OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

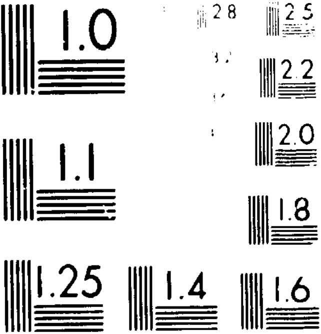
Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

11287

WATER WELL DRILLING METHODS, COSTS AND ECONOMIC ADVANTAGES FOR EACH TECHNOLOGY

BY

DAVID H. EADIE

PREPARED FOR

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

VIENNA AUSTRIA

1978

TABLE OF CONTENTS

WATER WELL DRILLING METHODS, COSTS, AND ECONOMIC ADVANTAGES FOR EACH TECHNOLOGY

History and Introduction:

About 2100 B.C. one of the kings of Egypt was reported to have completed 14 wells with 3,000 men. Four hundred years later Senacharib used pulleys to raise water. Jacob's well in Nablus originally went down to 73.5 meters (245 ft) and Joseph's well in Cairo was built in two lifts for a total of 88.5 meters (295 ft). The water was raised in the lower level by buckets on endless chain and buckets being powered by donkeys in a chamber at the bottom of the upper lift.

In 1833 at Grenelle near Paris a well was completed at a depth of 539 meters (1798 ft). A well drilled in 1857 to a depth of 576 meters (1923) just 71CM in diameter yielded over 5.5 million gallons of water daily as an artisian well with a flow 16 meters above the surface.

Methods of digging and drilling developed from these experiences. No theory was involved just practical experience and experimentation. The recovery of broken tools and difficult rock conditions and a variety of soil conditions were the tools to develop the right methods or technology to face each situation.

Anyone who has travelled across the country of Iran and in and around Quetta in Pakistan have been amazed at the extent of the quanat system of underground wells and horizontal canals connecting the wells. They were built at a time of very low wages and possibly no wages. They were economic at that time but none have been built for years.

In the late 1960's in Burhampur in India a well was drilled into the same aquifer as was supplying a 101 well quanat in a matter of two days as compared to an estimated 4,000 man year for the other system. However, the old system only needed a man for maintenance, whereas the modern well needed electricity for the pump. Levels of technology are of concern to those who are involved in the water resource development. It is the purpose to outline various methods of water well drilling capacities for a variety of soil and rock conditions, their capital costs and labour skill requirements as well as the suitability to the community needs. In particular emphasis will be made on suitability of pumps and the testing of the well capacities.

Water Cycle:

The hydrologic cycle as it is also called has no beginning nor end. Radiation from the sun on the huge ocean surfaces and ground masses evaporates water into the atmosphere and collects into clouds. It returns to earth as rain, snow, and hail. This soaks into the earth through direct perculation or from the streams, rivers, and lakes to eventually return to the oceans. We are most concerned about the water that soaks into the earth below the vegatation level and from this we get huge resources of ground water that can be extracted in the form of water wells.

It is estimated that 80,000 cubic miles of water are evaporated from the oceans and that 24,000 cubic miles are collected on the earth masses. It is estimated that there is 10 times the annual rainfall stored as ground water. However, not all of it is available. There are basically tow zones or depths for this water. The upper called the zone of aeration consists of the soil next to the roots of vegetation on the surface and then the area of suspended water in the open pores of the soil that is partially filled. At the bottom of this level there is a shallow capillary rise that ends at the water table. The zone of saturation is below this area and the ground water is under hydrostlic pressure.

The water held in any of these zones are subject to the particular nature of the soils. Very fine particles like clay while holding a huge volume of water in its pores does not allow water to move through the formation. Wells in this material are unsuccessful. Where as in coarser materials like sand with large open spaces water moves fairly freely.

Ground water stratas that have a coarse materials where the water flows easily are called aquifers. The pressure of the water at the water table is at atmosphere pressure and progressively increases as the depth increases, this fact is important as in pumping wells the water table moves down due to a variety of causes and where the water is pumped to (i.e. level) is the hydrostatic head. This is measured in feet or meters and is called the head of water. For example, if the pump is operating and the water table drops in the well to 25 meters from the surface of the tank where the water flows to this the hydrostatic head of water and the pump will have to be designed for this capacity. The pump will have to be inade to suit this maximum head.

The water table does not move very much but around the well due to the permeability of the soil, openings in the screens of diameter of well etc. all influence the flow into the well when pumping. This influence is called the cone of depression or commonly called drawdown. This aspect of well design is called well hydraulics and is very important.

In some areas generally in valleys or depressed areas such as Pantnagar N. India and Alice Springs, Australia wells drilled flow freely above ground. These are called artesian wells and are caused by the hydrostatic head or water table is above the surface opening of the well. These wells if anticipated require special preparations to be made when drilling. However, as in Figure 2, the well can also be artesian when the water level is ordinarily above what would be an ordinary well. This is due to the pressure of the water in the confined artesian aquifer below.

In explaining the hydrological water cycle, it has been demonstrated that the water that reaches the zone of saturation has taken the route of infiltration from the surface and from lakes and rivers. In some areas rain is very quickly absorbed into the ground eventually to the water zone of saturation sometimes rivers replenish the zone like the Narbada in India or the White Nile in the Sudan. The rate is governed by the porosity of the ground. The steep hillsides do not replenish as quickly as gentle slopes. Heavy rains compact soils in flat areas and run off. rapidly where as gentle rains are absorbed. Soil condition is very influential on recharge of the zone of saturation The water in this zone is generally on the move from one area to another depending on recharge and discharge. Only in rare unusual conditions such as in the area near the Egyptian and Lybian boarder is the water relatively stationary and very old.

Gelogical conditions for Acquifers:

Water is to a large degree stored in a variety of rock formation: Sedimentary rock in particular makes up 5 percent of the earth crust but holds about 95% of the ground water. These rocks are the result of erosion and weathering and over centuries are deposited on ocean bottoms and on land.

Many of these soft and hard rocks are relatively impermeable but due to earth movements and other actions crack and form openings for water to flow which dissolves much of the more soluble materials to form crevices and cavities for the storage of water. It is to be noted that the movement of this water is sometimes very slow and this effects the ability to recharge the resevoir for water. In several countries water has been determined to be over 20,000 years in one location. In others the flow is quite fast and recharge is quick.

Well Drilling Methods:

The term well drilling methods is being used here to include all methods used in creating holes in the ground for well construction. As such, it includes methods such as boring, jetting, and driving, which are really not drilling methods as commonly understood. We will not include the open dug well as this is a well covered in other papers. We will discuss the bored, jet, percusiion, calyx, mud rotary, air rotary, air down the hole percussion, and reverse circulation methods, their advantages and disadvantages, as well as capacities and relative costs.

What is the best method for drilling water-wells? There is really not single answer to this question, each method has advantages related to cost factors, ease of construction, the nature of the formation to be drilled, the well diameter and the respective depths, the actual intended use of the water well, and the water from the well, and the sanitary protection that would be required for that item.

The methods of drilling and installing wells are so numerous that only the basic principles and some of their applications can be described here. The basic principles in each case, however, give some idea of the limits of practical use of any one method under various conditions.

The geologic conditions dictate two general types of wells. The well that taps the aquifer of consolidated and unconsolidated rock consists basically of a top portion of pipe call the casing, and extending through the loose over-burden material until it is bedded into the rock below, then the rest of the borehole is open access to the rock for extracting the water through the aquifer. The well that taps the aquifer of water-bearing sand must necessarily be provided with a casing through the over-burden materials and connected further down into the well with casing until it reaches the particular aquifer to be pumped and there a well screen will be fitted to keep the sand out and allow the water to permeate through the screen.

It is convenient to think in terms of well construction as four or five different distinct operations. There include sighting the well, the actual drilling operations, installing the casing, fitting a well screen where appropriate, cementing the top of the well to provide the sanitary protection, developing the well, in particular, where the sand-type formations are found, and then to test the well to determine its drawdown and its capacity and finally, to complete the installation by installing the appropriate pump. In some wells, those in sand formations will quite often be drilled oversize, and the material between the borehole and the well screen, which may be some considerable distance, will be accurately graded granuals of sand and this is called artificial gravel packing, of a well and this is sometimes an additional operation for large wells used for major municipal water systems or irrigation wells.

Some of these wells or some of these operations can be carried out simultaneously. When drilling by the cable-tool method, or the cable-tool percussion method in unconsolidate formations, particularly, top soils and that, the casing is installed as the drilling operations procedes. You drill down the certain depth, preferable, the length of a suitable piece of casing and you would drive that in and continue on through, drilling through that casing, and until you have hit the bedrock and then you drive your casing so that it is into the bedrock, you cut it off, and then you continue drilling in the rock formation below without any further interruptions. When driving a well point, however, opening the borehole installing the well casing and the well screen are all done at the same time. Methods of installing well screens and the procedure for development work will be examined in a later section of this article.

Boring:

Boring of small diameter wells from 10CM to 20CM is commonly undertaken with hand turned earth augers identical to the common fence post auger, though power augers are sometimes used. One type has a bit with curved blades attached to a length of pipe about 1.5 meters long to this is filled a handle. As the depth increases small sections of pipe are added.

The hole is started by forcing the bit into the soil with a turning motion. Turning is continued until the auger is full of material. The auger is then lifted from the hole, emptied and returned to use. The short extensions are added as depth increases. Wells shallower than 5 meters require no other equipment. Deeper holes require the use of a light tripod with a pulley on top, so that the auger shaft can be inserted and removed from the hole without disconnecting all shaft sections.

Whatever methods of driving hand or power is used, a starting hole is first made by digging to a depth of 60CM or so. As driving is generally easier in a saturated formation, the starting hole should be filled with water. The well point is a well made piece of equipment generally covered with a fine bronze screen and has a long sharp point on the end. Only good points should be used as they take tremendous abuse in being driven into the soil. Every 1.5 meters a new length of riser pipe should be added as depth increases.

If the pipe available can be threaded with plain straight threads and the couplings have recessed ends, the pipe when fully tightened to couplings will be very strong and not be loosed by driving. Oil field techniques are identical for casing, tapered pipe threads create many problems.

The weight of the driving tools may range from 35 kilos to 150 kilos. Heavier tools require a power hoist or light drilling rig. One method that can be considered for light us would be the power from a small car or light truck. The rear axle is lifted up, the rubber tire from one wheel removed, the inside of the rim to be used as a capstan with the rope wrapped around one and one half time. The axle turning slowly in low gear while the other wheel is on the ground stopped. As one tightens the rope on the rim, it will raise the weight for driving slack off the rope on the rim and the weight will fall down, tighten the rope and away it comes up again. A more permanent arrangement can be made with a pulley and clutch on a small diesel engine.

A cable-tool rig for drilling percussion type wells is perfect for driving well points.

This method is used in boring to depths of about 15 meters in clay and silt some sand formations not subject to caving can also be bored. If there are any small stones that the auger cannot pick up it is generally advisable to bore snother hole near by, sometimes a large coul spring can be used to pick out a stone but it is very difficult.

One very interesting example of this type of boring was used in Irian Jaya, Indonesia i a new settlement. A soil sample auger of 75MM diameter was used to penetrated the soil (sandy clay) and with depths of about 5 meters, two men could complete a hole in two hours. Into this they put a 2" pipe with coconut fiber rope wrapped around the portion of pipe with 10MM holes drilled around the lower portion. With a standard pitcher pump on top this serve a household adequately.

Driven Wells·

These wells are constructed by driving into the ground a well point fitted to the lower end of tightly connected sections of pipe. The manufactured well point must be sunk to som depth within the aquifer and below the water table. The riser pipe above the well point functions as the well casing.

The equipment used included a drive hammer, drive cap to protect the top of the riser pipe during driving a tripod and pulley and strong rope with or without a winch. A light drilling rig may be used instead of a tripod if available. Well points can be driven by ha. It cannot be over stressed that the riser pipes must be well threaded and screwed up tight as the driving will loosen the threads.

Slack joints in driving can be tightened up regularly with pipe wrenches but only by turning the pipe carefully. Violent turning can often damage the well point and its bronze screen.

Driven wells can be installed only in unconsolidated formations relatively free from stones and boulders. Hand driving can be undertaken to depths of about 10 meters: machines much more but not often over 30 meters. Driven wells are most often for domestic use and ca be fitted only with small hand pumps and some types of shallow well jet pumps. In most case the cost of equipment and tools are low and generally available. Skills are modest and no special training is necessary except where a power winch is used. Care must always be used the weight for driving under power is considerable and dangerous.

Jetting:

The jetting method of well drilling uses the force of a high velocity stream or jet fluid to cut a hole into the ground. The jet of fluid loosens the subsurface materials and transports them upward and out of the hole. The rate of cutting can be improved with the use of a drill bit which can be rotated as well as moved in an up-and-down chopping manner.

The fluid circulation system is similar to that of conventional rotary drilling describe later in this chapter. Indeed the equipment can be identical with that used for rotary drilling, with the exception of the drill bit. A tripod made of 2-inch galvanized iron pipe is used to suspend the galvanized iron drill pipe and the bit by means of a U-hook (at the apex of the tripod), single-pulley block and manila rope. A pump having a capacity of approximately 150 gallons per minute at a pressure of 50 to 70 pounds per square inch is use to force the drilling fluid through suitable nose and a small swivel on through the drill pip and bit. The fluid, on emerging from the drilled hole, travels in a narrow ditch to a settli pit where the drilled materials (cutting) settle out and then to a storage pit where it is again picked up by the pump and recirculated. The important features of settling and storage pits are described in the later section of this chapter dealing with hydraulic rotary drilli A piston-type reciprocating pump would be preferred to a centrifugal one because of the grea er maintenance required by the latter as a result of leaking seals and worn impellers and other moving parts.

The spudding percussion action can be imparted to the bit either by means of a hoist or by workmen alternately pulling and quickly releasing the free end of the manila rope on the other side of the block from the swivel. This may be done while other workmen rotate the drill pipe. The drilling fluid may be and is very often plain water. Depths of the order o 50 feet may be achieved in some formations using water as drilling fluid without undue cavi When caving does occur, then a drilling mud as described in the later section on hydraulic rotary drilling should be used.

The jetting method is particularly successful in sandy formations. Under these conditi a high rate of penetration is achieved. Hard clays and boulders do present problems.

Hydraulic Percussion:

The hydraulic percussion method uses a similar string of drill pipe to that of the jetting method. The bit is also similar except for the ball check valve placed between the bit and the lower end of the drill pipe. Water is introduced continuously into the borehol outside of the drill pipe. A reciprocating, up-and-down motion applied to the drill pipe forces water with suspended cuttings through the check valve and into the drill pipe on the down stroke, trapping it as the valve closes on the up stroke. Continuous reciprocating motion produces a pumping action, lifting the fluid and cuttings to the top of the drill pip where they are discharged into a settling tank. The cycle of circulation is then complete.

Casing is usually driven as drilling proceeds.

The methods uses a mimimum of equipment and provides accurate samples of formations penetrated. It is well suited for use in clay and sand formations that are relatively free of cobbles or boulders.

Sludger:

The sludger method is the name given to a forerunner of the hydraulic percussion method described in the previous section. It is accomplished entirely with hand tools, makes use of locally available materials, such as bamboo for scaffolding, and is particularly suited to u in inaccessible areas where labor is plentiful and cheap. The first description of the metho is believed to have come from Bangladesh, where it has been used extensively.

In the sludger method, scaffolding is erected over the well site as per sketch. The reciprocating, up-and-down motion of the drill pipe is provided by means of the manually operated bamboo lever to which the drill pipe is fastened with a chain. A sharpened coupling is used as a bit at the lower end of the drill pipe. The man shown seated on the scaffolding uses his hand to perform the functions of the check valve as used in the hydraulic percussion method, though, in this case at the top instead of the bottom of the drill pipe. A pit, approximately 1 meter square and 60CM deep, around the drill pipe, is filled with water which enters the borehole as drilling progresses. On the upstroke of the drill pipe its top end is covered by the hand. The hand is removed on the downstroke, thus allowing some of the fluid and cuttings sucked into the bottom of the drill pipe to rise and overflow. Continous repetition of the process causes the penetration of the drill pipe into the formation and creates a similar pumping action to that of the hydraulic percussion method. New lengths of drill pipe are added as necessary. The workman whose hand operates as the flap valve changes position up and down the scaffolding in accordance with the position of the top of the drill pi Water is added to the pit around the drill pipe as the level drops. When the hole has been drilled to the desired depth, the drill pipe is extracted in sections, care being taken to prevent caving of the borehole. The screen and casing are then lowered into position.

Wells up to 250 feet deep have been drilled by this method in fine or sandy formations. Reasonably accurate formation samples can be obtained during drilling. Costs are confined t labor and cost of pipe, and can therefore, be very low. The method requires no great operat skills.

Cable-Tool Method:

Cable tool percussion is one of the oldest methods used in well construction. It emplo the principle of a free falling heavy bit delivering blows against the bottom of the hole and thus penetrating into the ground. Cuttings are periodically removed from the hole by a Dart valve bailer or Sand pump. The drill rig has separate cables for the bailer and drill line as well as a hoisting cable. The reason for this is that it is not necessary to change cable as different tools are used.

The basic components of a cable tool drill rig are a power unit either diesel or petrol This unit operates through a power transfer arrangements with clutches and brakes to power initially the butt reel for the main drilling cable and the sand line (bailer) and a hoistin line. Also, there will be a clutch to operate the spudding beam that gives the up and down drilling action to the drill line and to the drilling tool. In many cases a cathead drum is also mounted to be used for winching pipe and other items as required. There is a mast o derrick that generally telescopes and folds horizontal on top of the rig for transport. All of this equipment is often directly mounted on a truck of appropriate size and in some cases on a 4 wheel trailer. Some units are mounted on skids. When truck or trailer mounted there are screw or hydraulic jacks to level the machine generally right under the derrick to take the most of the load. Often a drilling platform is built around the well hole so that a level solid area can enable safe work on the drilling tools. A drain way is also necessary to dump the Dart bailer and Sand Pump. Several 200 leter drums of water are necessary to ha a good drilling action.

The drilling line is most important in cable tool drilling as it has a very important function. Universally it is called a Left hand lay cable made of mild Plough Steel. It is commonly used in ½", 5/8", and 3/4" sizes and has a configuration of 6 strands of 19 wires each with a hemp core. The Left hand twist turns the string of tools in the hole in a dire tion that lengthens up the threads on the drilling tools as they are all right hand threads The operator of the rig generally holds on to the cable with a gloved hand. The objective to operate the machine at about 40-45 strokes a minute and let out sufficient line on the b reel to the drilling side of reel (note there are two sections of the bull drum, one for st age of line and the other for a small amount of drilling line on one layer so that it will wear excessively on other line during the spudding action.) The objective is to have the b strike the bottom when the line is stretched tauntly and on the rebound be lifted up on the return of the spudding beam. As the hole deepens a little line is released to keep the li operating properly. The hand on the line will tell the driller the whole story what is goi on.

The four items in the drilling string of tools are described as the drill bit, drill s jars and rope socket. The drill bit is a heavy piece of steel with generally a chisel face and with a deep wide groove up both sides called water courses. Generally, the bits are ab 1.2 meters to 1.5 meters long and in the 15Cm size, weigh up to 80 kilos each. They are threaded with a tapered thread that is very accurately made. They should be protected at a times when not connected with their rubber or steel caps. The bits can be sharpened in two ways. The older way is to heat them in a forge and hammer them to the desired shape. This takes strength and is very hot hard work. A large furnace and blower are used and sledges t work the shape in. This hand forging of bits will be described separately in Appendex A. There is another more convenient method but this requires electric welding equipment. The b is built up by welding steel layers as close as possible in composition to the original stee

On this after bit is built up nearly to final size is to weld on a cushion layer of steel on which the hard facing rod is welded. This cushion is important. The layers are generally n more than 2MM thick at any time. The welds are ground with a portable grinder to shape , as in sketch # . The hard facing method allows the bit to be kept to the correct diameter. ring gauge is essential to keep the diameter accurate.

The drill stems are just heavy bits of steel added to the bit to give it drilling weigh They have wrench flats on both ends. Generally all the flats used for the string of tools w be the same size. The chain wrenches are very heavy and one size is adequate.

The next item is the jars, commonly called drilling jars. as separate from the fishing jars sometimes used. The jars consist of a pair of linked steel bars which can move in a vertical direction of 15 to 25CM. Jars are used to provide the necessary upward blows when necessary to free a string of tools stuck or wedged in a hole. Fishing jars have much longe strokes up to 85CM and are used in fishing or recovering tools which have come loose from a drill string in a well.

The rope socket often now the Prosser type connects the wire rope to the drill string. It also is the swivel to allow the string of tools to rotate. The connection of the wire rope to the ferrule in the socket is accomplished by the bending back of the wire rope in th socket and pouring in melted babbit metal. It is a very secure connection. At regular intervals, the socket should be examined for wear on the wire rope and if indicated a piece wire rope cut off and rebabbited.

The bailer on the sand line (3/8 wire rope) is ordinarily a piece of pipe with a check valve in bottom or more commonly a bell and tongue type called a dart valve. The bailer is emptied by lowering the filled bailer on to a timber pushing the valve up and allowing the water and cuttings to flow out. It can be messy. The sand pump is similar but has a rod ar plunger to pull up the sand through the check valve in the bottom.

Now it is particularly important to notice that all the threads on the string of tools are right-handed. Now if we use a conventional wire rope which has a left lay, and most ropes are right-handed lay and as they operate in a well going up and down like that and du to the tension and release of tension on the cable, there is a slight twisting action.
Now if it is right-handed lay wire rope and right-hand threads on the drill string, there i a very definite possibility that the string of tools could unthread itself. And so, the important thing is that all the wire ropes used in drilling all are without exception, left-hand lay and they twist in the opposite direction so that at all times, threads on the strin of drilling tools tighten themselves. and do not loosen. It is important in drilling any we to make sure that the well cable is perfectly clean, no sand or grit can get on to part of i where it will operate through the drilling rig to wear earlier than its expected life. All the threads on the drilling string are all made to API designs, and its important that thes tapered threads always be protected by their caps that come with the tools when they are

bought, and these caps protect the threads from any real damage or nicks that can destroy their accuracy. Another very important thing to remember is that when you put a bit and the jars, and the stem, and the socket, each time you do that, you wipe all the threads with a graphite grease, a particular kind of graphite grease that you put on with a brush, and you keep it beside the drill rig all the time, and this keeps the threads lubricated so tha you can run the string together tightly and take them off easily, and the graphite acts as lubricant. This is very important, and should not be disregarded. Another very important thing in cable-tool drilling are the wrenches that you have to tighten up, these large threa ed portions of the drill string. They are what they call chain wrenches, and are particula made for each type of drill string on each portion, you fit the set of jars are the first item fitted to the string of tools, because the socket is always on the wire drill cable. Basically you fit the wrench into the sockets of the drilling jars and lay that on some heav timbers over the hole and grease your joints and then swing your rope socket in and turn it and it will swivel quite capably in there and then you put the matching wrench on top of tha then you take the chain and fit it into the hooks on either end of either wrench and they as they offset on their lever, you just tighten them up on the lever. You disconnect the tool in exactly the same way. As these wrenches are over a meter long in most cases, there can tremendous pressures generated in tightening up these joints and it is important that they are tight. The lower wrench when fitted on the wrench flats on the various drill sections. can be used as the base and holding fixture to thread the sections into while using the to of the well hole.

It is important when the full string of tools are laid down on the ground that the wir rope does not bend too sharply at the socket end. There is a special wire cap to reduce th bond and it must be always used. Drilling by the cable-tool method in unconsolidated formations requires that the casing closely follows the drilling bit as the hole deepens. Thi necessary to prevent the top soil and loose formation caving in the hole. The usual start drilling is to dig a hole to put in a short piece of pipe about a meter to 1.2 meters long. When one is drilling with a long string of tools, it is wise to have a drill guide on the derrick for the first few meters of the hole, later when the drill string is completely in the hole, the drill guide will not be necessary. When the depth is deep enough for a full length of casing to be driven and this generally is anywhere from 6-7 meters, the time come to be prepared and equip the rig to drive the casing into this depth. To make a real tight sanitary seal where the casing will come in contact with the rock, a drive shoe will be fit to the end of the casing. This protective casing shoe is generally threaded on the end of casing pipe and is of a harder material and has a sharp edge, this does not interfere with inside diameter of the pipe. To drive this first casing length with the shoe attached in, is necessary to fit onto the drill string of tools a set of drive shoes or drive clamps, as they are sometimes called. These are made of two heavy steel forgings and are bolted to the upper winch square of the drill stem and is used in the form of a hammer.

The total weight of the drill string plus the drive shoes or clamps will provide the necessa weight for driving, as it is lifted and dropped repeatively by the spudding action of the drilling machine, thus driving the casing into the ground. There are alternative methods of driving small casing into wells. and any reasonable way is an exceptable pattern. However, the drive shoe is simple, durable, and gives a tremendou impact to the casing.

It is important that the first 15-20 meters of casing be driven vertically. Proper alignment of the string of drilling tools centrally within the casing when the tools are allowed to hang freely is a necessary precaution. Periodic checks should be made with a plu bob or carpenters level, used along the pipe at several positions at right angles to each other to ensure that a straight and vertical hole is being drilled.

Cable-Tool Drilling Rate and Capacity:

The speed of drilling and rate of progress with a cable-tool rig depends upon a number of basic factors: (1) the hardness of the rock, (2) the diameter and depth of the hole, (3) the dressing of the bit, (4) the weight of the tool string, and (5) the stroke rate and leng Cable-tool drilling more than any other drilling method is to a large extent an art rather than a science; and the capable driller continually increases his skill and knowledge.

The capacity of a cable-tool rig depends on the weight of tools which it can handle saf ly. The tool weight is determined largely by the diameter of the bit and the diameter and length of the drill stem. However, as the hole is deepened, the rig must support more and more of the cable weight in addition to that of the tools. There is a limit to the depth at which a cable-tool rig can be safely used to drill a given size hole. On the other hand, th more shallow the hole, the larger is the feasible bit diameter. Smaller, commercially available cable-tool rigs capable of handling 300 pounds of tools, can usually drill a five-inch hole to a depth of about 300 feet, while the largest rigs are capable of handling three tons of tools, can drill a similar size hole to 5,000 feet. With medium and high capacity rigs, 18-inch to 24-inch holes are commonly drilled to depths of several hundred feet. With increased depth, more time is required in removing the tools, bailing, and reinserting the too Increasing cable length requires a reduction in tool weight and rate and length of the strok These and other factors decrease the rate of drilling, increase costs, and necessitate smal hole diameters with increasing depths. However, it may be economical to drill to depths of more than 2,000 feet, although water wells are rarely drilled to such depths using the cab tool drilling method.

The cable-tool rig in the hands of a skilled operator, is probably the most versatile all rigs because this rig can drill satisfactorily over a wide range of conditions. The method's drawback compared to other rig types is its slower rate of progress and depth limi tions.

Although cable-tool drilling offers certain advantages under special circumstances, th method as mentioned previously, has not significantly developed since its inception. It ca under certain conditions, compare favorable with the general economic efficiencies of rotar type methods.

Cable-Tool Samples:

Cable-tool sampling and formation logging are simpler and more accurate than with most other rig types. The cuttings bailed from each drilled interval usually represent about a five-foot zone. When casing is used, there is little chance of contamination of the sample, thus making the method particularly useful in certain types of mineral exploration. A chan in lithology can usually be recognized by the response of the rig to the changed drilling condition, at which time samples can be taken at a shorter interval. In some unconsolidate formations, casing can be sunk by merely bailing and driving, so that samples are relatively unbroken and representative. The samples are not contaminated by drilling mud and clay and shale and silt fractions are not likely to be lost by dispersion in the drilling fluid. Cuttings of unconsolidated formations are usually not finely crushed, and some are of sufficient size to permit geological identification and description. When a potential aquifer is encountered, tests for yield and quality of water are made by bailing or, if of sufficient ir portance, by pumping.

Samples of unconsolidated formations are highly representative if taken with a sand-pump type bailer; whereas, a dart-valve bailer, used primarily for consolidated rock drilling usually requires additional drilling and breaking of the gravels, hence the samples are less usefull, especially for sieve analyses purposes.

Cable-Tool Field Use:

The obvious advantages of the cable-tool rig are its suitability for use in rugged terrains and in developing countries where wages are low. The initial cost of a cable-tool rig complete with tools is generaly one-half to two-thirds that of a rotary rig of equivalent capacity. The rigs usually compact requiring less accesory equipment than other types and a more readily moved in rugged terrain where roads are poor. The simplicity and ruggedness of design and ease of repair of these rigs and tools are particularly advantageous in isolated areas. In general, the method requires less skilled operators and smaller crews than other drilling rigs of similar capacity. The low horsepower requirements are reflected in lower fuel consumption, an important consideration when fuel costs are high or sources of fuel are remote. While slower than other rigs in drilling some formations, cable-tool rigs can usual drill through boulders and fractured, fissured, broked, or cavernous rocks. The method requ res much less water for drilling than most other commonly used rigs, an important considerat in remote arid and semi-arid locations. The cable-tool method is alos readily adaptable for use in hollow-rod jetting and mud=scow drilling.

One of the most important advantages of the cable-tool method is the ability to acquir qualitative data on the water-bearing characteristics and static heads of various formations as casing is being driven. Water quality data can be obtained by bailer samples as each formation in turn is opened to the bottom of the casing, and upper formations are cased off.

The disadvantages- a relatively slow rate of progress, and economical and physical limi ation on depth and diameter- have been mentioned previously. A further disadvantage of the cable-tool rig is the necessity of casing while drilling in unconsolidated materials. The necessity of driving casing requires a heavier-walled pipe than would otherwise be required some installations. Screens often must be set by "pull-back" or "bail-down" methods. The former method is sometimes extremely difficult or impossible in deep or large-diameter well and the latter may give rise to problems in alignment.

The advantages and disadvantages of the cable-tool system in comparison with the rotary system have been summarized. The major advantages of the cable-tool system as opposed to ot drilling systems (rotary, etc.) are listed below:

(1) Economics:

(a) Lower initial equipment cost, hence lower depreciation.

- (b) Lower daily operating cost, including maintenance, personnel, and water requirements.
- (c) Lower rig-up time and expense.
- (d) Lower transportation costs.
- (e) Drilling rates comparable to rotary in hard rocks at shallow depths.

(2) Better cutting samples.
(3) Easy identification of water-bearing strata.
(4) No circulating system.
(5) Minimum contamination of producing zones.

The major disadvantages of the cable-tool method as opposed to other drilling systems are summarized below:

1. Limitation on penetration rate.
2. Limitation on depth (the depth record for the cable-tool method is 11,145 feet, drilled in New York, 1953.)
3. Lack of control over fluid from penetrated formations.
4. Lack of control over borehole stability.
5. Frequent drill-line failures.
6. Lack of experienced personnel.

The more important general aspects of cable-tool drilling have been treated in a number of publications.

Air Percussion Rotary Drilling:

Another form of air drilling is percussion or downhole-hammer drilling. Percussion drilling tools and techniques are gaining acceptance and are no longer considered a specialt application. Percussion rotary drilling is the rotary technique in which the main source of energy for fracturing rock is obtained from a percussion machine connected directly to the bit. The circultating system, drill stem, etc., are unchanged from that used in the conventional air rotary method. The percussion method incorporates a single-cylinder, reciprocati, air engine driven by the circulating air. The extremely rapid hammer blows - delivered with relatively light weight on the bit - increase bit life and help to control deviation while maintaining relatively high penetration rates.

Until the last few years, bottom-hole percussion tools were made to operate on 100 psi air pressure primarily because of the availability of 100 psi compressors. Since reliable higher pressure compressors (200-250 psi) are available, the trend is toward the use of higt pressure tools, and turbine compressors will probably be available in the not-too-distant future. The reason for commercial development of 100 psi percussion tools is that the limi piston area restricts the air that can be ported because the piston diameter has to be approximately two inches less than hole diameter. consequently, the amount of air required operate the piston is less than that needed to clean the hole.

High-pressure tools (200 psi) operate with approximately twice the hammer-blow frequenc of 100 psi tools. Thus all of the energy in the compressed air can be ported to the piston resulting in penetration rates double that obtained with 100 psi tools. Most carbide bit wear is the result of the carbide scrubbing against rock face during rotation; therefore, b life is generally longer with high-pressure tolls because with faster penetration, less car bide is worn per foot of hole drilled.

One of the latest developments in downhole percussion air drilling is a button bit wit replaceable, tungsten-carbide buttons. The bit, as originally designed, has buttons set fr the face side to a predetermined height above the bit face. Buttons are removed with a spe ial punch through access holes at the back of the drill bit.

Within the last two years, the button bits have been modified so that either button se ting or removal can be accomplished within a few seconds from the face side of the bit. Th new system utilizes a gas-pellet gun - the first gas pellet sets the buttons to a specifie height above a special base and sleeve arrangement, and the second loosens the sleeve for removal of the entire three-piece button assembly.

The proper size drill pipe is critically important. In the typical case previously d cussed, if five-inch drill pipe were used, only 350 cfm would be required to maintain the r commended 4,500 feet per minute annular velocity. Thus, the same hole-cleaning ability can obtained with less air (100cfm) by selecting a larger size drill pipe. In many cases, hole cleaning problems can be solved more economically by increasing drill pipe size rather than by increasing compressor capacity

In the typical case of a 5 1/4-inch diameter tool (used to drill a 6 1/4-inch hole wit a 4½-inch drill pipe) only 200-225 cubic feet per minute of air can be ported to the piston yet 310 cubic feet per minute is required to maintain an annular velocity of 3,000 feet per minute, the minimum to clean the hole in this type of drilling. A recommended 4,500 feet pe minute annular velocity requires 460 cfm of air.

Thus in normal operation, from 110 to 235 cfm of air, compressed to 100 psi, is used sol ly to provide enough return velocity to assure that the hole is cleaned properly. If an adequate supply of air is not ported to the bit, the energy of the available air is utilized in power for the bit, and adequate cleaning is not accomplished. Some of the more recent 100 ps tools have multiple pistons to increase piston area and, thus, to utilize energy that is wast with the single-piston tools, depending on the size of the compressor used.

Bottom-hole pneumatic tools generally require only sufficient "pull-down" (2,000 to 4,0 pounds) to keep the bit closed in the tool. Additional pull down (rig weight) does not mate ially increase penetration rate but does result in accelerated bit wear.

Water injection into the iar stream is recommended as an economical method to control dust, to prevent cuttings from "balling up" around the drill pipe which could bridge the hol and prevent circulation, and to seal any air leakage inside the tool between closely matched parts. Water injection cools the drilling air to assure that the air temperature supplied w not be excessive.

The downhole percussion technique can be modified to combat excessive ground water infl by incorporating foam. Drilling for ground water in crystalline, methamorphic, or other roc with high compressive strength is drawing particular interest and no doubt will expand as th method of drilling improves.

Field Operations:

This method of drilling is most efficient in consolidated rock formations which do not require casing. It is not usually satisfactory for use in boulders or in unconsolidate form tions although the method has found some success in such material. Continued drilling in we clay may plug the air holes in the bit and stop the hammer operation. Hard and abrasive cu tings which are wet should not plug the bit and can be blown from the drill hole. However, some cuttings do get into the hammer cylinder which requires cleaning after 500 to 1,000 fee of drilling.

The depth of drilling is limited by the diameter of the hole and the volume and pressu of the compressor in use. The depth at which cuttings can be effectively removed from the ho is also governed by the weight of the rock and the volume of water in the hole.

Often pull-down pressure with the rig at ground surface is not recommended to increase the penetration rate. As with any other type of rotary drilling, such procedure places the drill pipe in compression and causes crooked holes, key-seating, etc. The use of drill coll for weight with the drill pipe rotated in tension is to be preferred. Depending upon the ty of rock formation, the air percussion method may penetrate 50 to 100 percent faster than the standard tricone rotary bit.

Recommended pull-down is in the range of 3500-4000 pounds. This can be obtained advantageously with drill collars. The hammer percussive blows at operating air pressures of 80-200 psi range from 600 to 1,000 per minute, depending upon the pressure and hammer design. Rotary speeds at an optimum bit index angle of 11 degrees vary according to the bit diameter, and type of formation, and hammer blows per minute. For the optimum index angle, rotary spee would vary from 18-30 rpm. The most economical rotating speed is that which gives the highes rate of penetration without excessive bit wear, and therefore, depends on specific field con itions.

Reverse Circulation Rotary Drilling:

Reverse-circulation rotary drilling, with little application in the petroleum industry, has found considerable success in the mineral exploration and ground water industries. In mineral exploration, reverse-circulation drilling is applicable when the quality of the samples is critically important. Reverse-circulation coring also found widespread acceptance i recent years, e.g.,"Con-Cor". etc.

Reverse-circulation rotary drilling has a reversed flow of drilling fluid when compared to the system used in the conventional rotary method. The drilling fluid dlows through the suction end of the rig pump - rather than the discharge end - through the swivel, the kelly and the drill pipe. The drilling fluid and cuttings move upwatd inside the drill pipe and are discharged by the pump into the mud pit. The fluid returns to the borehole by gravity flow, moving down the annular space around the drill pipe to the bottom of the hole, pickin up cuttings, and re-entering the drill pipe through ports in the drill pipe.

The drilling fluid used with this method can be described as muddy water rather than as drilling mud. Suspended clay and silt which recirculate with the water are mostly fine materials that are picked up from the subsurface formations as drilling proceeds. Bentonit or other drilling fluid additives are seldom added to the water to make a viscous fluid.

To prevent caving of the hole. the fluid level is kept at ground level at all times. The hydrostatic pressure of the water column, plus the inertia of the body of water moving downwards outside the drill stem, support the borehole wall. Erosion of the wall is not a problem because velocity in the annular space is low.

Water is lost from the hole into all permeable formations that are penetrated. Some o the suspended fine particles in the fluid are filtered out on the wall of the hole, resulti in a thin mud deposit that partially clogs the pores and reduces the loss of water. A considerable quantity of make-up water is required, however, which must be readily available a all times when drilling in highly permeable formations.

Water loss can increase suddenly, and if the fluid level in the hole drops below the ground surface, caving can result. Water loss can be resuced by adding clay to the water (usually avoided unless necessary). One of the major problems in reverse circulation rotary drilling is preventing caving of clays and shales. Caustic soda in the fluid to raise the to about 10.5 may be successful.

provided the clays are wetted in their native state. Dry porous clays and shales do not stabilize with increased pH.

Sodium silicate, in the ratio of four percent to ten percent, may be effective with cla and shales of this type. If the clay interval is thin, the treatment may be made directly a the hole. If the interval is relatively thick, then all of the fluid should be treated. I the treatment is still unsuccessful, the section should be cased, or high viscosity, low weight, low water-loss bentonitic muds prepared for use as the drilling fluid.

From 20 to 500 gpm of make-up water, depending on the hole diameter, may be needed at times when drilling through highly permeable sediments. Drilling in coarse, dry gravel pose the greatest difficulty because of the high water loss potential Much of the high water lo es commonly occure above the water table. This loss can be reduced by drilling the hole wit a large auger or similar rig to the water table or into a relatively tight formation near th water table. The surface casing is then installed and grouted prior to deepening the hole with the reverse-circulation rig.

The mud pit or water supply pit should have a volume of at least three times the volume of material to be removed during the drilling operation. Circulation rate for the water use in drilling is commonly on the order of 500 gpm or more.

A centrifugal pump, with large passageways, is employed in order to handle large cuttin One type of rig uses an ejector, operated like a large jet pump, which prevents the cutting from passing through the centrifugal pump. The limitations of some rig pump necessitate the use of drill pipe in lengths of ten feet. However, many other rigs are equipped with a pum arrangement which enables the drill pipe to be filled with water before starting circulatio with the regular centrifugal or jet pumps. Using this system, 20-foot and longer lengths o drill stem can be used. Six-inch O.D. drill pipe is commonly used so that rock material up to a five-inch diameter can be brought up through the pipe.

The drill pipe commonly has flanged joints of approximately 11 inches in diameter. Th smallest borehole that can be drilled by this method is about 18 inches in diameter which p vides sufficient annular space at each flanged joint.

Wells with diameters to 60 inches can be drilled; the diameter of the hole must be lar in relation to the drill pipe, so that the velocity of the descending water will be slow. Descending velocity of one foot per second or less is the general rule. The bit and drill pipe are rotated at speeds varying from ten to 30 revolutions per minute.

Reverse circulation offers an inexpensive method of drilling large diameter holes in s unconsolidated formations. Where geologic conditions are favorable, the cost per foot of borehole increase little with increase in diameter. Drilling cost for a 36-inch or 40-inch hole is only moderately higher than for a 24-inch hole.

Most wells drilled by this method, therefore, have a diameter of 24 inches or larger-completion of the well by gravel packing is dictated by factors perculiar to this drilling method.

Conditions that favor the use of the reverse circulation method of drilling are sand, silt, or soft clay formations; absence of clay or boulders; or static water level of ten feet or more below surface. However, if the static water level is within ten feet of the surface it is possible to construct a high retaining wall around the pit for rig placement in order to obtain the desired head differential, thereby, maintaining hole stability. Conditions may limit the use of this method are:

(1) A static water level which is too high.

(2) The lack of an adequate water supply to supplement drilling fluid.

(3) Stiff clay or shale formations.

(4) A considerable number of cobbles or boulders.

Any cobbles or boulders, larger than the drill pipe or the openings in the drill bit, cannot be brought up in the drilling operation. The bits used cannot break cobbles, as soon as a few collect in the bottom of the hole, no further progress can be made. The drill pipe and bit must be pulled periodically, and the stones fished out by means of an orange-peel bucket so that drilling may continue.

The low content of suspended solids in the water of the annulus forms a relatively thin filter cake preventing excessive fluid loss. This thin filter cake is cleaned out more readily when developing the well than is the less previous mud cake that is common to the mud rotary method.

Auger-Bucket Drilling:

The auger-bucket drilling system has been used primarily for surface water development, or water-table wells. Other economical and practical applications are: gravel testing, foundation holes, pier holes, seep holes, soil testing, etc.

The hole is bored without casing until the water-bearing formations are reached or hole caving begins. Concrete casing with a steel shoe is then lowered into the hole. The steel shoe fits over the bottom of the concrete casing to keep it from breaking and also to provide a cutting edge.

A suction is created when the auger bucket is removed for emptying. The removal of the formation materials and the weight of the casing force the casing to settle and shear the walls of the hole. If caving occurs at shallow depths or the well is relatively deep, temporary metal casings 1/4-inch to ½-inch thickness are used because the concrete casing generally has a wall thickness of at least two inches. The steel casings are of telescoping diameters like the ones used in standard cassion drilling. When satisfactory water capacity has been obtained the screen and well casing are centrally located within the drilled hole, the gravel placed, and the cassions removed in the usual manner.

In gravel testing, after the topsoil has been penetrated, "sand flaps" are installed in the bottom of the auger bucket to trap the gravel. Steel casing is used to retain the walls of the hole and aid in penetration. A clamsheel or trapping bucket, or plunger-type bucket, is used if sand in the gravel tends to seep past the sand flaps. Clamshell buckets, stone hooks and tongs, dynamite. and rams' horns are used for rock and boulders in large diameter shallow holes.

In difficult formations, chopping buckets and pilot hole are often employed. A smaller auger bucket is used to bore a "lead hole" which enables the cutting blades of the larger bucket to later ream the hole.

Water Problems:

Small amounts of water in the formation may be detected by a significant reduction in the amount of dust returns and the presence of mud pellets in the dust exhaust. This is considered a precarious condition since the pellets tend to agglomerate in the hole near the bit and cause the drill pipe to stick. Partial remedies are to (1) stop drilling and blow the formation in an attempt to dry it; (2) reduce the drilling rate; and (3) inject water to increase the water-to-rock chip ratio.

Almost complete elimination of dust and replacement with a substantial water spray imposes no immediate drilling problem if the compressors have sufficient power to lift the water, and there are no caving or sloughing formations above the water producing zones. If such exist, the hole should be drilled with drilling mud until the casing is set. If sloughing is not expected air drilling can continue until there is a tendency for the bit to stick.

In a "weeping" zone, calcium stearate or silica gel dry powder, added to the air stream by a solids pump, is effective. An injection rate of one to four percent of the cuttings weight is required. The finely ground powder coats the cuttings and effectively repels any water.

Forming agents used to overcome water problems are organic materials added approximately one part to 1200 parts of water. In general, a flow of about 2,000 gallons per hour marks the end of economically drilling with air.

Air Drilling Efficiency:

As mentioned previously, the injection of compressed air as a circulating medium is not new to the drilling industry. It has been in common use since the late 1800's. The 1950's and the first big uranium boom provided the greatest impetus to the use of air. Prior to this, most air uses were for operation of mining and construction percussion equipment, and the prime object was to provide the percussive impact. During the 1950's many steps were taken in the use of air in exploratory drilling work, but all operations were not successful; the common problem was thought to be "not enough volume - not enough pressure." It was not unusualy to find one or two large construction-type compressors (costing $25,000 to $50,000) providing air for a drilling machine costing $10,000. The extremely high cost of the operations forced many of the operations out of business. More importantly, some individuals were forced to reexamine the principles involved in air circulation. This reexamination and much subsequent research has given the industry a basis for a logical, economical approach to the use of air as a circulation fluid.

It is reported that air, as used with conventional rotary drilling equipment (where no impact force is involved) need not be delivered at high pressure. This provides for significant economy. Most exploratory holes used for civil engineering work are less than 250 feet in depth. Air pressures of 40-50 psi are more than adequate for recovery at such depth. A blower delivering approximately 375 CFM @ 105 psi will cost approximately $16,000. Thus, the dollar value saved in the use of an adequate volume of low pressure air versus superfluous high pressure at the same volume can be as much as $12,000. The terms blower and compressor are not well defined; however, there does seem to be a tendency to refer to air blowers when considering pressures below 100 psi and air compressors when referring to 100 or more psi.

Most blowers and compressors use oil in the air stream for cooling and/or lubricating internal parts such as pistons or vanes. A minimum pressure of 30 to 50 psi must be maintained internally for the presently available machines to insure adequate lubrication of the mechanism. The minimum pressure of 30 to 50 psi is a machine requirement rather than a circulation requirement. Recent experiments, with a radically new blower, delivering 400 CFM @ 20 psi, demonstrate that the pressure as low as 20 psi will provide cuttings removal, pressure also plays an important part in bit cooling. Too low a pressure could cause inadequate bit cooling.

It is reported that all circulation fluids have two primary functions: (1) cooling of the bit (2) removal of cuttings from the hole. Liquid-mud fluids can be altered by using barites and other weighting additives to stabilize the hole. Air cannot meet this function; however, air is seldom guilty of causing hole caving.

Bit cooling is accomplished by refrigeration. Air which is pulled into the blower and compressed is carried under pressure through the mast standpipe, swivel, hose, and tool string to the bit. The sudden release of pressure as the air leaves the bit causes a considerable drop in temperature of the air. It is not uncommon under certain atmospheric conditions, to find ice on the bit. The actual temperature drop will be dependent upon, among other factors the pressure released. This cooling principle is essentially the same as that used in modern refrigerating units.

Air Requirements:

Chip or cuttings removal is accomplished by the flotation effect or buoyancy of the released air on its way up from the bit to the surface. The velocity of this upward-moving air will be the most important factor in determining how effective air drilling will be. Davis believes that this velocity is effected by three factors: (1) hole diameter, (2) drill stem O.D. and, (3) blower output volume. The first two of these factors concern the annular area. The annular area is defined as the area of the hole minus the area of the drill stem As an example, the annulus area of a four-inch diameter hole drilled with 2 7/8-inch O.D. drill stem is:

$$(4^2 \times .785) - (2.875^2 \times .785) = \text{Annular Area}$$

$$12.57 - 6.49 = 6.08 \text{ square inches}$$

The annular area must be kept full of upward moving air in order to assure good chip removal. Logically the smaller the annulus area, the less the air volume requirement to assure good recovery. The annular area can be reduced in two ways: (1) the hole diameter should be the smallest possible considering the use intended and the need for about 5/16-inch minimum radial chip clearance between the drill stem and the hole wall. The cost to adjust hole diameter is usually limited to the bit cost. (2) stem size (O.D.) should be the largest possible consistent with the need for 5/16-inch radial chip clearance as mentioned above. The cost to adjust stem size is limited to the purchase price of a new larger string which, even though expensive, will be much less than the only remaining alternative which is to use a blower with greater output.

The minimum recommended up-hole velocity for good chip removal has been determined by field work to be about 4,000 feet per minute. When drilling in soils, as in the case of most engineering investigations, the recommended minimum is 4,500 ft/min.

The conversion of blower volume to up-hole velocity, or vice versa, is based on the equation:

$$Q = AV$$

where: Q = Volume (cu. ft.)
A = Area (sq. ft)
V = Velocity (ft/min/)

For example, a hole of any depth must be filled with air moving at 4,500 ft/min. and the volume must be the same that would be required to fill a 4,500 ft. deep hole once.

The 4,500 FPM needed for good recovery is obtained as follows:

$$\text{CFM} = \frac{A \times (4500 \text{ feet} \times 12)}{1728}$$

Referring to the four-inch hole with 2 7/8-inch stem had an annular area of 6.08 square inches. Using the above, the volume needed to remove chips in the example hole is:

$$\frac{6.08 \times 4500\ 12}{1728} = 190 \text{ cu. ft/min}$$

Gravel Packing Operations:

The gravel packing of drilled wells using an outer casing and wells drilled by either reverse circulation or the standard rotary method have met with equal success both in the petroleum and ground water industries.

Two types of gravel packing are in general use -- the uniform-grain-size pack and the graded-grain size pack. The former has been widely accepted in recent years, especially when manufactured screens are used because the size of the openings can be controlled.

In the case of a graded pack, the formation material may invade a graded pack at the gravel-formation interface, partly filling the pores and resulting in reduced permeability. With a well sorted (uniform) gravel pack, the fines of the formation can travel between the grains and be pulled into the well during development, thereby increasing the formation permeability while retaining the highly permeable nature of the pack.

To prevent segregation of the graded pack during placement, special equipment is needed. The tremie, or ordinary four-inch pipe, is normally filled with pack material and allowed to settle four or five feet at each application. On the other hand, the uniform-grain size pack can be shovelled into the well with acceptable results, although segregation can occur causing bridging, etc.

The pack material often must be processed on the site when the desired size is not readily available from local sources. Lack of availability is the big disadvantage of the uniform-grain=size pack. The most important physical propoerty of uniform-grain-size material is the particle size as represented by the mean grain diameter which is the 50 percent grain size. To prevent the movement of formation material, it is necessary to provide a pack in which the mean grain size of the pack material bears a specific relationship to the mean grain size of the formation material.

Not all water-bearing formations require gravel packing; however, any formation can be successfully gravel packed, assuming special emphasis is placed on drilling fluid removal and development prior to gravel packing operations. Generally, formations with an effective size (a size such that only ten percent of the formation if finer) of o.01 inch and a uniformity coefficient of two or more can be safely developed without a gravel pack, providing there are few vertical changes in sizing in the formation. As the formation becomes coarser, the desirability of the gravel pack decreases; however, exceptions to the above are common.

Field Selection:

Probably the four most common reasons for gravel packing are:

(1) to increase the specific capacity of the well.

(2) to minimize sand flow through the screen in fine formations.

(3) to aid in the construction of the well.

(4) to minimize the rate of incrustation by using a larger screen slot opening where the formation is relatively thin but very permeable, and the chemical characteristics of the

ground water suggest a potential for significant incrustation.

Probably the most common cause of sand pumping wells is the use of a gravel pack that is too coarse for at least part of the formation. A relatively thin interval of fine sand, sandwiched between coarser sand and gravel, may continue to sift through the pack indefinitely. The gravel (or sand) pack should be selected as a ratio of the finest part of the formation to be screened. This problem is caused by two factors: (1) poor sampling and (2) lack of care in selecting the gravel pack size.

Field Operations:

Placement of gravel by a reverse-circulation system is generally accepted as being more effective than the "tremie" method. The method is usable for wells of any depth; with certain modifications for relatively deep gravel pack applications.

If the velocity of the descending stream in the annular space is about the same as the velocity at which a particle of "gravel" falls in a fluid, no separation of sizes can occur In a light drilling mud, the velocity of the fall of the particle will be less than one-half foot per second.

The volume of fluid that must be circulated to attain a given stream velocity can be calculated from the area of the annular space in the wells. In practice, a fluid velocity less than the calculated fall velocity can be used to effectively prevent segregation. For example, with a light drilling fluid, circulating rates could be approximately 40 to 50 gpm for carrying 1/8-inch particles into place around the screen and 20 to 30 gpm for transporting 1/16-inch particles. In large diameter wells, practical considerations may require circulation rates lower than those ideally required to prevent total separation.

In gravel-packed installations incorporating the rotary drilling method, reverse-circulation of the drilling mud may be started at a relatively slow rate. The pumping rate will often depend upon the flow of mud through the well screen openings, and water should be added to thin the mud so that circulation can be increased. As soon as the desired circulation is attained gravel may be put into the screen.

Thinning of the mud with water does not increase the risk of formation caving, since the descending fluid weight per gallon has been reduced. Once the introduction of the granular material is started, the weight of the material builds up the effective weight per gallon of the fluid; therefore, caving is seldom a problem.

When circulating by the method illustrated, the two limiting factors of the pumping rate will be the head loss of the fluid flow within the well itself and the suction capability of the pump.

In relatively deep wells, total friction loss in the system quickly surpasses the suction characteristics of the pump. In such cases, the fluid must be pumped into the annular space under pressure introducing the granular material into the stream after proper circulation has been established.

As sand and water are pumped into the annulus and around the screen in deep applications, the return flow of fluid passes through the well-screen openings, then up to the surfacr through the pipe used for suspending the screen assembly, or the well. The lower end of the return flow pipe (the stinger) almost reaches the bottom of the screen. During the emplacement operation, the pressure gauge is carefully monitored, with the flow of water-granular material slurry being controlled at a constant rate. As the material is emplaced to the top of the main screen, a slight pressure increase occurs, signaling that the level of the gravel pack has reached the top of the main screen.

As slurry emplacement continues, an abrupt pressure increase occurs when the material reaches and encloses the "tattle-tell" screen.

The pumping method using the reverse-circulation techniques requires proper organization, an experienced crew, and reliable equipment.

Another method, originally developed by the oil industry has been referred to as the "cross-over" method of gravel-packing. Water, carrying the gravel-pack material is circulated down the drill pipe, into the "cross-over" tool, and out the two sides into the annulus around the extension pipe above the screen and upward from the bottom of the hole. Water circulates through the screen to the open end of the "stinger" pipe located near the bottom of the screen then moves upward to the two openings in the "cross-over' toll above a rubber seal.

Although this method appears simple, it requires elaborate and relatively expensive equipment in addition to considerable skill and operating techniques in order to assure continuous flow without plugging or causing a blow-out. High pressures are required as the gravel is placed. When placement is completed, a special slip-packer is needed to seal the areas between the screen lap-pipe and the casing.

Well Casing:

Casing is used in many types of well design, ranging in diameter from 1 to 1½-inches in driven wells to 36-inches in some large irrigation, municipal, and industrial wells. Depths at which the casing is set range from ten feet or less to over 1,000 feet. Standard-weight pipe, with casing diameters up to siz-inches is usually adequate for the depths at which these small sizes are set. For installations of greater depth, particularly in unconsolidated formations, where collapse loads become significant, the wall thickness to diameter ratio becomes important, and heavier walled pipe is mandatory. A relatively new method of installing casing has been developed which allows casing emplacement during rotary drilling. This method can eliminate loss of rig time when drilling in unconsolidated formations.

There are five products for the water well and plumbing industries as distinguished from the oil field products. They are:

1. Standard pipe
2. Line pipe
3. Reamed and Drifted pipe
4. Drive pipe
5. Water Well Casing

Standard Pipe is pipe which comes in a range of sizes, from 1/8-inch to six-inch nominal inside diameter. The sizes are designated by the approximate inside diameters, although the pipe is not exactly these diameters. Each size is available in one wall thickness only, which is classed as "standard weight." The threads on all sizes of pipe are tapered 3/4 inch per foot in diameter, but the threads in the couplings of sizes two inch and smaller are untapered. The couplings are short and not recessed.

Line Pipe in sizes from 1/8-inch through 36-inch larger sizes are also available but not to API specifications. Threaded and coupled line pipe are available up to and including a 12-inch size. Larger sizes are available with plain or beveled ends only on special order. As with standard pipe, the threaded size are designated as nominal inside diameters. In sizes to six inches (inclusive) the pipe has the same I.D and O.D. as standard pipe, so the only difference is in the threads and the couplings. All sizes of line pipe have tapered threads on the pipe and the couplings; the couplings are long and recessed. For sizes above six inches, a choice of two or three wall thicknesses are available: Therefore, these sizes must be indicated by weight or wall thicknesses in addition to diameter.

Drive Pipe is similar to line pipe but is threaded to produce a joint where the end of the pipe abut when threaded up tight.

Water Well Casing is a thin-walled, fine-threaded casing which differs in dimensions and threads from all other casing items. Water well casing is fitted with recessed couplings which are shorter and smaller in outside diameter than an equivalent diameter of line pipe. The thread is sharp and tapered 3/8=inch per foot in diameter.

When using any of these products for casing a well, particular attention should be paid to the threading specifications. Some of the thread dimensions are different for each type of pipe, so an improper joint and a possible casing failure can result, for instance, from attempting to join line pipe and standard pipe.

The threading of pipe and casing is an important and precise operation. When the matching threads of a pipe and coupling are cleanly cut and accurately aligned, the resulting joint is dependable. When the threads are improperly made, the resulting joint may be weak and unsatisfactory.

The threading process is monitored very closely at the mills. A poorly threaded joint will rarely come from a reputable modern mill. Unfortunately, threads cut outside of the mill are often of lower quality. Many things cause inferior threads e.g., improperly dressed, dull, or incorrectly positioned chasers in the die, etc. Threads should be carefully inspected, and any imperfections corrected if good joints are required. The subject of thread-cuttings is complex and is not covered in any detail here.

TABLE 1

Nominal Size	Actual ID (in)	OD (in)	Wall (in)	Class
2	2.067	2.375	0.154	Std.
2	1.939	2.375	.218	X
2	1.687	2.375	.344	None
2	1.503	2.375	.436	XX
4	4.026	4.500	.237	Std
4	3.826	4.500	.337	X
4	3.438	4.500	.531	None
4	3.152	4.500	.674	XX
8	8.125	8.625	.250	None
8	7.981	8.625	.322	Std.
8	7.625	8.625	.500	X
8	6.875	8.625	.875	XX
8	6.813	8.625	.906	None
12	12.000	12.750	.375	Std.
12	11.938	12.750	.406	None
12	11.750	12.750	.500	X
12	10.750	12.750	1.000	XX

Comparision of OD,ID and wall thickness with clasee for elected sizes of line pipe.

Certain types of tubular products are considered to be oil industry goods as distinguishe from water well items. Due to differences which can cause confusion and trouble, the separa- tion of the two is desirable since the requirements in these two fields are different.

TABLE 2

Size OD (in)	Nom.Wt. T & C (lbs)	Wall Thickness (in)	Inside Diameter (in)
4½	9.50	0.205	4.090
4½	11.60	.250	4.000
4½	13.50	.290	3.920
5½	13.00	.228	5.044
5½	14.00	.244	5.012
5½	15.35	.275	4.950
5½	17.00	.304	4.892
5½	20.00	.361	4.778
5½	23.00	.415	4.670
6 5/8	17.00	.245	6.135
6 5/8	20.00	.288	6.049
6 5/8	24.00	.352	5.921
6 5/8	28.00	.417	5.791
6 5/8	32.00	.475	5.675
7 5/8	20.00	.250	7.125
7 5/8	24.00	.300	7.025
7 5/8	26.40	.328	6.969
7 5/8	29.70	.375	6.875
7 5/8	33.70	.430	6.765
7 5/8	39.00	.500	6.625

Four of the API casing sizes availble. Note variation in wall thickness and resultant variation in inside diameter.

API Casing:

API casing is always designated by the nominal weight of the outside diameter and the wall thickness. Sizes range from 4½-inches to 20-inches inclusive. Table 2 shows four sizes and the weights available in these sizes.

On certain specifications of API casing, two lengths of couplings - long and short - are available because of different requirements. The threads used are called the API standard round thread. This thread differs materially from the threads used on the water well products previously described.

As will be seen from the sizes in TAble 2, the size and the weight of the casing must be designated to assure that the items, such as tools, or well screens and pumps can be fitted correctly into these casings since there is a range of inside diameters. When API standard-round thread is needed, care must be exercised to avoid confusion of this thread with other pipe threads. Mixing the threads could result in a misfit which could lead to a casing failure.

Another oil field product which occasionally wanders into water well use is "non-upset" API tubing. This is made in sizes ranging from 1,900-inch O.D. to 4½-inch O.D. Sizes below 4-inch and 4½-inch sizes have eight threads per inch. All these threads have 3/4 inch taper and are of the API round-thread form. Failure to distinguish these items from regulary water well pipe has frequently caused misfits and trouble. The use of oil field products should be avoided in water well design, unless, there are very good reasons, aside from expediency.

Casing Life:

In a water well, the casing is generally received from the supplier in a black condition as a result of an oil coating which protects the casing from atmospheric corrosion during shipment and for a reasonable length of time in storage. Because of objectionable tastes and odors, more durable coatings are seldom practicable in water wells.

Two important approaches to ensure the extension of casing life are;first, to install a casing with a relatively thick wall and, second, to select the casing on the basis of its resistance to corrosion. Corrosion and incrustation, important features in casing longevity, are covered in detail later in this text.

Field Operations For Cable Tool Drilling:

It is stated that the cable tool or percussion method of drilling is used in the construction of most high capacity wells (in excess of 500 gallons per min.) in the southwest United States. The formation characteristics in deep, unconsolidated alluvial basins require that the casing be installed by driving or jacking coincident with drilling. Following installation, the casing is either selectively perforated or screened in the desired aquifers.

Consideration must be given to the following factors in selecting casing to be installed in wells drilled by the cable tool method:-

1. The casing must have a smooth exterior to minimize seizing up the formation.
2. The casing must have a smooth interior to permit passage of drilling tools.
3. The inside diameter must be large enough to accommodate the pump.
4. The casing should be manufactured from steel having physical properties that resist the severe stresses from drilling and handling.
5. The casing must have sufficient wall thickness to resist stresses from placement and subsequent production.
6. Within economic limits, the chemistry of the steel should promote long life of the casing.
7. The joint design must provide reliable coupling with high joint efficiency.

One solution to these requirements has been achieved with two ply, slip joint well casing which has been developed over the past 70 years. Double walled casing is manufactured from high strength copper bearing steel, in four foot lengths. The inside and outside joints are offset two feet. The inner casing fits to the outer casing with a tolerance not exceeding 10/1000ths of an inch. Strength and durability are thus enhanced from inherent structural qualities rather from the efficiency of the welded joint.

For field assembly, the inside joints are flush and the outside joints are separated, approximately 1/8 inch so that a circumferential weld can join he outside joints to the inside joints. In order to withstand severe driving forces the bottom 20 feet of the casing is reinforced and is welded to a forged, heat treated drive shoe.

The inside diameter of well casing is generally two inches larger than nominal pump bowl diameter. There are instances, however, when greater learance between pump bowls and column pipe well casing may be desirable. Table three shows minimum inside diameter of the casing as a function of nominal bowl diameter and yield range. Minimum wall thickness is selected primarily from the following considerations:-

1. Required durability
2. Maximum drawdown during production
3. Physical requirements for installation

Generally, casing durability can be anticipated from accumulated data in other wells of the same area. If highly corrosive ground water conditions xist, casing durability can be extended by increasing the wall thickness.

It is stated that during production under ideal conditions a cone of epression surrounds the casing with a negligible pressure differential imposed on the casing. Under normal field conditions, unless the casing is perforated bove the pumping level lowering the water level inside the casing produces a pressure differential on the casing equal to the difference between the standing water level and the pumping level. Wall thickness must be adequate to ustain this pressure.

Physical requirements for installation depend primarily on the nature of the formation and the total depth. Jacking forces in excess of 250 tons have been required to install some types of casing. Tables are given for double walled casing for collapsing pressures and weights, axial crushing strength and recommended minimum wall thickness as a function of well depth and diameter.

TABLE 3

nominal bowl dia. (inches)	Operating pump speed (RPM)	Yield (gpm)	Minimum Casing I D (in)
8	3500	200-1200	10
	1800	100-600	
	1200	160-400	
10	1800	200-1500	12
	1200	370-670	
12	1800	400-2300	14
	1200	250-1500	

TABLE 3 CONTINUED

Nominal Bowl Dia. (inches)	Operating Pump Speed (RPM)	Yield (gpm)	Minimum Casing ID (in)
14	1800	1000-4500	16
	1200	700-3000	
16	1800	2000-5200	18
	1200	1300-3400	
18	1800	3200-4100	20
	1200	2200-4000	
	900	2800-3000	
20	1200	3100-4400	24
	900	2300-3600	
22	1200	7500	24
	900	5600	

Although the use of double wall or stove pipe is not general use today in the United States because of readily apparent deficiencies, the foregoing discussion briefly summarizes its design features for purposes of comparison with the commonly used single wall casing.

With standard cable tool methods of well construction the requirement for medium weight casings, particularly with large diameters, precludes the use of relatively expensive ferrous and non-ferrus metals in fabrication. Experience and test data indicate that well durability can be extended by the addition of 0.20 percent copper to steel. Recent tests with corrosometer probes indicate that under minimal corrosive conditions, "splash" zone is higher than that in the submerged zone. The corrosive environment in the "splash" zone is equivalent to a moist atmosphere in which copper bearing steel has twice the corrosion resistance of carbon structural steel.

TABLE 4

Collapsing Pressures and weights of Double Wall Casing.

	12 gal.		10 gal.		8 gal.		6 gal.	
Dia.	Coll.	Wgt.	Coll.	Wgt.	Coll.	Wgt.	Coll.	Wgt.
8	694	19.6	1540	25.3				
10	353	24.4	780	31.3				
12	204	28.0	450	37.3	780	45.9		
14	127	33.7	280	43.3	500	55.0		
16	85	38.3	188	49.9	336	62	565	75
18	60	43.2	130	55.5	239	70	388	86
20	43	47.8	96	61.5	170	78	280	96

TABLE 4 CONTINUED

	12 gal.		10 gal.		8 gal.		6 gal.	
DIA.	Coll.	Wgt.	Coll.	Wgt.	Coll.	Wgt	Coll.	Wgt.
22			72	67.3	127	85.6	212	105
24			56	73.2	96	93	163	114
26			43	80.5	78	98.5	127	121

Note: The collapsing values shown above are in feet of water. Weights are in pounds per lineal foot.

Approximate Axial Crushing Strength of Double Wall Casing in Tons.

Dia.	12 ga.	10 ga.	8 ga.	6 ga.
8	65	80	100	120
10	80	105	125	150
12	95	125	150	180
14	110	145	175	210
16	125	165	200	235
18		185	225	265
20		205	250	295
24		245	300	355

Field Operations For Rotary Drilling:

Most high capacity, gravel packed water wells are constructed by the rotary method of drilling. A typical well installation consists of:- conductor casing, grounded in place:blank well casing;screen casing;and gravel packing if applicable.

Consideration must be given to the following factors when selecting casing and screen to be installed when drilling by rotary methods:

1. The casing and screen must have a smooth interior to permit installation of pump and the operation of development equipment.
2. Casing inside diameter must be large enough to accommodate the pump. Screen inside diameter must be large enough to permit water flow without excessive head loss.
3. Casing and screen must have physical properties adequate to permit installation and to resist stresses from development and production.
4. Field connection joints must be equal to casing strength.
5. Casing and screen material must withstand a potentially corrosive ground water environment.
6. The shape of the screen openings should be designed to reduce plugging to

provide minimum resistance to water flow.

Casing and screen sections are subjected to tensile stresses during nstallation. Additional tensile stress is caused by the downward movement of gravel pack material during consolidation and well development. Although these stresses cannot be calculated. It is indicated that a factor of safety of 21 to 31 over theoretical casing and screen weight is adequate.

TABLE 6

Suggested minimum thickness for double wall casing

Depth of casing in feet	Diameter (in inches)								
	10	12	14	16	18	20	22	24	30
0-100	12	12	12	12	10	10	10	10	8
100-200	12	12	12	10	10	10	10	8	8
200-300	12	12	10	10	10	10	8	8	8
300-400	12	12	10	10	10	8	8	8	8
400-600	10	10	10	10	8	8	8	8	8
600-800	10	10	10	8	8	8	8	8	8
over 800	10	8	8	8	6	6	6	6	6

Note: Values are United States standard gage.

The casing yield strength applying only to a perforated casing can be computed by the following equation:-

$$Y_s = S_y (D_m\ T)$$

Where:-

Y_s = yield strength (lb)

S_y = yield strength of metal (psi.)

$D_m = \frac{d_1 + D_2}{2}$ (mean diameter, in.)

D_1 = Casing inside diameter (in.)

D_2 = Casing outside diameter (in.)

t= Casing wall thickness (in.)

Screen yield strength is a function of the casing cross sectional area between the perforations. The above equation is for wire wrapped screens. Equations for other types of screens can be obtained from various screen manufacturers. The columns critical strength must be considered an important factor in setting deep screens with casing or riser pipe.

Minimum wall thickness is determined primarily from the following conditions:-

1. Anticipated drawdown during production
2. Total well depth and cumulative effect of stresses imposed by movement of the gravel pack and formation materials during development.
3. Required durability

The critical collapsing strength of single walled steel casing may be estimated by the following equation:-

$$P = 50.2 \times 10^6 (D)^3$$

Where:-

P = Collapsing pressure (psi)
t = Casing wall thickness (in.)
D = Casing outside diameter (in.)

It is reported that the combined stresses imposed on the casing and screen during installation, development, and operation are difficult to estimate. Many wells have been constructed using casing with a collapsing strength of 40 pounds per square inch. As depth increases, greater allowance should be made for these stresses. Table 7 gives collapsing pressure and weight and recommended wall thickness as a function of depth and diameter for steel well casing.

TABLE 7

Collapsing Pressures and Weights of Steel Well Casing

	3/16		1/4		5/16		3/8	
Dia.	Coll.	Wgt.	Coll.	Wgt.	Coll.	Wgt.	Coll.	Wgt
8	1070	17	1800	22	5500	28		
10	600	21	1430	28	3000	35		
12	378	24	900	33	1770	41		
14	242	28	570	38	1140	48	2000	56
16	162	32	390	43	760	54	1350	[illegible]
18	116	36	275	49	540	61	940	72
20	85	40	202	54	390	68	690	80
22	64	44	153	59	300	74	520	88
24	49	48	118	65	230	81	400	96
26	39	52	93	70	181	88	317	104
28	31	56	74	75	147	94	245	112
30	25	60	60	81	119	101	205	120

Note: The collapsing pressures shown above are in feet of water. Weights in pounds per lineal foot.

With thin walled, large diameter casing, welded construction for field ssembly of both casing and screen sections is indicated for the following easons:-

1. The initial cost of casing designed for assembly by welding is less.
2. The uniformity of wall thickness at the joints
3. The increased efficiency of properly welded joints approaches 100 percent; whereas, standard threaded and coupled joints have an efficiency of approximately 60 percent. Either bellends or collars should be provided to facilitate welding and installation. Criteria for determing the inside casing diameter is the same as that previously described in the section on double wall casings.

The most commonly used metals for well casing and screen are listed in Table 35 with their approximate cost ratio using carbon structural steel as the base unit.

The cupro nickle alloys are most suited for sea water production wells with high sodium chloride combined with a high content of dissolved oxygen. Silicon bronze is used in wells with a ground water environment of high total hardness, high sodium chloride content, and low pH. Copper bearing steel has about twice the corrosion resistance of plain carbon steel. High strength, low alloy steel has at least three to four times the corrosion resistance of carbon structural steel.

Transite pipe has been used for casing water wells, although this pipe is unsuitable for the following reasons: -

1. Low joint strength.
2. Insufficient joint alignment to permit the passage of close fitting swabs.
3. Inability to sustain abuse, due to brittleness.
4. High cost of perforating.
5. High cost of installation.
6. Transite pipe cannot be perforated in a manner which will satisfy the requirements for high capacity wells.

Where considerable durability and high reliability are desired, the stainless steels having relatively high tensile and yield strengths and twice the modulus of elasticity of the copper alloys, offer the best solution. The cost of these metals has declined in recent years, and overall costs can generally be maintained within reasonable limits by predetermining the inside diameter and wall thickness required. Since the deterioration of these metals is minor over a period of time, the wall thickness and weight per unit can be strictly limited to the required collapsing strength imposed by the drawdown.

FISHING OPERATIONS:

Fishing operations can often be prevented by proper equipment care and attention. Loss, breakage, and the parting or collapsing of a string of casing is generally the result of carelessness and may be avoided with proper care of the equipment. A thorough periodic inspection of equipment will greatly reduce the frequency of fishing operations. Drilling cables should be carefully inspected for signs of weakness or unusual wear; drilling tools should be inspected for fatigue cracks particularly at welds, and tools should not be lowered into the well unless the equipment is in perfect condition. Fishing is the cause of annoying delays and financial loss in drilling operations.

Probably the majority of fishing jobs are the result of mechanical failures - either from overworking the tool or equipment or from the improper use of accessories in the drilling operation. The abuse of tools or the use of worn tools contributes to the need for a great number of fishing operations. Any work being done in the drilling, cleaning, or servicing of a gas, oil, or water well involves potential problems: (1) failure of the drilling tools or the casing or (2) erroneous procedure - either of which may necessitate fishing. Thus, the potential cost of fishing is frequently the cause of high drilling costs.

Field Operations:

Dipping or creviced formations, subsurface caverns, crooked or slanting holes, settling sands, boulders, etc. are conditions which contribute to drilling problems. Careful and deliberate assessment of these problems will greatly reduce the necessity of fishing operations.

When fishing is required, knowledge and past experience should be considered before recovering the "fish". In fishing, the operator must know what to do as well as what not to do, for many minor fishing jobs have become complicated because the problem was not properly handled early. Many simple jobs are made difficult when improper fishing tools and faulty judgment are employed. The first principle of fishing is never to run an unsuitable tool in the hole. If the proper tool is not available, fishing should not be attempted until the tool can be obtained or built. The vast majority of fishing jobs are simple and easily accomplished unless complicated by improper procedures.

If the operator is prepared for potential fishing problems the exact dimensions of all downhole drilling and fishing tools should be recorded. Some of the important tool measurements are: outside diameter and length of rope socket;diameter and length of the neck of rope socket; diameter and length of drill stem, etc. The measurements should include size of joints and outside diameter of pin and box collars as well as body size and length bits. A careful record of the depth of the hole and the overall length of the drilling string should be noted.

If fishing is difficult or becomes complicated, the cost of the tools, time, and labor may greatly exceed the cost of the hole, It may be more efficient to start a new hole. In any event, cost should be the main factor in deciding what action to take.

Fishing operations require skill, patience, and ingenuity. In many cases, the completion of the well depends upon success in recovering lost equipment. A great variety of special tools and procedures have been devised to assist fishing for cable-tool equipment, but many of the techniques are widely used with other drilling methods. Only common fishing tools are discussed. Many of these tools are rarely used;in some cases, a tool will be made for a particular purpose and never be used again. Only the largest contractors can afford to own more than a limited assortment of fishing tools. Many operators make a practice of renting tools when needed from local rental agents.

No amount of measurement at the surface can exactly determine the position of the lost tool in the hole or, in some cases, whether the top is free from obstruction. Impression block is often used to obtain an impression of the top of the tool before attempting any fishing operations. This is particularly necessary in rotary-drilled, uncased holes. Impression blocks have many forms and designs. A short block of wood having a diameter one inch less than that of the drilled hole fits tightly into the drill-pipe box collar. Warm paraffin wax, yelloe soap, or other plastic material fills the sub and then cools and solidifies. The block is carefully lowered into the hole until the "fish" is encountered. The impression block is then raised to the surface where the impression made in the wax or soap can be examined. By careful interpretation of the impression, the position of the "fish" and the best means of retrieving it can be determined.

The recovery of drill pipe that has twisted off in the hole is a frequent fishing operation. The break may either be due to shearing of the pipe or failure of a threaded joint. An impression block can be used to determine the exact depth and position of the top of the pipe, whether there has been any caving, or whether the pipe has become embedded in the wall of the hole. If the top of the pipe is unobstructed, either the tapered fishing tap or die overshot can be effective if used before the cutting in the hole settle "freeze" the drill pipe. The circulating-slip overshot, which permits the circulation of drilling fluid, is the best tool to use if the pipe has been frozen by the settling of cuttings around it. These tools are all illustrated.

The tapered fishing tap, made of heat-treated steel, is tapered one inch per foot from a diameter smaller than the inside of the coupling to a diameter equal to the outside of the drill stem. The tapered portion is threaded and fluted to permit the escape of chips cut by the "tap".

The tap is lowered slowly on the drill stem until it engages the lost pipe; the circulation is maintained at a low rate through the hole in the tap during this period. After engaging the lost pipe, the tap turns slowly by the rotary mechanism or by hand, and circulation is stopped until the tap is threaded into the pipe. Circulation should be re-established through the drill string before pulling the lost pipe.

The die overshot is a long tapered die of heat-treated steel designed to fit over the top of the lost drill pipe and cut thread when rotated. This tool is fluted to permit the escape of metal cuttings. Circulation cannot be completed to the bottom of the hole through the lost pipe since the flutes also allow the fluid to escape. The upper end of the tool has a box thread designed to fit the drill pipe.

The circulating-slip overshot is a tubular tool, approximately three feet long, with an inside diameter slightly larger than the outside of the drill pipe. The beveled lower portion of the tool helps to centralize and guide the top of the lost drill pipe into the slip that is fitted in the tapered sleeve. The slot cut through one side of the slip enables expansion of the slip as the tool contacts the drill pipe. When the tool is raised, the slip is pulled down into the tapered sleeve, thus, tightening the slip against the pupe. Circulation of fluid can then be established freeing the pipe for recovery.

A wall hook is used to straighten the lost drill pipe in the hole in preparation for removal by the tap or overshot tools. The wall hook is a simple tool that can be made from steel casing, shaped with a cutting torch. A reducing sub connects the top end of the tool to the drill stem. The wall hook is lowered until it engages the pipe, then slowly rotated until the pipe is fully within the hook. The hook is slowly raised to set the pipe in an upright position and then it is disengaged from the pipe.

A tapered fishing tap can be attached to the upper portion of a wall hook. Using this combined tool, the hook can realign the lost drill pipe and then, while being lowered, guide the tap into the drill pipe to complete both operations in one run. This method is particularly desirable when the drill pipe leans against the wall of a much larger hole.

The loss of a downhole casing is perhaps the most difficult fishing problem. The loss results from freezing, collapsing, telescoping, parting, or splitting of the casing. Freezing results from the caving of the wall against the pipe, accumulations of cavings or sand around the casing collars, contact with the walls in a crooked hole, or an improperly reamed interval in the well. Collapse of the casing is due to external pressure - generally hydrostatic. Caving of the walls or loose boulders pressing against the pipe may deform it. Telescoping of a column of pipe can result from either dropping or dirving the pipe carelessly when the lower end is frozen. A column of casing may part because of: extreme tensional strain, engendered by its own weight; an attempt to lift the casing when it is frozen; defective threads; or improperly coupled joints. The casing can split as a result of defective welding in the manufacturing process, drilling formation material which has "heaved up" into the casing, or improperly using a swedge, casing spear,or other fishing tools. Most of these difficulties can be avoided by proper selection and inspection of casing and by carefully coupling the joints before the casing is lowered into the well. Good judgment is also necessary in determining the depths at which a string of pipe can withstand strain. The condition of the walls of the well, the straightness of the hole, and the proper reaming of all sub-guage intervals have an important bearing on the success of a casing installation.

If the casing develops frictional contact with the formation(i.e., if it shows indications of being collar bound with mud or loose material from the walls) the casting can often be freed by being alternately raised and lowered a vertical distance of 20 to 40 feet, depending on the length of joints. If this procedure fails to relieve the friction, the well may be bailed down within the casing so that hydrostatic pressure can clear the space around the pipe.

If friction results from an attempt to lower a column of casing into a too-small hole, the best remedy is to pull the casing until the casing shoe is above the tight interval and to thoroughly under-ream the hole. Under such conditions, particularly if the casing has been driven, lifting the column against the friction with power available is often impossible without placing undue strain on the rig. In such cases, a combined pull and jar action of the rig is often successful. Another method is shown.

Many dangers are involved when pulling frozen or lodged casing. When the mechanical advantage of the reduction gear and hoisting block is considered, it is apparent that a sufficient force to pull the pipe apart or to collapse the rig mast can be generated. Men have been killed or injured by derricks that have collapsed and casing lines, hoisting blocks, or elevators that have snapped from the sudden release of tension when the casing pulls apart near the surface.

If friction is due to cavings in the bottom of the hole, or if friction is due to a restricted hole diameter, the casing can be mechanically driven at the surface to assure emplacement before freezing occurs. Alternate drivin and pulling is also effective to free the casing from wall friction. When casing is being pulled from a caving hole, freezing can occur several feet from the bottom, but by driving a short distance, the casing often can be freed.

If all other means of pulling frozen casing have failed, a casing connector can be used with considerable success. A casing connector is a tool with a tool-joint box; a mandrel top (similar to a rope-socket neck, but solid); and a shoulder between the neck and box threaded to fit a casing coupling. The casing connector may also be used to pull broken casing that remains in the bottom of the hole. The fishing string may be the same size as the lost casing, and a short stem can be connected between the spear and the casing connector. Thus, if the top joint of the casing is split, the spear may secure a firm hold.

If the casing can neither be pulled nor driven, it is possible to save that section which is not frozen. Thr freeze may be located by running a drive-down spear and testing for vibration. The spear is driven to the bottom of the casing and raised and jarred at regular intervals. No vibration will occur until the spear contacts the area where the casing is frozen. A casing ripper (or cutter) is then lowered just above the freeze and the casing is parted and removed. If tension is maintained, the casing should move when the parting operation is completed. To continue drilling, casing must be used that will telescope the casing left in the hole.

Collapse of the casing is caused by external pressure from hydrostatic head bearing on the pipe; by caving walls of the hole; by a loose boulder in the wall pressing against the pipe; or by sudden "heaving" of unconsolidated sand into the well from oil, gas, or water horizons. If casing is set to exclude ground water of undersirable quality, fluid accumulates outside the pipe to many feet above the casing shoe - at times even to the surface. The hydrostatic haed which can collapse the casing will vary with the density of the fluid. Fresh ground water develops a pressure of 0.433 pound per foot of depth and saline ground water (containing 34,000 parts dissolved salt per million) develops a pressure of 0.444 pound per foot of depth. For average conditions in making approximate computations, the fluid is assumed to have a density of 1.15 and develops a static pressure of 0.5 pound per square inch per foot of depth. Conservation computations assume that fluid outside the pipe extends to the surface and that a collapsing pressure is developed on the casing equivalent to a fluid head of the full length of the casing. This collapsing pressure can be a force of great magnitude reaching as much as 3,000 pounds per square inch in a well 6,000 feet deep.

Economics of each Drilling Method:

It is very difficult to put down on paper the actual costs of each type of drilling method, as applied to developing countries. Each have their own particular problems and expense factors. We have discussed in some detail the advantages and disadvantages of each type of operation, however, we have not described actual drilling times and areas of expense so that a realistic choice of technology or method would be most practical in each situation.

One of the most important facts to recognize that technology change and advance has nearly always been predicated by time or wage costs. The early dug wells involved a tremendous number of man days or months to produce. Some of the ganats of Iran and Pakistan took up to 30 to 40 years to develop with very low cost labour. Today that method is economically impossible.

The writer had an experience in India in Burhanpur,(Central India) where an air percussion drilled well 6" diameter, 250 feet deep was able to tap an aquifer of ½ million liters of water a day. This was accomplished in 14 actual machine hours. Not far away was a 105 well ganat over 2 kilometers long, supplying water of an equal amount It was over 300 years old and still operating. Historical fact states that it took 75 men 8 years to construct. Two men are utilized full time to keep it operational.

There have been many methods of drilling shallow wells in soft conditions using the simplest equipment in S. Asia. The limited capital equipment required and high labour imput certainly needs to be examined as to its appropriateness in present society.

Recently, in Bangladesh, a series of wells were drilled by the manual percussion method. This is a simple method of using a tripod, heavy steel casing pipe flush jointed a manual winch, and a sand pump bailer. In the particular formations drilled, it took 4 to 6 weeks to produce a well 50 meters deep. As the well was cased before fitting screens and pipe it was possible to penetrate a caving sand formation that might defeat other methods.

The advantages: (1) Labour intensive and provide jobs for unskilled.
(2) Capital equipment is simple, reasonably inexpensive amd does not break down readily.
(3) The hole is cased for poor formations.

The disadvantages: (1) Very slow if time is important
(2) Cost per meter of drilling is high
(3) Cannot drill hard formation.
(4) Equipment is heavy.

In hard rock formations like granite and basalt, the simplest method as demonstrated in India in the Deccan Trap plateau, was the core barrel or calyx method of drilling. This was simply a small tripod, a 5 hp diesel engine driving a rotary head made from a rear end of a truck. A small hand operated piston pump and a splined shaft running through the rear end and connected to a swivel joint that in turn was connected to a piece of pipe 6" in diameter inside. The end of the pipe was slotted with a series of small slots about 6mm wide and 50mm deep. As the pipe was rotating in the rock formation, a spoonful of chilled cast iron shot (very hard and brittle) was dropped down inside and this formed the cutting medium. It would take 8 hours to drill 30cm. The method is similar to diamond drilling except much slower.

The advantage: (1) Low cost of equipment and reasonably available
(2) Low labour skills
(3) Ability to drill large holes in rock.

The disadvantages:
(1) Very slow
(2) Reasonably expensive as far as man hours and wages.

The real technological change was forced generally be the cost of labour. In N. America, the cable-tool percussion method was the most common method of drilling water wells in all types of formations up and until the wage costs exceeded $2.50 U.S. currency per hour. A well say in basalt or limestone would take 5=8 days. On a cable-tool machine would take only 1 day or less, with an air percussion rig. The change to rotary mud and air methods became almost universally the accepted competative method of drilling. The change to high pressure air also was motivated by the higher wages paid to drillers in present day situations.

It is thus very important to evaluate the actual costs of each method of drilling. for each geographic area in the world. All too often the technological choice is made based on information and data available from very high wage cost areas. This is not appropriate at all times.

An example of wells drilled in say basalt, granite or limestone will illustrate the necessity to prepare an actual costing of each method of drilling, and choice of numbers of units needed to do the work.

Requirements: 60 wells a year.
15cm to 18cm diameter
Depth, 75 meters.
To be fitted with hand pump for a drinking water supply for a village.

Method 1- Purchase a modern air percussion rig truck mounted. Estimated capital cost with drilling equipment say 150,000 currency units. This unit based on operating expense time as determined be appendix B will work out at a cost less labour about 48 currency units per hour, plus cost of bits at 100 currency units per well. An average well will require the rig for about 12 hours so the cost of the well will be about 576 currency units. Wages for a crew of say 4 men would work out for N. America at 28 units per hour so a cost for labour would be 864 currency units. Travel time and other down time would add another approximately 300 currency units, for a total of 1164 currency units. Note profits are not included nor administration costs. Thus a cost per meter would be about 15.5 currency units based on air percussion drilling. This 60 well programme can be done in say 120 elapsed days or 4 months. For a country where labour rates say are 20% of N. America than the cost per meter would be 916/75 or 12.2 currency units. Again it will be required to have skilled people operate this unit.

Method 2- Purchase a trailer mounted cable tool rig. Estimated capital cost is 30,000 currency units. The operational cost of this unit less labour but including bit sharpening would be about 4 currency units per hour. The average well will require the rig to drill this well about 5 days of 18 hr. each day, or 360 currency units. Wages for crew fo two men per shift would be by N. American standards 900 units. Travel time and down time would add more than 50 currency units , a total cost of 1310 currency units. Thus a cost per meter would be about 17.4 currency units. For a country where labour rates are 20% of N. America the cost per meter would be 590/75 or 7.8 currency units.

This method would not require as skilled a staff as the air percussion method. This 60 well programme can be done in 300 working days or 1 year.

Where wage costs are low as compared to N. America, or Europe, cable-tool drilling is still very reasonable, for an on-going programme. If larger numbers of wells are needed, more cable-tool rigs can be utilized. This is important due to the greater possibility of breakdowns in equipment. An operation with one high powered rig will be zero if the expensive machine breaksdown. Whereas, the 3 or 4 cable-tool units can always be counted on to produce wells even if one unit is donw for the same or less capital expense.

It is well to note that based on same wage costs the air percussion rig in N. America is much cheaper per meter than the cable-tool method and is basically the reason for the technological change and the tremendous construction of air and mud rotary rigs.

The reverse circulation drilling method has little to compare with in simpler technologies except the manual jetting programme, so that comparision is not possible. It is important to recognize that the reverse circulation method is ideal in areas of a high watertable and soft formations. It is the only method for caving and sandy silt soils that otherwise must be cased to drill. There are two types of rigs. The Europeon type is for small shallow wells and is best designed to be put on a regular farm type tractor. It uses 100MM drill pipe and the pump runs from the front of the motor. The P.T.O. turns the table and operates the winch. It is a simple economic unit where one needs wells of 30cm diameter and 35 meters deep. A well this size can be drilled ready for casing and screen and packing in say 8-10 hours.

The large reverse rigs have a capacity of 100 meters and diameters over 1 meter. The drilling time regardless of diameter can be up to 5 meters per hour. The fitting of casing screen and gravel packing could be completed in approximately 24-36 hours. for 100 meter wells.

There are demands on reverse drilling that really effect the economics of drilling. The cost of transporting water to supply the hydrostatic pressure in the well can be expensive. It has been known to transport 200,000 liters of water, 175 kilometers to maintain the water for one well while drilling. Also boulders that must be picked out can effect production and expense. Although these wells require full lengths of large casings, expensive screens, and gravel packing, the volume of water makes these wells the cheapest per unit volume of water produced when large pumps are installed.

DEVELOPING AND COMPLETING WATER WELLS

Well development includes those steps in completing a water well that aim to remove the finer material from the aquifer. thereby clearing out, opening up or enlarging passages in the formations so that water can enter the well more freely. Development work is an essential operation in the proper completion of a water well. Developing a well brings it to its maximum capacity.

Three beneficial results are brought about:

1. Development corrects any damage to or clogging of the water-bearing formation which occurs as a side effect from the drilling.
2. Development increases the porosity and permeability of the natural formation in the vicinity of the well.
3. Development stabilizes the sand formation around a screened well so that the well will yield water free of sand.

All these results can be obtained for wells in unconsolidated aquifers if the wells are properly screened and development procedures are properly applied. The first two benefits also can be obtained for wells in consolidated aquifers, when the methods used are applicable to the type of rock in which the wells are drilled. The third point has no relation to rock wells.

A modern screened well, designed to obtain water from a sand aquifer, may be completed in either or two ways. One scheme-completion by natural development-relies upon the development process alone to generate, from the aquifer material itself, a highly permeable zone around the well screen. A naturally-developed well is the result.

Completion of this type of well depends upon pulling out the finer particles from the water-bearing formation, bringing them into the well through the openings of the well screen, and bailing or pumping them out of the well. Development work is continued until the movement of fines from the formation ceases and the formation is fully stabilized to prevent any furthur sand movement.

Removal of the finer particles leaves in place a naturally-developed zone of uniformly graded sand or gravel of high porosity and high permeability surrounding the well screen. Water can then move through this zone toward the well with negligible head loss. This results in reduced drawdown in the well.

Another way of providing a highly permeable envelope of granular material around the well screen is by artificial gravel packing. This involves deliberately placing artifically graded material around the screen in an annular space that is expressly provided for this purpose.

Some persons claim that development work is unnecessary when a well is artificially gravel packed. Experience has shown, however, that development work must be done after placing the gravel pack if maximum capacity is to be attained. Artificial gravel packing poses a special problem in development that is described later in this chapter.

Regardless of the type of well, the first objective of the development process is to remedy any temporary damage to the aquifer. Every method of drilling plugs off the pores of the water-bearing formation in one way or another.

Driving casing in the cable-tool method vibrates the sand around the pipe. Since vibration is an effective way to compact granular materials, the pipe driving operation packs the sand tighter and reduces its porosity. Recognizing this, good cable-tool drillers always try to work the pipe down through the water-bearing formation by bailing methods, and drive the pipe only when necessary.

Sands and gravels in unconsolidated aquifers generally are found to have been deposited in relatively loose fashion by various sedimentary processes. Arrangements of the grains is often such that the density is low and the porosity is high. While stable in their natural can be easily compacted when disturbed.

Drilling operations also cause some plugging of the openings in hard rock formations. Any material that has been forces into the fractures and crevices in the rock aquifer as the well is drilled must be removed later by development work.

In reverse circulation drilling, water without the deliberate addition of clay is used as the drilling fluid. Some silt, clay, and fine sand are picked up, however, from the formations penetrated during the drilling operation. These fine materials are recirculated with the water as drilling proceeds.

Some water is lost into the formation due to the excess fluid pressure that must be maintained to keep the hole open. As water is lost into the formation, varying amounts of silt and clay are filtered out and deposited on the wall of the borehole. Accumulation of these fines partially seals off the face of the hole. This effect actually assists the drilling operation by preventing excessive water loss.

The skin of material deposited on the wall of a hole drilled by the reverse circulation method is more easily removed than the mud cake formed by the drilling fluid in the conventional rotary system. In either case, the skin, or wall cake must be removed by development operations.

The first result, then, of good development work is to eliminate the inevitable "skin effect" and loosen up the sand around the screen to recover lost porosity. The second objective is to go beyond this and to substantially increase the permeability of the aquifer in the vicinity of the well. The basic charactor of the naturally-developed well, which we have already described, exemplifies this beneficial result.

The third beneficial result of development is the best understood by visualizing what happens throughout a series of cylindrical zones in a sand aquifer surrounding the screen. In a zone just outside the well screen, development removes all particles smaller than the screen openings, leaving only the coarsest material in place. A little farther away, some medium-sized grains remain mixed with the coarse. Beyond that zone, the material gradually grades back to the original charactor of the water-bearing formation. By creating this succession of graded zones of material around the screen, development stabilizes the formation so that no further sand movement will take place. The completed well will then yield sand-free water at maximum capacity.

Selection of the correct size or sizes of slot openings for the well screen is essential to successful well development. Sizes of openings are chosen which will permit removal of the desired proportion of the fine material from the formation.

For many types of formations, it is common practice to select a slot width that retains about 50 percent of the sand. Relatively larger openings, allowing more fines to be removed by development, can be chosen when the gradation is less uniform with a broad range from fine to coarse particle sizes in the formation. A more conservative choice must be made when the formation sand is uniform in grading. Alternating fine and coarse strate in the formation requires careful consideration by an experienced engineer or geologist in order to get the best results.

The slot size governs the extent to which the development work can be carried out. There is obviously a limit to the quantity of material that can be allowed to move through the screen. Too much removal may cause settlement of the overlying materials, which can result in undesirable effects upon the well.

When the well screen openings are too small, on the other hand, the yield of the well will be limited by inadequate development. Cementation or incrustation may also occur as the result of abnormally high velocity of flow near the well bore when maximum porosity has not been attained.

Artificial gravel packing poses a special problem in well development which is discussed later in this chapter.

Bridging of Sand Grains

The fundamental intent in the development operation is to cause reversals of flow through the screen openings that will rearrange the formation particles. This is essential to break-down bridging of groups of particles. Reversing the direction of flow by surging the well overcomes this tendency. The outflow portion of the surge cycle breaks down bridging, and the inflow portion then moves the fine material toward the screen and into the well.

Mechanical Surging

An effective means of surging the water in a well to develop the water-bearing formation is to operate a plunger up and down in the casing like a piston in a cylinder. The tool normally used is called a surge plunger, or surge block. A heavy bailer may be used to produce the surging action, but is not as effective as the close-fitting surge block.

Many drillers depend largely or entirely on surge plungers for developing screened wells. Others feel that this device is not effective and may, in some cases, even be detrimental.

The surge plunger is, nevertheless, the most generally used tool for development, particularly by cable-tool drillers.

A surge plunger differs from a swab in that the latter is ordinarily lowered into the casing to any selected point below the water level and then pulled upward to produce an inward flow of water. with no attempt to reverse the flow and cause a surging effect. Swabbing in this manner is used rather commonly in cleaning fine material from wells drilled in consolidated rock aquifers, but to a lesser extent in screened wells.

Surge plungers sometimes produce unsatisfactory results where the aquifer contains many clay streaks or clay balls. The action of the plunger can cause the clay to plaster over the screen surface. When the operation tends to do this, it may reduce the yield rather than increase it. There may also be hazard involved, because the surging can produce high differential pressures which may collapse the screen if it is partly or wholly plugged by clay or mud.

A surge plunger should not be operated unless a sufficiently free flow of water has been established so that the tool runs smoothly and freely. It should be used with particular care if the overlying formation consists principally of fine sand, silt or soft clay.

In summary, a surge plunger is a low=cost tool which is convenient to use. It is highly favored by the drillers who have used it successfully. Within its limitations and under appropriate well conditions, it will do an effective job.

Surge blocks may be of two types: a solid plunger, or a plunger with valved openings. The valve-type plunger gives a lighter surging action than the solid block. This is an advantage in developing tight formations, since it is always best to start surging lightly and to increase the force of the surge as the development proceeds. Plugging the openings of the valve-type plunger converts it to a solid-type plunger for use when greater surging force is necessary.

Enough weight must be attached to the surge plunger to make it drop readily on the downstroke. A common mistake in using a surge plunger is not having it weighted sufficiently. A drill stem or heavy string of pipe can provide the needed weight.

One kind of solid surge plunger that can be made readily in most shops, is made up of two leather or rubber-belt discs, are sandwiched between wooden discs, all being assembled over an extra-heavy pipe nipple with steel plates serving as washers under the end couplings. The wood discs should be good laminated stock that will not split. The leather or rubber discs should fit reasonable well in the casing.

Before starting to surge, the well should be bailed to make sure that some water will flow into the well and to remove any sand that may have settled in the screen.

<u>Using the Surge Plunger</u>

The following is a typical procedure, described in step-by-step fashion.

Lower the surge plunger in the well until it is 10 to 15 ft under water, but above the top of the screen. Keep it at least a few feet above the screen, so that it will not strike the lead packer. The water column transmits the action of the plunger to the screen section.

If a cable tool rig is being used, set the spudding motion on long stroke. Start surging slowly, then gradually increase the speed, keeping it within the limit at which the plunger will rise and fall smoothly without jerking. It is useless to run the machine faster than the speed at which the plunger will drop on the downstroke. If a rotary rig is being used, lift the plunger 3 or 4 ft before dropping it. Control the movement by using the hoist brake and clutch, if the sand line carries the tool: otherwise, handle the plunger by manipulating a manila line around the cat-head.

Continue surging for several minutes, then pull the plunger from the well and lower the bailer or sand pump into the screen. When the bailer rests on the sand that has been pulled into the screen, check the depth of the sand in feet by measuring on the sand line. Make a record of the amount of sand. Bail all of the sand out of the screen. Repeat the surging operation and compare the quantity of sand that brought in the first time. Bail out the sand and repeat surging and bailing until little or no sand can be pulled into the well.

Lengthen the period of surging as the quantity of sand brought in each time decreases. Total time for development may range from about two hours on small wells to two or three days on large wells with long screens.

A considerable part of the success of the work depends on the bailer and the bailing procedure. Results will be better when the bailing job is done thoroughly. The type of bailer generally favored for this work is the sand pump type, fitted with a good plunger and with a dump bottom valve. This tool, properly run, will do a first class job of cleaning out the screen. A relatively large bailer works best, especially if it is operated somewhat as a surging tool inside the screen, along with the operation of picking up the sand from the bottom of the screen.

The timing of the surging should be judged carefully to avoid continuing this operation when there is considerable amount of sand in the screen. The effect of the surging is more concentrated at the top of the screen, and this is accentuated if a good portion of the lower part of the screen is continuously blocked off by the accumulated sand brought in by the development process.

Valve-Type Plunger

The valve-type plunger pulls the water into the screen in the same manner as the solid plunger on the upstroke, but its surging action on the downstroke is milder, because some water passes up through the ports in the plunger. Less water is thus pushed back through the screen openings and into the formation.

Under some conditions, the column of water above the plunger may build up to the point where the upstroke brings water over the top of the well each time. This is not an essential feature, but it may assist by removing some of the silt and fine sand from the well as the surging operation is continued.

Care must be exercised when sand is pumped with the water, to avoid sand-locking the plunger in the casing. There is little danger of this occurring as long as the plunger is kept in motion. It is good practice to continue the spudding action even while spooling the cable to remove the plunger from the well.

In a well equipped with a long screen, it may prove more effective to operate the surge plunger in the screen itself, so as to concentrate its action at various levels. This practice aims to develop the well throughout the length of the screen. It has been used by some drillers with good results.

It is not necessary nor desirable to size the plunger to fit tightly in the screen. The plunger should pass readily through the screen or screen fittings. When surging in the screen special care must be taken to avoid the tool becoming sand=locked which can happen if sand fills in above the plunger.

Surging can cause movement of water vertically outside the well casing if the washing action should disrupt the seal around the casing in the overlying strata. When there is any indication that this is occuring, use of the surge plunger must be discontinued.

Surging with Air

Compressed air may be used effectively as a development tool. Many drillers do all their development work with air. To do the job, an air lift, with the air pipe inside an eductor or pumping pipe, is installed in the well.

The equipment needed for this method includes the following:

1. Air compressor and tank of required size.
2. Pumping pipe and air line in the well, with means for raising and lowering each independently of the other.
3. Flexible, high-pressure, air hose to permit raising and lowering the air line in the well.
4. Pressure gauge and relief valve to safeguard against accidental overloading.
5. Quick opening valve in the outlet of the tank for controlling air flow.

The compressor should be capable of developing a maximum pressure of not less than 100 psi and preferable 150 psi. A rough but usefule rule of thumb for determining the proper compressor capacity, is to provide about three-fourths of a cubic foot of free air for each gallon of water at the anticipated pumping rate.

The outlet of the compressor should be connected to the air tank in a way which will minimize resistance to the air flow. The outlet pipe leading from the tank to the well should be as large as, or larger than the air line in the well. The quick opening valve should be connected at a convenient point. A high-pressure hose connects from the outlet pipe of the tank to the air line in the well. This hose should be at least 15 ft long, to allow for moving the air lift assembly up and down.

Figure 283 shows the proper method of placing the pumping or eductor pipe and air line in the well. The pumping pipe is handled conveniently with the drilling or casing line, while handling the air pipe separately by means of the sand line or other available hoisting cable. A tee at the top of the pumping pipe is fitted with a discharge pipe at the side outlet. A bushing with inside opening large enough to clear the couplings of the air line is screwed to the top of the tee. Wrapping burlap or similar material around the air line just above the tee reduces spraying about the top of the well.

Table XXX shows the recommended sizes of pumping or eductor pipe and air line to be used for various sizes of wells.

Some variation from these sizes may be necessary for practical reasons but the combinations shown generally give good results.

Air development produces best results when the submergence ratio of the air line is about 60 percent. This is the proportion of the total length of air line that is below water while pumping.

To calculate submergence, the length of air line under water is divided by the total length of air line. If, for example, the air line is 180 ft long and the static water level is 61 ft below ground, the submerged length is 119 ft. The non-pumping submergence ratio is:

$$\frac{119}{180} = 0.66 \text{ or } 66 \text{ percent}$$

If the air lift is started and the water level drops to 74 ft., the submerged length becomes 106 ft and the submergence ratio while pumping is: $\frac{106}{180} = 0.59$ or 59 percent

Reasonably good results can be obtained by a skillful operator with submergence as low as 30 percent while pumping.

Before blowing any water or drilling mud out of the well with a sudden injection of air, the air left should be operated to pump water slowly from the well. This is done to make sure that some water is entering the well from the aquifer. so that excessive differential pressure will not occur when large volumes of air are released inside the well screen during the surging operation. For pumping alone, the air line needs to be lowered only far enough to have good submergence.

When starting development, the pumping pipe is lowered within about 2 ft of the bottom of the screen. The air line is placed so that its lower end is up inside the pumping pipe a foot or more. Air is turned into the air line and the well is pumped in the manner of a conventional air lift until the water appears to be free from sand. The valve at the outlet of the tank is then closed, allowing the pressure in the tank to build up to 100 to 150 psi. In the meantime, the air line is dropped so that its lower end is a foot or so below the discharge pipe. The valve is then quickly opened to allow air from the tank to rush suddenly into the well. This tends to surge the water outward through the well screen openings. Ordinarily, a brief but forceful head of water will also overflow or shoot from the casing and from the pumping pipe at the ground surface. If the air line is pulled up into the pumping pipe after the first charge of air has been released into the well, the air lift will again pump, reversing the flow and completing the surging cycle.

The well is pumped as an air lift for a short time, then another "head" of air is releasec with the drop pipe below the pumping pipe and the air line is again lifted to resume pumping. Surging cycles are repeated until the water is relatively free from sand or other fine particles. This shows that the development is approaching completion in the region near the bottom of the air lift.

The air lift assembly is then raised to a position a few feet higher and the same operations are repeated. In this way, the entire length of the screen is developed a few feet at a time. The air lift should finally be lowered to its original position near the bottom of the well and operated as a pump to clean out any sand that has accumulated inside the screen.

The well driller doing this work varies the procedure in detail so that the surging and pumping are done to best advantage in each well. There is no fixed routine which can be substituted for the drillers' skill acquired from practical experience.

Over-Pumping

The simplest method of removing fines from the water-bearing formation is by "over-pumping". Over-pumping means pumping the well at a higher rate than it will be pumped when it is put in service. This has some merit, because any well that is capable of being pumped at a high rate can be pumped at a lower rate without much danger of trouble.

There are objections to the method of development, however, which are commonly overlooked. Over-pumping may leave some of the sand grains bridged in the formation and thus only partially stabilized, and over-pumping often requires the use of high capacity pumping equipment that is not always conveniently available.

It may be a simple matter to over-pump in small wells or poor aquifers, but where a large quantity of water must be pumped, it may be difficult to obtain equipment of ample capacity at reasonably cost. The pumping equipment intended for regular use in the well is sometimes employed for over-pumping. Depending upon the type of pump, this may be accomplished either by driving the pump at a higher speed, or allowing the pump to discharge at the surface at a lower pressure than the normal operating pressure.

There is one serious objection to performing this work with the permanent pump. If considerable sand is being pumped with the water, the pump will be subjected to excessive wear, which reduces its efficiency. Under severe conditions, it is possible that the pump may sandlock. Should sand-locking occur, the pump must be pulled, disassembled, and cleaned carefully before being placed back into service. Over-pumping by itself seldom brings about best results or full stabilization of the aquifer.

Back-washing Procedures

The surging effect or reversal of flow required to develop the formation can be produced by three or four backwashing methods. One method consists of alternately lifting water to the surface by pumping, and letting the water run back into the well through the pump column pipe.

About the only type of pump, besides the air lift, that can be used practically for this purpose is a deep well turbine pump without a foot valve. The pump is started, but as soon as water is lifted to the ground surface, the pump is shut off. The water in the column pipe then falls back into the well. The pump is started and stopped as rapidly as the power unit and starting equipment will permit. The effect is to intermitently lower and raise the water level in the well, which produces inflow and outflow through the screen openings.

During the procedure, the well may be pumped to waste from time to time to remove the sand that has been brough in by the surging action.

The method described here is often called "rawhiding" the well. Some wells respond satisfactory to it, but the surging effect is not vigorous enough to obtain maximum results in most cases.

The results from a 12-inch well in Illinois provide a striking example of this situation. The 12-inch casing was driven to 211 ft, a 15 ft. long well screen with No. 60 slot openings was installed and the 12-inch pipe was pulled back to expose the screen in a coarse sand formation.

The static water level was at 15 ft, a turbine pump was set in the well, after a few cycles of starting and stopping, a yield of 50 gpm with 160 ft drawdown was obtained.

This appeared to be ineffective, so the pump was removed and the well was developed by surging and bailing. A 24-hour pumping test then gave a yield of 1,000 gpm with 51 ft drawdown.

Care must always be taken not to work too rapidly, because of the danger of sand-locking the pump. Pumping should be started at reduced capacity, and gradually increased to full capacity before beginning the surging operation.

Where the static water level is high enough to permit pumping by suction lift, another backwashing scheme can be set up, using a portable centrifugal pump which can take water from the well and recirculate it inside the well. The pump can be the common type used on construction jobs. A string of pipe let down in the well to about its full depth is connected to the discharge of the pump. Water is then pumped from the well and circulated back into the well inside the screened section. The turbulence thus created inside the well screen assists in developing the well.

High-Velocity Jetting

Jetting with water at high velocity is generally the most effective method of well development. This method has the following prime advantages:

1. The energy is concentrated over a small area with correspondingly great effectiveness.
2. Every part of the screen can be covered selectively, and if well screen openings are closely spaced and correctly shaped to direct the jet stream out into the surrounding formation material, complete development is achieved.
3. It is relatively simple to apply and is not likely to cause trouble from over-application.

A relatively simple jetting tool, together with a high-pressure pump and the necessary hose and piping, are the principal items of equipment needed. The forceful action of high velocity jets working out through the screen openings agitates and rearranges the sand and gravel particles of the formation surrounding the screen. The wall cake deposited on the borehole in the conventional rotary method of drilling is effectively broken up and dispersed so that the drilling mud can be easily pumped out.

The jetting action will also correct the damage to the formation resulting from any of the other methods of drilling.

The procedure consists of operating a horizontal water jet inside the well in such a way that the high velocity streams of water shoot through the screen openings. By slowly rotating the jetting tool and gradually raising or lowering it, the entire surface of the screen gets the vigorous action of the jet. A swivel is a convenience. Also, a clamp with a handle for turning the pipe should be provided. Screen openings of proper design permit the jet to do its work.

Fine sand, silt and clay are washed out of the water-bearing formation and the turbulence created by the jet brings these fine materials back into the well through screen openings above and below the point of operation.

Where possible, it is highly desirable to pump the well lightly at the same time that the high velocity jet is working. This is not practicable, but should be done where the size of the well, the available equipment, and the position of the static water level in the well permit.

In operation, the jetting procedure adds water to the well at a rate depending upon the size of the nozzles and the pump pressure. If more water is pumped from the well than the volume of water added by the jetting, the water level in the well will be kept below static level and some water will move from the formation through the well screen as the work proceeds. The movement of water into the well helps remove some of the material loosened by the jetting.

An added advantage of pumping is that the water removed from the well provides a continuing supply that can be recirculated through the pump and jetting equipment. Fine sand pumped from the well can be settled out in a tank or in a settling pit to avoid damaging the high pressure pump or the jetting nozzles.

The equipment required for jet development includes a jetting tool with two or more nozzles, high pressure pump, high pressure hose and connections, string of pipe, and a water tank or other water supply. A pump or air lift that will pump water from the well while the jetting is under way should be added when conditions permit its use.

A jetting tool is simply a piece of pipe with nozzles that eject water at right angles to the well bore. If two nozzles are used, they should be 180 degrees apart, three should be 120 degrees apart, and four should be spaced at 90 degrees, thus hydraulically balancing the unit during operation. Best results are obtained if the nozzles are designed for maximum efficiency, but straight drilled holes in a plug or cap will ordinarily be acceptably effective ive.

The size of pipe should be large enough to keep friction losses to a reasonable level. The sizes most generally used a 1½ inch standard pipe for pumping rates up to 50 gpm at depths to 100 ft, or 35 gpm to 200 ft; 2inch pipe up to 100 gpm at 100 ft.or 75 gpm at 200 ft; and

3-inch pipe up to 300 gpm at 100 ft., or 200 gpm at 200 ft. Use of these sizes will hold friction losses within acceptable limits.

The lowest velocity at which such a jet may be considered effective is about 100 ft per sec. Much better results can be expected when the pressure is increased to produce velocities of 150 to 300 ft per sec. Very high velocity may not result in sufficient additional benefit to pay for the added cost. Velocities obtained by using pressures higher than about 500 psi may cause some abrasion, particularly in brass sections.

Gravel-Packed Wells

When a well is drilled for artificial gravel packing, a thin skin of relatively impervious material is plastered on the wall of the hole as has been described. When the gravel has been placed around the well screen, this skin or wall cake becomes sandwiched between the gravel and the face of the natural formation. The principal object of the development work is to break up and remove this material that is caught between the gravel and the wall of the hole.

No matter what method od drilling is employed, the thin layer of material sandwiched at the outer face of the gravel pack must be removed. The presence of the gravel envelope creates some difficulty in accomplishing this job.

The thickness of the gravel pack and the grading of the material used for the gravel pack both have a considerable effect on what can be done by development to bring the well to maximum efficiency.

Surging operations are less effective than for wells that are designed for natural development. One of the reasons for this is that a properly-designed gravel pack is so permeable that there is more tendency for water to slosh up and down in the gravel envelope rather than to move into or out of the natural formation at places where it may be partially clogged. The thinner the gravel pack, the surer the driller can be of removing all the undesirable fine sand, silt and clay in the developing well. Polyphosphate dispersing agents effectively assist removal of the silt and clay.

Patience, intelligent observation and the right tools are required to complete a screened well correctly, whether it be naturally developed or artifically gravel-packed. Well development is not expensive in terms of the results that can be obtained. Proper development will improve almost any type of well.

Rock Wells Need Development

Drilling operations also cause some plugging of fractures and crevices in hard rock formations The action of the bit chips and crushes the rock and mixes it with water and other fine material to form a slurry that can be picked up with the bailer. The pounding of the bit forces some of this slush into the openings in the rock outside the borehole.

Any material that clogs the openings in the rock aquifer must be removed by development work. The full yield of the formation can only be realized if all the fractures and crevices can feed water freely to the well. Pumping alone sometimes pulls out the remaining slush since the openings in rock formations are likely to be large as compared to the pores in a sand formation. However, many drillers have found it desirable to use surging methods and other means of development of rock wells in order to bring them up to maximum capacity.

Explosives Used

Explosives are sometimes employed to shoot rock wells as a means of trying to develop greater capacity in a new well. The practice has shown good results in a fair percentage of cases. Because of the many unknown factors, however, it is difficult to tell in advance whether the shooting operation may produce beneficial results.

Charges of 30 to 500 lb are generally used, the size varying with the hardness of the rock to be broken and the depth at which the charge is to be detonated. Since the water pressure increase with depth, heavier charges must be used at the greater depths to overcome the confining effect of the greater water pressure. There is considerable difference of opinon as to the relative effectiveness of different sizes of shots. Some drillers say that it never does any good to use less than 200 lb in a single shot. Others think that a succession of lighter shots gives better results on the average.

Acid can be used in the development of wells tapping limestone aquifers. Acid dissolves limestone, and this action opens up the fracures and crevices in the formation around the open borehole- the intake portion of this type of well. This permits fine particles that may become lodged in the rock openings to be removed readily when water is bailed or pumped from the well.

Pumps:

When a well has been completed and it is believed that there is sufficient water available then the choice of a pump to extract this water must be made.

The pump in a well or on the surface has several functions other than moving the water out of the well. It must supply the force to move it to where it is needed and be able to force its way say into a hot water tank for heating or to being forced at high velocity out of a hose to fight a fire.

The pump to work needs an input of energy whether from a human arm and shoulder to operate a hand pump to a large electric or diesel engine for a centrifugal pump to irrigate a field.

For our purpose in well drilling in bores of 150MM to 200MM we are concerned generally with a modest variety of pumps.

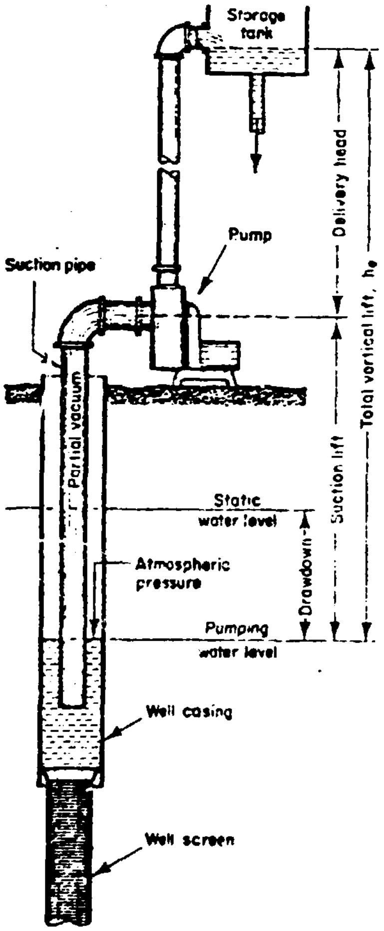
The Piston pump for hand operation is well known. One of the more recent developments have been improved types made in the Philippines and India. The major improvement has been made in steel fabrication in place of cast iron. Also new bearings and the use of rolled threads on piston rods have improved durability. It would be beneficial for new programmes involving hand pumps to contact UNICEF, New York, U.S.A., for their vast knowledge of hand pumps and installations. The Sholapur pump of India is an excellent example of experience and skill being applied to produce an outstanding pump.

The Piston pump are suitable for domestic use and small volumes. The most important pump for large wells are the centrifugal types in several forms. The simplest and for shallow wells based on a suction type lift has a range of only up to say 6-7Meters of actual lift from the water surface to the pump impeller. The variations of this type include the major power pumps namely turbine and submersable.

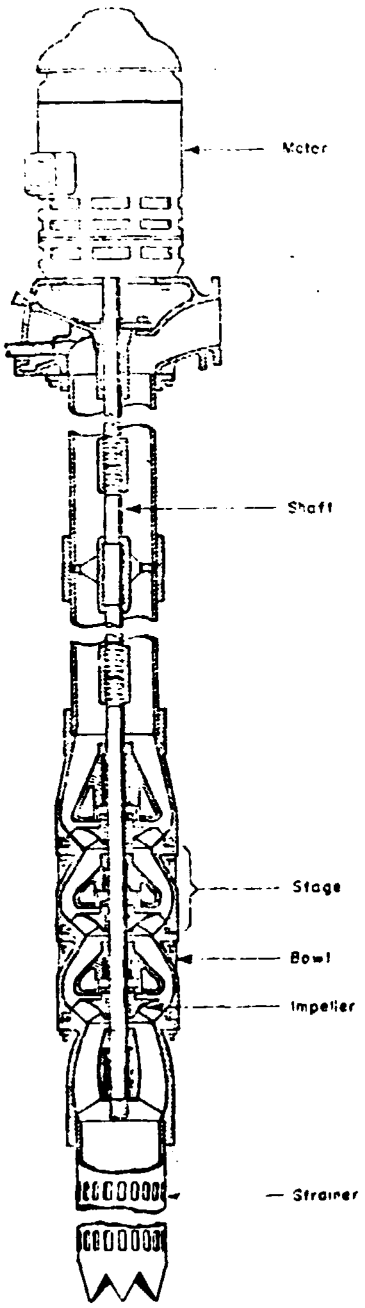
The Jet pump is a specialization of the centrifugal concept in that the energy put into water by the centrifugal pump is utilized by the eductor to transfer the motive power to more water than is pumped by the centrifugal. The eductor is a non mechanical medium in the bottom of the well and needs no maintenance or attention generally. The jet pump is ideal for domestic use and small volumes of water. There is one limitation in that two pipes plastic or otherwise are inserted in the well bore.

The Submersable pump is a recent development. It basically is an electric motor directly coupled with a series of impellers of a centrifugal pump. Although designed over 60 years ago it has been an accepted reliable pump for say 25 years. Increased use has been due to the improved electric motors, electric cables, and efficient water-tight seals.

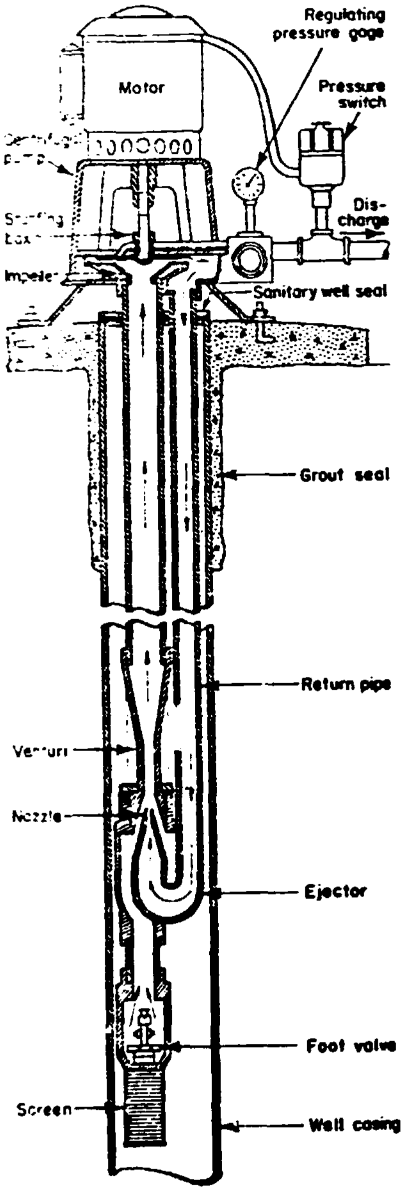
They are now manufactured with capacities in hundreds of horsepower and operating in depth of 200 meters and at capacities of over 20 atmosphers. The advantage of this type is the elimination of the long drive shafts of the turbine pump mentioned later. The elimination of bearings for the shaft and a pumphouse and the elimination of problems due to deflection [illegible]



PRINCIPLES OF PUMPING A WATER WELL.



THREE-STAGE LINESHAFT DEEP WELL TURBINE PUMP.



JET PUMP

deviations in vertical alignment of a well. In developing areas the submersable pump is ideal as there is little that can be tampered with. The electrical switch gear should be protected both electrically from low voltage to single phasing and also with low water cut off and of course, vandalism.

The Turbine pump for deep wells in particular when high volumes and isolation from an electrical source are very popular. The power unit can be driven by a right angle drive gear at the top by "V" type belts or direct drive either by diesel or electric motor. The best application for electric is the vertical hollow shaft motor made for these pumps. The bowl assembly which contain the impellers are immersed in the water so losses are minimal and each unit can be built to suit the particular needs of the well and user. Turbine pumps should be designed specifically for each situation for maximum efficiency. This makes them expensive and sophisticated. They are excellent for very large volumes of water however.

Selecting a pump or determining the specifications, requires the collection of a great deal of data on the well, its size, its function, quality of water, and the basic dimensions of the water resource, and consideration of the variations in this resource and future needs.

Location and operating conditions may greatly affect the selection of a pump for reasons of available power, temperature, protection from weather, contamination from outside sources, and abrasion of water contaminents. All these details must be available for the competant pump supplier to make the correct choice of equipment.

NOTES ON DRESSING AND HARDENING DRILLING BITS

The treatment of steel bits supplied for well-boring outfits is a subject to which operators should give great attention. The bits themselves form large heavy forgings, which cannot be handled with too much care when dressing and hardening if they are to give good service.

There are five cardinal points which should be carefully observed when dressing and hardening bits to obtain the best results in the field.

1. The Temperature to which the forging should be raised for dressing.
2. The Time taken to bringing the forging to the temperature for dressing.
3. The Temperature at which dressing should cease.
4. The Temperature to which the forging should be allowed to cool before reheating for quenching.
5. The Temperature to which the cutting edge of the bit should be raised for quenching to give the required hardness.

It is most important that bits, when being dressed should not be raised to temperature ($2,200^0$ F. or $1,200^0$ C., bright yellow) too rapidly, and the following table gives the approximate minimum time which should be taken to bring the bits up to this temperature:-

5^{3}/16" bits	(132 CM)	1.5 hours
6^{5}/8" bits	(1.68CM)	2.0 hours
8¼" bits	(2.10CM)	2.5 hours
10" bits	(2.54CM)	3.0 hours
12½" bits	(3.18CM)	3.5 hours
15½" bits	(3.94CM)	4.0 hours

Large bits would take proportionally longer time up to 24-in bits, which would require seven hours to bring up to temperature.

The above times are suggested by the Bridgeport Tool Co., U.S.A. and Mr. Sprang of that country gives a formula of one hour per inch of thickness to the centre of the section, which practically agrees with the Bridgeport times. It is suggested that these times should not be reduced to less than half under any circumstances. Emsco Engineering Co. give in their instructions for dressing bits twenty-five minutes for heating 6-in. bits. This appears to be low for this size of bit, and edge burning will occur through trying to push the heat. English Drilling Equipment Co., from actual times taken in the field, give forty-five minutes for the first heating of a 6-in. bit. The total time taken to dress and harden the bits was 120 to 140 minutes. The first heating appears to be rather less than the minimum time suggested by the American makers. Too much care cannot be given to the question of heating the bits when dressing them, if long and useful life is going to be obtained from the tool.

Steel starts to lose its carbon content at $2,000^0$ F., but at this temperature it is hard to spread, so a higher temperature, as stated above, is given as the best working heat. Heating above $2,200^0$ F. will cause a rapid loss of carbon, and should be avoided. It may also be observed that steel may lose its carbon without showing signs of burning. Loss of carbon means that the bit will be softened, therefore overheating or burning should be avoided. There is no way of correcting the decarbonisation of steel other than by cutting off the decarbonised portion. When cutting bits, it must be done under the hammer and never by the torch.

The time taken in heating the bit is not time lost, as the correct heating and uniform dressing will result in a better hardened bit, which will drill more hole and run longer. Rapid heating, on the other hand, makes dressing more difficult, more frequent heatings, and the possible cracking of the bit.

Bits should never be dressed after the heat has fallen to Dark Red, as below this temperature hammering tends to refine the surface of the steel, and causes small pieces to chip off after hardening, as well as giving a false impression of the hardness.

When the bit is dressed to the required shape, it should be allowed to cool to a temperature of 900^0 F. (580^0 C., dark blue) before reheating for quenching. If the steel is reheated at a higher temperature the coarse grain of $2,200^0$ F. is retained, which will give an apparent hardness, but the wearing quality will not be the same as a fine-grained steel.

After the bit has been cooled down, as above, it can safely be put into the furnace and raised slowly to the quenching temperature of 1,450 to $1,500^0$ F. (800^0 C.).

When this temperature is reached, a little salt sprinkled on the bit will melt and give the bit the apperance of being wet. When this temperature is reached, the bit should be allowed to soak in the furnace, with the temperature held for three-quarters to one hour to give the correct penetration and hardness. If this temperature is not exceeded the grain structure will not change and a good fine-grained cutting edge will be obtained. Before quenching, all the scale should be removed from the steel or it will not harden properly. The quenching tub should be sufficiently large not to allow the water to get too hot. The bit should be lowered vertically into the tub until the cutting edge is 2 to 3 in. immersed, or just over the wearing edge of the bit. The bit must not be moved about when in the quenching tub, or the water splashed above the immersed portion, otherwise surface cracks will be created which may cause splitting of the bit.

It is advisable to have a stool in the bottom of the tub to prevent the bit being immersed too deeply.

These notes refer to bits of average quality carbon steel, and when special steels are used, the makers' instructions for treatment should be very carefully followed.

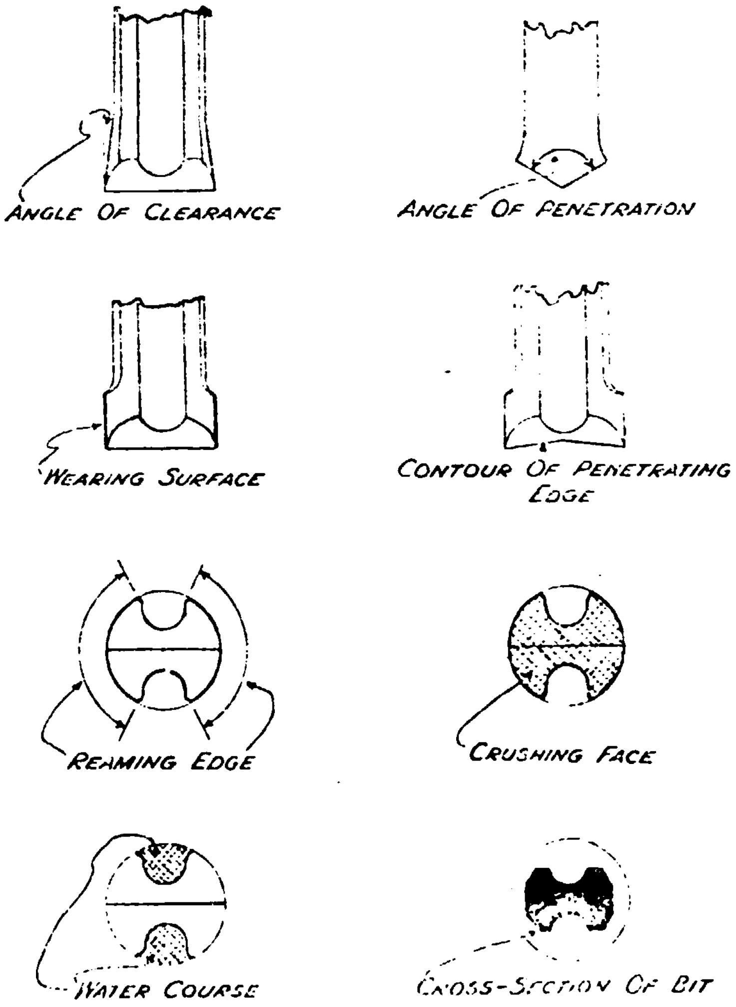
DRESSING DRILLING BITS

To assist those who may be interested in the dressing of drilling bits, the following notes may appeal.

It is impossible to lay down definite rules for the dressing of drilling bits, as conditions vary considerably, but a few general observations on the subject will assist in understanding the requirements of the driller and his difficulties.

The points to be considered when dressing bits are: angle of clearance, angle of pentration, wearing surface, reaming edge, area of crushing face, area of watercourse, contour of penetrating edge, corss-section of drill.

The sketches in Fig.12 illustrate the various terms used above.



Drilling Bit Terms.

Fig. 12

The shape of the cutting end of the bit depends on the formation which has to be penetrated, and the cases below will serve as a general guide.

Drilling Bits for Air Percussion Drilling:

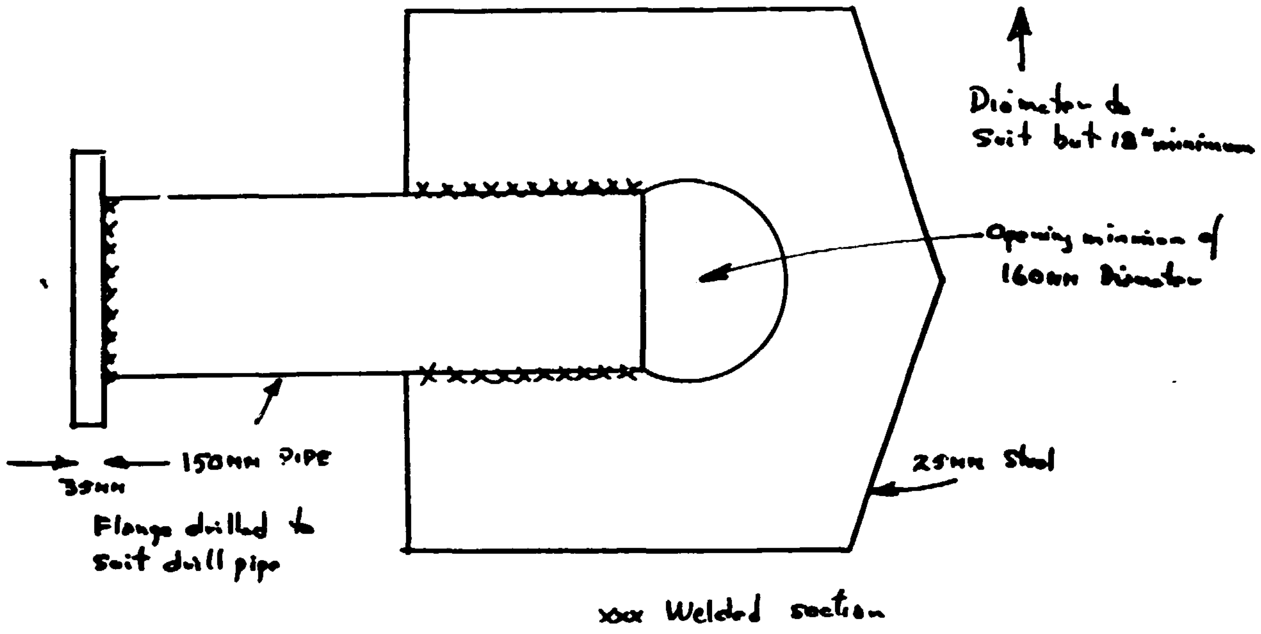
There are two basic types of drilling bits used and they are called (1) the carset pattern and (2) the button bit. The carset bit is the one that has been in long term use and follows closely on the design of bits used in the mining industry and formally in the cable percussion method of drilling. This is a cross-pattern bit where the air is exhausted through the bit into ports, one in the center bottom of the bit and the others in the sides. These bits are sharpened by the use of a silicon carbide or commonly called green grit grinding wheel and, as all the rigs are operated by compressed air it is possible to use air grinders to grind the bits to the original very blunt chisel shape. One of the particular requirements of sharpening these carset bits is to maintain the gauge in the hole, in other words the diameter of the bit has to be consistent with the hole diameter. It is not possible to put an oversize bit into a hole that has been drilled with an undersize bit. The other type is called the button bit, and is a much newer development and has many unique qualities. First it is much more durable and has much more life or drilling footage in it than the conventional carset bit. The carset bit is prone to break because of the turning action in the hole, whereas the button bit is much more sturdy and rigid and the buttons themselves are generally smaller. These bits can be sharpened quite easily, again with the same air grinder as the carset bits and again those bits that are on the perepheral edge of it will govern the gauge or the diameter of the hole to be drilled. Those two basic bits are similar in drilling capabilities, one lasts slightly longer and now is replacing the carset bit in the trade. Those are the two basic types of bits. They range anywhere in size from the small 4½ diameter bit which is used with 4" hammers which has really a very limited application in the water well business because there are few submersable pumps available that can be effectively used in this type of well. The standard bit is without exception, 6" in diameter or slightly larger. The 6" fits most available submersable pumps and is the popular one to use. When you are driving casing into a rock well, to have a sanitary well to eliminate surface contamination it is sometimes wise to drill a 6 5/8 to suit 6" pipe. For drilling larger holes than 6" by the air percussion method up to approximately 12 to 15" diameter can be performed by drilling a 6" hole to start with then following it up with a reaming type of bit that uses the 6" bore as a pilot and first reams out to say 8 5/8" to 9" and to follow us with larger button or carset reamers. The major requirement will be to clear these wells of the cuttings and this will involve a large volume of air. 900 to 1200 cubic feet would not be an unreasonable quantity for even an 8 5/8" hole.

The other basic part of this down the hole drilling are the hammers themselves. This is very sophisticated durable piece of equipment and will last for many many hours. But there are parts in it that do wear. The hammer itself can breakdown. The bit retainers themselves crack and fall out and it is important that this does not happen. When there is a bit in the well because it is possible to lose the bit and the bits and pieces of the retainer in the well too. Also, the cylinder can wear and these are all replaceable items and it is well to have a good stock of them on hand for a drilling operation. One modification that can be made to a hammer, in particular,is to braze onto the very top of the hammer next to the joint at the outside perepheral, a tungsten carbide powder, coarse particles of carbide brazed onto the top of the hammer so that it can be used as a cutting medium to back the drill out of the hole. There are times when rock particles fall in on top of the hammer particularly when there is a change of a drill rod and there is no cleaning the hole out and sometimes it is very difficult to pull the hammer out and you might have to drill out to recover the tools. There is one commercial product called Drill Tek that can be brazed and it makes it possible to drill out considerable distances and to salvage a well as well as tools.

In some countries, it is not very economical to rebuild any of the hammer bits in particular, but it is recommended to seriously examine the possibility of rebuilding these bits. Both carset and button bits. Particularly, in areas where foreign exchange is a problem. In an area where it is difficult to get import permits, because only a few countries make these bits, it is possible to rebuild them. Basically the carset bits are repaired by heating up the whole bit so that it is red hot and the silver solder melts out and then you can take the carbides out and it is wise to salvage all the silver. The carbides can be removed and again shimmed up with the pieces of copper wire and that in turn the carbides can be reversed and put out to the right correct gauge that is in diameter and then you can build what we call gates around each carbide with welding on thin steel plates. With the carbides inserted into the originally pockets supported with thin copper wire, and covered with flux, the silver solder can be again used in the same place as it was removed with some additions, of course, by heating up with large actylene and oxygen, or propane and oxygen torches so that the solder melts into the bit, melts onto the carbide and securely bonds it, and after the four carbides are brazed in and then these thin metal gates on the outside can be ground off and the bit sharpened in the standard conventional method. It is reasonable to assume that you could get another 75% of drilling footage on a rebuilt bit in the carset pattern. For button bit it is wise to power hacksaw off the end of the button bit, 25MM or so and drill new holes and if you do want to do them as a manufacturer does, which is ream the hole and use centerless ground carbides and they are then press fitted in, but possibly the best way for a field operation would be to drill the holes and braze the buttons in with silver solder. Silver solder is available in most parts of the world, with a good borax flux and a good acetylene torch it is possible to rebuild even buttom bits so that they would have a longer life. A great deal of encouragement is needed to overcome the sales promotion that those bits cannot be repaired. Where wage costs are low in comparision to the high cost of the drill bits it is reasonable to repair them. The outstanding example is in India near Hyderabed where bits are rebuilt and approximately 50% of all bits used in India are locally rebuilt.

Bits for Reverse Circulation Drilling:

Most bits for this reverse drilling are fabricated by the machine operators to suit the particular needs of the formations and diameter. Pipe the same diameter and wall thickness of the drill pipe is generally used with an opening in the bottom of the pipe as per sketch.



The material used is plain mild steel plate of 25MM thickness and is often hard faced at the cutting edge by electric welding.

For cemented gravels and hard laterite formations, it is now possible to drill them with "Alaska" type auger bits with replaceable carbide inserts bolted to the cutting surface. Although they are expensive initially they are effective in drilling through hard formations.

Appendex B

THE COSTING SYSTEM OF POWERED EQUIPMENT AND DRILL RIGS OF VARIOUS SIZES

(1) In drawing up this costing system necessarily includes a number of estimates and assumptions (without which it could not be operated). Costs based on these could however be misleading unless provisions were made for a continual watch to ensure that the estimates are adjusted in the light of actual values.

(2) Attention is also drawn to the wide range of other data available from the operation of the costing system such as this, e.g., comparision of operating time and idle time (and analysis of the latter by cause), fuel consumption of each type of unit.

(3) This costing system appears to lend itself to modification in accordance with different sets of economic conditions.

A. Cost per hour, other than administration is composed of:-

The estimated irreducible costs based on the number of operating hours per year.

Annual interest, averaged

Insurance premium per annum (third party, five etc.)

Motor tax where applicable

Storage or garaging cost per annum

For purposed of comparision 10 percent for large units or 5% for small motorized units of half the purchase price (Identified by the coding A) may be taken as an estimate of (a) above except for annual interest which must be actual.

This total divided by the total number of hours will give the estimated irreducible cost, per hour.

B. The estimated depreciation and repair costs:

(1) Depreciation calculated as follows. Purchase price of the unit divided by the estimated total operating life of the unit.

$$\text{or } \frac{A \text{ (estimated irreducible costs)}}{H \text{ (life time of the unit)}}.$$

Since in the case of tractors and wheeled units the life of the motor and chasis exceeds that of tires and or tracks and undercarriage. The depreciation may be calculated in two parts, viz. motor and chasis, tires and track or undercarriage. In each case the purchase price is to be divided by the corresponding number of operating hours the sum of of the two resulting figures representing the depreciation per hour.

(2) Estimated cost per operating hour for repairs expressed as a fraction (v) of the depreciation per operating hour, this fraction being assessed according to indices based on experience.

Special conditions in determining depreciation and repair cost, when operating hours of a unit are lower than established in Table I (appended) The depreciation must be calculated differently than above. This is due to the fact that the unit loses value not only through wear and tear but by becoming out of date. The depreciation is taken then to be;

$$\frac{\text{purchase price of the unit}}{\text{life until absolete x establishment annual operating hours/kilometers}}$$

$$\text{or } \frac{A}{N \times J}$$

In the case of the repairs the formula is as follows:

$$\frac{\text{purchase price of unit} \times \text{life until absolete} \times \text{estimated annual operating hours} \times \text{cost of repairs per operating hr as a fraction of depreciation per operating hour as seen in Table I.}}{\text{standard life x standard life}}$$

$$\text{or } \frac{ANJR}{H^2}$$

A simplication of above may be as follows: A minimum depreciation say 1 percent of purchase price per month-may be fixed, the normal fraction $\frac{N}{H}$ in table I for repairs may be used (Recommended by Caterpillar) Tractor co.in developing countries TEQ80003)

C. Unit or machine costs directly incurred when working.

1. Cost per operating hour for gasoline or diesel oil consumption.
2. Cost per operating hour for lubrication of engine transmission hydraulic systems estimated at 20% of fuel costs above.
3. Additional costs for maintenance and cleaning include necessary cleaning materials (estimated at 15% of operators normal wage per hour)

D. Wages and Associated Expenditure

(a) Wages per hour of the unit operator

(b) Health insurance housing allowance or housing

(c) Fring benefits e.g. special travel allowances, etc.

This sum of B C and D represent the variable costs per operating hour/kilometer. The costs of operating hour consists of ABCD above give the average cost of operation per unit. However, this does not include the costs of moving the equipment to a working site or any of the service facilities that might be required e.g. transport of fuel to work site. For convenience, an estimate of 10% of the average cost of operation per hour (ABCD) would be suitable if a daily transfer was required.

Note: In the explanatory comments is an example of how a calculation is prepared.

Resource Material for Preparation of this Paper:

Hand Book on Ripping	Caterpillar Co.
Basic Earth Moving Costs	Caterpillar Co.
Highway Engineering Handbook	Wood McLaw Hill
Agriculture Engineering Handbook	Ritchie McLaw Hill
Ford Tractor Manual	Ford Motor Co.
Costing System for mechanical equipment	FAO Rome

Type of Unit	Estimated Number of Operating hours in Life time joint	Life of machine until technically Out-of-date	Cost of Repairs per Operating hour expressed as a fraction of depreciation per operating hour
Cable Tool Rigs:	20,000	20	0.6
Petrol Engine-	5,000	4	1.0
Diesel Diesel-	8,000	5	0.9
Air Percussion Rigs:	10,000	10	0.7
Small(100hp)-	8,000	4	0.9
Large(250hp)-	6,000	5	0.9
Mud Rotary Rigs:	10,000	10	0.7
Small(100hp)-	8,000	4	0.9
Large(250hp)-	6,000	5	0.9
Reverse Circulation:	20,000	20	0.6
Small(50hp)-	8,000	4	0.9
Large(250hp)-	8,000	5	0.9
Compressors:			
Small(50hp)-	8,000	5	0.8
Large(200hp)-	6,000	5	0.9
Trucks:			
3 ton diesel-	5,000	4	0.7
Heavy Duty Truck with rigs mounted on-	5,000	20	0.6
Tractors:			
50-75hp diesel	10,000	10	0.9
Tires for Tractors:	3,000		
Tires for Trucks:	2,000		
Backhoe 75hp-	8,000	5	0.8
Welders:			
25hp petrol-	3,000	5	1.0
60hp diesel-	8,000	5	0.9
Pumps:			
hand-	5,000	20	1.0
electric, small	20,000	20	0.6
Turbine pumps:	20,000	10	0.7
Submersable pumps:	20,000	10	0.6
Trailors, unpowered:	16,000	10	0.6

Appendix C
Requirements for a typical
Cable Tool Percussion Drill Rig
Trailer Mounted

Basic Rig: To drill 150MM and 200MM holes. Joint size, 2" x 3" API 7 threads. 3 1/4" wrench collar. 4 1/4" pin collar. 4 3/8" box collar.

Drilling Tools:		Weight/Kilos
1 only	Swivel wire line socket complete with 5/8" swivel for wire line.	40
1 only	Extra swivel for above	2
1 only	Wire line cover with 2 3/4" neck.	2
1 only	4 3/8" drill jars	100
1 only	4' x 16' drill stem	300
2 only	Alloy 6" drill bits	220
1 only	Alloy 8" drill bits	270
1 only	4" drill gauge	2
1 only	6" drill gauge	2
1 set	Tool wrenches cast steel claw handle 3 1/4" wrench squares	50
1	Wrench bar with chain for above	5
1	Bailer link quick change	2
1	4 1/2" x 14' Dart valve bailer	50
1	4 1/2" x 6' Chickering sand pump	25
1 set	Drive clamps, 3 1/4" wrench squares with bolts and wrench.	50
1	Outside drop drive head 150MM pipe	35
	Inside drop drive head 200MM pipe	45
Fishing Tools:		
1	Swivel socket	40
1	Fishing jar, 4 3/8" x 30" stroke	80
1	Fishing Stem, 3 3/4" x 10' long	200
1	Regular wire line bumper for 150MM hole.	100
1	Corrugated friction socket	90
1	150MM full circle slip socket with extra slips for box and pin collars.	125

1	Combination socket for pin and rope sockets	75
1	Latch jack for 150MM	80
1	Center rope spear for 150MM	75
1	Wire line knife	200

Pipe Handling Tools:

1	150MM slotted type pulling plug	30
1	200MM slotted type pulling plug	60
1	150MM elevators cast sled	50
1	200MM elevators cast sled	100
1	Casing ring with slips for 150MM and 200MM	200
2 sets	#34 size chain tongs (for up to 200MM pipe)	30
2	50 tonne hydraulic jacks.	75

Wire Line Outfit:

300 meters 3/8" x 6 x 7 steel sand line	100
300 Meters 5/8" x 6 x 10 mild plough steel drill left lay cable	200
100 Meters 5/8" x 18 x 7 non-rotating casing line	150

Representative Drill Rig for drilling 6"-8" holes in consolidated and non-consolidated formations:

Sanderson Cyclone 36 Cable tool rig, trailer mounted with 4 wheels 4000 kilos

Volume crated about 16 meters cubic

Dimensions 2.62 meter long less derrick
1.8 meter wide
1.8 meter high

Derrick dimensions: 7 meters x 3 x 4 meters

Motor: Diesel, 35 hp
Transmission: 4 speed

Cat Head (2)

Tool Guide: Split bowl type

Spool Device, for cable on bull reel

Capacity:

Depth of hole	Surface	35meters	100 meters	150 meters	200 meters
Maximum weight of tools for 5/8" cable in kilos	600	535	475	420	390