THE STOVEPIPE OR CALIFORNIA METHOD OF WELL DRILLING AS PRACTICED IN ARIZONA

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THE STOVEPIPE OR CALIFORNIA METHOD OF DRILLING WELLS AS PRACTICED IN ARIZONA

INTRODUCTION

The shallow groundwaters in Arizona available for irrigation are found in the unconsolidated valley fills of Recent Geologic Age, consisting of alternate strata of clays, sands, and gravels with some boulders. It is by tapping the more porous of these water bearing strata of sands and gravels that a supply of water sufficient for irrigation purposes is secured.

The first types of wells put down were the ordinary dug wells or pits, sometimes as large as 10 feet in width by 30 feet in length, with plank curbing and framed with heavy timbers. In most cases it was found almost impossible to get these wells deep enough into the water bearing strata to furnish sufficient water for irrigating. Since 1910 a number of wells have been sunk using reinforced concrete caissons as curbs. This type of well has proved to be very satisfactory where the first water stratum furnishes sufficient water, but its use is very limited by this condition.

The drilled well that may be driven to any desired depth, properly perforated to tap the water bearing strata, has proved to be satisfactory. It has the additional advantage that alkaline or other undesirable water bearing strata may be cut off.

The well for irrigation purposes is ordinarily from 16 inches to 20 inches in diameter and from 150 feet to 300 feet in depth. To drill a well of this type, in material consisting of loose boulders, gravels, running sands and clays, it has been found that the California or stovepipe method of well drilling is the most successful. This method was originated in California somewhat over thirty years ago, where conditions, similar to those in Arizona, had to be met.

Strictly speaking, the California or stovepipe method of well drilling is the drilling of wells with a mud-scow using the stovepipe casing forced down with hydraulic jacks. The mud-scow is a hollow drill tool, similar to the ordinary sand bucket or bailer, but it is made extra heavy and is equipped with a heavy steel cutting shoe. It serves both as a drilling tool and as a bailer for cleaning out the hole. In Arizona the drilling is often done with solid tools or a combination of both solid tools and the mud-scow.

CASING

Stovepipe Casing

Stovepipe casing, or double stovepipe casing as it is sometimes called, is made of double thickness sheet steel, of from 8 to 16 gauge, made up into inside and outside joints. These joints are made in two, three and four foot lengths, from 4 inches to 36 inches in diameter, rolled into shape and with vertical single rivetted lap joints. The inside joints are made just small enough to telescope

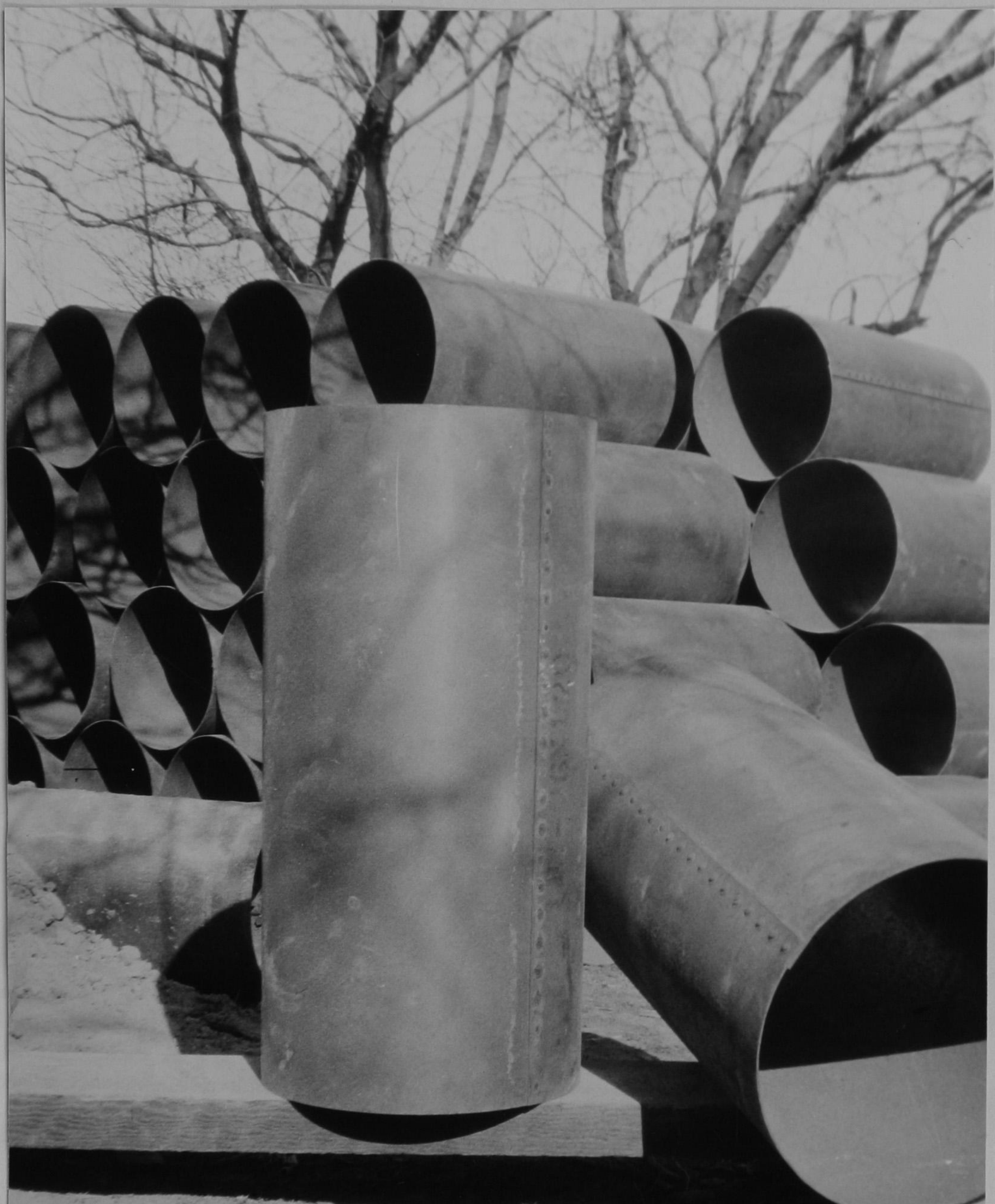


Fig. 1.- An inside and an outside joint of 18-inch stove-pipe casing with a pile of casing in the back-ground.

into the outside joints and make a snug fit. The inside and outside joints are put together over-lapping each other by one-half the length of a joint; thus two inside joints butt together midway from the ends of an outside joint. In Fig. 1 an inside and an outside joint are shown with a pile of casing in the background.

The proper weight of casing to be used, theoretically depends upon the diameter of the well and the depth to which it is to be drilled. The character of the formation in which the well is drilled must also be taken into consideration. If the material is hard and cemented, or full of large boulders, or consists of loose caving gravel the chances are that a very great pressure will be required to force the casing down, in which case heavier casing than ordinarily used is desirable. Practical experience has shown that for wells 18 inches and larger, in diameter, or wells 250 feet or more in depth, 10-gauge casing should be used. For wells 16 inches in diameter and less, up to 250 feet deep, the 12-gauge casing has been found satisfactory. In cases where the life of the casing must be taken into consideration it may be cheaper to use the 10-gauge casing although drilling conditions will permit the use of lighter weight. For small diameter wells the 14 gauge casing is sometimes used.

In general, wells put down for irrigation purposes are not less than 12 inches in diameter. High capacity turbine centrifugal pumps are, as a rule, more efficient in types with large diameter bowls, and for this reason wells of 24 inch and 26 inch diameter are in many cases put down. Mention should be made here that several large pump manufacturers are now building high capacity propellor axial flow turbine pumps which require no larger than 16-inch casing. Another system is to use 24-inch casing down to the depth at which the bowls of the pump are to be set and from there on use only a 12-inch or 16-inch. Oftentimes when starting a well in new territory,where it is not known how far a single string of casing can be carried,the hole is started with a large casing so that it may be reduced later on to a smaller size. In some territory it is known that a single string of casing can only be forced to a certain depth, so the starting size is always large anough that it may later on be reduced.

In describing stovepipe casing the weight or thickness is specified by the gauge of the sheet steel, the inside diameter and also the length of joint desired are given. Table I gives the weightsper foot of stovepipe casing of various diameters and thickness.

TABLE I. WEIGHTS PER FOOT OF DOUBLE STOVEPIPE CASING

Diameter of casing	Gauge of Casing				
	16	14	12	10	8
In.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
6	8.6	10.7	15.1	19.3	----
8	11.2	14.0	19.6	25.3	----
10	13.9	17.4	24.4	31.3	----
12	16.3	20.7	29.0	37.3	----
14	19.2	24.1	33.7	43.3	55.0
16	21.9	27.4	38.3	49.3	62.0
18	24.7	30.9	43.2	55.5	70.0
20	27.3	34.1	47.8	61.5	78.0
22	29.9	37.4	52.3	67.3	85.6
24	32.5	40.7	57.0	73.2	93.0
26	----	----	62.5	80.5	98.5

If additional casing is needed to complete a well it should be secured from the same manufacturer as that already in the hole. It is sometimes found that there is enough difference in size between the casing of two manufacturers that they will not fit together. For this reason also the weights of stovepipe casing may vary somewhat from those given in Table I.

Stovepipe casing is not water-tight when first put together, but after standing in a hole for some time rust is formed and silt and clay also gradually work into any openings so that it does become practically water-tight.

Specials

Specials are inside or outside joints made either longer or shorter than regular joints. They are often called just "longs" or "shorts" and are used when a difference in length of the inside and outside casing joints causes the horizontal butt joints between the casing to creep together. They are often made in the field by cutting off 5 or 6 inches of the end of a regular joint with a cold chisel and finished off with a file.

Sections

Built up lengths of stovepipe casing in which the inside and outside joints are rivetted together are called sections. They are made to order in any length specified and the cost is about 10 percent more than for ordinary casing. The use of sections effects a saving of time in putting together the string of casing when starting a hole in the bottom of a pit that has already been dug, for the casing must reach up to the ground surface. They are used for the same purpose when the size of the hole is reduced in starting the second and smaller string of casing inside the first.

Adapters

In wells in which two sizes of casing have been used an adapter may be set down in the well over the top of the inside casing when it has been cut off. Often in the process of cutting off the inside casing the top joint left in the well springs out of shape or is knocked to one side. The adapter helps to keep it in shape and also center it, and in addition serves as a funnel to direct objects into the lower casing.

A type commonly seen in Arizona is made of single thickness rivetted sheet metal of the same gauge as the casing. It is made in the shape of a double funnel with a short, straight section in the center about 1 foot long, and the same diameter as the inside casing. The two ends are slightly less in diameter than the large casing and taper down to the short center section in about three feet. The overall length of an adapter of this type is approximately 7 feet.

Adapters are often made up according to the ideas of the individual driller to fit special conditions.

Starters

The starter consists of a specially built-up section of 2, 3 or 4-ply casing which is rivetted to a properly recessed steel drive shoe or well ring. The built-up section is made of the same gauge sheet steel as the casing and may consist of only 2-ply casing or of both the 3-ply and the 2-ply casing. For shallow wells and where no particular trouble is expected in forcing the casing down light starters are used, made up of only 10 or 12 feet of 2-ply casing. On the other hand, if considerable difficulty is expected in putting down the casing or the well is to go down 400 or 500 feet or more, a heavy starter is required. It may be made up of from 9 to 15 feet of 3-ply and from 6 to 9 feet of 2-ply casing. Sometimes no starter is used but the casing started on the drive shoe. However, in most cases the starter is used as it makes it much easier to start and keep a well straight and plumb.

Well Rings

Steel drive shoes or well rings are made in sizes from 3 inches to 20 inches in length and from 1/2 inch to $1\frac{1}{2}$ inches in thickness, the size depending partly upon the diameter. The sizes most commonly used in irrigation wells are those 10 and 12 inches in length and 1 or $1\frac{1}{4}$ inches thick. The inside of the shoe is recessed for a distance of 6 or 8 inches and to a depth of two or three thicknesses of casing, depending upon the kind of starter used, so that the inside of the starter and shoe form a smooth surface. The starter and shoe are securely rivetted together.

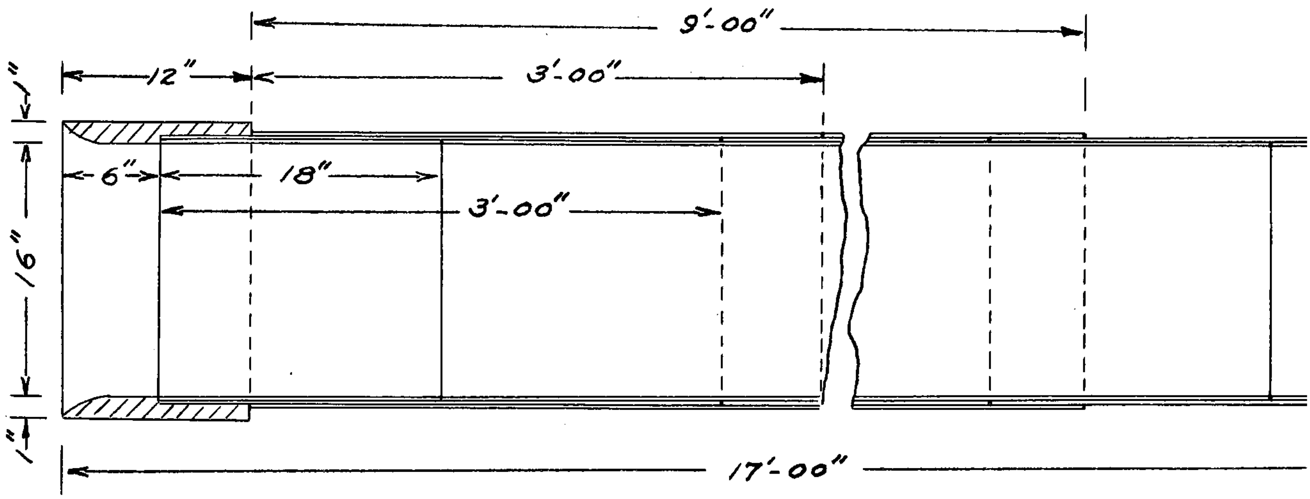


Fig. 2. A three-ply starter and 12-inch by 1-inch shoe or well ring for 16-inch casing.

Starters built up as the one shown in Fig. 2 have been used in a large number of wells near Tucson, Arizona. The wells were drilled in the Recent valley fills consisting of strata of clays, gravels, sands and boulders.

Other Casing

Sometimes single stovepipe casing is used for casing wells. The joints are then put together with single strap rivetted butt joints or with single rivetted lap joints. However, where the expression"stovepipe casing" is used, the double stovepipe casing is always referred to.

For small wells second-hand screw casing or standard pipe is sometimes used when it can be secured at low cost.

DRILLING RIGS

General Features

In Arizona there are in general two types of drilling rigs used in putting down stovepipe casing. The first type includes those rigs similar to the regular California mud-scow rig and the second type the ordinary churn drills put out by many manufacturers. Only portable drilling rigs are considered here, for as a rule they are the kind used for water well work.

The drilling machinery of all rigs is mounted upon a heavy bed frame which is supported on trucks. It is important that this frame be correctly designed and that the sills and cross pieces be of ample size straight grained, clear timber. The rig itself should be so designed that excessive stress is not developed in any of its members while drilling. The drilling rig is subjected to the racking strain of alternately picking up and dropping, from thirty to fifty times a minute, a heavy string of tools weighing between one and two tons.

The engine is usually mounted on the same frame as the rig and in the case of steam rigs the boiler also, except on very large rigs where the boiler is separately mounted. The running of the engine is alone sufficient to impart a continuous vibration to the rig. Practically all the manufacturers of portable drilling rigs now put out machines equipped with gasoline or oil engines. It has been the aim of manufacturers to design a gasoline or oil engine which can be operated under varying loads, with a wide range of speed and which is under the immediate control of the operator. Some manufacturers now claim that their rigs are equipped with oil engines which fulfill these requirements.

So far as drilling alone is concerned most drillers prefer the steam engine to the internal combustion engine. The speed of the steam engine is under the absolute control of the operator. It is more flexible and will carry loads that the gas engine would at once stall under. The steam engines used on drilling rigs are all of the reversible type so that their direction of rotation may be almost instantly reversed.

Under Arizona conditions, however, where the cost of boiler fuel together with the haulage charges on both fuel and water would in many cases be prohibitive, the rig with the gasoline or oil engine is preferred.

California Rigs

The machine shown in Fig. 3 is one similar to those usually seen in Arizona, of the California portable type, and it is to be referred to in the following description, unless some other figure is designated. The running gear is easily detached so that the rig may be lowered onto heavy mud sills, 14 inches by 14 inches or larger and the rear wheels are also lowered to level up the machine. This

Fig. 3.- A California or mud-scow rig of the type most commonly seen in Arizona.

has the advantage of lowering the center of gravity of the whole rig. Other drillers may just support the front end of the machine on two screw jacks taking the weight off the wheels.

The mast is made in the shape of an "A" frame of 3-1/2 inch by 11-inch timber strongly laced and braced, and stands about 36 feet high. In drilling position it is held vertical by two diagonal 3-inch by 5 inch braces from the rear end of the rig frame and by guy wires to the side. In moving position the mast rests in a horizontal position on its hinged supports in front, and upon uprights in the rear.

The distinguishing feature of the California type of rig is the walking beam, which may be of either wood or steel and is pivoted on the top of the mast. The walking beam on this rig is made of two 10-inch, twenty pound channel irons 10 feet long. The pivot bearing is supported by a car spring to take part of the jar and strain off the rig when drilling. The crown pulley is placed on the front end of the walking beam and the rear end is connected to the rig irons by the tail rod. In this case the tail rods are double strength 2-inch pipe, both ends fitted with bearings. A reciprocating motion is given the walking beam by the crank to which the lower end of the tail rod is fastened. A stroke of 12, 18, or 24 inches is secured by changing the position of the crank pin. The tail rods of pipe or wood are most commonly used but sometimes steel cable is used for this purpose as may be seen in Fig. 4. The large rig shown in Fig.5

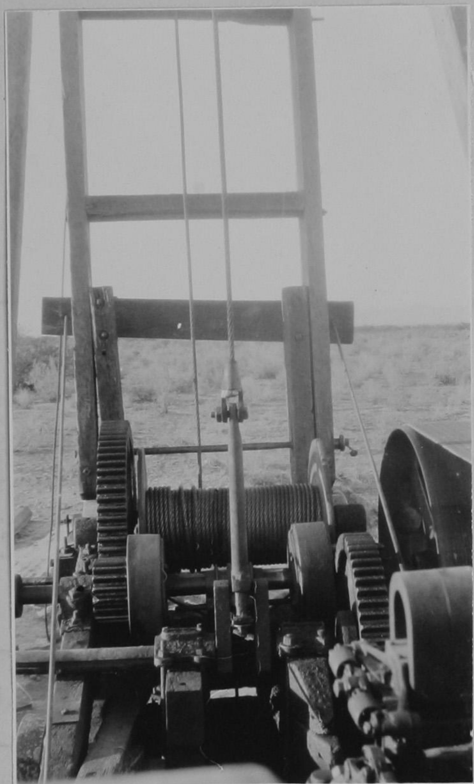
Fig.4.- A small California type rig which is not equipped with a sand line or hydraulic pump.

Fig. 5.- A large tractor rig of the California type. The frame work to the right of the rig was used in testing out the well with an airlift.

has wooden tail rods.

The rig irons are located on the front end of the rig and the power is transmitted from the band wheel shaft by spur gearing and chain drive. The sand line reel is above the frame on the back of the vertical mast braces and just below is the drilling line reel. In back of this is the crank shaft with its gearing and then the band wheel and shaft. The clutches are all of the internal expanding drum type with a composition brake lining. In Fig. 6 the similarity in the arrangement of the rig irons of two California rigs is easily noted, although the rig on the right is much the larger of the two. The driller has complete control of his tools and the various parts of the machine from his position in front of the rig, the sand line and drilling line clutch handles being on the right side, the drilling and pump clutch handles on the left side, and the pressure gage and valves to the hydraulic jacks in the center. The governor of the engine is also controlled by a lever at the front of the rig enabling the driller to adjust the speed of the engine without leaving his tools.

The hydraulic pressure pump is seen on the near side of the rig placed on a shelf and is chain driven direct from the band wheel shaft. The hydraulic pressure pumps are all of the double acting solid plunger type. The cylinders and frames are made of semi steel castings and the valves and seats of special bronze. The crank shaft is made of special steel and the plungers of steel or bronze. They may be either chain-driven, direct-gear driven, or belt and gear



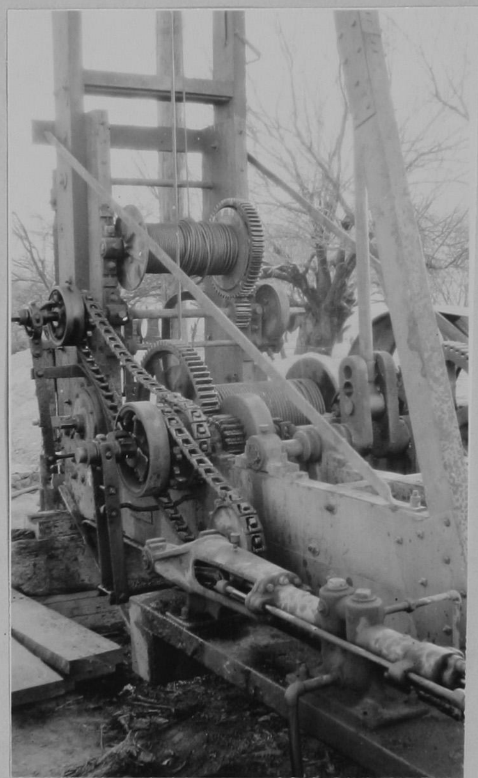


Fig. 6.- The similarity in the rig irons and their arrangement on California or mud-scow rigs is clearly shown above.

driven. The pumps are all tested under a very high hydraulic pressure before they leave the factory, one company testing their pumps to 4000 pounds pressure although they are assumed to be operated at about 2000 pounds pressure per square inch. The size of the pump is designated by the diameter of the plungers and the length of the stroke. The table given below shows the different size pumps made by the Commercial Iron Works, and the size jacks they will handle.

Table II. HYDRAULIC PRESSURE PUMPS AND THE CORRESPONDING SIZE HYDRAULIC JACKS

Diameter of Plungers	Stroke in inches	Capacity G. P.M.	R. P. M.	Pressure in Pounds	Size of Hydraulic Jacks	Approximate Weight
$1\frac{1}{4}$	7	8	110	2000	6" or 7"	500
1-3/8	7	9-1/2	110	2000	7" or 8"	550
1-1/2	7	11-3/4	110	2000	2pr 7"	600
1-5/8	7	13	110	2000	2pr 8"	650

The power on the rig shown in Fig. 3 is supplied by a 20 H.P. horizontal oil engine mounted on the rear of the frame. The engine is of the electric ignition type, equipped with a high tension magneto and operating on tops, a fuel oil of between 38° and 42° Beaume gravity.

The cooling water is circulated by a 1-inch centrifugal pump belted to the engine. The tank for cooling water is just behind the engine. The California type rigs used in Arizona are all equipped with internal combustion engines, the larger sizes burning tops, the smaller ones burning either distillate or gasoline. In California the first rigs of this type were operated with steam power probably because they were modified from the standard rigs to meet special conditions encountered in water well drilling. In *"Water-Supply and Irrigation Paper" No. 140, are some excellent plates showing the earlier types of these rigs which are very similar to the rigs used at present except that they are equipped to use steam power.

Practically all the so-called California or mud-scow rigs are built along lines similar to the rig which has been described. Because of the high freight rates most rigs are built up by the individual drillers who order their rig irons and mount them according to their own ideas. This results in some changes in the minor details of the rigs but does not result in any radical departure from the ordinary type.

The small rig in Fig. 4 is not equipped with either hydraulic pumps or a sand-line. The cable by which the bailer or sand-bucket is lowered into the well has by common usage become known as the sand-line. This rig is used only on small diameter and shallow holes, only an 8 H. P. gasoline engine

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*Charles S. Slichter, 1905. Field Measurements of the Rate of Movement of Underground Water being used for power. This rig has steel cable in place of tail rods and has shock absorber springs connected in the cable near the top. Fig. 5 shows one of the heaviest of the California Traction type rigs ever used in this State. It is equipped with a 25 H.P. engine and is rated as capable of drilling a 24-inch well to 1000 feet. The tail rods on this machine are of wood.

Few tractor drilling rigs of any type are seen in Arizona partly because of the increased first cost but also because of the added weight, this increasing the difficulty of moving.

Churn Drills

Churn drilling rigs when used in putting down large stovepipe wells are equipped with hydraulic pumps as auxiliary equipment. The churn drilling rig is not as efficient in the use of the mud-scow as the California rig, for it has been developed essentially for the use of solid drop tools. Just recently one of the large companies manufacturing churn drills has advertised that they now put out a rig equipped and adapted for the use of a mud-scow and stovepipe casing.

Ordinarily the walking beam is a part of the churn drilling rig and a special spudding attachment is used for spudding in the well over the mast. The expression "spudding in a well" is now generally accepted as meaning that the actual drilling has been started. Strictly speaking, it is the drilling of a well over the mast or derrick when the hole is first started. These spudding attachments are all designed to give a reciprocating motion to the tools so that the downstroke is made in much less time than the upstroke. Thus, the tools are dropped quickly and picked up slowly. Except on the small rigs not equipped with walking beams it is assumed that the spudding arrangement working over the crown pulley or the mast is to be used only to a depth of one or two hundred feet. For this reason the masts are not made as strong as on California rigs where all the drilling is done over them.

All churn drill rigs are equipped with some sort of spudding arrangement to give the tools a reciprocating motion up and down when first starting a hole. The different manufacturers all give reasons why their rigs are the best in this respect, but all of them are somewhat similar in that they endeavor to give a quick drop to the tools and pick them up with a steady stroke. The constant bending of cable or rope over pulleys when drilling this way causes them to wear out rapidly and to prevent this many of the spudding arrangements have been designed so that the pulleys run over the cable.

The portable churn drill in Fig. 7 is a steam rig with a T boiler mounted on the rear of the frame. This rig embodies several features of the standard rig in its construction. The walking beam is pivoted on a sampson post on the right side of the rig and is connected by the pitman to the wrist pin in the crank arm of the band wheel. The bull wheel gear is driven by a spur pinion and shaft on the other

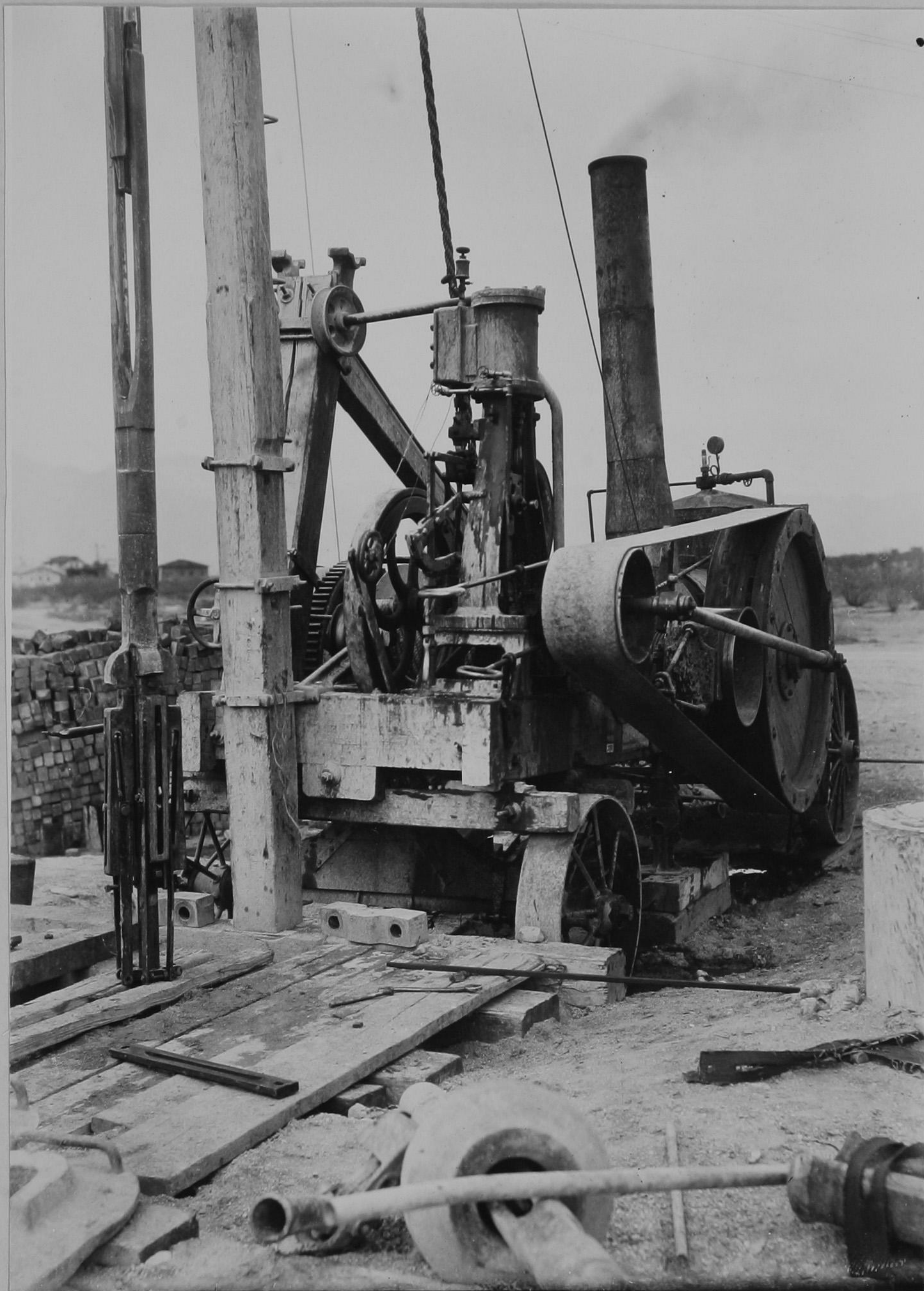

Fig. 7.- A portable steam rig of the churn drill type with single pole mast.

end of which is a friction pulley operating on the outside of the band wheel. The bull reel is equipped with a wooden brake wheel about 3 feet in diameter and a 6-inch steel brake band. The sand reel is operated direct by a friction pulley on the end of the shaft working inside the band wheel. The spudding arm to which is attached the spudding pulley is given a variable speed by the sliding link connection to the crank pin of the band wheel. The engine is of the vertical reversing type mounted on the left front of the frame where it partly balances the sampson post and walking beam on the right.

Most churn drills are equipped with walking beams all designed for the purpose of giving a long stroke to the tools when the hole gets deeper and to decrease the wear and tear on the cable or rope. In drilling over the mast all the parts of the rig are subjected to greater strain than when the walking beam is used because of the increased leverage. There are several different types of walking beams, the center beam, the double beam, and the side beam. The first two types are claimed to balance the rig much better than the side beam especially for small rigs. It cannot be said that any one rig is superior to the others. They all have some particular points that are very good or they could not continue to be sold. A well rig is one machine that must make good or it is very soon off the market.

DRILLING TOOLS AND EQUIPMENT
Drilling Tools

Practically all drop tools are now made with the tapered screw joints. A joint called the I & H joint is now recognized as standard. This joint is made with a taper of 24^{o}, or 1/4 inch to 1 inch, with either seven or eight threads per inch or seven flat threads per inch. The size of a joint given, as 2 inches by 3 inches by 7 inches is one whose diameter at the end of the pin is 2 inches; the diameter at the base of the pin is 3 inches and it has seven threads per inch. The drilling tools are made with square sections at each end upon which the heavy tool wrenches are used in setting up the screw joints. The size of the joint is always marked on the collar, the round part of the tool between the joint and the wrench squares. The tapered joint has proved to be superior to other types in strength and also has an additional advantage in that only a few turns are necessary to screw a joint up tight.

The string of tools ordinarily used with the California or mud-scow rig consists of a cable or rope socket, jars, sub from jars to mud-scow and the mud-scow. In Fig. 8 a string of tools with a mud-scow are shown hanging from the walking beam. The regular string used with the churn drill consists of rope or cable socket, jars, stem, and bit.

Rope sockets are made in several different styles, the most common types being the Solid socket and the New Era socket. In the Solid socket the hole is drilled straight

Fig. 8.- Complete string of tools used with a mud-scow

Fig.9.- A drilling stem with drive clamps bolted onto the upper wrench squares.

through the socket and the rope is well wrapped with strands of the rope and forced into the straight hole where it is held in place by iron rods which are pointed and driven through the center of the rope and then rivetted on both ends. The New Era socket has a hole drilled in the end the size of the rope which is brought out the side of the socket with a gradually increasing diameter. The rope is pulled thru the socket a couple of feet and a number of loose strands are inserted between the three plies of the rope near the socket. Below this the rope is well wrapped and then pulled up into the tapered hole where it wedges fast. The piece left sticking out is cut off.

Steel cable sockets are usually made with a tapered hole drilled thru them increasing in diameter towards the bottom of the hole. The end of the cable is pulled thru, the strands separated and part of them bent back. The cable is then pulled back into the socket and melted babbitt poured in. This, when cool makes a joint that will not pull out. Care must be taken that babbitt metal is used and not lead, for the lead will not hold. A light, steel cable socket, much used with the mud-scow, is made with a jaw socket with a square hole and pin. The New Era rope socket may be used with steel cable also, but requires more babbitt metal to fill the large hole. Both rope and cable sockets are as a rule made with a threaded box on the lower end for fastening to other tools.

A set of jars is made up of two pairs of linked bars having a play or stroke of from 6 to 36 inches. The ordinary drilling jars used with solid tools have a stroke of only 6 to 12 inches while those used with a mud-scow are long stroke or fishing jars having a stroke of about 30 inches. The jars do not help in the drilling in any manner and are used only as a safety measure in case the tools become stuck in the hole. An upward blow may then be struck with the jars which has proved much more effective in getting the tools loose than a steady pull on the drilling cable. A box joint is cut on one end of the jars and a pin joint on the other. Jars are made by hand of a special composition steel.

A sub or substitute is used to connect tools with either different size joints or different types of joints. In connecting the jars to the mud-scow the sub is made with the taper pin joint on one end and a tongue on the other with a round hole in it. This is called a pin and tongue sub. A box and tongue sub is used between jars and a jaw cable socket.

The mud-scow is made of heavy pipe or of about 1/4 inch plate. It is fitted on the bottom with a plain flap valve and a heavy cutting shoe somewhat similar to a casing or drive shoe, but flared out slightly to give it clearance in cutting. The upper end is fitted with two heavy ears which are securely rivetted to the body of the scow and extend about two feet. A round bolt is used to fasten the tongue of the sub to the ears or jaws of the mud-scow forming a knuckle joint.

With drop tools a stem is used below the jars to give weight to the string of tools. For use with portable rigs they are usually not over 18 or 20 feet in length and about 4 inches in diameter, and are made with the regular box and pin joints. The length of the stem which can be used is limited by the height of the mast or derrick on most small rigs. A stem is shown in Fig.9 without any jars. It has been used for driving casing only and the drive clamps may be seen bolted near the top.

The bit used with the drop tools in water well work is called a spudding bit; it is only about three to four feet long and is thinner than the regular drilling bits. This type of bit has been found more satisfactory for drilling in the unconsolidated or cemented formations in which our wells are drilled. In Fig. 10 is shown the type of bit commonly used in well drilling work, while in Fig. 11 is shown a bit used in regular drilling work. Regular drilling bits are five or six feet in length and may be what is known as a welded bit or an all-steel bit. In the welded bit the upper or pin end of the bit is made of soft steel which will not crystalize; the lower end is made of a high carbon tool steel which admits of taking a good temper. The all-steel bits are made of the tool steel throughout and the pin even though annealed has a tendency to become crystalized due to the constant hammering which it receives from the stem and thus makes a weak place in the string of tools. The regular bits are used by well drillers in Arizona for small holes 6 or 8

Fig. 10.- The type of bit ordinarily used in water well work.

Fig.11.- A Mother Hubbard or all steel hard rock drilling bit.

inches in diameter in hard formation.

A bailer or sand bucket is used for cleaning the drill cuttings out of the hole. They are usually made out of a length of pipe or casing and fitted with a bail on one end and either a dart or flap valve on the other. The sand bucket with the flap valve has to be up-ended to empty it, so as a rule sand buckets over 16 feet in length are not used.

Fishing Tools

Fishing tools are made for almost every conceivable kind of fishing job, but the number of tools used makes it practically impossible for the ordinary driller to carry a stock of them. The most common fishing tools are: manila and wire rope knives for cutting the drilling line off close to the tools, horn or slip sockets for taking hold of loose tools in the hole or to take hold of the collar of tools in the hole, a combination socket to take hold of a pin or the neck of a rope socket, a rope or wire line spear for catching hold of a broken drilling line, and a spud for loosening tools fast in the hole or spudding around them. A number of fishing tools are shown in Fig. 12. Most fishing tools are operated on a regular string of tools with fishing or long stroke jars. Several companies have been organized in California who make a business of renting out fishing and drilling tools. They send out a rental list and usually charge a certain amount for the first day and so much for every day thereafter. Rental charges are computed from the time the tools leave the company until returned to

Fig. 12.- A group of fishing tools looking from left to right consisting of horn socket, combination socket, slip socket, and slips, rope knife and rope spear.

Fig. 13.- Setting up the tools with a circular track and jack.

them and the user also pays all freight or transportation charges. Fishing tools are costly and in many cases the rental alone is prohibitive for it is not known that they will be successful even if tried.

Manila and Steel Cable

Both manila cable and steel cable have been used for drilling line but the steel cable being cheaper and having a longer life is now being used almost altogether. Manila drilling line is known as hawser laid made up of the three main plies which in turn are each made up of three other plies of the best grade manila hemp. Manila cable has more stretch or spring than steel cable and is more flexible. It puts much less strain on the drilling machine and for shallow holes has several other advantages over the steel cable. For these reasons sometimes a "cracker" or short piece of manila cable is used next to the drill tools and then spliced to the steel cable.

The sand line is a steel cable usually from 3/8 to 5/8 inches in diameter.

Hydraulic Jacks

One of the most important parts of the equipment used in putting down stovepipe casing is the set of hydraulic jacks. They are made in sizes from 6 inches to 10 inches in diameter and the usual length of stroke is from 4 feet 6 inches to 6 feet, depending partly upon the length of the casing joints used. The jacks are made to withstand pressures of from 2000 to 4000 pounds per square inch, with semi-steel cylinders and heads, the heads being securely fastened with heavy, steel bolts from one end to the other. The piston rod is of cold drawn steel securely fastened to the piston at one end and fitted with a steel clevis on the outside end.

Tool Wrenches

Wrench squares are provided on all tools with screw joints upon which heavy forged steel wrenches are placed in tightening up the joints. A set of wrenches consists of a right and a left hand wrench. In setting up the joints a circular track and jack are used with the wrenches as is shown in Fig. 13. Joints 2 inches by 3 inches by 7 inches and smaller may be set up with a lever bar and chain in place of the jack and circular track.

Temper Screw

The temper screw is the tool used to connect the drilling cable to the walking beam on a churn drill. There are several types but are all made on the same general principle and consist of a frame or reins, main screw with yoke, a ball bearing swivel and clamps for fastening to the drilling cable. One of the types most commonly used may be seen in Fig. 14.

Drive Clamps

Drive clamps of forged steel weighing from 50 to 300 pounds are made for driving pipe. They are recessed to fit the wrench squares and are held in place by a very heavy bolt on each side. In driving casing they are usually clamped to the upper wrench square of the stem. In Fig. 15

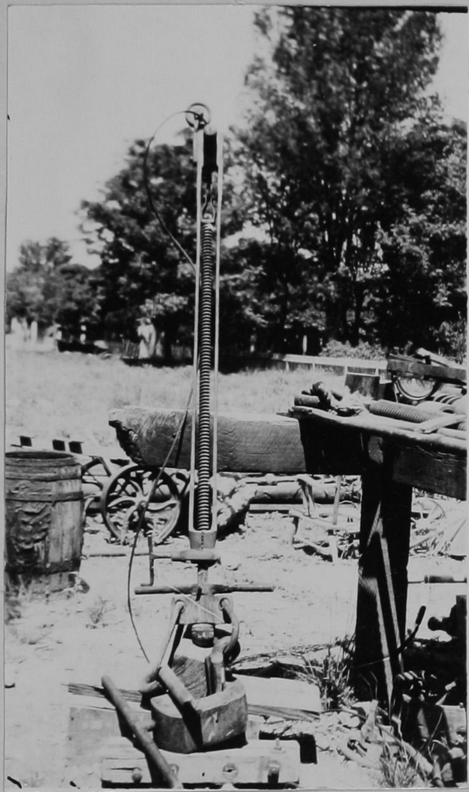

Fig. 14.- Temper screw; note the heavy construction of the cable clamps.

Fig. 15.- Set of drive clamps weighing about 150 pounds, used in driving casing.

a set of drive clamps with bolts is shown.

DRILLING OPERATIONS

Setting up the Rig

Usually the rig is brought up to the well site in travelling position and placed so that the hole will be approximately where desired, that is within 2 or 3 feet. The front end of the rig is raised with jacks and blocked up to take the weight off the running gear, or the running gear may be removed and the frame lowered onto heavy mud sills. Sometimes the rear wheels are set on blocks and wedged or they may be lowered into small holes dug in the ground, as may be necessary to level the frame of the rig. The rig shown in Fig. 3 has been set on heavy blocks in both front and rear. The placing of a rig on a solid foundation saves the rig from much wear and tear besides increasing the efficiency of the rig as a whole.

Putting the mast up is accomplished on almost all rigs by a small windlass on the front end of the machine which is either hand operated with a crank or with power from the engine. To save time the drilling and sand lines are threaded through their respective pulleys and the guy wires and braces are fastened to the mast before it is raised. The guy wires and braces are now securely fastened.

The tools are next strung up, the screw joints being set up with a wrenching bar and chain or with a sledge hammer used on the ends of the wrench handles. The latter method is used when the tools are put together on the ground surface and the jack and track are used after the hole has been started and the tools can be lowered into it. Most drillers make a chisel mark across the joint after it has been set up and they can then tell immediately on inspection where it has started to loosen up. The tools hanging from the mast serve as plumb bob for lining up the mast in a vertical position and at the same time the rig is given a final leveling all around. On churn drills using a walking beam it is necessary to make a final adjustment of the mast, either forward or backward, in order that the end of the walking beam and the outer end of the crown pulley will be approximately in the same vertical line.

Installation of the Jacks

While the driller and helper are busy setting up the rig a couple of laborers are usually engaged to dig a pit for the hydraulic jacks and the anchor timbers. The center of the pit is located where the drill hole is to be. This pit is usually about 5 feet wide by 12 feet long and about 9 feet deep. The length is determined partly by the length of the anchor timbers and the depth is made so that the tops of the jacks are just above the ground surface. A hole 2 or 3 feet deep and a couple of feet in diameter is dug in the center of the pit in which the starter is placed. The two anchor timbers are then placed in position, one on each side of the starter, and plank flooring laid across them from one side of the pit to the other. When it is expected that

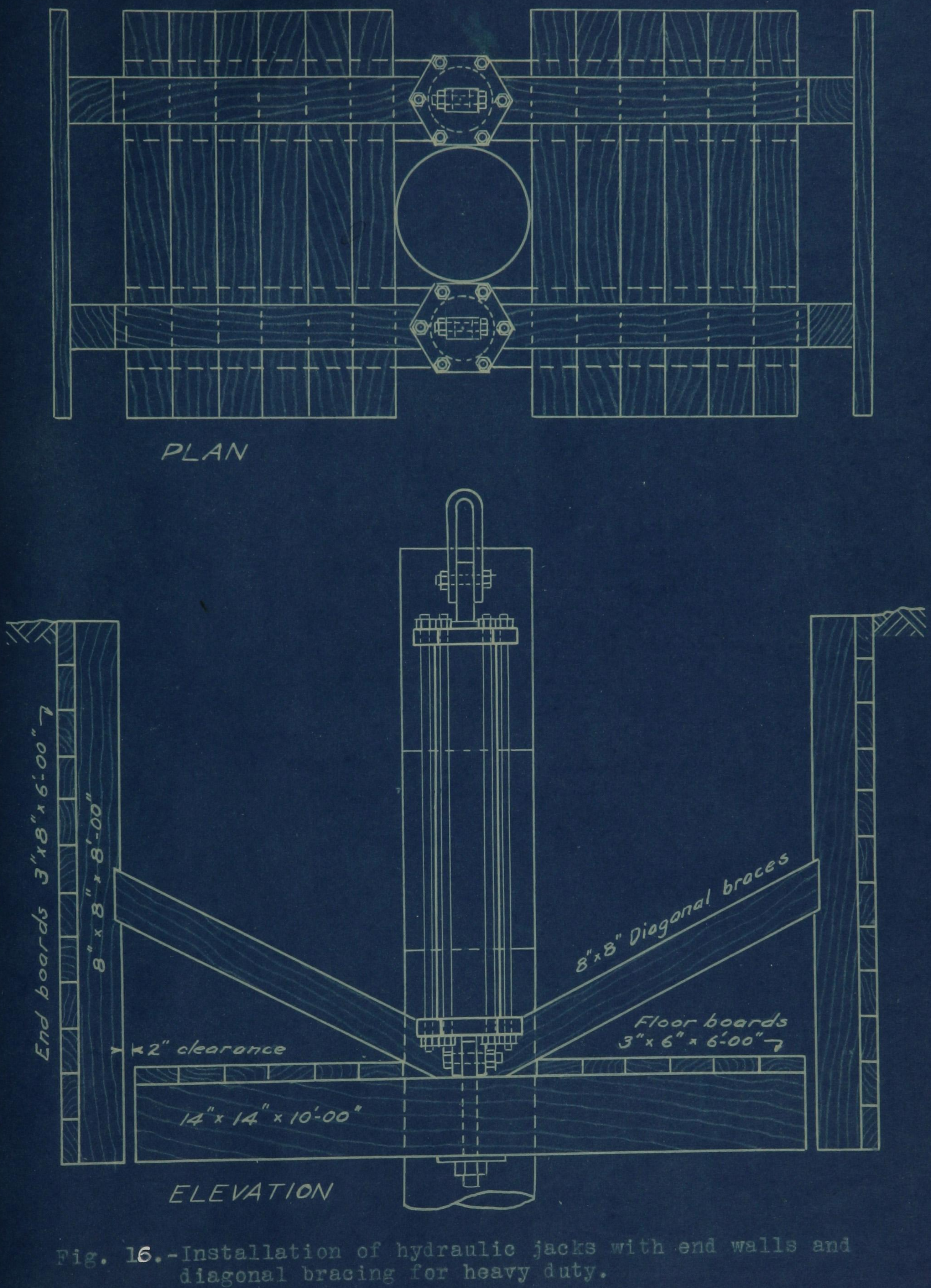

Fig. 16.-Installation of hydraulic jacks with end walls and diagonal bracing for heavy duty.

very heavy duty will be required of the jacks, an installation such as is shown in Fig. 16 should be made. Ordinarily diagonal braces are only run out to pieces of planking set against the ends of the pit, but the full capacity of the jacks can not be developed in this way. The starter is lined up and plumbed up and then braced in position. The piping between the hydraulic pump and the jacks should be carefully put together and the jacks tested before the pit is covered up.

It is in locating the jacks that the ordinary churn drill is at a disadvantage. On many rigs the mast does not overhang far enough in front so that there is sufficient room to dig a pit for the jacks. Sometimes the pit is dug and the jacks are installed before bringing up the rig. A temporary four post derrick from 30 to 40 feet high may be used in place of a mast and the pit dug within the derrick legs.

Size of Drilling Tools

If the drilling is to be done with a mud-scow it should be about 2 inches less in diameter than the casing. Smaller mud-scows can be used, but are not quite so satisfactory. If a bit is used the size will depend to a great extent upon the character of the formation. If it is hard the hole may be but little larger than the size of the bit in which case the bit should be just small enough to clear the inside of the casing. In loose, caving material the bit may be several inches smaller than the casing.

Drilling

Actual drilling is started when the tools have been lowered to the bottom of the starter, the slack drilling line reeled up,and the clutch on the spudding attachment thrown in, lifting the tools up and dropping them. The position of the tools is adjusted while in motion. Until water is reached, it must be supplied from the surface, for drilling with either a mud-scow or regular bit. Between 30 and 40 strokes per minute are made with the mud-scow and between 50 and 60 with the regular bit. In spudding in, however,the tools are run slower than this until they are below the ground surface. Drilling with a bit should all be done with a tight cable, this helps to keep a straight hole and speeds up the drilling. The mud-scow is allowed to hit a good solid blow on the bottom of the hole.

The action of the mud-scow in drilling is very similar to that of a sand bucket used in cleaning out a well. A suction is created upon the upstroke, when the flap valve is closed, which has a tendency to pull all the loose material up from the bottom. On the down stroke the valve opens and the suspended material enters the mud-scow through the bottom. The mud-scow is built heavy enough so that it also makes a satisfactory cutting tool except in very hard formations. As the drilling progresses the mud-scow must be withdrawn from the hole from time to time and emptied. Various methods are used in up-ending the mud-scow to empty it. One method is shown in Fig. 17, another method is to raise the bottom end of the mud-scow up with the sand line.

In drilling with the mud-scow the length of stroke is varied according to the material drilled in. In hard or partly cemented formation the long stroke is used but in loose sand or gravel the short stroke of about 18 inches is used. If the long stroke is used in a loose formation rocks or boulders may be thrown up through the mud-scow and fall between it and the casing. This happened in a 24-inch well near Tucson, where the mud-scow was wedged in solidly. The driller who is an experienced man in the work spent six weeks trying different tools and methods to get it loose. All the tools that he was able to grab hold of the mud-scow with, broke on pulling with the heavy jacks. He finally had a special forged steel hook made and threaded for 4-inch pipe. Using double strength 4-inch pipe for rods he was able to hook onto the mud-scow and pull it loose with jacks. One reason why this was wedged so tightly was that the mud-scow had more of a bell-shaped cutting shoe than is ordinarily used.

When the bit is used for drilling, the cuttings from the bottom of the hole are usually fine enough to form a thin mud with the water which is added from the top as drilling progresses. As this mud becomes thicker the drilling is slowed down. It soon becomes necessary to pull out the tools and clean out the hole. A bailer or

Fig. 17.- A method of emptying the mud-scow with only one line.

Fig. 18.- Forcing stovepipe casing down with hydraulic jacks.

sand bucket is used for this purpose and it is necessary to make two or three runs with it to clean out all the cuttings. The number of feet that can be drilled without bailing out is called a run. In ordinary material mixed with clay, runs of from 3 to 5 feet are usually made, but in sand, gravel, or boulders, which settle to the bottom as soon as they are drilled up, the hole sometimes has to be bailed every 6 inches. It is in this kind of material that the mud-scow shows its superiority over the ordinary drop tools.

If in drilling, very large boulders are encountered or if the formation becomes very hard the mud-scow must be replaced by a stem and bit. The mud-scow rig is at a disadvantage in this kind of drilling. The stroke is too short and slow and it does not give the necessary snap to the tools which permits of rapid drilling.

The City of Tucson had four 20-inch wells put down to a depth of 500 feet in the northeast section of the city where the formation is partly sand, gravel, and clay, but is mostly a very hard cemented sand and gravel or caliche. In the competitive bidding for this work a contractor using churn drills equipped to put down stovepipe casing was awarded the contract. The drilling was even harder than was expected, sometimes not over two or three feet being made in a day. At times the casing was very hard to move and both the drive clamps and hydraulic jacks were used at the same time. On one occasion, before water was reached, they could not move the casing with the hydraulic jacks. The helper was lowered into the hole and with a cold chisel and hammer was able to cut off enough of a large boulder which was holding the casing shoe to let it pass. The churn drill properly equipped to handle stovepipe casing is probably superior to other drilling rigs for drilling of this type.

When drilling in sticky clay or gumbo, both kinds of drilling tools have their disadvantages. The mud-scow is equipped for this work with a heavy knife blade welded across the diameter of its cutting shoe to help in keeping the clay from balling up. With the drop tools a solid blow cannot be struck as the tools will stick and then have to be jarred loose again. Clay which does not mix readily is difficult to make footage in, by either method.

The weight of the casing is in most cases sufficient to cause it to follow the tools for the first 40 or 50 feet without using the hydraulic jacks. Unless in clay or cemented formation,an open hole is very seldom carried more than the length of the mud-scow ahead of the casing or if drop tools are used, not more than 10 or 15 feet ahead. The common practice is to put on two joints of casing at a time, denting each joint with a heavy pick in three places around the circumference. This unites the inside and outside joints and thus prevents the casing from separating in case the upper part is tight in the hole and the lower part hanging loose.

Forcing the casing down with hydraulic jacks takes very little of the driller's time; in fact, he may be drilling at the same time. The clevises from the top of the hydraulic jacks are hooked over the ears of the casing or well cap as shown in Fig. 18. By simply throwing the clutch to the hydraulic pump and operating the proper valves the jacks are worked. In action, they move slowly and steadily either up or down as desired.

For some wells of small diameter, both the light churn drill and California type rig are used without hydraulic jacks. The drive clamps are used on the stem and the casing is driven down. Fig. 4 shows a small California rig of this type which is not equipped with a sand line so that when solid drop tools are used the drilling line has to be changed over to the bailer to clean out the hole. If the mud-scow is used for drilling, then to drive the casing, a change is made to the drop tools where the weight of the stem may be utilized.

Some drilled wells are to be equipped with high capacity turbine pumps of over 2000 gallons per minute. To take advantage of the high efficiencies obtained with these pumps when made with large diameter bowls the wells are put down with 24 or 26-inch casing to the depth at which the bowls are to be set. That is, a 24 or 26-inch well is drilled to 70 or 80 feet and the remainder of the hole is finished with either 12 or 16-inch casing.

In reducing to the smaller size casing it is necessary to start it from the ground surface with a starter. In order that the inside string of casing may be started in the center of the drilled hole, the starter is sometimes blocked out to almost the size of the large casing. Instead of adding one joint of casing at a time sections 20 to 25 feet long are ordered. They are put on in the same manner as single joints but are picked extra deep to keep the sections from pulling apart, as they are lowered. As soon as the shoe reaches the bottom the drilling proceeds as before.

Where two sizes of casing are used the inside casing is cut off a few feet above the bottom of the outside casing. Ordinarily some type of a ripper or a perforator with which a long cut can be made, is used for this purpose. A single cut 3 or 4 feet long is made and as this is as long, or longer than a single joint the casing may then be pulled apart. To straighten out and center the top joint of an inside string of casing, where it has been cut off, an adapter is very often used. It also serves as a funnel into the smaller casing.

After the casing has been cut off and withdrawn, the top of the inside casing is sometimes left in such shape that tools cannot be lowered into it. To straighten out a place of this kind,or a place where the casing has been dented in by a large boulder, or where the casing has collapsed, a swage is used. The swage is a large heavy piece of cast-iron or steel shaped like a hugh plumb bob about two feet in length and slightly smaller than the casing in diameter. The swage is lowered on the tools with long stroke jars and also with a sinker bar above the jars.

In a 26-inch well in the Salt River Valley it was found impossible to get the pump suction into the inside casing. Repeated attempts were made and finally an impression block of hard soap was sent down on the bottom of the tools. When pulled out it showed that the inside casing was leaning over to the side, just enough to keep the long pump suction,which hung vertically, from entering, while at the same time the mud-scow entered without difficulty. After the trouble was located the pump was put in by slanting it at just the proper angle to enter the inside . casing.

Another case is reported in the same valley where after all other means had failed, a diver was sent down into a well to locate the trouble.

The depth to which a hole is to be drilled is in many cases decided before work is started. This is only safe, however, when the well is drilled in proved territory and where the water strata are known to lie uniformly throughout. Most wells are contracted for a certain depth with a provision in the contract that if sufficient water bearing strata are not encountered in this depth that the well is to be drilled deeper at the option of the owner.

It is always desirable to stop a hole either in clay or some cemented formation so that sand or gravel has no opportunity to come in from the bottom and fill up part of the hole. In case a hole is stopped where there is a possibility of this happening, the bottom of the hole should be cemented or filled up with coarse gravel and then boulders, for a distance of eight or ten feet.

LOG OR RECORD OF THE WELL

The importance of keeping a careful and accurate log of a well cannot be too strongly emphasized, and it should be considered just as much a part of the driller's contract as the drilling of the well. The driller in too many instances makes note only of the depth to water and probably the principal water bearing stratum. Later, if the owner asks for it, he makes up the rest of the log from memory and as a result it is usually inaccurate and unreliable.

The owner should insist that the driller keep a careful log, made up from day to day of the material passed thru, describing it as best he can. In addition, samples of each change in formation should be preserved in tin cans and plainly labeled. This daily log should also include the progress made with the casing, any variations in water level, size, number, and location of all perforations, and a record of the developing of the well if done by the driller. To this should be added any additional information that the owner may have, concerning the well.

In an article on the*"Construction of Driven Wells, Mr. John Oliphant, probably the ranking authority on pneumatic pumping, says "A driller should be required to furnish a complete log and this should be as carefully preserved as

*Oliphant, John - Construction of Driven Wells. Engineering and Contracting 58:259, S.13,22.

a deed to the property." In many instances in this State the value of the well is equal to and sometimes exceeds that of the land which is to be irrigated by it.

The Irrigation Division of the University of Arizona has from year to year been adding to its collection of well logs and miscellaneous data on wells. These records are now considered among the most valuable of those kept on file in this office. They are needed in any study of underground waters, but are also of considerable value to individual owners of wells. This is attested by some of the inquiries received, of which the following may be considered fair samples. How deep was my well when first drilled, and how far was it cased? Was the casing in my well perforated? Can you furnish me with a log of the formations in my well? Most of these inquiries have been from owners of land which has changed hands since the wells were drilled, but they serve to indicate the value of preserving complete and accurate well logs.

PERFORATING

Importance of Properly Perforating the Casing.

The perforating of the casing is the cutting of a sufficient number of holes in it of the proper size opposite the water bearing strata, to allow the water to enter the casing without an excessive loss of head due to friction.

The number of holes depends upon the amount of water which is expected to be developed in a stratum. This is determined by the water bearing capacity of the stratum. If the material is open or porous provision should be made for the entrance of a large amount of water and the perforations can be put close together, care being taken, however, not to materially weaken the casing. In tight formation in which no definite water strata are located, it may be assumed that the water will seep in all along the casing and an average of four holes per foot would be sufficient.

In water bearing material containing some coarse gravel or boulders large perforations may be made. This is the condition found in most of the wells in the Santa Cruz and Rillito Valleys near Tucson and also in the Salt River Valley. Some of the wells producing the largest yields have been perforated with holes one-half inch in width by 3½ inches in length. As many as ten holes equally spaced in a ring around the casing and the rings 10 or 12 inches apart, are made. The logs of the wells put down in the northeast section of Tucson for municipal purposes show that almost all the material from the ground surface to the botton of the wells was tightly cemented together. Few definite water strata were detected by the drillers and it was thought that some water was making its way into the well at all points from the water surface to the bottom. For this reason the casing was perforated with large holes as described above, but only six holes per lineal foot of casing were put in. Where the water is found in sand

and comparatively small gravel, smaller perforations must be made.

As a rule it is not advisable to perforate in quick sand. It usually carries little water and in many cases it is almost impossible to keep the sand out of the well. Several patented screens with very fine perforations are on the market, for use in fine sand. But because of their high cost and the uncertainty as to whether their use will be satisfactory, they have as a rule been little used in Arizona.

From the preceding paragraphs it may be seen that in perforating the well a complete and accurate log is indispensable, for upon it depend the size, number and location of the perforations. In perforating, holes should be cut for several feet on both sides of the water stratum.

Most of the perforators in general use today will be found satisfactory if properly handled. However, certain precautions should always be taken before using any perforator. Several test holes for inspection purposes should be made close to the surface, both before and after perforating. Before lowering the perforator in the hole, it should be carefully gone over, all badly worn parts replaced, nuts tightened up, and cotter pins put in where needed. The experience of the operator in the use of a particular type of perforator and also the adaptability of the drilling rig for its use should be considered. It is only in the last few years that the importance of having a well casing properly perforated has been recognized by drillers. Now, if a well does not develop the expected capacity the perforating is the first thing checked up. One of the last wells put down by the Pima Farms Company near Tucson supplied only a comparatively small amount of water when tested. The well was reperforated at once, although there was no reason to suspect that the work was not properly done in the first place. Several wells which were drilled a number of years ago have been reperforated recently and in several instances their capacities have been increased.

In Fig. 19 are shown four field samples of perforated casing. The casing on the extreme right was perforated with a Mills Knife, the lower center one with a perforator designed by the Reclamation Service, the one on the extreme left with a Star Four-Way Perforator run twice, and the one on top of the preceding two by a Mackey Four-Way perforator. In all four specimens it may be noted that any beads formed by the knife blades on going through the casing are left on the outside and results in the holes all being larger on the inside than on the outside of the casing. Thus any particle that starts into the hole goes right on through without sticking and plugging up the hole.

Many types of perforators have been patented and still more homemade ones may be found in use. A few of those which have met with favor in this State are described in the

Fig. 19.- Four samples of perforated casing.

following paragraphs.

The Mills Knife

In Fig. 20 is shown a patented perforator known as the Mills Knife. It cuts only one hole at a time and is made in sizes to perforate from 6-inch to 26-inch casing inclusive. The perforator is held in place or suspended on the sand line. The knife blade or cutter is made of a single piece of flat tool steel, held in place by a pin upon which it pivots. It is operated by a lever action with a 2-inch pipe from the top of the well. To secure sufficient pull to force the knife blade through the casing, the drilling line or sand line is strung through a set of blocks, one of which is attached to the 2-inch pipe. The weight of the 2-inch pipe is sufficient to pull the knife blade back out of the hole and the position of the knife blade may then be changed by turning on the 2-inch pipe. This perforator cuts a good clean hole and has proved to be reliable. It has an advantage over most other perforators, for it may be worked upwards from the bottom of the hole, thus eliminating any danger from running sand coming in on the perforator from holes cut above. Each hole may be accurately located with respect to the preceding holes and the spacing of the holes may be varied at the will of the operator.

Fig. 20.- A 16-inch Mills Knife Perforator backed up to use in 18-inch casing.

The Star Four-Way Perforator

A Star Four-Way perforator is shown in Fig. 21 which is operated on the regular drilling tools. It is fastened below the jars and a sinker bar or short stem is used above to give weight to the tools in driving. A trip is provided so that it may be operated at any desired depth from the surface. It has four sets of cutters mounted on discs which revolve on pins, whose ends are engaged in slanting slots. In operation the releasing of the trip allows the lower part of the perforator to expand sufficiently to hold it in place by friction against the sides of the casing.The weight of the tools is used in driving the main body of the perforator downward, causing the revolving discs and cutters to be forced outward by the slanting slots which serve as guides. Further driving forces the cutters to punch through the casing, the discs revolving as the perforator moves down.

In using the Star perforator it is the common practice to start near the bottom, run down, and then come back further up and run down again, rather than to start at the top and run to the bottom and take chances on sand running in on the perforator from above. If not enough openings are provided by running once it may be run twice, as was done in the sample shown in Fig. 19. An objection to running twice is that no control over the position of the perforator is had, and the second row may be right along the side of the first row and the casing greatly weakened and forced

Fig. 21.-The Star Four-Way Perforator only partly assembled but showing how the rolling knives work in the grooved slots.

out of round. This is probably the reason why one of the rows of perforations shown in the Fig. 21 is not as good as the other. This perforator was used in the East Well of the University of Arizona where screw casing was used. It proved very satisfactory in this well and it is believed that the Star perforator is better suited for use in screw casing than in stovepipe casing.

The Mackey Four-Way Perforator

The MacKey Four-Way Perforator is shown in Fig. 22 where it was used in perforating the 12-inch stovepipe casing used in the Agriculture Building well of the University of Arizona. Tests of this well showed that a discharge of 705 gallons per minute was secured with a 10.6 foot draw-down which is the highest specific capacity of any well in this section showing that the cross-sectional area of the perforations was at least sufficient. The perforator is hung on either the sand or drilling line and thus the position of the holes vertically can be regulated. The roller knives are set in steel blocks which are held in place in the main shell by rectangular holes in the shell. The heavy grooved knife-frame is shown removed from the frame. In use it is operated on the tools and when driven downward the wedge-shaped knife-frame forces the roller knives through the casing.

Other Perforators

The Reclamation Service Perforator is also designed to cut four holes at a time, but evidently is not to be

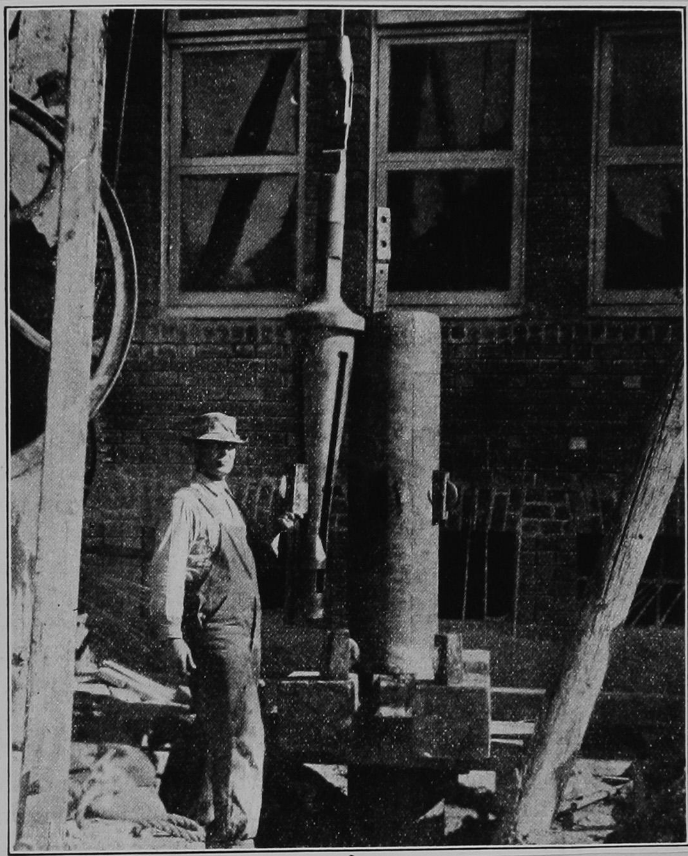

Fig. 22.- Mackey Four-Way Perforator, showing the four roller knives and the grooved knife-frame removed from its shell.

depended upon at all times. The specimen casing shown in Fig. 19 shows a perfect cut on the front side but out of the four there were two good holes, one fairly good, and the fourth was only dented and not cut through.

A home-made perforator or ripper for small casing is shown in Fig. 23. It was made out of a pair of old jars and is operated on the tools. To lower the perforator in the hole the knife is tied down, but in such a manner that when lowered to the desired position in the hole a very slight jarring releases the knife. It can be pulled up to any point desired but cannot be lowered except by driving and cutting a hole in the casing. A spring holds the knife blade out against the casing and the blows of the tools first force it through the casing and then the whole perforator is driven downward cutting a vertical hole or slot. The casing is perforated by alternately pulling the perforator up and driving it down. Each time the perforator is brought up higher than the preceding time in order that the holes made will not run together. If a second row of holes is desired the process is repeated. The objections to using it as a perforator are that only one series of vertical holes can be cut at a time and the tendency is to make the holes too long. It is advisable to use perforators of this type only in small casing, not over 8 inches in diameter.

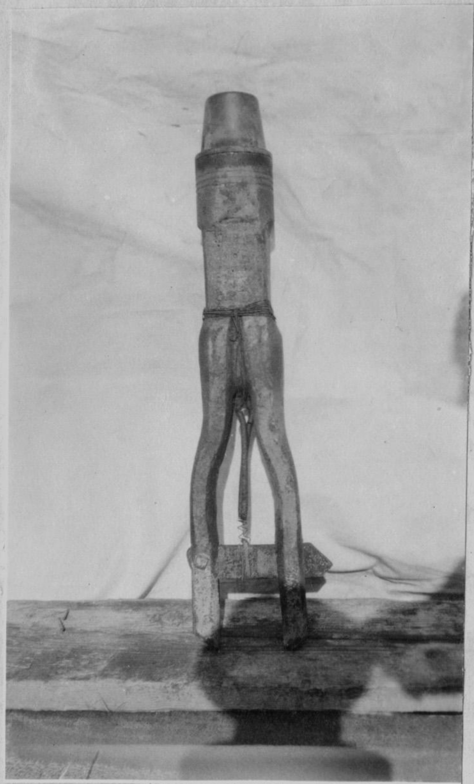

Fig. 23.- Homemade ripper or perforator made out of set of wornout jars.

Fig. 24.- Developing and testing a well with air lift. The air valve was opened quickly throwing a spray of water out 75 to 100 feet horizontally.

DEVELOPMENT OF THE WELL

Object of Developing the Well

The object in developing a well is to provide a path of the least possible resistance for the water to enter the well casing from the water bearing strata. This object is accomplished by cleaning out the perforations and opening up the water bearing strata. All the fine material, not only adjacent to the casing but for several feet away, is brought into the well where it may be bailed or pumped out. It can be truly said that the efficiency of a well depends upon the thoroughness with which it has been developed as well as upon the perforating.

The most commom methods of developing wells are the use of a mud-scow, pumping with a deep well pump, and using an air lift.

Developing with a Mud-scow

Because the rig is already on the ground and no additional equipment is required the mud-scow method of developing the well is the one most generally used. Usually the same mud-scow is used as in drilling, although some drillers prefer to use one that will give a little more clearance between it and the casing. A long stroke is used and the mud-scow is worked up and down in front of the perforations, usually starting from the top of the hole and gradually working down. It is necessary to bail out the hole from time to time, for in some cases more material is taken out of the well in developing than when it was drilled. When sand and gravel is no longer brought in by the action of the mud-scow there is no further use in continuing with it. *On seven wells, varying in depth between 230 and 360 feet, put down by the Continental Rubber Company in the Santa Cruz Valley, an average of 45 hours was spent on each well in developing with a mud-scow. Ordinarily two or three days' time spent in developing the well is sufficient but occasionally more time than this is required to get all the loose material out.

Some drillers always use a plugged mud-scow in developing, that is one in which the flap valve is fastened down. For this purpose a pole may be wedged in between the valve and the knuckle joint on the bailer or a special shaped hook which fastens from the bottom of the bailer may be used. It is not certain that developing with a plugged mud-scow has any advantage over developing with the flap valve open.

Developing with a Deep Well Pump

The propellor or turbine types of deep well pumps have been found the best adapted to the developing of wells. Propellor pumps are made that can be installed in a 7-inch casing while the smaller size turbine pumps require a 12-inch casing. These pumps are not equipped with a

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*From records of G.E.P.Smith, Consulting Engineer for Continental Rubber Company.

priming device of any kind so they are set deep enough that they will be covered with water at all times. A very long suction is used which causes the water to be in movement for practically the entire depth of the well when pumping. By using this long suction practically all of the sand that enters the casing through the perforations is pumped out with the water. At first the pump is started and stopped repeatedly. Thus the direction of the water is first upward and then downward as the water from the discharge column surges back into the well. This is called rawhiding a well and is used for about a half a day before the pump is run steadily. The well should be pumped continuously for from 48 hours to 72 hours,and at intervals during this time the process of rawhiding should be repeated. This method has the advantage over the mud-scow method in that all the information required for properly designing the pumping plant is secured at the same time.

The method as outlined in the preceding paragraph was used by a local machinery company in testing out and developing a well near Tucson, Arizona. On first starting the pump a discharge of only 320 gallons per minute was secured but at the end of 72 hours the pump was throwing over 800 gallons per minute. Continued pumping on this well brought the discharge to over a thousand gallons per minute. If the discharge at the end of the first day had been taken as the capacity of the well and the well had been equipped accordingly the owner would have been utilizing less than one-half of his investment in the well.

Developing the Well with Compressed Air

A third method of developing a well where an air compressor is available is by pumping with compressed air. This method is particularly well adapted for use in very deep wells of small diameter. The air line consists of small pipe usually not over an inch in diameter and is run down several hundred feet in the well. The water can be pumped from much greater depth than with the ordinary pumps. The air can be turned on or off at the will of the operator by merely opening or closing a valve. In this manner the entire column of water can be instantly started or stopped.

In Fig. 24 is shown a 700 foot well in the San Pedro Valley being developed with the air lift. In the figure the air has just been turned on and the high velocity and force with which the water comes out of the ejector pipe is clearly shown. The water mixed with air is thrown horizontally a distance of between 75 and 100 feet. This well is owned by the Apache Powder Company and is in the artesian belt, the water standing within five feet of the ground surface. When pumping steadily a discharge of 200 gallons per minute was secured with a 100 foot draw-down.

Another method of using compressed air for developing wells is to cap the well and then turn the compressed air into the casing. This forces the water back out through the perforations and by alternately taking the air pressure off and on practically the same results are reached as with the other methods.

The *Tucson Farms Company in developing a series of eighteen wells in a cross-cut in the Santa Cruz Valley, used a combination of the two previously described methods of developing with air. The wells were capped and then equipped with air and discharge lines. In this way the pressure in the well could be run up to 35 or 40 pounds; then by opening the discharge valve a suction was created into the well. This constant ramming back and forth was continued until no more sand could be pulled into the well. It was found that by this method the capacity of the wells was increased about 50 percent.

Developing a well by any of these methods should be followed as soon as possible by continuous pumping for several days. In almost all cases the capacity of the wells will be found to increase. It is very probable that many wells throughout the State were never properly developed, for many of them after having been pumped for some time are found to be filled up with sand almost to the suction pipe. This may be attributed to lack of developing in the first place.

*Hinderlider M.C., Irrigation of the Santa Cruz Valley, Engineering Record, Vol. 68, No. 8 Aug. 23, 1923.

TESTING OF WELLS

Before an efficient and properly balanced pumping plant can be designed it is necessary that the specific capacity of a well be determined. The pump used in testing does not necessarily have to be as large as that which is permanently installed afterwards. To be on the safe side it is probably best to test the well for at least 25 percent of the desired capacity. Within ordinary limits it has been found that the capacity of a well varies almost directly as the draw-down. The draw-down capacity curve in Fig. 24 shows this very clearly. It is taken from the data secured in testing the University of Arizona Well No.2, March 1922. There are special cases where this is not true; for instance if most of the water comes from one thin water bearing stratum and this is uncovered an increase in the draw-down does not materially effect the capacity, or if a large percentage of the water bearing strata are uncovered it does not hold true.

Sometimes permanent plants are installed without first testing the well, in which cases it is assumed that sufficient water will be secured because of the number of feet of water strata encountered, or because other wells in the vicinity have yielded large supplies. However, when it is taken into consideration that the efficiency of the poorly designed pumping plant not only effects the cost of pumping for the first year but for the entire life of the plant as well, it may be seen that the comparatively small additional amount required for testing the well is a very profitable investment.

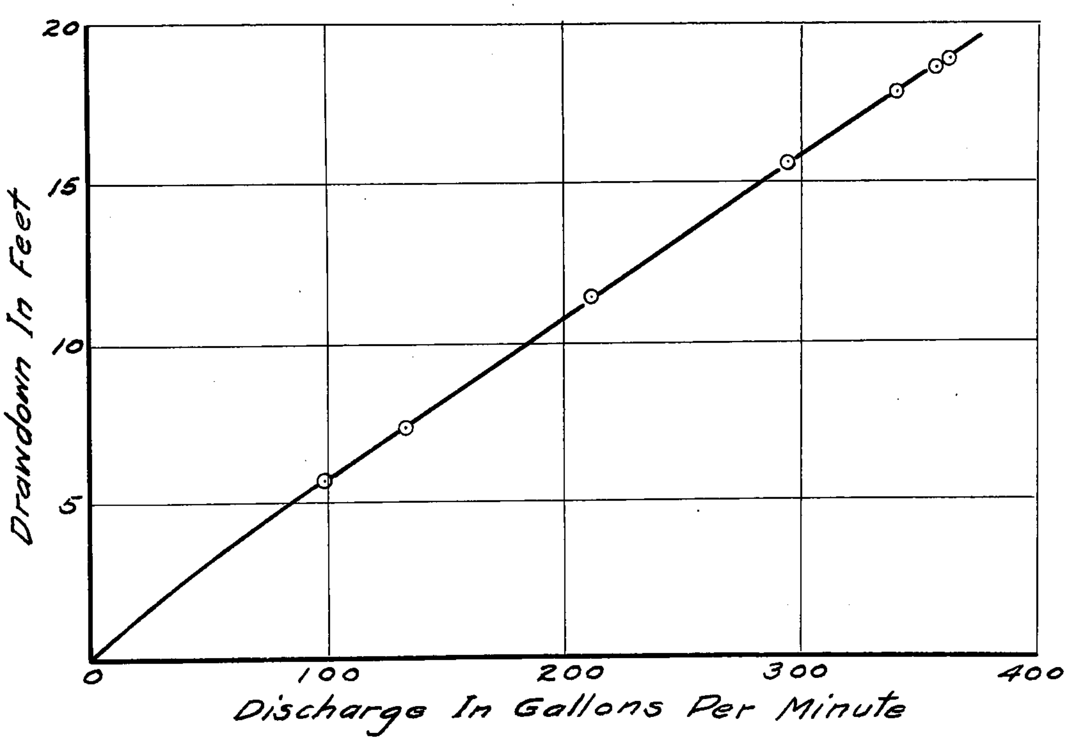

Fig. 25.- Drawdown-capacity curve of the University of Arizona Well No. 2.

COST OF DRILLED WELLS

The cost of the completed well may be separated into the following items: the cost of casing, of drilling, and perforating, and of developing.

Casing

The cost of the casing constitutes about 50 percent of the cost of the completed well so the owner can well afford to spend some time in its consideration. For points in the southwest casing is quoted f.o.b. Phoenix, Arizona, El Paso, Texas, and Los Angeles, California.

Stovepipe casing 12 inches and under in diameter takes the third class freight rate. Stovepipe casing, over 12 inches in diameter takes one and one-half times the first class freight rate. Because of the very high freight rates on large size stovepipe casing, it is important that in comparing prices from different dealers, that the freight rates be considered also. Sometimes to take advantage of the lower freight rate the casing is only rolled and punched at the factory and then nested for shipment, in which case it takes a fourth class rate. The difficulty of rivetting the casing in the field is so great that it is a question whether there is any real saving.

There is but little difference between the cost of shipping casing over 12 inches in diameter, by freight or express. For instance the frieght rate from Phoenix to Tucson is $1.67 per cwt. and the express rate is $1.81 per cwt. Casing is usually furnished by the owner and most contracts stipulate that any delays due to lack of material, to be furnished by the owner, shall be paid for at so much per day, usually from $20 to $30 per day. For this reason casing must often be shipped by express.

Price quotations on stovepipe casing are subject to market changes at all times. A list price on stovepipe casing f.o.b. Phoenix, Arizona, is given below. On

February 1, 1924, this list was subject to a 20 percent discount.

Table No. III. LIST PRICE PER FOOT OF STOVEPIPE CASING

Diameter of casing in inches	Gauge of Casing				
	16	14	12	10	8
6	$1.27	$1.52	$2.02	$2.57	---
8	1.54	1.85	2.49	3.14	---
10	1.83	2.20	3.12	3.89	---
12	2.13	2.57	3.62	4.58	---
14	2.45	2.94	4.14	5.27	$6.64
16	2.77	3.33	4.68	5.92	7.58
18	3.10	3.70	5.25	6.64	8.29
20	3.44	4.13	5.82	7.32	9.14
22	3.79	4.54	6.37	8.02	10.00
24	4.10	4.93	6.98	8.62	10.79
26	----	----	7.54	10.17	12.67

Stovepipe casing ordered in sections costs about 10 percent more than the regular joints. The cost of two-ply starters is approximately 25 percent more than casing and three-ply starters are about twice the cost of casing.

The list price of well rings or drive shoes f.o.b. Phoenix, Arizona, is given in Table IV. These prices were not subject to any discount on February 1, 1924.

Table No. IV. PRICE OF STEEL WELL RINGS OR DRIVE SHOES -- FEBRUARY 1924

Size in inches	DIAMETER OF CASING										
	6	8	10	12	14	16	18	20	22	24	26
6 by $\frac{3}{4}$	$10	$13	$15	$20	$23	$26	$ 28	$ 31	$35	$37	--
8 by $\frac{3}{4}$	16	17.50	19	25	27	33	36	42	47	51	--
8 by 1	--	20	25	30	32	37	42	48	55	60	--
10 by 1	--	--	29	32	34	39	48	61	67	74	--
10 by $1\frac{1}{4}$	--	--	--	--	46	51	59	73	80	88	--
12 by 1	--	--	--	36	38.50	45	58	68	83	90	$99
12 by $1\frac{1}{4}$	--	--	--	42	48	54	62	80.50	94.50	112.50	121.50
16 by 1	--	--	--	--	--	--	84.25	93	102	114	125
16 by $1\frac{1}{4}$	--	--	--	--	--	--	102.75	118.25	130.50	145	154.75

Price of Drilling and Perforating

Practically all well drilling is contracted for at so much per foot; in case the exact depth desired is not known both a minimum and maximum depth which will be drilled at this rate is stated. Sometimes an increasing rate per foot is made for each additional hundred feet of depth after a certain depth has been reached. The common practice is to include the perforating in the price paid for drilling,but the developing is usually paid for extra. Ordinarily the rate for extra work such as developing or setting in a pump is between $25 and $30 per day. Where material, such as casing, is to be furnished by the owner and delays are occasioned through material not being on hand the same charge as for extra work is sometimes made by the contractor.

In general the price of drilling increases both as the diameter and depth of the hole. The footage which can be made per day depends upon the character of the material or the formation in which the well is drilled. For this reason drilling prices are as a rule from 20 to 25 percent lower in the Casa Grande Valley and the lower Gila Valley than in the Santa Cruz Valley or in Pima County. In the Salt River Valley they are approximately the same as in Pima County. Strong competition for drilling jobs always results in a lowering of drilling prices to a certain extent. The actual prices paid and their variation are shown by the following cases.

The contract price for the three wells put down by the City of Tucson and referred to on page was $5.00 per foot. Perforating and developing were to be paid for extra at $40. per day. These wells were each 20 inches in diameter and 500 feet deep in a partly cemented formation of sand, gravel and clay of Pleistocene Age.

The contract price on an 18-inch well, drilled to a depth of 208 feet in the unconsolidated valley fill of the Santa Cruz Valley was $4.00 per foot and included the perforating of the well. This well was completed in February 1924.

A 16-inch well in the Casa Grande Valley just recently completed was drilled to a depth of 227 feet for $3.00 per foot, including the perforating.

The Apache Powder Company's well previously referred to, which was drilled 756 feet deep and cased with 16-inch stovepipe casing, was sublet for $5.00 per foot including the perforating. Except for a little sand in the first 50 feet of the well the formation consisted almost entirely of a sticky clay which made the drilling slow.

In 1922, a 12-inch well 151 feet deep was contracted for by the University of Arizona at $3.50 per foot including the perforating. The well was in cemented sand, gravel and clay from the surface practically to the bottom.

The price of drilling has remained almost the same the last three years and there seems to be no reason for any change in it for the next few years. Table V gives the approximate price of drilling for various sizes and depths of holes and represents as nearly as possible an average of present prices. It was assumed that the moving charges on the drilling rig would not be over $50 or $60. The table has been submitted to three of the leading drilling contractors in the State and their criticism and corrections incorporated.

Table V. APPROXIMATE COST OF DRILLING PER FOOT

Diameter of: hole	Depth of Hole in Feet						
Inches	100	200	300	400	500	600	800
6	$2.25	$2.00	$2.00	$2.00	$2.00	$2.00	$2.00
8 10	2.25	2.25	2.50	2.50	2.50	2.75	3.00
12 14	3.50	3.50	3.50	3.75	4.00	4.25	4.50
16 18	4.00	4.00	4.00	4.25	4.50	4.75	
20 22	4.50	4.50	4.50	4.75	5.00		
24 26	5.00	5.00	5.00	5.25			

Note: Prices include perforating but not developing of well.

It is the common practice to include the perforating in the contract price for the drilling; however, if it is to be paid for extra the prices paid usually average around $25 or $30 per day. The number of feet that can be perforated in a day will differ with the different perforators. Some of the Four-Way perforators will finish up a hole in a day, while with the Mills Knife for example, probably 50 feet per day of 12 holes per foot should be considered a good average day's work.

Cost of Developing

In figuring the cost of developing a well by the use of either a deep well pump or the air lift the local facilities for securing the necessary equipment and installing it constitute the major portion. For this reason no general costs can be given for these methods.

The developing of a well with a mud-scow will ordinarily take between two and three days for wells of about 150 feet of perforated casing, the time spent depending partly upon how thoroughly the work is done. In a very loose formation with running sand, several days may be spent in pulling this sand into the hole and bailing it out, until a very large cavity is formed outside the casing. On the other hand when the gravels and sand are partly cemented very little material is pulled into the hole and one day is probably sufficient. In most cases it is desirable to supplement the mud-scow in developing the well by pumping the well for several days.

FUTURE DEVELOPMENT

The California or Stovepipe method of drilling wells has proved to be the most satisfactory method for drilling water wells in the unconsolidated valley fills found in most of our valleys. Indications are that this same method combined with the rotary method would prove much more satisfactory for the drilling of large diameter deep wells in some of our valleys where the material consists mostly of thick bads of clays or silt. The San Simon, Sulphur Spring, Gila and San Pedro Valleys are examples of such formations.

The slump in agricultural products of the past two years caused practically a complete cessation in the drilling of irrigation wells during this period; in fact large numbers of fully equipped plants have not been operating. Conditions are now improving and a large addition to the number of irrigation wells may be looked for in the next few years.

The advent of cheap hydroelectric power will mean that thousands of acres of virgin soil will be reclaimed by pump irrigation. The formation of power districts for pumping is even under present conditions taking place. The lower Gila Valley has just recently entered into a contract for the construction of over a hundred miles of transmission line from Yuma to Wellton to serve a vast country as yet undeveloped. The Casa Grande Valley has sold its power district bonds and is now entering into a contract with the Phoenix Water Users for power.

Even under the gravity irrigation systems the drilled well has found a place, as is evidenced by the increasing number of wells put down by the Salt River Valley Water Users' Association for drainage purposes.

There are hundreds of thousands of acres of the finest agricultural land in the State of Arizona which can never be put under cultivation except by irrigation from wells, and it is in developing the natural resources of our State in this way that the California or Stovepipe method of well drilling will prove of greatest value.

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