FAO CORPORATE DOCUMENT REPOSITORY

Title: Self-help wells...

Produced by: Natural Resources Management and Environment Department

More details

◀ ☰ ▶

4. Small diameter wells

4.1 Bored or augered wells

This method of excavation consists of shaving or cutting material from the bottom of the hole by the rotation of a cylindrical tool with one or more cutting lips. The process is quite analagous to boring a hole in wood or metal with an auger or drill. The excavated earth normally feeds upward and is contained in the body of the auger where it remains until the auger is emptied. The auger is both rotated and raised and lowered by means of a vertical shaft which extends upward from the auger to a convenient point above ground level from which it can be rotated. Rotation is frequently accomplished by human power applied to a handle attached to the vertical shaft. However, the auger may be driven by other power sources such as animal or engine power. In this case, the power source drives a horizontal ring gear. Two projections extending upward from the ring gear drive a bar known as a "kelly" which lies across a diameter of the ring. A square section of the auger shaft fits through a square hole at the centre of the kelly bar which causes the auger shaft to rotate with the kelly bar while allowing it vertical freedom.

Each time the auger is filled with excavated material, it must be brought out of the hole for emptying. In order to accomplish this, the auger shaft must be divided into sections which can be uncoupled and set aside.

Several types of earth augers have been used successfully for boring wells (Figure 3). The cylindrical bucket auger is a sheet metal cylinder with an attachment for the auger shaft at the top. The bottom has a helical form with a single cutting lip. It may be hinged and latched, so that it can be opened for emptying. The two-bladed auger consists of two cylindrical blades attached to the auger shaft. The blades are cut and bent at the bottom to form cutting lips. This type of auger is frequently used for boring post holes.

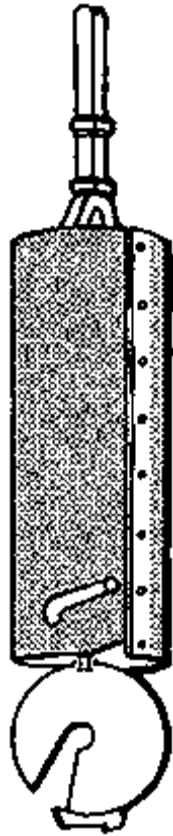**Fig. 3. Earth augers. (a) cylindrical bucket auger**

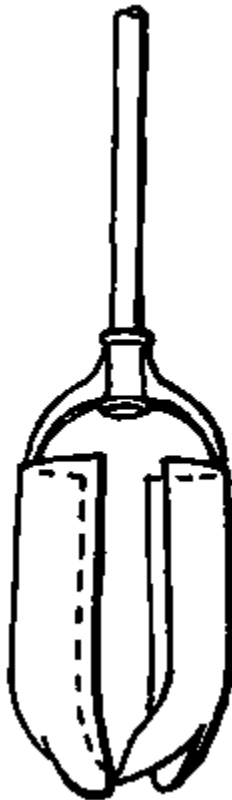**Fig. 3. Earth augers. (b) two-bladed auger**
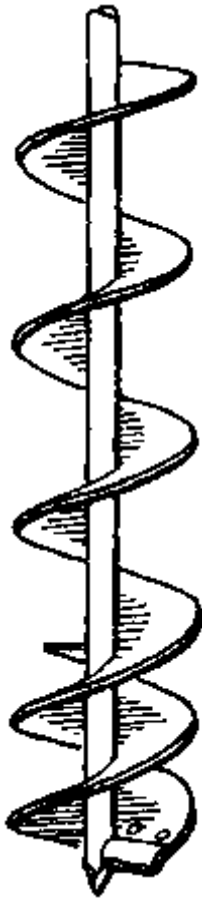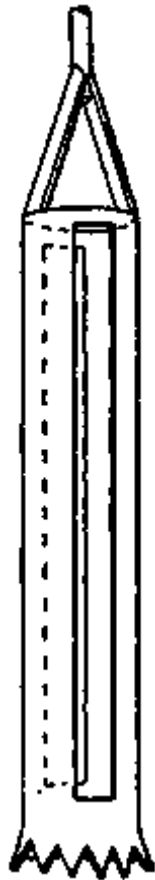

Fig. 3. Earth augers. (c) helical auger

Fig. 3. Earth augers. (d) tubular auger

A third type of earth auger (Figure 4) has a spiral of helical form. This type of auger normally has two cutting lips, one of which is mounted on the leading edge of the helix. It is sold commercially for power boring of holes or for planting trees.

A fourth type of "auger" device (Figures 5 and 6) has been used by the author in sticky or heavy clay soils where conventional augers with cutting lips did not function well. This consists of a slotted piece of tubing or pipe with the lower end cut into a tooth and flared configuration. The upper end was attached to a conventional auger shaft. This auger is alternately rammed downward and then rotated. The downward motion causes soil to be forced up inside the auger where it adheres and the rotation breaks this soil free from the bottom of the hole. A small quantity of water may be maintained at the bottom of the hole for lubrication.

Most types of augers work well on a wide variety of soils. The type used may depend largely on what can be obtained or built locally. When selecting or building an auger, several principles should be observed:

> - the cutting lips or edge should cut a diameter slightly larger than the body of the auger above them, so that the auger will not drag on the sides of the hole
>
> - the cutting lips should be angled in such a way that only the cutting edge and not the surface behind it comes into contact with the surface to be penetrated; this improves penetration and reduces drag
>
> - as the height to diameter ratio of an auger increases, the straightness of the hole tends to increase (i.e. a tall, small diameter auger tends to bore a straighter hole than a short, large diameter auger)
>
> - the body of the auger must be capable of holding the excavated material until the auger can be removed from the hole for emptying. Finely divided material has a tendency to flow out of the auger if openings are too large. When the water table is reached, augers cannot normally retain the cuttings and deepening of the well must be carried out by one of the other methods described. \

Fig. 4 Locally fabricated helical auger attached to pipe extension

Fig. 5 Locally fabricated cylindrical "auger" used in sticky soils

Drilling is accomplished by ramming downwards and then twisting. Auger teeth should be flared outwards to give clearance between auger and hole. Smaller tool is for cleaning compacted soil from the auger.

**Fig. 6 Cylindrical auger with pipe extension and handle attached**

Tripod is used to support auger during drilling.

Augers cannot normally penetrate stone. However, thin layers or small pieces of stone can sometimes be pulverized or dislodged and removed by means of a percussion bit or a spiral auger ("ram horn") made of steel rod in a form similar to a corkscrew. If the stone can be penetrated or removed, boring can be continued. If not, a different process or new location must be tried.

The necessity of emptying the auger each time it is filled places some practical limits on the depth of augered holes. Since the sections of the auger shaft must be uncoupled each time the auger is emptied, the time required for emptying increases with the depth of the hole. To minimize the number of couplings, the lengths of auger shaft or "extensions"

should be made as long as practical. Frequently, auger shafts are made from lengths of water pipe which range in length from 6.1 to 6.4 metres (20-21 ft). Extensions (Figures 7 and 8) may be coupled by means of a socket attached to the top of each one. The bottom of the next extension is inserted into this coupling and held there by a pin through the socket. Normal threaded pipe couplings do not make satisfactory attachments, since they wear under prolonged use. An overhead structure of some type is needed to steady the long extensions and to ensure that they are maintained vertical during the drilling operation. It is also convenient to lean the extensions against this structure when they are uncoupled. The overhead structure for steadying and guiding the extensions might consist of a tripod with a crosspiece between two legs (Figures 9 and 10) or of two vertical posts set in the ground with a crosspiece between them. The handle or other device for rotating the auger shaft should be designed to mount at any point along the extensions, so that it can be maintained at a suitable working height (Figure 11).

Fig. 7 Auger extension and handle
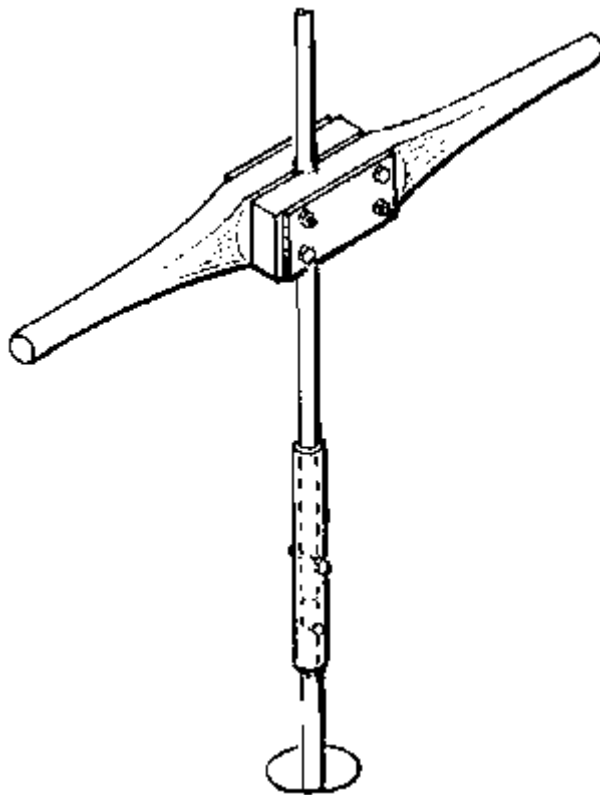
Fig. 8 Coupling for auger extensions made from larger pipe and welded to the top of an extension.

The succeeding extension is pinned in place by a 10 mm bolt. During coupling or uncoupling the bottom of the coupling is supported by the notched board. The short length of rod is inserted to prevent the extension from being accidentally dropped down the hole.

Fig. 9 Tripod used to support long auger extensions during drilling
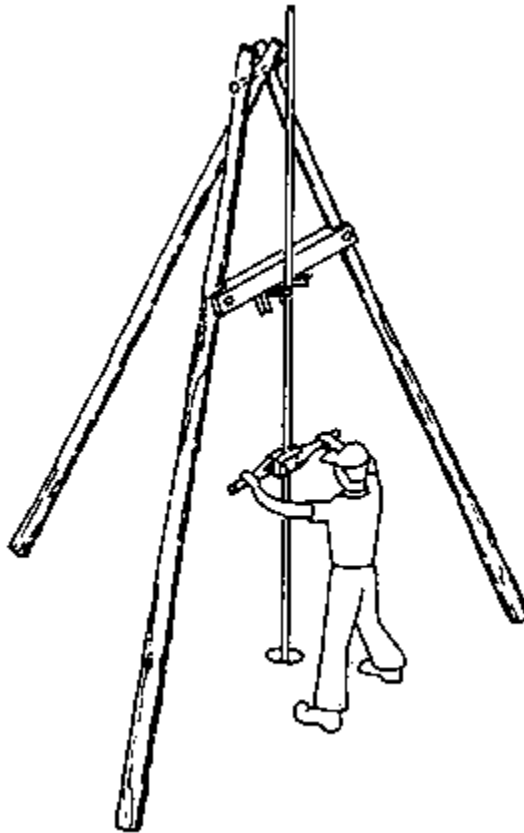
Fig. 10 Tripod used to support long auger extensions during drilling

Fig. 11 Drilling with a helical auger

Fig. 12 Reaming blade for enlarging hole attached to top of auger

After the approximate well location has been selected, the overhead support can be set up, and the exact location determined by hanging a plumb line from the overhead auger guide. A small starting hole for the auger can then be dug. It is important to get the auger starter as close to vertical as possible.

The deepest hand augered well known to the author is approximately 38 metres (125 feet). This well was bored by a crew of workers who were paid by the metre and was bored at a very reasonable cost. However, under other economic conditions the practical limit for hand boring may be less. When augering becomes too slow, it may be more practical to continue with a different method.

Some earth augers may be equipped with a blade for reaming to the desired well diameter (Figure 12). Boring an exploratory hole prior to digging a large diameter well may also be a good investment where conditions are uncertain.

4.2 Driven wells

The driven well consists of a pointed perforated pipe or a pipe with a pointed well screen attached which has been driven into an aquifer. The pipe with pointed well screen is driven into place in much the same way a nail is driven into wood. Normally special pipe with thick walls and specially designed couplings are used to resist the driving forces. Under suitable conditions this method can yield a finished well in a very short time. While the well diameter is normally small and the yield relatively low, a number of driven wells may be coupled together and pumped with a single pump. Because driven wells are quick to construct, they may be used as a temporary source of water and then be pulled up when no longer

needed. Driven well points may be installed and used for dewatering an excavation during construction. Unlike other well construction methods, material is merely forced aside and not excavated by the driving process. This means that little is learned about the material through which the well pipe passes. This kind of well can, however, be used for exploratory purposes to determine static water level and rate of inflow versus drawdown. Hard formations cannot be penetrated by this process. Barring impermeable strata the depth to which such a well can be driven depends on the build-up of friction between the well pipe and the material penetrated and the transmission of the force of the driver down the length of pipe. Twenty-five to thirty metres (80-100 feet) would probably be a maximum. A driven well point might be employed to finish a hole which had been excavated down to the water table by some other method such as an auger.

Driving is normally accomplished by alternately raising and dropping a weight used as a driver (Figure 13). The driver is guided on either the inside or the outside of the pipe causing it to strike squarely and accurately. If the driver is designed to strike the upper end of the pipe a driving cap is screwed onto the threads to protect them. Alternatively the driver may be designed to strike a clamp made for that purpose around the outside of the pipe. A long, thin driver which fits inside the pipe and which strikes a flat surface on the inside of the well screen point may also be used. This latter technique eliminates compressive loading on the pipe normally caused by driving and makes heavy drive pipe unnecessary.

Fig. 13 Devices for well driving. (a) guided on outside of pipe

Fig. 13 Devices for well driving. (b) guided on inside of pipe

Fig. 13 Devices for well driving. (c) driving on clamp
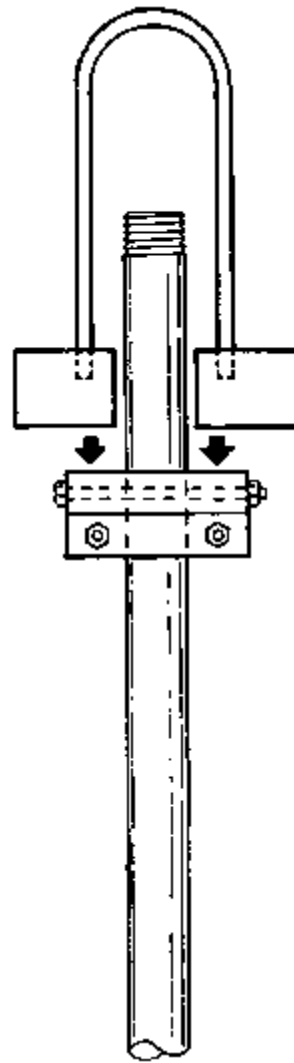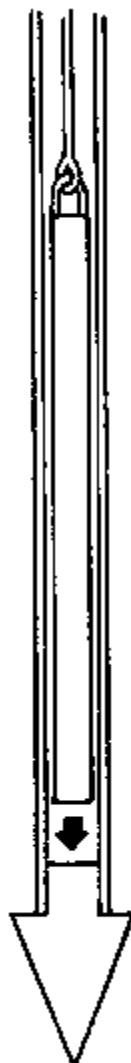
**Fig. 13 Devices for well driving. (d) driving on inside of point**

Well screens for driving must have sufficient strength to withstand the forces caused by the driver and the abrasion of the material through which they pass. One common type (Figure 14a) consists of a perforated drive pipe fitted with a point. The perforated section of the pipe is wrapped with a layer of brass screen of the desired fineness and the screen is protected from damage by wrapping it with a layer of perforated brass sheet. Both layers are soldered to the pipe. Another type of well screen (Figure 14b) is manufactured by wrapping trapezoidal rod in a spiral around a set of round longitudinal rods placed in a circular pattern with all intersections welded. This type of screen has the advantage of having a high percentage of open area and a slot shape which cannot become wedged full of fine sand particles.

Fig. 14 Drive points and screens. (a) perforated pipe with screen

Fig. 14 Drive points and screens. (b) spiral trapezoidal wire
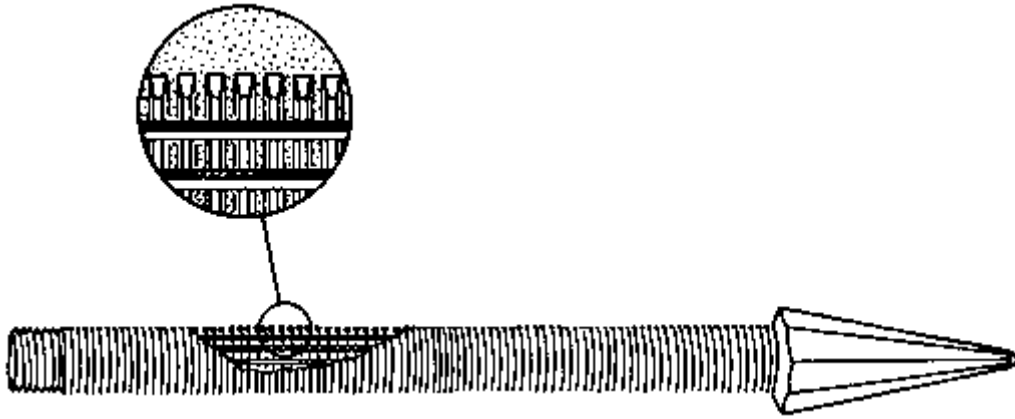
A drive point can be fabricated locally from pipe (Figure 15). The point is made by: (i) flattening the end of the pipe to a gradual taper similar to the working end of a screwdriver or cold chisel; (ii) cutting out a 'V notch from the corners of the flattened end to a point at the middle of the pipe near where the taper starts; (iii) bringing the two resulting points together to a single point; (iv) welding the two sides of the point together; and (v) filing or grinding away any irregularities to yield a smooth point. If welding equipment is not available the point can be forge-brazed or welded. A collar should be welded or riveted above the point to increase the size of the hole to a diameter slightly greater than that of the pipe couplings used. Alternatively, a point may be forged from solid steel and welded or riveted to the end of pipe. In this case care should be taken to make a shoulder on the back of the point which butts against the end of the pipe quite accurately and make the largest diameter of the point greater than that of the pipe couplings to provide clearance.

Fig. 15 Drive point fabricated from pipe. (a) forming point on end of pipe
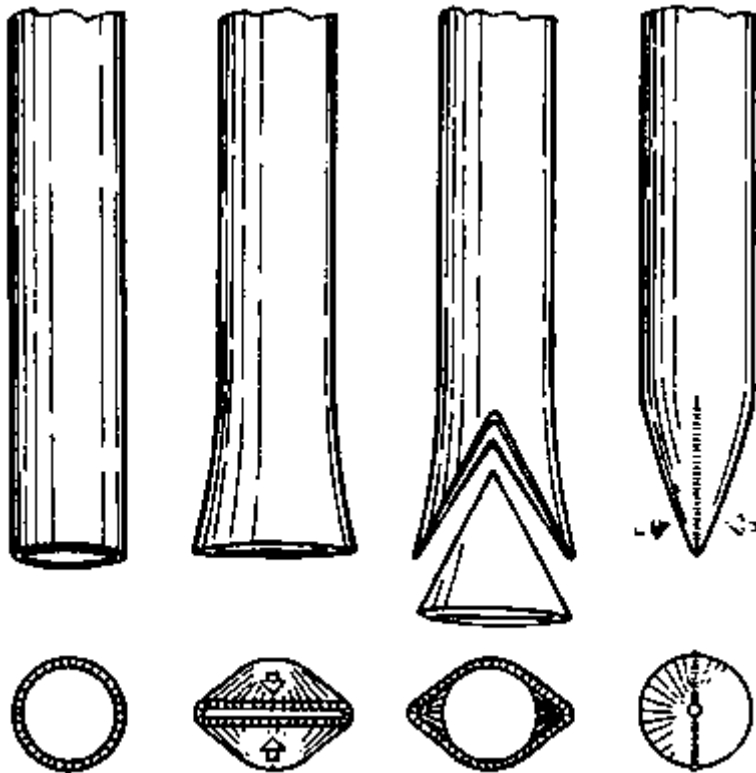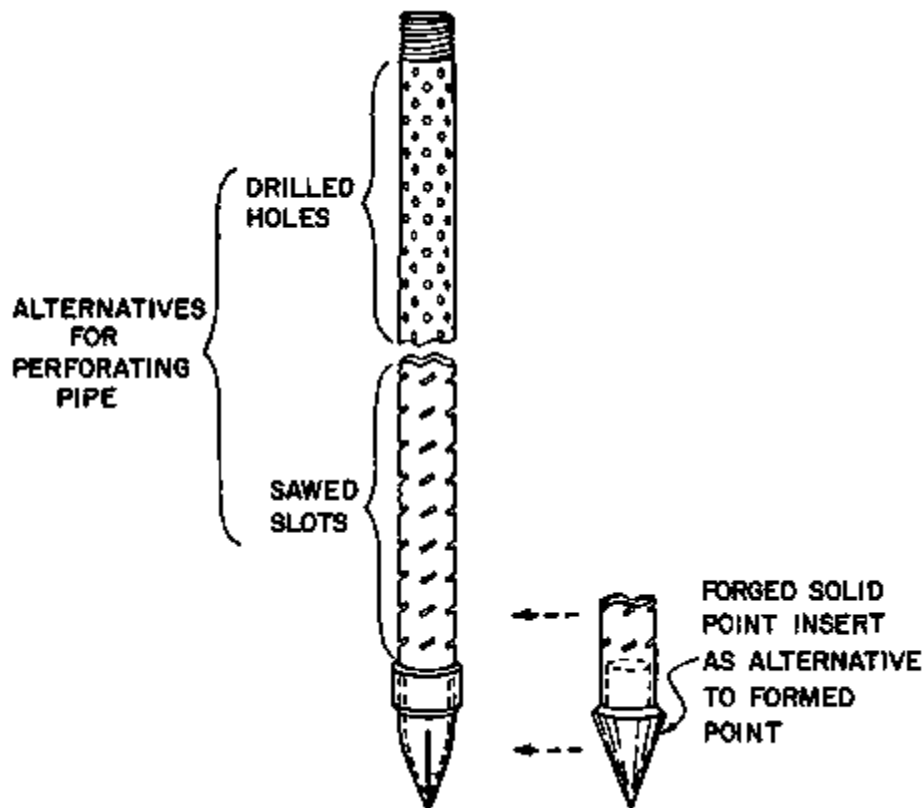

Fig. 15 Drive point fabricated from pipe. (b) alternative perforations and points

Perforations may be made by drilling holes of the desired screen size or by making a series of short diagonal hacksaw cuts (Figure 15b). In either case enough strength must be retained in the pipe to permit driving. This can best be assured, in the case of the saw cuts, by leaving several longitudinal strips unperforated. If larger perforations are made and covered with screening of the desired mesh soldered around the pipe, the screening should be protected from being slit or stripped back by: (i) wrapping and soldering sheet metal with coarse perforations around it and (ii) having an outside diameter greater than the outside diameter of the screening either on the point or on a collar attached to the pipe below the screen.

If driving is attempted using ordinary pipe and couplings, shearing or stripping of the pipe threads or breaking of the pipe at the threads will probably occur. It should be noted that the threads on standard weight pipe cut through more than half of the wall thickness, thus greatly reducing the strength of the pipe where it is threaded. Drive pipe and couplings, in addition to being heavier than standard pipe, are designed so that the pipe ends butt together inside the coupling. This results in most of the driving force being transmitted by the ends of the pipe rather than by the threads. In addition, the couplings are frequently longer than normal couplings with a bore on each end which extends back over the non-threaded portions of the pipe to give lateral reinforcement to the weaker threaded ends.

If drive pipe and couplings are not available several techniques may be used to improve the strength of ordinary pipe. These <u>may</u> allow ordinary pipe to be used for driven wells if care is exercised:

   i. If a suitable well point is available, driving may be done on the inside of the well point rather than at the top of the pipe.

   ii. If driving must be done near the top of the pipe, it should be done on a clamp around the outside of the pipe rather than on the end of the pipe itself.

   iii. Stress on the threads can be decreased by one of the following:

- running a threading die further along the pipes, so that the pipe ends may be butted together at the centre of the coupling;

- placing a short collar inside the coupling for both pipe ends to butt against;

- welding collars to the outside of the pipe which butt against the ends of the coupling.

4.3 Jetted wells

This method makes use of a high velocity stream of water to excavate the hole and to carry the excavated material out of the hole. It therefore requires some type of pump, either motor or hand-powered, of reasonable capacity, as well as a supply of water. It is possible to separate the water and the excavated material in a settling pool or tank and to reuse the water, thus minimizing the quantity required. Since this method depends on the erosive action of water, it is obvious that extremely hard materials cannot be penetrated. However, semi-hard materials may be penetrated by a combination of hydraulic and percussion effects. This is accomplished by raising and dropping a chisel-edged jetting bit. Coarse materials such as gravel require a greater water velocity to move them vertically out of the hole than do finer materials. However, very fine, hard packed materials such as clays require a high water velocity to dislodge them. Water pressure of 3 kg/cm^2 (40 psi) for sand and 7-11 kg/cm^2 (11-150 psi) for clay or gravel have been recommended. Under good conditions, drilling progress is very fast.

Two basic schemes are used:

(1) Water is pumped down a jetting tube or pipe which is used inside a temporary or permanent casing (Figure 16a). The excavation of material by the stream of water allows the casing to descend and the excavated material is carried upward out of the well via the annular space between the jetting tube and the casing. Rotating the casing and cutting teeth on its bottom edge increases the rate of descent. If the casing sunk during the jetting operation is temporary, the final casing with screen attached is lowered inside the temporary casing, which is then jacked out of the hole. Alternatively, the permanent casing may be sunk during the jetting operation. In this case, the well screen is lowered inside the casing and the casing is then jacked up far enough to expose the well screen to the aquifer.

(2) Jetting may be done by pumping the water down through the casing itself with the excavated material being carried up through an annular space around the outside of the casing (Figure 16b). If jetting is interrupted before the casing is sunk to the full desired depth, so that the suspended material settles around it, difficulty may be experienced in re-starting the jetting process. When an open-ended casing is used, a well screen is subsequently lowered and the casing raised slightly to expose the well screen. Alternatively a string of casing with a special self-jetting point on the end of a well screen may be used. The jetting orifice at the end of the well screen is closed by a check valve which is held against its seat either by buoyancy or by a spring when not held open by the pressure of the jetting water. In some cases a smaller string of pipe passes down through the inside of the casing and screen and is screwed into the top of the jetting point. The pipe is used to transmit the jetting water from the pump to the point, without leakage out through the screen. After the jetting operation, this pipe is unscrewed and removed.

An overhead pulley or hoist facilitates handling casing and jetting pipe. In some cases it may be desirable to drive the casing at intervals as described in other sections.
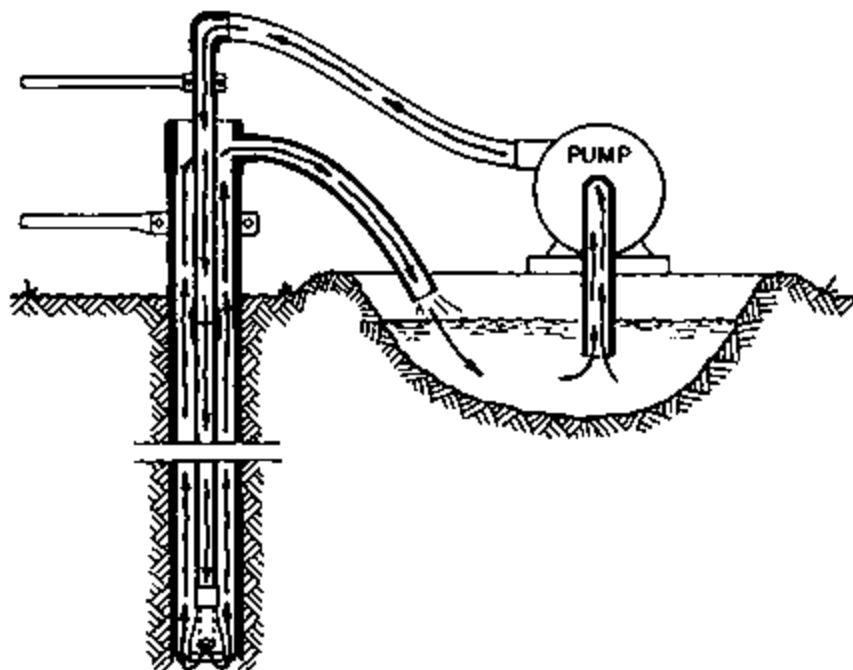
Fig. 16 Well jetting. (a) using jetting tube
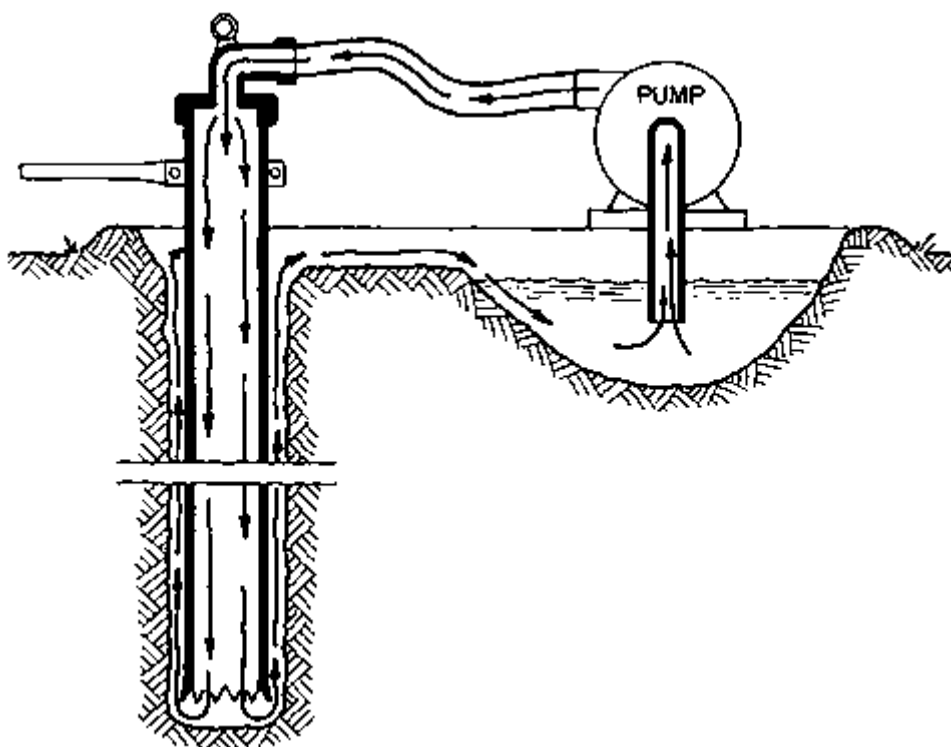
**Fig. 16 Well jetting. (b) jetting in casing**

4.4 Hydraulic percussion (also hollow rod method)

In this method the hole is kept full of water and a combination of mechanical and hydraulic action do the excavating (Figure 17). A chisel-edged cutting bit is attached to the bottom of a string of drill pipe. The hollow bit has inlet ports a small distance above its cutting edge.

During drilling the drill pipe is alternately raised and dropped. Pressure due to the impact of the cutting bit in the bottom of the hole and the inertia of the water cause a mixture of water and cuttings to enter the inlet ports of the cutting bit. This causes the already full drill pipe to overflow. A check valve in the cutting bit prevents the mixture of water and cuttings from flowing out of the ports when the drill stem is raised. The cuttings may be settled out from the water in a pool or barrel after the mixture overflows from the drill pipe and the water can then be recycled. Hydraulic percussion is limited to drilling through relatively fine materials, since coarse materials will not rise to the surface through the drill pipe. This method has been used to depths of more than 900 metres (3 000 feet) in alluvial areas where neither hard formations nor coarse materials were encountered.

A variation of this method has been traditionally used in various parts of Asia. In the traditional method the check valve is replaced by a hand of one of the drillers who seals off the top of the pipe on the up-stroke and removes his hand on the down stroke to allow overflow. In the traditional method the hollow drill stem as well as the casing may be made of bamboo (Figure 18).

Fig. 17 Hydraulic percussion
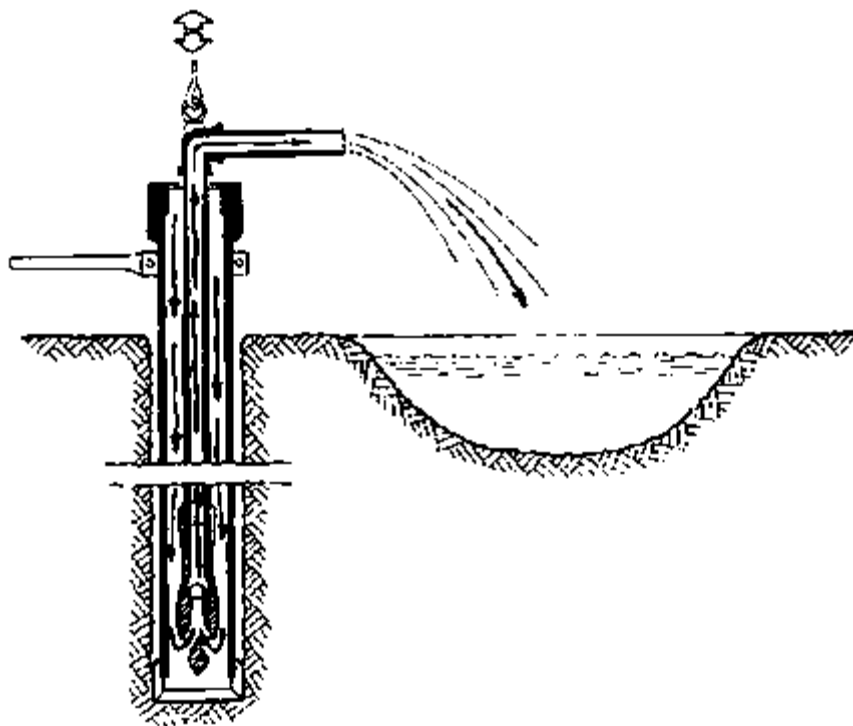
Fig. 18 4 inch diameter bamboo screen - bamboo strips wired to metal rings, then wound with coir rope

4.5 Percussion (also cable tool method)

This method consists of repeatedly raising and dropping a chisel-edged bit to break loose and pulverize material from the bottom of the hole. A small amount of water is kept in the hole, so that the excavated material will be mixed with it to form a slurry. Periodically the percussion bit is removed, and a bailer is lowered to remove the slurry containing the excavated material. The bailer or bailing bucket consists of a tube with a check valve at the bottom and a bail for attaching a cable or rope to the top. When it has been raised and dropped a number of times to fill it with the slurry it is brought to the surface for emptying. Bailing is repeated until the hole has been adequately cleaned, at which time drilling is resumed; drilling and bailing are then alternated. If the hole is unstable, casing is lowered

and the driving of casing is alternated with the other two processes. In loose granular material, such as sand, bailing alone may be sufficient to remove the material from the bottom of the hole and allow the casing to be sunk. A heavy bailer with a cutting edge at its lower end, known as a "mud scow" is used for this purpose.

The percussion method is versatile, allowing all types of materials to be penetrated. However, in very hard stone, progress is slow. While this method is frequently associated with large, motorized, truck-mounted equipment, it can be successfully scaled down and used with manpower, or small engines (Figures 19 and 20). It may be used in conjunction with other methods when conditions are encountered such as hard or loose materials which make it more suitable.

Fig. 19 Balling well with 6 cm diameter bailer

Fig. 20 Bailing well with manpower. Hand winch is being used to raise the full bailer from the bottom of the well.

Fig. 21 Locally forged percussion drill (weight approximately 80 kg)

Fig. 22 Locally fabricated bailer with heavy rubber check valve

Equipment for percussion drilling can be fabricated locally (Figures 21 and 22). A heavy leaf spring from a large truck or bus makes a good cutting edge for a percussion bit (Figure 23). It should not be heated during fabrication unless skills are available for rehardening. The leaf spring can be cut to a chisel edge (90-120° included angle) using a high-speed steel hacksaw blade. The spring steel cutting edge can be fitted into the end of a slender piece of mild steel 2-3 metres (6-10 feet) long such as an 'I' beam, two pieces of channel iron back to back, or a piece of pipe flattened at one end to fit closely around the spring steel. The spring steel should be welded or riveted in place. If possible, the upper end of the spring steel piece should butt against a notch cut into the supporting bar. This is to lessen the impact during loading on the welding or rivets during use. All transitions between the spring steel piece and the supporting bar should be bevelled, so that there are no sharp corners to catch on the side of the hole either on the upstroke or the downstroke. The cutting edge should be wider than the widest dimension of the supporting bar, so that there will be clearance around the bar in the drilled hole. The weight of the bit can be increased by adding material such as by attaching flat iron bars to the web of the beam or channel or filling the pipe with concrete, possibly using broken pieces of cast iron as the aggregate. A starting weight of 50-60 kg (110-130 lb) might be appropriate for a 10 cm (4 inch) diameter well.

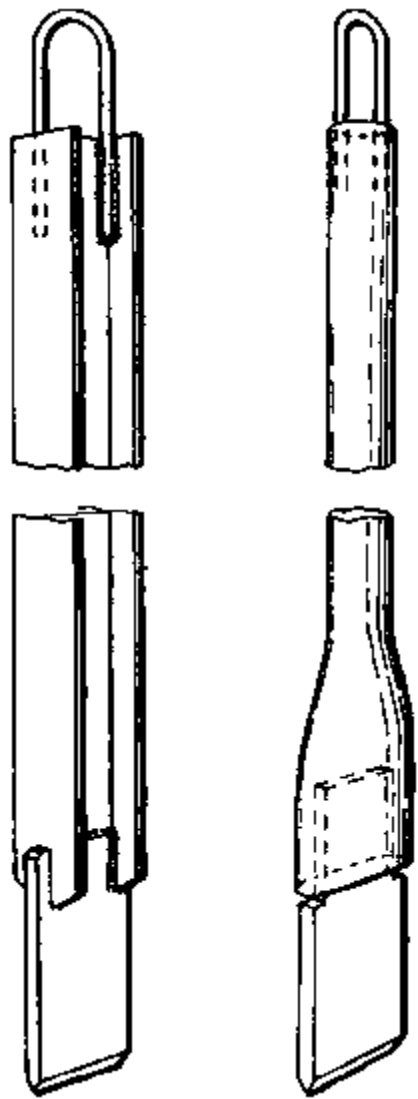**Fig. 23 Percussion bits, locally fabricated**

Fig. 24 Bailer, locally fabricated

A bailer can be made from a piece of steel pipe or tubing (Figure 24). A ring for the check valve seat may be forged from flat stock to fit securely into the lower end of the pipe where it is held in place by welding, rivets, or bolts. The valve consists of a disk of heavy rubber reinforced by a piece of flat metal and attached to the valve seat at one edge.

Both the bailer and the percussion bit should have a rather large bail or loop fixed at the upper end for attaching a rope or cable. The large size facilitates "fishing" or retrieval of the tool in the event that the rope or cable breaks or becomes detached.

4.6 Hydraulic rotary

This method employs a drilling bit at the bottom of a stem of rotating drill pipe. Cuttings are removed by pumping water or a mixture of water and various clays down through the drill stem. This "mud" entrains the cuttings and carries them up through the annular space between the drill pipe and the wall of the hole. When they reach ground level, the cuttings can be settled out in a small pond and the "mud" recirculated. If the reverse flow path is used ("mud" pumped to the surface through the hollow drill pipe) the system is called reverse rotary. The reverse rotary system allows larger particles of cuttings to be brought to the surface, because the upward flow velocity inside the pipe is greater than that through the annular space, due to the smaller flow cross section inside the pipe.

A second function of the drilling "mud" is to seal and stabilize the walls of the hole to prevent collapse and excessive loss of the fluid being circulated. This sealing of the walls,

however, can greatly reduce or prevent the inflow of water to the well unless proper steps are taken to "develop" the well.

Two types of drilling bits are normally used: (i) a "fish tail" with two stationary blades for use in soft materials and (ii) a rotary bit with three or more gear-like rollers which roll around on hard material to crush and pulverize it.

Hydraulic rotary drilling is normally done with large engine-powered equipment. This method is used almost exclusively in oil well drilling and is also commonly used in water well drilling where wells are deep and much solid rock must be penetrated.

There are at least two exceptions to the large-scale equipment normally used for this method. The first is a system based on a small, hand-held, vertical shaft, air-cooled engine. A gear reduction unit integral with the engine has an output shaft which rotates at approximately 60 rpm. Drill pipe of 1¼ inch nominal size is attached directly to this shaft. A "tee" swivel near the top of the drill pipe allows water to be pumped down through it and return to the surface via the annular space around it. A fish-tail bit is used for penetrating soft materials. For hard materials a core drill is used. This is a tubular drill of hard, abrasive material which cuts an annular groove and leaves a cylinder of uncut material inside the drill. This uncut cylinder can be removed from the hole by wedging fine lead shot between the core and the inside of the core drill and removing it from the hole along with the drill. Alternatively, a core extractor with spring steel fingers for gripping the core may be used for removal. A second small engine is generally needed to drive a pump for circulating water.

A second system used in Bangladesh is completely hand operated, and is based on the reverse rotary system. A string of drill pipe with a cutting bit at the bottom is rotated in the hole by hand. A hand suction pump attached by means of a swivel to the top of the drill pipe is used to raise water and cuttings. Water is supplied to the annular space around the drill rod by a hand pump attached to two temporary driven wells.

Animal power has also been used to drive rotary drilling equipment.

4.7 Casing and screens

Casing serves two major functions : (i) to support the sides of the hole against collapse; and (ii) to exclude contaminated surface water. The screen, which allows the water to enter the well while preventing entry of the aquifer materials, may be a perforated section at the lower end of the casing or may be a separate structure attached to the casing.

Depending on the drilling method used and the materials penetrated, the casing may be sunk as an integral part of the drilling operation, as in the case of jetting; it may be placed after the hole is completed; or it may be placed at some intermediate point, such as when the water table is reached and the sides of the hole will collapse if not supported.

A number of different materials have been used successfully for well casing. These include wrought iron pipe or tubing, tubing rolled from sheet metal, pipe made of plastic such as polyvinylchloride (PVC) or glass reinforced plastic (GRP), asbestos-cement pipe, concrete tile, clay tile, bamboo/coir casing (made of bamboo strips attached to steel hoops and wrapped with coconut husk fibre cord and burlap), large diameter bamboo stems with the node membranes removed and split palm trunks. The type of casing used will be determined by (i) what materials are available locally; (ii) what skills are available locally; (iii) the relative costs of labour and materials; (iv) the drilling method being employed; (v) the nature of the geologic formation; and (vi) minimum acceptable life of the well.

A particularly noteworthy example of low cost, locally manufactured casing is the bamboo

and coir casing developed in India (Figures 25, 26, 27 and 28). This casing consists of longitudinal strips of split bamboo riveted to hoops spaced approximately 25 centimetres apart. The assembly is then wrapped circumferentially with coir (coconut husk fibre) rope until the entire length is covered. On those sections of the casing which penetrate the aquifer the coir rope serves as a strainer or screen. On the remainder of the casing the coir rope may be covered with burlap which is coated with asphalt. Sections of casing are butted together and are attached by several longitudinal steel ties riveted to the end hoops of the respective sections.

The life of these bamboo/coir casings is said to be two or three years. At the end of this time it is necessary to bore a new well and to line it with a new casing. The use of bamboo/coir casings is an excellent example of ingenuity and local labour, and skills being used to save scarce capital and foreign exchange.

In Egypt date tree trunks are cut into one or two metre lengths, cleaned on the outside, split, and hollowed out. During hand percussion drilling with a bailer and an under reaming bit, the two halves are inserted into the hole and driven to depths of 100 to 200 metres.

Where galvanized sheet metal is readily available, casings can be made by rolling strips into tubing with a longitudinal seam (Figures 29 and 30). In one case 1 m x 2 m sheets of galvanized steel were split lengthwise into three equal strips. A single 90° bend was made along one edge and a 90° bend plus a 180° bend was made along the other edge. These were "rolled" by means of a 2 metre long wooden "V" block over which the sheet metal was laid while downward force was being applied to a length of 2 inch diameter pipe placed on top of it. By moving the sheet metal from side to side across the "V" block a reasonably round contour could be obtained. The previously bent edges were hooked together and bent over to form a seam. To accomplish the final rounding of the casing the piece of 2 inch pipe was supported on blocks near its ends and used as an anvil. The casing was slipped over the pipe and a mallet of wood or other relatively soft material was used to do the finish forming.

Fig. 25 Coir casing. Split bamboo strips are spaced around steel rings and the assembly is wrapped with coir cord.

Fig. 26 Coir casing. The coir wrapping serves as the well screen at the bottom end of the casing.

Fig. 27 Coir casing. Casing which is above the aquifer is coated with asphalt and burlap.

Fig. 28 Coir casing being lowered into bored hole.

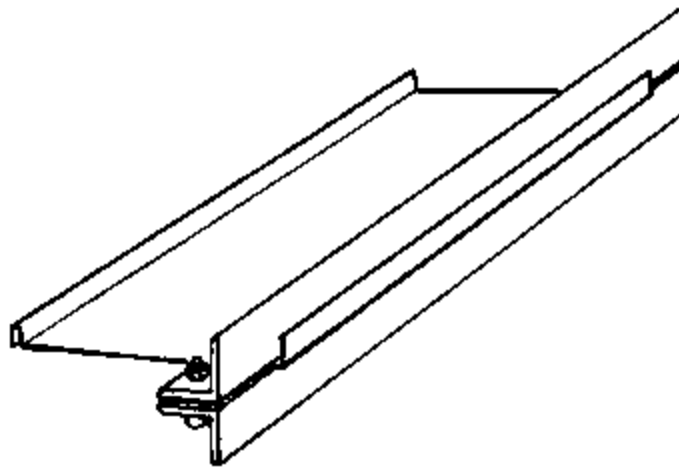**Fig. 29 Fabricating sheet metal casing. (a) edges clamped between angle irons and bent with mallet**

Fig. 29 Fabricating sheet metal casing. (b) rolling strip with pipe and wooden "V" block
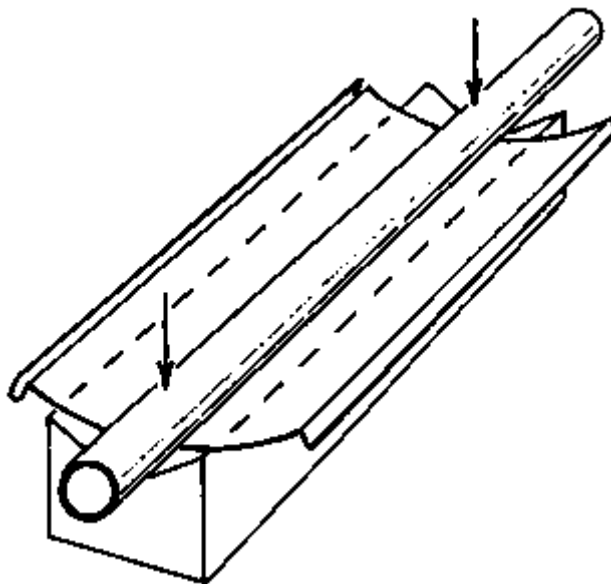
Fig. 29 Fabricating sheet metal casing. (c) hooking edges together to form seam
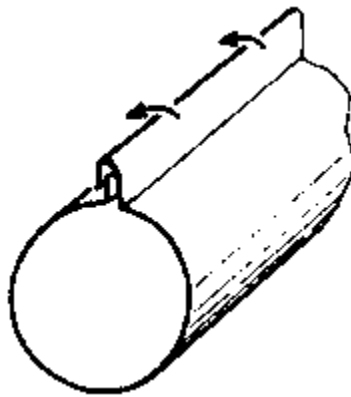
Fig. 29 Fabricating sheet metal casing. (d) crimping seam and rounding casing with pipe anvil and mallet
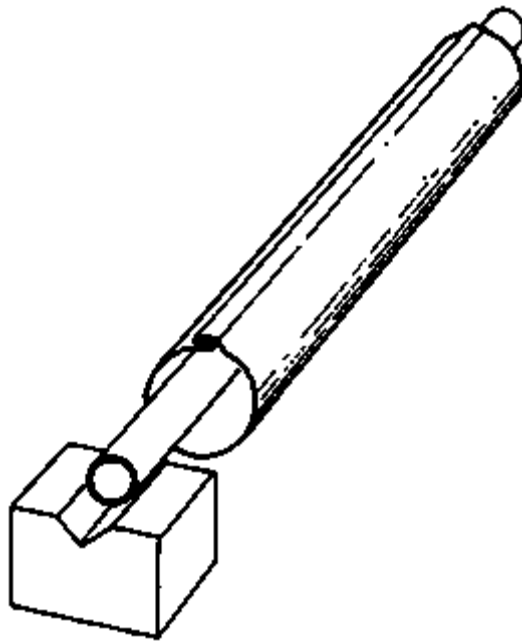
Fig. 30 Fabricating casing from galvanized sheet metal

The sheet metal casing is normally joined by slipping one end inside another and then soldering the joint. Short longitudinal strips of sheet metal lapped across the joint and soldered onto both lengths of casing can be used to further strengthen the joint, and are a worthwhile practice. Ends can be made to fit together by selective assembly, by lightly crimping one end, or by intentionally making the casing slightly tapered by varying the width of the seam from end to end.

In the "California Stovepipe" method, two light sheet metal casings are used, one fitting snugly inside the other. Joints on the inside casing come at the midpoint of the outer casing sections and vice versa. The two layers are assembled and spot welded together as they are sunk, thus creating a laminated casing which is relatively stiff and resistant to buckling.

Asbestos-cement soil pipe and concrete or clay tile are frequently made with bell and spigot joints to allow one end to slip loosely into the adjoining end for a short distance. When using such pipe or tile as casing the bells point downward to minimize entry of loose material through the loose joint into the well. The lengths may be lowered into the well singly by means of a set of hooks attached to a cord. The hooks and cord fit inside the casing and hold onto the lower end of the casing until it is in place and the hooks are released by pulling on a second cord. Alternatively, if the string of casing is not too. heavy, the joints may be wired together as they are assembled over the well and the casing lowered from the top end. This technique would be limited to relatively shallow wells by the weight of the string of casing.

Clay, concrete and asbestos cement tiles are relatively fragile and will break if such operations as percussion drilling or bailing are attempted inside them. If such operations are required for sinking the casing into the aquifer, it is necessary that the lowest section of casing be of some more durable material such as steel tubing or pipe.

Polyvinylchloride (PVC) tubing or pipe is the plastic material most commonly used as well casing. It is normally much less expensive than steel, lightweight, easy to cut and perforate and insert. Sections are joined by means of painting the ends with a solvent to soften them and then slipping them into a coupling where they fuse as the solvent evaporates.

Perforation of casing to allow its use as a well screen can be accomplished by drilling or by slitting with a hacksaw as was described in the section on well points.

A number of techniques have been used to help sink the casing as drilling progresses :

i. Driving: This technique was discussed earlier in connection with sinking well points. It can be used normally only with heavy wrought iron casing using special drive couplings which allow the casing ends to butt against each other, thus protecting the threads from deformation. As pointed out earlier, driving is accomplished by raising and dropping a weight which is guided either on the inside or the outside of the casing and which strikes either on a special driving cap screwed onto the end of the casing or on a clamp around the outside of the pipe.

ii. Jacking: This technique (Figures 31 a and 32) makes use of timber anchors buried alongside the well and jacks to maintain a downward force on the casing as drilling continues.

iii. Weights (Figures 31b and 32) such as bags of soil or drums of water may be piled on a support clamped around the pipe. Alternatively, a platform on which the drillers' stand may be clamped to the casing (Figures 31 c and 33).

iv. Weights (Figure 31 d) on a lever which applies force to the casing.

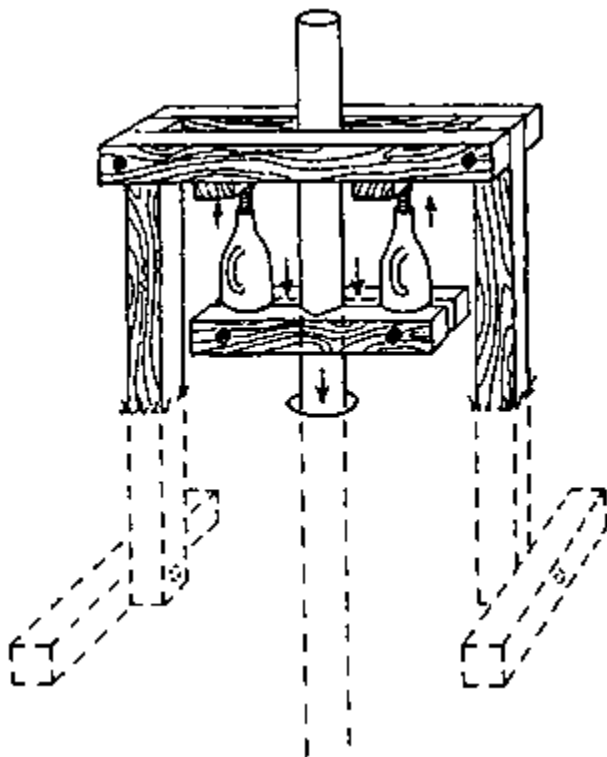### Fig. 31 Sinking casing. (a) with help of jacks

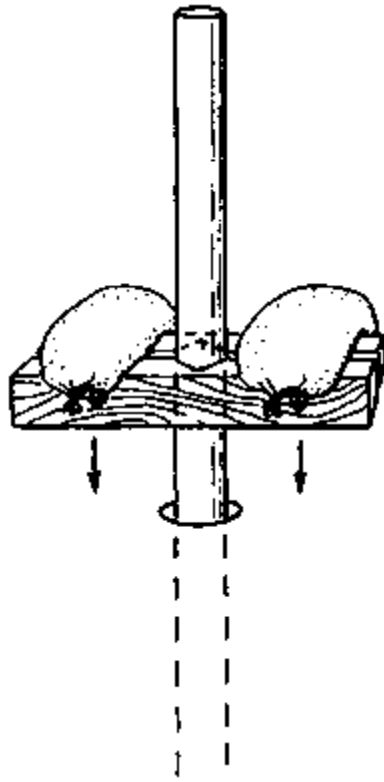### Fig. 31 Sinking casing. (b) weighting with sacks of soil

Fig. 31 Sinking casing. (c) using weight of drilling crew on platform
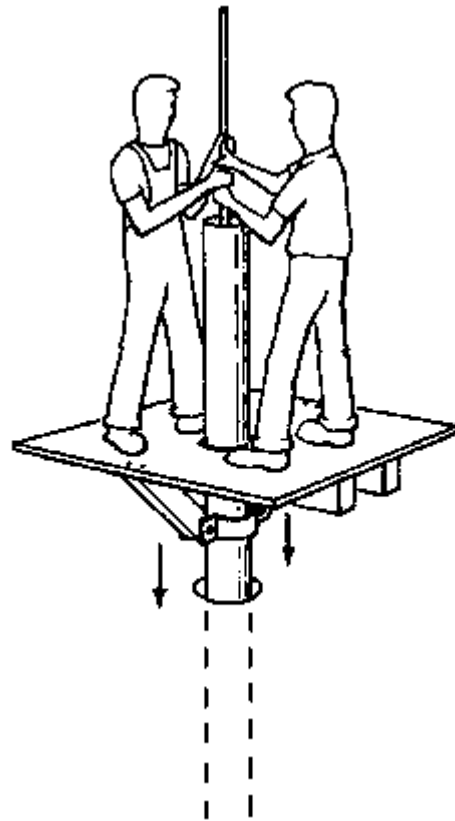

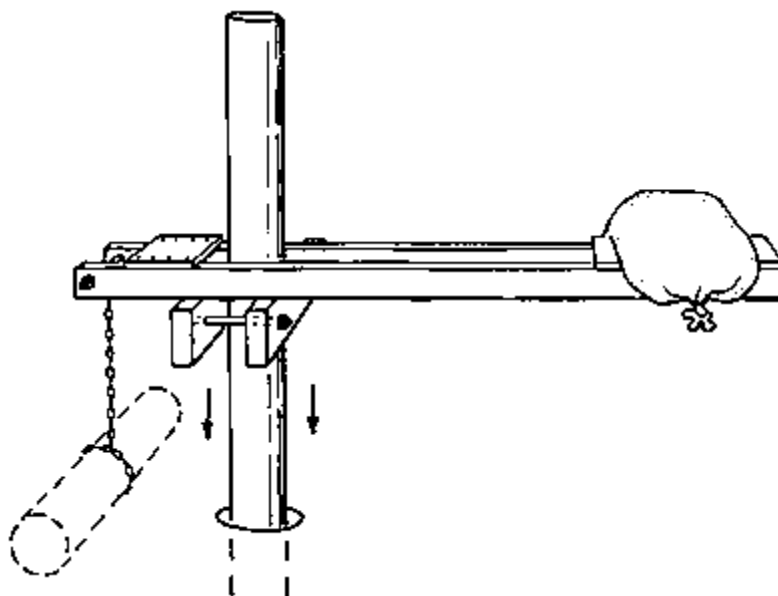**Fig. 31 Sinking casing. (d) using a lever and soil sacks**

Fig. 32 Sinking casing. Two methods are being used: (a) Workers near casing are tightening nuts on large screws attached to timber anchors beneath the ground and to top of casing. (b) Note large concrete weights clamped around casing just beneath upper end. A second set of weights is located just above the ground surface.

Fig. 33 Sinking casing. Weight of drillers is being used to help sink the casing. Workers on the ground are rotating the casing as drilling proceeds.

4.8 Methods for obtaining vertical reciprocating motion

A number of well drilling operations require a raising and dropping motion. These include percussion drilling, bail down, hydraulic percussion and driving of casing. Large scale percussion rigs obtain such a motion by cable with one fixed end running over a pulley at the end of a pivoted arm reciprocated by a crank and connecting rod. The closest analogue to this in man-powered equipment, Figures 34, 3 5 and 36, consists of a rope or cable coming vertically out of the well, running over a pulley, then running parallel to the ground at about shoulder height, and finally anchored to a tree or post. To obtain the reciprocating motion a crew of 4-6 men line up facing the rope and alternately pull down and release the rope in unison.

Another device successfully used consists of a lever pivoted over a horizontal axis, Figure 37, with the drilling tools attached to the shorter end and a crew of several men applying a reciprocating motion to the longer end. Weights could be added to the longer end to counterbalance partially the drilling tools if desired.

Fig. 34 Pulling on anchored horizontal rope to obtain reciprocating motion
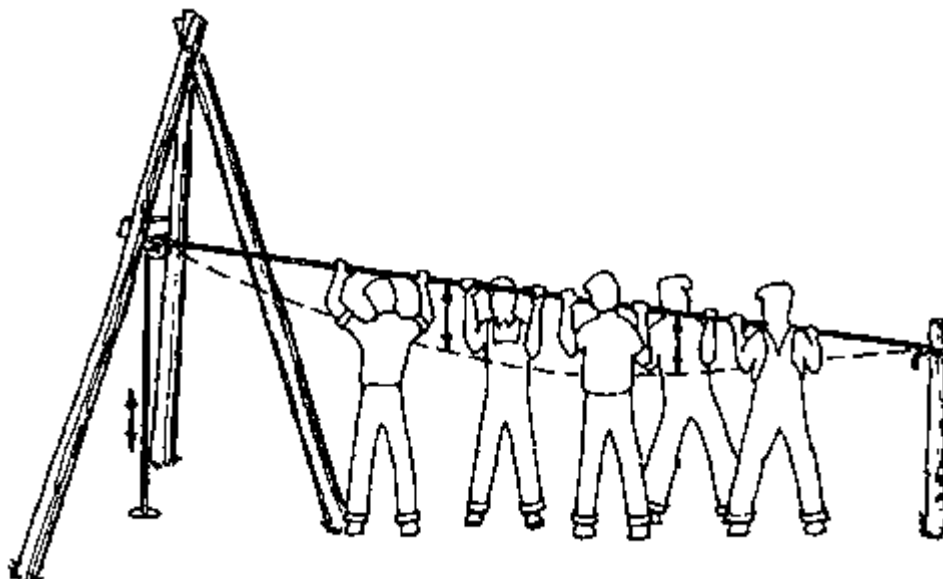
Fig. 35 Percussion drilling. Raising and dropping motion is obtained by pulling down on rope and releasing. (A)

Fig. 35 Percussion drilling. Raising and dropping motion is obtained by pulling down on rope and releasing. (B)

Fig. 36 Tripod mounted pulley used to obtain reciprocating motion for percussion drilling and bailing

Fig. 37 Using lever to obtain reciprocating motion
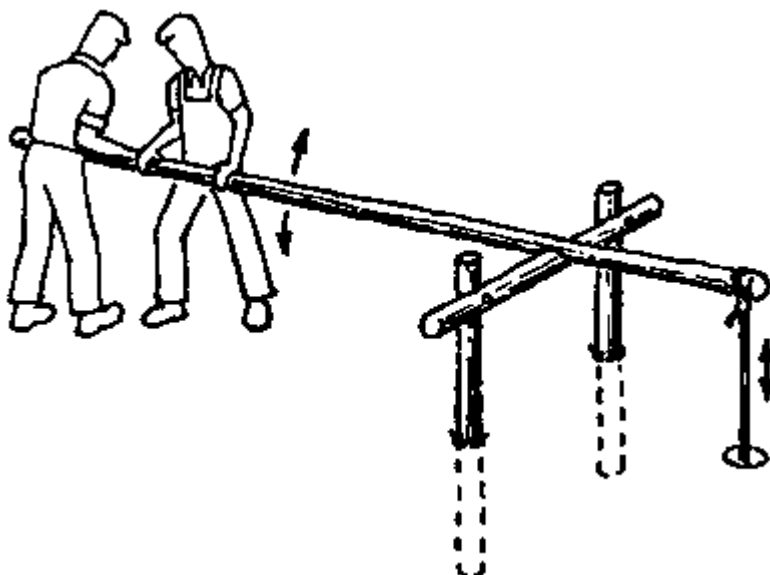
There are a number of variations of the spring beam or spring pole system, Figures 38, 39 and 40. In Figure 38 the drilling line is attached to the end of a horizontal wooden cantilever beam somewhat reminiscent of a diving board. The stiffness of the beam can be adjusted either by changing the number of leaves in the spring or by changing the position of the support nearest the end of the beam where the tools are attached. Depending on the stiffness of the beam, the elasticity of the rope or other material attaching the tools to the beam, the mass of the tools, and the nature of the materials being penetrated, the system will have some natural frequency. That is, if the beam is bent and then released, the system will oscillate at a constant number of cycles per minute with a continually

4. Small diameter wells

decreasing length of stroke until the motion is completely damped out by friction in the system. If on each downstroke a downward pull is applied, the system can be made to oscillate indefinitely with a minimum work input. In practice, a work crew stands around the line attached to the spring beam and supplies a downward force at appropriate intervals to keep the system oscillating. Alternatively, a separate rope for each can be attached to the beam. Each worker places his foot in a loop or stirrup and supplies the necessary motion with his leg and foot. This method is sometimes referred to as "kicking down a well". As the mass of tools, depth of hole and material penetrated change, the natural frequency of the system changes. This can be compensated for by adjusting the stiffness of the beam either by changing the number of leaves or the unsupported length. A greater tool mass will decrease the number of oscillations per minute while a greater beam stiffness will increase them.

Slightly less sophisticated, but widely used in North America during the first half of the 19th century is the spring pole (Figure 39). This is made from a tree 8-10 m long with a diameter tapering from approximately 20 cm at one end to 10 cm at the other. The large end is anchored to the ground possibly by piling rocks or logs on it. It is supported by a fulcrum at approximately one-third of the length from the lower end. The upper end might be at a height of 2.5-3.0 m. Stirrup ropes could be attached to the upper end for oscillating the pole.

In both the case of the spring beam and the spring pole, an overhead pulley is necessary for pulling the tools out of the hole and for bailing. This pulley would normally be supported on a separate structure such as a tripod.

Figure 40 shows a Chinese well drilling device which makes use of a large bow to obtain the oscillating motion. This general type of device goes back at least 2 600 years and has been credited with drilling to depths of 1 000 m. Such wells were used to obtain brine from which salt was made in the interior of China. The drill line is made of sections of split bamboo which are spliced together by cutting interlocking notches where ends overlap and banding the splice together with steel or hemp. Good bamboo has about the same tensile strength per unit of weight as mild steel. It is obviously not as flexible as rope or cable, however, and so the large diameter reel shown is used to wind up the bamboo drill line. Some dimensions given for the device pictured in Figure 39 are:

Length of Bow	12 - 15 m
Diameter of Bow	20 - 25 cm
Diameter of Steel Cable for Bow String	15 - 16 mm
Diameter of Reel	4 m (approximately)

A rotating drum or "cathead" driven by any convenient power source is frequently used in well drilling operations (Figure 41). If a rope is wrapped loosely around the rotating drum, it will remain stationary while the drum rotates. When one end of the rope is pulled taut, however, friction will cause the rope to move with the drum surface and the rope and drum combination can be used as a windlass. By alternately pulling the rope taut and letting it go slack, it is possible to raise and drop a weight such as a percussion bit, a set of hydraulic percussion tools, or a bailing bucket. By continually keeping the end of the rope taut as it feeds off the drum, the system can also be used to pull the tools out of the well.

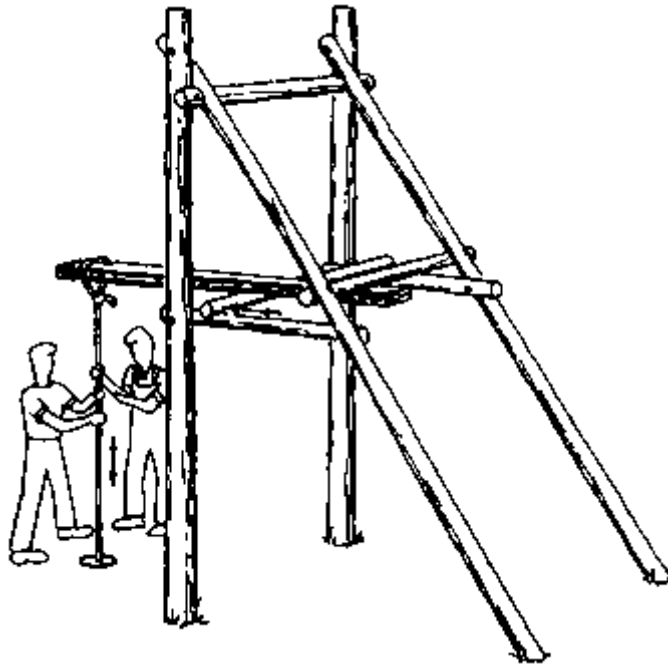**Fig. 38 Spring board for obtaining reciprocating motion**

Fig. 39 Spring pole for obtaining reciprocating motion..
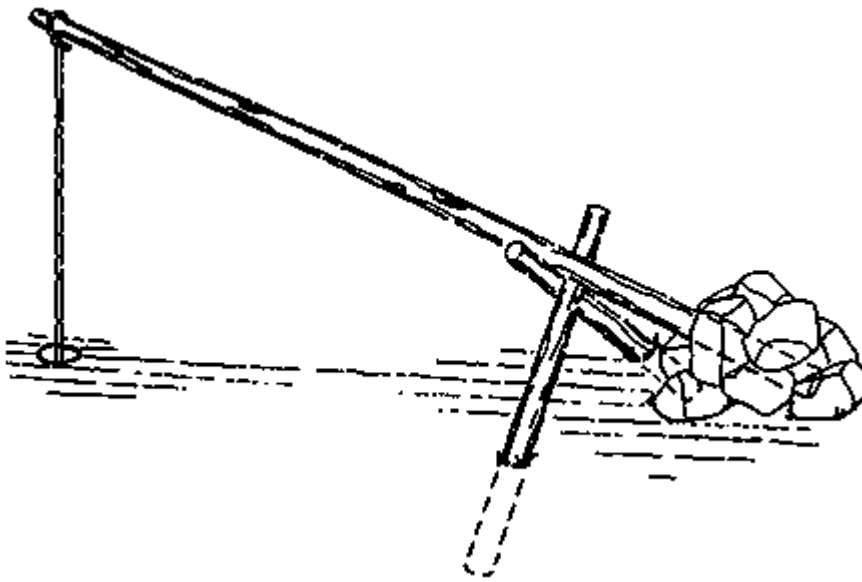
Fig. 40 Traditional Chinese drilling equipment. (a) rig with bow for obtaining reciprocating motion and reel for bamboo drill line
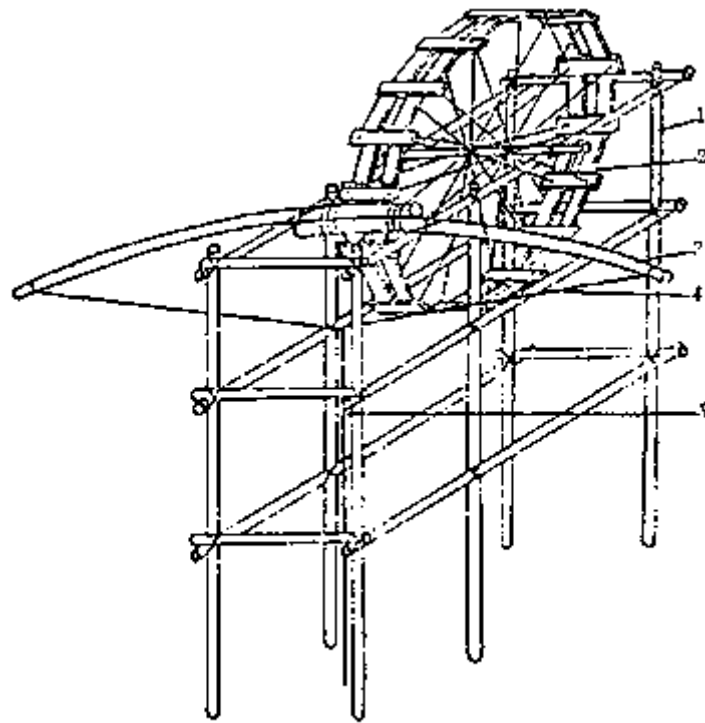
图 1 人工钻示意图
1—本架；2—辊子；3—弓子；4—弓子绳；5—立绳

Fig. 40 Traditional Chinese drilling equipment. (b) splice in split bamboo drill line

图 2 竹篾接头示意图
1—竹篾；2—方扣；3—铁箍

Fig. 40 Traditional Chinese drilling equipment. (c) drilling tools

图 5-9 锥具
1—空锥: 2—实锥: 3—加重锥: 4—扭滑
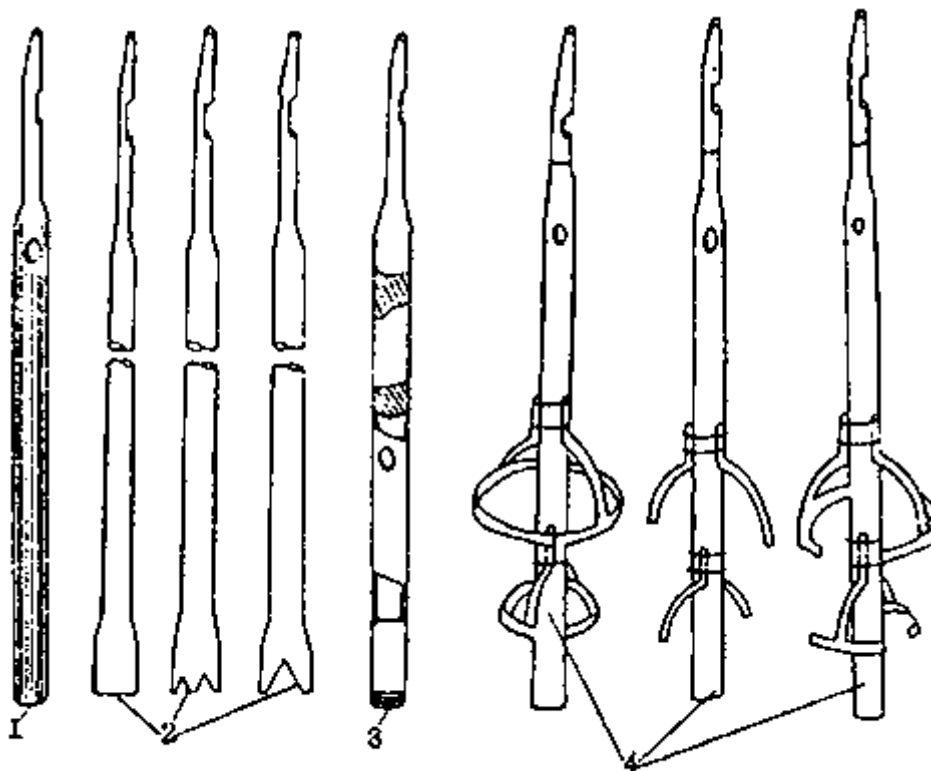
Fig. 41 Rotating drum or "cathead" to obtain reciprocating motion or for use as a winch
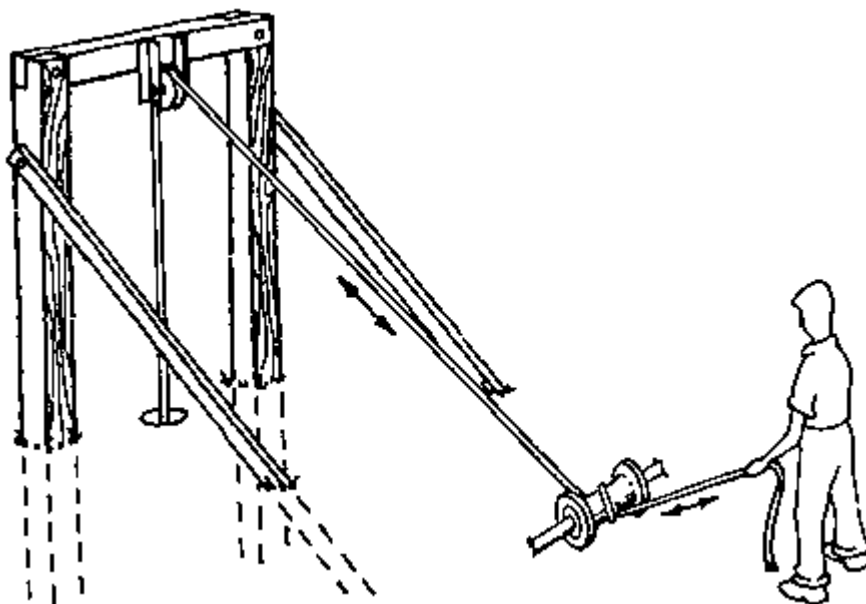
4.9 Rope

Drilling systems such as augering, jetting and hydraulic percussion make use of a string of pipe or tubing to connect the actual drilling tools with the power input at or above ground level. Whenever tools must be brought up to the ground surface it is necessary to disconnect the lengths of pipe one by one and to set them aside. Returning the tools to the bottom of the hole requires a reversal of this procedure. As the hole becomes deeper, this process becomes more time consuming and progress is thus slowed. Early percussion

drilling was carried out with rigid drill stems made of wooden or steel sections coupled together. These likewise had to be coupled and uncoupled every time tools were put into or taken out of the hole. In present day percussion drilling and bailing, on the other hand, the tools are normally connected flexibly to the power input by a rope or cable. This means that the tools may be quickly removed from or returned to the hole merely by pulling up or letting out the rope without any disconnecting or connecting.

Both manilla rope of 25-40 mm (1-1½ inch) diameter and steel rope or cable of approximately 10 mm (3/8 inch) diameter have been used successfully in self-help well drilling operations. To extend the life of the wire or manilla rope, the maximum practical pulley diameter should be used. Locally made ropes with short or coarse fibres, such as coir (coconut husk fibre) may be undependable and short-lived and cause delays and losses far in excess of the money saved by their use..

The drill lines of split bamboo successfully used in Asia for over 25 centuries were mentioned earlier.

4.10 Well development and finishing

The term well development refers to the process of removing the finer particles from the aquifer immediately around the well screen in order to make the aquifer more permeable and thus to decrease the resistance to flow of water into the well. This means that for a given rate of pumping the drawdown of the well and consequently the pumping height will be decreased. In order to develop a well, it is important that the openings in the well screen be chosen of the proper size. This necessitates collecting material taken from the aquifer during the process of drilling. One rule-of-thumb states that the openings should be of such a size that the smallest 2/3 of the aquifer particles will pass through them.

Development is accomplished by causing the water to alternately flow into and out of the well. During inflow some small particles will be carried into the well through the screen, but other small particles will bridge between particles too large to pass through the screen. The reversal of flow will dislodge such particles and give them the opportunity to pass through the screen during the next period of inflow. The fine material entering the well is ultimately removed with the water. Removal of the fine material during development, in addition to increasing the capacity of the well, saves the pump which is later installed from abrasion.

Bailing the well is probably the simplest method of development. Each time the bailer is raised and dropped water surges into and out of the well. Fine material entering the well is trapped inside the bailer and removed from the well. The amount of fine material in the bailer indicates how far the process of development has proceeded. A special type of bailer known as a sand pump has a piston inside it. This piston is attached to the bailer line in such a way that it travels upward inside the bailer as the line goes from slack to taut. The motion of this piston has a strong surging effect on the well and helps to draw sand into the bailer.

A surge block, which acts as a piston or plunger inside the casing, can be attached to a string of pipe and made to travel up and down for the purpose of development. A surge block may consist of two or more wooden disks fastened together with rubber between them which makes contact with the inside of the casing.

Wells may also be developed by pumping water out at a high rate to create a large drawdown. Pumping is suddenly stopped and a large quantity of water which has been accumulated is allowed to run down into the well to reverse the flow through the aquifer around the screen. Compressed air may also be used to surge a well during development operations.

If an aquifer consists of fine particles without much variation in size, it may not be possible to increase the permeability around the screen adequately by the development techniques described above. In this case the capacity of the well can be increased by gravel packing, i.e. by introducing material around the screen which has a particle size greater than that found in the aquifer. Use of a gravel pack allows larger screen openings to be used, and hence gives greater percentage of inflow area. It also surrounds the screen with a layer of material of higher permeability than the aquifer itself.

One way to introduce the gravel is initially to sink a temporary casing of a diameter greater than that of the final casing and screen. The final casing and screen are lowered inside the temporary casing and are held concentric by guides while the gravel is introduced into the annular space between the casings. The temporary casing can then be jacked out of the hole. Another method is to drill the hole somewhat larger than the casing down to the water table. The casing is then lowered and the annular space between the casing and the hole is filled with gravel. As sinking of the casing into the aquifer proceeds, some of the gravel descends with the casing. During development, more of the gravel descends to occupy the volume left by the sand passing through the screen into the well. Gravel may also be introduced around the screen through several small holes drilled for this purpose around a. small circle concentric with the well.

The size and gradation of the gravel used should be such that very little of the material of the surrounding aquifer can flow into the voids between the gravel particles. If this happens, the permeability of the gravel pack may be greatly reduced. The screen opening size is selected as large as possible without allowing any of the gravel pack material to enter the well.

After the well has been developed it is usually desirable to fill in and seal the annular space between the outside of the casing and the hole. This operation known as grouting is carried out to prevent any dirty surface water from flowing directly into the well and to give the upper end of the casing firm support. A mixture of portland cement and water mixed to a fairly liquid concistency is the most commonly used grouting material. A clay-water slurry is sometimes also used at greater depths where changes in moisture will not cause shrinking and swelling of the clay.

Where the use of pumping equipment for placing the grout is not practical, it must be flowed into place by gravity. The annular space between casing and hole should probably not be less than 5 cm (2 inch). A long, slender rod can also be used to make sure the grout flows into all voids. The grout should extend from the surface to a depth of at least 6 m (20 feet) to ensure an adequate sanitary seal between casing and drilled hole.

4.11 Problem solving

No endeavour is without problems, but those encountered in the drilling of small diameter wells may seem more difficult since they generally occur in a location where they cannot be seen. Consequently, a high degree of "feel", deduction, reasoning and ingenuity must be developed to diagnose and to overcome problems. Well drillers have two cardinal rules concerning problems :

(1) Prevent problems before they occur rather than trying to remedy them after they occur. This requires a great deal of alertness to sounds, feel, physical condition of tools and cuttings and continually trying to anticipate what things could possibly go wrong.

(2) In trying to remedy a problem, do not do anything quickly or ill-considered which could make the problem more difficult or impossible to solve.

In drilling wells, particularly with labour-intensive systems, at least three types of problems arise:

a. Small tools dropping into the hole. Any tool small enough to fit into the hole and regularly used around the hole will sooner or later get dropped in. To prevent this, all such tools should be tied to some stationary object with strong cord. Long slender objects, such as auger extensions which are regularly coupled and uncoupled, should have a safety device, such as a piece of rod slipped through them to prevent them from sliding down the hole if dropped accidentally. "Fishing" techniques for removal of objects from the hole are discussed later.

b. Tools stuck in the hole. While some cases of stuck tools are probably inevitable, proper design and maintenance can minimize the number of cases. The cutting edges of tools should be made and maintained so that they cut a hole large enough to allow clearance around the remainder of the equipment. Tools should be designed with reasonably smooth transitions in cross-section so that sharp shoulders do not exist which could become hooked under an irregularity in the hole or above which excavated particles could be wedged. When tools do become wedged in the hole, it is usually necessary to make use of some force-multiplying device such as a chain hoist or automotive jacks to pull them free. Since the force required to free the tool can often be considerable (even if only a small piece of gravel is wedged between the tool and the casing), equipment should be built to withstand several tons of pull. If there is concern for the rope, cable or a string of pipe breaking during hard pulling, it is usually possible to hook directly onto the stuck tool with a properly designed hook at the end of another stronger rope, cable or string of pipe. Pulling can then proceed on the latter or on both attachments. The necessity of hooking onto the tops of tools should be kept in mind when they are designed. For example, bailers and percussion bits should be made with large, easy-to-hook bails.

Commercially made percussion tools include a set of "jars". This is a heavy close fitting pair of links built into the drill system. Since the links can slide within each other, the part of the drill stem above the jars can be pulled up a short distance before the drilling bit leaves the bottom of the hole. This small relative motion and the mass of the upper drill stem and line can be used to drive a stuck drill bit upward to free it. The impact of the jars exerts a greater force than can normally be obtained by a steady pull. If the drill bit is stuck above the bottom of the hole, the jars can also be used to drive downward. The forerunner of jars was two or three heavy chain links connecting the upper and lower part of the drill stem. These, however, take a heavy beating on both the upstroke and the down-stroke and are relatively short-lived.

c. Tools which become detached in the hole. The occurrence of this problem can be minimized by continually checking the condition of the tools and fasteners. However, when a detached or dropped tool must be removed from the hole, the process is referred to as "fishing". Frequently special tools must be fabricated to accomplish this task. This may require both considerable ingenuity and a good deal of trial and error. An impression block may be valuable in designing fishing tools. This is a shallow cylindrical container of a diameter which just fits in the hole, with an open bottom and the top attachable to a string of pipe or a bailer. The container is filled with a substance such as soap, wax or grease hard enough to hold its shape, but soft enough to take an impression. It is carefully lowered onto the object to be fished, so that the impression left on the block gives information on the shape, location and

orientation of the object which is useful in choosing the tools and strategy to be used in fishing. An impression block can be made of a thick wooden disk with a strip of sheet metal nailed around the outer edge. The wooden block can be studded with nails to anchor the impression material.

Some commonly used fishing tools are shown in Figure 42. Other tools must be devised to suit a given problem.

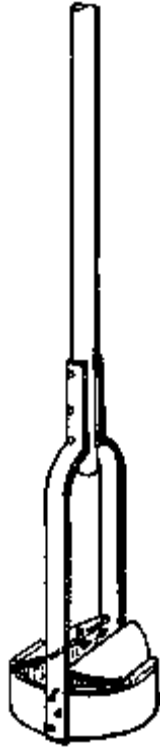**Fig. 42 Fishing tools. (a) for retrieving lengths of pipe**

Fig. 42 Fishing tools. (b) sheet metal cylinder with teeth which bend together to close bottom for picking up small objects

Fig. 42 Fishing tools. (c) spear for retrieval of broken rope or cable with latch for picking up bits or bailers

Fig. 42 Fishing tools. (d) hook with guide for attaching supplemental line to stuck tool