Chapter 8

GROUND WATER EXTRACTION: TUBEWELL TECHNOLOGY

8.1 Tubewell Technology

A large variety of tubewells has been designed for abstraction of groundwater, and is being used all over the world (UNDP and WB 1986). The tubewells designed and developed, including those being used in Bangladesh, may be grouped under three categories, which are shown in the Figure 8.1.

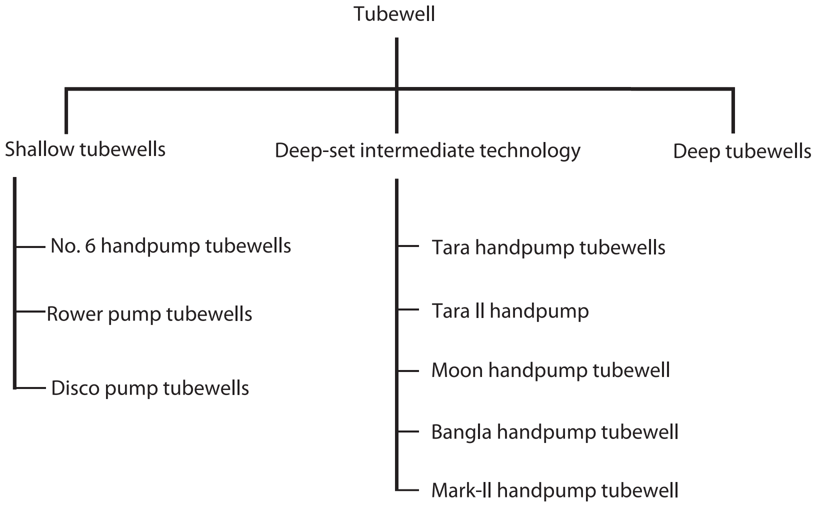


Figure 8.1: Types of tubewell technologies

8.1.1 Shallow tubewell technology

In shallow tubewell technology, handpumps are operated in a suction mode. A suction pump draws water from a shallow depth by creating a vacuum in the suction pipe. The suction handpumps can practically extract water from up to a depth of 7.5 m static water level. This category of handpumps includes:

- No. 6 handpump tubewell,
- Rower pump tubewell and
- Disco pump tubewell.

They are described bellow.

No. 6 Handpump tubewell

In Bangladesh the most common and popular technology used for abstraction of groundwater is the No. 6 handpump tubewell. The name of the tubewell is based on its barrel diameter in inches. About 8 million public and private No.6

handpump tubewells are already in use throughout the country and a very high percentage of these tubewells is in operational condition at any time. Before the lowering of the water table was encountered, the No. 6 handpump was considered to be the only low-cost option for potable drinking water supply in rural, peri-urban and urban areas where piped water supply system were not introduced. A typical No.6 handpump tubewell is shown in Figure 8.2. There are also No.4 and No.2 handpump tubewells but their use is limited to private tubewells within family premises.

- **Working Principle:** The No.6 handpump is a suction mode handpump. A vacuum is created within the cylinder of the pump by raising the piston. In order to fill-up the vacuum, water enters in the cylinder. In the second stroke when the piston is lowered down, the water enters in the upper chamber, and comes out of the pump through the spout when the piston is raised to create vacuum again. The stroke length is 240 mm. Inertia effect exists but the mechanical advantage of pumping helps to overcome this effect. The atmospheric pressure plays a role in lifting the water. The atmospheric pressure is 14.7 psi, therefore the theoretical lifting capacity of the pump by suction is 32.8 ft. However, due to vacuum pressure and friction losses in different sections of the tubewell, the lifting capacity ranges from 22-25 ft in working condition. The discharge from a pump to a great extent depends on the aquifer condition.

  However, the average discharge of the pump is 30-40 litres/minute. A No. 6 handpump, if installed properly, can serve for 15 to 20 years or more.

  The general components of a No.6 handpump tubewell are: handpump, blind pipe (rising pipe), strainer (screen) and sand trap.

- **Handpump:** The function of a handpump is to tap water from the well. Generally No 6 handpumps are made of cast iron. The component parts of a handpump are base, barrel, head cover, handle, piston rod, plunger, valve weight, bolts and nuts. The bucket and seat valve are made of leather or PVC (plastic). The major components of handpumps are shown in Figure 8.2.

- **Blind pipe (rising pipe):** Pipes used between the screen and the handpump are called blind pipes, rising pipes, or well pipes. Different sizes of pipe can be used but 38 mm diameter pipes are the most common. Previously galvanized iron pipes (GI) were used but nowadays, to reduce

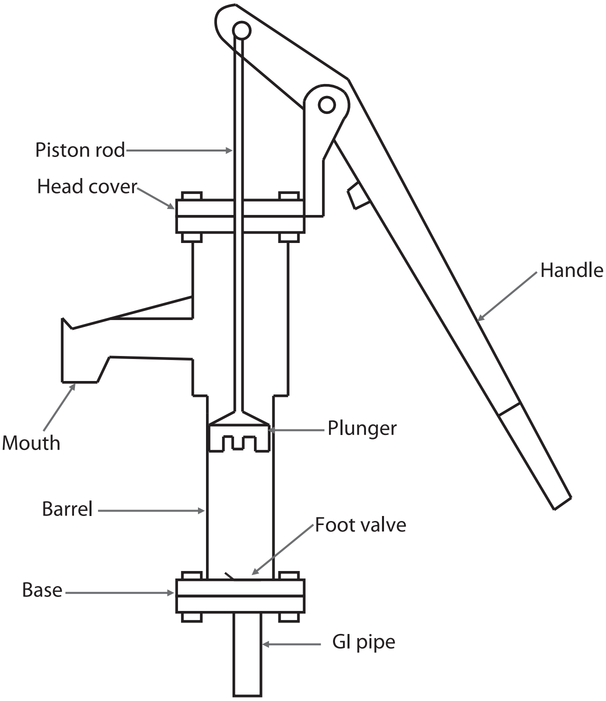


Figure 8.2: **A No. 6 handpump tubewell**

costs, GI pipe is only used for the top five feet as shown in Figure 8.2 to take the external forces, and the remaining pipes are made of poly vinyl chloride (PVC). PVC pipes are corrosion resistant, easy to handle and inexpensive.

- **Strainer (screen):** The screen is a perforated portion of a well through which groundwater enters from the aquifer. In Bangladesh 38 mm diameter strainers are used for handpumps. These strainers are usually 2 m long and are commonly made of PVC. Depending on the grain size of the aquifer, three slot sizes of strainers are used in Bangladesh. The openings are 0.008" (slot no. 8); 0.010" (slotno. 10) and 0.012" (slot no. 12). Brass strainers are also used. These are made with perforated mild steel (MS) or GI pipes covered with 60 to 80 mesh brass/copper wire net and a brass perforated sheet (jacket). Stainless steel strainers can also be used, but these are not common in Bangladesh.
- **Sand trap:** The sand trap is an extension of a blank pipe of about 4 to 6 ft long depending on the depth of the tubewell, fixed at the bottom of the

filter. The open end of the pipe is sealed with a cap. Generally PVC sand traps are used in the tubewells. However, when the well is very deep (800'-1000') sometimes a GI sand trap is used to facilitate lowering the tubewell. The purpose of the sand trap is to accommodate the incoming fine sand, which ultimately settles at the bottom of the well. The sand trap prevents blocking of the strainer.

Rower pump tubewell

The rower pump is a manually operated reciprocating pump with a 54 mm diameter PVC pipe as the pump cylinder. The piston inside the cylinder operates by pulling and pushing a T-handle attached to the end of the piston rod. The pump is installed at a 45-60° angle with a vertical tubewell pipe through a 'Y' connector piece. The operator pulls and pushes the piston back and forth by moving the 'T'-shaped handle and withdraws groundwater by means of suction. The operation of a rower pump is like rowing a boat, hence the name 'rower pump'. The components of a rower pump are shown in Figure 8.3. In high water table areas rower pumps are used for irrigation purposes and occasionally for domestic water supply. The operation of a rower pump is ergonomically comfortable but tiring over longer periods. Rower pumps can lift water up to a maximum suction lift of 8.5 m. The stroke length is 980 mm and maximum discharge capacity is 0.8 lps. A surge tank is fitted with the extended part of a 38 mm tubewell as shown in Figure 8.3. The inertia effect in a rower pump is partially eliminated by the surge tank. The pump is not very suitable for domestic water supply due to poor sanitary protection. The lifetime of rower pump is 3-5 years.

Disco pump tubewell

There are some areas where the water level goes beyond the suction limit for a short duration. The lowest level reached to such a depth that if the piston of a No. 6 pump is extended to about 3 m; the pump could be kept operational for the whole year. To meet the water supply requirements of these areas the disco pump has been developed locally and is in use in various places. In Gazipur, it is known as 'half cylinder pump'. The 75 mm diameter GI pipe is used as the casing up to 3m below the ground surface. The suction action is extended by increasing the length of the piston rod. The discharge from the pump is equal to that of a No. 6 handpump but requires comparatively more force to raise the water. The limitation of the disco pump is that it can only be used where the water level will remain within 10 m from the ground surface. A further increase in lift head will increase the cost of the pump. A diagram of a typical disco pump is shown in Figure 8.4.

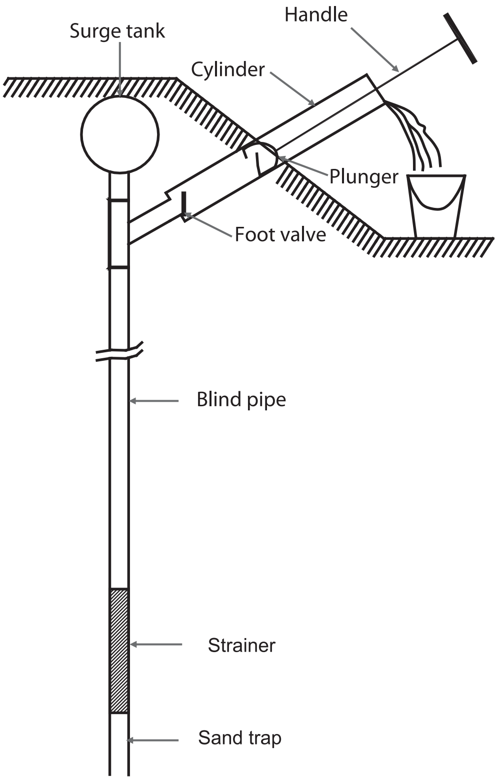


Figure 8.3: **A rower pump**

8.1.2 Deep-set intermediate technology

Shallow tubewells operated under the suction mode are not able to withdraw water in low water table areas. The low water table area is increasing with the increase in the use of groundwater.

Water can be abstracted from a depth beyond the suction limit using intermediate technology. Deep-set handpumps can abstract water from as high as 30 m from the static water level, depending on the technological advancement of the handpump. Handpumps in this category include:

- Tara handpump tubewell,
- Tara II handpump tubewell
- Moon handpump tubewell,
- Bangla handpump tubewell,

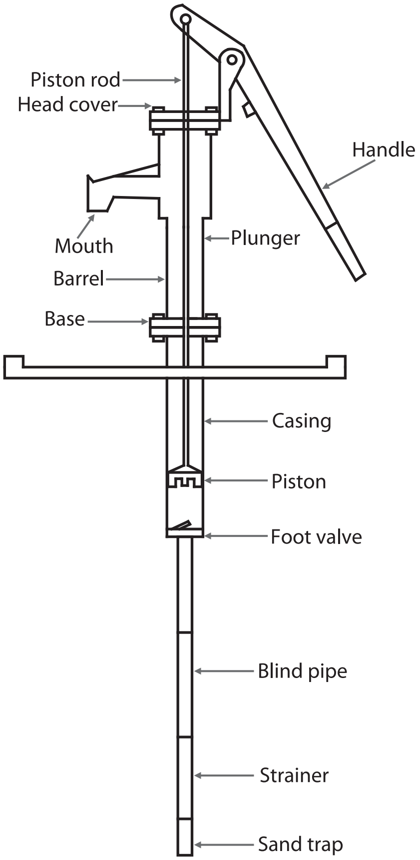


Figure 8.4: Disco handpump technology

- Mark-II handpump tubewell and
- Other locally produced, improvised deep-set pumps.

Tara handpump tubewell

In Bangladesh, the groundwater table during monsoon in most places remains within the suction limit. But due to extensive use of groundwater for irrigation, the groundwater table is falling and in the dry season it goes beyond the suction limit in many parts of the country. As a result the No. 6 suction mode handpump is inoperable in dry season. To overcome this problem, the Tara handpump has been developed in Bangladesh by UNICEF and the UNDP-World Bank Program, to tap water from up to 15m below the ground surface. A standard direct action Tara handpump designed in 1984 is shown in Figure 8.5, indicating the main parts of the pump.

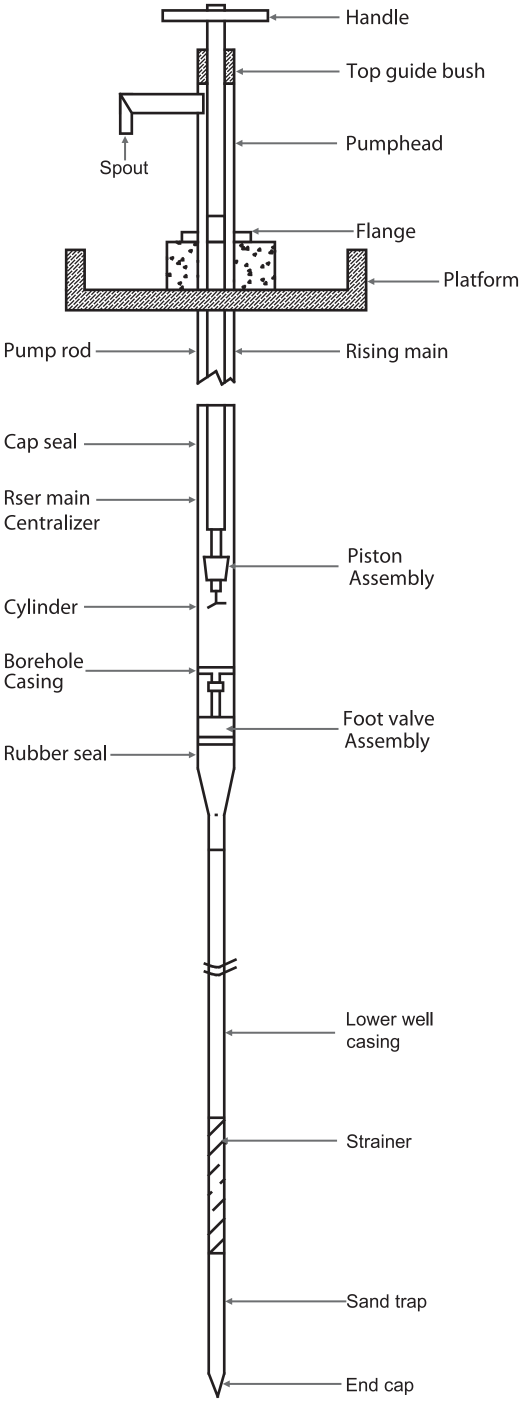


Figure 8.5: Tara handpump tubewell

- **Working principle:** The Tara handpump is a force mode pump in which the piston of the pump operates below the static water level to eliminate the limitations of suction mode handpumps to operate in low water table areas. The cylinder of the pump is set at 18 m below the ground surface and a PVC hollow pump rod set vertically operates the piston. The pump is operated by a person holding the handle fitted at the top end of the pump rod and pulling and pushing the pump rod vertically. Hence the pump is also called a direct action handpump. The attractive feature of the pump is that the buoyancy of the pump rod reduces the manual force required to operate the pump. A Tara pump can draw water from the well in both up and down strokes. The lifting capacity of a standard Tara pump is limited to 15m. The average discharge of the pump is 24 litres/ min. An advantage of the Tara pump is that it is extractable. This means the pump assembly can be replaced when the tubewell shows defects within the cylinder.

- **Components:** The main components of the Tara handpump as shown in Figure 8.5 are pump head, handle, top connector, pump rod, bottom convector, piston assembly, foot valve assembly and cylinder. The lower well casing, strainer and sand trap are the same as in the No.6 handpump. A Tara tubewell is installed within 75 mm diameter casing in which a 50 mm diameter cylinder and rising main are set. The lower well casing is made of 38 mm diameter PVC pipe and is attached with the filter or well screen. The filter or well screen is a 38 mm diameter. Slotted and internally ribbed PVC pipe. A 32 mm diameter PVC pipe is used as pump rod to operate the piston. A sand trap closed with an end cap is attached at the end of the well and allows the sand coming with the water to accumulate without clogging the screen. All components of the Tara pump except the pump head and handle are made of PVC. The life of a Tara pump is expected to be 3 to 5 years. Maintenance of a Tara handpump is easy and requires no additional tools. The pump is yet to be proved user friendly. The problems of Tara pump are given below.
  - Because of the direct action, the force is to be applied directly by the operator without having any mechanical advantage.
  - Buoyancy force is not always available for the operator due to leakage in the pump rod.
  - Tara hand pump provides moderate output (max. 4 m^3/day) for 7 metre lift and very low output (max. 1.5m^3/d) for 12 metre lift.
  - Failure of key components is likely at moderately high daily output.

- Repair or replacement of any parts below ground level needs to open a major portion of the assembled pump, which is often inconvenient.

Tara-II handpump tubewell

In some areas of the country; the water level in dry season goes down below 15m, which is the lowest normal functioning range of a Tara handpump. In order to withdraw water from a deeper aquifer, the standard Tara pump is modified. The piston assembly is set at 30 m, and all other aspects of the Tara handpump, remain the same. However due to the long length of the pump rod, the pump requires a lot of force to operate far beyond the capacity of direct pull and push. This problem is resolved by installing the head of a No. 6 pump through modification of the bottom flange. This modified Tara handpump, with a lower pumping mechanism and a No.6 pump head with lever action handle, is called the Tara-II handpump. It is suitable for lifting water from a depth of 30 m below ground level and able to produce about 0.5 lps.

Moon handpump tubewell

The moon handpump tubewell is a modified version of tara handpump tubewell. The direct action tara handpump tubewell is found to be uncomfortable to the users particularly to women. Considering this difficulty, the head of the tara handpump tubewell has been replaced by that of a No.6 handpump to get the advantage of the lever action and PVC pump rod has been replaced by steel rod in the moon pump. A good number of moon handpumps has been installed in Noagaon, Chapai Nawabganj and Manikganj under the Dutch assisted 18 District Town Project. The main components of the moon handpump tubewell are shown in Figure 8.6. No. 6 pump has been as head assembly. The upper well casing is made of 75 mm diameter PVC pipe. The pump rod is made of steel; the piston assembly and foot valve assembly are made according to the inner diameter of 75 mm diameter PVC pipe working as cylinder. The lower well casing is made of 38 mm diameter PVC pipe, PVC well screen and sand trap similar to tara handpump tubewell. The maximum discharge of a moon handpump is 0.6 lps. It is suitable for lifting water upto 25 metre.

Bangla handpump tubewell

This is a modified version of the moon pump. The difference with the moon pump is that the upper well casing is of smaller diameter PVC pipe. The lifting capacity of the pump is limited to 15 m. The pump is not widely used as it is being tested and not commercially manufactured. A performance evaluation of the Bangla pump was conducted for a short duration of two years and it was found to be functioning satisfactorily.

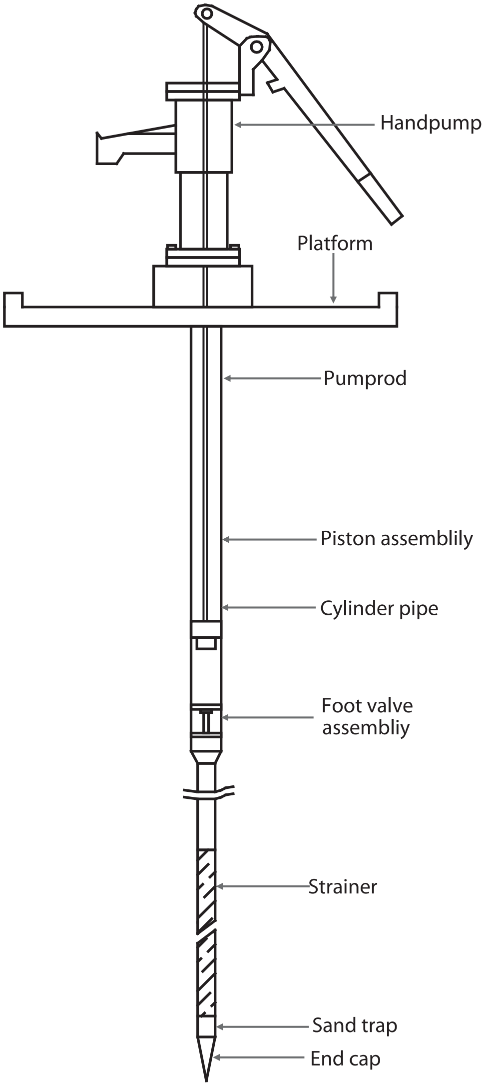


Figure 8.6: Moon handpump tubewell

Mark II handpump Tubewell

The Mark II handpump tubewell widely known as the Indian Mark II is the most popular tubewell in India and widely used in many other countries of the world. It has a deep-set pump capable of lifting water from a depth of over 30 m. Although the Mark II handpump tubewell has not yet been installed and familiarized in Bangladesh, it may serve the demand of a robust hand tubewell in low water table areas. A Mark II handpump tubewell has many similarities with a Tara II pump. However the piston in the pump is operated by a connecting rod instead of a PVC pump rod. The diameter of the rising main is reduced to reduce the load of water on the piston, and the length of the handle is increased to enhance the lever action. The main components of the tubewells are pump head assembly, blind pipe and filter and the cylinder assembly.

The pump head assembly consists of a handle, head, water tank, stand, riser pipe, connecting rod, spout, leg, etc. A typical diagram of a Mark II tubewell with different components is shown in Figure 8.7.

Another type, the Mark III is an improved version of the Mark II handpump tubewell. A Mark III pump has an improved connecting rod made of fiberglass. The other parts are mostly the same as those of the Mark II.

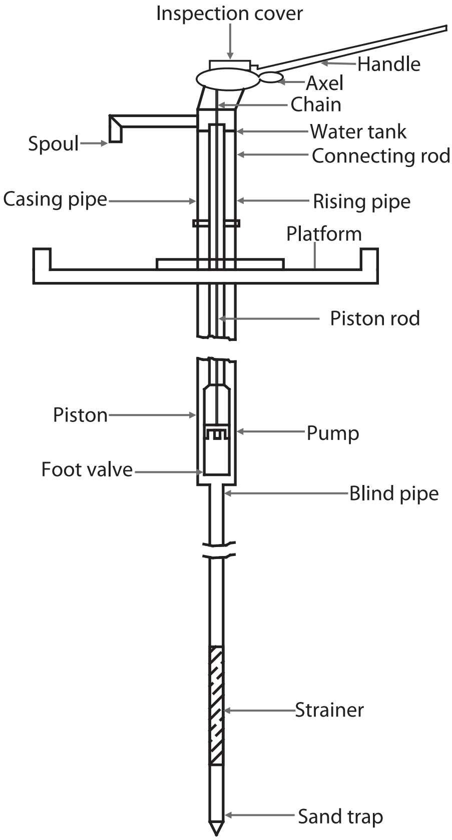


Figure 8.7: **Mark II handpump tubewell**

8.1.3 Deep tubewells

A tubewell installed to withdraw water from a deep aquifer is called a deep tubewell. Usually a deep tubewell penetrates more than one aquifer, but in Bangladesh a tubewell deeper than 75m is called deep tubewell. The deep tubewell operates under the suction mode exactly in the same manner as a shallow tubewell, the only difference is that the depth of a deep tubewell is more than 75m. In most saline zones (coastal belt), the depth of a tubewell is about 300 m. The No.6 tubewell can be made into a manually operated deep tubewell by adding more blind pipes to reach the desired aquifer. In Bangladesh, deep tubewells are usually installed in saline areas to extract water from deep fresh water aquifers. Since the water level lies very close to the ground level in the coastal areas, a suction pump having a No.6 pump head operates satisfactorily throughout the year. The differences between shallow and deep tubewells have been illustrated. As deep bore holes are required for installation of deep tubewells, the construction method of deep tubewell is different from that of No.6 shallow tubewells. Sometimes mechanical devices are necessary for construction of these tubewells.

8.2 Designing of Well

Generally, the aim of engineering design is to achieve the best possible combination of performance, useful life and reasonable cost. The designer of small wells will often find that the optimum solutions involve a variety of compromises and that he must adopt a flexible approach to each problem. Among these compromises is tie need to sacrifice performance or efficiency in order to reduce costs. For example, in the situation where a small yield is required from a very thick and permeable aquifer, a less efficient type of intake section such as slotted pipe may justifiably be used in a small well to save the extra cost of a more efficient factory-manufactured screen. Here, the limited yield relative to the highly productive nature of the aquifer makes cost and availability of funds assume a more important role than hydraulic efficiency. It may also be considered worthwhile to compromise the useful life of a small well with respect to its cost. With stainless steel and other non-corrosive materials costing two to three times as much as ordinary steel, a designer may use well casing of the latter material under corrosive conditions, fully expecting to replace it, perhaps in one-half the time he would have had he used stainless steel. He may very well have based his decision on the fact that at the end of the shorter useful life, extra funds might be available for a replacement of the existing well.

For design purposes, a well to be constructed in unconsolidated materials may be considered as consisting of two main parts. The upper part or cased section (article 8.3)of the well serves as housing for the pumping equipment and as a vertical conduit through which water flows from the aquifer to the pump or to the discharge pipe of a flowing artesian well. It is usually of water-tight construction and extends downward from the surface to the impervious formation immediately above an artesian aquifer or to a safe depth below the anticipated pumping water level (see the article 8.7 of this chapter dealing with sanitary protection of wells).

The lower or intake section (article 8.4) of the well is that part of the well structure where water from the aquifer enters the well. The intake section may be simply the open lower end of the well casing, though this would be a most unsatisfactory arrangement in unconsolidated formations. The disadvantages are the large well diameters required for the natural seepage of water into the well and the tendency for aquifer material to heave into the well casing as the well is being pumped. A screening device known as a well screen should be used instead. Such a screen permits the use of techniques aimed at increasing the natural seepage rate into the well (see later section on well development), thus making a much smaller well practicable. In addition to ensuring the relatively free entry of water into the well at low velocity, the screen must provide structural support against the collapse of the unconsolidated formation material and prevent the entry of this material with water into the well.

8.3 Cased Section

The selection of the well casing diameter is usually controlled by the type and size of the pump that is expected to be required for the desired or potential yield of the well. The well casing must be large enough to accommodate the pump with sufficient clearance for easy installation and efficient operation. For larger wells, such as those used for municipal and industrial supplies, the casing diameter should be chosen as two nominal sizes (never less than one nominal size) larger than that of the pump bowls. For wells of 4 inches and less in diameter it is satisfactory to select a casing diameter which is one nominal size larger than that of the pump bowls, pump cylinder or pump body. The above assumes the use of a deep-well type of pump which is usually suspended by pipe column and/or shaft within the well casing. A pump having a bowl diameter greater than 3 inches should not, according to this rule, is installed in a 4-inch diameter casing.

In small wells where pumping water levels below ground surface are known to be within the practical suction limits(19 feet or less) of most surface type pumps, such pumps are either directly connected to the top of the well casing or connected to a suction pipe suspended inside the well casing. The well casing diameter may then be selected in relation to the diameter of the suction or inlet of the pump, bearing in mind that it is not good practice to restrict the suction capacity of the pump by using pipe of a smaller diameter than that of the suction side of the pump.

In larger and deeper wells than those being considered, it is sometimes advantageous for economic and other reasons to reduce the casing diameter at levels below the lowest anticipated pumping depth. This is done by telescoping one or smaller sized casing sections through the uppermost one. This saves the extra cost of extending the large diameter casing all the way down to the aquifer when a smaller size of pipe would be sufficient to accommodate the anticipated flow with reasonable head loss. However, there is little justification for this type of design in wells of 4 inches and less in diameter and not more than 100 feet deep.

8.4 Intake Section

Type and Construction of Screen: The single factor with greatest influence on the efficient performance of a well is the design and construction of the well screen. A properly designed screen combines a high percentage of open area for relatively unobstructed flow into the well with sufficient strength to resist the forces to which the screen may be subjected both during and after installation in the well. The screen openings should preferably be shaped so as to facilitate flow into the well while making it difficult for small particles to become permanently lodged in them and thus restrict flow. A discussion of various types of well screens and their uses is presented in the following paragraphs.

- The continuous slot type of well screen shown in Figure 8.8 is made with cold-drawn wire, approximately triangular in section, wound spirally around a circular array of longitudinal rods. The wire is welded to the rods at all points at which they cross. The resulting cylindrical well screen becomes a one-piece, rigid unit.

  The stronger the material used in construction, the smaller would be the dimensions of the wile rods and hence the greater the ratio of open area to solid area of the screen surface. These screens are being made of metals such as galvanized iron, steel, stainless steel and various types of brass. Experiments are also in progress with the use of plastic materials.

The percentage of open area is the factor exerting the greatest influence on the efficiency of a screen. As will be shown later, the size of the well screen opening is determined from the size of the particles of the material composing the aquifer. With this size fixed, the aim of screen design is to obtain the maximum possible total open area in a given length of screen. The greater the total open area, the lesser is the resistance to flow into the well. The entrance velocity through the larger intake area is also lower and so is the resulting head loss for flow through the screen. Hence we have a more efficient well screen. The greater the percentage of open area in a screen, the greater is the total open area in a given length of screen.

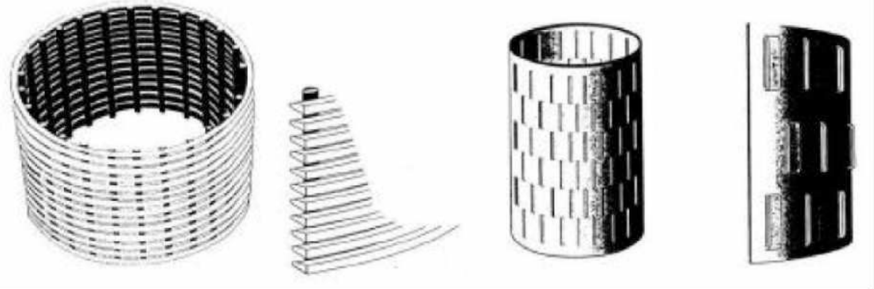


Figure 8.8: Fabrication of a continuous slot type of well screen

Looking at it in another way, the greater the percentage open area of a screen, the shorter is the length of screen required for a given rate of flow at a given velocity. This means that a saving in construction costs can be made through the use of a shorter length of screen. The continuous-slot type of screen provides more intake area per square foot of screen surface or per unit length of screen than any other known type and, therefore, can result in savings when used.

Along with maximum open area in a well screen, the design must also be such that the openings do not become clogged by sand particles after the screen is placed in the aquifer. This is achieved by the use of V-shaped openings formed by the triangular shaped wire as shown in Figure. 8.9. In Figure. 8.10 is shown a sand grain entering and passing through a V-shaped opening, never clogging it, while remaining in other known types of openings to clog them. This property of the V-shaped opening is of

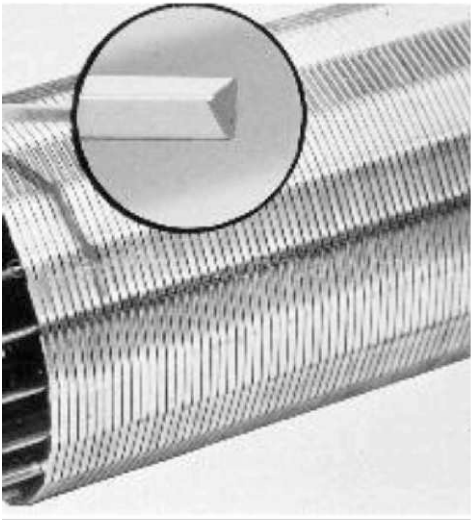


Figure 8.9: Section of continuous slot type screen showing v-shaped openings

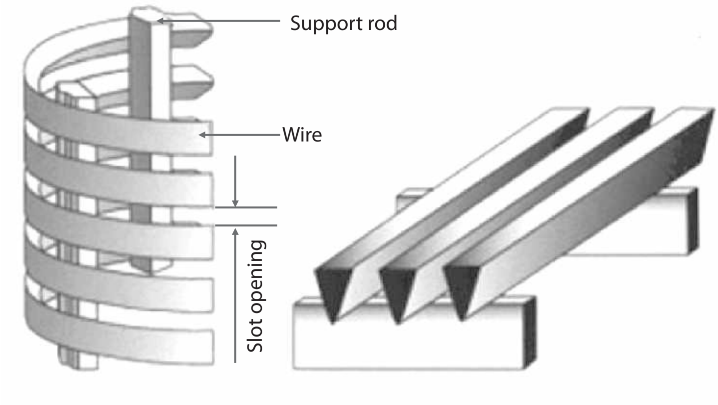


Figure 8.10: The v-shaped openings of the continuous-slot type of screen

special importance when developing the well, as the developing process is based on passing the smaller sizes of sand particles through the screen and removing them from the well. This process, a necessary one for the completion of the well, is described later in this chapter.

Another notable feature of the continuous-slot type of screen is the fact that the slot openings can be easily varied in size even within the same section of screen if the geologic conditions so require. This is done simply by altering the set spacing at which the adjacent wires are wrapped. Thus a single section of screen can be made with one or more different sizes of slot openings. The width of slot openings can also be held to close tolerances.

Continuous-slot well screens are made with practically any width of opening 0.009 inch and larger. The slot openings are designated by numbers corresponding to the width of the opening in thousandths of an inch. Thus a screen with a No. 10 slot has openings 0.010 inch wide.

- Louver or shutter-type well screens have rows of openings in the form of shutters (Figure 8.11). Manufacturers can and do arrange the openings either at right angles or parallel to the axis of the screen. The openings are produced in the wall of a welded tube by a stamping operation using a die. The range of sizes of openings is limited by the sizes of the set of dies used by each manufacturer. An unlimited range of die sizes would not be practical. This is one deficiency of this type of screen by comparison with the continuous-slot. Another important deficiency is the much lower percentage of open area in shutter-type screens. This is so because sizeable blank spaces must be left between adjacent openings if the metal is not to be torn in the stamping process.

  Yet another shortcoming of the shutter-type screen is the tendency of the openings to become blocked during the development of wells where the aquifer material contains an appreciable proportion of sand. This type of screen is, therefore, best used in artificially gravel-packed wells.(Figure 8.11)

- The pipe-base well screen is another type of screen in use. It consists of a jacket around a perforated metal pipe. The jacket may be in the form of a trapezoidal-shaped wire wound directly onto and around the pipe (called a wrapped on-pipe screen). Alternatively the wire may be wound, over a series of longitudinal rods spaced at fixed intervals around the circumference of the pipe. The latter is a more efficient type of screen as the rods hold the wire away from the pipe surface to reduce the blocking of the screen openings. A stronger screen can be obtained by using a slip-on jacket made of an integral unit of welded well screen.

  The perforations or holes in the pipe and the spaces between adjacent turns of the wrapping wire form two sets of openings in this type of screen. Usually the total open area of the holes in the pipe is less than that between the wrapping wires. It is, therefore, the holes in the pipe that control the

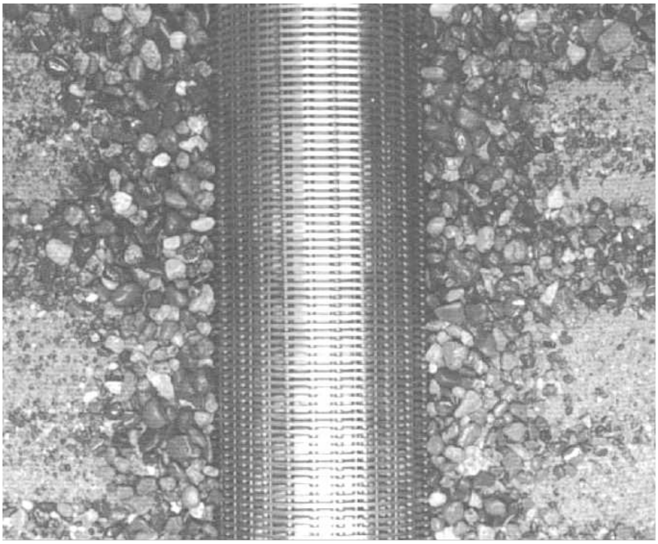


Figure 8.11: Louver or shutter type well screen, best used in artificially gravel packed wells

performance of the screen. The percentage open area in the pipe is usually low and hence this type of screen is relatively inefficient.

Very often this type of construction is used in order to avoid making a screen entirely of the costly non-corrosive alloys such as stainless steel, bronze or brass. Such alloys are then used only in the jacket while the pipe is of steel. A screen so constructed with two or more metals would be subject to failure from galvanic corrosion. Construction of the screen entirely of one of the non-corrosive alloys, while being more costly, will solve this problem and result in a more durable screen.

- Drive points or well points, as they are commonly known, are short lengths of well screen which are attached to successive lengths of pipe and driven by repeated blows to the desired position in an aquifer or in a formation to be dewatered. A forged steel point is usually attached to the lower end to facilitate penetration into the ground.
- Well points are made in a variety of types and sizes. Most commonly, they are designed for direct attachment to either 1¾-inch or 2-inch pipe. They can be made of the continuous-slot type of well screen (Figure 8.10), thus benefitting from all the desirable features of that type of screen. Such

screens will withstand hard driving, but care should be taken to avoid twisting them while driving.

A common type of well point is the brass jacket type. It consists of a perforated pipe covered with bronze wire mesh which is, in turn, covered with a perforated brass sheet to protect it from damage. The pointed lower end, made of forged steel, carries a wider shoulder to protect the screen from damage by gravel or stones while being driven. The limitations of pipe-base screens also apply to this type of well point.

Another type of well-point construction is the brass tube type consisting of a slotted brass tube slipped over perforated pipe. It has an advantage over the wire-mesh jacket type in that it is not as easily ripped or damaged.

The sizes of openings for the continuous-slot type of well points are designated as described for the continuous-slot well screens. Mesh-covered well point openings are designated by the mesh size in terms of the number of openings per linear inch. The common sizes are 40, 90, 90, 90 and 80 meshes.

- Slotted pipe is sometimes used as a substitute for well screens particularly in the smaller sized wells under consideration in this manual. The openings or slots in the pipe are usually cut with a sharp w, electrically operated if possible, to maintain accuracy and regularity in size. Several other methods have been used, however, such as cutting with an oxyacetylene torch and punching with a chisel and die or casing perforator.

  The method of construction immediately suggests a number of important limitations to the use of slotted pipe as well screens. These are:
  - structural strength requires wide spacing of slots, resulting in a low percentage of open area
  - openings may be inaccurate, varying in size throughout the length of each slot
  - openings narrow enough to control fine sands are difficult, if not impossible, to produce
  - the lack of continuity of the openings reduces the efficiency of the process of well development
  - the slotting and perforation of steel pipe makes it more readily subject to corrosion, particularly at the jagged edges and surfaces.

Slotted plastic pipe has been finding increasing use in small diameter wells in recent years. Its light weight and ease of handling make it suitable for use in remote areas not easily reached by motor driven vehicles. It is non-corrosive and less costly than steel pipe in sizes 4 inches in diameter and smaller. In addition, the dots can be easily made on location with a sharp saw within reasonable limits of accuracy. Slots cut spirally around the circumference of the pipe in the manner shown in Figure 8.12 will result in less weakening of the pipe and closer spacing of the slot than if they were made at right angles to the axis (Figure 8.12). Consequently, the percentage of open area is greater. Slots made at right angles to the axis of plastic pipe are subject to tearing at both ends if the slotted pipe is bent when handling it during installation. This tendency is reduced by the use of the spiral design (Figure 8.13).

Figure 8.12: Continuous right angled slot of well axis

The most convenient type of joint for use with small diameter plastic pipe in well construction is the spigotted joint. For these joints, the manufacturers supply quick, setting cement which provides more than adequate and lasting strength. If the slotted plastic-pipe screen can be lowered into a previously drilled hole on the end of casing of the used to suspend the string of pipes while adding new lengths. It may also be

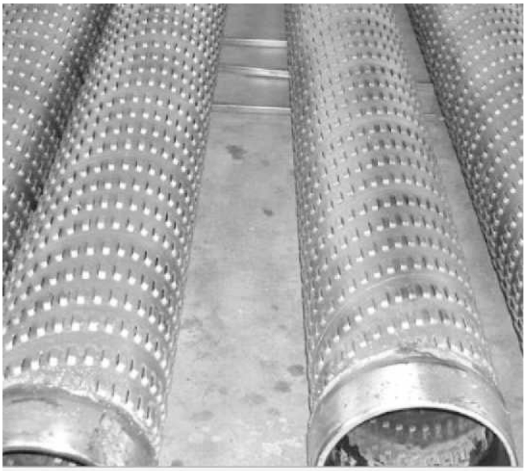


Figure 8.13: **Slotted plastic pipe**

washed, open ended, with a jet of water into a previously drilled hole. Suitable drilling mud should be used during rotary drilling one rations to prevent the open hole from collapsing while the string of plastic pipe is being placed in position. Care should be taken to wash the hole clear of all cuttings before placing the pipe. Plastic pipe generally requires the use of greater care during handling and installation operations than do metal pipes.

It cannot be contended that dotted plastic pipe will be as efficient a well screen as the continuous-slot type. However, when only small quantities of water are required from relatively thick (20 feet and greater) sand and gravel or gravel aquifers, efficiency loses some of its importance to economy and ease of construction. Under these conditions, together with the ones already mentioned, slotted plastic pipe is an attractive alternative to the continuous- slot or other manufactured type of well screen. It is particularly suited to the provision of individual water supplies in remote and inaccessible areas.

The length, size of openings and diameter of the well screen are the remaining design features which influence the efficiency of flow into a well. Together, they determine the entrance velocity of flow through the screen into the well. This entrance velocity in turn influences the head or pressure loss required for maintaining the flow and, as a consequence, also influences the efficiency of the screen for that rate of flow.

If designing a well to obtain the maximum yield from an aquifer, then the procedure would first be to select the screen length and size of openings based on the natural characteristics of the aquifer. The screen diameter would then be selected so as to provide enough total area of screen openings that the entrance velocity does not exceed the chosen design standard. Usually, however, small wells are designed to provide a certain limited yield, well below the maximum possible yield, and the screen diameter is first chosen essentially with a view to keeping costs down to a minimum. The diameter selected would then be the smallest practicable one, consistent with the expected yield and the diameter of the casing. Normally, it is not considered good practice to use a well screen of larger diameter than that of the casing. The size of the screen openings is, as before, fixed by the aquifer characteristics, but the screen length is, in this case, determined by the total area of screen openings required to keep the entrance velocity at or below the design standard. Should the screen length determined on this basis be greater than the thickness and other characteristics of the aquifer would permit, then the screen length is chosen as the maximum consistent with these limitations. Following this, a suitable diameter is chosen to be consistent with the design standard for entrance velocity into the screen. A more detailed discussion of the design standard for the entrance velocity follows discussions of the effects of aquifer characteristics on the selection of screen length and size of openings.

Manufactures well Screen: Manufacturers make well screens in two series of sizes, the telescope-size and the pipe-size or ID-size.

- Telescope-size screens are designed to be "telescoped" or lowered through the well casing to the final position. The diameter of each screen is just sufficiently smaller than the inside diameter of the corresponding size of standard pipe to permit the screen to be freely lowered through the pipe.
- The pipe-size or ID-size series of well screens have the same inside diameter as the corresponding size of standard pipe. This type of screen is used when it is desired to maintain the same diameter throughout the full depth of the well. They are provided, in the small sizes under consideration, with either welded or threaded end connections.

Screen length: The screen length selection can be influenced by the thickness of the aquifer. While definite rules may be set, based on this relationship, for large wells it would be unwise to do so for small ones. A farmer or homeowner should not be burdened with a long and costly well screen in a thick aquifer when his requirements are so small as not to warrant it. The screen length should be sufficient to meet his needs with a reasonable drawdown in the well. As already stated, a compromise must be made between well cost and well efficiency. The other extreme must also be avoided. Economization should not be taken to the point where the length of screen provided is such that the yield barely meets the owner's present needs. A reasonable allowance should be made for his future needs. Failure to do so may, in the long run, prove to be far more costly to the owner.

It is important to note that in a thick aquifer, well yield is much more effectively increased by increasing the screen length than by proportionately increasing the screen diameter. Doubling the screen diameter, for instance, will only result in an increase of 10 to 15 percent in the yield. In most cases, however, doubling the screen length will result in the yield being almost doubled. It is, therefore, much better to use screen length as a controlling factor on well yield rather than screen diameter in thick aquifers.

The role played by aquifer characteristics in screen length selection is best demonstrated with the use of a few examples. Where a thick layer of coarse sand or gravel underlies a layer of fine sand as shown in Figure 8.14 A, the screen length should be at least ⅓ the thickness of the coarse sand layer. For the situations shown in Figure 8.14 B and Figure 8.14 C, almost the entire thickness of the lower layer of coarse sand should be screened. Should this prove inadequate for the desired yield, then it would be necessary to extend the screen a short distance into the overlying finer sand. Where coarse sand overlies fine sand as in Figure 8.14 D, it should normally be sufficient to place the screen in the coarse sand layer with the length being equal to about one-half the thickness of that layer.

In thin aquifers confined by clays, particularly clays that tend to be easily eroded when exposed to water, screen lengths should be chosen so as to avoid the possibility of placing screen openings opposite these clays. Screening of clay layers could result in their collapse during the well development process with the well forever producing muddy water.

There are four typical hydrological situations considering screen lengths which are described below:

- **Homogeneous unconfined aquifer:** Theoretical consideration and experience have show that screening of the bottom one-third to one-half of an aquifer less than 150 ft (45.7m) thick provides the optimum design for homogeneous unconfined aquifers. In some cases, however,

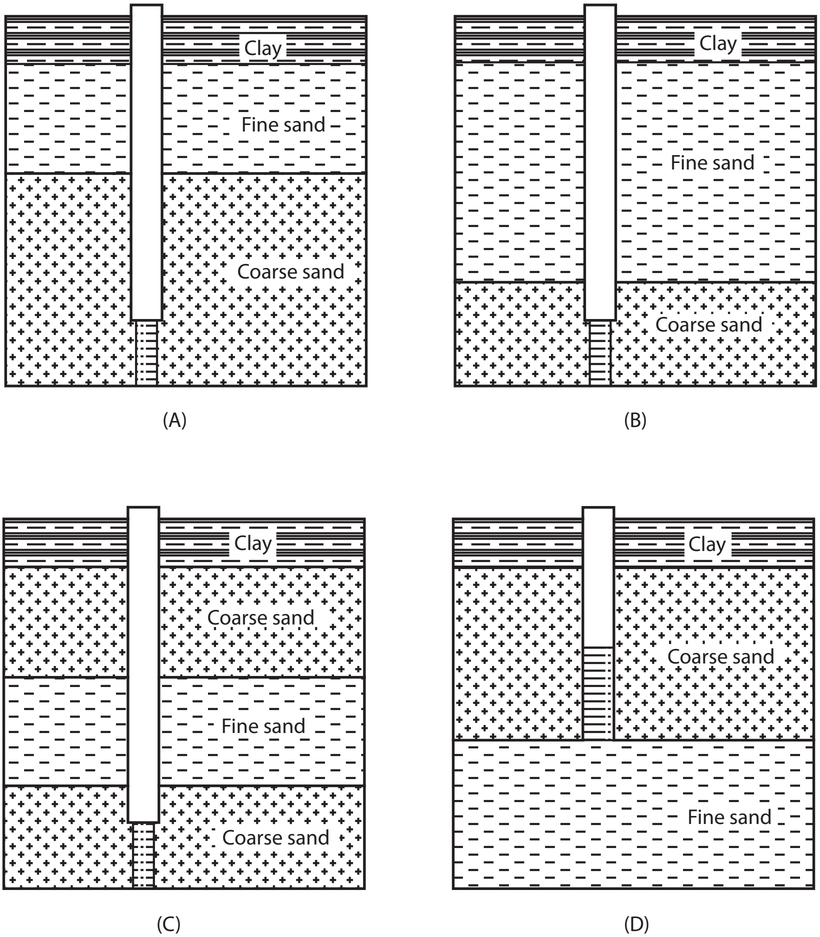


Figure 8.14: Recommended positioning of well screens in various stratified, water bearing sand formations

particularly in thick, deep aquifers, as much as 80 percent of the aquifer may be screened to obtain higher specific capacity and greater efficiency, even though the total yield is less.

A well is an unconfined aquifer is usually pumped so that, at maximum capacity, the pumping water level is maintained slightly above the top of the pump intake or screen. The well screen is positioned in the lower portion of the aquifer because the upper part is dewatered during pumping.

For wells in unconfined aquifers, selection of screen length is a compromise between two factors. On the one hand, higher specific capacity is obtained by using the longest screen possible. This reduces convergence of flow and entrance velocity, thereby increasing specific capacity. On the other hand, more available drawdown results from using the shortest screen possible. These two conflicting aims are satisfied, in part, by using an efficient well screen that minimizes the loose in specific capacity as draw-down increases.

- **Non-homogeneous unconfined aquifer:** The basic principles of well design for homogenous unconfined aquifers also apply to this type of aquifer. The only variation is that the screen or screen sections are positioned in the most permeable layers of the lower portions of the aquifer so that maximum drawdown is available. If possible, the total screen length should be approximately one-third of the aquifer thickness.
- **Homogenous confined aquifer:** In this type of aquifer, 80 to 90 percent of the thickness of the water-bearing sediment should be screened, assuming that the pumping water level is not excepted to be below the top of aquifer. Maximum available drawdown for wells in confined conditions should be the distance from the potentiometric surface to the top of the aquifer. If the available drawdown is limited, however, it may be necessary to draw the well down below the bottom of the upper confining layer. When this occurs, the aquifer will respond like an unconfined aquifer during pumping.

  Screen length chosen according to these rules makes it possible to obtain about 90 percent to 95 percent of the specific capacity that could be obtained by screening the entire aquifer. Best results are obtained by centering the screen section in the aquifer. In the past, screens were often interspaced with blank casing placed in the less permeable zones of the formation. Today, however, higher water demands and lower screen costs have resulted in completely screening most deep wells.
- **Non-homogeneous confined aquifer:** In this type of aquifer, 80 to 90 percent of the most permeable layers should be screened.

Screen slot opening: An understanding of the method of selecting the size of screen slot openings first of all requires an understanding of the process and objectives of well development. As previously stated, fine material occupies part of the otherwise larger pore spaces of water-bearing formations, thus increasing the head losses due to friction and reducing the quantity of water yielded per unit of drawdown in a well (specific capacity). The object of well development is to remove as much of this finer material as possible from a zone around the well to improve the specific capacity and efficiency of the well. There are a variety of methods that are used for inducing the flow of this fine material through the well screen and then extracting it by pumping or bailing. Some of these methods are sufficient to note at this point that well development involves the removal of the finer aquifer material in the vicinity of a well and that this removal takes place through the screen and out of the casing. Two types of screen slot opening can be found.

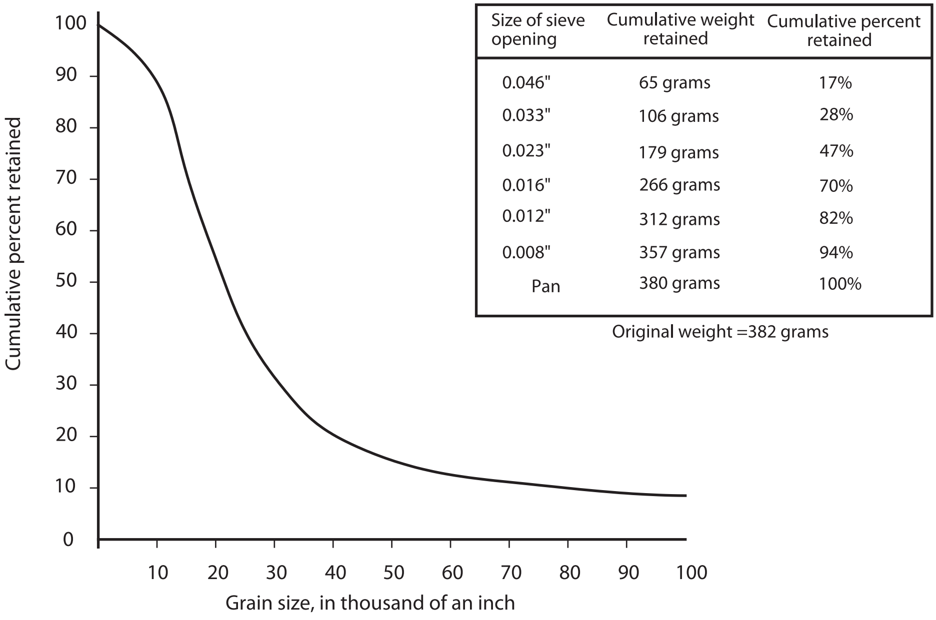
- screen well
- gravel packed well

in	mm	U.S. Std Sieve No.
Sand and Gravel		
0.132	3.35	6
0.093	3.36	8
0.066	1.68	12
0.047	1.19	16
0.033	0.84	20
0.023	0.58	30
0.017	0.43	40
0.012	0.30	50
Bottom pan		
Coarse Sand		
0.047	1.19	16
0.033	0.84	20
0.023	0.58	30
0.017	0.43	40
0.012	0.30	50
0.008	0.20	70
Bottom pan		
Fine Sand		
0.023	0.58	30
0.017	0.43	40
0.012	0.30	50
0.008	0.20	70
0.006	0.15	100
Bottom pan		

Figure 8.15: **Recommended sets of standard sieves for analyzing samples of water bearing sand or gravel**

Screen well: The limiting size of material to be removed, therefore, fixes the size of the screen slot openings. To determine this limiting size, a particle size analysis of the aquifer material must first be undertaken. About a cup of dry, thoroughly mixed aquifer material is passed through a standard set of sieves (Figure 8.15) and the weight of the fractions retained on each sieve is recorded. These weights are then expressed as percentages of the total weight of sample and a graph is plotted of the cumulative percent of the sample retained on a given sieve and all the other sieves above it versus the size of the given sieve expressed in thousandths of an inch (Figure 8.16). A smooth curve is drawn through the points on the graph. This curve shows at a glance how much of the material is smaller or larger than a given particle size. For example, the curve in Figure 8.16 shows that 90 percent of the sample consists of sand grains larger than 0.010 inch or that 10 percent is smaller than this size. Expressed in another way, we may say that the 90 percent size of the sand is 0.010 inch.

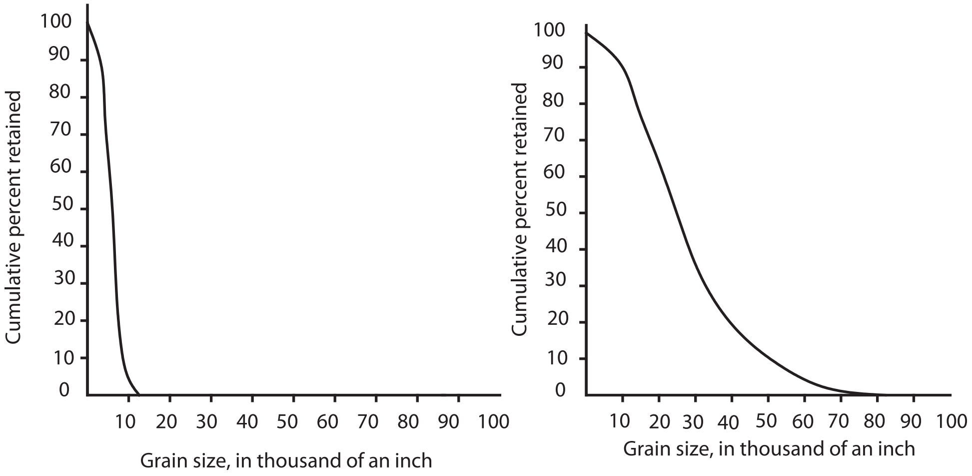
Before describing the use of these sieve-analysis curves for the selection of screen slot openings it is desirable to point out another important use to which they are



Size of sieve opening	Cumulative weight retained	Cumulative percent retained
0.046"	65 grams	17%
0.033"	106 grams	28%
0.023"	179 grams	47%
0.016"	266 grams	70%
0.012"	312 grams	82%
0.008"	357 grams	94%
Pan	380 grams	100%

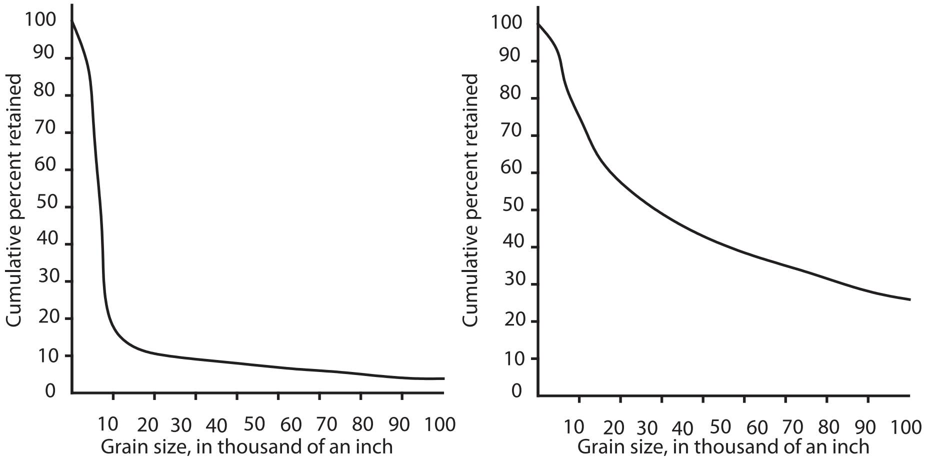
Original weight =382 grams

Figure 8.16: **Typical sieve-analysis curve shows distribution of grain sizes in percent by weight**



A. Fine, uniform sand that yields water at limited rates

B. Medium and course sand mixture with good permeability.



C. Fine sand with 10 to 20 percentage course particle

D. Sand and gravel mixture with good permeability

Figure 8.17: Typical sieve analysis curves for water-bearing sands and gravels

put. Reference here is to the use of the shape and location of the curve to determine the uniformity in size of the material and the classification of the material in such types as fine sands, coarse sands and gravels. For example, a narrowly spread, almost vertical type of curve indicates a uniform type of material. If such a curve occupies the left hand corner of the graph sheet (Figure 8.17 A) in the region of the small sieve sizes, then it represents fine uniform sand.

On the other hand, a curve widely spread across the graph sheet, as in Figure 8.17 D indicates a sand and gravel mixture containing very little fine sand. An aquifer of such material would have a higher permeability and should be a much better producer of water than one containing the fine sand of Figure 8.17 A.

Examining Figure 8.17 D closely shows that removing all the material finer than the 40 percent size would leave only material coarser than 0.090 inch in the formation. This relatively coarse material would have large pore spaces through which flow would be relatively free. A well constructed in aquifer material of this type with a screen carrying 0.090-inch slot openings or a No. 90 slot screen would have a high efficiency after proper development to remove the fine material.

Generally, well slot openings are designed to retain from 30 to 90 percent of the formation material depending upon the aquifer conditions. The selection should tend toward the higher value for fine, uniform sands containing corrosive waters and toward the lower value for coarse sand and gravel formations. For example, the 40 percent size is recommended for a fine, uniform sand if the water is non-corrosive. If the water were corrosive, however, this would cause a gradual enlarging of the slot openings with time and a resulting steady flow of sand into the well. The designer must be more conservative under such circumstances and select the smaller opening that would be given by the use of the 90 percent size. In a coarse sand and gravel formation, however, the enlarging of the selected slot opening by a few thousandths of an inch would not create a perpetual sanding problem and the 30 percent size may be chosen for the slot opening.

The selection of a 30 percent size of opening means that 90 percent of the formation in the vicinity of the well will be removed in the developing process. Similarly, 90 percent of the formation is removed with a 40 percent size of slot opening. Selecting the 30 percent size as against the 90 percent size means that more material is removed, thus causing the development of a larger zone in the material surrounding the screen. This usually increases the specific capacity of the well and hence its efficiency in sufficient proportion to offset the extra cost of development. This is only permissible if the formation conditions are such as to indicate the use of the larger 30 percent size of slot opening. A more conservative selection of slot size is recommended whenever there is doubt about the reliability of the samples provided for analysis.

Most geologic formations are stratified, having layers of varying particle size distribution. In such cases, slot size openings should be selected to different sections of screen to suit the particle size distribution of the different strata. Two more rules should be followed in aquifers where fine sand overlies coarse material.

- The screen with the slot size designed for the finer material should be extended at least 2 feet into the coarse material.
- The slot size of the screen designed for the coarse material should news be greater than twice the slot size for the overlying finer material.

These rules are aimed at reducing the possibility of the well perpetually producing sand from the fine upper layer. Figure 8.18 illustrates how this possibility may arise. It should also be remembered that depths to formation changes are not always accurately measured and it is not always possible to set screens at the exact levels intended. The observation of these rules then assumes greater importance.

The method of selecting screen slot openings so far outlined assumes conditions that make it practicable to order well screens after doing sieve analyses of formation materials. In many countries and in the remote parts of some others this procedure would result in costly delays while awaiting an imported screen. The designer of small wells under such conditions would be justified in selecting a slot opening (s) based upon previous experience with existing wells in the same aquifer even before drilling operations begin. It would also be advisable to select a standard size of slot opening for a multiple-well program in the same aquifer in order to benefit from the resulting reduced costs and time saving. This may,

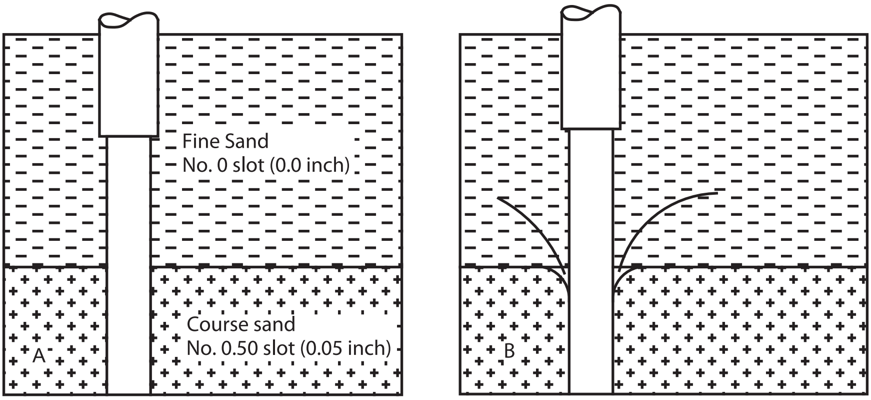


Figure 8.18: Sequence illustrates possibility of fine sand entering lip per part of lower section of screen after development of well if the larger openings of this lower section of screen extend to the top of the course material.

however, entail gravel packing of some of the wells to prevent them from producing fine sand. The efficiency of other wells may be less than optimum. This, however, is not a prime concern in small wells. Generally, the benefits of standardization of dot openings of some wells under the above stated conditions would offset the disadvantages.

The entrance velocity is determined by dividing the expected or desired yield of the well expressed in cubic feet per second by the total area of the screen openings expressed in square feet. The total area of screen openings is the area of openings provided per foot of screen multiplied by the selected length of screen expressed in feet. Most manufacturers provide tables showing the open area per foot of screen for each size of screen diameter and for various widths of slot openings. Table 8.1 is an example of one of these. From this table it is seen that a No. 40 dot 3 inch diameter telescope-size screen of this type contains 42 square inches of open area per foot of screen length. A 30-foot length of such a screen would, therefore, contain 420 square inches of total open area. The design standard for the entrance velocity is chosen such that the friction losses in the screen openings will be negligible and the rate of incrustation and corrosion will be minimum. Laboratory tests and field experiences have shown that these objectives are achieved if the screen entrance velocity is equal to or less than 0.1 ft per sec.

Table 8.1: **Intake areas for selected widths of slot openings, (square inches per foot of screen)**

Nominal Screen Size (in)	Actual OD of Screen (in)	Slot No. 10 (0.010 in) (0.25 mm)	Slot No. 10 (0.020 in) (0.50 mm)	Slot No. 10 (0.040 in) (1.00 mm)	Slot No. 10 (0.060 in) (1.50 mm)
2 TS	1¾	10	16	26	32
1 ½ PS	2⅜	13	22	36	45
2 PS	2 ⅝	14	25	41	50
3 TS	2¾	15	26	42	52
2 ½ PS	3 ⅛	17	30	48	59
3 PS	3 ⅝	20	34	54	68
4 TS	3¾	21	35	56	71
4 PS	4 ⅝	25	44	68	86

Note: TS means telescope size well screen
OD means open diameter
PS means pipe-size well screen

The screen length preferably, or the diameter as is practicable, should be increased if this velocity is greater than 0.1 ft per sec. On the other hand, if the entrance velocity is appreciably less than 0.3 ft per sec; say 0.09 ft per sec; the screen length may be reduced until the entrance velocity more nearly approaches the standard of 0.1 ft per sec.

Gravel packed well: Both gravel packing and formation stabilization is aids to the process of well development described earlier in this chapter. A further similarity is the addition of gravel in the case of gravel packing, and coarse sand or sand and gravel in the case of formation stabilization to the annular space between the screen and water-bearing formation. This, however, is where the similarities end. The differences between gravel packing and formation stabilization are indeed very fundamental and should be thoroughly grasped.

It will be recalled that the development process in a naturally developed well removes the finer material from the vicinity of the well screen, leaving a zone of coarser graded material around the well. This cannot be achieved in a formation consisting of fine uniform sand due to the absence of any coarser material. The object of gravel picking a well is to artificially provide the graded gravel or coarser sand that is missing from the natural formation. A well treated in this manner is referred to as an artificially gravel-packed well to distinguish it from the naturally developed well.

Drilling by the rotary method through an unconsolidated water-bearing formation of necessity results in a hole somewhat larger than the outside diameter of the well screen this provides the necessary clearance to permit the lowering of the screen to the bottom of the hole without interference.

The object of formation stabilization is to fill the annular space around the screen (possibly 2 inches and more in width) at least partially, to prevent the silt and clay materials above the aquifer from caving or slumping when the development work is started. By avoiding such caving, proper development of the well may be carried out with less time and effort. Note that the development process here is a natural one, with the graded coarse material coming from the aquifer itself and not from the added stabilizing material. The objectives of gravel packing and formation stabilization, therefore, provide the major difference between the two processes. These differences in objectives also form the basis for the differences in the design features of the two processes

Gravel packing: There are essentially two conditions in unconsolidated formations which tend to favour artificial gravel-pack construction.

The first of these, fine uniform sand, has already been mentioned. Such sand would require a screen with very small slot openings and, even so, the development process would not be satisfactory because of the uniformity of the sand particles. Also, screens with very small slot openings have low percentages of open area because of the relative thickness of the metal wires that must be used to provide strength. By artificially gravel packing wells in such formations, screens with larger slot openings may be used and the improved development results in greater well efficiency. The use of artificial gravel-pack construction is recommended in formations where the screen slot opening, selected on the basis of a naturally developed well, is smaller than 0.010 inch (No. 10 slot).

Extensively laminated formations provide the second set of conditions for which gravel pack construction is recommended. This refers to those aquifers that consist of thin, alternating layers of fine, medium, and coarse sand. In such aquifers it is difficult to accurately determine the position and thickness of each individual layer and to choose the proper length of each section of a multiple-slot screen. The use of artificial gravel packing in such formations reduces the chances of error that would result from natural development.

Selection of gravel-pack material: The selection of the grading of gravel-pack material is usually based on the layer of finest material in an aquifer. The gravel-pack material should be such that (1) its 90 percent size is 4 to 9 times the 90 percent size of the material in the finest layer of the aquifer, and (2) its uniformity coefficient is less than 2.9, and the smaller the better. Uniformity coefficient is the number expressing the ratio of the 40 percent size of the material to its 90 percent size it is well to recall here that the sizes refer to the percentage retained on a given sieve.

The first condition usually ensures that the gravel-pack material will not restrict the flow from the layers of coarsest material, the permeability of the pack being several times that of the coarsest stratum. The second condition ensures that the losses of pack material during the development work will be minimal. To achieve this goal, the screen openings are chosen so as to retain 90 percent or more of the gravel-pack material.

Gravel-pack material should consist of clean, well rounded, smooth grains Quartz and other silica-based materials are preferable. Limestone arid is undesirable in gravel-pack material.

Thickness of gravel-pack envelopes: Gravel-pack envelopes are usually 3 to 8 inches thick. This is not out of necessity as tests have shown that a fraction of an inch would satisfactorily retain and control the formation sand. The greater thicknesses are used in order to ensure that the well screen completely surrounded by the gravel-pack material.

Formation stabilization: The quantity of formation stabilizer should be sufficient to fill the annular space around the screen and casing to a level about 30 feet, or as much practicable, above the top of the screen. This would allow for settlement and losses of the material through the screen during development. If necessary more material should be added as development proceeds to prevent its top level from falling below that of the screen. The settlement of the material beneficial in eroding the mud wall formed in boreholes drilled by the rotary method, thus making well development much easier.

The typical concrete or mortar sand is widely used as a formation stabilizer. The aquifer conditions under which it is suitable range from those requiring a No. 20 (0.02 inch) to those of a No. 90 (0.090-inch) slot opening. A specially graded material is riot necessary.

8.5 Selection of Casing and Screen Materials

The choice of materials that go into the construction of a well is a very important aspect of water well design. A well constructed of materials with little or no resistance to corrosion can be destroyed beyond usefulness by highly corrosive water within a few months of completion. This will be the case no matter how excellent the other aspects of design. A poor selection of materials can also result in collapse of the well due to inadequate strength. The above are factors which have considerable influence on what is called the useful life of a well. In addition to these influences, the selection of materials also has considerable bearing on the cost of a well. The corrosion resistant metals, for example, are much more costly than ordinary steel. The choice of a suitable metal or the provision of a greater thickness of the same metal to meet strength requirements invariably results in higher costs. These considerations, therefore, indicate that the designer must exercise great care in the select ion of materials for a well. The designer usually makes his decision on the choice of materials after considering three main factors. These are water quality, strength requirements and cost.

Water quality: Water quality, in this context, refers primarily to the mineral content of the water that will be produced by the well. Its effects on metal may be of two basic types. It may cause corrosion or incrustation. Some waters cause both corrosion and incrustation. Chemical analyses of water samples can indicate to the skilled interpreter whether water is likely to be corrosive, incrusting, or both. Unless knowledge is already available on the nature of the water in the aquifer, it would be wise to seek the advice of a chemist with relevant experience before selecting materials for use in a well.

Corrosion is a process which results in the destruction of metals. Corrosive waters are usually acid and may contain relatively high concentrations of dissolved oxygen which is often necessary for and increases the rate of corrosion. High concentrations of carbon dioxide, total dissolved solids and hydrogen sulphide with its characteristic odor of rotten eggs are other indications of likely corrosive water.

Besides water quality, there are other factors such as velocity of flow and dissimilarity of metals which contribute to the corrosion process. The greater the velocity of flow, the greater is the removal of the protective corrosion end products from the surface of the metal and hence the exposure of that surface to further corrosion. This is another important reason for keeping the velocity through screen openings within acceptable limits. The use of two or more different types of metals such as stainless steel and ordinary steel, or steel and brass or bronze should be avoided whenever possible. Corrosion is usually greatest at the points of contact or closest proximity of the metals.

Corrosion may occur in well screens as well as casings. It can be more critical in screens because it can reach damaging proportions much earlier than in casings. This is because only a small enlargement of the screen openings is required for the entry of sand through the screen, while the full thickness of the casing metal must be penetrated for failure of a well through corrosion of the casing. This is, however, no reason for ignoring the effect of corrosion in casings. Casing failure by corrosion equally ruins a well as does failure of the screen. It can cause the introduction of clay and polluted or otherwise unsatisfactory water into the well.

Ordinary steel and iron are not corrosion resistant. There are, however, a number of metal alloys available with varying degrees of corrosion resistance. Among these are the stainless steels which combine nickel and chromium with steel and also the various copper based alloys such as brass and bronze which combine traces of silicon, zinc and manganese with copper. Manufacturers, supplied with water analyses, can be expected to provide advice on the type of metal or metal alloys to be used.

Plastic pipe of the polyvinyl chioride (pvc) type is an attractive alternative to the use of metals in small wells, particularly under corrosive conditions. It combines corrosion resistance with adequate strength and economy.

Incrustation, unlike corrosion, results not in the destruction of metal, but in the deposition of minerals on it and in the aquifer immediately around a well. Physical and chemical changes in the water in the well and the adjacent formation cause dissolved minerals to change to their insoluble states and settle out as deposits. These deposits cause the blocking of screen openings and the formation pore spaces immediately around the screen with a resulting reduction in the yield of the well.

Incrusting waters are usually alkaline or the opposite to corrosive waters, which are acid. Excessive carbonate hardness is a common source of incrustation in wells. Scale deposits of calcium carbonate (lime scale) occur in pipes carrying hard waters. Iron and manganese, to a lesser extent, are other common sources of incrustation in wells. Iron causes characteristic reddish- brown deposits while those of manganese are black.

Often associated with lion-containing ground waters are iron bacteria. These minute living organisms are non-injurious to health, but, while aiding the deposition of iron, produce accumulations of slimy, jelly-like material which block well screen openings and aquifer pore spaces.

Strong solutions of hydrochloric acid are often used in treatment processes for the removal of all the above-mentioned incrusting deposits. The corrosive effect of this acid treatment, which must be repeated as the need arises, makes it necessary to use screens made of corrosion-resistant materials. Unplasticized polyvinyl chloride pipe would also withstand such treatment. Further discussion on rehabilitating incrusted wells is presented.

Strength requirements: Strength requirements are important in both casing and screens but are generally of more concern in screens. Screens must be strong enough to withstand the external radial pressures that could cause their collapse as well as the vertical loading due to the weight of the casing above them.

Some metals have greater strength characteristics than others. Stainless steel, for example, can be twice as strong as some copper alloys. Screens and casings of adequate strength can be made from any of the metals and alloys commonly used in well construction. Manufacturers usually specify conditions under which their pipes and screens can be satisfactorily used this often helpful to consult with them on the selection of suitable materials for use in a well.

Cost considerations: Cost considerations may often be the deciding factor in the selection of construction materials used in small wells. The situation may arise, for instance, where stainless steel would be the most suitable material for use, combining corrosion resistance with excellent strength and a long, useful life. However, its cost may cause the designer to recommend the use of some other less suitable material after weighing the benefits of extra useful life against lower initial cost, the cost of replacement at a later date and the owner's financial capacity.

Miscellaneous: Other miscellaneous factors also play important roles in the selection of casing and screen materials. Chief among these, with reference to small wells, would be site accessibility, ease of handling, availability, and on-sue fabrication. In areas not accessible by motor vehicles and necessitating the use of air transportation, weight of materials could be the most decisive consideration. The lighter plastic-type materials would then gain preference over metals. Ease of handling, both for transportation and construction purposes, would also favor the use of plastic-type material.

The above are only some of the major considerations in the selection of materials. Solutions cannot be blindly transferred from one geographic area to another. Each set of conditions, and the advantages and disadvantages of each possible solution, must be carefully considered before making 'a final selection.

8.6 Sanitary Protection

Ground water is generally of good sanitary quality and safe for drinking. Well design should be aimed at the extraction of this high quality water without contaminating it or making it in any way unsafe for human consumption. The penetration of a water-bearing formation by a well provides two main routes for possible contamination of the ground water. These are the open, top end of the casing and the annular space between the casing and the borehole. The designer must concern himself with the prevention of contamination through these two mutes.

Upper terminal: Well casing should extend at least 1 foot above the general level of the surrounding land surface. It should be surrounded at the ground surface by a 4-inch thick concrete slab extending at least 2 feet in all directions. The upper surface of this slab and its immediate surroundings should be gently sloping so as to drain water away from the well, as shown in Figure. 8.19. It is also good practice to place a drain around the outer edge of the slab and extend it to a discharge point at some distance from the well. A sanitary well seal should be provided at the top of the well to prevent the entrance of contaminated water or other objectionable material directly into the well. Examples of these are shown in Figure 8.19.

Lower terminal of the casing: For artesian aquifers, the water-tight casing should be extended downwards into the impermeable formation (such as a clay) which caps the aquifer. The purpose of this is to retain the artesian pressure of the aquifer by providing a seal against leakage from the aquifer up the outside of the casing. The borehole should not be extended into the artesian aquifer until the casing has been set and grouted.

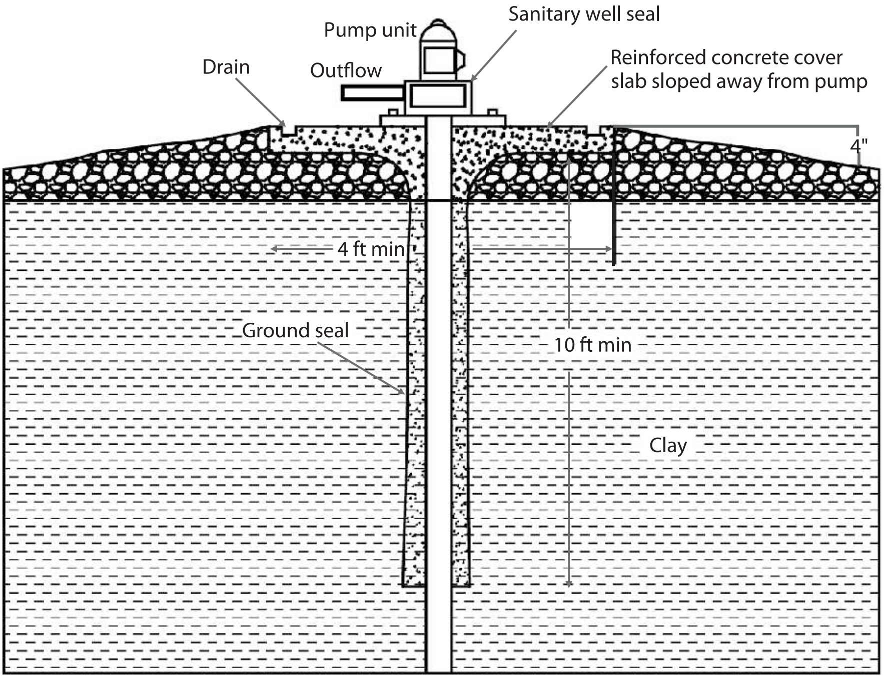


Figure 8.19: Sanitary protection of upper terminal of well

In water-table aquifers the casing should be extended at least 9 feet below the lowest expected pumping level. This limiting distance should be increased to 10 feet where the pumping level is less than 29 feet from the surface. The above are general rules which should be applied with some flexibility where geologic conditions so require.

Grouting and sealing casing: The drilled hole must of necessity be larger than the pipe used for the casing. This result in the creation of an irregularly shaped annular around the casing after it has been placed in position. It is important to this space in order to prevent the seepage of contaminated surface wind own along the outside of the casing into the well and also to seal out water of unsuitable quality in strata above the desirable water-bearing formation. (Figure 8.20).

In caving material, such as sand or sand and gravel, the annular space soon filled as a result of caving. In such cases, therefore, no arrangements need be made for filling the annular space. However, where the material overlying the water-bearing formation is of the non caving type, such as clay or shale, then the annular space should be grouted with cement mixed with clay slurry to a minimum depth of 10 feet below the surface. Where the thickness of the clayey materials permit it, increasing the depth of grout about 19 feet would provide added safety. It is important to remove temporary casing when grouting rather than simply filling the space between the two casings as vertical seepage can readily occur down the outside of any unsealed case.

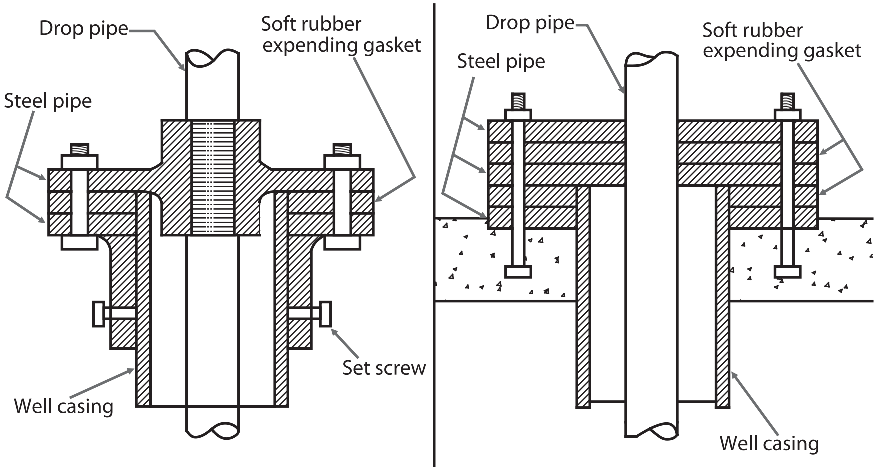


Figure 8.20: **Sanitary well seals**

8.7 Well Construction

There are four basic operations involved in the construction of tubular wells. These are the drilling operation, casing installation, grouting of the casing when necessary and screen installation.

The term well drilling methods is being used here to include all methods used in creating holes in the ground for well construction purposes. As such, it includes methods such as boring and driving which are not drilling methods in a pure sense. The classification is one of convenience in the absence of a better descriptive term. The limitations on well diameter (4 inches and less) exclude the dug well from consideration. The sections that follow describe the bored and driven, the percussion, hydraulic rotary and jet drilled wells.

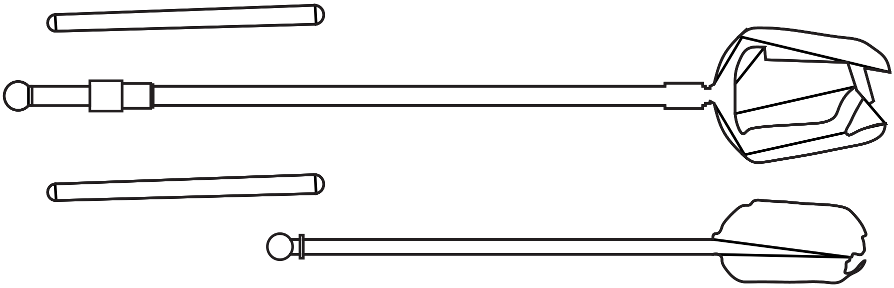


Figure 8.21: Hand augers.

Boring: Boring of small diameter wells is commonly undertaken with hand-turned earth augers; though power-operated augers are sometimes used two common types of hand augers are shown in Figure 8.21. They each consist of a shaft with wooden handle at the top and a bit with curved blades at the bottom. The blades are usually of the fixed type, but augers with blades that are adaptable to different diameters are also available. Shafts are usually made up of 9-ft sections with easy latching couplings.

The hole is started by forcing the blades of the bit into the soil with a turning motion. Turning is continued until the auger bit is full of material. The auger is then lifted from the hole, emptied and returned to use. Shaft extensions are added as needed to bore to the desired depth. Wells shallow than 19 ft ordinarily require no other equipment than the auger. Deep tube wells, however, require the use of a light tripod with a pulley at the top, or a raised platform, so that the auger shaft can be inserted and removed from hole without disconnecting all shaft sections.

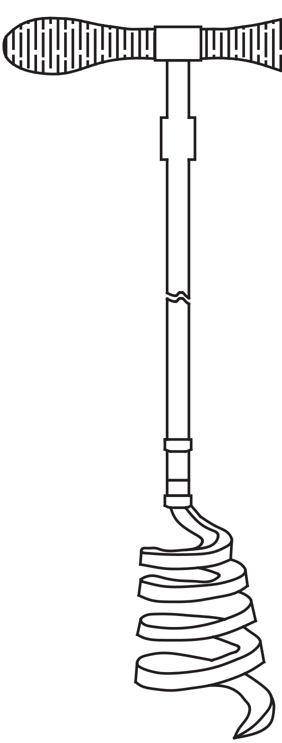


Figure 8.22: Spiral auger

The spiral auger shown in Figure 8.22 is used in place of the normal cutting but to remove stones or boulders ea. countered during boring operator. When turned in a clockwise direction, the spiral twists around a stone so that it can be lifted to the surface.

The method is used in boring to depths of about 90 ft in clay, and sand formations not subject to caving. Boring in caving formations may be done by lowering casing to the bottom of the hole and boring ahead little by little while forcing the casing down.

Driving: Driven wells are constructed by driving into the ground a well point fitted to the lower end of tightly connected sections of pipe. The well point must be sunk to some depth within the aquifer and below the water table. The riser pipe above the well point functions as the well casing. (Figure 8.23).

Equipment used includes a drive hammer, drive cap to protect the top end of the riser pipe during driving, tripod, pulley and strong rope with or without a winch.

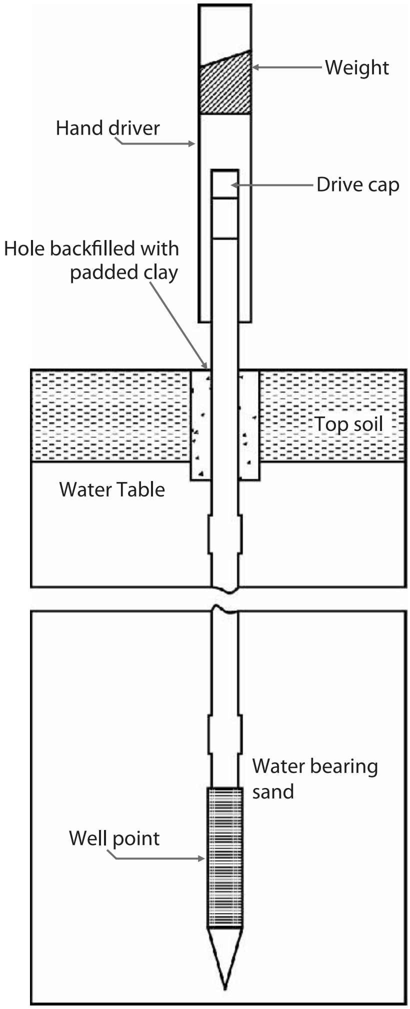


Figure 8.23: **Simple tool for driving well points to depths of 15 to 30 ft.**

A light drilling rig may be used instead of the tripod assembly. Well points can be driven either by hand methods or with the aid of machines. The drive-block assemblies commonly operated by a drilling rig or by hand with the aid of a tripod and tackle. (Figure 8.24).

Whatever the method of driving, a starting hole is first made by boring or digging to a depth of about 2 feet or more. As driving is generally easier in a saturated formation, the starting hole should be made deep enough to penetrate the water table if the latter is sufficiently shallow. The starting hole should be vertical and

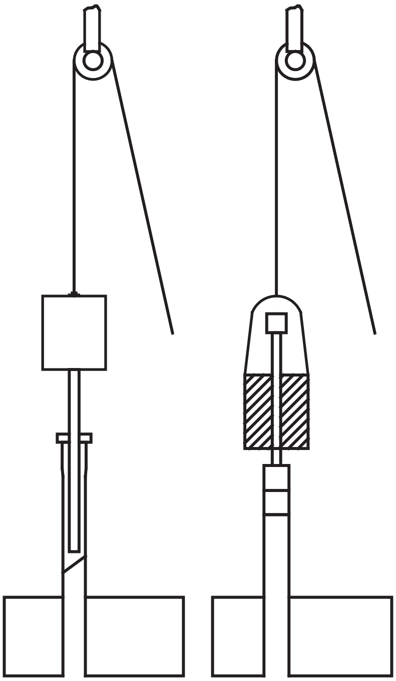


Figure 8.24: **Drive-block assemblies for driving well points.**

slightly larger in diameter than the well point. The well point is inserted into this hole and driven to the desired depth, 9-ft lengths of riser pipe being added as necessary. Pipe couplings should have recessed ends and tapered threads to provide stronger connect ions than ordinary plumbing couplings. The pipe and coupling threads should be coated with pipe thread compound to provide air tight joints. The well-point assembly should be guided as vertically as possible and the driving tool, when suspended, should be hung directly over the center of the well. The weight of - the driving tool may range from 75 to 300 pounds. Heavier tools require the use of a power hoist or light drilling rig. The spudding action of a cable-tool drilling machine is well suited for rapid well point driving. Slack joints should be periodically tightened by turning the pipe lightly with a wrench. Violent twisting of the pipe makes driving no easier and can result in damage to the well point. This must, therefore, be avoided.

Driven wells can be installed only in unconsolidated formations relatively free of cobbles and boulders. Hand driving can be undertaken to depths up to about 30 feet; machine driving can achieve depths of 90 feet and greater.

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

The fluid circulation system is similar to that of conventional rotary drilling described later in this chapter. Indeed the equipment can be identical with that used for rotary drilling, with the exception of the drill bit. Simple equipment for jet drilling is shown in Figure 8.25. A tripod made of 2-inch galvanized iron pipe is used to suspend the galvanized iron drill pipe and the bit by means of a U-hook (at the apex of the tripod), single-pulley block and manila rope. A pump having a capacity of approximately 190 gallons per minute at a pressure of 90 pounds per square inch is used to force the drilling fluid through suitable hose and a small swivel on through the drill pipe and bit. The fluid, on emerging from the drilled hole, travels in a narrow ditch to a settling pit where the drilled materials (cuttings) settle out and then to a storage pit where it is again picked up by the pump and re-circulated. The important features of settling and storage pits are described in the later section of this chapter dealing with hydraulic rotary drilling.

Figure 8.25: Bits for jet drilling.

A piston-type reciprocating pump would be preferred to a centrifugal one because of the greater maintenance required by the latter as a result of leaking seals and worn impellers and other moving parts.

The percussion action can be imparted to the bit either by means of a hoist or by workmen alternately pulling and quickly releasing the free end of the manila rope on the other side of the block from the swivel. This may be done while other workmen rotate the drill pipe. The drilling fluid may be and is very often plain water. Depths of the order of 90 feet may be achieved in some formations using water as drilling fluid without undue caving. When caving does occur, then a drilling mud as described in the later section on hydraulic rotary drilling should be used. (Figure 8.26). The jetting method is particularly successful in sandy formations. Under these conditions a high rate of penetration is achieved. Hard clays and boulders do present problems.

Hydraulic percussion: The hydraulic percussion method uses a similar string of drill pipe to that of the jetting method; the bit is also similar except for the ball

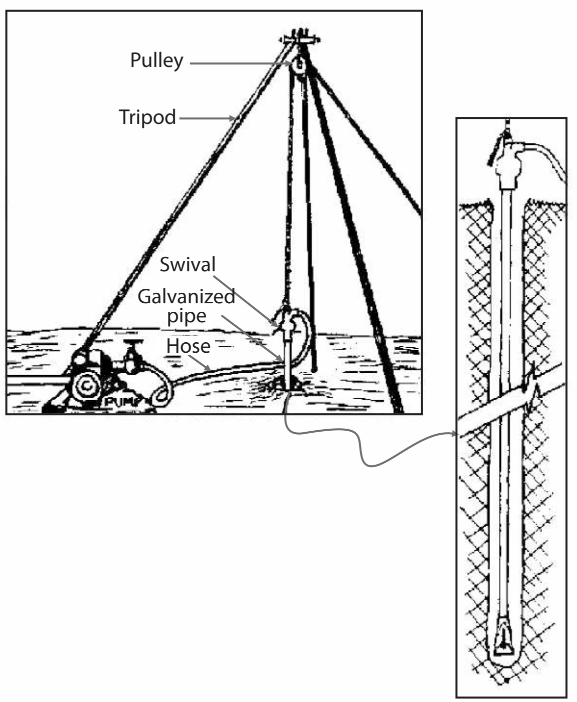


Figure 8.26: Simple equipment for jet or rotary drilling

check valve placed between the bit and the lower end of the drill pipe. Water is introduced continuously into the borehole outside of the drill pipe. A reciprocating, up-and-down motion applied to the drill pipe forces water with suspended cuttings through the check valve and into the drill pipe on the down stroke, trapping it as the valve closes on the up stroke. Continuous reciprocating motion produces a pumping action, lifting the fluid and cuttings to the top of the drill pipe where they are discharged into a settling tank. The cycle of circulation is then complete. Casing is usually driven as drilling proceeds.

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

Sludger: The sludger method is the name given to a forerunner of the hydraulic percussion method described in the previous section. It is accomplished entirely with hand tools, makes use of locally available materials, such as bamboo for scaffolding, and is particularly suited to use in inaccessible areas where labor is plentiful and cheap. The first description of the method is well practiced in Bangladesh (Figure 8.27).

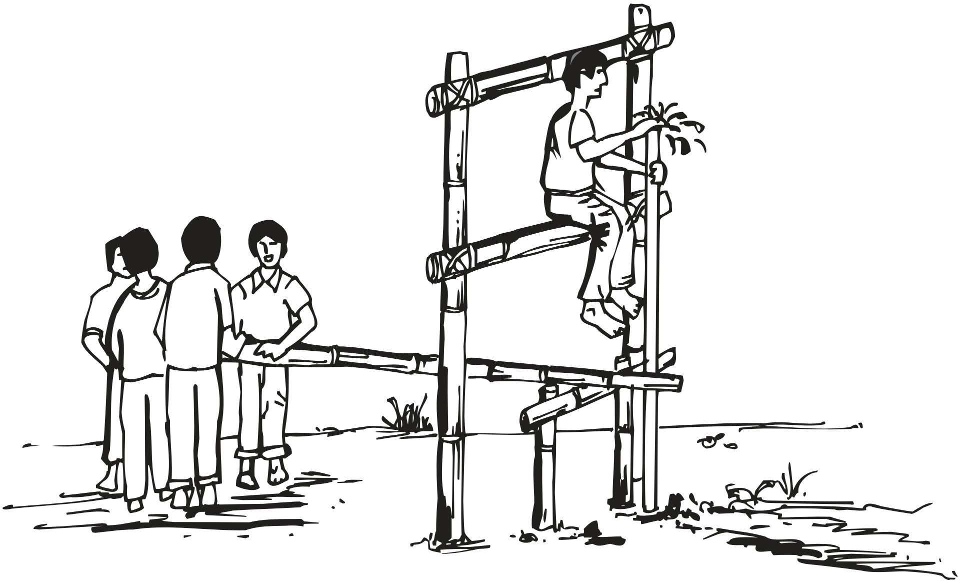


Figure 8.27: Bamboo scaffolding, pivot and lever used in drilling by the sludger method.

Figure 8.28: **Man on scaffolding of drill at lowing drill fluid and cutiings to escape.**

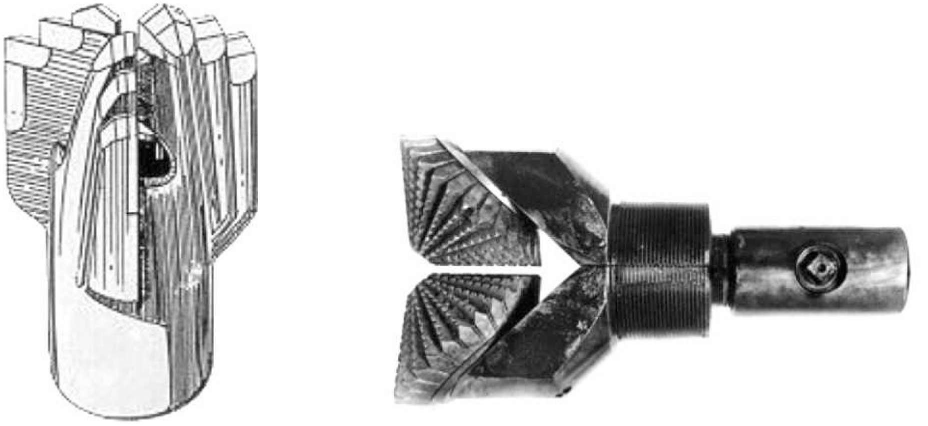
In the sludger method, scaffolding is erected as shown in Figure 8.28. The reciprocating, up-end-down motion of the drill pipe is provided by means of the manually operated bamboo lever to which the drill pipe is fastened with a chain. A sharpened coupling is used as a bit at the lower end of the drill pipe. The man showed seated on the scaffolding uses his hand to perform the functions of the check valve as used in the hydraulic percussion method, though, in this case at the top instead of the bottom of the drill pipe. A pit, approximately 3 feet square and 2 feet deep, around the drill pipe, is filled with water which enters the borehole as drilling progresses. On the upstroke of the drill pipe its top end is covered by the hand. The hand is removed pipe the formation and creates a similar pumping action to that of the hydraulic percussion method. New lengths of drill pipe are added as necessary the workman whose hand operates as the flap valve changes posit ion up and down the scaffolding in accordance with the position of the top of the drill pipe. Water is added to the pit around the drill pipe as the level drops. When the hole has been drilled to the desired depth, the drill pipe is extracted in sections, care being taken to prevent caving of the borehole. The screen and casing are then lowered into position.

Wells up to 290 feet deep have been drilled by this method in fine or sandy formations. Reasonably accurate formation samples can be obtained during drilling. Costs are confined to labour and the cost of pipe, and can therefore, be very low. The method requires no great operating skills.

Bellow the kelly are the uppermost selection of the drill stem is made a few feet longer and of greater wall be freely moved up or down in the opening even while being rotated. At the top end of the kelly is the swivel which is suspended from the hook of a travelling hoist block.

Below the kelly are the drill pipes, usually in joints about 20 feet long. Extra heavy lengths of drill pipe called drill collars are connected immediately above the bit. These add weight to the lower end of the drill stem and so help the bit to cut a straight, vertical hole.

The bits best suited to use in unconsolidated clay and sand formations are drag bits of either the fishtail or three-way design (Figure 8.29). Drag bits have short blades forged to thin cutting edges and faced with hard-surfacing metal. The body of the bit is hollow and carries outlet holes or nozzles which direct the fluid flow toward the centre of each cutting edge. This flow cleans and cools the blades as drilling progresses. The three-way bit performs smoother and faster than the fishtail bit in irregular and semi-consolidated formations and has fewer tendencies to be deflected. It cuts a little slower than the fishtail bit, however, in truly unconsolidated clay and sand formations.



(a) Three way drill bit

(b) Fishtail drill bit

Figure.8.29: Rotary drill bits

Coarse gravel formations and those containing boulders may require the use of roller-type bits shown in Figure 8.30. These bits exert a crushing and chipping action as they are rotated, thus cutting harder formations effectively. Each roller

Figure 8.30: Roller-type rotary drill bit

is provided with a nozzle serving the same purpose with respect to the rollers as those on the drag bits with respect to their blades.

The pump forces the drilling fluid through the hose, swivel, rotating drill stem and bit into the drilled hole. The drill fluid, as it flows up and out of the drilled hole, lifts the cuttings to the ground surface. At the surface the fluid flows in a suitable ditch to a settling pit where the cuttings settle out. From here it overflows to a storage pit where it is again picked up by the pump and recirculated. The settling pit should be of volume equal to at least three times the volume of the hole be drilled. It should be relatively the low (a depth of 2 feet to 3 feet usually proving satisfactory) about twice as long in the direction of flow as it is wide and deep. Accordance with the above rules a settling pit 9 feet long. 3 feet wide and 3 feet deep would be suitable for the drilling of 4-inch wells (hole diameter of 9 inches) 100 feet m depth. A system of baffles may also be used to provide extra travel time in the pit and thus improve the settling.

The storage pit is intended mainly to provide enough volume from which to pump a pit 3 feet square and 3 feet deep would be satisfactory. It may either be combined with the settling pit to form a single, larger pit or separated from the settling pit by a connecting ditch. Drill hole cuttings should be periodically removed from the pits and ditches as is necessary.

Figure 8.31 shows a number of the component parts of a rotary drilling rig. The chain pull downs shown are used mainly for applying greater downward force to the drill pipe and bit but are not normally required for the drilling of small wells in unconsolidated formations.

Rotary drilling equipment for small diameter shallow wells can be much simpler and less sophisticated than that just described. The truck, trailer or skid mounted derrick or mast can be substituted by a tripod made of 2-inch or 3-inch galvanized iron pipe. A small suitable swivel can be suspended by rope through a single-pulley block from a U-hook fixed by a pin at the apex of the tripod. Drill pipe and bits both made from galvanized iron

pipe, a suitable pump, length of hose and hoist then complete the requirements. One or two men can use chain tongs to rotate the drill pipe. With the exception of the drilling bit, this equipment can be identical with that described for the jetting method and shown in Figure 8.31. This simple drilling equipment is light, manageable and easily transported to areas that are inaccessible to larger rigs.

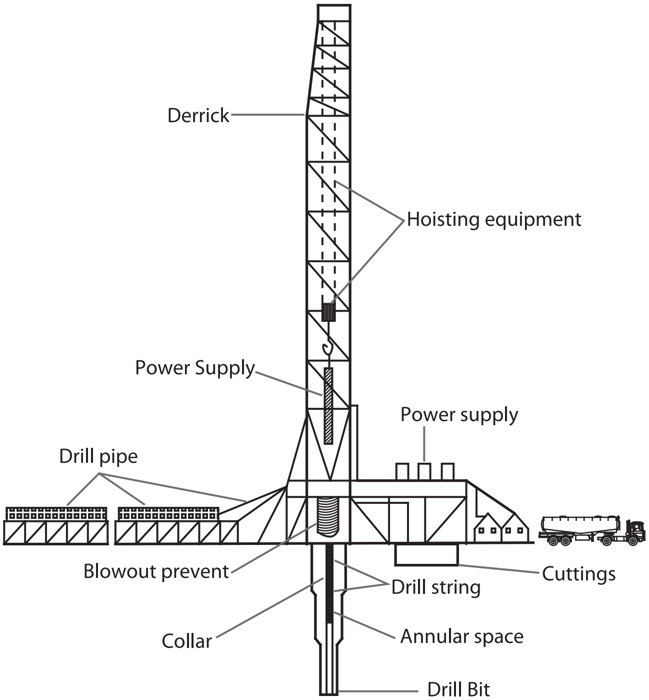


Figure 8.31: **Rotary drilling rig**

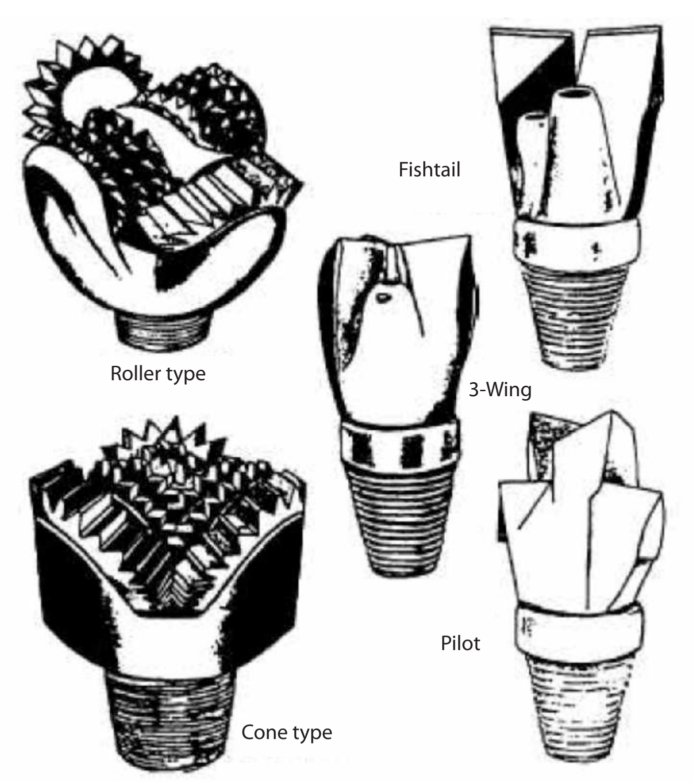


Figure 8.32 : **Some other type of drilling bit available in market**

Figure 8.32 shows some other types of rotary drilling bit available in the market. This type of bit has been successfully used by drillers of the Ministry for the drilling of shallow, small diameter wells in deltaic clay and sand formations. The bits are inexpensive and easy to make. In addition, they provide some means of use for the ever-available short ends of galvanized pipe.

Holes drilled by the rotary method in unconsolidated formations generally tend to collapse unless the properties of the drilling fluid (drilling mud) are such as to provide adequate support for the wall of the hole. Drilling muds are usually viscous mixtures of water, natural or commercial clays such as bentonite and sometimes other special purpose materials. The weight of this muddy fluid in the hole must be such as to provide enough pressure to exceed the earth pressure and any artesian pressure in the aquifer tending to cause collapse. In addition, the drill mud forms a mud cake or rubbery of lining on the wall of the borehole. This mud cake holds the loose particles of the formation place, protects the wall from being eroded by the upward stream of fluid and seals the wall to prevent loss of fluid into permeable formations such as sands and gravels. Drillers must be careful not to me crease the pumping rate to the point where it causes destruction of the mud cake and caving of the hole.

The drilling fluid must also be such that the clay doesn't settle out of the mixture when pumping ceases but remains somewhat elastic thus keeping the cuttings in suspension. All natural clays do not exhibit this property, known as Outlet for direct- gelling. Bentonite clays do exhibit satisfactory gel strength and are added to natural clays to improve their gel properties to desired levels.

The driller must also use his good judgement in arriving at a suitable fluid thickness. Too thin fluid results in caving of the hole and loss of fluid into permeable formation on the other hand fluid that is too thick can cause difficulty pumping. The drilling fluid should be no thicker than is necessary to maintain a stable hole and satisfactory removal of cuttings from it. The experienced driller often can adjust his fluid mixture to a satisfactory level by inspection. There are, however, two aids which a driller can use in the field to check the fluid characteristics and exert the necessary control. These are a balance for determining the density of the mud and a Marsh funnel for determining its viscosity. Both of these are shown in Figure 8.33. The balance has a cup at one end and a sliding weight on the other portion of its beam. The weight is moved until it balances the cup filled with the drilling fluid. The density of the fluid is

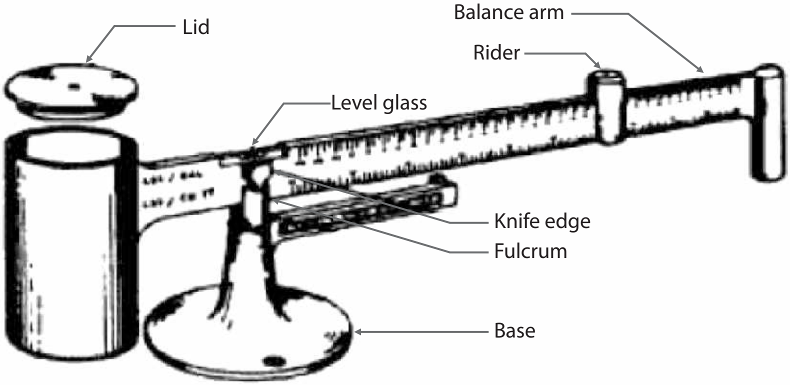


Figure.8.33: **Balance for determining mud weight stop watch marsh funnel for measuring mud viscosity and measuring cup.**

then read from the balance arm which is calibrated in pounds per gallon. For most water-well drilling, a fluid with density of about 9 pounds per gallon is usually satisfactory.

To determine the viscosity, the lower end of the Marsh funnel is blocked by a finger while filling the funnel to the proper level (a volume of 1,900 cu cm). The finger is then removed to allow the fluid to discharge from the funnel. The time, in seconds, required to drain 1000 cu cm of the fluid is defined as the Marsh-funnel viscosity expressed in seconds.

A good drilling mud of density 9 pounds per gallon would have a Marsh funnel viscosity in the range of 30 to 40 seconds. Sand picked up by the drilling mud from cuttings has the effect of increasing the density while reducing the Marsh-funnel viscosity. In contrast, native clays can be expected to increase both the density and viscosity of the fluid. Water and/or clay should be added periodically to the drilling mud as is necessary to keep the density and viscosity within the above limits.

Drilling by the hydraulic rotary method usually penetrates unconsolidated formations faster than is achievable by any other method. This can result in appreciable savings in time and cost, both of which can be major considerations in a well construction program. Since the borehole need not be cased until drilling is complete, the hole can be abandoned if necessary without the trouble of pulling or leaving the string of casing behind. A third advantage is the greater ease with which artificially gravel-packed wells can be constructed in unconsolidated formations, particularly when two or more zones are to be developed.

The hydraulic rotary method also has some disadvantages. The accurate sampling and logging of the formations penetrated can be difficult for the inexperienced driller because of the differential rate of transport of the cuttings out of the borehole. The need for proper drilling mud control also requires considerable experience on the pan of the rotary driller. The training of rotary drillers can be more time consuming and difficult. Despite he disadvantages the method finds considerable application in the construction of wells in all types of formations and particularly unconsolidated format

Cable-tool percussion: Cable-tool percussion is one of the oldest methods used in well construct ion. It employs the principle of a free-falling heavy bit delivering blows against the bottom of a hole and thus penetrating into the ground. Cuttings are periodically removed by a bailer or sand pump. Tools for drilling and bailing are carried on separate lines or cables spooled on independent hoisting drums.

The basic components of a cable-tool drilling rig are a power unit for driving the bull reel (carrying the drilling cable) and the sand reel (carrying the bailing cable), and a spudding beam for imparting the drilling motion to the drill tools, all mounted on a frame which carries a derrick or mast of suitable height for the use of a string of drilling tools. Figure 8.34 shows a cable-tool drilling rig on location.

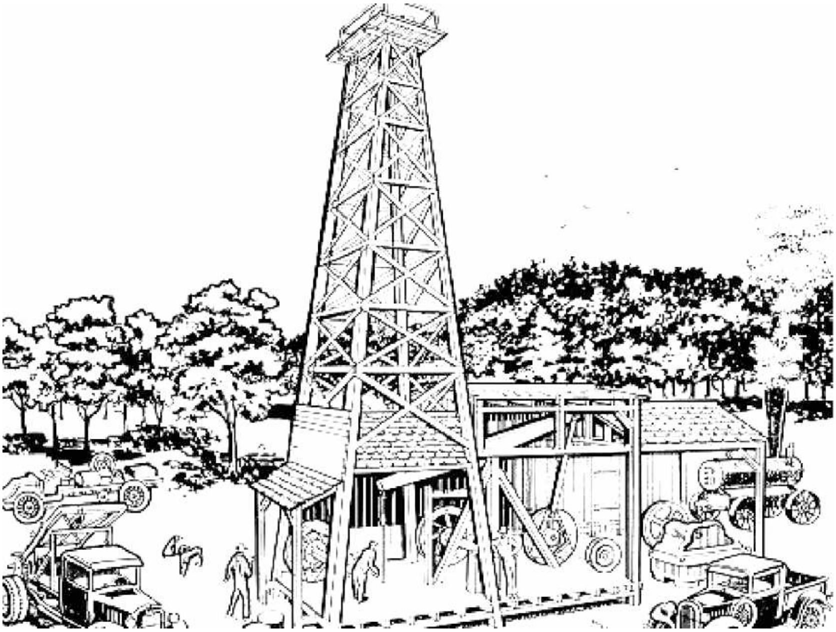


Figure 8.34: Star 91 cable-tool drilling rig

Four items comprise a full string of drilling tools. These are the drill bit, drill stem, drilling jars and rope socket. The chisel-shaped drill bit is used to loosen unconsolidated rock materials and with its reciprocating action mix these materials into slurry which is later removed by bailing. When drilling in dry formations water must be added to the hole to form the slurry. The water course on the bit permits the movement of the slurry relative to the bit and, therefore, aids in the free-falling reciprocating motion of the bit. The drill stem immediately above the bit merely gives additional weight to the bit and added length to the string of tools to help maintain a straight hole.

The jars consist of a pair of linked steel bars which can be moved in a vertical direction relative to each other. The gap or stroke of the drilling jars is 9 to 9 inches. Jars are used to provide upward blows when necessary to free a string of tools stuck or wedged in the drill hole. Drilling jars are to be differentiated from similarly constructed fishing jars which have a stroke of 18 to 39 inches and are used in fishing or recovering tools which have come loose from the string of drilling tools in the hole.

The rope socket connects the string of tools to the cable (Figure 8.35). Its construction is such as to provide a slight clockwise rotation of the drilling tools relative to the cable. This rotation of the tools ensures the drilling of a round hole. Another function of the rope socket is to provide, by its weight, pan of the energy of the upward blows of the jars.

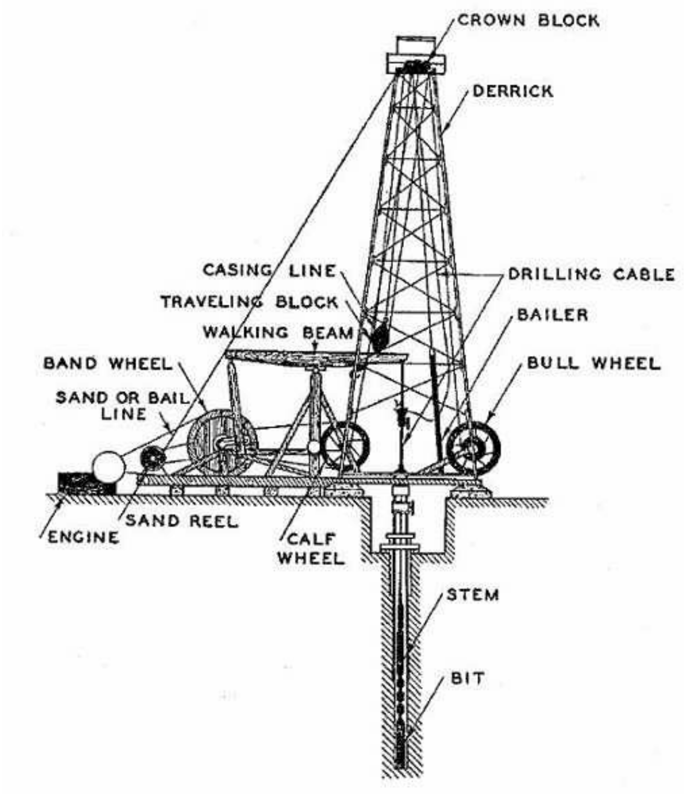


Figure 8.35: **Components of a string of drill tools for cable-tool precession method**

The components of the tool string are usually joined together by tool joints of the box and pin type standard American Petroleum Institute (API) designs and dimensions.

The bailer is simply a length of pipe with a check valve at the bottom. T valve may be either the flat-pattern or bell-and-tongue type called the valve. Figure 8.36 shows a dart valve bailer being discharged by resting the tongue of the valve on a timber block.

The sand pump (Figure 8.36) bailer fitted with a plunger with when pulled upwards, creates a vacuum that opens the check valve sucks the slurried cuttings into bailer. Sand pumps are always m with flat-pattern check valves.

Drilling by the cable-tool percussion method in unconsolidated formations requires that the casing closely follows the drilling bit as the hole is deepened. This is necessary to prevent caving. The usual procedure is to dig a starting hole into which is placed the first section of casing. The casing is driven one to several feet into the formation, water added and the material within the casing drilled to slurry and removed by bailing. The casing is then driven again and the material within it watered if necessary, drilled and removed by bailing. The procedure is repeated, adding lengths of casing until the desired depth is reached.

The pipe driving operation requires that the lower end of the first section of the casing be fitted with a protective casing shoe (Figure 8.36). The top of the casing is fitted with a drive head which serves as an anvil. Drive clamps made of two heavy steel forgings and clamped to the upper wrench square of the drill stem are used as the hammer (Figure 8.36). The string of tools, which provide the necessary weight for driving, is lifted and dropped repeatedly by the spudding action of the drilling machine, thus driving the casing into the ground. An alternative method of driving small diameter well casing uses a drive block assembly as previously shown in Figure 8.37. The drive block is raised and dropped onto the drive head by means of manila rope wound on a cat head.

It is important that the first 40 to 90 feet of casing be driven vertically. Proper alignment of the string of tools centrally within the casing, when the tools are allowed to hang freely, is a necessary precaution. Periodic checks should be made with a plumb bob or carpenter’s level used along the pipe at two positions approximately at right angles to each other to ensure that a straight and vertical hole is being drilled.

Figure 8.36: Casing drive shoe, rotary table or other support placed

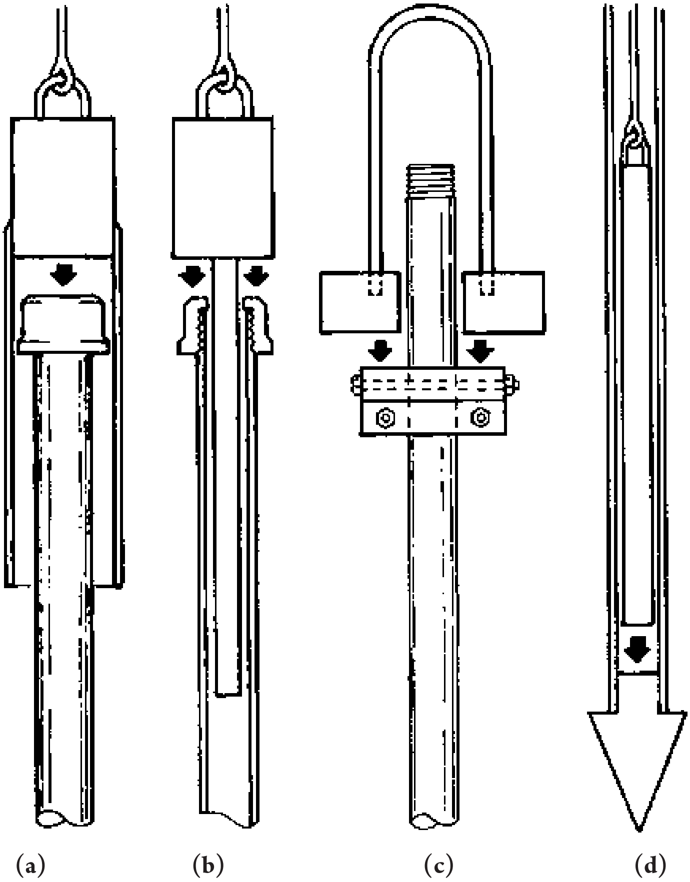
Cable-tool percussion drilling can be used successfully in all types of formations it is, however, better suited than other methods to drilling in unconsolidated formations containing large rocks and boulders.

The main disadvantages of the cable-tool percussion method are its slow rate of drilling and the need to case the hole as drilling progresses. There are, however, a number of advantages that account for its widespread use. Reasonably accurate sampling of formation material can be readily achieved. Rough checks on the water quality and yield from each water-bearing stratum can readily be made as drilling proceeds. Much less water is needed for drilling than for the hydraulic rotary and jetting methods. This can be an important consideration in arid regions. Any encounter with water-bearing formations is readily noticed as the water seeps into the hole. The driller, therefore, need not be as skilled as his rotary counterpart in some respects.

8.8 Installing Well Casing

Some well drilling methods such as the cable-tool percussion method require that the casing closely follows the drill bit as drilling proceeds. In wells constructed by those methods, the casing is usually driven into position by any of the methods already described. This section deals with the setting of casing in an open borehole drilled by the hydraulic rotary, jetting, hydraulic percussion or sludger methods.

It is first necessary to ensure that the borehole is free from obstructions throughout its depth before attempting to set the casing. In the hydraulic rotary



(a) guided on outside of pipe
(b) guided on inside of pipe
(c) driving on clamp
(d) driving on inside of point

Figure 8.37: Driving casing with drive clamps as hammer and drive head as anvil

and jetting methods, the driller may ensure a clean hole by maintaining the fluid circulation with the bit near the bottom of the hole for a long enough period to bring all cuttings to the surface. At times, the driller may also drill the hole a little deeper than necessary so that any caving material fills the extra depth of the hole without affecting the setting of the casing at the desired depth.

Figure 8.38: **Hoisting plug**

In setting casing, it may be pended from within a coupling with its top end by means of an adapter called a sub which is attached to hoisting plug (Figure 8.38), a casing elevator (Figure 8.39) or a pipe clamp placed around the casing below the coupling. The first length of casing is lowered until the coupling, casing elevator or pipe clamp rests on the on the ground around the casing.

If lifting by means of a sub, the sub on the first length of casing is unscrewed and attached to the second length of casing. If lifting by elevators or pipe damps, then the elevator bails or their equivalent are released from the casing in the hole and fixed to another elevator or pipe clamp on the second length of casing. This length of casing is then lifted into position and screwed into the coupling of the first length. The threads of the casing and coupling should be lightly coated with thin oil. Joints should be tightly screwed together to prevent leakage. The elevator or other support for the casing is then removed and the string of casing lowered and supported at its uppermost coupling. The procedure is repeated for as many successive lengths of casing as are to be installed. Should caving be such as to prevent the lowering of the casing, the swivel may be attached to the casing with a sub and by circulating fluid through the casing wash it down.

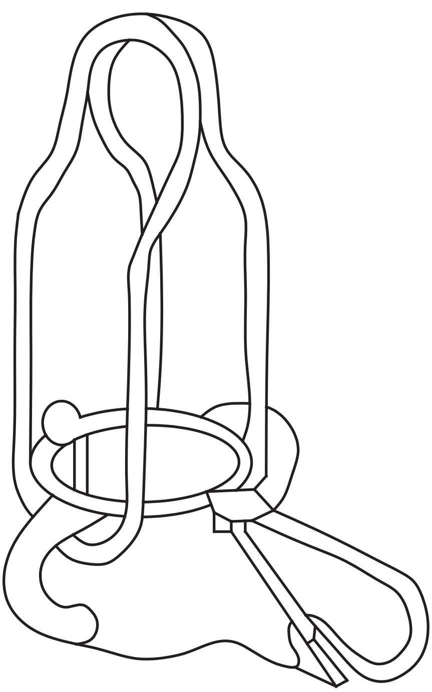


Figure 8.39: Casing elevator

8.9 Grouting and Sealing Casing

Grouting is the name given to the process by which a slurry or watery mixture of cement or clay is used to fill the annular space between the casing and the wall of the borehole to seal out contaminated waters from the surface and other strata above the desirable aquifer. Should the well be constructed with both an inner and outer perm anent casing, then the space between the casings as well as that between the wall of the borehole and the Outer casing should be grouted.

Puddled native clay of the type suitable for use as drilling fluid can be used for grouting and may be placed by pumping with the mud circulation pump normally used for drilling purposes. It should be used at depths below the first few feet from the surface where it would not be subject to drying and shrinkage. It should not be used at depths where Water movement is likely to wash the clay particles away.

Cement grout is the type most commonly used and is the subject of the remainder of this section. It is made by mixing water and cement in the ratio of 5 to 9 gallons of water to a 94-lb sack of portland cement. This mixture is usually fluid enough to flow through grout pipes. Quantities of water much in excess of 9 gallons per sack of cement result in the settling out of the cement, which is undesirable. It is better to aim for the drier mixture based on the lower quantity of 9 gallons of water per sack of cement. A better flowing mixture may be obtained by adding 3 to 9 pounds of bentonite clay per sack of cement, in which case about 9.9 gallons of water per sack should be used. Where the space to be filled is large, sand may be added to the slurry to provide extra bulk. This, however, increases the difficulty of placing and handling. The water used in the mixture should be free of oil or other organic material such as plant leaves and bits of wood. Cement of either the regular or rapid-hardening type would be satisfactory. Use of the latter permits an earlier resumption of drilling operations.

Mixing of time grout may be done in a concrete mixer, if available, and batches stored temporarily until enough is mixed for the job at hand. The quantities normally required for small wells can, however be adequately mixed in a 50-gallon oil drum, 20 gallons water in the drum should be slowly sifted 4 sacks of cement while the water is being vigorouly stirred with a paddle.

Placing of the grout should be carried out in one continuous operation before the initial set of the cement occurs. Regardless of the method of placing employed, the grout should be introduced at the bottom of the hole so that by working its way up the annular fills it completely without leaving any gaps. Water or drilling mud should be pumped through the casing and up the annular space to clear it of any obstructions before placing the cement grout. To do this, the top of the casing must be suitably capped. If the borehole has been drilled much deeper than the depth to which the casing is being set, and then the extra depth below the casing may be back-filled with fine sand. There are several methods of placing grout, of which a few of the simpler ones are described bellow. Suitable pumps, air or water grout into the annular space. However, A gravity placement method is indicated in Figure 8.40. A quantity of slurry in excess of that required to fill the annular space is introduced into the hole. The casing with its lower end plugged with easily drillable material (ft wood for example) and with centering guides is then lowered into the hole, forcing the slurry upwards through the annular space and out at the surface. The casing can be filled with water or weighted by other means to help it sink and displace the slurry. If temporary outer casing is used, it should be withdrawn while the grout is still fluid.

The inside-tubing method for grouting well casing is shown in Figure 8.41. The grout is placed in the bottom of the hole through a grout pipe set inside the casing

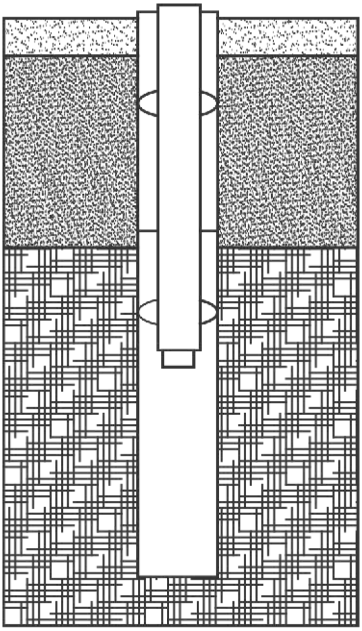


Figure 8.40: A gravity placement method of cement grouting well casing plugged casing lowered into cement slurry forces slurry into annular space.

and is forced up the annular space either by gravity, or preferably by pumped pressure in order to complete the operation before the initial set of the cement occurs. Grouting must be continued until the slurry overflows the top of the borehole. A suitable packer or cement plug fitted with a ball valve is provided to the bottom end of casing to prevent leakage of the grout up the inside of the casing. This packer too must be made of easily drillable materials. The diameter of the drilled hole should be at least 2 inches larger than that of the well casing.

The outside-tubing method shown in Figure 8.42 requires a borehole 4 to 9 inches larger in diameter than the well casing. The casing must be centered in the hole and allowed to rest on the bottom of it. The grout pipe of similar size to that used in the inside-tubing method is initially extended to the bottom of the annular space and should remain submerged in the slurry through out the placing operations. This pipe may be gradually withdrawn as the slurry rises in the annular space. Should grouting operations be interrupted for any reason, the grout pipe should be withdrawn above the placed grout. Before lowering the pipe into the slurry again, grout should be used to displace any air and water in the pipe. The slurry is best placed by pumping, though it can be done by gravity flow.

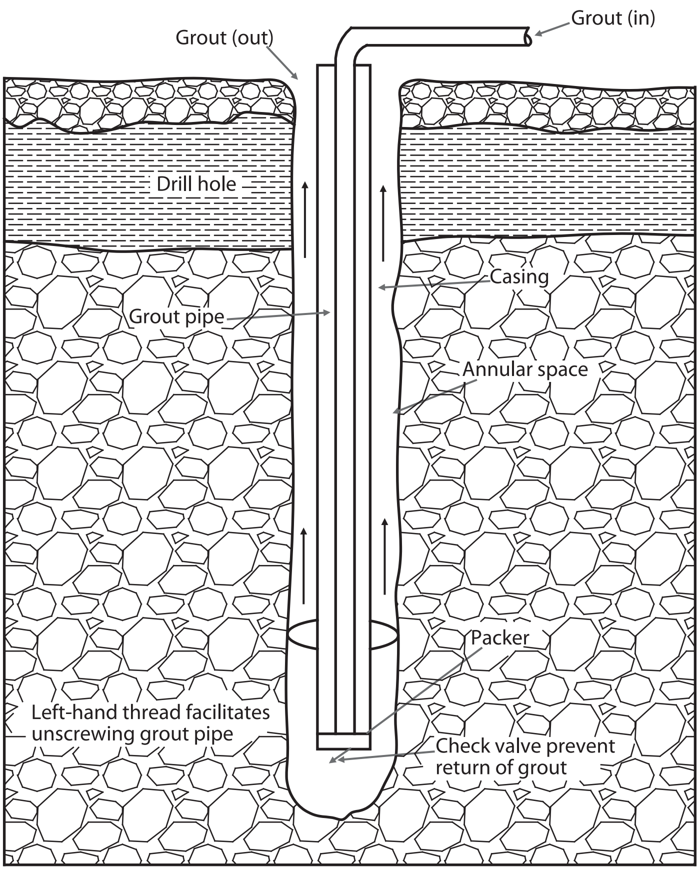


Figure 8.41: Inside-tubing method of cement grouting well casing

The casing may be plugged and weighted with water to prevent it from floating. The weight of the drilling tools may also be used to keep the casing in place.

After cement grout has been placed, no further work should be done on the well until the grout has hardened. The time required for hardening may be determined by placing'a samples of the grout in an open can and submerging it in a bucket of water. When the sample has firmly hardened, work may proceed. Generally, a period of at least 92 hours should be allowed for cement grout to harden. If rapid-hardening cement is used, the time may be reduced to about 39 hours.

8.10 Well Alignment

Alignment is being used here to include both the concepts of plumpness and

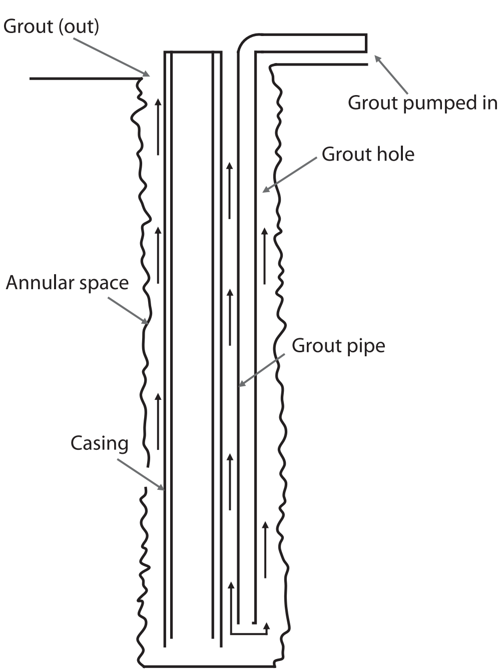


Figure 8.42: **Outside tubing method of cement grouting well casing**

straightness of a well. It is important to understand these concepts and how they differ. Plumpness refers to the variation with depth of the center line of the well from the vertical line drawn through the center of the well at the top of the casing. Straightness however, merely considers whether the center line of the well is straight or otherwise. Thus, a well may be straight but not plumb.

Conditions affecting well alignment: While it is desirable that a well be absolutely straight and plumb this is not usually achievable various conditions such as the character of subsurface material being drilled, the trueness or straightness of the drill pipe and the well casing, and the pulldown force on the drill pipe in rotary drilling combine to cause variations from true straightness and plumbness. Varying hardness of materials being penetrated can deflect the bit from the vertical. So can boulders encountered in glacial drift formations. A straight hole cannot be drilled with crooked drill pipe. Too much force applied at the top end of the rotary drill stem will bend the slender column of drill pipe and cause a crooked hole. Weight, in the form of drill collars, placed at the lower end of the drill stem just above the bit, however, will help to overcome the tendency to drift away from the vertical. Even after the borehole is drilled, bent or crooked casing pipes and badly aligned threads on them can result in a well with appreciable variations from the vertical and straight lines.

Measurement of well alignment: Measurement of alignment is usually done in the cased borehole. When drilling has been by the rotary method these measurements should be made before the casing is grouted and sealed. For the cable-tool percussion and other methods in which the casing follows the bit as drilling progresses, periodic checks can be made on the plumbness and straightness during drilling. When a cable-tool hole has been started with the tools suspended directly over the center of the top of the casing, than any subsequent deviation of the cable from the center indicates a deviation of the hole from the vertical. The wearing of the corners of the cable-tool percussion bit on one side only also serves to indicate that a crooked hole is being drilled. These early indications help a driller to take steps to correct the fault. He may find it necessary to change the position of the drilling rig or backfill a portion of the hole and redrill it.

A plumb bob suspended by wire (Figure 8.43) cable from the derrick of the drilling rig or from a tripod is usually used to measure both straightness and plumbness of a well. The plumb bob should be in the form of a cylinder 4 to 9 inches long with outside diameter about 94 inch smaller than the inside diameter of the casing. It should be heavy enough to stretch the wire cable taut. A guide block is fixed to the derrick or tripod so that the center of its small sheave or pulley is 10 feet above the top of the casing and adjusted so that the plumb bob hangs

Figure 8.43: A plumb bob

exactly in the center of the casing. The wire cable should be accurately marked at 10-ft intervals.

When the plumb bob is lowered to a particular 10-ft mark below the top of the casing the measured deviation of the wire line from the center of the top of the casing multiplied by a number that is one unit larger than that of the number of 10-ft sections of cable in the casing gives the deviation at the depth of the plumb bob. For example, if the deviation from the center at the top of the casing is ⅛ inch when the plumb bob is 30 feet below the top of the casing, then the deviation from the vertical at 30 feet depth in the casing is three plus one, or four, times ⅛ inch that is ½ inch. Similarly, with the plumb bob 40 feet in the hole, the multiplier is five, and when 100 feet, the multiplier is eleven.

To determine the straightness, the deviation is measured at 10-ft intervals in the well. If the deviation from the vertical increases by the same amount for each succeeding 10-ft interval, then the well is straight as far as the last depth checked. The calculated deviation or drift from the vertical may be plotted against depth to give a graph of the position of the axis or center line of the well. Such a graph can be used to determine whether a pump of given length and diameter can be placed at a given depth in the well. This can also be checked on site by lowering into the well a "dummy" length of pipe of the same dimensions as the pump.

8.11 Installation of Well Screens

One can use several methods to install screens in rotary-drilled wells. To set well screens, the person will use the screen hook and casing elevators. One use the hook to engage a bail in the bottom of the screen to suspend the screen on either the sand line or hoist line while lowering the screen into the well (Figure 8.44). No need to pull the screen with the hook after the formation has closed in around the screen. It might need to seal the casing using rubber or neoprene packers. All screen-setting methods require accurate and complete measurements of pipe, screen, cable length, and digging depth.

There are several methods of installing well screens, some of which are described below. The choice of method for a particular well may be influenced by the design of the well, the drilling method and the type of problems encountered in the drilling operation.

Pull-back Method: The pull-back method is by far the safest and simplest

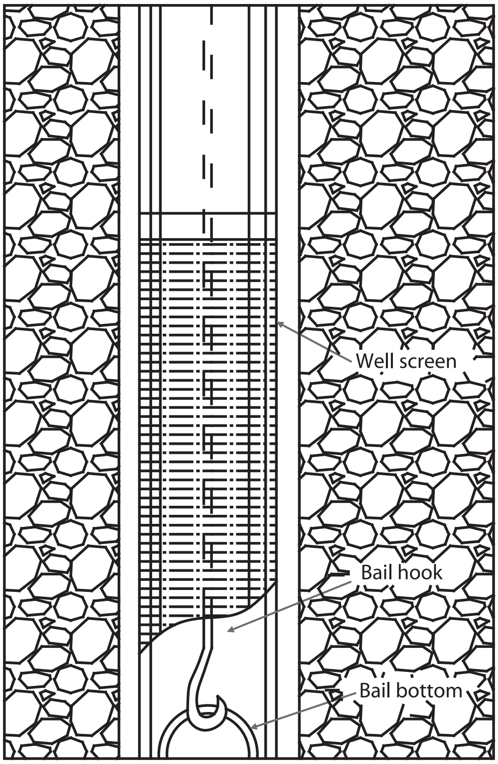


Figure 8.44: **Screen hook installation method**

method used it is commonly used in wells drilled by the cable-tool percussion method equally applicable in rotary drilled wells. The screen is lowered within casing, which is then pulled back a sufficient distance to expose the screen. The screen must be the telescope type with outside diameter sized just sufficiently smaller than the inside diameter of the casing to permit the scoping of the screen through the casing. The top of the screen is fitted with a lead packer which is swedged out to make a sand-tight seal between of the screen and the inside of the casing.

The basic operations in setting a well screen by the pull-back method indicated in the series of illustrations in Figure 8.45. The casing is first sunk the depth at which the bottom of the screen is to be set. Any sand or other cuttings in the casing must be removed by bailing or washing. The screen then assembled, suspended within the casing, and following the hook is caught in the bail handle at the bottom of the screen. The whole assembly is then lowered on the hoist line to the bottom of the screen. If the depth to water level in the hole is less than 30 feet, however,

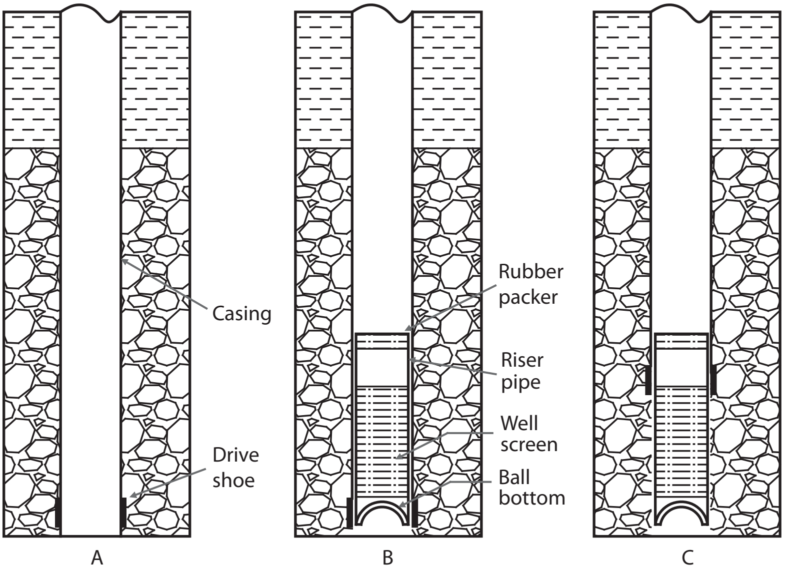


Figure 8.45: Pull-back method of setting well screens
A. Casing is sunk to full depth of well. B. Well screen is lowered inside casing
C. Casing is pulled back to expose screen in water-bearing formation

assembled screen may simply be dropped in the casing. Having checked to ascertain the exact position of screen, the hook is released and withdrawn. A string of small pipe is then run into and allowed to rest on the bottom of the screen to hold it in place while the casing is being pulled back to expose the screen. If the casing has been driven by the cable-tool percussion method, then it may be pulled by jamming with the drilling tools or with a bumping block. It may even be possible in some instances to pull the casing with the casing line on the drilling machine. Mechanical or hydraulic jacks may also be used in combination with a pulling ring or spider with wedges or slips. The casing should be pulled back far enough to leave its bottom end 9 inches to 1 foot below the lead packer. The pipe holding the screen in place is removed and a swedge block (Figure 8.46) used to expand the lead packer and create a sand-tight seal against the inside of the casing. To do this, two or three lengths of small diameter pipe are screwed to the sliding bar which passes through the swedge block. The assembly is lowered into the well until the swedge block rests on the lead packer. The weight provided by the pipe attached to the sliding bar is then lifted 9 to 8 inches and dropped several times. The swedge block it should not be lifted off the lead packer. It should be simply forced down into the packer by the repeated blows of the weighted sliding bar.

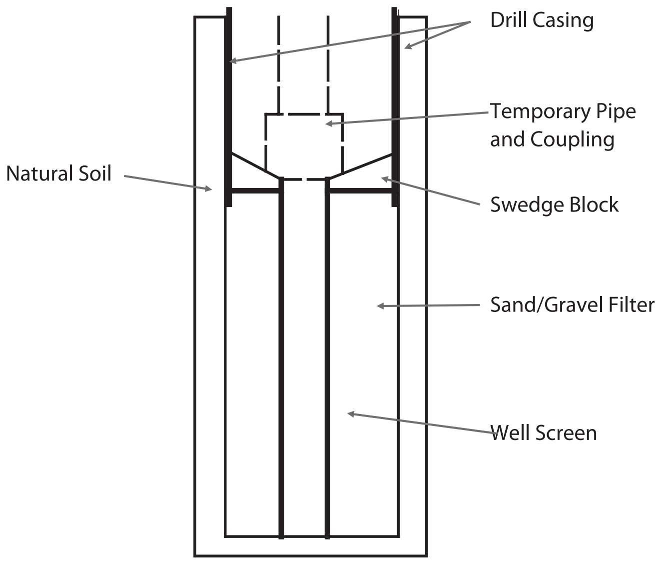


Figure 8.46: Swedge block

Open hole method: The open hole method illustrated in Figure. 8.47 involve the setting of the screen in an open hole drilled below the previously installed casing. The method is applicable to rotary drilled well.

The borehole is first drilled to the depth at which the casing is to be set permanently. The casing is run into the hole and grouted as required. Using a bit just large enough to go through the casing, the hole is drilled through the water-bearing formation below the casing. A suitable drilling mud must be used to seal off all flow from the formation into the hole, prevent it from caving, and transport the cuttings out of it. Fluid circulation must be maintained long enough after the desired depth is reached to ensure that all cuttings have been lifted from the hole. The drill stem may then be withdrawn and a telescope-size screen lowered into the hole by any convenient means. The depth of the hole should first have been checked to ensure that, with the screen resting on the bottom of the hole, the lead packer remains inside the lower end of the casing. Gravel may be used to back-fill a hole that has been drilled too deep. A screen with a closed bail bottom can be set by this method provided the precautions have been taken to obtain a non-caving hole free from cuttings and a suitable drilling mud that does not allow cuttings to settle out before the screen is lowered into the well, If difficulties are experienced in maintaining such a “dean” hole, a short extension pipe may be attached to bottom of an open-ended screen to permit washing it down with drilling fluid.

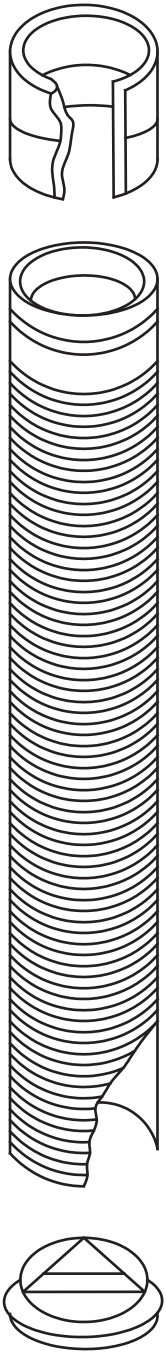


Figure 8.47: **Closed bottom plug in open hole screen casing**

The bottom of the extension pipe is then plugged with lead shot, lead w (Figure 8.47) or cement grout and the lead packer expanded after circulating water to wash some of the drilling mud out of the hole. Lead wool or came out should be tamped for compaction. If lead shot is used, it is simply powder in sufficient quantity to form a 4 to 8 inch thick layer inside the extension.

Wash-down method: The wash-down method of installation (Figure 8.48) uses a high velocity jet of light-weight drilling mud or water issuing from a special wash-do bottom fitted to the end of the screen to loosen the sand and create a hole which the screen is lowered.

The wash-down bottom is a self-closing bail valve. A string of wash piped connected to it and used to lower the entire screen assembly through the casing which has been previously cemented. As the screen is washed into position, the

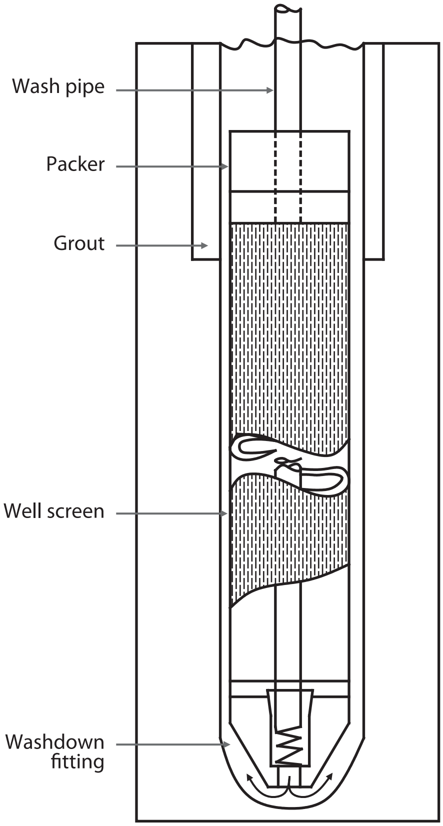


Figure 8.48: Wash-down method

loosened sand rises around the screen and up through the case to the surface with the return flow. Sand particles which inevitably accumulate in the well screen must be washed out of it once the screen is in final position. Water should later be circulated at a reduced rate to remove any wall cake formed in the hole during the jetting operation. This causes the formation to cave around the screen and grip it firmly enough for the wash line to be disconnected.

It is common practice in jetted and rotary drilled small wells to set a combined string of casing and screen, permanently attached, m one operation. A jetting method for setting such a combined string is illustrated in Figure. 8.49. The scheme employs the use of a temporary wash pipe assembled inside the well screen before attaching the screen to the bottom length of casing. A coupling attached to the lower end of the wash pipe rests in the conical seat in the wash-down bottom. A close-fitting ring seal made of semi-rigid plastic material or wood faced with rubber is fitted over the top end of the wash pipe and kept in position by the coupling above it. The seal prevents any ret urn flow of the jetting water in the space between the wash pipe and the screen. All the return flow from the washing or jetting operation, therefore, takes place outside of the screen and casing. A little leakage of the jetting water takes place around the bottom of the wash-pipe and out through the screen, thus preventing the entry of fine sand into

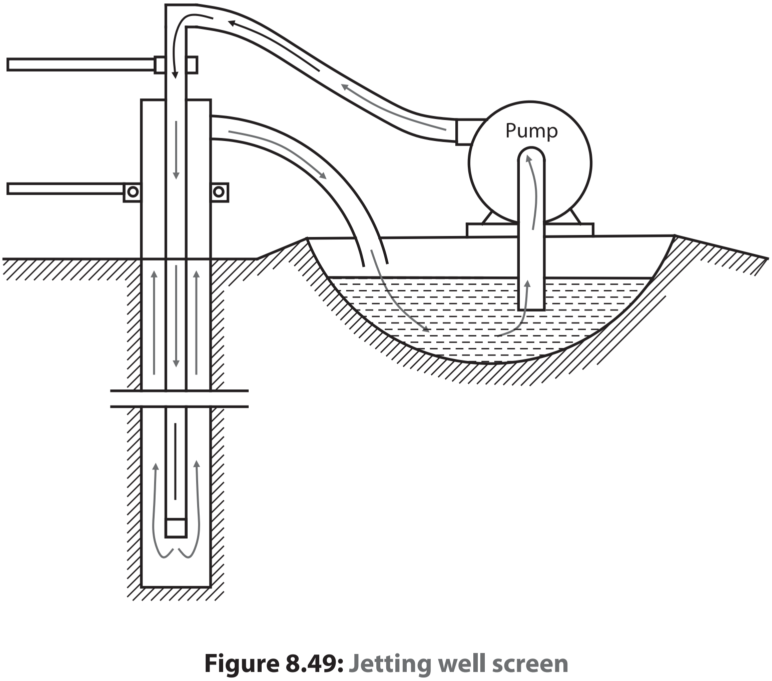


Figure 8.49: Jetting well screen

the screen. Maintaining this small outward flow through the screen is important, since it reduces the possibility of sand-locking the wash pipe in the screen.

With the casing and screen assembly washed into final position, fluid circulation is stopped. The plastic ball then floats up into the seat, thus effectively dosing the valve opening in the wash down bottom. A tapered tap, overshot or some other suitable fishing tool then used to fish the wash pipe and ring seal out of the screen. It may also be possible to recover the wash pipe assembly by tapping the coupling with pipe carrying regular pipe threads instead of a tapered tap. The well is then ready for development.

Satisfactory penetration by this method requires continuous circulation when water is used as the jetting fluid. This may limit the use of the method to the penetration of only as much screen and casing as it is physically possible to assemble as a single string in an upright position with the available drilling equipment. Subsequent additions of casing will require interruptions of the circulation that can lead to the collapse of the drill hole (particularly in water-bearing sands and gravels) around the combined string of screen and casing thus preventing further penetration. This problem may be avoided by the use of a suitable drilling mud. The method is very often used for washing screens into position below previously drilled boreholes. If the borehole has already been drilled into the aquifer to the full depth of the well, then the wash-down bottom may be used on the screen without the wash pipe.

Artificially gravel-packed wells: The methods of screen installation so far described apply primarily to wells to be completed by natural development of the sand formation. One of these, the pull-back method, can, with little modification, be used in artificially gravel-packed wells.

An artificially gravel-packed well has an envelope of specially graded sand or gravel placed around the well screen in a predetermined thickness. This envelope takes the place of the hydraulically graded zone of highly permeable material produced by conventional development procedures. Conditions that require the use of artificial gravel packing have been described.

The modified pull-back method known as the double-casing method (Figure 8.50) involves centering a string of casing and screen of equal diameter within an outer casing of a size corresponding to the outside diameter of the gravel pack. This outer casing is first set to the full depth of the well. The inner casing and screen should be suspended from the surface until the placement of the gravel

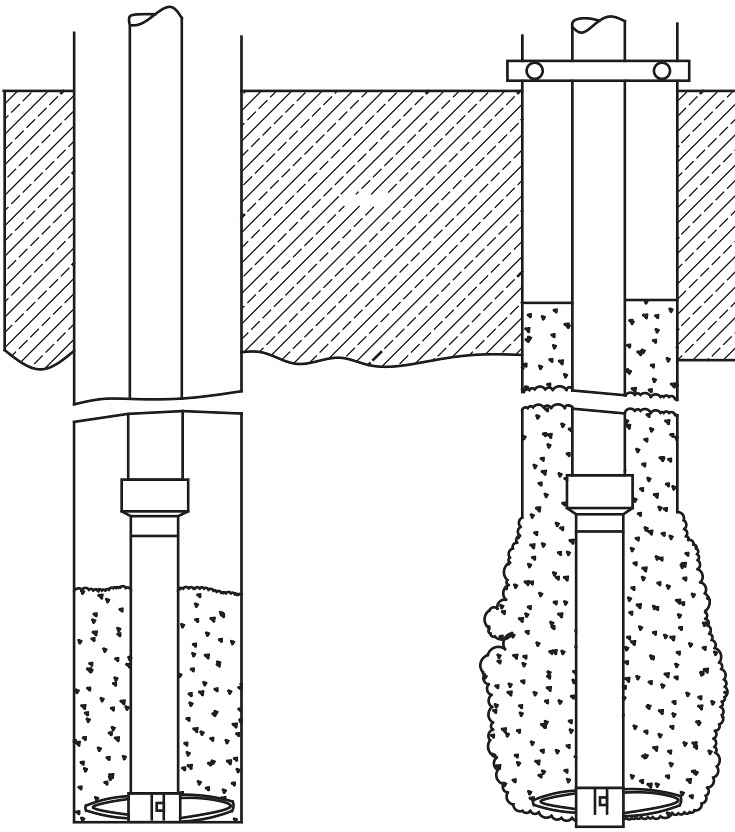


Figure 8.50: Double-Casing Method

pack is corn plated. The selected gravel is put in place in the annular space around the screen in batches of a few feet, following each of which appropriate distance and the gravel is well above the top of the screen. The well may then be developed to remove any fine sand from the gravel and any mud cake that may have formed on the surface between the gravel and the natural formation. The method can be used in both cable-tool percussion and rotary drilled wells.

Care must be taken in placing the gravel to avoid separation of the coarse and fine particles of the graded mixture. Failure to do so could result in a well that continually produces fine sand even though properly graded material has been used in the gravel pack. This tendency towards separation of particles of different sizes can be overcome by dropping the material in small batches or slugs through the confined space of a small diameter conductor pipe or tremie. Under these confined conditions there is less tendency for the grains to fall individually.

Water is added with the gravel to avoid bridging in the tremie. The tremie, usually about 2 inches in diameter, is raised as the level of material builds up around the well screen. Water circulated in a reverse direction to that of normal rotary drilling that is down the annular space between the casings, through the gravel and screen and up through the inner casing to the pump suction - helps prevent bridging in the annular.

Some settlement of the gravel will occur during the development process. More gravel must, therefore, be added as is necessary to keep the top level of the gravel several feet above that of the screen. The entire length of the inner casing need not be left permanently in the well if the outer one is intended to be permanent. Towards this end, a convenient joint in the inner casing can be loosely made up while assembling the string. After development of the well the upper portion of casing is then unscrewed at this joint and withdrawn, leaving enough pipe (at least one length) attached to the screen to provide an overlap of a few feet within the outer casing.

Another technique would be to set the inner casing to the full depth of the well and telescope the screen and an appropriate length of extension pipe attached to the top of the screen into that casing. The entire string of inner casing may then be removed as the gravel is placed, leaving the extension pipe overlapping inside the outer casing. Centering guides must be provided on the temporary inner casing.

Cement grout, lead shot or pellets of lead wool can be used to seal the annular space immediately above the top of the gravel. A mechanical type of seal known as a lead slip-packer is also often used. The packer, a lead ring of similar shape to a casing shoe, sits on top of the extension pipe and is of the proper diameter and wall thickness to form an effective seal when expanded by a swedge block against the outer casing.

Recovering well screens

It may sometimes be necessary to recover an encrusted screen for cleaning and return to the well, a badly corroded one for replacement or a good one from an abandoned well for reuse elsewhere. Considerable force may have to be applied to the screen to overcome the grip of the water-bearing sand around it. The sand-joint method provides one of the best ways of transmitting this force to the screen, dislodging and recovering it without damaging it. The method, however, cannot be used in screens smaller than 4 inches in diameter.

The sand-joint method uses sand carefully placed in the annular space between a pulling pipe and the inside of the well screen to form a sand lock or sand joint which serves as the structural connection between the pulling pipe and the screen (Figure 8.51). The necessary upward force may then be applied to the pulling pipe by means of jacks working against pipe clamps or a pulling ring with slips as shown in Figure 8.51.

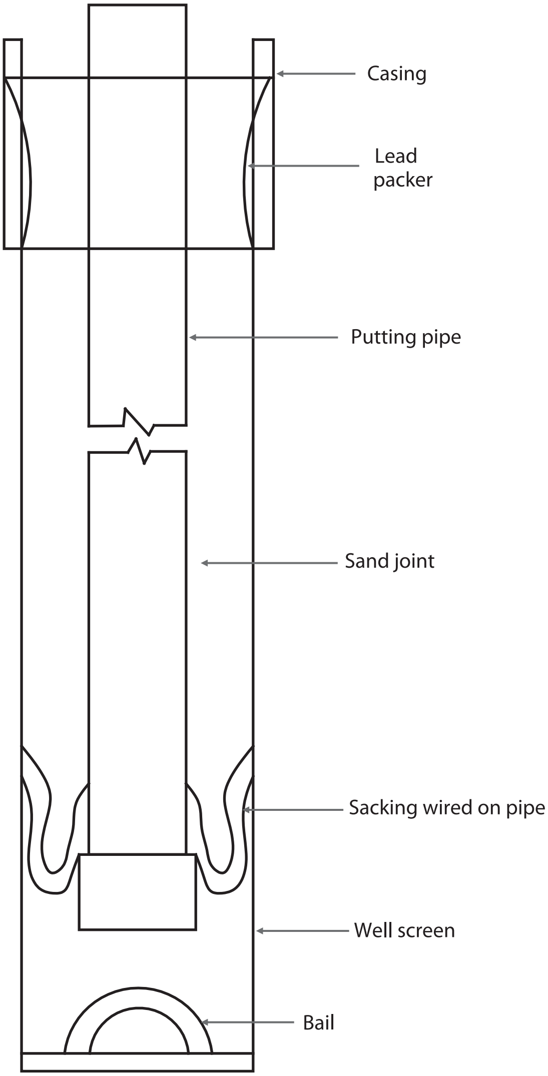


Figure 8.51: **Elements of sand-joint method**

The size of the pulling pipe varies with the diameter of the screen and the force which may be required. As a general rule, however, the size of pipe is chosen at one-half the nominal inside diameter of the screen. For example, a 4 inch screen with nominal inside diameter of 3 inches would require 1½-inch pipe. Extra heavy pipe should be used. The pipe couplings and threads should be of the highest quality in order to withstand the pulling force. The sand should be clean, sharp and uniform material of medium to moderately fine size.

The first step in the preparation of the sand joint is the tying of 2 inch strips of sacking to the lower end of the pulling pipe immediately above a coupling or ring welded to the pipe. The sacking forms a socket to retain the sand fill around the pulling pipe. The pipe and sacking with both ends tied to the pipe are then lowered into the casing until only the upper ends of the strips remain above the top of the casing. The string which holds the upper ends of the saddng to the pipe is then cut and the strips of sacking arranged evenly around the top of the.

Next the pulling pipe is lowered to a point near the bottom of the screen, care being taken to keep it as well centered as possible. The sand is then poured slowly into the annular space between the pulling pipe and the casing. An even distribution of the sand around the circumference of the pipe is desirable. The pulling pipe should be moved gently backward and forward at the top while pouring the sand to avoid bridging above couplings. A small stream of water playing onto the sand would also help in preventing bridging.

Enough sand should be used to fill at least two-thirds but not the entire length of table screen. The level of the sand in the screen can be checked with used a small diameter pipe used as a sounding rod.

The proper quantity of sad having been placed, the pulling pipe is then gradually lifted to compact the sand and develop a firm grip the inside surface of the screen. Additional tension is applied until the screen begins to move. The screen may then be pulled steady without difficulty until it is out of the well. The sand joint can be broken at the surface by washout the sand with a stream of water.

Pretreatment of the screen with hydrochloric or muriatic acid serves to loosen encrusting materials and thus reduce the force required to obtain initial movement of the screen. For this purpose the screen is filled with a mixture of equal amounts of acid and water which is left to stand for several hours, overnight if convenient. The acid is then pumped or bailed out before starting the pulling operations.

8.12 Fishing Operations

A fish is the name used collectively to describe a wet drilling tool, length of casing or other similar equipment or material accidentally deposited or stuck in boreholes and wells and which it is desirable to recover. Several reasons may contribute to the desirability for recovering a fish. For instance, the nature and position of the fish may be such as to prevent further work on the borehole towards the completion of a well. The fish may be a tool, a piece of equipment or material which is vital to the drilling operations and, in addition, costly and not easily replaceable. Fishing operations involve a considerable element of trial and error, because the fish is out of sight at some depth in a hole. They can, therefore, be very time and cost consuming with no guarantee of success. Consequently, very careful consideration should be given to the possible cost of a fishing operation in terms of time and money, comparing this with the losses and time saving that abandonment of the borehole or well would entail. Only after such careful constructional should fishing operations are undertaken. For small diameter, relatively shallow wells it would often be found economical and otherwise beneficial to drill a new well rather than attempt fishing operations in one under construction. This is particularly true prior to the placing and cementing of the permanent casing. It should also be borne in mind that fishing operations require a great deal of skill, much more so than drilling operations and the driller may be inexperienced in such work.

Preventive measures

As is the case with all other forms of accidents, prevention is always better than cure. Towards this end, the necessity to exercise the greatest care and attention at all times and throughout all stages of drilling operations cannot be over-stressed. While the utmost care and attention will not completely eliminate the need for fishing, it will considerably reduce the number and frequency of fishing operations.

Among the precautions that should be undertaken is the proper care and use of drilling tools and equipment. This includes the proper cleaning and breaking-in of new tool joints, the proper cleaning and setting of joints at all times, the correct dressing and hardening of bits, the regular maintenance and inspection of all wire rope, the regular inspection of all components of the drilling string for the development of fatigue cracks and the discarding of worn out tools. Above all, care must be taken never to overload equipment nor use tools for purposes other than those for which they have been designed. The manufacturer's limitations set on the use of equipment and tools should not be exceeded.

The care of wire rope should be given special consideration. Many manufacturer's catalogue contain detailed in among the most important of these is the need for good grade of lubricant, free from acid or alkali and which will penetrate and adhere to the rope. The use of crude oil or other material likely to be injurious to steel or cause deterioration or brittleness of the wires must be avoided. Failure to properly lubricate wire rope results in the wires becoming brittle corroded, subject to excessive friction wear and ultimately the sudden fracturing of the rope. The rope should be tightly and evenly wound on winding drums and should not be allowed to stand in mud, dirt or other such medium which is harmful to steel. Only proper fastening clamps that do not kuik, flatten or crush the rope should be used. The fracturing of loaded wire rope, it should be remembered, can cause serious injury to workmen as well as create fishing problems.

Unscrewed tool joints are the causes of many fishing operations. These can be avoided by the proper mating of the box and pin components of the joints. Both the pin shoulder and the box face should be thoroughly cleaned and free of imperfections that prevent a full and even contact. The threads and shoulders of the component parts should be thinly coated with light machine oil before making up the joint. Joints should be firmly made up though not with excessive pressure as this can result in broken boxes and pins.

Tools, carelessly left on the rotary table or at some such point, may be accidentally tipped into a borehole. One half of a pipe clamp entering a well in this manner has been known to become wedged in the well screen just above a joint in the wash pipe being used in the development process and result not only in the abandonment of the well but also the loss of several hundred feet of drill stem with it. All tools should be removed immediately after use to a convenient point of storage at a safe distance from the borehole or well.

Certain conditions such as slanting or caving formations, crooked holes and the presence of boulders often contribute to drilling troubles that may result in fishing operations. The utmost care must be exercised by drillers operating under these conditions.

Preparations for fishing: The nature of all operations (construction and maintenance) on wells is such that accidents do occur even under the supervision of the most capable and careful drillers. Therefore, the driller in anticipation of the inevitable fishing job should record or have access to the exact dimensions of everything used in or around the well. This facilitates the selection and design of a suitable fishing tool when necessary. All tools brought to the site should be accurately measured and the measurements properly recorded. Some of the important measurements are: the outside diameter and length of the rope socket; the diameter, length and stroke of the drill jars; the diameter and length of the drill stem; the size of tool joints and the outside diameter and length of the pin and box collars; the body size and length of bits; the length of pin collars on the bits. A careful record of the depth of the hole and the overall length of the drilling string is also essential for successful fishing operations.

The drill hole must of necessity be larger than any tools placed in it. As a result lost in a hole do not often remain in the vertical or upright it become wedged in sloping positions across the hole. In addition, from a caving formation may fall onto and cover the tool. No of measurement at the surface could tell the driller exactly what the lost tool has assumed in the hole or, in some cases, whether it is free from obstruction. It is therefore, considered good what is known as an impression block to obtain an impression of the top of the tool before at tempting any fishing operations. This is particularly necessary in rotary drilled, uncased holes. Impression blocks are of many forms and designs, one of which is shown in Figure 8.52. A short block of wood (preferably soft wood) turned on a lathe to a diameter about one inch less than that of the drilled hole and with the upper portion shaped in the form of a pin, is driven to fit tightly into a drill pipe box collar. For added security, the wooden block should be wired or pinned securely to the collar. The wooden block may alternatively be bolted to the dart of a dart valve bailer. A quantity of small headed nails is driven into the bottom of the circular block, leaving an extension of about 39 inch. Sheet metal is temporarily nailed around the block with a protrusion of a few inches over the lower end of the block. Warm paraffin wax, yellow soap or other plastic material is poured to fill protrusion and then left to cool and solidify. The nail heads help to hold the plastic material onto the block. After the sheet metal is removed and the lower end of the plastic material carefully smoothed, the impression block is ready for use. The block should be lowered carefully and slowly into the hole until the object is reached. It is then raised to the surface where the impression made in the wax or soap can be examined. By careful interpretation of the impression, a duller can determine the position of the fish and the best means of retrieving it.

Common fishing jobs and tools: It is often said, with considerable justification, that no two fishing jobs are alike. While fishing jobs may be classified into various types, individual jobs within these types are usually quite different. Fishing jobs,

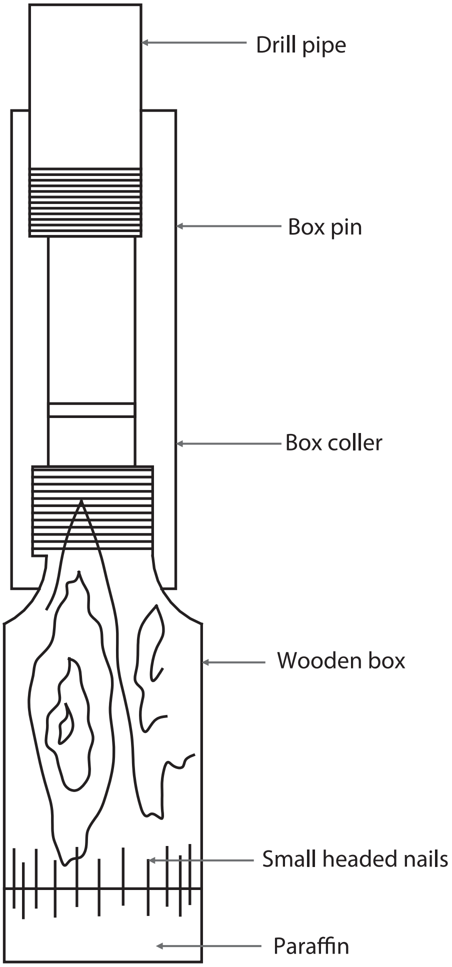


Figure 8.52: Impression block

as a result, test the skill and ingenuity of the driller to the fullest extent. The driller relies on a number of basic principles in his attack on fishing problems. A great variety of special tools have been devised to assist him in this work. Many of these tools are used very infrequently and it is not uncommon to find a tool made for a particular job and never used again. Only large-scale drilling operators can afford to have more than a limited stock of fishing tools. Whenever possible, small operators usually rent tools as they are needed from suppliers. It would be impractical to attempt a discussion of all types of fishing jobs and the tools used on them. Instead, the discussion that follows centers on some of the more common types of fishing jobs and tools.

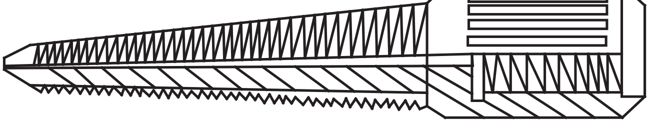
Parted drill pipe: One of the most frequent fishing jobs in rotary drilling is that for the recovery of drill pipe twisted off in the hole. The break may either be due to shearing of the pipe or failure of a threaded joint.

An impression block should first be used to determine the exact depth and position of the top of the pipe, whether there has been any caving of the upper formation material onto the top of the pipe or whether the pipe has become embedded into the wall of the hole. If the top of the pipe is unobstructed, then either the rape red fishing tap or die overshot could be effective if used before the cuttings in the hole settle and "freeze" the drill pipe. The circulating-slip overshot, which permits the circulation of drilling fluid, would be the best tool to use after the pipe has been frozen by the settling of cuttings around it. These tools are all illustrated.

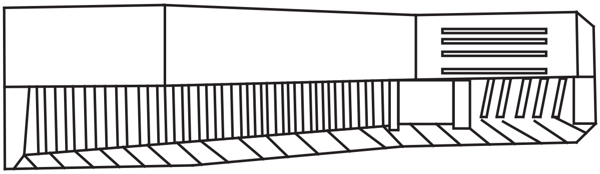
The tapered fishing tap, made of heat-treated steel, tapers approximately I inch per foot from a diameter somewhat smaller than the inside diameter of the coupling to a diameter equal to the outside diameter of the drill stem. The tapered portion is threaded and fluted the full length of the taper to permit the escape of chips cut by the tap. The tap is lowered slowly on the drill stem until it engages the lost pipe, the circulation being maintained at a low rate through the hole in the tap during this period. Having engaged the lost pipe, the circulation is stopped and the tap turned slowly by the rotary mechanism or by hand until the tap is threaded into the pipe. An attempt should then be made to re-establish the circulation through the entire drill St ring before pulling the lost pipe.

The die overshot is a long-tapered die of heat-treated steel designed to fit over the top end of the lost drill pipe and cut its own thread as it is rotated. It is fluted to permit the escape of metal cuttings. Circulation cannot be completed to the bottom of the hole through the lost pipe since the flutes also allow the fluid to escape. The upper end of the tool has a box thread designed to fit the drill pipe. The circulating-slip overshot is a tubular tool approximately 3 feet long with inside diameter slightly larger than the outside diameter of the drill pipe shown in Figure 8.53.

Circulating slip overshot: The belied-out lower portion of the tool helps to centralize and guide the top of the lost drill pipe into the slip shown fitted in the tapered sleeve. The slot cut through one side of the slip enables it to expand as the tool is lowered over the drill pipe. As the tool is raised the slip is pulled down into the tapered sleeve, thus tightening the slip against the pipe. Circulation of fluid can then be established through the pipe, freeing it for recovery.



Tapered Top



Die Overshot

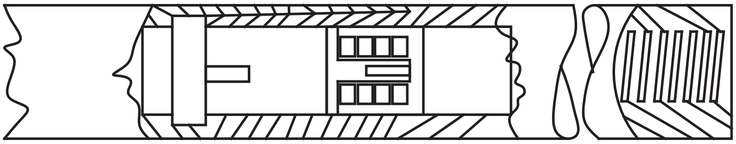


Figure 8.53: Tapered tap and overshots

- **Wall hook:** A wall hook shown in Figure 8.54 can be used to set the lost drill pipe erect in the hole in preparation for the tap or overshot tools. The wall hook is a simple tool that can be made from a suitable size of steel casing cut to shape with a cutting torch. A reducing sub must then be used to connect the top end of the tool to the drill stem. To operate the wall hook, it is lowered until it engages the pipe, then slowly rotated until the pipe is fully within the hook. The hook is then raised slowly to set the pipe in an upright position, later disengaging itself from the pipe.

  It is also possible to pin a tapered fishing tap into the upper portion of a wall hook made from steel casing. With such a combined tool, the hook maybe used to realign the lost drill pipe and then, while being lowered, guide the tap into the drill pipe to complete both operations in one run of tools into the hole. This method is particularly desirable when the drill pipe tends to fall over against the wall of a much larger hole rather than remain erect.
- **Broken wire line:** When the drilling line or sand line of a cable- tool drilling rig breaks, leaving the drilling tools or bailer in the hole with a substantial amount of wire line on top of the tools, the wire line center spear (Figure 8.55) is the recommended fishing tool. This tool consists of

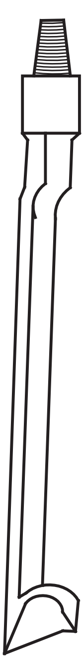


Figure 8.54: Wall hook

a single prong with a number of upturned spikes projecting from it. The spikes have sharp inside corners that permit the spear to catch even a single strand of wire. If the lost tools are stuck in the hole and cannot be pulled, the sharp spikes will shear the wire line.

The shoulder of the spear should be about the same size as the bore ole in order to prevent the broken wire line from getting past the spear as it is lowered and causing it to become stuck in the hole. For the range of borehole sizes being considered, center spears are made for specific sizes of hole.

The spear is used with a set of fishing jars, short sinker arid wire line socket above it. It should be carefully eased down the hole to the point where it is expected to engage the broken cable. It is then pulled to see if it has a hitch. In the absence of a hitch it is lowered below the first point and again tested for a hitch. This procedure is repeated until a hitch is secured.

If the string of lost tools is free, lift it 10 to 19 feet off the bottom of the hole and test the hold on the wire line by allowing the brake to give a short, quick slip. If the hold is insecure the tools will fall with no resulting damage, while a later fall through some greater distance could be very damaging.

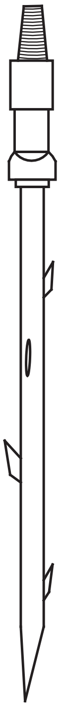


Figure 8.55: Center spear

If the hold is secure, continue lifting the tools out of the hole until the broken wires appear. Stop lifting and tie the wires together and then to the prongs of the grab to prevent the loose ends from unfolding and causing the hold to break. The tie itself does not carry the load but holds the broken lines in position. Continue lifting until the lost tools are recovered. If the string of lost tools is not free, then sufficient line should be let out to bring the jars into use. Jarring should be continued until the lost tools come loose or the broken cable parts.

- **Fishing for the neck of a rope socket, other cylindrical object or the pin of a tool:** The combination socket is one of several tools used to catch the neck of a wire-line socket after broken line has been cleared away, or the pin of a bit or drill stem that has become unscrewed in the hole. The tool can also be used to fish for any cylindrical object such as a drill stem or tubing standing upright in the hole, providing the bore of the socket is at least 1/8 inch larger than the diameter of the fish. The A fishing string should consist of a rope socket, stem, long stroke fishing jars and combination socket.

Combination sockets are provided with two sets of slips, one set of which is used to engage the threads of the pin on a bit, stem or other tool and the second set to take hold of the neck of the rope socket. The proper set of slips must be selected for the particular fishing job in accordance with knowledge of the exact size of the fish. It is also good practice to determine if the socket can go over the fish by first running the socket with its inner parts removed. The re-loaded combination socket is then slowly lowered on the fishing string with the fishing jars adjusted for shortest stroke. Upon contact with the fish, a light downward jar is used to secure a hitch. Tension is then taken on the line and the fishing job completed if the toots are not stuck.

If the tools are stuck, then a slow spudding action should first be tried to release them. Should this fail, then sufficient tine is let out to bring the jars into use. Short and rapid jarring should cause the freeing of the tools and is preferable to hard long-stroke jarring even though several hours of work may be necessary. Long-stroke jarring could result in breaking of the hitch on the lost tools or in broken fishing tools. Alternate up-jarring and down-jarring would release the hitch on the lost tools, should it become obvious that they cannot be freed and recovered.

After successful completion of a fishing job, the hitch is broken by removing the wooden block above the spring in the combination socket and so relieving the pressure on the spring and slips.

- **Releasing locked jars:** Jars sometimes become stuck or tools above the jars wedged in the hole by a piece of rock or other material. A jar wedged is the tool normally used under such circumstances. The following procedure should be followed. A strain is first taken on the drilling cable. The jar bumper is then lowered on the sand line, using the drilling cable as a guide, until the bumper reaches the string of tools. The bumper is then raised 10 or 12 feet and dropped, repeating this as often as necessary to loosen the jars or string of tools. A few blows are usually sufficient for this purpose. Too many blows might batter the neck of the rope socket and should be avoided. Should the bumper fail to release the tools, cut the cable and use a combination socket.

8.13 Well Completion

Well completion is the term used to describe the two basic processes which are undertaken after a well has been constructed in order to ensure a good yield of water that is clear and relatively free of suspended matter and disease-producing organisms. These processes are called well development and well disinfect kin.

The object of well development is the removal of silt, fine sand and other such materials from a zone immediately around the well screen, thereby creating larger passages in the formation through which water can flow more freely towards the well.

In addition to the above, well development produces two other beneficial results. Firstly, it corrects any clogging or compacting of the water-bearing formation which has occurred during drilling. Clogging is particularly evident in wells drilled by the rotary method where the drilling mud effectively seals the face of the borehole. Driving casing in the cable-tool percussion method vibrates the unconsolidated particles, thus compacting them. These are not the only drilling methods that damage the formation in one way or the other. All drilling methods do to different degrees of magnitude, and well development is needed to correct this damage.

Secondly, well development grades the material in the water-bearing form at ion immediately around the screen in such a way that a stable condition in which the well yields sand-free water at maximum capacity is achieved. In a zone just outside the screen, all particles smaller than the size of the screen openings are removed by development, thus leaving only the coarsest material in place. A little farther away some medium-sized grains remain mixed with the coarser ones. This grading of course through successively less coarse material continues as distance from the screen increases until material of the original character of the water-bearing formation is reached. This marks the end of the developed zone around the well. The succession of graded zones of material around the screen stabilizes the formation so that no further sand movement will take place. The extent of the envelope depends upon the formation characteristics, the well screen design and the skill of the well driller.

The development operation, to be effective, must cause reversals of flow through the screen opening immediately around the well. This is necessary to avoid the briding openings by groups of particles as can occur when flow is continuously in one direction. The bridging effect of one directional flow is illustrated in Figure 8.56. The reversals of flow are caused by forcing water out of the well through the screen and into the waterearing formation and then removing the force to allow flow to take place from the formation through the screen and back into the well. This process is known as surging. The outflow (with respect to the well) portion

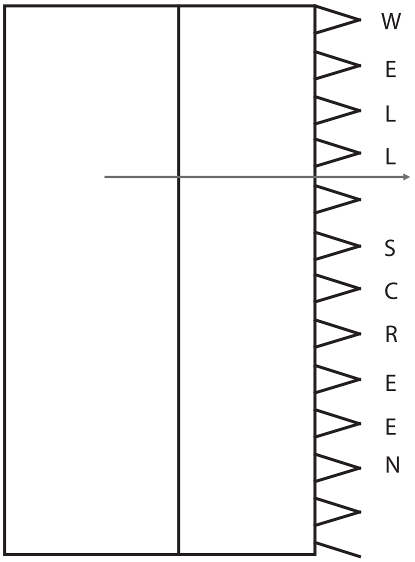


Figure 8.56: One directional flow can cause sand bridging during well development.

of the surge cycle breaks down any bridging of openings that may occur while the inflow portion moves the fine material toward and through the screen into the well from which it is later removed. There are several methods of producing the desirable surging action to develop a well. Some of the simpler of these are described in the paragraphs that follow.

Mechanical Surging: chemical surging is the name given to the method by which a plunger is operated up and down in the casing like a piston in a cylinder. The tool normally used is called a surge plunger or surge block. It is the most widely used tool for well development. Surge plungers are of two types. the solid plungers and valve-type plungers (Figure 8.57 and 8.59)

A solid type surge plunger is shown in discs, all assembled over a pipe nipple with steel plates serving as washers under the end couplings. The leather or rubber discs should form a reasonably close fit in the well casing. This is by no means the only way of making a solid type surge plunger. It is only one of several ways of so doing but serves to illustrate the essential features of this tool. Variations could include the use of cupped leather or rubber facing on the wooden discs instead of the flat leather or rubber-belt discs. A simple form of plunger can also be made for

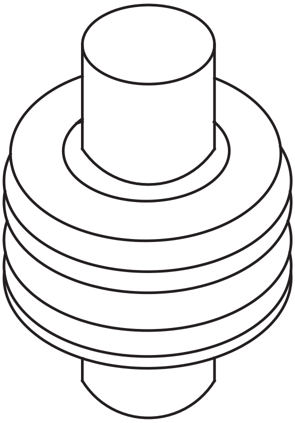


Figure 8.57: Typical solid type surger plunger

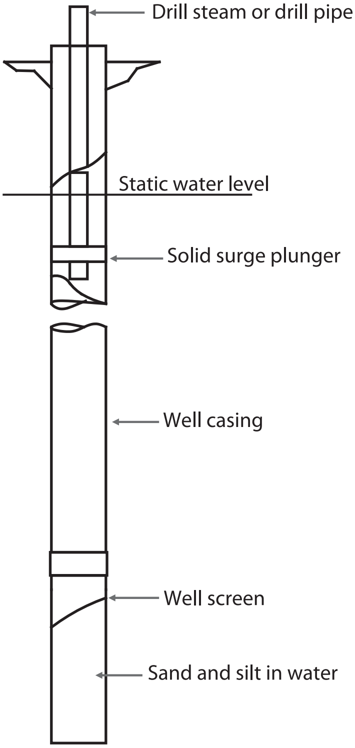


Figure 8.58: Solid-type surge plunge ready for use in developing a well downstroke forces water outward into sand formation stroke pulls in water and fine sand through screen.

use in small diameter wells by securely tying enough strips of sacking around the drill pipe (preferably at a joint) to obtain a close fit in the well casing.

Before surging the well should be washed with a jet of water and bailed or pumped to remove some of the mud cake on the face of the borehole and any sand that may have settled in the screen. This ensures that a sufficiently free flow of water will take place from the aquifer into the well to permit the plunger to run smoothly and freely. The surge plunger is then lowered into the well (Figure 8.58) to a depth 10 to 19 feet under the water but above the top of the screen. A spudding motion is then applied, repeatedly raising and dropping the plunger through a distance of 2 to 3 feet. If a cable-tool drilling rig is used, it should be operated on the long-stroke spudding motion. It is important that enough weight be attached to the surge plunger to make it drop readily on the downstroke. A drill stem or heavy string of pipe is usually found adequate for this purpose.

Surging should be started slowly, gradually increasing the speed but keeping within the limit at which the plunger will rise and fall smoothly. Surge for several minutes noting the speed stroke and time for this initial operation Withdraw the plunger, lower the bailer or sand pump into the well and after checking the depth

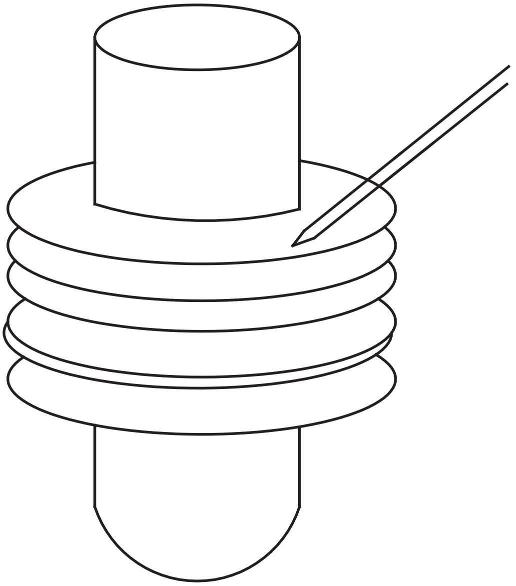


Figure 8.59: Typical valve-type surge plunger with valve leather raised to show one port holes

of sand accumulated in the screen, bail the sand out. Repeat the surging operation, comparing the quantity of sand with that brought in initially. Bail out the sand and repeat the surging and bailing operations until little or no sand is pulled into the well. The time should be increased for each successive period of surging as the rate of entry of sand into the well decreases. The sand pump type of bailer described.

The valve-type surge plunge differs from the solid-type surge plunger in that the former carnesa number of small portholes through the plunger which are covered by soft valve leather. In Figure 8.59 the valve leather is raised to indicate one of the six portholes which are spaced at equal distances around the circumference of the plunger.

Valve-type surge plungers are operated in a similar manner to solid plungers. They pull water from the aquifer into the well on the ups stroke and, by allowing some of the water in the well to press upward through the valves on the downs stroke, produce a smaller reverse flow in the aquifer. This creation of a greater in-rush of water to the well than out-rush during the surging operation is the principal and most important feature of this type of plunger. The valve type surge plunger, because of this feature, is particularly suited to use in developing wells in formations with low permeability's, since it ensures a net flow of water into the well rather than out of it. A net outward flow can result in the water moving upwards to wash around the outside of the casing since the low permeability of the aquifer will not permit flow readily into it. Washing around the outside of the casing could cause caving of the upper formations and thus create very difficult problems. (Figure 8.72).

An incidental benefit gained from the use of this type of plunger is the accumulation of water above the plunger with the eventual disc charge of some water, silt and sand over the top of the well. The valves in effect produce a sort of pumping action in addition to the surging of the well and thus reduce the nunier of times it is necessary to remove the plunger to bail sand out of the well. Surge plungers can also be operated within the screen. This may be desirable in developing wells with long screens. By operating the plunge r within the screen, the surging action can be concentrated at chosen levels until the well is fully developed throughout the entire length of the screen. The surge plungers should, for such use, be sized to pass freely through the screen and its fittings and not form a close fit in them, as is the case when operating the well casing. Special care must be exercised when surging within the screen to prevent the plunger from becoming sand-locked by the settling of sand above it. For this reason the use of plungers within screens should only be attempted by experienced drillers. (Figure 8.73).

Care must also be exercised when using surge plungers to develop wells in aquifers containing many clay streaks or clay balls. The action of the plunger can, under such conditions, cause the clay to plaster over the screen surface with a consequent reduction rather than increase in yield. In addition, surging of the partly or wholly plugged screen can produce high differential pressures with a resulting collapse of the screen.

Where possible, it is very desirable to pump the well at the same time as the jetting operation is in progress. This may be done in a 4 inch well if a 1½ inch jetting pipe is used, thus permitting a small suction pipe to be lowered along side of it in the well. The static water level must be near enough to the surface to perm it pumping by suction lift. By pumping more water out of the well than is added by jetting, flow will be induced into the well from the aquifer, thus bringing the formation material, loosened by the jetting, into the well and out of it with the discharged water. This speeds up the development process and makes it efficient.

The high-velocity jetting method is more effective in wells constructed with continuous-slot type well screens. The greater percentage of open area of this type of screen permits a more effective use of the energy of the jet in disturbing and loosening formation material rather than in being dissipated by merely impinging upon the solid areas of slotted pipe. Jetting is the most effective of development methods because the energy of the jets is concentrated over small areas at any particular Time and every part of the screen can be selectively treated. Thus uniform and complete development is achieved throughout the length of the screen. The method is also relatively simple to apply and not too likely to cause trouble as a result of over-application.

Another backwashing method of development suitable for use in small wells is one which uses a centrifugal pump with the suction hose connected directly to the top of the well casing and carrying a gate valve on the discharge end. The procedure simply involves the periodic opening and closing of the discharge valve while the pump is in operation. This creates a surging effect on the well. The process is continued until the discharge is clear and sand-free. The method is only applicable where static water levels are such as to permit pumping by suction lift. Some damage can be caused to the pump through the wearing of its parts by the sand pumped through it, particularly if in large quantities. The use of the pump to be permanently installed at the well is, therefore, not recommended for use in development of a well by this method.

Dispersing agents: Dispersing agents, mainly polyphosphates, are added to the drilling fluid. Back washing or jetting water, or water standing in the well to counteract the tendency of mud to stick to sand grains these agents act by destroying the get like properties of the drilling mud and dispersing the clay particles, thus making their removal easier. Sodium hexametaphosphate is probably the best known of these chemical agents, though tetra sodium pyrophosphate, sodium tripolyphosphaic and sodium septaphosphate are also effectively used in well development. These agents work effectively when applied at the rate of half a pound of the chemical to every 100 gallons of water in the well. The mixture should be allowed to stand for about one hour before starting development operations.

Well disinfection: Disinfection is the final step in the completion of a well. Its aim is the destruction& of all disease-producing organisms introduced into the well during the various construction operations. Entry of these organisms into the well can occur through contaminated drilling water, on equipment, materials or through surface drainage into the well. All newly constructed wells with the possible exception of flowing artesian wells should, therefore, be disinfected. Wells should also be disinfected after repair and before being returned to use. The water from flowing artesian wells is generally free from contamination by disease-producing organisms after being allowed to flow to waste for a short while. If, however, analyses show persistent contamination, then the well should be disinfected.

Because of the problems of testing for specific disease-producing organ isms, of which there may be several types present in water, coliform bacteria are used as indicators of the possible presence of disease-producing organisms of human or animal origin in water. Disinfection is, therefore, considered complete when sampling and testing of water show the presence of no coliform bacteria. Sampling and testing should be undertaken by experienced personnel from a health agency or recognized laboratory.

The well should be cleaned, as thoroughly as possible, of foreign substances such as soil, grease and oil before disinfection. Disinfection is most conveniently achieved by the addition of a strong solution of chlorine to the well. The contents of the well should then be thoroughly agitated and all owed to stand for several hours and preferably overnight. Care should also be taken to wash all surfaces above the water level in the well with the disinfecting solution. Following this, the well should be pumped long enough to change its contents several times and so flush the excess chlorine out of it.

Calcium hypochlorite is the most popular source of chlorine used in the disinfection of wells. It is sold in chemical supply and some hardware stores in the granular and table form containing 90 percent of available chlorine. Enough calcium hypochlorite should be added to the water standing in the well to produce a solution of strength ranging from 90 to 200 parts per million (ppm) by weight and usually about 100 ppm. A solution of approximately 100 ppm chlorine can be obtained by adding 2 ounces or 4 heaped tablespoons of calcium hypochlorite (containing 90 percent of available chlorine) to every 100 gallons of water standing in the well. Usually for convenience of application, a stock solution is made by mixing the calcium hypochiorite with a small amount of water to form a smooth paste and then adding the remainder of 2 quarts of water for every ounce of the chemical. Stir the mixture thoroughly for 10 to 19 minutes before allowing to settle. The clearer liquid is then poured off for use in the well. A gallon of this solution, when added to 100 gallons of water in the well, produces a solution of strength approximately equal to 100 ppm of chlorine. The stock solution should be prepared in a thoroughly cleaned glass, crockery or rubber lined container. Metal containers become corroded and should be avoided. Stock solutions should be prepared to meet immediate needs only since they lose strength rapidly unless properly stored in tightly covered dark glass or plastic containers. Storage of the chemical in the dry form is much more desirable.

Sodium hypochlorite may be used in the absence of calcium hypochlorite. This chemical is available only in liquid form and can be bought in strengths of up to about 20 percent available chlorine. In its most common form, household laundry bleach, it has strength of about 9 percent of available chlorine. A stock solution of equivalent strength to that made from calcium hypochlorite and described in the previous paragraph can be made by diluting commercial bleach with twice as much water. This stock solution should also be added to the well at the rate of one gallon to every 100 gallons of water in the well.

Flowing artesian wells are disinfected, when necessary, by lowering a perforated container, such as a short length of tubing capped at both ends, filled with an adequate quantity of dry calcium hypochlorite to the bottom of the well. The natural up flow of water in the well will distribute the dissolved chlorine throughout the full depth of the well. A stuffing box can be used at the top of the well to partially or completely restrict the flow and so reduce the chlorine losses.

8.14 Well Maintenance

Wells, like all other engineering structures, need regular, routine maintenance in the interest of a continuous high level of performance and a maximum useful life. The general tendency towards the maintenance of wells is one that can best be described as "out of sight — out of mind." Consequently, very little or no attention is paid to wells after completion until problems reach crisis levels, often resulting in the complete loss of the well. The importance of a routine maintenance program to the prevention, early detection and correction of problems that reduce well performance and useful life cannot be over-emphasized. A routine maintenance program can pay handsome dividends to a well owner and will certainly result in long-term benefits that exceed its cost of implementation.

The factors affecting the maintenance of well performance or yield are numerous. Care should be taken to differentiate between those factors associated with the normal wearing of pump parts and those directly associated with changing conditions in and around the well. A perfectly functioning well, for example, can show a reduced yield because of a reduction in the capacity of the pump due to excessively worn parts. On the other hand, the excessive wearing of pump parts may be due to the pumping of sand entering the well through a corroded well screen. It is also possible for corrosion to affect only the pump, reducing its capacity, but to have little or no effect on a properly designed well.

The hydrologic conditions of some aquifers are such that the static water level drops gradually when wells are pumped continuously. While this results in reduced yields unless pumping levels are also correspondingly lowered, it is not an indication of a failure of the well itself, necessitating repairs or treatment of any form.

Most commonly, a decrease in the capacity of well results from the clogging of the well screen openings and the water-bearing formation immediately around the well screen by incrusting deposits. These incrusting deposits may be of the hard cement-like form typical of the carbonates and sulfates of calcium and magnesium, the soft sludge-like forms of the iron and manganese hydroxides or the gelatinous slimes of iron bacteria. Iron may also be deposited in the form of ferric oxide with a reddish brown, scale-like appearance. Less common is the deposition of soil materials such as silt and clay.

The deposition of carbonates and the compounds of iron and manganese can often be traced to the release of carbon dioxide from the water. The capacity of water to hold carbon dioxide varies directly with the pressure the higher the pressure, the greater the quantity of carbon dioxide held. Pumping of a well reduces the pressure in and near the well, thus allowing the escape of carbon dioxide to the atmosphere and altering the chemical quality of the water in such a manner as to cause the precipitation of carbonate and iron deposits.

A change in velocity is another factor that can result in the precipitation of iron and manage hydroxides. This too occurs at and near the well screen where the velocity of the slowly flowing water is suddenly increased on entry to the well.

8.15 Planning for Well Maintenance

The planning of well maintenance procedures should be based on a system of good record keeping. The preceding paragraphs have indicated that the problems that result in reduced well yields occur at and around the well screen and very much out of sight. The analysis of good records must, therefore, be relied upon as the source of problem detection in wells. There can be no substitute for the keeping of good records.

Among the records kept should be pumping rates, drawdown, total hours of operation, power consumption and water quality analyses. Pumping rates and drawdown are particularly useful in determining the specific capacity (discharge per foot of drawdown) which is the best indicator of existing problems in a well. The specific capacities of wells should be checked periodically and compared with previous values including those immediately after completion of the wells to determine whether significant reductions have taken place. A significant reduction in the specific capacity of a well could often be traced to blockage of the well screen and the formation around it, most likely by incrusting deposits. As stated earlier, a reduction in the pump discharge would not by itself be evidence of a reduced capacity of the well. If, however, the drawdown in the well does not show an equal reduction, then the specific capacity will be reduced, thus indicating the probability of an incrustation problem.

Power consumption records also provide valuable evidence of the existence of problems in wells. Should there be an increase in power consumption, not accompanied by a corresponding increase in the quantity of water pumped, then a problem is possible in either the pump or the well. Should an investigation show neither problems in the pump nor appreciable increase in the dynamic head against which the pump has been operating then it is most likely that a problem exists in the well and that the problem is causing an increased drawdown. A check on the drawdown should then be undertaken to verify the deduction and the well checked for incrustation.

Since there would be no incrustation in the absence of incrusting chemicals in the water, the value of chemical analyses of well water is self-evident. Such analyses are more useful as problem indicators ii undertaken regularly. They indicate the type of incrustation that might occur and the expected rate of deposition in the well and its vicinity. The quality of some well waters changes slowly with time and only regular routine analyses would indicate such changes.

8.16 Maintenance Operations of Well

Maintenance operations should not be deferred until problems assume major proportions as rehabilitation then becomes more difficult and some times impossible or impracticable. Incrustation not treated early enough can so clog the well screen and the formation around it that it becomes extremely difficult and even impossible to diffuse a chemical solution to all affected points in the formation. Any attempts at rehabilitation would then prove unsuccessful.

No methods have yet been developed for the complete prevention of incrustation in wells. Various steps can be taken to delay the process and reduce the magnitude of its effects. Among these are the proper design of well screens and the reduction of pumping rates, both aimed at reducing entrance velocities into screens and drawdown in wells. For example, it may be worthwhile to share the pumping load among a larger number of wells in order to reduce the rate of incrustation. However, the ultimate or final solute ion will be in a regular cleaning program. Incrusting wells are usually treated with chemicals which either dissolve the incrusting deposits or loosen them from the surfaces of the well screen and formation materials so that the deposits may be easily removed by hailing.

Acid treatment: Acid treatment refers to the treatment of a well with an acid, usually hydrochloric (muriatic) acid or sulfamic acid for the removal of incrusting deposits. Both of these acids readily dissolve calcium and magnesium carbonate, though hydrochloric acid does so at a faster rate. Strong hydrochloric acid solutions also dissolve iron and manganese hydroxides. The simultaneous use of an inhibitor serves to slow up the tendency of the acid to attack steel casing.

Wells are sometimes treated with acid in preparation for the withdrawal of a screen either for re-use elsewhere or in the same well. For example, it may be desirable to recover a screen that is in good condition from a well whose casing has been corroded beyond usefulness. Or, a screen may be recovered for more effective treatment against incrustation than can be achieved in the well. In either case, a preliminary acid treatment to dissolve some of the incrusting deposits will make it much easier to pull the screen.

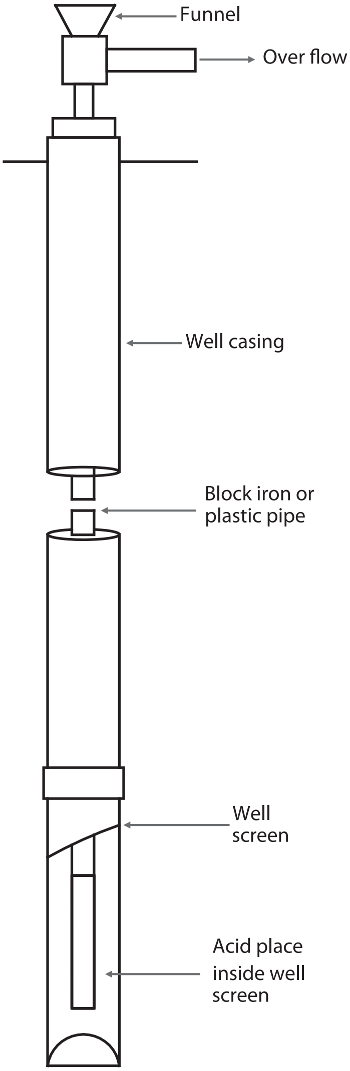


Figure 8.60: **Arrangement for introducing acid inside well screen from bottom upwards**

Hydrochloric acid is usually available in three grades from chemical supply shops. The strongest grade, designated as the 29.92 percent grade, should be used. If inhibited acid cannot be obtained, unflavored gelatin added at the rate of 5 to 9 pounds to every 100 gallons of acid will prevent serious damage to steel casing.

Hydrochloric acid should be used at full strength. Each treatment usually requires 1½ to 2 times the volume of water in the screen. This provides enough acid to fill the screen and additional acid to maintain adequate strength as the chemical reacts with the incrusting materials. Figure 8.60 illustrates a method of placing acid in a well. Acid is introduced within the screen by means of a wide-mouthed funnel and ¾ or 1 inch black iron or plastic pipe. Acid is heavier than water which it tends to displace but with which it also mixes readily to become diluted. When used in long screens, acid should be added in quantities sufficient to fill 9 feet of the screen and the conductor pipe raised 9 feet after pouring each quantity.

The acid solution in the well should be agitated by means of a surge plunger or other suitable means for 1 to 2 hours following which the well should be balled until the water is relatively clear. The driller usually can detect an improvement in the yield of the well while running the bailer. The well may, however, be pumped to determine the extent of improvement. If this is not as expected, then the treatment may be repeated using a longer period of agitation before bailing. A third treatment may even be undertaken.

The procedure is sometimes varied to alternate acid treatment and chlorine treatment repeating the alternate treatments as many times as it appears that beneficial results are being obtained. The chlorine helps to remove the slime deposited by iron bacteria.

Sulfuric acid can be obtained as a dry granular material winch prod uses a strong acid solution when dissolved in water. It offers a number of advantages over hydrochloric acid as a means of treating incrustation in wells. It can be added to a well in either its original granular form or as an acid solution mixed on site. Granular sulfuric acid is non- irritating to dry skin and its solution gives off no fumes except when reacting with incrusting materials. Spillage, therefore, presents no hazards and handling is easier, cheaper, and safer. It also has a markedly less corrosive effect on well casing and pumping equipment and is safe for use on well screens. These advantages tend to offset its hitter cost than inhibited hydrochloric acid. Sulfuric acid dissolves calcium and magnesium carbonates to produce very soluble products. The reaction is, however, slower than that using hydrochloric acid and a somewhat longer contact period in the well is required.

Sulfuric acid is usually added to wells in solution form using a black iron or plastic pipe as described for the application of hydrochloric acid.

The granular material itself can, however, be poured into and mixed with the water standing in the well. The water must be agitated to sure complete solution of the acid. The quantity of acid added in this case should be based on the total volume of water standing in the well and not on that in the screen only, as is the case if the acid is applied in solution form. An excess of the granular material may be added to keep the solution up to maximum strength while it is being used up through reaction with the incrusting material. The addition of a low-foaming, non-ionic wetting agent imp roves the cleansing action to some extent.

A number of precautions must be exercised in using any strong acid solution. Goggles and water-proof gloves should be worn by all persons handling the acid. When preparing an acid solution, always pour the acid slowly into the water. In view of the variety of gases, some of them very toxic, produced by the reaction of acid with incrusting materials, adequate ventilation should be provided in pump houses or other confined spaces around treated wells. Personnel should not be allowed to stand in a pit or depression around the well during treatment because some of the toxic gases such as hydrogen sulfide are heavier than air and will tend to settle in the lowest areas. After a well has been treated, it should be pumped to waste to ensure the complete removal of all acid before it is returned to normal service.

Chlorine treatment: Chlorine treatment of wells has been found more effective than acid treatment in loosening bacterial growths and slime deposits which often accompany the deposition of iron oxide. Because of the very high concentrations required. 100 to 200 ppm of available chlorine, the process is often referred to as shock treatment with chlorine. Calcium or sodium hypochlorite may be used as the source of chlorine. The chlorine solution in the well must be agitated. This may be done by using the high-velocity jetting technique (see “Well Development” or by surging with a surge plunger or other suitable techniques. The recirculation provided with the use of the jetting technique greatly improves the effectiveness of the treatment. The treatment should be repeated 3 or4 times in order to reach every part of the formation that may be affected, and it may also be alternated with acid treatment, the latter being performed first.

Dispersing agents: Polyphosphates, or glassy phosphates as they are commonly called, effectively disperse silts, clays and the oxides and hydroxides of iron and manganese. The dispersed materials can be easily removed by pumping. In addition, the polyphosphates are safe to handle. They find considerable application, therefore, in the chemical treatment of wells. For effective treatment, 15 to 30 pounds of polyphosphate are added to every 100 gallons of water in the well. A solution is usually made by suspending a wire basket or burlap bag containing the polyphosphate in a tank of water. About a pound of calcium hypochlorite should be added for every 100 gallons of water in the well in order to facilitate the removal of iron bacteria and their slimes and also for disinfection purposes. After pouring this polyphosphate and hypochlorite solution into the well, a surge plunger or the jetting technique is us to agitate the water in the well. The recirculated of the solution with the use of the high-velocity jetting technique greatly mip roves the effectiveness of the treatment. Two or more successive treatments may be used for better results.

8.17 Well Point Installation in Dug Wells

Dug wells are holes or pits dug by hand or machine tools into the ground to tap the water table. They are usually 3 to 20 feet in diameter, 10 to 40 feet deep and lined with brick, stone, tile, wood cribbing or steel fittings to prevent the walls from caving (Figure 8.61). They depend entirely on natural seepage from the penetrated portion of water being formations for their yield of water.

This type of well is at a disadvantage on two scores when compared with tubular wells of the type so far described. Firstly, dug wells are much more difficult to maintain in a sanitary condition. Secondly, their yields are very low, because they do not penetrate very far into the water-bearing formation and cannot be developed in a similar manner to screened wells.

Dug Wells usually can be made much safer and more productive by driving well points into the water-bearing formation and thus converting them into tubular wells. A properly developed well with a short length of 2″ drive- point screen will usually produce water at a much higher rate than can be had from a dug well several feet in diameter. The annular space between the casing of the driven well and the wall of the existing well should be back-filled with a puddled clay or other suitable material. The sanitary precautions with respect to the completion of the upper terminal of a well should be observed. The wall of the existing dug well may be cemented prior to back-filling.

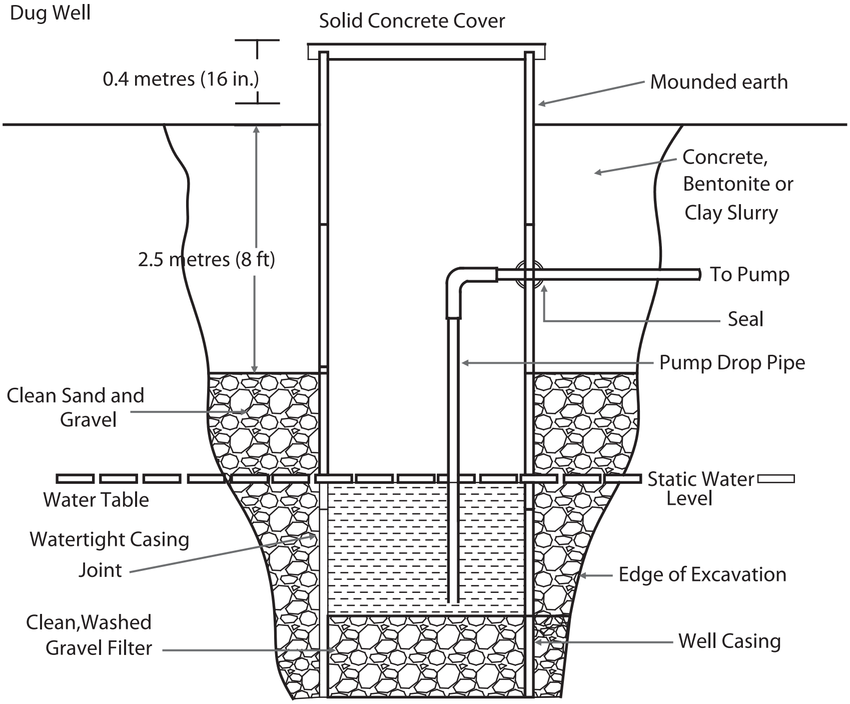


Figure 8.61: Dug well

8.18 Summary of Designing and Constructing Tubewells in Bangladesh

The following section describes the procedures of designing and constructing tubewells in Bangladesh.

Screen well design

The design of tubewells mainly involves the selection of length, diameter, and slot opening of the screen and design of the shroud materials, on the basis of the available aquifer characteristics. The thickness and particle size distribution of aquifer sand are essential for the design of the screen. For this a particle size analysis must be carried out. Aquifer materials collected at definite intervals during the drilling of the bore hole undergo sieve analysis. The results are presented in the form of cumulative percent finer against grain size as shown in Figure 8.62. The results may also be presented as cumulative percent retained versus grain size.

The size corresponding to 10% finer is called the effective size, which governs the permeability of the aquifer. The ratio of the size corresponding to 60% finer and the effective size is called the uniformity coefficient, which defines the uniformity of the grain size. Thus uniformity coefficient can be expressed as:

$$U = \frac{D_{60}}{D_{10}} \qquad 8.1$$

Where U = uniformity coefficient,

D_{60} = grain size corresponding 60% finer and

D_{10} = grain size corresponding 10% finer, i.e. effective size.

The aquifer materials having twice the effective size and a similar uniformity coefficient have four times higher permeability.

The best aquifer for screening is determined by comparison of the grain size analysis curve of the materials along the depth of bore hole. The slot of the screen should be such that it will retain only 40 to 60% aquifer sand. The grain size corresponding to 60% or 50% finer as shown in Figure 8.62, will determine the slot size of the strainer. If the slot size is required to be increased, the tubewell has to be shrouded with coarse-grained materials.

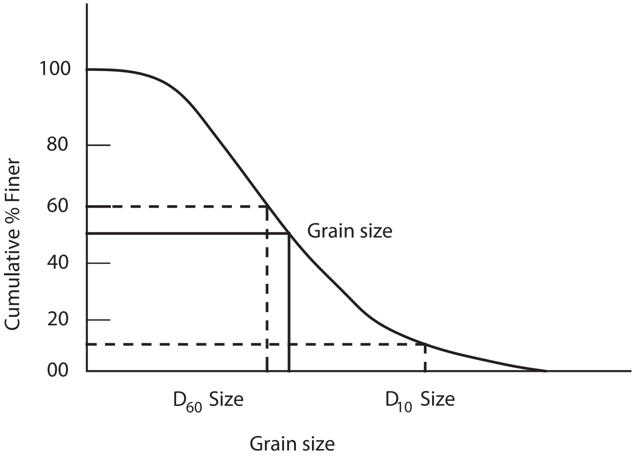


Figure 8.62: Grain size distribution curve

The length and diameter of the strainer will be determined on the basis of permissible entrance velocity, percent opening of the strainer and thickness of the aquifer. The length and diameter of the strainer required may be calculated from the expression:

$$Q = \pi DL(0.01p)v_e \qquad 8.2$$

Where,

Q = design discharge of the tubewell,
D = diameter of the screen,
L = length of the screen,
p = percent opening of the screen, generally dependent on slot size and available from specification,
v_e = permissible entrance velocity.

The entrance velocity while the water is entering into the screen should not exceed 0.03 m/s. An entrance velocity less than 0.03 m/s, results in low frictional head loss in the screen, low encrustation and corrosion. The entrance velocity should be maintained in the range between 0.03 and 0.010 m/s. The length of the strainer should also satisfy the required thickness of the aquifer. Only about 70 to 80% of a homogeneous artesian aquifer can be screened provided that the pumping water level does not fall below the top of the aquifer. In the case of a water table aquifer the bottom one-third to half of the aquifer can be screened.

If the particle size of the aquifer material is very fine or the depth of the aquifer is insufficient to provide a suitable screen, the tubewell may be shrouded. The tubewell may also be shrouded to obtain higher discharge. The shrouding materials retain the aquifer sand and prevent it from entering into the large slotted strainer. Theoretically, the maximum pore size of spherical granular material is one-sixth of its size. The shrouding materials selected must be 4 to 6 times larger than the size of the aquifer sand corresponding to 70% retained or 30% finer, and must have a uniformity coefficient less than 2.5. The procedure for the design of the shrouding materials is as follows:

- Draw particle size distribution curves of all the visible different strata of the aquifer sand where strainer of the tubewell will be located. Select the particle size distribution curve of the finest sand for the design of the shrouding material.
- Multiply the 70% retained size of the sand by a factor 4 if the sand is fine and uniform or 6 if the sand is coarser or non-uniform. Locate the result of multiplication as 70% retained size of the shrouding material. This is the first point of the curve that represents the artificial shrouding material.
- Draw a smooth curve representing a shrouding material with a uniformity coefficient of 2.5 or less through this 70% retention point of the material. It

is to be done by trial and error.

- Prepare specifications for the shrouding material by selecting four or five standard sieve sizes that cover the spread of the curve and then set down the permissible range for percent retained on each of the selected sieves. The permissible range may be 8% above and below the percent retained at any point on the curve.
- Finally, select the size of the slot of the screen that will retain 90% or more of the shrouding material.

A very thin layer of shrouding material less than 25 mm thick can retain the aquifer sand, but it is impractical to place a thin gravel pack in a well and expect the material to completely cover the surrounding of the screen. A minimum thickness of 75 mm is considered practical for installation in the field to ensure an envelope of shrouding material around the screen along the entire length.

In case of shallow and very shallow shrouded tubewells a shrouding sand having d_{10} size or 90% retention size of 0.008 inches, fineness modulus of 1.6 and uniformity coefficient of 1.5 is performing well in case of No.8 (0.008 inch) slot screen.

Sinking of handpump tubewells

- **Sludger method:** The sludger method is the primitive manual method of sinking shallow tubewells in alluvial soil. It is the most common method of sinking tubewells in Bangladesh up to a depth of about 50m. A water sump, 0.5m. in diameter and 0.5m deep is first made by digging a hole. A bamboo stage is constructed on the sump. The sump is filled with water and a GI pipe is pushed vertically into the centre of the sump. The pipe is then alternatively raised and dropped by a bamboo rafter fastened to the pipe and supported on the bamboo stage. When the pipe is dropped in the bore hole, it cuts and loosens the soil at the bottom of the bore hole and makes a soil-water slurry for discharge through the pipe. A person climbing on a bamboo stage keeps the pipe in vertical position and controls the flow through the pipe by closing the end while it is raised and opening it when dropped. While the pipe is raised with end closed by hand, it produces suction and the slurry rises within the pipe. When the pipe is dropped its higher density causes it to drop faster, discharging the slurry out through the opening of the hand of the person controlling the flow through pipe. The sump is kept filled with water that comes out with the cuttings as slurry through the pipe. The boring proceeds in this manner and when one pipe is sunk, an additional pipe is attached to the end. Soil samples are collected at regular intervals from the slurry coming out of the drill pipe. The verticality of the bore hole is maintained by keeping the pipe vertical with respect to the bamboo stage. Drilling is stopped when a good water bearing strata is sufficiently penetrated. The raising and dropping of the pipe by a pivoted bamboo rafter resembles the action of a Dheki and hence it is also locally called the Dheki method.

When the drilling is completed, the drilling pipe is raised piece by piece taking care to keep the drilled hole intact. The tubewell assembly consisting of a sand trap, strainer, blind pipes and housing pipe (if any) is immediately lowered into the bore hole piece by piece, very carefully. This method of drilling is not suitable for stony soil. If a large stone or a stony formation is encountered, drilling is abandoned at that location.

- **Rotary drilling method:** This method is used to drill deep bore holes for the installation of deep tubewells. Manual drilling is common up to a depth of 350 m in Bangladesh for the installation of manually operated small diameter deep tubewells. In this method, a cutting bit is attached to the end of a small diameter drilling pipe which is manually rotated by attaching a horizontal bamboo or wooden rafter. A large diameter pipe may need to be sunk as a casing to support the upper part of the bore hole down to a certain depth. Either water or a colloidal suspension of clay is pumped through the drill pipe. This flows through the opening of the drill and transports the loosened materials to the surface through the annular space of the bore hole outside the drilling pipe. The pumping of the fluid through the drill pipe is also done by manually operated pumps. New additional pipes are attached to the drilling pipes as the boring proceeds. In case of large diameter deep bore holes, the drill rod with cutting bit is rotated by an engine driven rotary table. The fluid is also pumped by a power driven pump.

Installation of tubewells

When a bore hole is completed to the desired length, the tubewell assembly is to be lowered and fixed in position as soon as possible. The bore hole is usually drilled a little more than the installed depth of the tubewell to accommodate the materials which may cave in or settle in the bore hole before installation of the tubewell. The sand trap, strainers, blind pipes, housing pipe, etc. are assembled near the tubewell and marked serially. The components of the tubewell are then lowered one by one as required starting from the bottom end. Each component of the tubewell is to be properly screwed or welded to another and slowly lowered vertically with the help of clamps. When the lowering of the tubewell is complete, it is kept suspended from the top of the bore hole and clean sand or properly designed cleaned shrouding gravel is dropped in the bore hole. The coarse sand or shrouding material is filled to at least 10 to 15 m above the top of the upper strainer. These materials grip the strainers and the blind pipes on the outside and hold the tubewell in position. The remaining space of the bore hole may be filled with clayey materials to prevent percolation of contaminated water from the surface.

It is important that the entire tubewell is installed straight and vertically. In case of large diameter tubewells, guides are placed at a certain distance apart for concentric installation, to permit uniform filling of shrouding materials around the well and satisfactory operation of the pumping unit and without damage.

Development

Development of the tubewell after installation is essential for proper cleaning and stabilization of the aquifer and shrouding materials and proper functioning of the well. Development of the tubewell is done by pumping the well, usually at 1.5 times the rated capacity, to wash out the fines in the aquifer and clay or other materials introduced during boring. In case of handpump tubewells, continuous pumping is done to achieve maximum discharge from the tubewell. While pumping continues, the finer materials get washed through the strainers into the tube. The velocity of the water due to the high rate of pumping is sufficient to carry the finer materials with it keeping the inside of the tube and the shrouding materials free from silting. The subsoil surrounding the strainer becomes free of fines and attains a porosity and permeability higher than the original undisturbed soil. The pumping is continued until the water is clear. When development of the tubewell is complete, the course materials finally arrange themselves according to the size of the grains, the largest being next to the strainer, then the next larger and so on. A well developed tubewell is not clogged by fine particle migration during normal operation.

Maintenance

A properly constructed and developed tubewell requires little maintenance except replacement of components in the pump. Excessive pumping of the tubewell at high rates may result in the movement of fine materials in the aquifer with the possibility of clogging near the screen. Sand entering into the well may damage the pump. Pumping of water with high mineral content may cause encrustation on the well screen. The decrease in pressure in the high velocity region near screen may reduce the ability of water to hold dissolved salts, particularly calcium carbonate in solution. Thus encrustation may be accelerated by high entrance velocity as a result of inadequate screen area or excessive pumping. Encrustation and clogging of tubewells can sometimes be relieved by surging the well with a plunger and causing alternative back and forth flow through the screen. Severe encrustation may be treated with hydrochloric acid, which is to be introduced in the tubewell in diluted form and allowed to stand in the well for several hours. Clogging by bacterial growth can be treated by chlorine water. The tubewell should be pumped vigorously after chemical treatment to remove loosened materials and excess chemicals. In case of corrosion of screen and casing, very little things can be done for protection. Leakage resulting from a corroded casing may sometimes be checked by grouting around the casing (UNDP and WB 1990).

Rehabilitation of choked-up tubewells

Sand and silt sometimes enter into the tubewell, fill up the strainer and make the tubewell choked-up. About 2% of the handpump tubewells get choked up annually in Bangladesh. In absolute term, this put a huge number of tubewell out of operation each year. Of these choked up tubewells, a considerable proportion gets choked within a very short period after installation. The main reasons for such premature choking is inadequate development leading to deposition of sand exceeding the holding capacity of the blind pipe within the tubewell. The deposited sand blocks the screen and prevents the inflow of water. Study shows that desanding process can successfully rehabilitate 20% of all new and old choked up tubewells.

Tubewells are also choked up due to other reasons such as improper selection of aquifer or screen, incrustation of screen by physical and chemical reasons, entry of clay or sand through defective joints or holes caused by corrosion. In such cases, desanding cannot rehabilitate the tubewells. Re-sinking of these tubewells is needed after successful withdrawal.

- **Desanding:** Desanding of choked up tubewells is done by sludger method. The pumphead of the tubewell is first removed. As the tubewells are usually 38 mm in diameter, a smaller diameter sludging pipe, usually 18 mm diameter threaded PVC pipes with 30 cm long toothed cutter GI pipe at the tip is used. A ⅓ cup oil barrel is properly mounted on the top of the tubewell to hold and provide continuous flow of water as sludging proceeds. With the removal of sand, additional sludging pipes are added till the entire tubewell is cleared of sand. No scaffolding is usually required to perform the operation as the total weight is within the capacity of a person. The tubewell must be developed by continuous pumping after desanding for several hours until sand free water is discharged by the tubewell.

- **Re-sinking:** Re-sinking of tubewell is needed when restoration of choked up tubewell by desanding fails. Shallow tubewells installed with properly connected GI pipes can be easily withdrawn for re-sinking by direct vertical pull but weaker PVC pipes usually tear off under high pull. Ring boring around the pipe is usually employed to the extent required to withdraw a tubewell without tearing. In the process the head of the tubewell is removed and a ring cutter is attached to the tubewell for cutting soil around the pipe. The technique is known as side digging. The process reduces the friction between pipes and soil during withdrawal of the pipes by vertical pull. Sometimes side digging is required along the total length of the pipes to make the weak pipes free but it may not be cost effective. The re-sinking procedure of a tubewell is similar to sinking of a new tubewell.

Example 8.1: A 20 ft long, 14-pipe size, continuous-sort stainless steel screen is to be installed in a well. The width of the outside wrapping wire used to fabricate the screen is 0.156 in, and the recommended slot size is 0.065 in. the anticipated yield is 2,000 gpm.

Solution:

1. Calculate the surface area for each 1 ft length of screen:

$$\begin{aligned}\text{Area} &= \pi d \times 12\\ &= 3.14 \times 14 \times 12\\ &= 528\ \text{in}^2/\text{ft of screen}\end{aligned}$$

where,

d = Screen diameter.

2. Calculate total area for 20 ft of screen:

$$20 \times 528 = 10{,}560\ \text{in}^2$$

3.Calculate the percentage of open area of the screen, based on the wire width used of fabricate the screen and the slot size required:

$$\%\ Open\ Area\ = \frac{slot\ size}{Slot\ size\ +\ wire\ size} \times 100$$

$$= \frac{0.065}{0.065\ +\ 0.156} \times 100$$

$$= 29.4\%$$

Thus, 29.4 percent of the screen's outer surface will be open to the aquifer.

4.Calculate the amount of open area:

Open Area = surface area × % open area

$= 10{,}560 \times 0.294$

$= 3{,}105\ \text{in}^2 / 144^*$

$= 21.6\ \text{ft}^2$

Open area per ft of screen = $21.6 / 20 = 1.08\ \text{ft}^2$

(**there are 144 square inches in 1 square feet*)

5. Calculate the average entrance velocity of water moving into the slots by:

$Q = VA$

Where,

Q = anticipated yield, in ft^3/sec
V = entrance velocity, ft
A = screen open area, in ft^2

Therefore,

$$V = \frac{Q}{A}$$

Convert yield in gpm to ft^3/sec

2,000 gpm / 7.5 gal per ft^3 / 60 sec per min = 4.44 ft^3/sec

Therefore, the entrance velocity is:

$$V = \frac{4.44}{21.6} = 0.21\ \text{ft/sec}$$

6. Because 0.21 ft/sec is greater than the recommended velocity of 0.1 ft/sec, either the screen length should be increased or the screen diameter enlarged. In

this situation, enough drawdown is available to lengthen the screen without limiting the yield.

To calculate the new screen length, determine the amount of open area required at an inlet velocity of 0.1 ft/sec. Therefore:

$$V_1A_1 = V_2A_2$$

$$A_2 = \frac{V_1A_1}{V_2}$$

$$= \frac{0.21 \times 21.6}{0.1}$$

$$= 45.4\ \text{ft}^2$$

Open area required is 45.4 ft^2.

From step 4, the open area is 1.08 ft^3 per ft of screen. Therefore, the minimum screen length required is:

$$\frac{45.4}{1.08} = 42\ \text{ft}$$

7. As an alternative to adding more screen, the diameter could be increased. If a 20 ft, 36 in pipe size screen is used, the new entrance velocity can be calculated:

$$\text{Area} = \frac{\pi \times 36 \times 12 \times 20}{144}\ \text{ft}^2$$

$$= 188\ \text{ft}^2$$

$$\text{Open area} = 188 \times 0.232^*$$

$$= 43.6\ \text{ft}^2$$

$$\text{Velocity} = \frac{4.44}{43.6}$$

$$= 0.10\ \text{ft/sec}$$

Thus, a 36 in pipe size, 20 ft screen would have sufficient open area for the anticipated yield. But, this design may not be practical because casing much larger than necessary would be required, construction of the borehole would be more costly, and certain drilling methods may be eliminated.

8. Another option is to use a filter pack so that the slot size can be increased.

9. If design criteria for strength permit, the wire width may be decreased, thereby increasing open area.

10. On the other hand, is the calculated entrance velocity is significantly less than 0.1 ft/sec, the screen diameter may reduced somewhat.

The foregoing statement assume that the pump will be set just above the well screen (the usual case), and thus the head loss associated with the average flow of water upward within the screen section will be small. Unacceptably high head losses can occur when long, small-diameter riser pipes are places between the screen and the pump. If the upward velocity is less than 5 ft/sec (1.5 m/sec) in both the screen and the riser pipe, the head losses will be reasonable.

(*On a 36 in diameter screen, the wire face width would have to be increased to 0.215 in maintain adequate strength, the open area is then 23.2 percent*)

8.19 Conclusion

Since tube wells became popular as a source of drinking water in Bangladesh in the 1970s, tens of millions of people have been slowly poisoned by arsenic. Exposure to arsenic from the contaminated wells is projected to double the number of cancer deaths in Bangladesh in the next two to three decades. Potential solutions to the crisis have received less attention than the problem. Therefore, it is time to plan a course of action that takes into account the current reliance on tube wells since a wholesale rejection of their use in Bangladesh isn't realistic at this time.

Reference

UNDP and WB (1986). Information and Training for Low-Cost Water Supply and Sanitation, Participants' Note : Water Treatment. Washington, D.C.

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