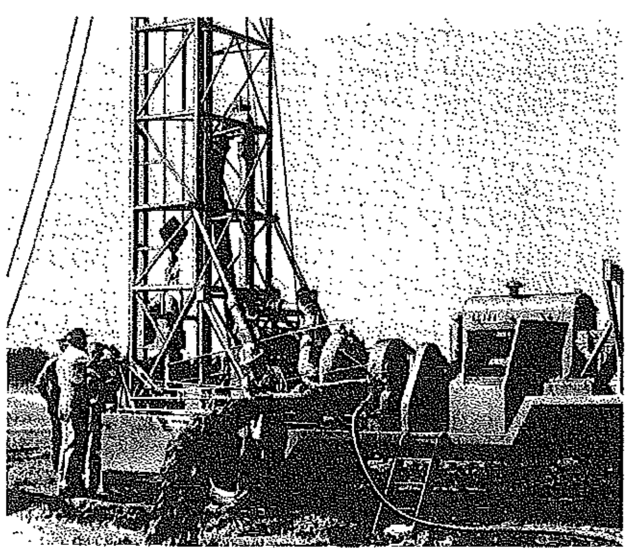


Fig. 11 Reverse Circulation Drilling

the space between the drill pipe and the hole wall. A large diameter cutting bit, such as shown in figure 10, provides the cutting action and is actuated by turning the drill pipe. Cuttings and even rocks are sucked and lifted up through the inside of the drill pipe and are discharged in a pit beyond the drill rig. The reverse circulation principle eliminates the need for the heavy drilling mud needed in conventional rotary drilling and which sometimes tends to seal off the water-bearing sand. It also overcomes the disadvantages of the slower method of drilling-casing, which often requires weeks to complete a shallow well.

FACTORS AFFECTING CAPACITY OF CABLE TOOL DRILLS

The three major factors affecting the capacity of a given size drill are diameter of hole, depth of hole and type of formation. For example, a small, relatively lightweight drill rig can put down a hole 8 inches (20 cm.) in diameter to a depth of 300 feet (91m.). However, at depths of a thousand feet (305 m.) the same machine could only drill a hole 4 inches (10 cm.) in diameter. The reduction in hole size at the greater depth is necessary due to the greater weight of the drill string as the hole gets deeper, which places a greater load on the machine. Drilling in heavy clay formations which tend to collapse against the drill string may limit the capacity of the machine, because of the increased work load in driving pipe.

To determine approximate allowable cable tool weight, use the following formula: Allowable tool weight equals maximum tool weight minus cable weight per foot times depth in feet. (see next page)

U. S. MEASUREMENTS

Allowable tool weight at 785 feet for a rig with a maximum surface tool weight of 1285 lbs. using cable weighing .63 lbs. per foot would be calculated as follows:

> Multiply depth of hole in feet (785) by the weight of a foot of cable in lbs. (.63). The result (494.5) represents weight of cable and is subtracted from maximum tool weight (1285 lbs.) for an allowable tool weight of 790.5 lbs. at 785 feet.

1285 - (785 x .63) = 790.5 lbs. allowable tool weight

To determine maximum drilling depth when tool weight is known, use the following formula: Maximum drilling depth equals maximum depth capacity of machine in feet minus tool weight divided by weight per foot of cable.

METRIC MEASUREMENTS

To determine approximate allowable tool weight in the situation above, multiply depth of hole in feet (785) by the weight of 30.48 cm. of cable in kgs. (.285). The result (224 kgs.) represents weight of cable and is subtracted from maximum tool weight (582 kgs.) for an allowable tool weight of 358 kgs.

582 - (785 x .285) = 358 kgs. allowable tool weight

To determine maximum drilling depth when tool weight is known, use the following formula: Maximum drilling depth equals maximum depth capacity of machine minus tool weight in kgs. divided by weight per 30.48 cm. of cable.

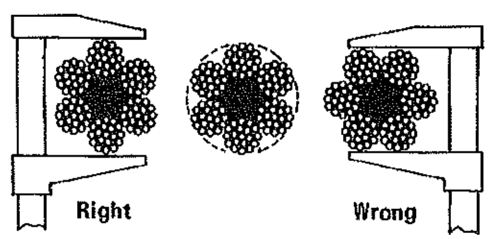
In determining cable tool capacity it is important to consider not only the tool weight a machine can handle on the bull reel at a given depth, but also the weight of the casing equipment which the calf reel and mast can handle at a given depth. In other words, the driller must relate the hole that he's going to drill, to what he's going to do with that hole after he is finished. For example: It is possible to drill a hole to a given depth with a smaller machine than should be used. However, this drill may not be able to handle the casing on it or the pump column.

In casing reels for example, figures for line pull on the first wrap of line can be very misleading as they express the possible lift capacity with the traveling block or hook in the lowest position. A moment's thought shows that in pulling or running casing the pull load must be handled with the traveling block or hook in a much higher position. Sufficient line to move the traveling block or hook from the lower to the higher position or vice versa must be spooled on reel - plus at least three coils initially on the reel for checking purposes. On some reels the spooling of this amount of line so fills the drum that actual performance with the block in the highest position is radically reduced.

It is also important that the driller take into consideration the strength of various size cables.

FACTORS AFFECTING CAPACITY OF ROTARY DRILLS

The major factors affecting the depth capacity of a rotary drill are: hole diameter, type of formation, and the required rate of penetration. These factors determine the size of mud pump, draw works, drill pipe, and derrick the rig must have to perform properly. It is possible, under favorable conditions, to drill a hole somewhat deeper and larger than the drill is rated for, but at a reduced penetration rate. Generally the depth a rig is rated for is determined by the weight of the desired string of drill pipe which can be handled safely by the drawworks and the derrick. The diameter of hole is determined by the volume of fluid the mud pump will supply. However, the depth will be limited by the amount of pressure which will be built up in a certain number of feet of the selected drill pipe until the maximum pressure rating of the pump is reached. This leaves the variables of the type of formation and the penetration rate desired.



MEASURING WIRE ROPE

When replacing worn line it's important that the new line fit properly. A common error is measuring the old line's diameter incorrectly which results in ordering an undersized replacement. When this happens, the new line will not only have insufficient strength but will be apt to deteriorate quickly and cause damage to the sheaves.

The true diameter of a line is the diameter of a circle that will just enclose it. Measuring from the crest of one strand to the opposite strand will give you this diameter. If the calipers are used in such a manner that they contact two strands on each side, the diameter measured will be too small.

EQUIPMENT FOR CABLE DRILL

Following are equipment and accessory tools that a driller should have to run a cable rig efficiently. Bear in mind that no attempt has been made here to specify either machines or auxiliary equipment by size. Such recommendations are based on hole diameter requirements, hole depths, types of formations to be drilled and the specific requirements of the driller. Further, each manufacturers' specifications for the equipment listed will vary. The list is provided to give the driller a general idea of the amount and type of equipment needed.

1 complete drill rig, either truck, trailer or skid mounted depending on use and terrain.

Ample supply of casing ... and proper diameter cable for bull reel, sand reel and casing reel.

Drill string including:

1 swivel socket and mandrel
1 drilling jar
1 drill stem
2 (at least) drill bits for each size hole
1 drill line saver
1 set wrenches
1 wrench tightener

Fishing tools including:

1 Babcock non-swiveling wire line socket
1 fishing jar
1 wire line grab with latch jack bottom
1 combination socket
1 full circle slip socket
1 fishing stem

Bit dressing equipment including:

1 bit chipper with handle
1 bit lifter
1 anvil block
1 blower hose
1 fan blower and driving belt
1 forge
2 hand sledges
1 bit gauge for each diameter bit
1 quenching tank.
1 hot chisel with handle
1 fuel mixing valve

Bailing equipment including:

1 dart valve bailer (for each hole size)
or 1 flat valve bailer
or 1 sand pump

Miscellaneous:

2 casing elevators for each size hole
drive heads for each size casing
drive clamps

EQUIPMENT PACKAGE FOR JET DRILLING

Add the following to the basic machine:

drill rods
jet hose
return hose
suction hose
chisel bit
water swivel

EQUIPMENT PACKAGE FOR HOLLOW ROD DRILLING

Add the following to the basic machine:

drilling bit
ball check
valve section with housing and valve seat
drill rods
return hose
swivel

EQUIPMENT PACKAGE RECOMMENDED FOR ROTARY DRILL RIG

The following suggestions cover basic equipment needed on a rotary drilling operation. No attempt is made here to specify units by size, weight, horsepower, etc. Such recommendations must be based on hole depth and diameter, types of formations to be drilled and the expected requirements of the driller.

Truck or trailer mounted rotary drill rig — including

power unit
mud pump or air compressor
draw works drive case
double drum draw works
sand reel
derrick
rotary table
kelly bar
leveling jacks
swivel

Operating Equipment:

roller bits of various sizes and types
casing block with swivel hook
swivel hose
suction hose with connections
set of elevators

EQUIPMENT PACKAGE RECOMMENDED FOR ROTARY DRILL RIG (Cont'd)

rotary breakout tongs
kelly to swivel sub
kelly to drill pipe sub
kelly line
drill pipe line
sand line
light plant
line scale weight indicator
set pipe slips
set adjusting tools and wrenches
hydraulic jack
hoisting plug
kelly drive bushing
API regular bit sub
bit sub lifting plug
set breakout slips
mud mixing gun
pipe or casing holder
sizes of bit breakers for roller bits
engine hour meter
lights in derrick for night operation
tool box
drill pipe and drill collars

Fishing Tools:

tapered tap
die overshot
circulating slipover shot

EQUIPMENT NEEDED FOR REVERSE CIRCULATION MACHINE:

Basic truck or truck 4-wheel trailer or semi-trailer mounting, including transfer case:

draw works
sand reel
rotary table
water swivel
reverse circulation pump
derrick
power unit
priming pump
main drive case

Operating Equipment:

6" swivel with bail and flanged gooseneck (15.2 cm.)
6" special foot valve (15.2 cm.)
6" special flanged kelly sub (15.2 cm.)
Elevator for 6" flanged drill pipe (15.2 cm.)
Rotary pipe holder
Hoisting line 1/2" 6 x 19 FC X 400 ft. long (1.27 cm. 6 x 19 FC X 121.9 m.)
Hoisting line 1/2" 6 x 19 FC X 300 ft. long (1.27 cm. 6 x 19 FC X 91.44 m.)
6" x 20 ft. flanged end swivel hose (15.2 cm. x 6.1 m.)
6" discharge pipe (15.2 cm.)
Sand line 1/2" x 500 ft. long (1.27 cm. x 152.4 m.)
6" Quick opening valve (15.2 cm.)
2" x 20 ft. suction hose with quick coupling and foot valve (5.08 cm. x 6.1 m.)
Ratchet wrench for drill pipe
Tool kit for maintenance and lubrication
Heavy duty tool box
Ladders
Cathead
Leveling jacks, screw type

BUYING LINE PULL RATINGS

Always ask the manufacturer how he rates his line pull capacity. On a bare reel? On a half-reel? On a full reel?

You get your best pull on a bare reel — but you seldom work with one.

As your line rolls in, the reel diameter changes — and pull capacity goes down. To keep the best pull ratio possible, look for machines that offer wide reels. Then as your line reels in, it layers over a wider area and keeps working at better pulling capacity for a longer time.

MOUNTINGS

Drill manufacturers will mount rigs anyway you like. Cable rigs are put on trucks, trailers or skids. Rotaries are usually truck or trailer mounted.

In some countries of the world, where back roads are non-existent and bridges have low load limits, the more portable the rig, the better. In many places users disassemble mounted rigs for barging across rivers. These people find it helpful to have rigs on lighter mountings that disassemble easily. Skid-mounting or platforms that can be lifted from trucks are the answer to this situation.

A trailer-mounted rig is also recommended, because it can be towed by any method (truck or animal) and can carry extra tools and pipe. When it is set up and working, the prime mover can be used elsewhere.

If truck mounting is desired, most manufacturers will furnish the truck or let the customer furnish the truck. However, since size is important, the manufacturer of the drill will ask that certain specifications be followed. It is also possible to furnish mud pumps and air compressors as auxiliary equipment mounted on separate trailers, or skids.

CHAPTER 3 GEOLOGY

In order to determine whether or not water may be found in certain areas and in certain quantities, it is necessary for the driller to have a basic knowledge of geological formations. By examining samples of the material he is drilling, the driller can estimate the likelihood of finding water.

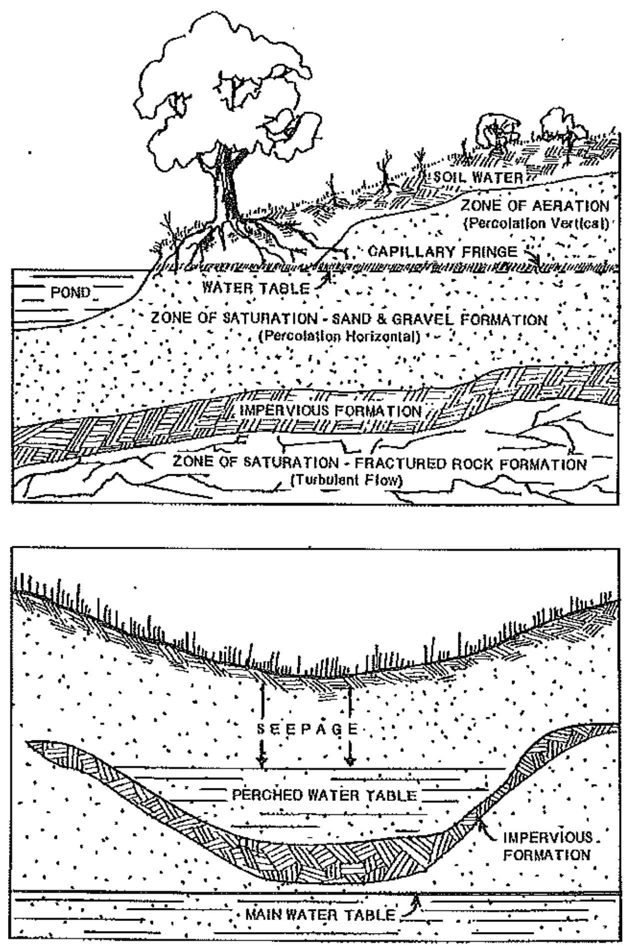


Fig. 12 Ground water movements and perched water

ROCK TYPES

Geologists classify rocks in three major groups, a) igneous rocks, or those which have cooled and solidified from an originally molten mass; b) sedimentary rocks, or those resulting from deposition of sediments by water, wind, or chemical precipitation and later consolidation; and c) metamorphic rocks or those of either of these first two groups which have been altered by heat, pressure, solutions, or other means.

Igneous rocks include the coarser-grained types such as granite, syenite, diorite and gabbro; and the finer-grained types such as rhyolite and basalt (trap). The coarse-grained rocks have cooled and become solid at great depths under the earth's surface whereas the fine-grained rocks have cooled at or near the surface (such as lava flows). In rocks such as granite, water is found in joints or fractures of the rock and occasionally in the upper weathered zone of the rock. Normally only a very small amount of water can be obtained from wells drilled in such rock. Some lava flow type of igneous rocks, however, may be quite porous and wells penetrating these porous zones may yield a considerable quantity of water.

Sedimentary rocks include shale, sandstone, conglomerate, limestone, dolomite, gypsum, etc. These rocks are the result of compaction and consolidation of loose sediments such as clay, sand, gravel, lime muds, fossil shells, etc., and chemical precipitates or evaporation products such as salt, gypsum, etc.

The terms clay, silt, sand, and gravel properly refer only to the size of the particles that compose a sediment. They are sometimes used, however, to imply the composition of the sediment as well -- "sand", for example, usually referring to particles of silica (S_1O_2).

Water is often found in abundance in the openings between the particles of the medium - and coarse-grained unconsolidated sediments such as sand and gravel. Fine-grained sediments, such as clay, may contain much moisture; but due to the small size of both the clay particles and the pore space between these particles it is difficult to obtain much water from such sediments.

When sediment consolidates to form sedimentary rock, the proper rock name is applied -- clay becoming shale, sand becoming sandstone, gravel becoming conglomerate, etc. Water occurs in these rocks just as in the original unconsolidated sediments — but due to compaction and cementation the porosity of the rock is usually less than that of the original loose material. Water may also be found along the bedding planes and in joints of sedimentary rocks.

Limestone is a sedimentary rock composed chiefly of calcium carbonate (lime) formed by precipitation of a fine-grained limy mud, by the accumulation of many animal shells in oceans or lakes, or by other means.

Dolomite is a rock similar in most respects to limestone but containing calcium and magnesium carbonates. Dolomite may be distinguished from limestone by testing with hydrochloric acid. A limestone will effervesce or "fizz" rapidly in cold, dilute acid while the reaction with dolomite is slow. Since both limestone and dolomite are somewhat soluble in water, solution openings and cavities up to the size of large caves may be formed. Ground water may be obtained from small pores of limestone or dolomite, just as in a sandstone, but most water is obtained from cracks, crevices and larger solution openings.

Metamorphic rocks include slate, quartzite, marble, schist, etc. They are the result of the long action of heat, pressure, and solutions upon igneous and sedimentary rocks. With the exception of marble, which is a metamorphosed limestone, most rocks in this group are dense and only small quantities of water can be obtained from cracks or joints. Marble may contain larger solution openings, similar to those found in limestone, from which more abundant supplies of water can be obtained.

Geologists group certain rock units which can be mapped or traced by the study of well cuttings over a considerable area into "formations". Each formation is given a name, usually referring to some geographical place where the formation is well exposed at the surface.

A driller should become familiar with the types of rocks and the names of formations likely to occur in his area in order to keep accurate logs of the wells drilled. At the same time, after some experience, the driller may be able to anticipate deeper drilling conditions in any particular well once he knows what formation he is in. Many Geological Survey organizations will be glad to examine well cuttings and furnish the driller with a description of the rock types and names of formations penetrated.

POROSITY AND PERMEABILITY

The porosity of a rock or soil is a measure of the amount of void or space present in the material such as the space between individual sand grains in a sandstone. Porosity is usually expressed in percent. For example, in 100 cubic feet (2,830 liters) of a sandstone of 38 percent porosity there will be 62 cubic feet of solid sand particles and 38 cubic feet of open space. Porosity, therefore, is a measure of the amount of water that can be contained in any given volume of rock or soil. The amount of water that can be extracted from a rock by means of a well penetrating it will not exactly equal the total amount of water in the rock. This is because a thin film of water will continue to cling to each rock particle even after the rock is dewatered by pumping. The amount of water available for extraction is often referred to as the effective porosity.

More important in ground-water studies, however, is the ability of a rock or soil to transmit water and yield it to a well. This factor is known as permeability, and is related not only to the number and size of openings in a rock but also to the degree of interconnection of these openings.

Determinations of permeability by pumping test means are subject to some criticism in that certain assumptions must be made concerning the water-bearing formation which may not seem completely justified. On the other hand, the field determinations of permeability usually give a far more accurate picture of actual conditions since minor irregularities which might affect the results of small scale laboratory tests would tend to average out in a large pump-

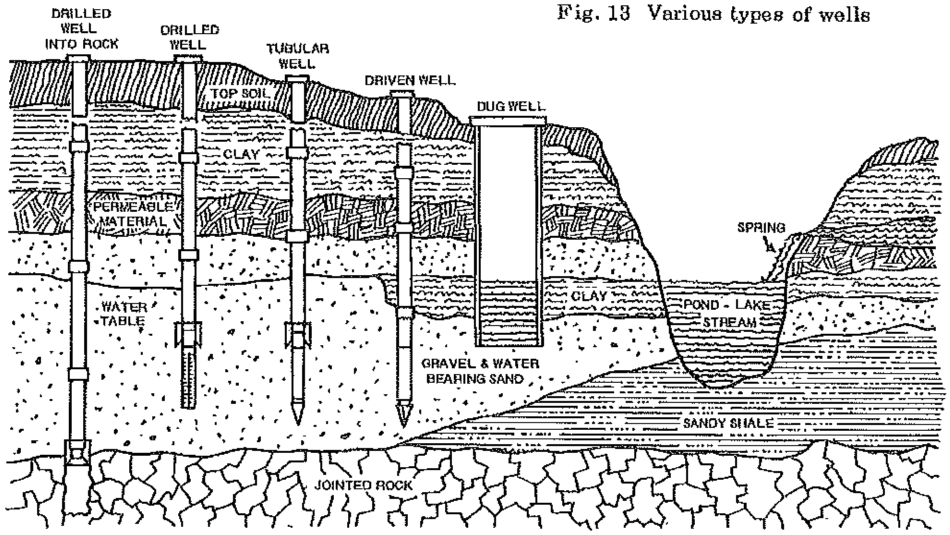


Fig. 13 Various types of wells

ing test. Moreover, it is almost impossible to collect a sample in the field, for later analysis in the laboratory, without disturbing the original character of the material sampled.

An excellent summary of methods for determining permeability is given in the U.S. Geological Survey Water-Supply Paper 887, "Methods for Determining Permeability of Water-Bearing Materials". This report is available from the Superintendent of Documents, Washington, D.C.

Much additional work is being done in this field of research and the results can be seen in the publications of such organizations as: American Geophysical Union, American Water Works Association, American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, and others.

Water producing formations or aquifers vary as to the volume of water produced. Formations in which the driller is likely to find water are as follows:

Clean gravel deposits. Clean, coarse gravel free from sand is the finest water producer available. Such a formation absorbs water readily, holds it in large quantities, and gives up its water easily.

Sand and gravel mixtures. Sand and gravel mixtures are also water producing formations and vary in the proportion of sand and gravel, some mixtures having a high proportion of sand which is less desirable as a water producer. Better water producers are those mixtures where the percentage of gravel to sand is high.

Clay formations. Clay formations, can and do produce low yield wells - 2 to 3 gallons (7.6 to 11.4 liters) per minute. In some areas this is the only source of water.

Consolidated formations. Consolidated formations consist of various types of porous sedimentary rock and range from fair to good water producers. One type of water producing rock is sandstone. If clay is found with the sandstone as the adhesive force holding the sand together, it is a poor water producer. However, if the sandstone is held together by silica or calcium carbonate, it can be a good water producer.

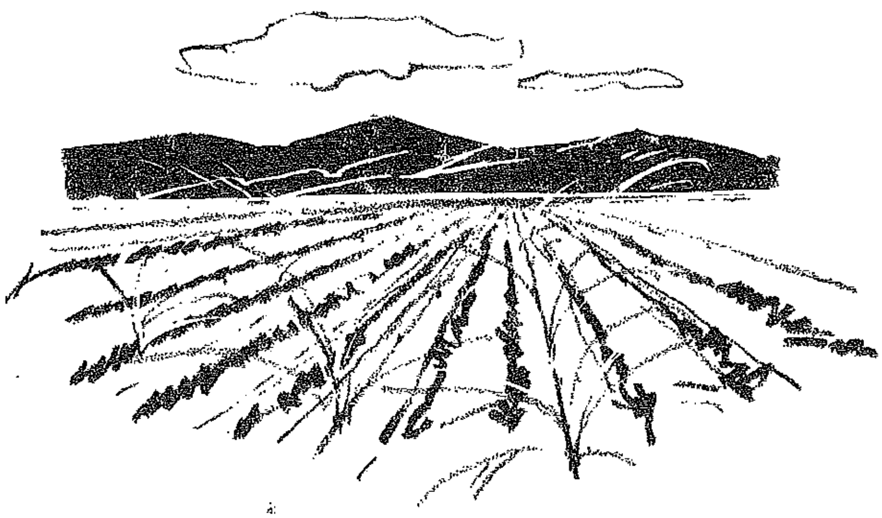
Limestone is an excellent source of water in sedimentary rocks. Frequently limestone will have large openings such as underground caves. These may hold water bearing seams with a large yield but of poor quality.

Basalt is a good source of water, if it is young geologically, because it tends to have a spongy formation. Older beds, however, are more tightly packed and are not good water producers.

Hard rock such as granites, porphyries, and other crystalline types of rocks are generally poor water producers. The poorest water producers are the metamorphic rocks such as gneisses, schises, quartzes, slates and soapstone.

Figure 13, shows the various types of wells such as dug, bored, driven, tubular or drilled. Each is essentially an opening in the ground from which a supply of water can be obtained. The first three types are usually shallow, not over 50 feet (15.24 meters) The drilled wells are developed by well drilling machines capable of penetrating through hard consolidations and rock formations to depths of over 1000 feet (305 meters).

CHAPTER 4 WELL REQUIREMENTS - A GROWING DEMAND



As population increases and industry grows, greater and greater quantities of water are being required all over the world. It is, therefore, important for the driller to understand the requirements demanded of the wells he is drilling, as this dictates both the type of well he would drill and the type of equipment he would use.

Generally speaking, small diameter wells ranging up to 8 inches (20.3 cm.) in diameter are used for domestic water well requirements, farm wells, recreational uses such as swimming pools, etc. Larger diameter wells ranging from 12 to 36 inches (30.5 to 91.4 cm.) and beyond are generally used for air conditioning requirements, residential subdivisions, industrial use, irrigation.

In order to determine whether a well will yield sufficient water to satisfy the requirements for which it is being drilled, the following information on water consumption can aid in determining well requirements:

INDUSTRIAL REQUIREMENTS (Approx.)

Steel, highly finished	65,000 gals. per finished ton (246 kl./907 kg.)
Aluminum	960 gals. per pound ingot (3.6 kl./453.6 gr.)
Oil Refining	770 gals. per 42-gal. barrel (2.9 kl./159 kg.)
Paper Manufacture	30 gals. per pound of paper (113 liters/453.6 gr.)
By-product Coke	3,600 gals. per ton of coal (13.6 kl./907 kg.)
Coal Washing	200 gals. per ton of coal (757 liters/907 kg.)
Distilling	300-600 gals. per bu. mashed grain (1.14-2.27 kl./35.2 liters)
Cotton - fiber to fabric	37 gals. per pound of goods (140 liters/453.6 gr.)
Cotton Cloth Processing	5-18 gals. per pound of goods (19-68 liters/453.6 gr.)
Tanning	800 gals. per 100 lb. hide (3 kl./45.4 kg.)
Brewing	470 gals. per barrel (1.8 kl.)

AGRICULTURAL REQUIREMENTS (Approx.)

Tomato Canning	60 gals. per bushel tomatoes (227 L./35.2 L.)
Corn Canning	1,000 gals. per ton of corn in husks (3.8 kl./907 kg.)
Meat Packing	6,000 gals. per ton on the hoof (22.7 kl./907 kg.)
Dairying	5 gals. per gallon of milk (19 L./3.785 L.)
Corn Syrup	30-40 gals. per bushel corn (113-151 L./35.2 L.)

FARM-DOMESTIC (Daily Requirements)

Each member of family, for all purposes including kitchen, bath, etc.	100 gals. (378.5 L.)
Each horse	10 gals. (37.85 L.)
Each steer or dry cow	12 gals. (45.7 L.)
Each cow producing milk	25-30 gals. (94.6-113.6 L.)
Each hog	2 gals. (7.6 L.)
Each sheep	1½ gals. (5.7 L.)
Each 100 chickens	4 gals. (15 L.)

PUBLIC BUILDINGS

Hotels and Schools	0.8 gal. per min. per fixture (3 L.)
Apartment Buildings	0.3 gal. per min. per fixture (1.1 L.)
Hospitals	0.4 gal. per min. per fixture (1.5 L.)
Office Buildings	0.7 gal. per min. per fixture (2.6 L.)
Mercantile Buildings	0.6 gal. per min. per fixture (2.2 L.)

STANDARD FIXTURES (Flow of Water)

Bath	10 gallons per minute (37.8 L.)
Lavatory	5 gallons per minute (18.9 L.)
Tank Closets	5 gallons per minute (18.9 L.)
Valve Closets	30 gallons per minute (113.6 L.)
Shower	5 gallons per minute (18.9 L.)
Sink	10 gallons per minute (37.8 L.)
Laundry Tub	10 gallons per minute (37.8 L.)
Garden Hose (3/4" nozzle)	5 gallons per minute (18.9 L.)
Continuous Drinking Fountain	1½ gallons per minute (5.7 L.)

STANDARD FIXTURES (Contents)

Bathtub	30 gallons (113.6 L.)
Shower (each)	30 gallons (113.6 L.)
Lavatory	1½ gallons (5.7 L.)
Flushing water closet	6 gallons (22 L.)

IRRIGATION

Irrigation requirements will vary according to a number of factors such as type of crop planted, the underground geological formation (a sandy sub-structure will absorb water much more rapidly than a clay substructure, for example), terrain contour such as hills, etc., and the condition of the surface soil itself. However, the following table will indicate some general rules of thumb for computing irrigation requirements:

TABLE 2 IRRIGATION REQUIREMENTS

Number of Acres covered in twelve hours pumping

Gal. min.	1 in. deep (2.54 cm.)	3 in. deep (7.62 cm.)	6 in. deep (15.24 cm.)	12 in. deep (30.48 cm.)
100 (378.5 L.)	2.96	.883	.442	.221
300 (1.1 kl.)	7.96	2.655	1.327	.663
900 (3.5 kl.)	23.85	7.96	3.98	1.99
1200 (4.5 kl.)	31.82	10.61	5.305	2.65
1600 (6 kl.)	42.35	14.15	7.075	3.535
3000 (11.3 kl.)	79.50	26.50	13.25	6.625
6000 (22.6 kl.)	159.10	53.00	26.52	13.26
10000 (37.8 kl.)	265.00	88.30	44.20	22.10
14000 (53 kl.)	371.00	123.70	61.80	30.95

(Courtesy Missouri Water Well Drillers Association Handbook - 1965)

RELATION OF WELL DIAMETER TO YIELD

The yield of a well depends upon many factors, among which are (a) the permeability of the water-bearing formation, (b) the draw-down when pumping, (c) the "radius of circle of influence" of the well, and (d) the well diameter.

The yield of two similarly constructed wells, all other factors being equal, is not directly proportional to the diameter of the wells. That is, doubling the diameter will not double the yield, or even come close; and the driller must bear this in mind when determining the diameter of the hole to be drilled.

Assuming a radius of circle of influence well has on surrounding water bearing formations of 1000 feet, the following figures show the relative yield from wells of different diameter -- still assuming that the character of the formation, well construction, etc. are identical for all cases:

Well Diameter (Inches)	Relative Yield %	Well Diameter (Inches)	Relative Yield %
4	1.00	24	1.27
6	1.04	48	1.42
8	1.08	120	1.65
12	1.15	240	1.92

It can be seen then, that increasing the well size does not increase yield proportionately. For example, an 8-inch well will yield only 8 percent more water (with the same draw-down) than an identical 4-inch well at the same location.

The diameter of a well, however, should be selected only after a careful consideration of all factors such as the desired yield; the type of well construction; the type of pumping equipment to be used; the physical character of the water bearing formation, etc.

One principal reason for increasing pipe diameter is to provide sufficient space for pumping equipment large enough to yield the quantity of water required. It is important also to note that increasing the size of the pipe will not necessarily increase the amount of water depending on the water available in the formation. A 6 inch diameter pipe, for example, might yield just as much water as an 8 inch pipe, if the well could yield a given maximum amount of water per minute and the pumping equipment in the 6 inch well could deliver this maximum quantity per minute.

The yield of a well also depends on the makeup of the formation. A well yields more water rapidly as the coarseness of the material increases. Thus a well finished in coarse material can provide a large quantity of water easily, because of the speed that the water enters the well. Increasing pipe diameter will not provide as great an additional yield as increasing pipe diameter in a well developed in a finer formation.

It should also be emphasized that, all other conditions being equal, the amount of sand-free water which can be obtained from fine water-bearing sands is directly proportional to the diameter of the well. This is because increasing the well diameter will decrease the velocity of the water as it enters the well and consequently reduce the danger of pumping fine sand.

OTHER USES FOR DRILLED HOLES

1. Oil Wells

Both the rotary and percussion drill equipment described in principle in this book are used to drill oil and gas wells to varying depths.

2. Seismographic Drilling

This is a process wherein rotary or percussion drills are used to put down a number of holes in a particular formation. An explosive charge is then dropped to the bottom of each of the holes and the charges are exploded simultaneously. The vibration readings which are taken from this are then used to analyze the type of formation in which the holes were drilled.

3. Blast Holes

Both rotary and percussion drills are used to drill holes in which dynamite charges are placed to shatter rock or coal in mining, quarrying operations, highway construction and dam construction.

4. Coring

To obtain a more complete picture than is furnished by cuttings, cores are required. These are obtained by use of a core barrel attached to the bottom of the drill pipe instead of the regular bit.

Most core barrels consist of two concentric tubes with a space between for the passage of circulating fluid. (See figure 14). As the bit penetrates the formation, a core of material protrudes up into the inner tube where it is held by a lifter or gripping device.

Core barrels are usually long enough to take 10 feet of core after which they are pulled up. Another type used in drilling deep wells is made so that the inner tube can be withdrawn through the drill pipe. Thus it is necessary to pull the drill pipe only when replacing worn out cutters or bits.

5. Sampling

Successful well drilling whether for water or for geological information requires that the driller recognize formations and changes in formations as he drills down through them. He must keep a written log of formations. The log should also contain an accurate account of the depth of the bit below the surface to log formation changes correctly.

When properly taken, rotary samples usually identify water bearing formations in shallow water well drilling. Samples are taken every 5 feet; more often, if necessary. After taking each sample, the bit is hoisted about one foot off the bottom of the hole and rotated slowly while the mud circulation is kept up to full volume. As the mud comes to the surface, it is screened carefully and the samples are placed in a suitable container.

After this operation is completed, drilling is resumed for another 5 feet and the sampling processes repeated. In this way as the hole goes deeper, the driller gets an accurate sampling of the various formations through which he is drilling.

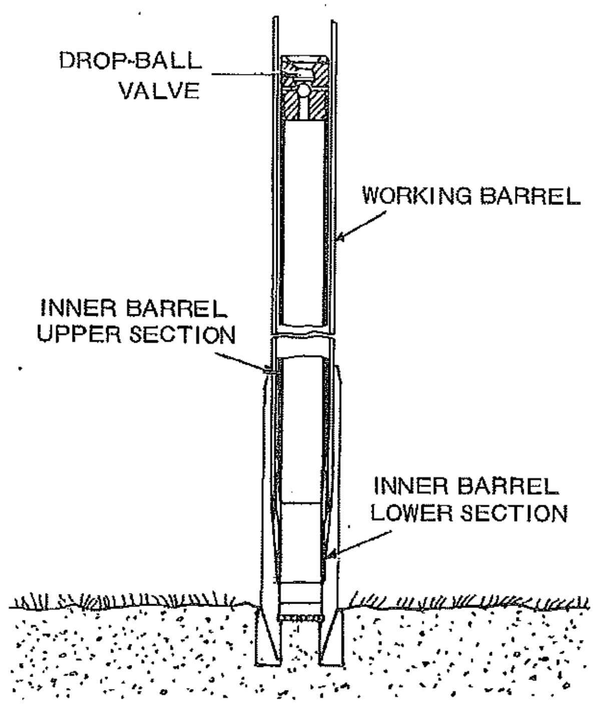


Fig. 14 Core Barrel

HOW DEEP A WELL?

Specialists in drilling petroleum wells are used to depths of 6,000 to 26,000 ft. (1829 to 7925 m.). But the rigs they use are beyond the price range of the waterwell driller.

For all practical purposes, the average driller has a choice of equipment with a reach from 300 to 6,000 ft. (91.4 to 1829 m.).

The cable rig drill range is from 300 to about 4,000 ft. (91.4 to 1219 m.) drilling depth.

CHAPTER 5 THE CABLE TOOL DRILLING MACHINE

The cable tool drilling machine drills holes by the percussion method of drilling. The hole is constructed by the striking and cutting action of a drilling bit that is alternately raised and dropped. The drill bit, a long, chisel-edged tool, breaks the formation into small fragments. The reciprocating motion of the drilling tool mixes the loosened material into a sludge that is removed from the hole at intervals by a bailer or sand pump. The drilling tools are operated by suitable machinery which is usually of the portable type mounted on a truck or trailer so that it can be moved readily from job-to-job.

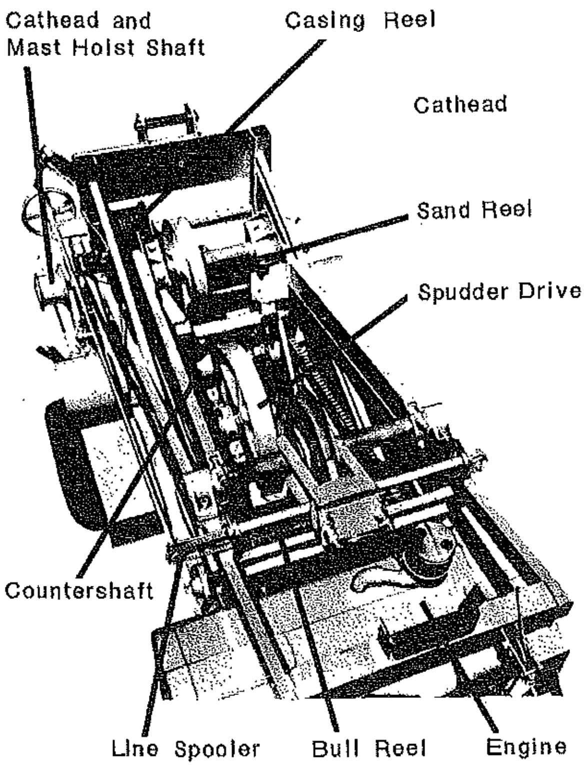


Fig. 15 Principal components of cable tool drilling machine made by Speedstar Division of Koehring Company.

The frame. The main frame is made of electrically welded steel. All shaft bearings are mounted directly to the main frame. Each bearing is kept in alignment by either a machine seat or steel blocks welded to the frame. The power unit can be gasoline, diesel, LPG or natural gas. Power is transmitted from the engine to the countershaft by V-belts.

Spudder. The spudding gear is in the center of the frame and is supported between two bearings mounted on center I-beams. The assembly consists of two forged crank arms driving two forged pitmans which in turn operate two spudder arms.

Bull reel. The bull reel hoists and lowers the drilling tools into the well. It is usually driven by a roller chain and is engaged by a clutch mounted on the counter shaft. The bull reel drum has a divider which separates the working and storage side for the drill cable.

Casing reel. Sometimes called the calf reel, the casing reel is used to handle the casing pipe, well pipe and pump.

Sand reel. The sand reel is used to hoist and lower the bailer which removes drill cuttings from the well. It is friction or chain driven from the countershaft and is mounted on antifriction bearings.

Mast or derrick. The telescoping type structural steel mast ranges in height from 36 to 60 feet (11 to 18.29 m.) and handles working loads of from 15,000 pounds (6804 kg.) to 45,000 pounds (20412 kg.) depending on the model. The mast lays on the machine for transporting.

Pitman. Pitman arms connect the end of the spudding beams to cranks. The spudding beams impart the reciprocating or up and down drilling motion to the drill tools.

Derrick head shock absorbers. The derrick head shock absorbers consist of rubber discs located beneath the crown sheave. Each disc consists of two concentric rubber rings permanently bonded to a steel plate. As the tool string drops in its drilling motion, it squeezes the rubber discs together. When the tool hits bottom and tension is removed from the discs, they expand and provide a snap-action which tends to pull the tools off the ground as the motion of the spudding arm brings them back up for the next drilling stroke.

Countershaft. The countershaft is mounted on precision type roller bearings and is provided with disc type clutches for driving the bull reel, casing reel and spudder.

Cat-heads. Cat-heads are reels located at the working end of the machine and are clutch driven from the countershaft. They are generally used for moving heavy materials at the job location.

Traveling blocks. A traveling block with swivel hook is used with the casing reel for handling casing over the hole.

PRINCIPAL OF OPERATION

In percussion drilling there are basically three major operations: first, drilling the hole by chiseling away the rock, clay or other material with the up and down motion of the drill bit; second, removing the cuttings with a bailer as they accumulate in the hole; third, when necessary, driving the well casing down into the hole as the drilling proceeds. This casing pipe ranges anywhere from 4 to 24 inches (10 to 61 cm.) in diameter in most percussion type drilling operations, and is used to keep the well hole secure from cave-ins and seepage of water or impurities surrounding the hole above the water table level. In the case of cable tool drilling in caving formations, drive pipe is set in the hole immediately, or as soon as the hole is a few feet deep. It may be necessary to drive the first joint by use of tools. Place block over top of pipe and set bit on block or place drive clamps on lower stem square for light operation. As the drill bit moves down into the formation, the casing tends to follow the bit into the hole. When it reaches the point where the top of the casing is at ground level, the drill tools are removed from the hole and another length of casing is screwed or welded to the top of the length that is in the ground. When the drive pipe friction resistance is greater, the casing is driven into the ground using drive clamps attached to the top wrench square of the drill stem. This triple action of drilling, removing cuttings, and driving down the casing continues until water bearing strata or solid formations are reached.

TOOL SELECTION

The most important factors affecting the selection of the proper tools are the hole size or range of hole sizes, the capacity of drilling machine, the height of the mast, the type of formation and the joint size. The joint size determines the size of the wire line socket and the drilling jar. The diameter and length of the drilling stem will remain a variable, but generally the length of the stem should not exceed half the height of the mast of the drilling machine. Thus, if the mast is 36 feet high, (10.97 m.), the drill stem should not be longer than 18 feet (5.49 m.). Also keep in mind that the water course in the drill bit provides a passage for the fluid, and stirs cuttings to hold them in suspension. A better penetrating rate will be obtained from long water course bits because of improved mixing of fluid and drill cuttings.

The first factor in selecting tools is the machine's tool weight capacity. The weight of any single tool for given size hole is primarily governed by two factors: joint size and length of the bit and stem. It is best to use tools with a joint as large in diameter as is consistent with the diameter of the hole, provided that the weight limitation of the machine is not exceeded, rather than carry the weight in tool length.

Although the original cost of the tools will be slightly higher, the amount of service gained in using larger joints will more than offset the difference in cost. Downtime can be expensive if tools with small joints prove inadequate. In many areas, formations may be so difficult to drill that more consideration must be given to the joint size than otherwise necessary.

Tool sizes. Recommended tool lists are divided into two categories: first, those tools for smaller drill rigs where the joint sizes, which determine tool diameters and thus weights, are of necessity limited in size but adequate for normal or average drilling; second, those tools for larger, big capacity machines where joint sizes present no weight limiting factors. These are large as is consistent with the well bore diameter. In selecting drill tools for a particular operation the driller should consult with the drill rig manufacturer's representative and insofar as possible should furnish the following information:

1. diameter and depth of the well
2. outside and inside diameter of the casing
3. capacity of the machine
4. size and type of drill
5. size and type of drill line
6. character of the formation (if known)
7. any other information that might disclose the need for special equipment

THE DRILL STRING

The drill string consists of a series of drill tools, each attached to the other, which are used in the cable tool drilling operation. In selecting the tools it should be remembered that the drill machines were designed for certain capacities and that a string of tools carefully selected to match the capacity of machine will prove most practical. Generally speaking, operating at proper speed with a tool weight which the drill rig will lift smoothly and drop rapidly with a good, clean, sharp blow results in the best drilling time. Operating speeds naturally vary with the character of the formation being drilled. A complete string of drilling tools from top to bottom is shown in figure 16 on the following page.

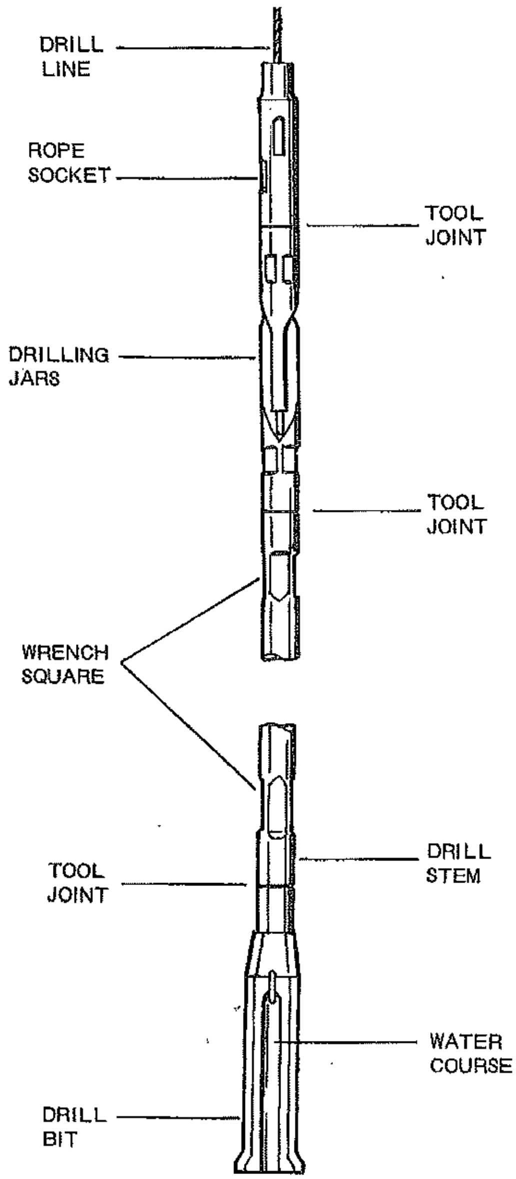


Fig. 16 Drill String

The rope socket and mandrel. Prosser swivel sockets are the type most commonly used in the industry. Connection is made by passing the wire line down through the hollow body of the socket and setting the end of the line into swivel or mandrel. There are two methods (the wet and the dry) of setting the wire line in the swivel.

Wet method. First, the wire is wrapped tightly with a binder of soft wire or electrician's tape, and pulled through the swivel from the small bore, as shown in figure 17. Second, binder wire is placed approximately 4 inches (10.16 cm.) from the end binder. Next, the end binder is removed and the strands opened up and thoroughly cleaned with gasoline. The flared end of the cable is then drawn into the swivel hole until

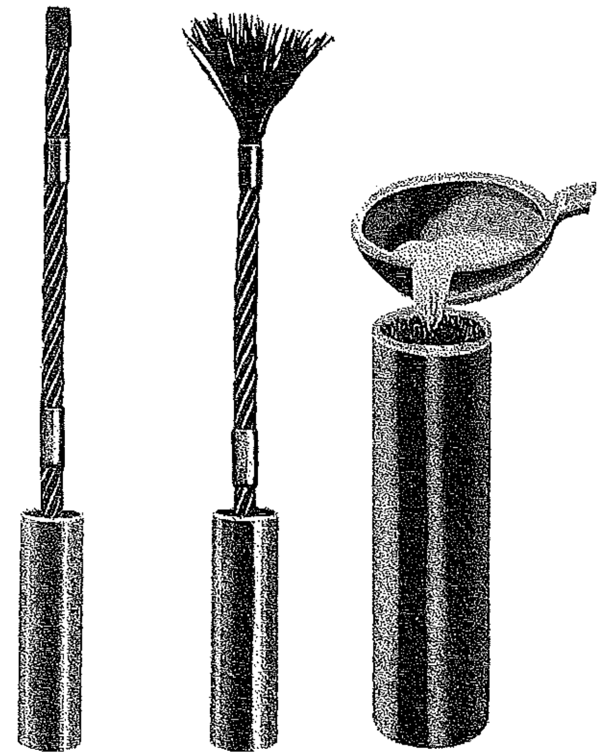


Fig. 17 Wet Method

the ends are even with the end of the swivel. The space around the wire at the bottom is plugged with putty or clay. Pure zinc is melted and poured in, to fill the socket with one pouring. The mandrel then drops into the socket and the cable is ready for use. Care must be taken in heating the zinc to about 830^{0}F. as overheating or burning results in a weak binding between the metal and the swivel.

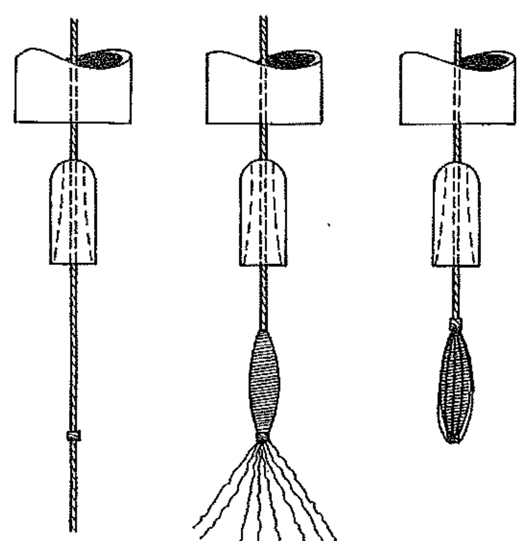


Fig. 18 Dry Method

Dry method. When no zinc is available use the dry method as follows: the cable is inserted through the socket and swivel as described above. The cable is backed with a wire binder about 6 inches (15.24 cm.) from the end to prevent the cable from unlaying past this point. The operator then uses a piece of soft wire or cotton string and wraps it tightly around the binder, building it up to a diameter of an inch and a half (3.81 cm.) and a length of three inches (7.62 cm.), tapering in each direction from the center of the ends. Next, he unlays the strands, bends them back over the knot of soft wire and cuts off the core. He then pulls the ends of the strand against the cable, and inserts them in the swivel. A hammer is used to drive the knot into the swivel. This method, if properly used, will be satisfactory in all shallow well water drilling.

Rope saver. The rope saver is a wire line attachment that slips over the neck of the drill line socket. It prevents the line from kinking at this point when the tools are raised from any position other than the vertical. It has a quarter-circle rope groove which the line should follow when the tools are raised. If this rope saver is not used it may result in a serious kinking of the line at the rope socket neck.

Drilling jar. Drilling jars consist of two connecting links, with a pin on the upper link and a box on the lower end (figure 20). The pin end connects into the box end of the swivel socket and is directly under it. Jars are needed when drilling in soft formations and the tools are likely to stick. If jars are not used, care must be taken when using freshly dressed bits to keep them from sticking. Jars are seldom used when the pipe is being driven as this just creates wear on the jars. New jars come in various size strokes. These increase as the jar heads wear. Jars are not safe when wear has increased the stroke too greatly. The severe service required of jars makes it necessary to inspect them daily for cracks or chips.

If the tool string should become stuck in the hole, the cable should be loosened and the jar links opened to their full length. On the upstroke the upper section of the jars and the socket will jar the tools loose when the jar links snap together. Generally, this will loosen the tools and drilling can be continued.

Drill stem. The drill stem furnishes the necessary weight to the drill string (figure 21). These vary in size and length depending on the tool weight capacity of the machine. In shallow depths a single stem is sufficient. For deeper driving, another stem can be connected to the line to add greater weight. The stem is always placed below the jars, except when reaming or on special jobs. The stem must be handled carefully as even a slight bend in it will cause trouble. Each drill unit should have extra joints to fit those in use for replacement purposes. If a pin or box is damaged beyond repair, the defective joint should be cut off and a new one welded on.

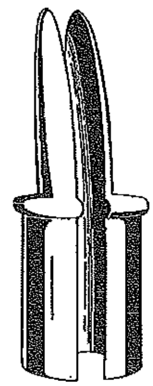


Fig. 19 Rope Saver

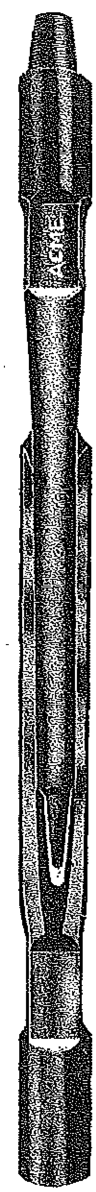


Fig. 20 Drilling Jars

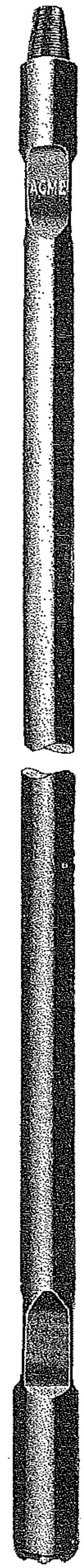


Fig. 21 Drill Stem

Fig. 22 Bit

be handled carefully as even a slight bend in it will cause trouble. Each drill unit should have extra joints to fit those in use for replacement purposes. If a pin or box is damaged beyond repair, the defective joint should be cut off and a new one welded on.

Bit. The bit, of course, is the tool which does the actual drilling. The pin end of the bit screws into the box of the drill stem. The bit consists of the cutting edge, the body in which the water channels are formed, the wrench square, the shank and the pin. The regular pattern bit (figure 22) is the best all-around bit. The bit is never allowed to wear down below gauge, especially when drilling in the harder formations since the diameter of the hole will decrease as the gauge for outside diameter of the bit wears down. Other types of bits include the Star bits and spudding bits. The wrench square on the bit, of course, is used to tighten, remove or insert a drill bit into the tool string.

Tool joints. A tool joint, is the tapered end and the conforming box into which the pin fits. Each tool in the string has a pin and a box except the bit which has only the male end and the swivel socket which only has the box or female end. Joints are machined to close tolerance. Good care and careful handling are essential to keep them in proper condition. They should be kept clean and free from rust. Do not attempt to make up a joint if the threads are battered. A tool joint must be water tight. If a leak occurs, inspect shoulders for depressions and collars for cracks.

Tool wrenches. A set of tool wrenches, one right handed and one left handed, should be included with each tool string. Tool wrench squares must conform to the squares on drilling and fishing tools.

BAILING

Bailing is the process of removing drill cuttings from the well by means of a bailer or vacuum sand pump. The bail is attached to the sand reel line and is lowered into the hole after the drill string has been removed.

In bailing it is not necessary to raise the bailer more than a few feet off the bottom of the hole in any formation to obtain a valve action which will pick up the cuttings. Bailers are available in the following types:

Dart valve bailer. This type of bailer is used in most bailing operations. The dart valve opens when it contacts the cuttings at the bottom of the hole. When the bailer is lifted, the dart valve automatically closes and traps the contents in the bailer. In raising or lowering the bailer in the hole, some indication as to condition of the hole may be noted. If the cuttings or sand and gravel are too heavy, or in too great quantity, a sand pump is used.

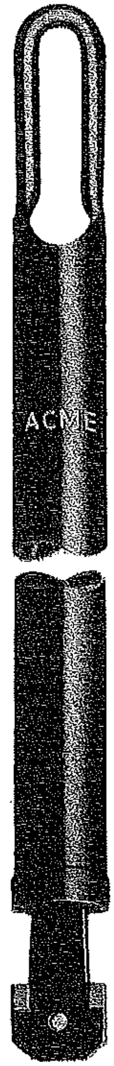


Fig. 23
Dart Valve Bailer

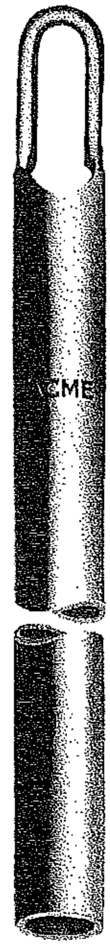


Fig. 24
Flat Bottom Bailer

Fig. 25
Sand Pump

To remove the cuttings from the dart valve bailer, it is surfaced and set down on the ground forcing the dart valve into the bailer body and releasing water and cuttings. Occasionally foreign matter may wedge dart valve in open position. Obstruction should be removed so bailer can retain its load.

Flat bottom bailer. The flat bottom bailer is used in the same manner for the same purpose as the dart valve bailer. Cuttings and fluids are forced through a flapper type valve as the bailer is raised and lowered at the bottom of the hole. Flapper plate closes when bailer is raised. The design enables this type of bailer to clean out closer to the hole bottom than regular dart valve bailers. It is used in some sand and gravel formations where the proper function of the dart valve bailer is not possible. Unlike the dart valve bailer the flat bottom bailer must be upset for dumping unless a removable flat bottom bailer is used. The operator merely sets the end of the bailer on the ground, pays out line from the sand reel so that the bailer is stretched out flat on the ground and the contents can run out the top.

Sand pump. The sand pump is used in sand and gravel where the dart valve bailer will not pick up the material. It is made of tubing with a hinged flap valve and a plunger that works inside the barrel. The sand line is attached to the top of the plunger rod. The sand pump is lowered to the bottom of the hole, allowing the plunger to travel to the bottom of the sand pump. When the plunger is raised, material is sucked into the bailer. When the plunger reaches the top of the sand pump bail, it raises the pump and the hinged valve closes. Pump is emptied by releasing locking latch on side of pump bottom and turning bottom one-quarter turn. Some sand pumps have a hinged valve on the lower end that may be tripped for emptying the contents. Sand pumps are usually available in 10 foot (3 m.) or 20 foot (6.1 m.) lengths.

PIPE DRIVING EQUIPMENT

Equipment needed to drive pipe or casing into the hole as the drilling operation proceeds consists of the following:

Drive clamps. Drive clamps, used in driving casing or pipe, are attached with bolts and nuts to the square of the drill stem at the pin end. When driving, the clamps strike the drive head or coupling at the top of the casing, thus driving the casing into the ground with each stroke. The stem serves as a guide through the head and furnishes the necessary weight for driving.

Drive heads. Drive heads are used at the top end of the upper joint of pipe to protect the threads from being damaged and the casing being collapsed. They are made in the following types: outside drop, inside drop, and screw.

During the driving operation the outside drop drive head is put in place on the pipe by a "skirt" which extends down about 12 inches around the top of the pipe.

The inside drop drive head drops down inside the pipe instead of slipping over it. Frequently it is more practical because the driller can use it with pipe which varies slightly in dimension.

A screw type drive head is equipped with threads and screws into the drive pipe coupling far enough for the head to set against the top of the coupling. This type of head when properly screwed in and seated against the coupling is practically an integral part of the drive pipe.

Drive shoe. In driving pipe or casing, a drive shoe is always attached to the lower end of the pipe to prevent the pipe from collapsing in formations where it is subject to damage by driving. Drive shoes are threaded to fit the pipe or casing, and the inside diameter

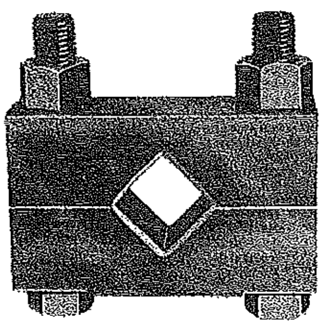


Fig. 26
Drive Clamp

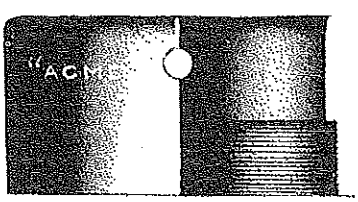


Fig. 27 Drive Head

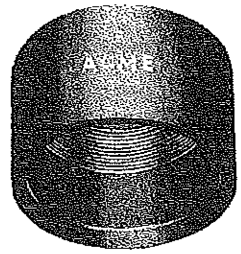


Fig. 31 Drive Shoe

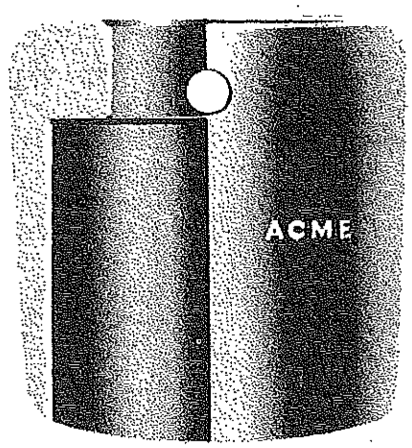


Fig. 28 Outside Drop Drive Head

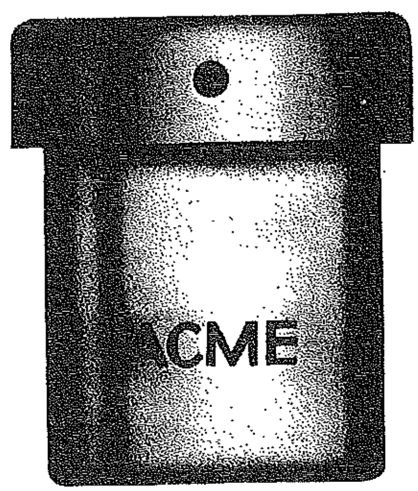


Fig. 29 Inside Drop Drive Head

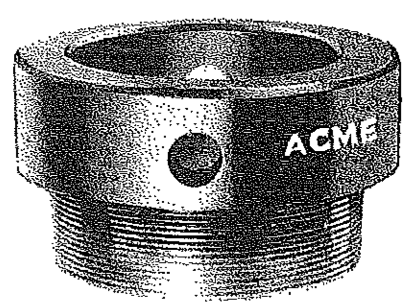


Fig. 30 Screw Type Drive Head

of the pipe. These shoes are of forged, high carbon steel without welds. The base of the shoe is beveled to form a hardened cutting edge.

Casing elevators. Casing elevators are used to raise or lower strings of pipe or casing. They are usually purchased in sets consisting of two elevators of the same size. When used in sets, the casing ring is not required. One elevator supports the pipe, the other elevator is used to handle the next joint. If the casing ring is used, one half set, or one elevator, is sufficient.

Casing elevators are generally manufactured in two types; the heavy pattern elevator used to raise and lower heavy strings of pipe or casing and the light pattern elevator which is used to raise or lower light strings of casing or pipe.

FISHING TOOLS

Fishing means working at recovery of tools, cable, sockets, etc. which are lost in the hole because of breakage of some part of the line or breakage of the tools themselves. It also involves getting hold of a string of tools stuck in the hole after the cable is purposely cut. A minimum stock of fishing tools should include Babcock rope socket, fishing stem, fishing jars, latch grab, friction socket, combination socket, and full circle slip socket.

Babcock sockets. For fishing work the Babcock socket is used instead of regular swivel socket. This is to reduce to a minimum the rotation of the fishing tools. The Babcock socket may be attached to the drilling line by either the wet or dry method already described.

Fishing jars. Fishing jars are of the same construction as drilling jars, except that their stroke is much longer. The fishing jar is usually attached above the fishing tool and below the fishing stem. A certain amount of up-jarring or upward pull can be done with the regular short stroke jar, but they give the driller small chance to control his jarring operation. If the object being jarred moves upward a short distance the jars will start hitting up or down too quickly; or, in other words, hitting both ways. This is almost sure to break a hold. Sometimes it takes days to get a hold of the tool and may be impossible to repeat. Thus, it is not wise to attempt a fishing job without regular fishing jars.

The fishing stem attaches to the Babcock socket. This tool is next in line on the fishing string and threads into the fishing jar. This fishing stem can be identical to the drilling stem but it is generally shorter depending on the hoisting capacity of the machine. Generally fishing stems have a maximum length of 10 feet (3.048 m.).

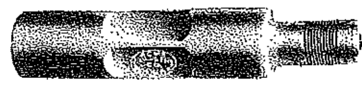
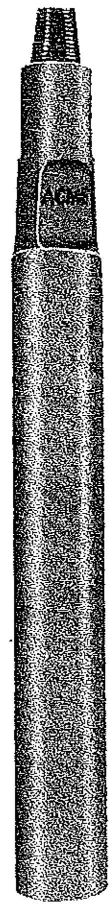


Fig. 32 Babcock Socket



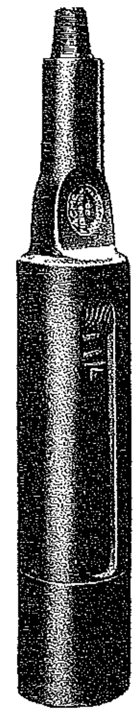


Fig. 35
Full Circle Slip Socket

Fig. 34 Friction Socket

Fig. 33 Fishing Jars

Friction socket. When a bit is unscrewed or broken off a friction socket is used first. No serious attempt should be made to recover the lost tool while running this socket for the first time. The driller should set the fishing tools down on top of the lost tool and drive down lightly with the jars. He then pulls the fishing tools to the surface and examines the marks on the socket. If they show the socket went over the end of the tool, he should run the fishing tool back in the hole and drive the socket far enough over the lost tool so it takes a friction grip strong enough to pull up the tool. If the marks on the socket show that it went down next to the lost tool, this tool should be stopped as it will only buckle the string and drive the lost string deeper into the wall of the hole.

Full circle slip socket. The full circle slip socket has hardened steel slips which will take a firmer hold on the lost tool than the ordinary friction socket. The slips are in various sizes, for catching a broken drill stem box collar, pin collar, or other round objects. Its use is desirable when the tools to be recovered are frozen in the hole by cave-ins or drill cuttings. The slips are not used with the socket until after it has been run to determine whether or not the socket goes over the lost tool. Otherwise the slips may be lost or badly damaged.

After catching hold of the lost tool, care should be taken to avoid hitting down on it with the jars, as this also breaks or damages the slips so that the hold is broken.

The split design of the slips permits four slips to be held in their proper position in the socket by two reins. Reins are fastened together at the top end by a bolt. A short distance below this bolt a pin passes across the body of the socket. The purpose of the pin is two-fold; one, it prevents the slips from being pulled out of the socket and lost in the hole in case of a broken tool, and two, it prevents the socket from going over the lost tool too deeply and damaging the slip assembly and tension spring. The pin will not stand much jarring, and it is important to flag or mark the line to indicate top of the lost tools and to keep careful check of measurements when taking the hold. It may or may not be necessary to jar down to set the slips. Do not jar both up and down unless the lost tool cannot be loosened otherwise.

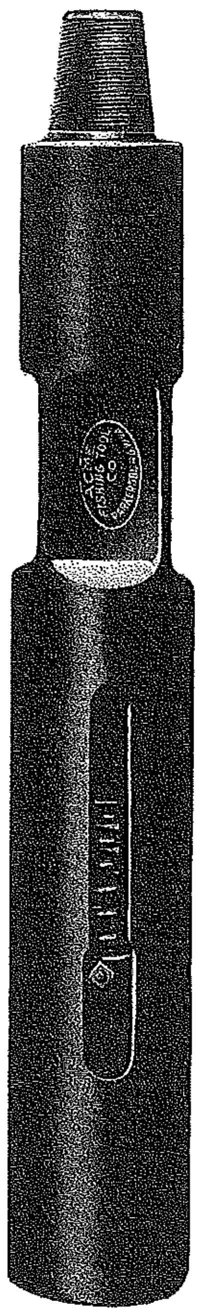


Fig. 36 Combination Socket

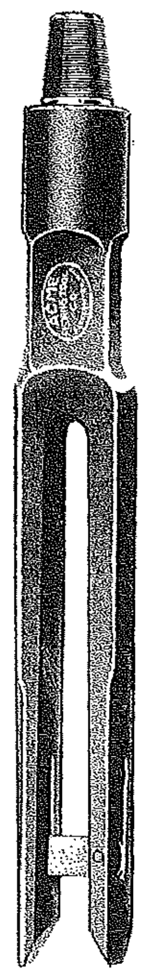


Fig. 37 Latch Jack

Combination socket. The combination socket is made to catch the neck of the rope socket or pin of any bit or tool which becomes unscrewed in the hole. It can also be used to catch any cylindrical object such as tubing standing upright in the hole, providing the bore is at least 1/8 inch (.32 cm.) larger than the diameter of the piece to be caught.

Latch Jack. The latch jack is used for fishing out bailers or sand pumps. A latch jack consists of two heavy prongs with a latch on the bottom which works inside the prong body. It has a pin joint on the top for attachment to the fishing string. Size is based on the hole diameter in which the jack is used, and on the joint size of the fishing tool string. The latch jack is lowered into the hole until contact with the lost object is made. The latch is then pushed upward by the hook or ring of the bailer. As the bailer hook slips past the latch, the latch drops down and secures the bailer. If the tool has been hooked, additional power will be needed to pull it loose from the hole. If not, the latch jack should be lifted and lowered again until a catch is made.

PREPARATION FOR DRILLING

Well Log and Sampling. Before the actual drilling operation is explained, it is important to point out that a well log should always be kept. This is a written record of the geological formations met as the well is drilled. It also includes a record of the pipe in the hole and any other pertinent information that will help in the drilling. In cable drilling accurate measuring marks should be observed at all times. This is most useful and important when drilling in any type of formation, hard or soft. If the exact length of the pipe and hole is not known, as well as the depth at which water bearing formations are met, the pipe may be driven through the formation shutting it off completely. The color of mud or samples is used in logging the well mainly to tell the difference between beds of material. Samples are taken with each change of formation and additional samples made every 5 feet (1.524 m.). These samples are caught by dumping the first bailer load into a bucket.

Water supply. A water supply is needed for drilling wells with a cable drilling machine. Crevices or a dry sand may absorb water making it necessary to add water sometimes in large volumes as the hole is drilled. When sufficient water for drilling is found at a shallow depth, no additional water is needed. Under average conditions 4 gallons (15.14 litres) are required for 1 foot (.3048 m.) of 6" hole (15.24 cm.) and 5 gallons (18.93 litres) for 1 foot (.3048 m.) of 8" (20.32 cm.) hole. The water is needed in order to make a mud solution of cuttings and allow drilling progress by removal of material when bailing.

Setting up drill. Regardless of the type of drill mounting, truck mounted, trailer mounted or skid mounted, drill must be properly set up at the drill site. In setting up the drilling machine the crib mount should be set in the desired place (figure 38). The driller should make sure that cribbing is level and has sufficient mud sills, properly distributed to prevent settling or misalignment of the drill after drilling has started. Four 2 x 12 inch (5.08 cm. x 30.48 cm.) timbers 5 feet long (1.52 m.) will suffice unless the well is drilled in a swampy or poorly drained location. Steel or concrete or other wood can be used also. In such cases, additional mud sills are needed. The weight of the machine should rest on the cribbing rather than on the tires, so the driller should take care that the derrick is properly blocked and loads are carried on the derrick jacks instead of on the hinge pin. (figure 39)

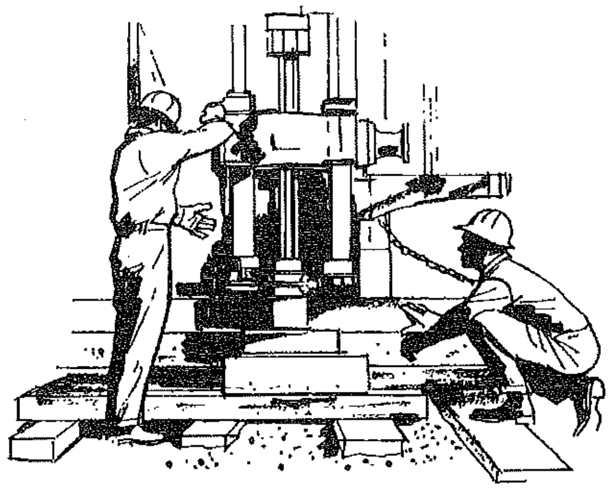


Fig. 38 Placing Cribbing Under the Machine

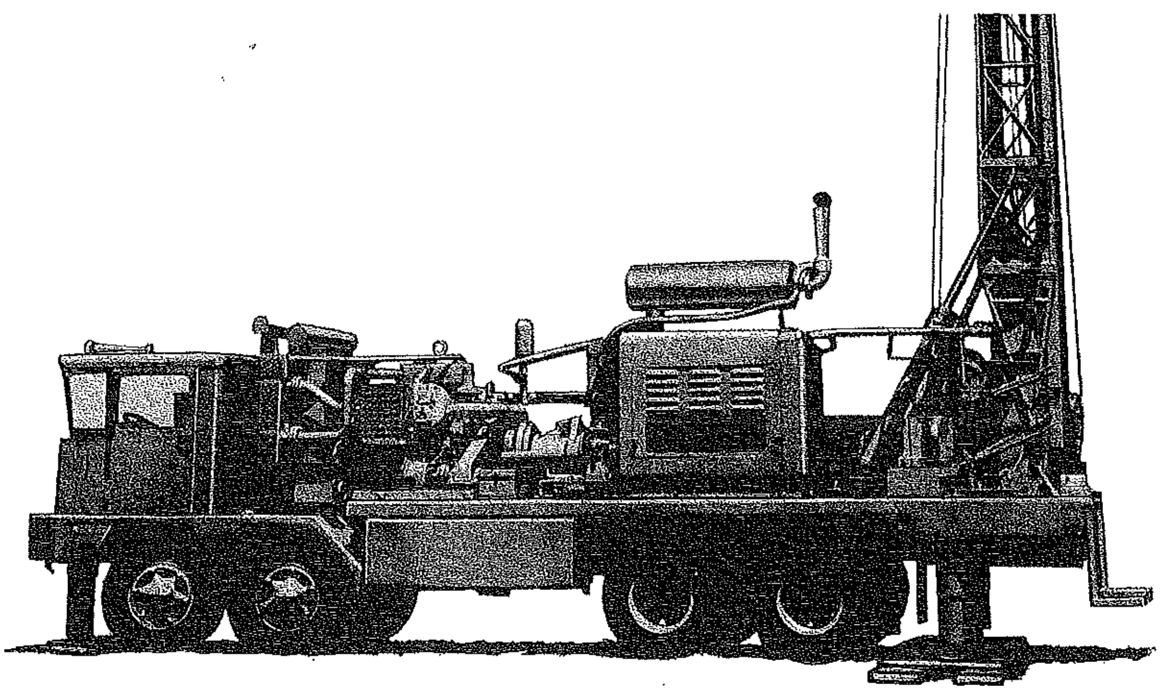


Figure 39 Leveling the Machine

After the drill has been properly leveled, the pin locking the mast in travel position is removed and the mast is raised.

Attaching wire rope to the drums. If the machine has not already been equipped with cable, this, of course, must be attached before the drill can be put to work.

Cable of the proper diameter is based on the size of the machine.

Spooling the bull reel. The spool on which the cable is wound should be placed in position so that the spool rotates as the cable is pulled from the spool (figure 40). The cable should never be unwrapped from the spool when it is in a stationary position because this will cause the cable to "kink" and become damaged. The line should come off the bottom of the reel and pass through a snatch block at the bottom of the drill rig. The line is then passed over the crown sheave at the top of the derrick and down through the drilling line guide. It is then strung under the spudding sheave and back over the heel sheave and onto the storage side of the bull reel where it is anchored by pulling it through two holes in the drive sprocket and secured with a clip or "U" bolt.

Next the bull reel is engaged and the cable is spooled onto the bull reel. When the excess line has been stored, the line is passed through the cross-over and the divider and the rest of the line wound on the working end of the drum.

Spooling the sand reel. The sand line is spooled onto the sand reel in a similar manner (figure 41).

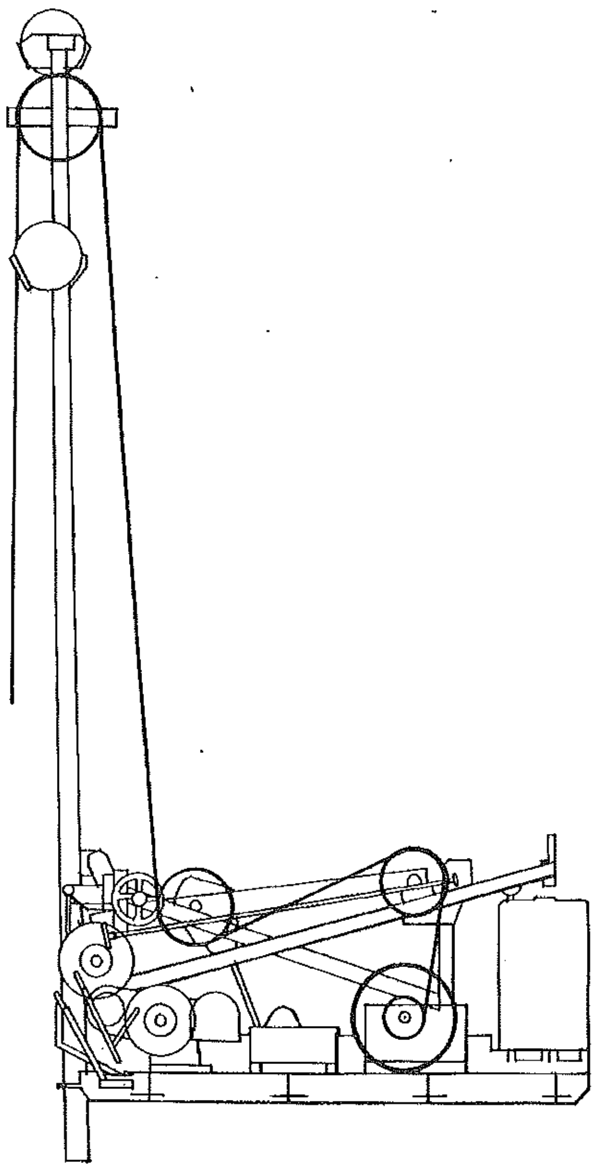


Fig. 40 Spooling the Bull Reel

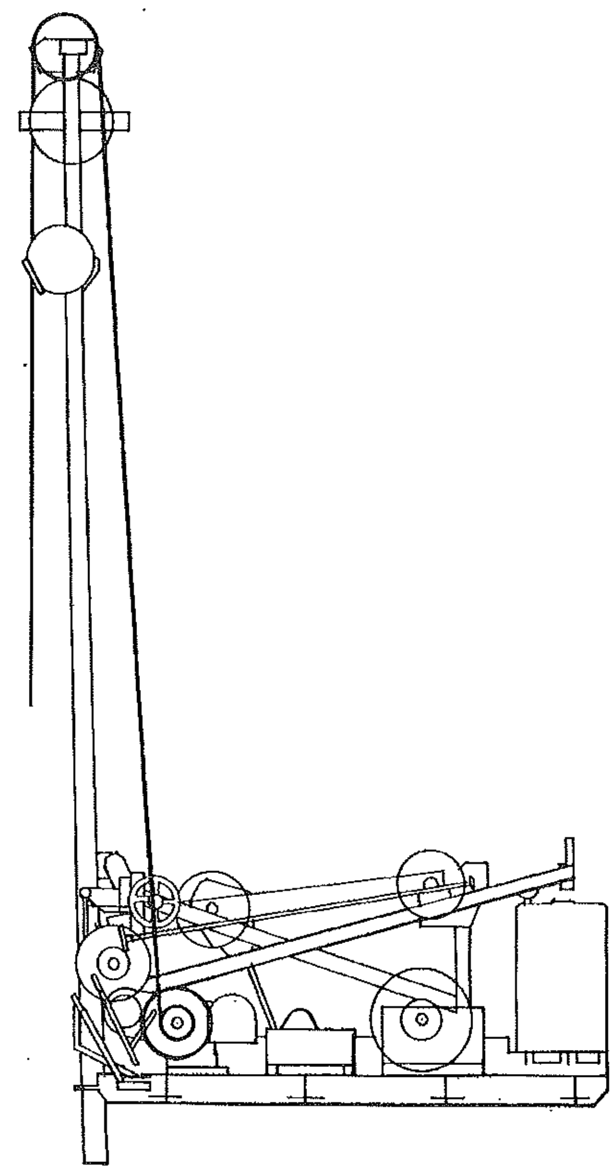


Fig. 41 Spooling the Sand Reel

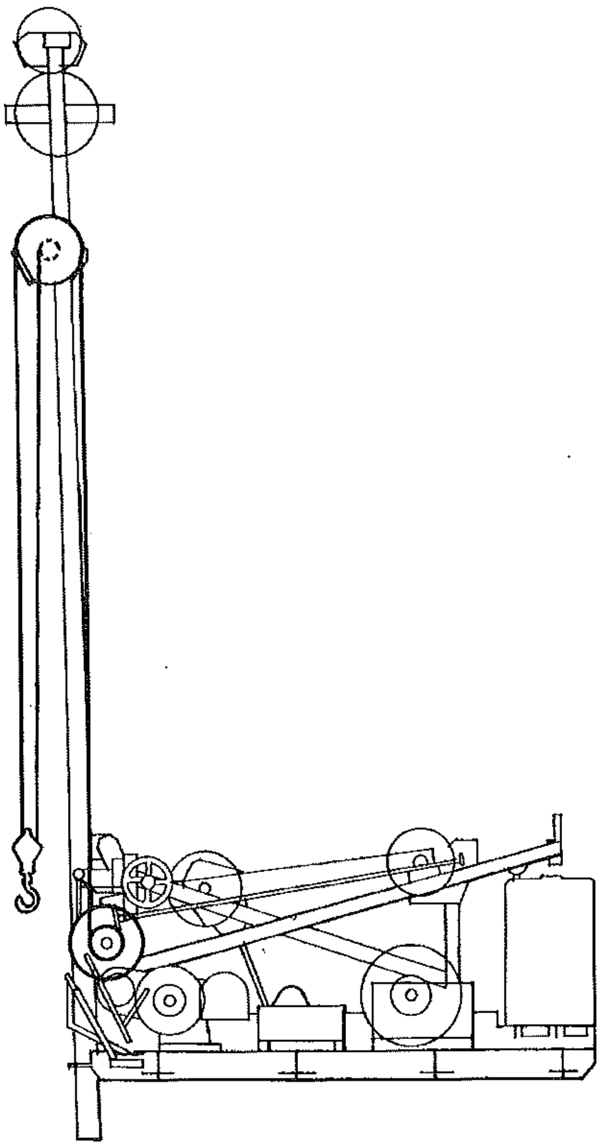


Fig. 42 Reeving the Casing Line

Reeving the casing line. In reeving the casing line, it should be reeved through the casing line sheaves in the derrick head, passed through the travelling block and finally anchored near the mast base.

EXTENDING THE DERRICK

The derrick is raised, extended, telescoped and lowered by a friction clutch and brake control. The raising line has an individual drum used for no other purpose. After the derrick is extended to its full height, it is secured in place by a swinging plate which forms a seat for the upper section to rest on. Mast braces attached to each of four corners of the drill frame and upper points on the mast give stability and add to the capacity of the mast. To provide extra strength for unusually heavy work, 2 or 4 guy wires may be attached at the mast top and anchored to the ground (at 90° positions) by means of steel stakes or buried anchors. If 2 guys are used, anchor at 180° position.

STRINGING THE TOOLS

After the derrick has been fully extended, the rope socket is attached to the end of the drill cable. Next, the drilling tools are attached to the swivel with the drill jar being attached to the socket, the drill stem attached to the drill jar and the drill bit attached to the drill stem in that order. Next, the bull reel is engaged and the tools are hoisted up to the derrick. Be sure to use the wire rope saver when hoisting tools from the horizontal position.

SPUDDING IN

When the tools are swung on the mast they should hang directly down the center. The tools should then be dropped down to the ground hard enough to mark the spot where the hole will be drilled. In starting a hole in soft, unconsolidated formation, the driller should dig a hole about 3 feet (91.4 cm.) deep with a shovel. He should let the tools down until the bit rests on the bottom and fill the hole with water around the bit. He should start the tools by throwing in the spudder beam clutch and run in slowly and guide their movement by hand until a depth of 6 feet (182.88 cm.) or 8 feet (243.84 cm.) is reached. If a tool guide is not available for use in steadying the top of the tools, a man should be stationed in the mast for that purpose. In starting the hole in hard rock, the driller should dig or chisel out a hole 6" (15.24 cm.) deep at the spot where the drill will work. Then steady the tools in the same manner specified above.

Operating speeds differ with depths and character of the hole. The driller should run the drill only fast enough to permit smooth operation, and let the tools drop with a clean, hard blow. He should use a tight line in creviced and irregular formations. In hard rock and abrasive formations the driller should keep his bit to gauge. He should not allow it to wear to a point at which the next full gauge bit will stick, because this requires reaming of the hole before the bit will work free. Reaming causes undue wear on line, jars, joints and machine and loss of time. If drilling progress is not satisfactory, and the hole is straight and tools are working freely, the driller should change to either a longer or shorter stroke depending on the formation. Use the following as a guide: 57 to 65 strokes per minute, 18 inch (45.72 cm.) stroke; 50 to 57 strokes per minute, 22 inch (55.88 cm.) stroke; 43 to 50 strokes per minute, 32 inch (81.28 cm.) stroke; 35 to 43 strokes per minute, 40 inch (101.6 cm.) stroke. The harder the formation, the shorter the stroke.

Best drilling results come when the engine speed and line tension are coordinated with the gravity fall of the tools. As the downward pulling force compresses the rubber shock absorber in the derrick head, the tools "reach out" to strike bottom. Under these conditions the tools will deliver a quick chipping blow at the bottom of the hole and then snap back.

Bailing. While the tools are turning freely and are delivering a fast, snappy blow, there is no need for bailing. But as the mixture thickens and the operator has to reduce engine speed to keep the machinery in rhythm with the falling tools, the hole should be bailed. Usually 4 feet (121.92 cm.) to 6 feet (182.88 cm.) of hole can be made at each "run" of the tools. However, conditions differ greatly and no rule can be set. A clean hole drills better than one filled with thick mud. But in soft formations the mud tends to prevent the hole from caving. Therefore, sometimes it is better not to bail out all the mud and water but only the thicker and heavier part at the bottom of the hole. In this way the hole is kept in better drilling condition than if bailed out clean.

When drilling a consolidated formation the bailing operation is quite regular. After each "run" the tools are pulled from the hole and swung aside while the bailer is used. If the bailer goes to the bottom and the hole is in good condition, the "pick-up" will be indicated by two jerks on the sand line. The jerks are about one second apart and result from the pick-up of the bailer and the pick-up of the dart valve plus the fluid within the bailer. After lifting the bailer 4 feet (121.92 cm.) or 5 feet (152.40 cm.), it is lowered and raised once or twice more, as this helps to pick up any cuttings that might have settled at the bottom of the hole.

If the double jerk is repeated each time the bailer is lifted, it is safe to assume the hole is in good condition.

If only one jerk is noticed as the bailer is lifted, it did not reach bottom. The trouble should be corrected before drilling deeper. Trouble may be caused by flat hole, crooked hole, ball of mud, or projecting boulder.

Driving pipe. When the pipe does not follow the bit down into the hole, it is necessary to drive it in. Pipe is driven with the drilling tools, the drive clamps and usually the drive head described on page 25. First, drive clamps are bolted to the upper wrench square of the drilling stem for driving pipe. Next, a joint of pipe is set up and screwed into the casing string. The drilling tools are then lowered down onto the pipe far enough so the upper square on the drill stem is just above the top of the pipe to be driven. If necessary, when setting the first joint of pipe, the drive clamps can be used on the lower wrench square of the stem if sufficient shoulder is available. In the latter case extreme caution should be used to prevent the tool string from whipping. After the drive clamps are placed on the stem square, pull up on the tool so drive clamps are several inches above the drive head or top of the pipe. Start the spudding action on the machine and slowly lower the tools until the drive clamps make contact. The space between the clamps and the drive head puts the high tension on the shock absorber springs with each stroke of tools and gives the tools a quick, positive pick-up. Once the movement has started the tools can be run at ordinary drilling speed.

After driving for a few feet, the driving speed often will slow down or stop altogether. As the diameter of the hole is less than the outside diameter of the casing shoe, driving or forcing the shoe down through the smaller hole often plugs the pipe. When driving progress is delayed for this reason the tools are run to the bottom and the hole cleaned out. The bit is carried on the drill stem at all times while the pipe is being driven. The additional weight of the bit is important to give the necessary force for efficient pipe driving.

Drillers should not drill farther ahead of the drive shoe than is necessary to drive in one joint of pipe at a time; and never under any circumstances should he drill far enough ahead to place the rope socket below the shoe joint. When a new joint is set up for driving it usually will be found driving progress is slowed considerably, as the drive shoe approaches the bottom of the hole.

It is important that the first 40 or 60 feet (12.19 m. or 18.29 m.) of pipe go absolutely straight. A plumb bob or level used on two sides of the pipe will enable the driller to determine whether this is the case. After the casing is driven to a point where it is slightly off the ground, an additional length of casing is added to the casing string. If the casing is threaded, the new piece of casing is threaded on the one in the hole. If the casing is of the welded type, the new section is welded to the section already in the hole. In this connection, half lengths of pipe are better than the full 20 foot (6.10 m.) lengths. Operation is not only more simple, but it affords better control for driving, drilling, and bailing operations.

In cases when driving pipe is difficult the drilling jars should be removed from the drilling string.

DRILLING IN VARIOUS FORMATIONS

Each type of material that a driller works in presents its own set of problems. It is important, therefore, to know how to handle the pipe under these various conditions.

In soft clay, for example, drilling can be difficult because the clay does not mix well with the water and builds up on the bit so that the water channels become closed and the tools do not fall freely during drilling. As soon as this situation happens, pipe should be driven. Because the clay is soft, the pipe or casing is driven easily and can be pushed far down ahead of the hole. In fact, in heavy beds of this material it is not unusual to drive pipe as much as 75 to 100 feet (22.86 m. to 30.48 m.) at a time before removing the drive clamps and cleaning the hole. Pipe can be driven in this way until it stops moving under the driving blows. If the mixture changes to clay and fine sand, it is still alright to drive ahead of the hole but for shorter distances, such as 5 to 10 feet (1.524 m. to 3.048 m.). Sand causes greater friction against the hole and the pipe will move better if it is cleaned out and opened up a few feet below the pipe. Pipe will move well in sandy formations but not with the soft, springy action as in soft clay. However, there is some danger in driving pipe ahead of the hole. When boulders may be present, short drives are safer.

Hard clay. Hard clays generally do not present any drilling problems, and if there are no stones, big boulders, etc. to change the course of the drill bit and cause the hole to bend, the driller can continue drilling below the pipe until it appears that the bottom of the hole has started to cave. Actually when drilling in clay, it is good practice to drive pipe after the open hole has been drilled to the length of the drilling tool string.

Boulders and hard pan formations. Hard pan refers to extremely hard clays with a possible mixture of boulders. Drilling holes through boulders creates a problem because the drill bit tends to glance off the boulder and the hole can become crooked. The driller can usually tell when the drill bit glances off a boulder and the boulder strikes against pipe because the pipe will vibrate. This can be felt when the driller grabs the drilling cable. When this happens he should stop drilling and drive his casing with great care.

In cases where drilling is extremely difficult, dynamite sometimes succeeds in opening up the hole. If this is not successful, the driller can reduce the diameter of the drive pipe or must start a new hole.

Quicksand. Quicksand frequently presents serious problems to the driller. It comes into the hole and must be bailed out in large quantities before casing

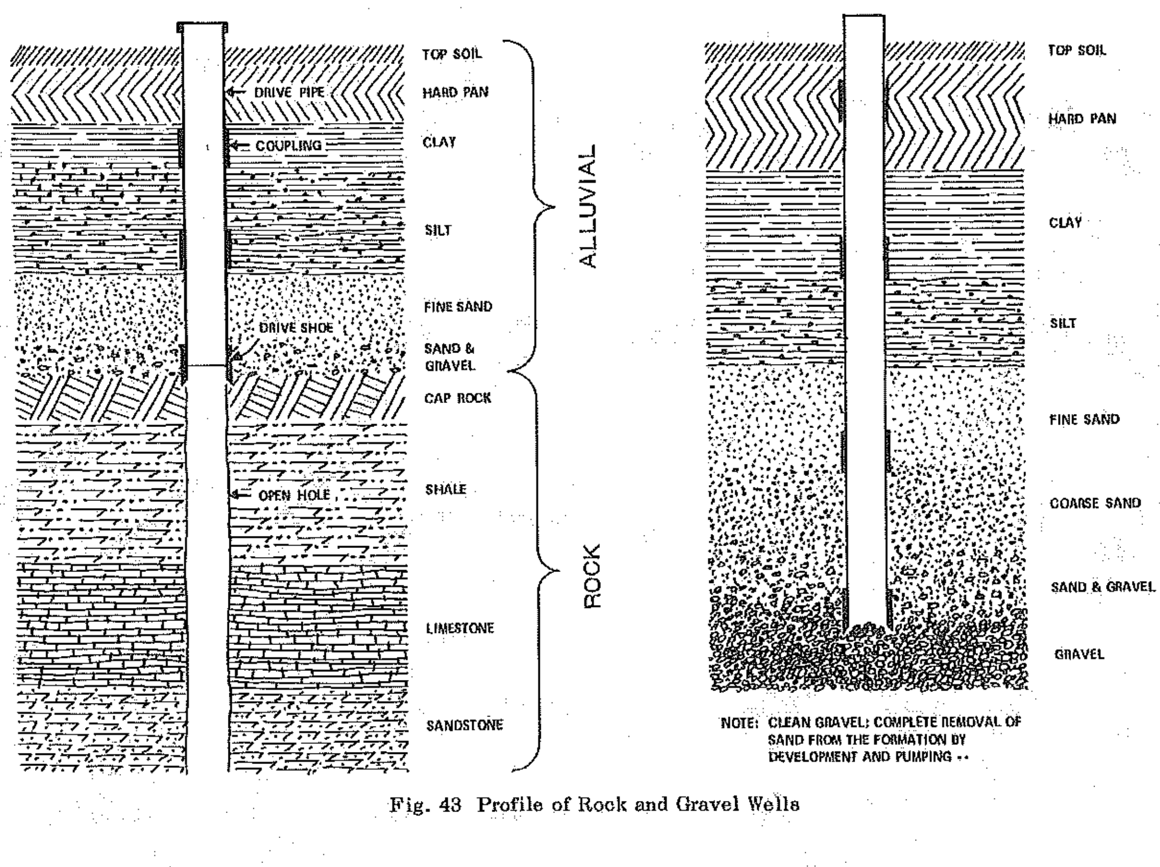


Fig. 43 Profile of Rock and Gravel Wells

can be driven further down and drilling continued. Also, pockets of clay or coarse sand in a quicksand layer cause the driller to believe that he has passed through the quicksand. The coarse sand will not rise if the water velocity through it is less than about 2½ feet (76.2 cm.) per minute. The drive pipe will shut off water and quicksand above such a sand or clay pocket, but after the drill passes through the pocket, the quicksand flows in again and immediately rises in the pipe. If the bed is 20 feet (6 m.) or more thick, the pipe cannot be driven through it, because of the resistance of the compact sand; and if water in the quicksand is under great head so as to force the sand up to or above the point at which the bed was struck, further progress may be almost impossible. In some wells quicksand has risen in the pipe 100 feet (30.5 m.) above the depth where it was struck.

Quicksand can be confined only by using water-tight casing, because it is so fine that it passes through a standard 100-mesh sieve. Quicksand not only requires laborious excavation, but the tools can get jammed in the hole and buried by sand unless it is withdrawn rapidly. The driller then not only must clean out the hole but must also recover the tools. If the tools are stuck, sand should be bailed out and a wash pipe an inch or two (.3937 to .7874 cm.) in diameter lowered down into the well. Water is then poured into the hole until the tools are partly freed. Then a slip socket is inserted over its upper end, and with the help of fishing jars it is jerked free. In removing tools from quicksand, they should be raised slightly at each upstroke and in this way gradually become freed. This should be done rapidly so that the sand cannot pack about the tools.

One method of partly overcoming quicksand is to fill the bottom of the well with mortar or Portland cement which sinks through the quicksand and sets. The hole may be then drilled through the cement which forms a wall to prevent further inflow of quicksand. Stone, clay and asphalt has also been used with some success.

Some drillers keep the drill hole full of water when drilling through quicksand. If the head of quicksand is 100 to 150 feet (30.5 to 45.7 m.) below the surface, the column of water in the well will exert enough back pressure to prevent the sand from rising in the pipe. The sand bailer may then be inserted and the well may be bailed through the column of water. Occasionally, because of uneven pressures in the hole, pipe may become bent when removing quicksand. Here again the remedy consists in keeping the hole full of water.

Sand and gravel formations. Sand and gravel formations are usually loose and have large amounts of water. Caving almost always happens during drilling in these formations and it is necessary to drive pipe a few feet ahead of the hole. Because the driller will often want to complete his well in a gravel formation, he should not drive pipe more than a few feet ahead of his hole as he may get his casing past the best formation.

Bedrock. When a driller reaches bedrock he can frequently drill down without adding any additional casing. However, it is necessary that a tight joint be made between the pipe and the rock in order to avoid leakage into the well at this point and possible contamination.

Actually, it is good drilling practice to go 4 or 5 feet (121.92 cm. or 152.40 cm.) down into bedrock with the casing shoe held a few feet above the rock formation. This type of drilling results in a slight taper forming as the hole is driven down, which results in a tight joint when the pipe is finally driven into the rock. The driller should note that pipe will bind considerably after each blow and the pipe should be carefully watched to see if it is actually moving deeper into the hole.

A good seal depends on the type of rock. In hard formations, for example, a good seal can be made after driving down for a few inches. On the other hand, it may be necessary or desirable to drill 10 or 12 feet (304.8 or 365.7 cm.) into shale to insure a good seal. The driller can usually tell if a good seal has been made when no foreign materials such as sand or small stones are mixed with the cuttings.

Sometimes it is desirable to cement the hole shut at the joint between the pipe and the rock. This, of course, requires a larger hole than the pipe diameter so that cement can be poured in the space between the hole wall and the pipe. This cement can either be forced down with a pump or poured down through a small diameter pipe which extends nearly to the bottom of the hole.

HOLLOW-ROD DRILLING

The percussion or cable tool is sometimes used with the hollow-rod drill attachment. A basic set-up of the machine and the derrick is the same as for the cable drill. The drill rod is attached to the end of the bull reel cable which is reaved over the crown sheave just as in the percussion drilling method. A small hole is dug in the ground and the bit is raised and lowered as in the percussion drilling method. A small amount of water is poured into the hole. As the tools fall, fluid and cuttings are forced into the drill pipe through a check valve which prevents their return to the bottom. Successive strokes completely fill the drill pipe and eventually the cuttings are ejected in a pulsating manner on each stroke. The cuttings are

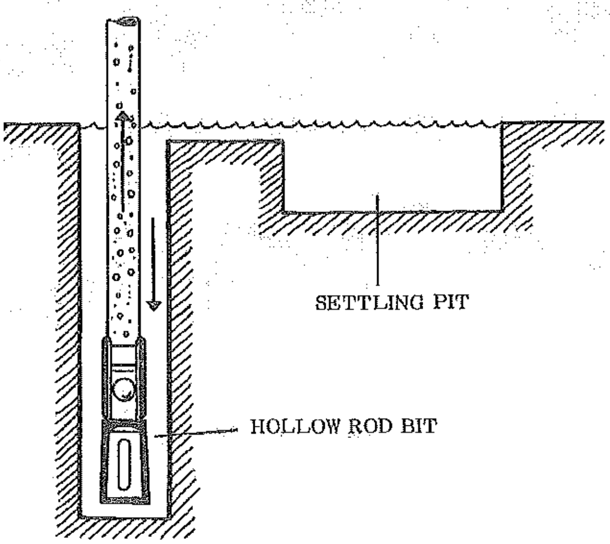


Fig. 44 Hollow Rod Drilling

screened out and the water returned to the hole. After the well has been drilled for a few feet the casing is set in place in the hole. The hollow-rod bit is then lowered into the casing and the drilling resumed. In unconsolidated formations the casing follows the drill bit into the hole. In consolidated formations the drill pipe and bit are removed and the casing driven into the ground. Drilling is then resumed. This method can be used to depths of several hundred feet or meters. The principal limitation in drilling by this method is the fact that it is limited to small diameter holes.

JETTING METHOD

For slightly larger holes, the jetting system is available. Drill rods and drill tools are practically identical to those used in the hollow–rod method, except that the check valve is omitted and a pump must be used. The drill rod with jetting hose attached is fastened to the end of the bull reel cable as shown in the diagram. Originally the pumps used were driven off the drill engine. Today larger pumps are powered with separate engines available in skid or trailer mountings. These centrifugal-type pumps will handle muddy or gritty water and maintain high fluid return velocities. This permits the drilling of larger diameter holes than was previously considered practical by this method.

Drilling operation in jetting is the same as for the hollow-rod method with the tool being lifted and lowered into the ground to obtain the drilling action. The difference is that the pump forces water in through the drill pipe and carries the cuttings out through the space between the drill pipe and the casing. By this method holes ranging from 400 feet (121.92 m.) to 700 feet (213.36 m.) deep can be obtained depending on pipe diameter.

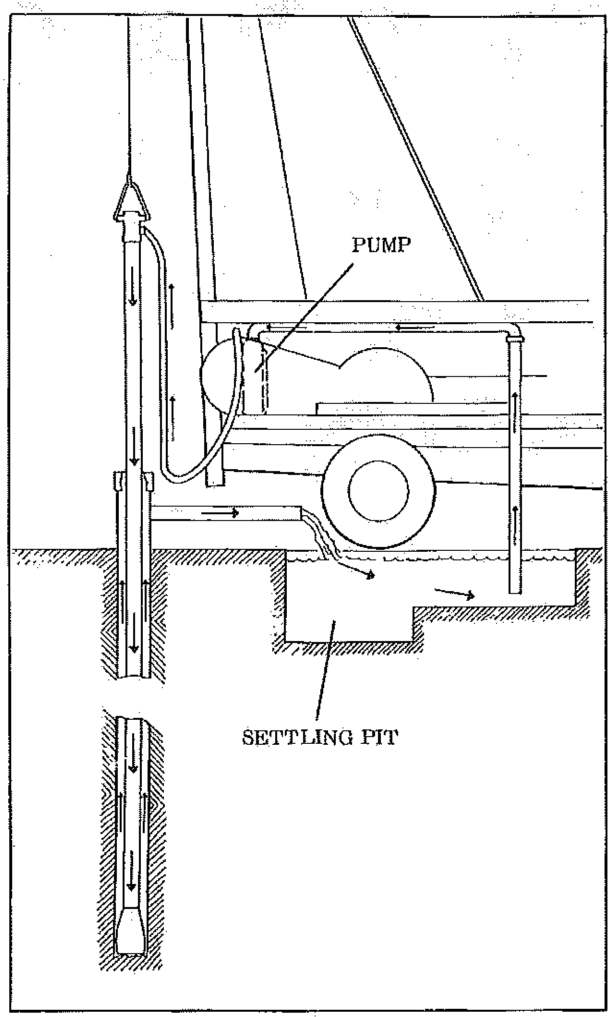


Fig. 45 Jetting Rig

For drill pipe sizes the following dimensions can be used as a guide.

DIAMETER HOLE	PIPE SIZE
4" to 6" (10.16 cm. to 15.24 cm.)	2" (5.08 cm.)
3" (7.62 cm.)	1¼" (3.17 cm.) Extra heavy pipe
2" (5.08 cm.)	1" (2.54 cm.) Extra heavy pipe

BIT DRESSING

As the drill bit pounds a hole through the various materials it wears out and becomes dull with use. During driving it rubs against the side of the casing and against the walls of the hole under the pipe or casing and thus wears out of gauge. Naturally, bits wear faster in abrasive rock formations than in soft clay or dirt. The bit should never be allowed to wear down below gauge, especially when drilling in the harder formations, since the diameter of the hole decreases as the gauge of the bit wears down. Thus, when the striking surfaces become worn, they must be heated and hammered to obtain the proper shape and gauge then reheated and hardened.

In order to properly heat the bits, it is necessary to forge at the drill site. Some drillers build movable forges from steel drums and line them with firebrick. More permanent types are shown in figure 46. The

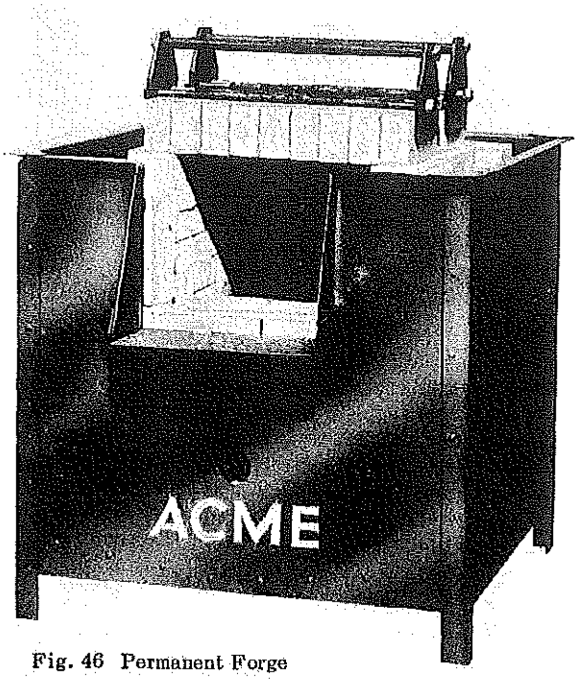


Fig. 46 Permanent Forge

driller can control the air from the blower with a piece of rope which he ties around the hose. By tying off the hose, there is less danger of rapid overheating on the outside of the bit which can damage it. The most desirable location of the forge is on the blower side of the machine. The forge can be set a few feet from the machine as determined by the blower hose.

A slack tub and anvil block are located close to the forge. The anvil block should be located so a man can swing a sledge on either side of the block when dressing bits. Fire clay should be mixed with water to form a paste which is used in laying up the brick in the forge. The fire pot holds in the heat without burning the metal forge. For heating 6 and 8 inch (15.24 cm. and 20.32 cm.) bits, a fire post 12" x 14" (30.48 cm. x 35.54 cm.) is recommended. If only 6" (15.24 cm.) bits are to be dressed, the 12 x 12 inch (30.48 cm. x 30.48 xm.) size is satisfactory. The tuyere pipe should project into the forge so the air blast enters the fire pot at the bottom near the center. As the fire pot walls are built up, the space between the brick and the metal wall is filled with earth. If only sand is available, it should be dampened and tamped.

After the bit has turned red on the under side, it should be turned in the fire for more even heating. The pin end of the bit should be lifted a couple of feet and the bit withdrawn slightly from the fire as it is turned. When the bit is hot enough, the operator should proceed with the bit dressing.

In bit dressing, one of the most important operations is to get the proper heat. The bit is heated to a bright, cherry red, being turned in the fire several times to heat both sides thoroughly. Heating a 6" (15.24 cm.) bit should take not less than 30 to 45 minutes. The bit is hot enough when the steel seems to be soft when a poker is rubbed along the side of the bit near the end.

In order to spread the bit to the proper gauge, the driller should start in the center using the heel of a sledge to draw the steel. He should stand to the side of the bit and as the blow is struck pull the sledge in the direction the steel is being worked. He should always pull the steel to the point and never to the corners, for as the points are filled the steel naturally crowds to the corners. By dressing the bit this way the corners are well stocked or thickened.

In drilling clay or other soft formations, the bevel or face of the bit is kept as short as possible. Long bevels cause the bit to stick and drag when the mud becomes thick. However, in rock the bevel is longer but here if the bevel is too long, it prevents the bit from turning and thus causes flat holes. Further, for drilling in soft, muddy formations, the bit is dressed with a feather edge or a flair which causes the bit to work freely in the hole as it cuts a clearance larger than the body of the bit. On the other hand, in hard rock the bit is dressed with a wearing surface. This is obtained by drawing down the steel after it has been spread giving the shoulders a greater thickness which acts as a protection and gives more wearing surface for the bit.

The bit works better if water channels are kept clean by cutting out the steel that spreads into them from repeated dressing. In cutting out a water channel the body of the bit should never be cut into as this permits water to enter when the bit is being tempered and causes the bit to crack. The peen of the sledge should be used after the bit is spread, driving the steel back into the bit. This also helps in keeping the corners stocked. All of the steel can't be worked out of the water channels this way so it is sometimes necessary to cut the steel away. The best method is to use a regular gouge, as this is shaped like a water channel and will not cut into the body of the bit if used properly.

The operator should never attempt to work the bit after the steel cools to a blue tinge. Steel worked at the wrong temperature becomes brittle and peels and cracks off when used.

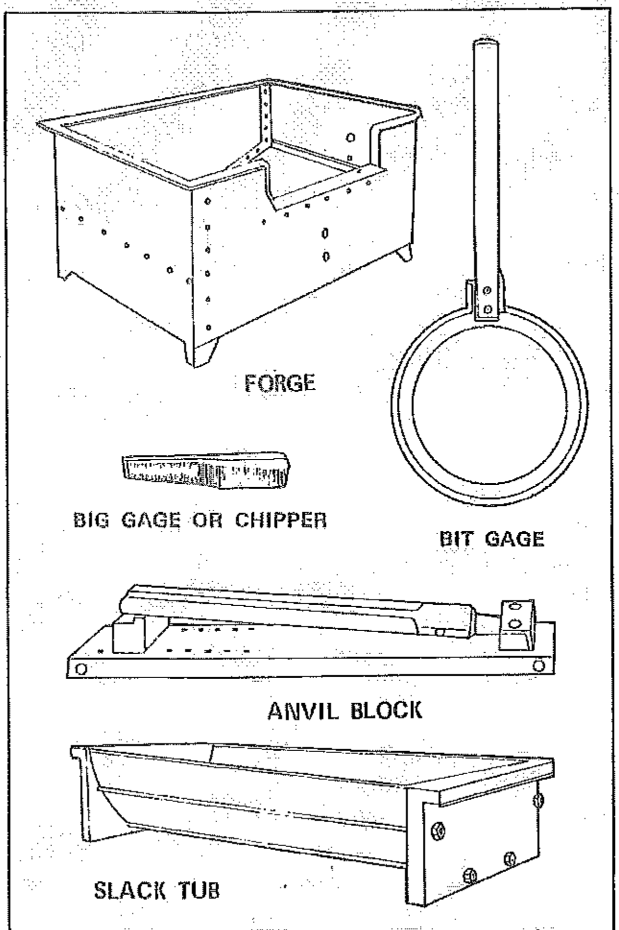


Fig. 47 Blacksmith Tools

After the bit has been dressed and cooled until all red color has disappeared, it is put back into the forge and heated for tempering. When it has reached a dull red color it should be removed from the fire to the slack tub. This tub should contain only enough water to reach as high as the corner of the bit. The bit should be left in the water until the red color has practically disappeared. When the bit is placed in the water the water boils vigorously around the bit end. In a short time small bubbles start rising on the end of the bit. This indicates the proper time to remove the bit from the water.

Next, a bright place should be filed along the bit side from a point a few inches above the corner down to the face of the bit. Different colors will show along the bright, filed edge. The color at the coolest spot, most distant from the face of the bit is dark blue. Dark blue, light blue, dark straw and light straw or copper are the colors noted progressively towards the end of the bit. Extreme hardness is indicated by the light straw and colorless portion next to the light straw color. The blue indicates a lesser degree of hardness. In a few minutes the color travels downward toward the face of the bit. When the dark blue has reached the corners and the straw or copper color has extended down over the face of the bit to the cutting edge the bit should be replaced in the slack tub and the water level raised over the corners of the bit. An average bit tempered in this way has a hardness suitable for drilling hard rock. As bit steel varies greatly the proper temper of the bit can be determined only after several trials. Another way to gauge heat in the field is with a heat-indicating chalk. Graded for various temperatures, the chalk will smoke when desired heat is reached.

Another method of tempering bits is with a common horseshoe magnet. To use the magnet without burning fingers it should be fastened on a wire handle about two feet long. After the bit has been dressed and allowed to cool until no color is visible, it should be replaced in the forge and heated to a temperature at which the magnet will not be attracted to the bit. Then it should be placed in a slack tub with water just covering the corners. Some useful points in regard to tempering the bit are as follows:

1. A bit dressed for the first time should be heated to a dull cherry red. Afterwards it can be heated to a full cherry red or if a great deal of hammering is to be done, to a bright cherry red. It is never heated higher than a bright cherry red. Starry-looking sparks called "yellow jackets" coming from the fire indicate that the steel is being burned and the bit would soon be ruined.

2. Sunlight makes judgment of the colors difficult. When the bit is examined in a bright light, the temperature is higher than it appears.

3. The cutting action of the bit should be watched after the first tempering and the hardness of the steel should be increased or decreased until the proper temper has been determined by actual use.

4. The water in the slack tub should always be kept clean.

SUGGESTIONS FOR DRESSING BITS

Eight important factors affect the design and method of dressing a drill bit to suit the formation being drilled and to get the most effective penetration. These are as follows:

1. ANGLE OF CLEARANCE (figure 48). This is the taper on the outside edges, see arrow. This bit shows a wide angle of clearance and no wearing surface.

2. ANGLE OF PENETRATION. This is the bevel on the cutting edge which penetrates the material at the bottom of the bore (see arrow).

3. WEARING SURFACE -- is the area on the side of a bit which has no clearance and is in contact with the bore walls (see arrow).

4. CONTOUR OF PENETRATING EDGE -- may be concave, convex, or straight. Degree of contour is measured in change of angle from straight line across bit bottom. Drawing shows concave edge.

5. REAMING EDGE -- is the outside edge, measured as a percent of the circumference. Drawing shows bit with 80% reaming edge.

6. AREA OF CRUSHING FACE -- is the bottom surface area of bit measured as a percentage of total-hole cross-sectional area. Shading shows crushing face with water course in white.

7. AREA OF WATER CHANNEL -- is that portion of bit bottom which is not crushing the material. Drill fluid and cuttings are passed through this water channel shown in black.

8. CROSS SECTION OF DRILL BIT -- is the size of the bit body at a point back from the crushing surface. (Arrow points to cross-sectional area.)

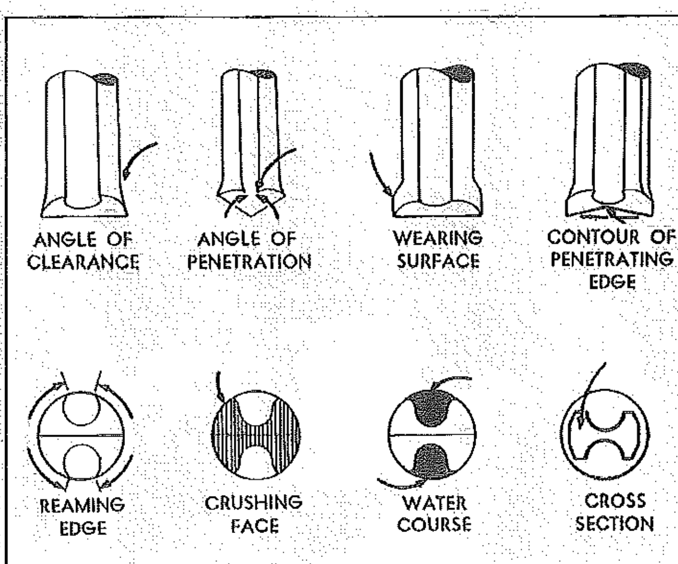


Fig. 48 Features of a Drill Bit

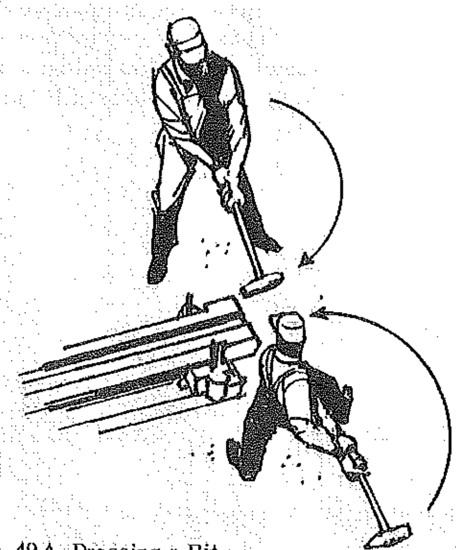


Fig. 49 A Dressing a Bit

Fig. 49 B

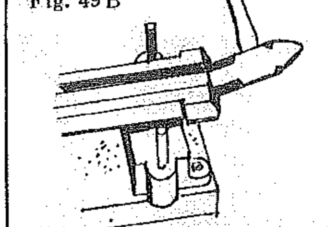


Fig. 49 C

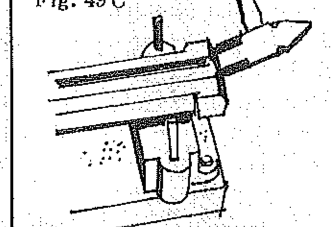


Fig. 49 D

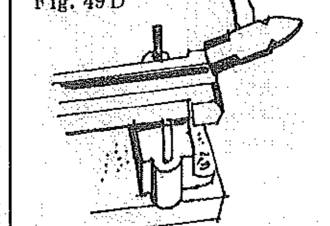
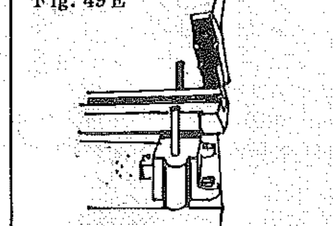


Fig. 49 E



With a careful study of operations, it is usually possible to arrive at a shape of bit that gives maximum drilling speed, and at the same time increases the footage that can be drilled between dressings and decreases the time and labor required to keep the bits in proper shape.

Shown here is the ideal way to dress a bit. It can be done by one man but it is desirable to have two on the job. They should be facing each other and each one should alternately swing his sledge and strike the bit as shown in 49 A.

49 B shows the sledge being struck against the center of the bit which is the starting point.

After each man strikes one or two blows, the next blow should be delivered toward the outer edges along the center line as shown in 49 C.

And finally, a like number of blows above the center line as shown in 49 D.

In order to draw out the corners of the gauge, each man should sledge heavily in the middle area of the bit (figure 49 E). Unless a long bevel bit is desired, corners should not be sledged.

Care should be taken that the bit dresser not stand too far forward or the bit penetration angle will be too flat. On the other hand standing too far back makes the bit penetration angle too sharp. Both men should strike with equal force to avoid crooked faces.

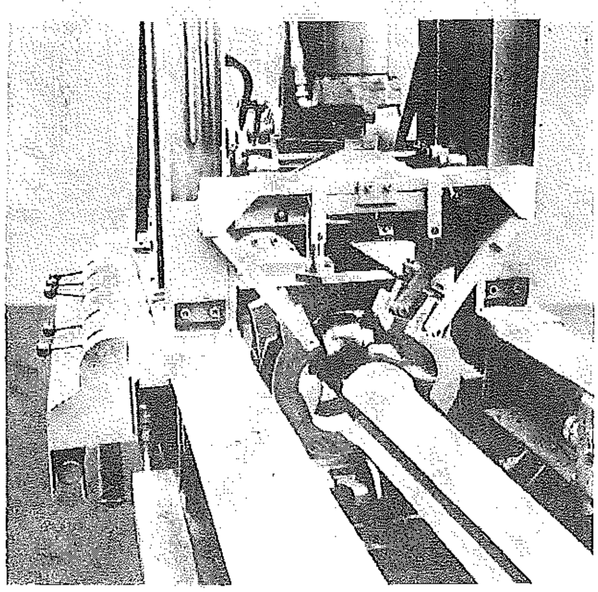


Fig. 50 Acme Hydraulic Bit Dresser

Bit Dressing Machines. If the drilling operation permits, it is advisable to dress bits with a hydraulic bit dressing machine. These are available in models which will dress bits up to 16 inches (40.6 cm.) in diameter and 9 feet (2.7 m.) in length. With equipment like this, the driller can dress bits faster and more accurately. The action of a hydraulically powered roller provides for the smooth displacement of the metal to the desired locations in the bit point without cracks, ruptures or lapses, usually associated with hammer-type bit dressers. The hydraulic roller pressure tends to upset the steel in depth, whereas the hammer-type moves the surface, frequently producing a "peeling" effect. By using this type of equipment the driller can obtain extremely accurately shaped bits (fig. 50).

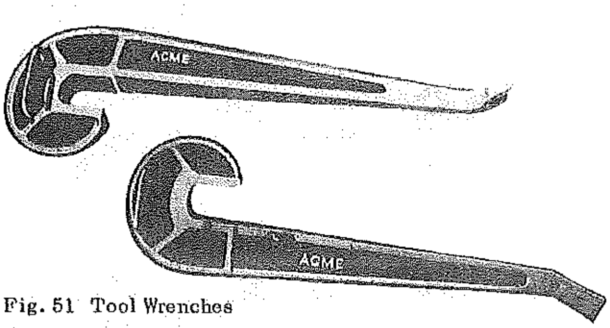


Fig. 51 Tool Wrenches

MISCELLANEOUS ACCESSORY TOOLS

Tool Wrenches. Tool wrenches are used to tighten and loosen cable tool joints and are purchased in sets of two wrenches, one left hand and one right hand. Tightening is referred to as "setting up", loosening is referred to as "breaking". To set joints the left hand wrench is placed on the lower square, the right hand on the upper square. To loosen or break joints, the positions are reversed.

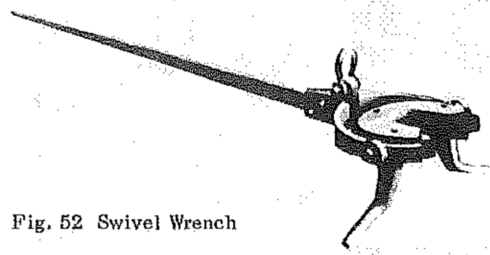


Fig. 52 Swivel Wrench

Pulling Jack. Pulling jacks are used to pull casing out when a hole has been abandoned or when the casing has to be removed for some other reason. These are available in hydraulic or mechanical models.

Casing Cutter. It is sometimes necessary to cut off and remove the top sections of pipe, particularly where more than one size has been installed. In these cases casing cutters are used. In operation the driller lowers the cutter to the desired point on the pipe and holds the cutter in position by use of clamps placed on the casing. When the casing is turned the cutters will bite in and cut the pipe.

RIGS RELATED TO USE OF HOLE

Depth of hole cannot always be the governing factor in the selection of drilling equipment. It is also very important to consider diameter and final use. Some other limiting factors on a drill are the mast and size of bull-reel. For example, you could drill a 2,500 foot hole (762 m.) with a machine, then not have enough capacity in mast or reels to handle the casing.

CHAPTER 6 ROTARY DRILLING

Rotary drilling, as we mentioned in Chapter II, is a method of making a hole in the earth's formations by means of a rotating drilling device which uses a feed mechanism to increase the penetration rate, and removes the cuttings by circulating mud or air under pressure to remove the cuttings from the hole.

BASIC COMPONENTS OF THE MACHINE

Mounting. The drill can be truck mounted, trailer mounted, or skid mounted depending on terrain and requirements of the job. The drill frame is the foundation for all units making up the drill. It generally consists of channel iron sills crossed by channel and I-beam members spaced at a width corresponding to the frame of the truck or trailer. The sills are usually interbraced with angle and structural shaped members located for maximum strength and welded together electrically.

A non-skid deck plate is welded and bolted on this structure. Holes are drilled in the channel iron sills so the frame can be bolted to the truck frame or skids. In skid mounting the skids generally consist of wide flange I-beams with the web cut out at the ends, and the bottom flange turned up to give them a runner effect. A number of channel irons are welded across the runners between which pipe is welded for bracing. The channel iron cross members are drilled to match the holes in the drill frame so they can be bolted together.

Power unit. This is the prime mover for the components of a drill rig. It consists of an engine using either diesel oil, gasoline, LP gas or natural gas for fuel. The size of the power package will vary according to the work to be done. Auxiliary power may be used for driving accessory equipment.

The truck engine can be used with a split shaft power take-off as is the case in smaller rotary drilling units. In larger machines a separate power unit is usually used.

Chain case. Power is transmitted from the engine by a multi-strand roller chain running over heat-treated sprockets and shafts. The power is transmitted from the chain transfer case to the winch, rotary table pull down, mud pump or other components of the rotary drill rig.

Rotary table. The rotary table rotates the drill stem or drill rod and the drilling bit. Most commonly used systems are a fixed, mechanical or hydraulic drive rotary table; or a top-head hydraulic drive or a power swivel.

The fixed rotary table, as the name implies, is stationary and is mounted on the truck frame at the base of the derrick. Because of its rigid strength this type of unit is well-suited for handling large diameter pipe.

The travelling head or top head drive moves up and down the derrick. Power is supplied by a hydrostatic transmission system consisting of a variable volume piston-type pump and fixed displacement piston-type motor. Rotation speeds are controlled at the driller's station.

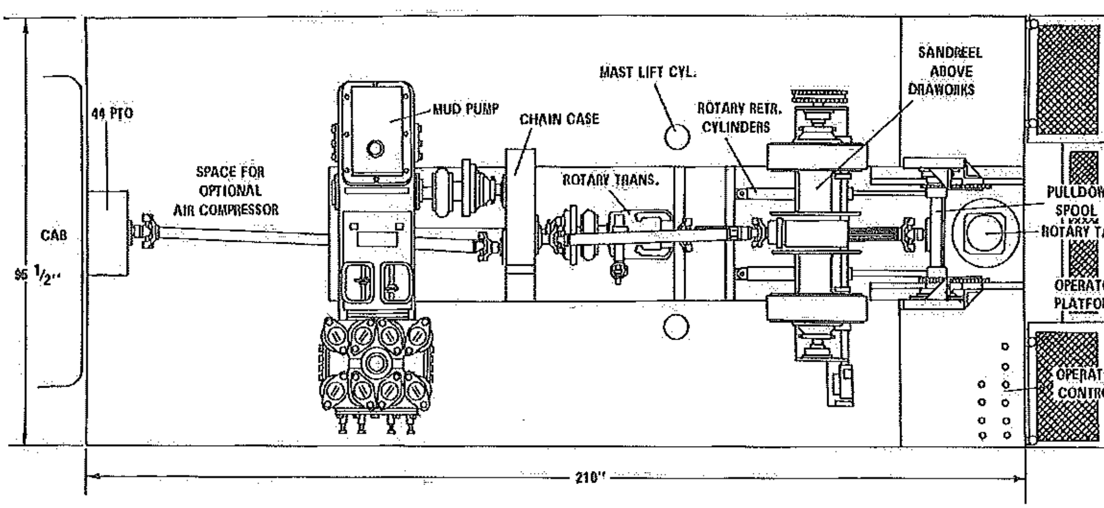


Fig. 53 Principal parts of SS-10 Speedstar Drill Rig

Break out tongs. Break out tongs are used to loosen joints in the tool string. The tongs are manually positioned over the rotary table and clamp around the kelly, drill pipe or tool shanks and stems to keep these parts from turning, while the rotary table turns the other section of the drill string.

Pull down equipment. Pull down equipment is used to apply thrust or pressure to the drilling bit, forcing it down into the material to be drilled. Pull down equipment employs a variable speed mechanism, generally hydraulic so that pull down pressure can be varied from 0 lbs. to 30,000 lbs. (13,608 kgs.) on larger units.

Draw works. The draw works consist of the two main hoisting drums, sand reel drum, and catheads, if catheads are included with the machine. Power is transmitted to the draw works from the chain case by means of a drive shaft.

Hoisting drum. The hoisting drum is connected to its drive by a friction clutch. It is used for pulling or running the drill pipe out of and into the hole and for running and pulling casing. A brake at one end controls the rate at which the line can be unspooled. The hoisting drum is equipped with wire cable which has a traveling block or a safety clevis at the end for attaching the article to be hoisted. On rigs designed for deep drilling, the main hoist generally has four speeds and line pulls will vary with the size of the unit.

Sand reel. The sand reel is directly ahead of the hoisting drum or above it, depending on the make of unit. The sand reel is generally used to swab or bail the hole but may also be used for other hoisting purposes. It generally operates at a faster speed and has less lifting capacity than the main hoisting drums.

Cathead. The cathead will lift light loads if the rope is wrapped around the load while the cathead is turning. Spinning catheads and jerk-line catheads can be used on larger machines to help break drill strings.

Derrick. This structure supports the rotating mechanism, drill pipe, and handling equipment such as blocks, pull down chains, hoisting lines, etc. It is usually constructed of tubular, cold-drawn seamless steel material electrically welded together.

At the very top of the derrick is a crown block containing sheaves over which the hoisting lines and sand line travel. An eye at the top anchors the end of the hoisting line when a traveling block is being used. The mast is raised and lowered by two hydraulic cylinders operated through control valves.

Fluid circulation system. Each rotary rig is usually equipped with a mud pump, an air compressor or both. Transmission lines pass the fluid through the drilling device to the bottom of the hole from which it carries cuttings to the surface. The volume of fluid available determines the largest diameter of hole that can be drilled. Various size mud pumps and air compressors are available depending on job requirements.

Levelling jacks. Hydraulic levelling jacks, one mounted at the front of the truck or trailer and two at the rear, are used to level the machine for drilling. Some machines have screw-type mechanical levelling jacks which perform the same job.

ACCESSORY EQUIPMENT

Swivel. The swivel is used to circulate fluid into the rotating drill pipe and for suspending the drill pipe in the well. It consists of a housing with trunnions to which the supporting bail is fastened, and is equipped with a packing unit which prevents leakage where the rotating and stationary parts meet.

Kelly. The kelly is the uppermost joint of drill pipe and is made from heavy walled, heat-treated tubing. There are two types available – a square type or a round, fluted type. Either type permits the drill pipe to be rotated by the rotary drive-table or top head drive and at the same time move vertically. The round kelly has three flutes, or grooves, evenly spaced and running length-wise to within a few inches of either end. The upper end has a left hand thread and is connected to the body of the swivel with a sub. The lower end has a right hand thread and is connected to a joint of drill pipe with a coupling referred to as the kelly-saver sub.

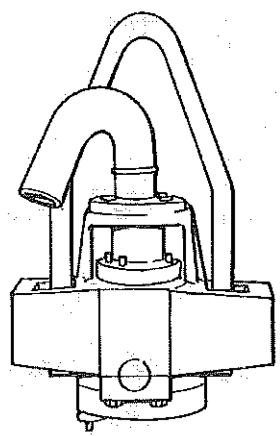


Fig. 54 Swivel

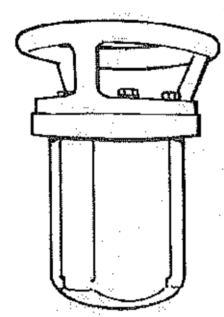


Fig. 55 Kelly Drive Bushing

Kelly drive bushing. The kelly drive bushing is cylindrical with a square driving head at the top end. The inner bore is slightly larger than the outside diameter of the kelly, and has three flutes spaced to match those in the kelly. Drive keys fit into these flutes and in those in the kelly, and are held in place by a plate fastened to the drive bushing.

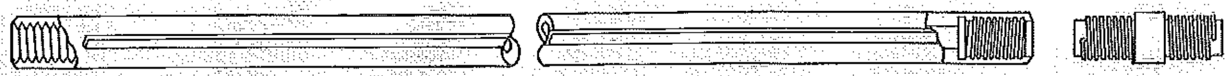


Fig. 56 Kelly and Sub

Hose. Hoses are used in the mud or air circulation system. These are as follows:

Swivel hose. The swivel hose is approximately 2 inches (5.08 cm.) diameter and is 17 to 20 feet (5.2 to 6.1 m.) long and has wire reinforcements to withstand high pressure. It forms a flexible connection between the stem pipe and the swivel. The swivel hose is subjected to abrasive fluid under pressure, and to continuous flexing.

Stand pipe hose. Stand pipe hose is about the same size and construction as the swivel hose but approximately 4 feet (1.22 m.) long. It furnishes a flexible joint so that the mast can be raised and lowered.

Suction hose. Suction hose connects the mud pump and the slush pit. It is approximately 20 feet (6.1 m.) long and 4 or 5 inches in diameter (10 or 12.7 cm.). It is a smooth bore hose reinforced with steel wire. It is connected to the mud pump by a quick disconnect coupling or union.

Mud mixing hose. This is a wire wrapped, high pressure hose which is used to carry water under high pressure while mixing mud.

Break out slip. When drill pipe is moved in or out of the hole, the break out slip is used to hold it while a joint of pipe is added or removed.

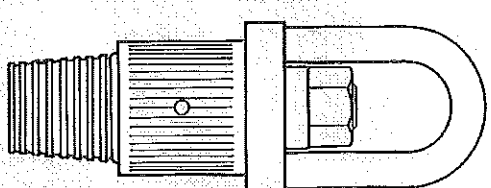


Fig. 57 Hoisting Plug

Hoisting plug. The hoisting plug is the connecting link between hoisting line and drill pipe. It is also used with a casing plug or adaptor to run or pull casing. It consists of a bail, roller bearing and a coupling like that used in the bottom of a kelly. The hoisting plug should be kept clean and the bearing and coupling threads oiled to insure smooth spinning.

DRILL STRING

A drill string consists of the following:

Drill pipe. Drill pipe is the pipe or rod to which the drill bit is connected. Drill pipe is made in many sizes and lengths with various types of joints or couplings. One end, called the pin, has a tapered V-thread; the other end, called the box, has an internal thread. As lengths of drill pipe are added, the pin end of one joint is connected to the box end of the other.

As the drill rods are subjected to great torsional strains the threads should be thoroughly cleaned and lubricated, before making up each joint. The lubricant is available from various manufacturers and aids in preventing the joints from becoming galled or too tight.

Drill collar. Drill collar is a heavy walled joint of pipe frequently used just above the bit in the drilling string. It provides extra weight just above the bit. This additional weight at the lower end of the string helps keep the hole uniform and straight. The drill collar outside diameter is larger than that of the drill pipe but small enough to clear the wall of the hole. The annular space remaining must allow enough room for an overshot die fishing tool in the event the drill collar twists off.

Substitute joints. A substitute joint, often called a sub, is an adaptor to connect two components when their threads do not match. Sometimes it is necessary to

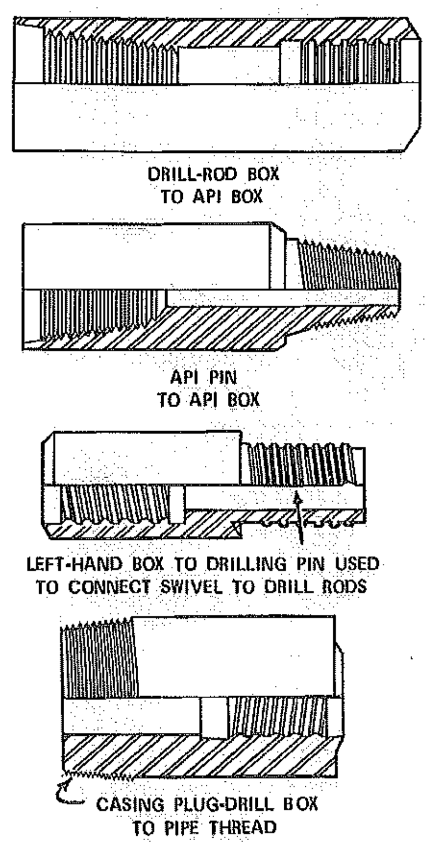
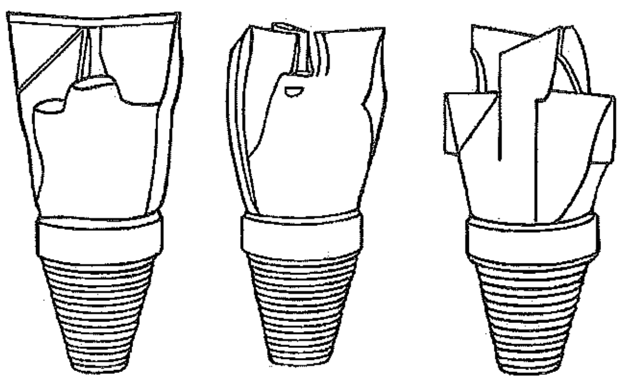


Fig. 58 Subs (Sectional)

combine two subs in order to make the connection. A special sub, called the kelly sub, is used at the pin end of the kelly to save the kelly from undue wear. As few substitute joints as possible should be used in the drill string because most pipe failures occur at the joints. Joints should be made up tightly.

Bits. The bit is a device that does the actual cutting or boring in the formation penetrated. It is screwed to a bit-sub and then attached to the lower end of the drill pipe. The type of bit for a particular job depends on the formation to be drilled and to some extent on the experience and skill of the driller. Bits come in various sizes and types. The most common are:



a. Fishtail b. Three-way c. Pilot

Fig. 59 Bits

a. The fishtail bit. This bit is made of steel. Its blades are wing-shaped and forged to a thin cutting edge turned slightly ahead. Cutting edges are faced with hard surface metal with tungsten carbide inserts at the outside corners. The bit body is hollow with a hole drilled on each side to direct circulating fluid down near the center of each cutting edge. The fluid jets down the side of the cutting edges and keeps them clean. The fishtail is especially good in loose sands and clay.

b. The three-way bit. This is much like the fishtail in design but with three cutting blades instead of two. The three blades make the action smoother in shattered or irregular formations. It also makes a better hole in semi-consolidated formations and has less tendency to deflect. In soft formations it cuts a little slower than the fishtail.

c. The pilot bit. This is sometimes called a six-way bit. It has cutting edges each with a hole for circulating fluid. Three of these blades cut a hole about half the diameter of that cut by the other three and protrude below them. The pilot feature makes this bit better for shattered formations and cemented sands than either the fishtail or three-way. It will cut somewhat harder formations with less strain on the drill rod.

All three of these bits have a shearing or scraping action and are not adapted to hard rock. They can be resharpened with welding equipment.

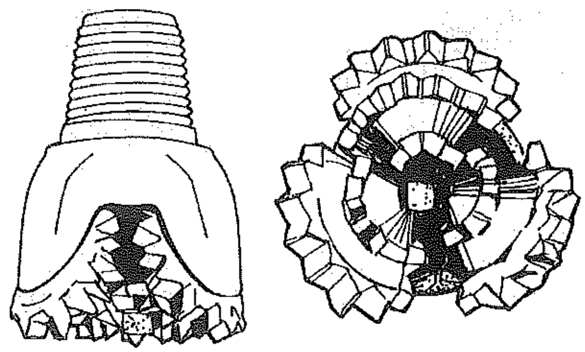


Fig. 60 Cone-type Rock Bit

d. Cone-type rock bit. A cone-type bit has three cones, a forged steel body and a cone axle or pin which forms part of the body. The cones have roller bearings fitted at the time of assembly. The shape of the cutting surfaces and the design of the teeth are varied to drill in a variety of formations. Some have inter-fitting or self-cleaning teeth. All cutting surfaces are flushed or cleaned by the circulating fluid.

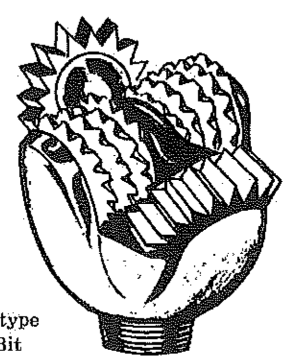


Fig. 61 Roller-type Rock Bit

e. Roller-type rock bit. The roller rock bit has four rollers or cutters and a steel body. Two cutters or rollers, on opposite sides of the body, are set at an angle from the axis of the bit. These cut outside clearance for the bit. The two other cutters or rollers are set in the housing at about a 90-degree angle from the first two and have horizontal axles. The latter cutters are somewhat conical in shape. The tooth design of the four cutters also is made to suit formations from soft to hard. They are not renewable. The cutting surfaces are flushed by the circulating fluid. All cutters have roller bearings.

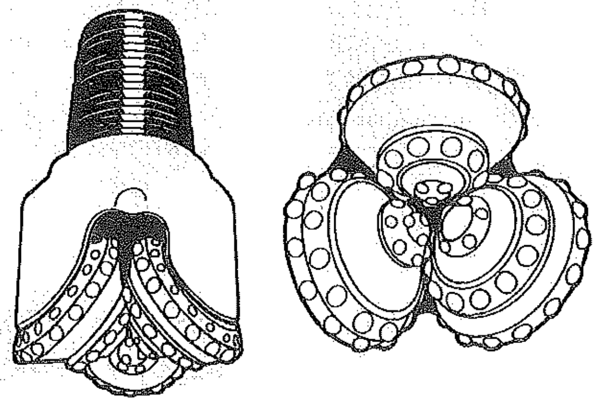


Fig. 62 Carbide Button Bit

f. Carbide button bit. This bit is specifically designed for use in hard abrasive formations, such as lime, dolomite, granite and hard, sandy shales normally too hard for steel tooth bits. Sintered tungsten carbide and forged alloy steels combine to provide abrasion resistance.

FISHING TOOLS

The most frequent fishing job in rotary drilling is caused by the twisting off of drill pipe. The break may be a simple shearing of the pipe or it may occur at a coupling. Sometimes the drill pipe is dropped accidentally into the hole. The first thing to determine when a break occurs is the exact depth of the separation. This helps to locate the top of the tool in order to couple it with a fishing tool. The three most important fishing tools are the tapered tap, the die overshot, and the circulating-slip overshot. Recovery of lost drill rod depends on whether the driller can set the fishing tool down on top of the rod and connect it.

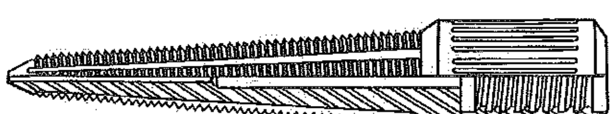


Fig. 63 Tapered Tap

Tapered tap. The tapered fishing tap is tapered about 1 inch (2.54 cm.) per foot (30.48 cm.) from a diameter somewhat smaller than the inside diameter of the coupling, ranging to a diameter equal to the outside of the drill rod. The tapered portion is threaded on and is fluted the full length of the taper. It is made of heat treated steel. Its action is similar to that of a machine tap, inasmuch as it cuts its own threads when rotated, and grips the lost drill rod. The flutes permit the material cut by the threads to escape. The upper end of the tap has a box to fit the drill rod pin.

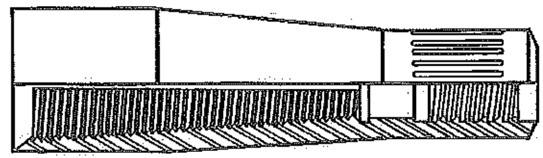


Fig. 64 Die Overshot

Die overshot. The die overshot (sometimes called die coupling) is a long tapered die of heat treated steel. It is threaded on the inside of the pipe and tapers at the rate of 1 inch (2.54 cm.) per foot (30.48 cm.) from a diameter somewhat smaller than the outside diameter of the small end of the drill rod coupling, and ranges to a diameter somewhat larger than the outside of the drill rod. It cuts its own thread as it is rotated on top of the lost drill rod. The tapered thread is fluted to permit escape of metal cut by the thread.

The upper end of the die overshot has a box thread to fit the drill rod. The tool is hollow but circulation cannot be completed to the bottom of the hole to the lost rods because the flutes allow the fluid to escape.

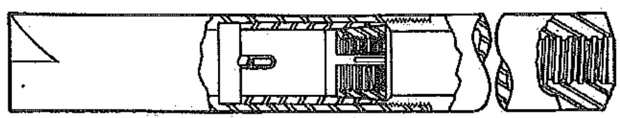


Fig. 65 Circulating-slip Overshot

Circulating-slip overshot. Circulating-slip overshot is a tubular tool about approximately 3 feet (91.44 cm.) long with inside diameter slightly larger than the outside diameter of the drill rod. The bottom is belled out and has a notch to aid the tool to center and slip over the lost drill rod. The outside tube or body is made of two pieces screwed together. The top of the lower section of the body is recessed to receive a rubber packing ring and a sleeve. The sleeve bore is tapered. On the inside of the sleeve is a ring-type slip whose bore is threaded with left hand threads. This slip has a slot cut through on one side so it can expand as the rod passes through it and tighten against them as it is pulled down into the tapered sleeve. The body, sleeve and slips are fastened together with lugs so they must rotate as a unit, yet have a small amount of vertical movement independent of each other. The upper end of the top section of the body is threaded to fit the drill rod coupling. After the circulating-slip over shot has gone over the stuck drill rod and is pulled upward, the slip grips the pipe, and the sleeve is pulled down against the rubber packing ring which expands and makes a seal between the fishing tool and the drill rod. This assures the operator that if circulation is completed it is through the lost drill rod.

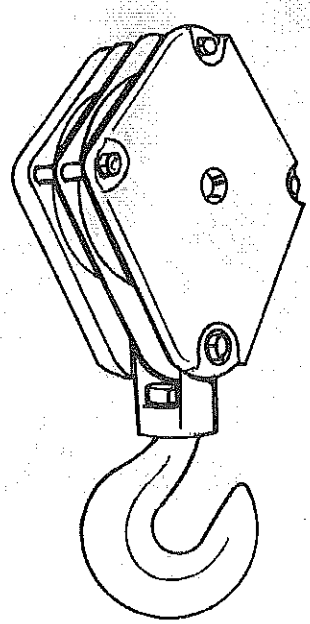


Fig. 66 Traveling Block

Traveling block. The mechanical leverage needed to safely handle a long string of pipe is gained through the hoisting or traveling block. This block contains one or more sheaves depending on the weight to be lifted. Traveling blocks can double and triple the weight lifting capacity of the engine, draw-works, etc. The limiting factor is the capacity of the mast or derrick.

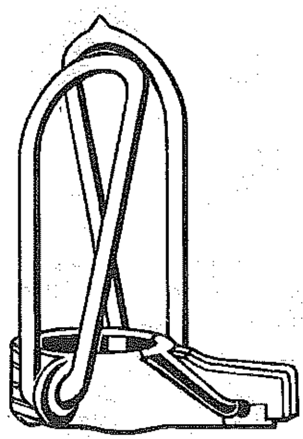


Fig. 67 Elevator

Elevator. An elevator on a drilling rig is a device used to lift pipe or casing. The simplest kind is a hinge clamp or ring with a quick locking device to prevent it from opening when clamped around the pipe. On each side of the clamp or elevator is a lug or eye, which holds the elevator bails or links. The bails are attached to the hoist. The bore of the elevator is slightly larger than the outside diameter of the pipe, permitting it to slip up against the pipe coupling or collar when the pipe is suspended.

MUD SYSTEM

Drilling mud has a number of functions in rotary drilling operations. These are as follows:

1. Removing cuttings. This is another essential of drilling mud. The removal of cuttings of a given size and density requires an upward mud velocity of sufficient pressure to force the cuttings out of the hole.

2. Cooling the bit. This is the simplest and one of the most essential duties of drilling mud. Practically any type of mud that can be pumped will perform this function. Otherwise the task of keeping the bits from burning might be a difficult one.

3. Preventing caving. By providing a hydrostatic pressure the drilling mud tends to hold loosely consolidated, cave-in formations in place. A column of fluid or mud in a water well exerts pressure equally in every direction at any point.

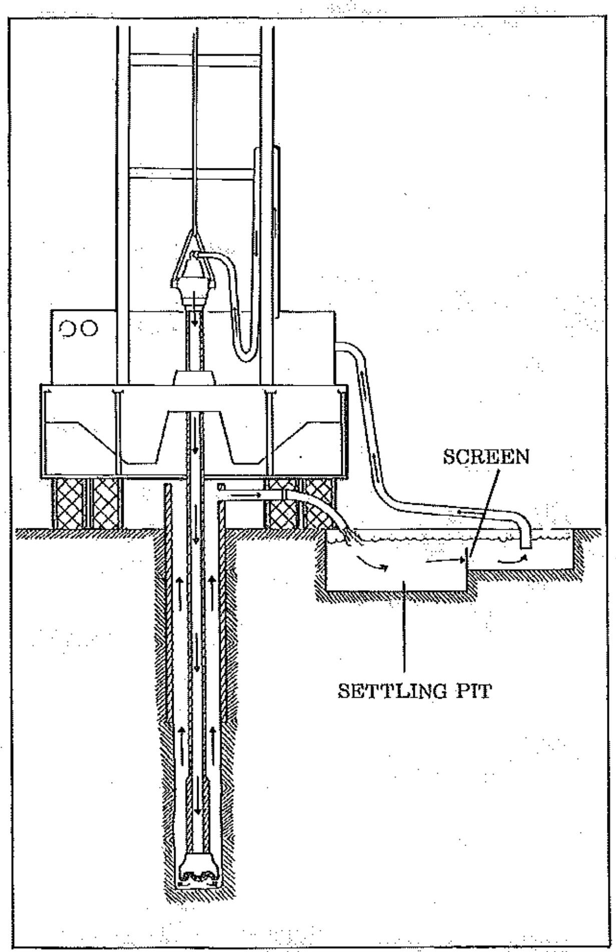


Fig. 68 Mud System

In consolidating loose or cavey formations such as gravel, sand, glacial drift, etc., the drilling mud should surround the particles of the formation and consolidate them by holding them in a matrix of jelled mud. Drilling mud also checks water intrusion in areas above the zone where the well will be completed.

4. Lubricating drill pipe. Good drilling mud covers everything with a slippery film that is an excellent lubricant. Thus drilling speeds can be maintained and power costs reduced.

5. Checking corrosion. A good drilling mud tends to check corrosion and rust.

When prepared muds are not available, native clays can be used for drilling purposes in emergencies but are inferior. Most of them contain too much sand which interferes with the sealing properties of the mud.

Preparing the mud for drilling. Mud can either be prepared in a slush pit dug in the ground near the drilling rig, or a portable mud container of metal can be used. In mixing either prepared or native mud, the mud pump and mud mixing hose are used. A small quantity of mud is placed either in the pit or box and mixed with the water. As the mud is formed, it flows out through a screen and into another pit where it circulates through the pump. When sufficient mud is mixed, the bypass valve is closed, the main stem point valve is opened and the mud is ready to be circulated into the hole.

AIR SYSTEM

Air drilling is basically the same as mud drilling except that the mud pump is replaced by a compressor assembly including cooling system, air receiver, and unloading system. The air line is connected to the swivel hose at the top of the kelly. The air is forced down through the drilling pipe and out through the holes at the bottom of the rotary drill bit. A small stream of water is often introduced into the air system to help cool the drill bit and control dust. The air serves to cool the drill bit and force cuttings up and out of the hole. The cuttings move up in the annular space between the drill pipe and the wall of the hole, and are collected at the top. Air is used principally in hard clay or rock formations, inasmuch as once the air pressure is turned off, loose cavey formations would cave-in against the drill pipe. This is not the case when mud is used.

Air, of course, is also used in down-the-hole drilling which was described on page 8.

OPERATING FUNDAMENTALS

Basically, there are three fundamental operations in rotary drilling. These are: drilling the hole, removing the cuttings, and setting the well casing. The technique of drilling the hole and removing the cuttings is completely different in rotary and percussion drilling, as is the technique for installing casing. As we discussed in percussion drilling, casing is pounded down the hole as the drilling operation is carried on. In rotary drilling, however, no casing is set at all until the water bearing strata is reached. Then the casing is lowered into the hole and the well is completed. In case of a rock formation, the casing is lowered to the point where the rock drilling was begun, and is then driven into the hole a short distance and, if necessary, sealed off with cement.

PREPARATION FOR DRILLING

After the drill site has been selected, the drill is moved into position. The first operation is to level the unit. If the drill is on skids, it is necessary to set it on cribbing approximately 24" high (60.96 cm.). The rig is jacked, or lifted with a power winch mounted on another vehicle and the cribbing placed so that the ends of the skids stick out about 2 feet (60.96 cm.). The cribbing is leveled and set on matting or a firm foundation.

If the drill is truck or trailer mounted and has no jacks, it is leveled by digging holes for the wheels on the highest side, or blocking up the low wheels.

In truck and trailer mounted units with jacks, the mechanical or hydraulic jacks are lowered to level the machine.

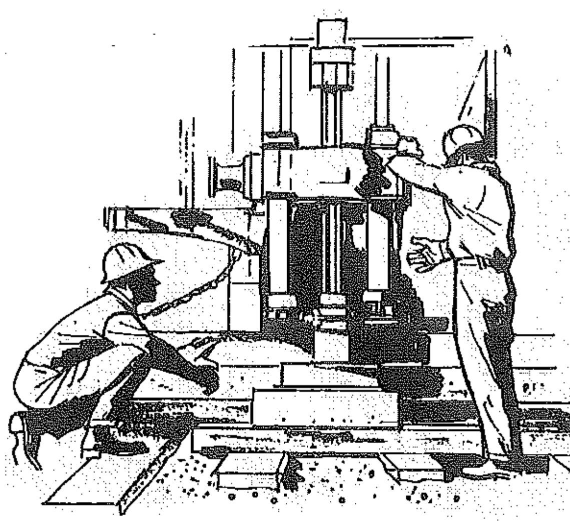
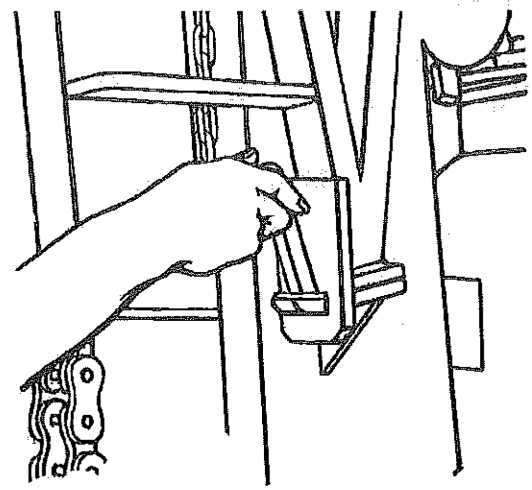


Fig. 69 Placing Cribbing Under the Machine

On machines powered by the truck engine the power take off is then engaged to supply power to the hydraulic pump. On machines having an outboard engine a clutch is engaged to power the pump. In either case the operator removes the pins from the base of the derrick and opens the hydraulic valve for the derrick hoist. Hydraulic power then hoists the derrick to upright position. During hoisting, the operator keeps a slight tension on the kelly, hoist and sand lines. After the derrick is in vertical position the pins are put in place to secure the derrick. A plumb bob or carpenter's level can be placed against the kelly to determine if the machine is leveled properly. If it is not level, the jacks should be further adjusted.

The driller then removes the cap from the lower end

Fig 70 A Derrick pins removed and replaced when derrick is up



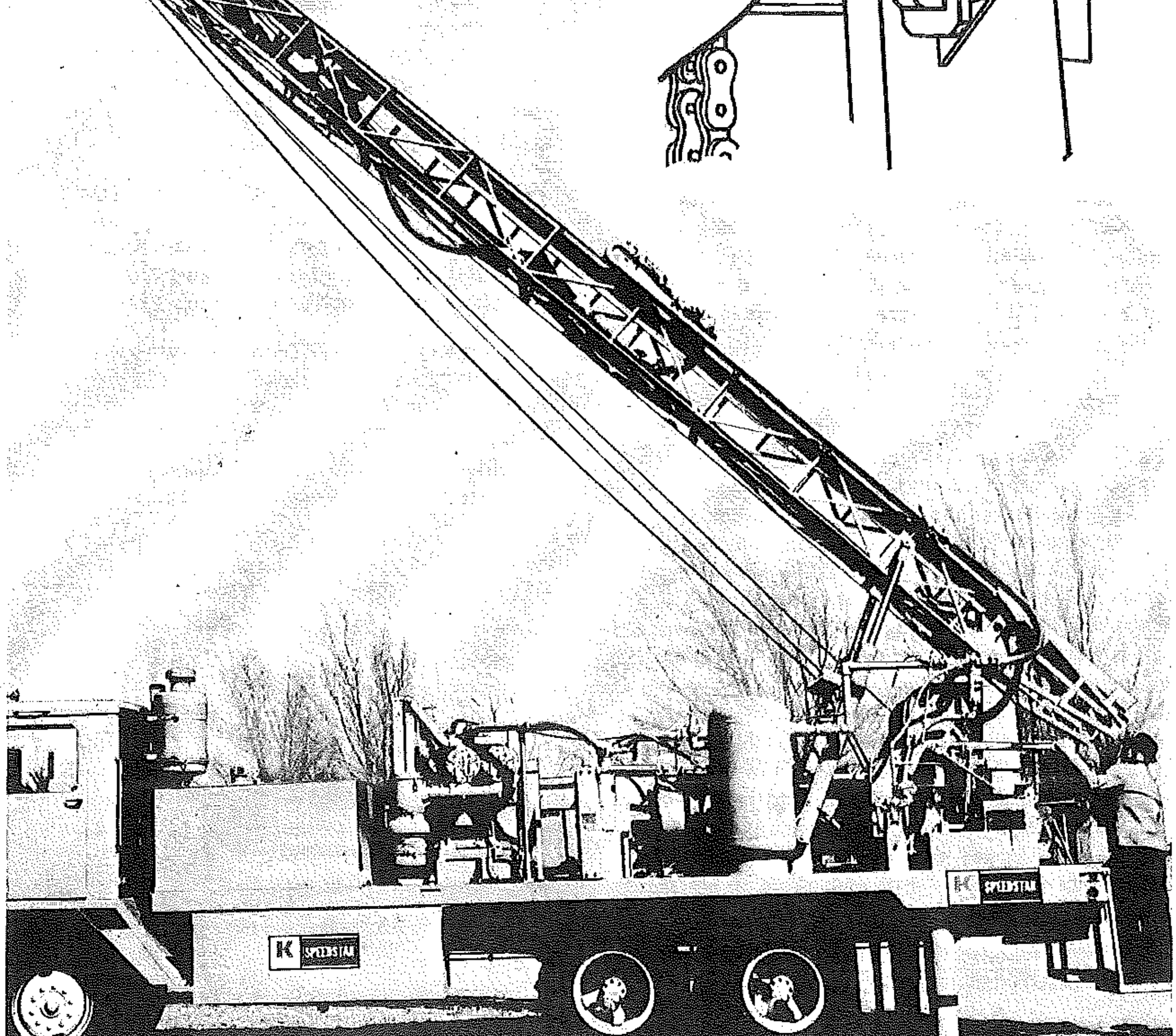


Fig. 70 B Derrick Part Way Up

of the kelly, and lowers the kelly so the kelly drive bushing drops into the rotary table. A bit is now attach- to the kelly with the proper sub.

During this operation the slush pit can be dug or the metal container set up. The fluid return ditch is dug from the mud pit to the main pit. The ditches enter and leave the settling pit in such a manner that the flow of fluid is reversed causing the cuttings to settle and keeping them from flowing to the main pit. Mud is placed in the main pit and both pits are filled with water. The suction hose screen is placed in the main pit at the opposite end of the return ditch. The suction hose is submerged at all times but does not lie on the bottom. The circulating fluid is kept as clean and free from abrasives as possible to protect the pump parts. The drill is now set up and ready for operation.

It will probably be necessary for the driller to mix additives with the mud, depending on the type of formation drilled. This is a highly technical subject and should be discussed with a mud expert.

Water supply. Water is essential when drilling wells by the rotary method. There is no set rule as to the amount of water required to drill any one hole. Some cases where the formations are compact, 3 to 4 gallons (11.36 to 15.1 liters) of water per foot (30.48 cm.) of hole drilled are sufficient. In other cases where formations are loose and extremely porous, a large supply is required. For ordinary purposes 750 to 1,000 gallons (2838.75 to 15.1 liters) of water per 8 hour shift is necessary.

Drilling. The mud pump is engaged and when circulation has started, the rotary clutch is engaged and the bit lowered to the ground by releasing the kelly drum brake. In a soft formation, weight of the kelly is probably sufficient to make the bit cut. If not, pressure should be applied to the bit by engaging the pull down.

When the length of the kelly is drilled down, the kelly is hoisted to return bit to the surface. The mud pump clutch is also disengaged to stop the flow of mud. The kelly is raised so that the flat on the sub is above the table. The driller then slides the break-out slips over the flat of the sub, and lowers the tools so that the slip is resting on the table. Break-out tongs are then attached to the flat of the sub and the bit is removed. At this point the procedure for adding tools to the drill string will vary, depending upon the driller. One successful procedure is as follows: After the bit is removed from the kelly sub, the rotary table is retracted. A hole stablizer or drill pipe joint is then attached between the kelly and the bit. This stablizer is almost as large as the diameter of the hole and is used to maintain a straight hole.

The drill bit is screwed to the bottom of the stabilizer and a hoisting plug is screwed to the top of the stabilizer. The hoisting line is then attached to the hoist plug and the stabilizer is lowered into the hole. If the hole has been drilled deeper than the length of the stabilizer a crowbar can be inserted through the bail so that the eye of the bail can be held at ground level. The driller then brings the rotary table to drilling position, puts a sand line down through the table and attaches it to the lifting bail on the stabilizer. He then raises the stabilizer so that the flat is above the rotary table. The lifting bail is removed and the kelly is screwed into the stabilizer. The stabilizer is lifted, the slip removed, the mud pump engaged, and the bit lowered into the hole. The rotary table is engaged and the drilling again commences.

After the stabilizer has been drilled down to full depth, it is pulled up so that the flat of the stabilizer is above the table. A breakout slip is placed over the flat and lowered into the rotary table. The stabilizer is then lowered and rests on the breakout slip. The tool joint is broken loose with the breakout tongs, and the kelly is pulled away from the tool string. Next, a hoisting plug is attached to a section of drill pipe which is raised up and screwed into the stabilizer pipe. This section is then lifted, the breakout slip removed, and the drill string is lowered into the hole. The breakout slip is placed at the top section of the drill pipe and the kelly is lowered and screwed onto the top section of the drill pipe. The kelly line is lifted, the breakout slip removed, the mud pump started, the rotary table started, and the drill pipe is lowered into the hole. This procedure is repeated until the desired hole depth is reached.

When it is necessary to change bits before the hole is completed, the kelly is disconnected, a hoisting plug inserted into the drill rod, which is then pulled in doubles or 30 foot lengths (9.14 m.). They should be handled carefully so the bottom ends of the rods will not get dirty. If the hole is completed, the drill rods are pulled in singles and placed on a rack.

DRILLING SPEEDS

Drilling in unconsolidated formations. In tests, holes varying in diameter from 4 to 20 inches (10.16 to 50.80 cm.) were drilled to depths of 940 feet (286.51 m.) in unconsolidated sand, gravel, and clay. When drilling a hole 4 inches (10.16 cm.) in diameter, drill speeds of approximately 60 feet (18.28 m.) per hour were obtained.

Drilling in hard rock. Drilling rates as high as 6.1 feet (1.86 m.) have been obtained in granite rock and 6.9 feet (2.1 m.) in basaltic rock. In this type of rock, however, the expenditure of rock bits is high. The rotary rock bit is a highly specialized part of the equipment and can not be resharpened or built up in the field. It must be replaced when worn out.

Speed adjustments. Adjustments in rotating speeds and bit pressures cannot be set into hard and fast rules. The same formation may require different drilling techniques in holes spaced only a short distance apart. A good driller knows from experience why each thing happens or why an operation is done in a certain way. He is able to visualize conditions at the bottom of the hole and knows the reaction of the bit in different formations. For example, a bit which becomes balled up when drilling in soft sticky formations creates stresses and vibrations in the drill rod similar to those caused by drilling in shattered, consolidated formations. A good driller can recognize formation changes and keep an accurate log of them. Experience is the only way to gain these qualifications.

LOST CIRCULATION

Lost circulation occurs in porous formations where the drilling fluid seeps into the formation instead of returning up through the space outside of the drill pipe and back to the mud pit or slush pit. These zones of lost circulation sometimes contain large supplies of water. Therefore, a test of the well always is made when circulation is lost.

Formations which drain off or absorb all or part of the mud offer problems ranging from minor inconvenience in loss of time to extreme conditions which make rotary drilling impossible. In such cases circulation must be restored or percussion drilling must be substituted.

Formations where lost circulation occur can be divided into three classes:

1. Formations which contain joints and fissures, such as quartzite, sandstone, limestone.

2. Shale which is jointed and fissured. However, this seldom drains off an excessive amount of circulating mud. Nevertheless, the mud absorbed causes the shale to swell and heave, filling up the hole. Special drilling mud and circulating equipment is available to counteract these conditions. However, under normal circumstances satisfactory drilling progress is usually made in this material by using a mud of high viscosity.

3. Sand and gravel are also lost circulation zones. The mud loss is continuous and should not be replaced with water but with mud. Water when used to maintain efficient volume for circulation soon loses the viscosity and weight of the mud and caving results.

Regaining lost circulation. When it is desirable to regain lost circulation, one of two methods can be used:

1. One satisfactory method in water well drilling is to drill through the zone of lost circulation, and set a string of well casing to a point somewhat below the porous zone. Here the chief requirement is a plentiful supply of water to circulate the cuttings away from the bit and into the formation. Mud is desirable for this purpose, but the quantity needed usually makes its use impossible. When using water to carry out the drill cuttings, it should be remembered to continue operating pump for a few minutes after drilling has stopped. This flushes the cuttings out of the hole and prevents the drill pipe from sticking when it is stopped to make connections.

   When the bottom of the porous zone has been reached, drilling is continued into the underlying formation.

2. Frequently circulation can be regained by mixing a fibrous material with the drilling fluid. There are special commercial preparations for this purpose. However, in an emergency, cottonseed hulls, bran, sawdust, shredded hay or other substances may be substituted. In some cases the hole must be abandoned. If circulation is lost in cavernous lime, the fluid level in the hole is checked and tested for fresh water. If the quality and quantity is sufficient the hole can be completed in this formation.

AIR ROTARY DRILLING

Set up operation for air rotary drilling is identical to that described above for mud rotary drilling except that air is used instead of mud. The attachment and removal of drill bit, stabilizer, drill pipe, subs, etc. is exactly the same.

DOWN-THE-HOLE HAMMER DRILLING

Down-the-hole hammer drilling as a method of drilling was discussed on page 8. Set up procedure is identical to mud rotary drilling and air rotary drilling described. Before attaching the tool, the drill string should be checked and, if necessary, the rotary head, kelly bar, and each joint of drill pipe washed and blown clean. This is especially important if the pipe was previously used for mud drilling.

The use of a "kelly saver sub" is recommended to keep tools several feet off the bottom while adding joints of drill pipe to the string. This will help prevent the tool from clogging with mud and cuttings. The down-the-hole drill should be screwed onto the drill pipe slowly and carefully, and should be tightened securely to the drill pipe by applying a wrench to the flats on the top sub, using slow rotary action.

The down-the-hole hammer should be tested above ground before lowering the drill. An air gauge tapped into a short length of pipe is placed above the tools during this test. The air is turned on but the tools should not be rotated. After observing operation a few minutes, the bit should be extended down to a piece of hardwood timber. Enough pulldown pressure should be applied to keep the bit pushed into the tool. The bit is now in drilling position and the tool starts operating with the piston striking the bit at high frequency. The air gauge should read at a 100 to 110-lbs. per square inch operating air pressure.

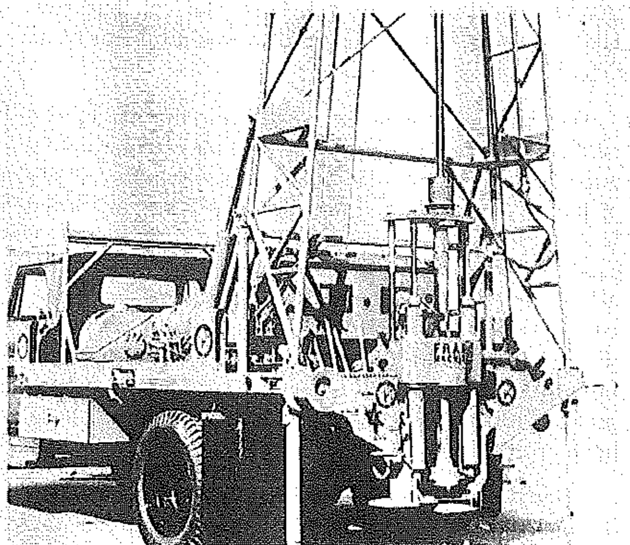


Fig. 71 Rotary Rig Ready to Drill

Starting a hole. The air is turned on and the bit rotated slowly, then fed down slowly until the bit starts hammering on the formation. Add just enough pulldown pressure to start breaking the rock. Measures should be taken to prevent the bit from wobbling or walking when it first strikes the formation because this can damage the corners of the carbides. When lowering the tool into the hole to resume drilling, avoid banging

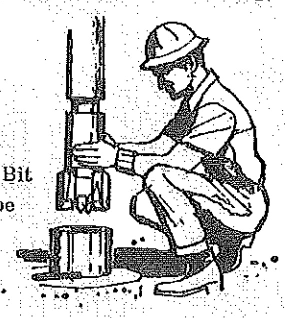


Fig. 72 Easing Bit into Pipe

the bit on the surface casing as it is started. As bottom is approached, the driller should go slowly, feeling his way to avoid damaging carbide bit on the bottom. When the bit initially contacts the formation, there should be no more than 2,000 lbs. weight on the bit, nor less than 800 lbs. (907 kgs. - 362.8 kgs.).).

Proper rotation speed is important in achieving long bit life and optimum penetration. 10 to 40 revolutions per minute is recommended. The slower rotation should be used in harder, more abrasive formations. Excessive rotation speeds wear out the carbide without a corresponding gain in penetration. In removing the down-the-hole hammer, the process is the same as for removing the rotary bit from the kelly sub.

REVERSE CIRCULATION DRILLING

Reverse circulation drilling is a method of rotary drilling. However, instead of circulating the drilling fluid or air down through the drill pipe and up the outside of the pipe, the process is reversed. Water is fed down through the space between the wall of the hole and the drill pipe. It is then pumped up together with the cuttings through the hollow part of the drill pipe and out into a discharge pit. This type of unit is used for rapid drilling of extremely large diameter holes in soft formations where the hazards of cave-ins are present. It is also a special advantage where boulders are present since solids up to 6 inches (15.24 cm.) can be brought to the surface through the drill pipe. This performance is possible because of the extremely high velocity of the water drawn up through the drill pipe by the suction pump. In the reverse circulation method, holes 18" to 60" (46 to 152 cm.) in diameter are drilled to depths of 600 feet (183 m.) using 6" (15.24 cm.) flanged pipe.

The reverse circulation principle eliminates the need for heavy drilling mud used in conventional rotary drilling. This mud sometimes tends to seal off water bearing sand. It also overcomes the disadvantage of the slow casing drilling method which often requires weeks to complete a large diameter shallow well.

In order to drill by this method, the driller should be reasonably sure that he will be drilling through soft, unconsolidated formation and that there is an extremely abundant supply of water in the water bearing strata. The unconsolidated formation is necessary because this type of drill will not drill through hard rock, and there is no point in having the extremely large diameter pipe unless adequate water is available.

A third important factor is to obtain an adequate supply of water for drilling. Much more water is needed for reverse circulation method. However, an adequate supply of drilling water is one of the least expensive requirements of the entire operation. When all these factors have been determined and the driller is ready to proceed, the following steps are taken:

1. After the well site is located, a settling pit is excavated with its nearest edge about 10 feet (3.04 m.) from the drilling machine. In normal depths, the volume of the pit should be at least three times greater than the displacement of the hole. The pit is made in two parts. One end is

designed to receive and hold the material removed from the hole as it is discharged with the drilling water. The second part of the pit contains the water that is re-circulated down the hole. A divider is placed between the two parts so that water is forced to rise over it, thus preventing material from re-entering the hole. If it is not practical to dig a hole, a tank can be used.

Regarding the amount of water needed, about three times more water is needed in the pit than will actually fill the completed hole. Thus, for example, in a 30 inch (76.20 cm.) hole being drilled to a depth of 200 feet (60.96 m.) it is necessary to have a settling pit of about 3,500 cubic foot (99,000 liters) capacity. Such a pit will hold about 26,000 gallons (98,410 liters) of water. While drilling, the pit must be kept full by a constant supply of water.

2. A trench is dug from the pit to the point where the hole is to be drilled, so that the water flows from the pit to the hole.

3. Because the drill bit is much larger than the drill pipe which rotates it, the drill pipe is first passed through the rotating table and then the bit is attached. The driller then lowers the bit to the ground and starts drilling. As he drills down, the water from the pit circulates around the bit.

4. The high-volume pump is then started and starts to draw the water and drilled material out through the drill pipe and back into the ditch. While drilling, the pit, must be kept full by a constant supply of water. The water supply can come from a nearby irrigation ditch or another nearby well. The water in its rapid movement upward through the drill pipe and circulating system carries the material loosened by the bit and is discharged into the settling pit. After separating from the material removed from the hole, the water re-enters the hole by means of the ditch or tube connecting the pit to the hole.

The water is of prime importance in holding the side wall. This is done by hydrostatic pressure. The weight of the water is circulated at about 1,000 gallons per minute (3785 liters). This may sound as if the side wall would be washed into the hole. It must be remembered, however, that while the velocity of the water passing through the drill stem is very high, the water passing downward into the hole is moving at a rate of 1/20 th or less of this speed -- slow enough so that no washing or caving results. With the water holding the side walls from caving, no construction casing is needed nor is the use of mud as a sealant necessary.

With a properly constructed settling pit, the muddy material taken from the hole is not recirculated. This leaves the hole clean and free of material that might otherwise penetrate the water bearing formation.

In formations containing boulders and materials that break out in chunks too large to enter the drill pipe or to pass through the circulation system, an orange peel bucket operated with the drill rig sand line is used to remove these large chunks, thus saving the time and other equipment it would take to break them into smaller pieces.

One improvement in the reverse circulation method of drilling is the use of compressed air circulating the drilling fluid. This provides an extremely high velocity of the drilling fluid, and permits greater drilling speed in loose, unconsolidated formations. Cuttings are removed faster, stoppages due to clogging of loose formations are reduced to a minimum and greater depths are possible. Penetration rates of up to 2 feet per minute (60.96 cm.) have been obtained with an average drilling rate of more than 40 feet per hour (12.19 m.) Compressed air depths down to 1,200 feet (366 m.) have been drilled successfully.

After the hole has been drilled to the proper depth, the bit is removed, the pump is stopped, and the well casing is lowered into the hole a section at a time. This casing may either be a flange type in which the sections are bolted together, or it can be welded.

Reverse circulation drilling is making amazing strides in the development of water resources throughout the world. Some drillers conclude that reverse circulation method of drilling is the fastest and most practical means for drilling large diameter holes in unconsolidated deposits, and for producing ground water where large quantities are available.

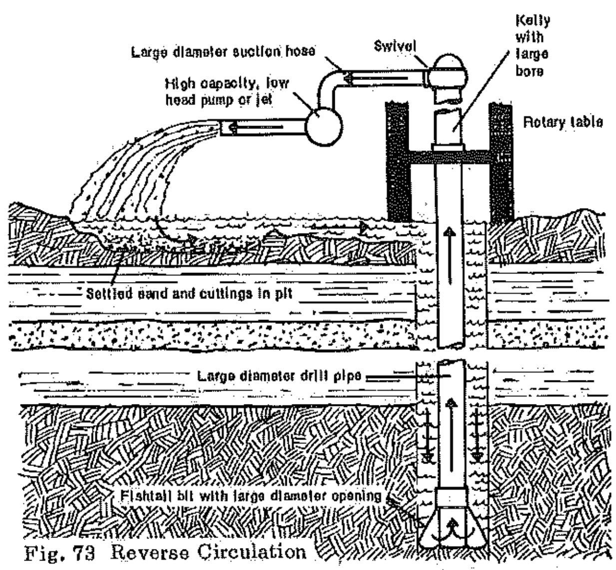


Fig. 73 Reverse Circulation

TABLE 3 ROTARY DRILL BIT TO DRILL PIPE SIZE RATIOS

DRILL BIT				DRILL PIPE					
SMALLEST		LARGEST		OD PIPE		TYPE JOINT	OD JOINT	
3-7/8"	9.84 cm.	7-7/8"	20.00 cm.	2-3/8"	6.03 cm.	API IF	3-3/8"	8.57 cm.
5-1/8"	13.02 cm.	12-1/42"	31.12 cm.	2-7/8"	7.30 cm.	API IF	4-1/8"	10.48 cm.
5-5/8"	14.29 cm.	18-1/2"	46.99 cm.	3-1/2"	8.89 cm.	API FH	4-1/4"	10.80 cm.
6-3/4"	17.15 cm.	26"	66.04 cm.	4-1/2"	11.43 cm.	API FH	5-1/2"	13.97 cm.

SELECTING A STRING OF ROTARY TOOLS

The selection of a string of rotary drilling tools is governed primarily by the relationship between the hole size desired, and the drill pipe size required to transmit the necessary torque. The total overall weight of the string must be within the capacity of the machine.

A proper relationship between bit sizes and drill pipe must be maintained. The drill pipe size is governed by the bit sizes, and once the drill pipe size is determined, the selection of the balance of the tools is almost automatic. Table 3 shows the size ratios between the rotary drill bit and the drill pipe.

In this table the smallest permissible bit with a given size of drill pipe is a fairly absolute specification. The drill bit must be sufficiently larger than the drill pipe to handle the upward movement of drilling fluid plus the cuttings carried from the bit. The "largest permissible bit" with a given size drill pipe is a variable which will be affected by depth, weight on the bit, speed of rotation, and type of formation.

It is sometimes practical to use a larger drag bit with a given size drill pipe in some very soft formations. A hole drilled with the largest permissible bit with a given drill pipe size can also be increased in diameter through the drilling of a small pilot hole, and reaming this hole in several stages to a larger diameter. By this method it is usually possible to increase the largest bit size in the above table by 1 line, i.e., 18-1/2" (46.99 cm.) with 2-7/8" (7.30 cm.) pipe. The drilling and reaming method of drilling larger holes generally makes it easier to drill a straight hole and has proven faster and more economical than drilling a large hole in one operation.

One or more drill collars are placed in the drilling string just below the bottom length of drill pipe. They are frequently the same OD as the tool joints, although for extremely large diameter drilling they may be somewhat larger to increase the weight on the bit. These collars are usually the same length as the drill pipe. Drill collars are sometimes used for the entire drill string, replacing the drill pipe, in shallow hard rock drilling. These tend to stabilize the string by furnishing less clearance, and add extra weight on the bit for easier hole starting. In such an application, careful attention should be paid to the total weight of the drill collars so as not to exceed the weight lifting capacity of the drilling machine.

Rotary drill bits normally have a pin joint; therefore, a double box bit sub is used to connect the bit to the bottom of the drill collar (or to the bottom of the kelly wear sub when starting a hole at the surface). Pin joints on rotary bits usually have API regular thread, and the size joint is governed by the size of the bit. Table 4 lists the size of the joints on various sizes of bits.

TABLE 4 STANDARD ROTARY BIT CONNECTIONS

Size Range of Bit		Standard Pin Joint	
3-1/8"	7.94 cm.	N Rod	
3-3/4-4-1/2"	9.53-11.43 cm.	2-3/8"	API Regular
4-5/8-5"	11.75-12.70 cm.	2-7/8"	API Regular
5-1/8-7-3/8"	13.02-18.73 cm.	3-1/2"	API Regular
7-1/2-9-1/2"	19.05-24.13 cm.	4-1/2"	API Regular
9-5/8" and larger	24.45 cm.	6-5/8"	API Regular

KEEP YOUR OLD ROTARY DRILL BITS

As you drill, bits wear and hole diameter gets smaller. Old, worn bits are usually the only ones that can reach hole bottom.

Always start your hole with a new bit. This keeps the widest diameter at the top of the hole and gives you clearance for changing to older bits as the hole goes down.

Smart drillers buy bits a few at a time and end up with a variety of staggered sizes. Where practical this allows them to use progressively narrower bits as the hole goes down.

CHAPTER 7 COMBINATION ROTARY - PERCUSSION DRILLS

Besides the rotary drills and percussion drills which have been fully described in this book, there are also available combination rotary and percussion drills. These combine all the work advantages of both types of drills. This, of course, means that when the drill operator comes up against a situation such as lost circulation in rotary drilling, he can switch to the cable tool method of drilling with the same rig and continue right on without wasting time and money attempting to seal off the area where the lost circulation occurred.

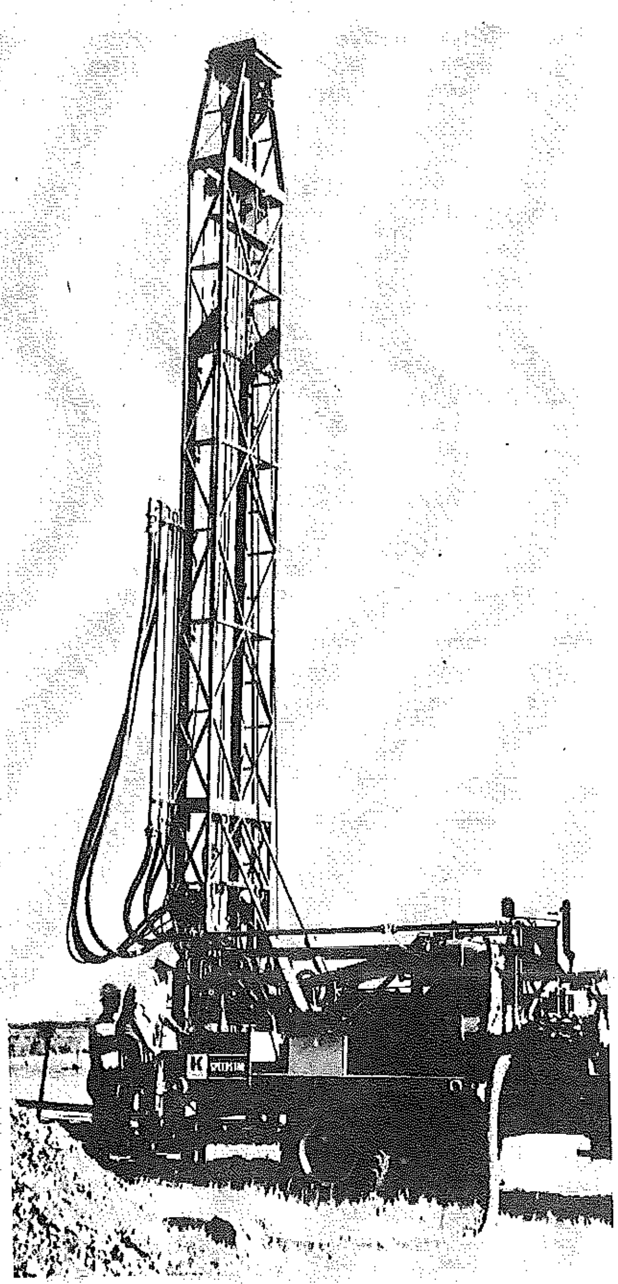


Fig. 74 Combination Rotary-Percussion Drill

Another big advantage of this type of unit, of course, is in high speed drilling. In soft formations, for example, the driller can put down approximately six times as much hole with the rotary bit on the drill as he can with the percussion unit.

These combination units have proved outstandingly successful in places where parts stocks are not always readily available. For example, in remote areas rotary operators have been held up waiting for a new shipment of rotary drill bits, or a replacement part for a mud pump, air compressor, or rotary table. With a combination, the driller can simply switch over to percussion drilling and keep going until his repair parts arrive. Lost time and a consequent lost income can be substantially reduced with this unit.

There is another advantage in areas where skilled drilling operators are not readily available. A relatively unskilled operator can operate the drill as a percussion rig, if a skilled rotary operator is not able to be on the job. In short, all of the advantages discussed in chapter II on both cable tool rigs and rotary rigs are combined in this unit.

As far as depth capacities are concerned, again using the machines manufactured by the Speedstar Division of Koehring Company as examples, it is possible to drill to depths of 5,000 feet (1524 m.) with rotary drilling, and 4,000 feet (1220 m.) with percussion drilling.

Quick, easy conversion. Conversion from one drilling method to the other can be conveniently and quickly accomplished. For example, on the Speedstar unit, the rotary table, swivel and kelly can be disconnected in a matter of minutes. Then the traveling block is removed, and the cable which has been attached to its anchor in lower mast section is hooked up to a swivel socket. The operator is then ready to attach a cable tool string and start drilling. To switch from cable tool to rotary, the process is simply reversed.

The derrick in the combination unit is similar to the percussion drill derrick. An extra rotary hoist line sheave and line rest have been added to provide for the rotary hoist reel line. Mud fluid standpipe. rotary cable strut anchors, transport clamp bracket and anchor have been added in the case of the Speedstar machine. In these machines, pumps and air compressors are available on separate trailer or skid mountings. This equipment is not available as integral parts of the drilling rig itself as in the case of straight rotary machines. Some drill operators have found it convenient to use an auxiliary truck as part of a combination rotary-percussion drill package. This truck carries an engine, air compressor, mud pump and drill pipe rack.

EQUIPMENT LIST

The equipment list for this machine would be similar to the combination equipment list for the cable rig and the rotary rig shown in chapter II. In selecting the equipment needed for the combination rig, a manufacturer's representative should be consulted for his advice.

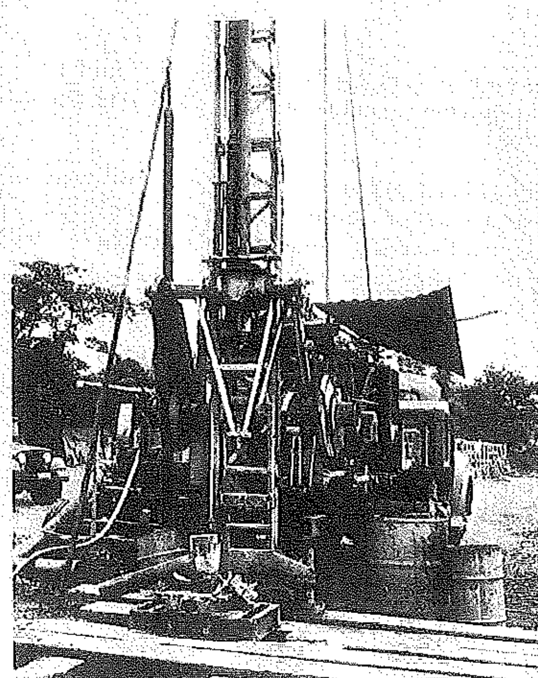


Fig. 75 Rotary Table Removed for Conversion

CHAPTER 8 COST ESTIMATION

Like any other businessman, the water well driller should keep a clear, and complete record of his costs. He should also be able to carefully estimate cost differences based on various types of formations, in order to arrive at cost figures that will give him a profit. There is a wide difference in costs from one area to another. In fact, where there are differences in formations, costs will vary from one area of a particular country to another.

Hard rock drilling, naturally, is going to cost the driller more than drilling in soft formations and, consequently, his charges to the customer in hard rock drilling would be higher. Following are other factors that will cause cost estimates to vary, and which the driller must consider in estimating his charges to the customer for drilling a well:

Terrain and condition of roads. Operation in extremely hilly or mountainous areas over rough back country roads will cause much greater wear on tires, transmission, shock absorbers, springs, etc. On the other hand, the driller operating on fairly flat terrain with good concrete or asphalt highways for travel should have lower maintenance costs.

Accessibility to parts. A driller operating in an area where parts are readily available can usually figure that even if his rig breaks down, he will be able to get it back into operation in a day or two. Serious breakdowns would, of course, take longer to repair. However, if such a breakdown occurs in a very remote area, it may take weeks or even months to obtain the replacement part. In this case the driller either has the choice of keeping on hand a substantial parts stock, or taking the chance of loss of income until the necessary parts arrive. If a large parts stock is maintained, the driller, of course, must consider his investment in these parts in determining costs. If such parts had not been purchased, the money invested in them could be invested somewhere else.

Labor. Labor costs will vary greatly from one part of the world to another. The going hourly rate for labor in a given area should be used in estimating the drilling costs.

Fuel and lubrication. Here again costs will vary widely from one part of the world to another. The driller should take the local per gallon, or per litre rate for fuel and lubricants in determining costs.

COST ESTIMATION

Here, for example, is one method of determining the drilling costs: First determine total cost of the unit.

Cost of new drill .... ________

Used truck or new truck .... ________

Drilling tools .... ________

Fishing tools .... ________

Cable, etc. .... ________

Hand tools .... ________

Total cost of machine .... ________

Next determine depreciation. Let us assume a total life of ten years for the drill rig. First subtract from the cost figures obtained above, the salvage or sale value for the rig, tools, drilling tools, etc. This figure is divided by ten, to give the average yearly depreciation. If a different number of years for depreciation is desired, this figure must be used.

Thus we have the following:

Total cost of machine .... ________

Less salvage value .... ________

Cost to be depreciated .... ________

Number of years for depreciation ..... ________

Average yearly depreciation .... ________

Next the following table is completed:

Depreciation cost per year
(based on ten year depreciation)..... ________

Yearly repair and maintenance costs
(based on 2,000 hours)* .... ________

Contractor's insurance per year .... ________

Labor: 2,000 hours per year
________ per hour .... ________

Bit Dressing Fuel:
________ gals. (liters) per year
________ per gal. (liter) .... ________

Engine (s) Fuel:
________ gals. (liters) per year
________ per gal. (liter) .... ________

Oil and Grease: cost per year .... ________

Replacement cost for bits, fishing
tools, cable, drill collar, drill pipe,
etc. per year .... ________

Interest cost on investment if
money is borrowed for equipment ..... ________

TOTAL .... ________

* 2,000 hours obtained as follows: 8 hours per day for a 5 day week for 50 weeks of operation. 8 x 5 x 50 = 2,000 hours operation per year.

Based on a 2,000 hours per year of operation, the total cost per year is then divided by 2,000 in order to obtain the per hour cost of operation. For example, if the total cost came to \$10,000 per year of operation, this divided by 2,000 hours would give a cost of \$5.00 per hour.

Next, the owner or operator must estimate the amount of footage per hour he feels he can drill in a given area on a particular job. In order to do this, he must make a fairly accurate estimate of the type of formations he will encounter in drilling. For example, if he is going to be in soft formations most of the way down to the water bearing strata, he can estimate a higher footage per hour than if he is drilling in hard rock. At any rate, let us assume that the operator can drill 2 feet (60.96 cm.) per hour. This figure would then be divided into his cost per hour, which in the above example of \$5.00 would be \$2.50 per hour per distance, or \$2.50 per foot of well drilled.

Next, the contractor would have to determine the per foot cost for casing. This would vary with the diameter of the casing. At any rate, the per foot (meter) cost of casing would then be added to the per foot (meter) drilling cost. This would give the driller his total drilling cost.

Now, based on the above per foot (meter) total cost, the driller should estimate the charge he is going to make for his services in order to obtain a profit. In addition to his costs, he should consider what the competitive charges are in the area. Taking the above figures as an example, suppose the driller charges \$4.00 per foot of hole, and can average about 2 feet (60.96 cm.) of hole per hour. Based on 2,000 hours of operation this would give him a total income of \$16,000 per year (\$4.00 x 2 feet x 2,000). Thus if total expenses were \$9,000, he would make a profit of \$7,000 for the year. If the owner was operating only one rig, he could add his own labor cost to his profits to determine his total income.

In estimating costs for rotary drilling, bit costs are substantially higher than for percussion rigs and, therefore, should be more carefully estimated in determining overall per foot (m.) cost. Following is a suggested chart that can be valuable in determining estimated rotary cost per hour using both a down-the-hole hammer and a rotary bit. The rotary bit would be used to drill through the overburden and the down-the-hole hammer would be used in the rock formations. The same chart can be used if only rotary bits or only down-the-hole hammers are used.

ESTIMATED ROTARY OPERATING COST PER HOUR USING DOWN-THE-HOLE AND ROLLER BIT

ITEM	COST
Labor - 2 men @ ________ per hour	________
Diesel fuel @ ________ per gallon (liter)	________
Lube oil (engine, drill hammer, etc.)	________
10% of basic rig cost for 2,000 hours for repairs & maintenance	________
* Per hour hammer bit cost @ ________ ea.	________
Per hour hammer cost $\frac{\text{(hammer cost)}}{\text{(est. hammer life)}}$	________
Per hour rod cost $\frac{\text{(rod cost)}}{\text{(est. rod life)}}$	________
Depreciation is based on 20% of basic rig cost for 2,000 hours	________
* Per hour roller bit cost in overburden	________
Per hour insurance and interest	________
Per hour road expense	________
Cost per hour	________
Average overall depth per hour	________
Cost per foot (cm.)	________
Cost of casing per foot (cm.)	________
TOTAL COST PER FOOT (cm.)	________

* Divide bit cost by total estimated feet of bit life to obtain per hour cost. For example, a bit costing $400 with a life of 1000 feet would cost $4.00 per hour.

In estimating drill costs it is a good policy to consult with the representatives of the drill rig manufacturer. These people have wide experience in drilling costs and can provide valuable help in assisting the driller to set up a realistic system for estimating costs.

CHAPTER 9 MAINTENANCE

Like any other piece of equipment, a water well drill operates better and lasts longer if it is properly maintained. A few extra hours of proper care each week will reward the owner with lower hole cost over the long run.

Following are a few suggestions which should give the driller an idea of the type of maintenance he should provide:

1. Clean the machine thoroughly with fresh water from time to time. This should be done frequently if the machine is exposed to sea water during travel, or if salt water is encountered during drilling operations.

2. The driller should be certain that the mud system, drill pipes and tools are thoroughly flushed of mud and drained of flushing water. This is particularly important when the machine is being moved to another drill site, is to be stored for any period of time or in freezing weather.

3. Battery terminals should be coated periodically with vaseline-based grease.

4. All chipped and cracked paint should be removed and the parts repainted once a year.

5. All unpainted ferrous metal surfaces should be periodically coated with light oil.

6. If storage is to be for prolonged periods, it is suggested that the machine frame as well as the truck be blocked in a way to remove the load from the tires and the truck's springs. If the truck is stored indoors, a means of ventilating is desirable. If the truck is stored outdoors, it is recommended that it be covered with tarpaulins tied to the truck or to ground stakes.

7. The following places should be checked for leakage: through the diesel engine and drilling air compressor cooling systems, at the chain case, rotary table, all crank cases, mud pump and pulldown speed reducers, throughout the two hydraulic systems, at the hydraulic tank and piping. Any leakage discovered should be corrected.

8. All exposed chains and wire ropes should be lubricated periodically.

9. Check and refill batteries as required.

10. Gauges should be checked periodically to determine if the equipment measured by the gauge is operating properly.

11. Air cleaners should be checked and the filter replaced when necessary.

12. Oil filter cartridges should also be periodically checked and replaced.

13. If the manufacturer provides a lubrication chart, this should be conveniently posted to serve as a reminder to the operator.

14. Crank case oil level should be maintained, with oil added when required.

15. Coolant level and engine radiator should be checked periodically. Water or anti-freeze should be added as required.

16. Tension of chains and belts should be periodically adjusted as required.

17. Holding power of all mechanical clutches should be periodically checked.

These are just a few of the more important maintenance checks that must be performed if the machine is to operate properly. It is strongly recommended that the manufacturer' s operating manual be followed to the letter whenever possible. In cases where this can not be done due to lack of maintenance supplies, emergency conditions, etc. any lapse in maintenance should be corrected just as quickly as possible.

FIELD CARE AND USE OF WIRE ROPE *

Wire rope is subjected to perhaps more abuse than any other part of the drill rig. With proper care, however, wire rope costs can be substantially reduced and profits consequently increased. Here are a few points which can help the driller keep wire rope in good operating condition over a longer period of time.

Handling on Reel

Use of binding or lifting chain. When handling wire rope on a reel with a binding or lifting chain, wooden blocks should always be used between the rope and the chain in order to prevent damage to the wire or distortion of the strands in the rope.

* Tool Pusher's Manual

TABLE 5	SAMPLE LUBRICATION TABLE FOR DRILLING OPERATORS		
Item	What	How	When
1. Crown block	fittings	4 or 5 shots	Every trip or at least every 24 hours
2. Cat line	fitting	3 or 4 shots	Every trip or at least every 24 hours
3. Traveling blocks	fittings	4 or 5 shots	Every trip or at least every 24 hours unless fishing, testing, etc.
4. Hook	fittings	3 or 4 shots	Once every 3 or 4 days
5. Swivel	fittings	On bottom seal, grease until it builds up pressure. Top seal takes 3 or 4 shots. Keep full.	Once every 8 hours
6. Rotary bushing	fittings	3 or 4 shots	Every trip or at least every 24 hours
Rotary table	fittings	2 or 3 shots	Every 8 hours
Rotary oil		Keep full	Every 8 hours
Rotary chain	drip system	Keep full	Every 4 or 5 hours
7. Tongs	fittings	2 or 3 shots	No set rule (left up to man working them)
8. Elevators	fitting	Fill until it works easily	Every trip
9. Draw works (Actual moving parts)	fittings	2 shots each	Every 8 hours
	transmission oil bath	Keep full to proper level	Every 4 hours

NOTE: Type and grade of lubricant for the various equipment is dependent on manufacturer's recommendations and loading conditions.

Use of bars. Bars for moving the reel should be used against the reel flange, and not against the rope.

Sharp objects. The reel should not be rolled over or dropped on any hard, sharp object in such a manner that the rope will be bruised or nicked.

Dropping. The reel should not be dropped from a truck or platform, this may cause damage to the rope as well as break the reel.

Mud, dirt or cinders. Rolling the reel in, or allowing it to stand, in anything harmful to steel such as mud, dirt, or cinders should be avoided. Planking or cribbing will aid in handling the reel and protect the rope against damage.

Handling During Installation

Stringing of blocks. Blocks should be strung to give a minimum of wear against the sides of sheave grooves.

Changing lines and cutoff. It is good practice in changing lines to suspend the traveling block from the crown on a single line. This tends to limit the amount of rubbing on guards or spacers, as well as chances for kinks. This practice is also very effective in pull-through and cutoff procedure.

Rotation of reel. The reel should be set up on a substantial horizontal axis so that it is free to rotate as the rope is pulled off, and in such a position that the rope will not rub against derrick members or other obstructions while being pulled over the crown. A snatch block with a suitable size sheave should be used to hold the rope away from such obstructions.

Jacking. The use of a suitable apparatus for jacking the reel off the floor and holding it so that it can turn on its axis is desirable.

Tension on rope. Tension should be held on the rope as it leaves the reel. This should be done by restricting reel movement rather than by restricting line movement directly. A timber or plank held against the reel flange provides a satisfactory brake action. When winding a rope on the drum, calf wheel, etc. enough tension should be kept on it to assure that it will be tightly wound.

Tight spooling. Pulling the rope back and forth between the drum and calf wheel under any more than just enough load to insure tight spooling is not recommended. Due to the small diameter of the calf-wheel spool, excessive tension on the rope being spooled may damage the line.

Kinking. Care should be taken to avoid kinking a wire rope.

Striking with hammer. Wire ropes should not be struck with any object such as a steel hammer, derrick hatchet, or crow bar which may cause unnecessary nicks or bruises. Even a soft metal hammer can damage the line. When it is necessary to crowd snaps together, any such operation should be performed with the greatest of care; and a block of wood should be placed between the hammer and rope.

Cleaning. Use of solvent may damage a wire rope: If a rope becomes covered with dirt or grit, it should be cleaned with a brush.

Number of wraps on drum. Nine wraps, or turns on the drum are enough if a suitable clamp is used on the drum end of the rope. As few as five wraps have been found to be sufficient on 26-inch (66 cm.) or larger diameter drums.

Position on drum. Rope should be positioned on the drum so that at pick-up the rope will not be closer than six rope diameters to the flange.

New wire rope. Whenever possible, a new wire rope should be run under a light load for a short period after it has been installed. This will help to adjust the rope to working conditions.

New coring or swabbing line. If a new coring or swabbing line is excessively wavy when first installed, two to four sinker bars may be added on the first few trips to straighten the line.

Care of Wire Rope in Service

Handling. The recommendations for handling should be observed at all times during the life of the rope.

Factor of safety. The factor of safety should be determined by the following formula:

$$\text{Factor of Safety} = \frac{B}{W}$$

wherein:

B – nominal breaking strength of the wire rope, in pounds (or kgs.)

W – calculated total static load, in pounds

a. When a wire rope is operated close to its minimum factor of safety, care should be taken that the rope and related equipment are in good operating condition. At all times, the operating personnel should use care to minimize shock, impact, and acceleration or deceleration of loads. Successful field operations indicate that the following factors of safety should be regarded as minimum:

	Minimum Factor of Safety
Cable-tool line	3
Sand line	3
Rotary drilling line	3
Rotary drilling line when setting casing	2
Pulling on stuck pipe and similar infrequent operations	2

b. Wire rope life varies with the factor of safety: Therefore, longer rope life can generally be expected when relatively high factors of safety are maintained.

Winding on drums. Rope should be kept tightly and evenly wound on the drums.

Maximum rope speed. Excessive speeds when blocks are running up light may injure wire rope. For existing drum conditions a maximum rope speed of 4000 feet (1219 m.) of rope travel per minute for hoisting or lowering is recommended. This speed also applies to cable-tool rigs.

Clamps. Care should be taken to see that the clamps used to fasten the rope for dead ending do not kink, flatten, or crush the rope.

Lubrication of wire rope. Wire ropes are well lubricated at the factory and have a certain amount of reservoir lubricant. Periodic inspections are desirable to determine when there is no longer any apparent lubrication left between wires. Ropes may be treated with a good grade of lubricant which will penetrate and adhere to the rope, and which is free from acid or alkali.

Rotary drilling lines. Care should be taken to maintain proper winding of rotary drilling lines on the draw works drum in order to avoid excessive friction. Also, avoid excessive friction in worn grooves of sheaves, slippage in sheaves, or excessive friction resulting from rubbing against a derrick member.

Worn drums. Roughly worn drums cause excessive wear on the rope.

Sheave alignment. All sheaves should be in proper alignment. Fast sheave should line up with the center of the hoisting drum.

Sheave grooves. From the standpoint of wire rope life, condition and contour of sheave grooves are important. Check them periodically. The sheave groove should have a diameter not less than that of the gage; otherwise a reduction in rope life can be expected. Reconditioned sheave grooves should conform to the recommended gaging practice for new sheaves. Each operator should establish the most economical point at which sheaves should be regrooved by considering the loss in rope life which will result from worn sheaves as compared to the cost involved in regrooving or replacing.

Installation of new rope. When a new rope is installed on used sheaves, it is particularly important that sheave grooves be checked.

Lubrication of sheaves. In order to insure minimum turning effort, all sheaves should be properly lubricated.

Attachment of Clips

Type and strength. The clip method of making wire-rope attachments is widely used. Drop-forged clips of either the U-bolt or the double-saddle type are recommended. When properly applied, the method develops about 80 per cent of the rope strength.

Turn back. The length of rope to be turned back when making a loop is dependent upon the size of the rope and the load to be handled. The recommended lengths, as measured from the base of the thimble are given in table 6.

Thimble. The thimble should be wired to the rope at the desired point. The rope is then bent around the thimble and temporarily secured by wiring the two rope members together.

Attachment of first clip. The first clip should be attached at a point about 4 inches (10.6 cm.) from the short end of the rope and tightened securely. The saddle of the clip should rest upon the long or main rope and the U-bolt upon the short end. All clips should be attached in this same manner.

TABLE 6 DETAILS OF LOOP FASTENINGS

1	2	3	4
Diameter of rope In. (cm.)	Number of Clips	Space between Clips In. (cm.)	Length of rope Turned Back Exclusive of eye In. (cm.)
3/8 (.95)	2	2 1/4 (5,71)	5 (12,70)
1/2 (1,27)	3	3 (7,62)	9 (22.86)
5/8 (1,59)	3	3 3/4 (9,52)	11 (27.94)
3/4 (1,90)	4	4 1/2 (11.43)	18 (45,72)
7/8 (2,22)	4	5 1/4 (13,33)	21 (53,34)
1 (2,54)	4	6 (15,24)	24 (60,96)
1 1/8 (2,85)	5	7 (17.79)	35 (93.90)
1 1/4 (3,17)	5	8 (20,33)	40 (101,60)
1 3/8 (3,49)	6	9 (22,87)	54 (137,16)
1 1/2 (3,81)	6	10 (25,40)	60 (152.40)

Position of short end of rope. The short end of the rope should rest squarely upon the main portion.

Number and attachment of remaining clips. The second clip should be attached nearest the thimble. The nuts for this clip should not be completely tightened when it is first installed. The recommended number of clips and the space between clips are given in table 6. Before completely tightening the second and any of the additional clips, some stress should be placed upon the rope in order to take up the slack and equalize the tension on both sides of the rope.

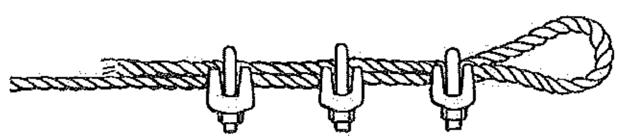


Fig. 76 Correct Way of Attaching Clips

Correct and incorrect attachment. When clips are attached correctly, the saddle should be in contact with the long end of the wire rope and the U-bolt in contact with the short end of the loop in the rope as shown in figure 76.

Tightening of nuts during installation. The nuts on the second and additional clips should be tightened uniformly, by giving alternately a few turns to one side and then the other. The application of a little oil to the threads will allow the nuts to be drawn tighter.

Tightening nuts after use. After the rope has been in use a short time, the nuts on all clips should be retightened, as stress tends to stretch the rope, and reduce its diameter. The nuts should be tightened at all regular inspection periods.

A GLOSSARY OF TERMS

Air line lubricator - device to feed a controllable amount of lubricant into the air for bottom-hole percussion tools.

Annular velocity - up hole or return velocity of the fluid or air in the annulus, usually expressed in feet per minute.

Annulus - area between the drill pipe and the wall of the hole.

API - American Petroleum Institute standards for equipment and parts.

Aquifer - water bearing formation.

Bailer - pipe with a valve at the bottom and bail at top end, used to remove cuttings from a hole.

Bailing - process of removing fluid and drill cuttings from the hole.

Bell socket - a fishing tool used to remove a broken joint of casing or a bailing tube.

Bit - tool at the bottom end of the drill string which does the actual drilling or cutting.

Bit breaker - heavy plate which fits in the rotary table and holds the drill bit while it is being unscrewed from the drill collar.

Bit gauge - an instrument used to check the diameter of the reaming edge on a bit when dressing.

Bit ram - a steel ram suspended and swung back and forth for use in dressing large cable tool bits. It is more effective than using a sledge.

Block - block and tackle on a rig used to handle well casing.

Bottom hole drill - a percussion hammer with carbide inserts installed on the cutting end of the drill. It is operated by compressed air.

Box - female or internal threaded connection on a drilling tool.

Breaking a joint - act of loosening and unscrewing joints in a string of tools.

Bull reel - drum which lowers and hoists drilling tools into and out of the well.

Cable tool drill - machine which uses the percussion method of drilling. Also known as a spudder, percussion drill, churn drill.

Calf reel - drum which lowers and hoists casing.

Casing - cylindrical steel pipe used in well drilling operations.

Casing block - block or sheave used to rig a multi-part line for handling casing.

Casing connection - tool which joins a section of casing to fishing tools so that the casing can guide the tools more accurately to the center of the hole.

Casing cutter - tool which cuts pipe or casing in the hole at a desired depth when the entire string cannot be removed.

Casing hook - hook associated with casing tackle and used to handle casing.

Casing perforator - knife which slots or cuts casing to admit water.

Casing shoe - forged steel threaded collar with a cutting edge. Attached to the bottom of the casing to protect the lower edge of the casing or drive pipe.

Casing spear - tool to loosen stuck casing and remove one or more lengths of casing from the hole.

Cat head - drum usually mounted at the side of a drill rig to which cable is attached to handle heavy work in drilling operations. Also handy for pulling wrenches to tighten or break pipe or tool joints.

Collar - section of drill tool between the wrench square and the pin or box joint.

Combination socket - fishing tool used to engage the neck of the rope socket or pin of a bit or tool which has become unscrewed in the hole.

Control console - horizontal or vertical panel on which are grouped all of the operator's various controls.

Corrugated friction socket - a tapered fishing tool with several indentations for taking a friction hold on bits or other tools lost in hole. Not for stem lost in a deep hole.

Crown block - assembly of wire-line sheaves mounted on the uppermost portion of the derrick.

Crushing face - area on the bottom of the drill bit which crushes the chips or cuttings during drilling.

Cutting edge - penetrating edge of the drill bit.

Cuttings - crushed material removed from the hole during drilling. Washed out while circulating mud-laden fluid in rotary drilling. Bailed out in cable tool drilling.

Dart valve - type of valve attached to the bottom of the bailer. Opens when the bailer strikes the bottom of the hole.

Derrick - framework used to support the crown block, top drive, pull down chains, hoisting lines in rotary drilling. Supports the tackle and drill tools in percussion drilling. Also referred to as a mast or tower.

Derrick hoist - power driven winch mounted on the drill frame which raises and lowers the derrick.

Draw down - the distance the water level drops in a well during pumping. The difference between the static level of the water and the pumping level.

Draw works - power driven winch or winches usually equipped with clutch and brake for hoisting or lowering a drill string.

Dressing - act of reshaping and bringing the drill bit to gauge.

Drilling motion - movement of percussion tools which produces a quick pick-up at the bottom of the hole for a sharp, clean drilling action.

Drill pipe - special pipe jointed and threaded at each end. Used to transmit rotation from the rotating mechanism. The pipe also transmits thrust or weight to the bit and conveys air or fluid which removes cuttings from the hole and cools the bit.

Drill stem - steel tool placed below the jars and the drill string to furnish the necessary weight to the string.

Drive clamp - clamp which fastens on the square of the drill stem for use in driving casing with a string of tools in percussion drilling.

Drive head - (Drive shoe) - forged steel threaded collar with a cutting edge attached to the bottom of the casing to trim off the side walls and protect the lower edge of the casing during driving.

Dust collector - device used in air drilling to control the dust and/or collect the cuttings which are discharged from a hole.

Dust diverter - collar and hose used to divert dust and cuttings away from the operator and the machinery.

Dynamic level - height the water reaches when an equalization between pumping and well intake recharge occurs.

Elevators - tools used to raise or lower tubing casing or drive pipe.

Fish - any object lost in the hole.

Fishing - act of attempting to recover the fish.

Fishing neck - an unthreaded extension of body, machined at the top of rope socket so that it can be picked up by the fishing tool.

Fishing tools - special tools used to retrieve debris or fish lost in the hole.

Flag - to tie a piece of string or other marker on a bailing, swabbing, or drilling line to enable the operator to know the depth at which the swab or bailer is operating in the hole.

Flat valve - flapper-type valve used on a bailer which opens to receive cuttings when the bailer is dropped into the hole.

Fluid - the medium, liquid, gas or air, used to remove cuttings from the hole being drilled, and for cooling the bit.

Frame - foundation to which all the components of the drilling machine are attached.

Friction socket - fishing tool sometimes used to recover an unscrewed bit or lightweight tool lost in the hole.

Full circle slip socket - fishing tool with hardened steel slips used to take a firmer hold on the lost tool than the ordinary friction socket.

G.P.H. - Gallons per hour.

G.P.M. - Gallons per minute.

Heel sheave - sheave at the fixed end of the spudding beam.

Hoisting line - wire rope used on the draw works to hoist and lower the drill string.

Horn socket - fishing tool used to remove drill bits with broken pin joints or joints which have unscrewed. Will not hold for jarring on tool.

I.D. - inside diameter.

Jar bumper - tool run on the sand line to bump the top of a tool string in order to help release tools stuck in the hole.

Jars - the jar is composed of two connecting links or reins with space or play between them. It is used to put a sudden upward shock on a tool string stuck in the hole.

Jar socket - fishing tool used to fish for broken jars in holes where clearance is not great enough for a slip socket.

Jetting - drill process in which water is forced down the drill stem and out of nozzles in the drill point.

Jetting bits - bits used in jetting.

Joints - piece of steel consisting of a pin or box collar or square which is welded on a tool. When used in connection with a pipe or tool, it is either the pin or box half of the joint.

Kelly - formed or machined section of hollow drill steel joined directly to the swivel at the top and to the drill pipe below. Flats or spines of the kelly engage the rotary table so that the rotation of the rotary cable is transmitted to the kelly, which, in turn transmits it to the drill pipe and consequently to the rotary bit.

Knocker - same as jar bumper.

Left lay wire rope - wire rope or cable twisted in the opposite direction to right lay cable. The strands twist toward the left as they recede from the individual. Left lay is used for cable tool drilling because the threads in the tool joints are right hand.

Leveling devices - used for leveling and aligning the drill during drilling operation, to provide stability, and good operation of equipment.

Making a connection - act of screwing a joint of drill pipe on the drill string suspended in the well bore.

Making hole - denotes progress in drilling.

Mandrel socket - same as bell socket.

Mother hubbard bit - drill bit with sharp shoulders. Useful in shale drilling.

Mounting - any motor truck, trailer, or semi-trailer on which a drill is mounted.

Log - written record of all events during the drilling of a well, usually recorded by the day.

Mud scow - heavy bailer used instead of a bit for drilling large diameter wells where heavy sand or a mixture of quick sand and clay are found.

O.D. - outside diameter.

Pipe handling equipment - any tools used for storing, adding and removing lengths of drill pipe or casing.

P.S.I. - pressure per square inch.

Pin - male threaded connection on a drilling tool or drill pipe.

Pipe tongs - tools used to tighten or loosen pipe at threaded joint.

Pitman - arm or rod connecting the crank-arm to the spudding beam.

Power take-off - means of transmitting power from the engine of a truck, tractor or other power package to the other components of the drilling rig.

Prosser socket - original swivel socket.

Pull down - means of applying thrust or weight to the bit through the drill string.

Pull down system - mechanism which provides pull down power to kelly. With hydraulic pull down, power may be applied in either direction.

Reamer - tool which enlarges a hole already drilled. It is also used to straighten a crooked hole in slanting, broken formations.

Reverse circulation - normal course of drilling fluid circulation is downward inside the drill pipe and upward in the well bore space surrounding the drill pipe. On special problems this normal circulation is sometimes reversed and the fluid returns to the surface through the drill pipe after being pumped down in the annular space.

Rig - drilling machine, complete with accessory equipment.

Rope saver - wire line attachment that slips over the neck of the drill line socket and prevents the line from kinking at this point when tools are raised from any position other than vertical.

R.P.M. - revolutions per minute.

Rotary drill rig - type of drill rig that utilizes two energy factors -- rotation, and pressure or weight, to drill a hole in rock or other formations.

Rotary drive - shaft, belt or chain to transmit driving power to the rotating element.

Rotary hose - air or mud hose that leads from the standpipe to the swivel. Known also as the fluid (air) or swivel hose.

Rotary table, power swivel and/or top rotation drive - means of transmitting rotation to the drill string and bit.

Run in - act of lowering the drilling or fishing tools into the hole.

Safety hook - hoisting hook equipped with spring-loaded latch to keep the load on the hook.

Sand pump - bailer made of tubing with a hinge flap valve and a plunger that works inside the barrel. It is used where the dart valve bailer will not pick up the material adequately as in sand and gravel.

Sand reel - drum for hoisting and lowering the bailer or sand pump.

Set casing - install steel pipe or casing in a well bore.

Set pipe - act of placing pipe or casing in the hole; or the act of cementing pipe or casing.

Setting-up a joint - tightening a tool joint.

Shock absorber - group of rubber discs located in the derrick head. The compression and expansion of these units help provide a good drilling motion, and also protects the derrick frame and machinery from shock and vibration.

Shooting - act of detonating an explosive to blow off pipe in a hole, or create a cavity in the hole to collect fluid.

Slip ring socket - fishing socket with circular slips.

Slips - wedge or wedges used to prevent the drill pipe from slipping through the opening in the table when the bit is off the bottom when adding or taking off a section of drill pipe. These may be hand or power actuated. Slips are also parts of a fishing socket equipped with serrations to engage tools lost in the hole.

Slip socket - tool used to catch a lost tool or fish.

Spider - casing ring.

Sinker - fishing stem or short drilling stem.

Spud - tool used to straighten bits or tools wedged into the wall of the hole so that the socket cannot engage them. It also loosens cave-ins around the bit or other tools so that a fishing tool can be used.

Spudder - another name for cable tool rig, percussion drill or churn drill.

Spudding beam - oscillating arm that imparts the drilling motion to the drill line.

Spudding gear - gear which drives crank-arm shaft.

Spudding-in - starting a hole.

Spudding sheaves - sheave of the free end on the spudding beam through which the drill line runs.

Square - squared part of a drill tool which fits the tool wrenches.

Stand pipe - vertical pipe or hose carrying either air or mud to the approximate middle of the mast where it is connected to the mud, rotary or swivel hose.

Stinger - swivel or mandrel for a swivel socket.

String - components including subs, adaptors, drill pipe, drill collar and bit joined together to form a drill string for drilling a hole.

Stringing tools - assembling tools to ready them for drilling.

Sub - substitute or adaptor used to connect from one type of thread or connector to another.

Swivel - mechanism which permits the passage of mud or air from a stationary hose to a rotating member such as a kelly or drill pipe.

Swivel pin hook - tool attached to the rope socket on the drilling line to lift strings of pipe with elevators.

Swivel socket - socket which allows the tool string to spin or turn during the drilling action.

Swivel wrenches - tools used to handle bits, and hold them in position when starting joints.

Tongs - instruments used in tightening or breaking a joint of pipe during a drilling operation. Their action is much the same as that of a pipe wrench.

Tool joint - threaded portions of the drill string which may be either box or pin type and usually manufactured to A.P.I. specifications or the standards of the diamond core drill manufacturers' association.

Tower - see derrick.

Under reamer - bit for reaming a hole below casing already in place. It slides through the casing and then opens to a larger diameter for reaming.

Transfer case - transmission that distributes power from the engine to other rig components.

Water course - channel part of a bit through which water or cuttings pass when the bit is working in hole.

Water injection system - used for adding water to the down-hole air stream thereby increasing the efficiency of the cleaning action. Also used for controlling dust while doing rotary air drilling.

Well log - same as log.

Wire line socket - tool by which a connection is made between the drill line and the drill stem.

Wrench - used in connection with a wrench bar or a jack and circle or track to set up or break joints. These are both right hand and left hand.

Wrench square - same as square.

CONVERSION FACTORS
MULTIPLIERS

MULTIPLY	BY	TO OBTAIN
Acres	160.	Square Rods
Acres	43,560.	Square Feet
Acres	4,840.	Square Yards
Acre-feet	43,560.	Cubic Feet
Atmospheres	14.7	Pounds per Square Inch
Barrels, Water	350.	Pounds
Barrels, Water	31.5	Gallons
BTU	778.3	Foot-Pounds
Centimeter	0.3937	Inches
Cubic Centimeters	0.006102	Cubic Inches
Cubic Feet	1,728.	Cubic Inches
Cubic Feet	0.03704	Cubic Yards
Cubic Feet	7.4085	Gallons
Cubic Feet	28.3	Liters
Cubic Inches	16.39	Cubic Centimeters
Cubic Inches	.76	Cubic Meters
Days	24.	Hours
Days	1,440.	Minutes
Feet	30.48	Centimeters
Feet	12.	Inches
Feet of Water (Depth)	.4335	Pounds per Square Inch
Feet per Minute	.01136	Miles per Hour
Feet per Minute	197.	Meters per Second
Feet per 100 feet	1.	Percent Grade
Foot	0.3048	Meters
Foot Pounds	.138	Kilogram Meters
Foot Tons	.33	Tonmeters
Furlongs	40.	Rods
Furlong	660.	Feet
Gallons (Imperial)	1.209	Gallons (U.S.)
Gallons (U.S.)	3,785.	Cubic Centimeters

MULTIPLY	BY	TO OBTAIN
Gallons (U.S.)	.1337	Cubic Feet
Gallons (U.S.)	3.785	Liters
Gallons per Minute	.1337	Cubic Feet per Minute
Gallons per Minute	34,286.	Barrels per Day
Hectares	2.471	Acres
Horsepower	33,000.	Foot pounds per Minute
Horsepower	1.014	Force de Cheval
Horespower	76.	Kilogram Meters per Second
Hundred weights	50.8	Milograms
Inches	.08333	Feet
Inches	2.54	Centimeters
Inches	.254	Millimeters
Inches of Mercury	.4912	Pounds per Square Inch
Inches of Water	.03613	Pounds per Square Inch
Kiloliter	1,000.	Liters
Kilometers	3,281.	Feet
Kilometers	.6214	Miles
Kilometers per Hour	54.68	Feet per Minute
League (statute)	3.	Miles
Liters	1,000.	Cubic Centimeters
Liters	.03531	Cubic Feet
Liters	.2642	Gallons
Meters	3.281	Feet
Meters	39.37	Inches
Meters	1.094	Yards
Miles	5,280.	Feet
Miles	1.609	Kilometers
Miles	1,609.3	Meters
Miles	1,760.	Yards
Miles per Hour	88.	Feet per Minute
Miles per Hour	1.609	Kilometers per Hour
Milligrams	1,000.	Grams
Milliliters	.001	Liters
Millimeters	.03937	Inches

MULTIPLY	BY	TO OBTAIN
Square Meters	10.76	Square Feet
Square Meters	.0002471	Acres
Square Yards	9.	Square Feet
Square Yards	.8361	Square Meters
Temperature (Degrees Cent.)	1.8 (Add 32 Deg.)	Temperature (Degrees Fahr.)
Temperature (Degrees Fahr.)	5/9 or 0.5556 (Subtract 32 Degrees)	Temperature (Degrees Cent.)
Tons (Long)	2,240.	Pounds
Tons (Metric)	2,205.	Pounds
Tons (Short)	2,000.	Pounds
Tons (Short)	1,016.0	Kilograms
Tons per Square Inch	1.575	Kilograms per Square Millimeter
Varas	2.7778	Feet
Weeks	168.	Hours
Yards	.9144	Meters
Yards	91.44	Centimeters
Years	8.760.	Hours

FOR REVERSE CONVERSION DIVIDE BY FIGURE GIVEN

MULTIPLY	BY	TO OBTAIN
Minutes	.01667	Hours
Months	30.42	Days
Months	730.	Hours
Ounces	.0625	Pounds
Ounces (Fluid)	1.805	Cubic Inches
Ounces (Troy)	31.10	Grams
Parts per Million	0.05835	Grains per Gallon
Pints	28.87	Cubic Inches
Pints	.125	Gallons
Pounds (Avoir.)	.4536	Kilograms
Pounds (Troy)	.3732	Kilograms
Pounds of Water	.01602	Cubic Feet of Water
Pounds of Water	27.68	Cubic Inches of Water
Pounds of Water	.1198	Gallons
Pounds per Cubic Foot	.01602	Grams per Cubic Cm.
Pounds per Cubic Foot	.593	Kilos per Square Meter
Pounds per Cubic Foot	16.02	Kilos per Cubic Meter
Pounds per Square Inch	2.307	Feet of Water
Pounds per Square Inch	.7	Meters of Water
Pounds per Square Inch	70.3	Grams per Square Centimeters
Pounds per Square Inch	.07	Atmospheres
Pounds per Square Feet	4.883	Kilos per Square Meter
Quarts (Liquid)	57.75	Cubic Inches
Quarts (Liquid)	946.4	Cubic Centimeters
Rods	16.5	Feet
Square Centimeters	.1550	Square Inches
Square Feet	144.	Square Inches
Square Feet	929.	Square Centimeters
Square Feet	.093	Square Meters
Square Inches	6.452	Square Centimeters
Square Miles	640.	Acres
Square Miles	259.	Square Kilometers
Square Kilometer	247.1	Acres

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