| **Sr. No.** | **Type of Sub-soil** | **K'/A** |
|---|---|---|
| 1 | Clay | 0.25 |
| 2 | Fine Sand | 0.50 |
| 3 | Course Sand | 1.00 |

By selecting the value of (K'/A) from the above table and calculating the value of K' from the equation Q = K' H, the value of A and hence the diameter of well may be obtained.

**2) Depth of Well**

The selection of well depth depend upon the thickness of water bearing formation, the depth of water table below the ground surface and anticipated drawdown in the well and storage depth while the well is in operation. The drawdown is usually taken as 4 to 6 m, when a horizontal centrifugal pump is used to lift water. The value of storage depth usually 2 m. The approximate depth of well is the sum of depth of water table below ground surface, drawdown and storage of depth.

It is desirable to complete a well to the bottom of an aquifer so that the full thickness of the aquifer is utilized. The greater available drawdown results in high yield. Where poor quality water is encountered in the lower part of an aquifer, the well may be limited to the depth which will not expose the formation having poor quality.

**Construction of Open Well**

Dug wells are usually constructed by hand using pick axe and shovels or power driven shovel of various designs. Many open wells are still constructed manually. In the manual method, one or more men start to dig, throwing out the dirt till the hole becomes deep. Then a second man or a group of men standing at intermediate points relay excavated material and dump it on the ground surface. The earth at the bottom is loosened and collected in buckets. Buckets and wheel barrows operated by suitable pulleys and lines are often used to lift the excavated materials. The bucket when full is lifted up by means of rope and pulley. In unstable material considerable care must be taken to prevent cave-in which may results in serious injury to the well drilling crew. The common practice in concrete lines wells is to allow the concrete lining to sink as the well is deepened.

**B) DESIGN OF TUBE WELLS**

Major steps involved in the design of tube wells are:

(i) Selection of suitable size of the well and casing;
(ii) Length and location of the screen, including slot size and shape, and percentage of opening;
(iii) Selection of casing and screen material, and
(iv) Design of gravel pack (if gravel pack is necessary).

The design element in tube wells includes the well diameter, well depth, well screen, gravel pack and well spacing.

**1) Well Diameter**

Choice of proper well diameter is important because it affects significantly the cost of the well. The diameter of the well should be sufficient to accommodate the proper size of the housing pipes, blind pipes and well screens to the desired depth in order to ensure good hydraulic efficiency of the well. The diameter of shallow tube well is usually same from top to bottom.

In case of deep tube wells, the well structure consists of two main elements. One main element is the part of well that serves as housing for pumping equipment and act as the vertical conduit (such as pipe) through which water flow upward to the pump. This is commonly cased portion of the well, although some of its length may be uncased where the well is constructed in consolidated rock materials. The other main element is the intake portion of the well where water enters the well from the aquifer. The yield of a well is a function of the diameter of its intake portion.

In a consolidated rock formation, the intake portion of the well is usually an open bore hole drilled into the aquifer to an adequate depth. The yield of such a well varies with the number, size and continuity of the openings in the rock that are encountered in drilling the bore hole in the aquifer.

The size (diameter) of a well needs to be carefully selected because it considerably affects the cost of well construction. It should be large enough to accommodate the pump used for groundwater withdrawal with a proper clearance (at least 5 cm) for installation and efficient operation.

It is true that largest diameter tube well will yield some more, but the percentage of increase may be relatively small. In case of unconfined aquifer, well yield will increase only 11 % by doubling the diameter of well screen and in case of confined aquifer; well yield will increase only 7 % by doubling the diameter of well screen. The value of increase in yield in a confined aquifer is less than a water table well because for the same discharge rate, the radius of influence is larger for the former.

**2) Well Depth**

The depth of a pumping well depends on the depth at which aquifer layers exist and the number of aquifers to be tapped. This information could be obtained from the well logs (also called 'lithological logs') of an area. It is desirable to complete a well to the bottom of an aquifer so that the full thickness of the aquifer is utilized. It also enables more drawdown, permitting greater well yield. If multiple aquifer layers exist in an area and money is not a constraint, pumping wells are drilled to penetrate two or more aquifer layers so that large well yield can be obtained for a longer time period. The poor-quality aquifer, if available, is backfilled or sealed in order to avoid the upward migration of the poor-quality groundwater when the well is pumped. The depth of well is usually determined from the log of a test hole, from logs of other nearby wells in the same aquifer.

**3) Well Screen**

A well screen is a strainer which separates the groundwater from the granular material in whose pores it is contained. Generally all the formations, except stable rock require well screens. Almost all the deep tube wells in India are of gravel pack type using slotted pipes as screens.

The followings are the basic requirements for any well screen:

1) Resistance to corrosion, incrustation and deterioration.
2) Enough structural strength to prevent collapse.
3) Suitability to prevent excessive movement of sand into the well.
4) Minimum resistance to flow of water into the well.

The quantity of water that can be tapped from a well depends primarily on matching the characteristics of the aquifers to the elements of the well screen. The well screen elements refer to the length of the screen and screen diameter.

**Design of Well Screen**

The design of a well screen (also known as 'strainer') involves the determination of screen length, location of the screen, percentage open area, size and shape of openings (slots), screen diameter, and the selection of screen material. These design points are discussed in subsequent sub-sections.

**Length of the Screen**

The length of a well screen is selected in relation to the aquifer thickness, available drawdown and stratification of the aquifer. The design procedure for the length well screen is depends on entrance velocity of water at the screen, slot size and effective open area per metre length of the well screen. Selection of screen length is actually a compromise between two factors viz., specific capacity of the well and drawdown in the well. A higher specific capacity can be obtained by using as long a screen as possible, while more drawdown results by using short screens. The theory and experience have shown that screening the bottom one third of the aquifer provides the optimum design of a screen. In homogeneous confined aquifers, about 70 to 80% of the aquifer thickness is screened (Raghunath, 2007).

To prevent rapid clogging, the length of the well screen is designed on the basis of the following equation,

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

Where, h = Minimum length of well screen (m)
Q = Maximum expected discharge capacity of well ($m^3$/min.)
A = Effective open area per metre length of the well screen ($m^2$)
V = Entrance velocity at the screen (m/min.)

**Size and Shape of Slots**

The size and shape of the openings (slots) in the screen depend on the gradation, and size and shape of the aquifer material so as to avoid entering of fine particles into the screen openings and to ensure that all the fine particles around the screen are washed out to improve the permeability of the aquifer material. Oversized slot will pump finer material and clear water is difficult to obtain, while under sized slot will provide more resistance to flow of groundwater. The problem of clogging is reduced as the well screen openings are increased. Therefore, the well slot openings are used as wide as possible by matching the opening with the grain size distribution of the material surrounding the screen. For naturally developed wells, the size of the opening is selected as 40 to 70% of the size of the aquifer material (Raghunath, 2007). If the opening size selected on this criterion is smaller than 0.75 mm, then the use of an artificial gravel pack becomes essential.

The slots may be done in different ways, vertical or horizontal, continuous or intermittent. Generally, horizontal slot opening give better control of unconsolidated material than do vertical openings. The width of slot depends on the grain size distribution of the aquifer and varies in practice from 0.2 to 0.5 mm depends on screen construction to as large as 2 to 5 mm.

**Percentage Open area**

Water flows more freely through a screen with large open area than through one with limited open area. When the open area of the screen is large, the entrance velocity is slow and the head loss at the screen is minimum. Corey (1949) observed that little or no increase in well efficiency results when the open area is greater than 15 percent of total surface area of the screen. Further an open area larger than about 15 percent affects the structural strength of slotted pipe well screen. Ahrens (1970) stated that little or no increase in well efficiency results from open area larger than about 25 where as efficiency falls rapidly as the open area becomes less than 15 percent.

When a screen is placed in an aquifer, sediment will settle around it and partially blocked the slot openings. Walton (1962) observed that on an average, about one half of the open area is blocked by aquifer materials. Thus it may be said that the effective open area average about 50 percent of the actual open area of the screen. Therefore a new screen should be designed.

**Screen Diameter**

After the length of the screen and the slot size has been selected, the screen diameter should be selected. Well screens (strainers) are available in a range of diameters. Suitable screen diameter is selected based on the desired yield of the well and the thickness of the aquifer. Screen diameter is selected based on the fact that entrance velocity of water will not exceed the design standard. The entrance velocity near the well screen should not exceed 3 to 6 cm/s in order to avoid incrustation and corrosion and minimize friction losses (Raghunath, 2007). The entrance velocity is calculated by dividing the yield of the well by the total area of the openings in the screen. If the value is greater than 3 cm/sec., the screen diameter should be increased to provide enough open area in order to decrease the entrance velocity.

**Screen Material**

The selection of screen material depends on the diameter and depth of the well, the type of aquifer layer, and the chemical composition of aquifer materials which dictates the quality of groundwater. The screen material should be resistant to incrustation and corrosion, and should have enough strength to withstand the column load and collapse pressure. The mineral content of the water, presence of bacterial slimes and strength requirements are important factors, which influence the selection of screen material.

The principal indicators of corrosive groundwater are: low pH, presence of dissolved oxygen, $CO_2$ > 50 ppm, and Cl > 500 ppm (Raghunath, 2007). The principal indicators of incrusting groundwater are: total hardness > 330 ppm, total alkalinity > 300 ppm, iron content > 2 ppm, and pH > 8. Slime producing bacteria are often removed by chlorine treatment. This is followed by acid treatment to re-dissolve the precipitated iron and manganese.

**Type of Screens**

The types of well screens are mainly decided based on the shape of screen openings (slots). Some of the commonly used screen types are shown in Figs. a, b, c, d. The V-shape continuous-slot type of well screen is fabricated by winding cold-drawn wire, approximately triangular in cross-section, spirally around a circular array of longitudinal rods. The V-shaped openings facilitate the fine particles to move into the well during development without clogging them. This type has the maximum percentage of open area per unit length of the screen, and the area of openings can be varied by adjusting the spacing of the wires wrapped (Raghunath, 2007). These screens are usually made of galvanized iron (GI), steel, stainless steel and various types of brass.

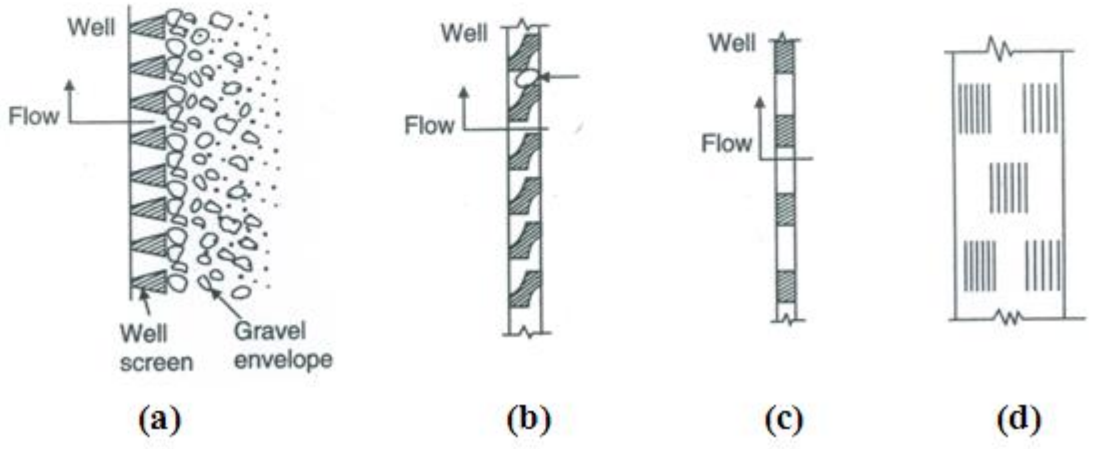


Fig. Types of commonly used well screens: (a) V-shape continuous slot screen, (b) Louver-type screen, (c) Rectangular slot screen, and (d) Pipe-base well screen or Metallic filter point. (Source: Raghunath, 2007)

The best type of screen opening is the V-shaped slot that widens towards the inside of the screen, i.e., openings are bevelled inside. A major factor in controlling head loss through a perforated well section is the percentage of open area. For practical purposes, a minimum open area of 15% is desirable, which is easily obtained with many commercial (manufactured) screens but not with pre-perforated casings (Todd, 1980). Therefore, manufactured screens are preferred to pre-perforated casings because of larger open area and the ability to tailor opening sizes to aquifer conditions.

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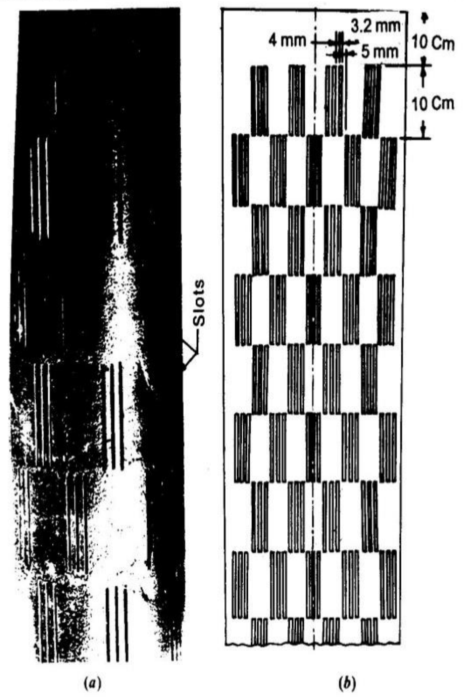



Fig. 5.10. Portion of a slotted strainer pipe used in tubewell casing: (a) General view. (b) Drawing showing slot dimensions and spacing as per Bureau of Indian Standards IS8110-1976.

**Common type of well screen used in India**

1) Slotted Pipes
2) Slotted pipe with pre-packed filters
3) Coir strainers
4) Bamboo strainer
5) Polythene strainer
6) Agricultural Strainer

## GRAVEL PACK

Gravel pack is a thin layer of course material specially gravel formed around the screened portion of a well. These characteristics increase the permeability and porosity of the pack material.

Design of Gravel Pack

Wells can be naturally gravel packed or artificially gravel packed.

**1. Natural Gravel Pack**

A naturally developed pack can be produced by removing the fine sand and silt from the natural formations and transporting them through well screen opening. In many situations, the grain-size distribution of aquifer material is such that a properly selected well screen allows finer particles to enter the well, and to be removed during well development. Thus, after the development of the well, coarser particles are retained outside the well screen and form a permeable envelope around the well screen which is known as a 'natural gravel pack' and the well is called a naturally developed well.

If the uniformity coefficient ($C_u$) of an aquifer material for a naturally developed well (without an artificial gravel pack) is 5, the selected slot size should retain 40 to 50% of the aquifer material. However, if the uniformity coefficient ($C_u$) is greater than 5, the slot size should be selected such that it should retain 30 to 50 % of the aquifer material (Todd, 1980).

**Effective Size '$d_{10}$'**

The term effective size is defined as formation particle size, where 10 percent of the sand is finer and 90 percent coarser.

**Uniformity Coefficient ($C_u$)**

This is a ratio expressing the variation in grain size of a granular material. It is the ratio of sieve aperture that passes 60 % of the material with the sieve aperture that passes 10 % of the material.

$$C_u = \frac{D_{60}}{D_{10}}$$

## 2. Artificial Gravel Pack

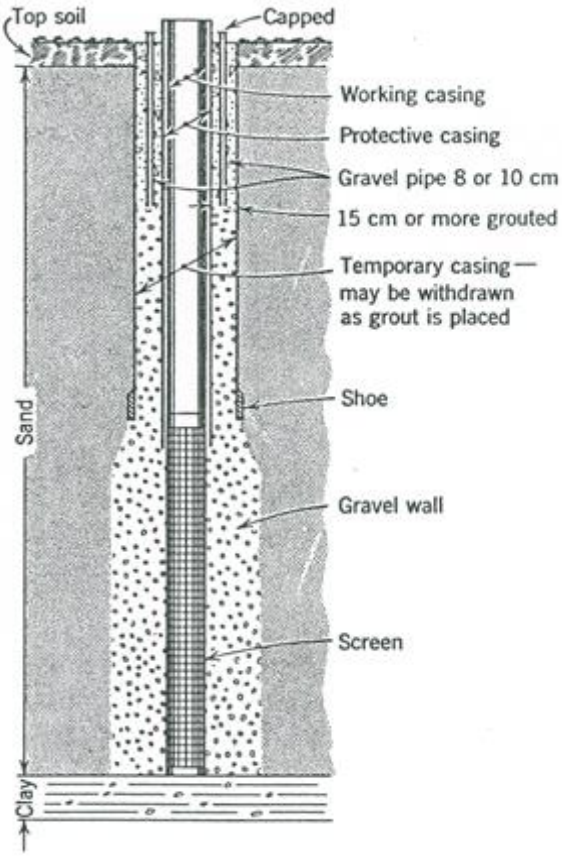
An artificial gravel pack can be provided by keeping the bore of the well somewhat larger than the well screen in the hole and filling the annular space around the screen with properly selected gravel. A good gravel pack material is clean gravel with rounded, smooth, uniform grains. These characteristics increase the permeability and porosity of the pack material. A gravel-packed well is the well having an artificially placed gravel envelope around the well screen. Gravel packing is done by placing an artificially packed gravel screen or envelope around the well screen.

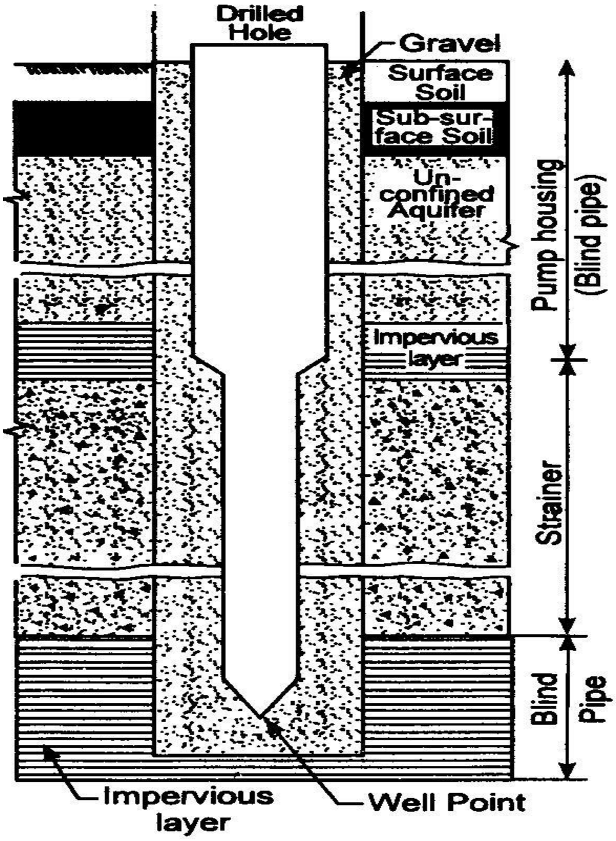
Salient advantages of the artificial gravel pack are (Todd 1980):

(i) It stabilizes the aquifer tapped by the well,
(ii) It avoids/minimizes sand pumping,
(iii) It allows to use a large screen slot with a maximum open area, and
(iv) It provides a zone of high permeability surrounding the well screen, which increases the well radius (known as 'effective radius' of the well) and well yield.

When a well screen of a pumping well is to be surrounded by an artificial gravel pack, the size of the screen openings is decided based on the size of the gravel used for gravel packing.

Fig. 5.8 Driven well




**Vertical Cross-Section of a Gravel-Packed Well**

Fig. 5.9 Section of a tubewell

## Design of Gravel Pack

Artificial gravel pack is required when the aquifer material is homogeneous with a uniformity coefficient ($C_u$) of less than 3 and an effective grain size ($D_{10}$) of less than 0.25 mm (Raghunath, 2007).

## P-A Ratio / Pack-Aquifer Ratio / Gravel Pack Ratio

$$\text{P-A Ratio} = \frac{50\ \%\ \text{size of gravel pack}}{50\ \%\ \text{size of aquifer}}$$

The P-A ratio should be 4:1, if the aquifer material is fine and uniform. However, if aquifer material is coarse and non-uniform, the pack-aquifer ratio should be 6:1. A pack-aquifer ratio of 5 has been successfully used in water wells (Raghunath, 2007). If the formation materials are sand and silt of appreciable non-uniform size, the value of P-A ratio may be 6 to 9. The gravel-pack material should have a uniformity coefficient ($C_u$) of less than 2.5. The maximum grain size of a gravel pack should be less than 1 cm and the thickness of the gravel pack should be between 10 and 20 cm (Raghunath, 2007).

The slot size of the well screen is selected as $D_{10}$ of the gravel-pack material to avoid segregation of fine particles near the screen openings. The width of screen slots ranges from 1.5 to 4 mm and the length ranges from 5 to 12.5 cm.

The gravel selected for a gravel pack should be clean, dense, rounded, smooth and uniform, and should mainly consist of siliceous material (the allowable limit for calcareous material is up to 5%). Particles of shale, anhydrite and gypsum are also undesirable in the gravel-pack material.

**Fig. 5.8 Driven well**

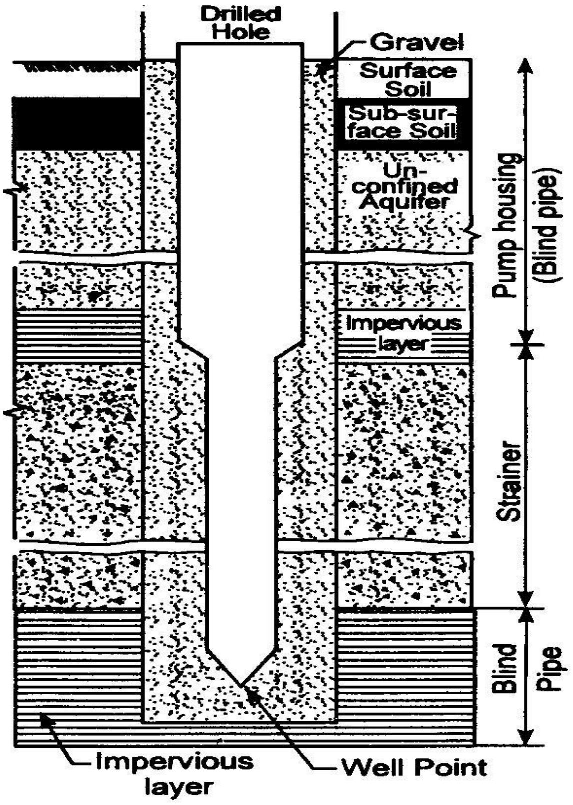



**Fig. 5.9 Section of a tubewell**

## TUBE WELL DRILLING METHODS

Drilled tube wells are constructed by standard drilling procedures utilizing the type of equipment best suited to the formations of the site. Tube well construction involves the three distinct operations namely, a) drilling operation, b) installation of casing and well screen, c) developing the well for maximum yield and sand free water. When artificial gravel packing is required, this forms a part of the well screen installation.

Different types of drilling rigs are manufactured to suit different drilling conditions. They are usually classified according to the method of drilling employed. Construction of 'deep wells' (wells with depths more than 15 m) having high capacity as well as large diameter and depth is generally accomplished by using drilling methods. Various drilling methods used for constructing deep wells can be classified as....

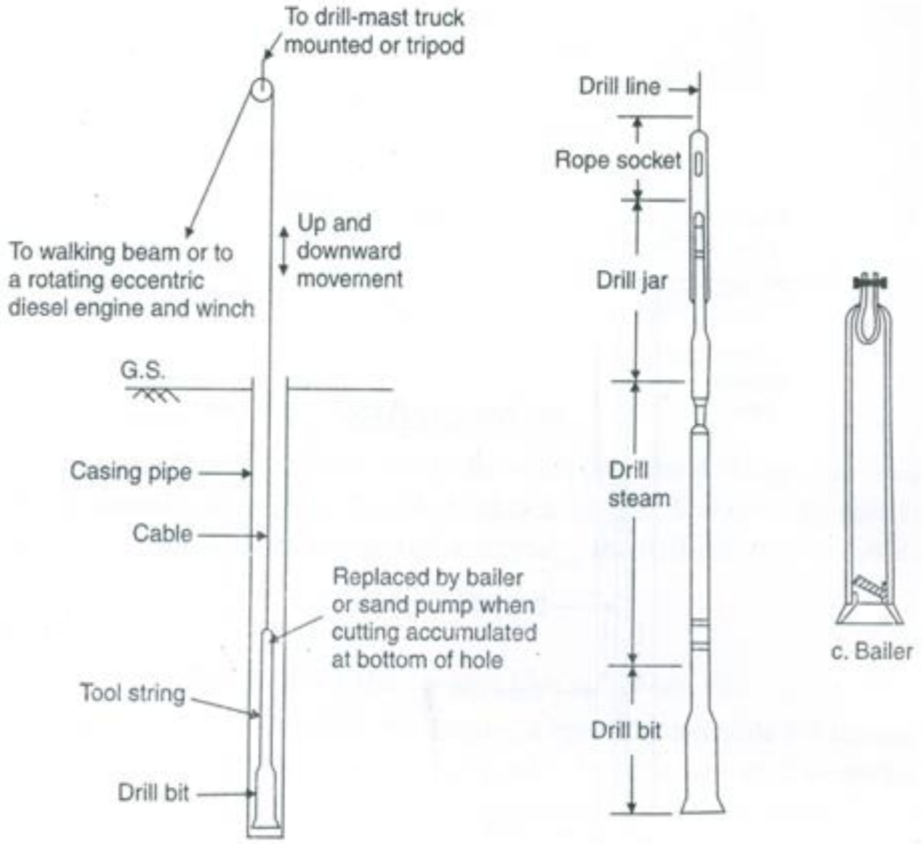
1) Percussion / Cable-Tool / Standard drilling
2) Rotary drilling including Direct Rotary, Reverse Rotary and Air Rotary.
3) Rotary-Percussion drilling / Rotary-cum-Hammer drilling

The choice of the equipment is mainly governed by the size and depth of hole to be drilled.

### 1) Cable -Tool Percussion Drilling

In cable-tool method, the drilling is accomplished with the help of a standard well-drilling rig, percussion tools and a bailer. Basically, the drilling procedure involves a regular lifting and dropping of a string of tools. On the lower end, a drill bit breaks/cuts the rock or other earth materials by impact. Thus, by repeated pounding and breaking/cutting operations, a borehole is formed. Drill bit is used as the cutting tool.

In particular, the percussion drilling equipment consists of a tool string (comprising a rope/swivel socket, a set of drilling jars, a drill stem, and a drill bit) suspended by a cable from a walking beam (truck mounted or tripod) or operated from a diesel engine, which lifts and drops the tool string.




1) Drill Bit: The most important part of the tool string is the drill bit (having a sharp chisel edge) which crushes/breaks almost all types of earth materials. The length of drill bits varies from 1 to 3 m and they weigh up to1500 kg (Todd, 1980). Drill bits of various shapes are manufactured for drilling in different subsurface formations.

2) Drill Stem: The drill stem is a long steel bar that provides additional weight to the bit and its lengths helps in maintaining a straight vertical hole while drilling in hard rock.

3) Drilling Jars: Drilling jars consist of a pair of narrow linked steel bars and help in loosening the tools when they stick in the hole. Under normal tension on the drilling line, the jars remain fully extended. When tools get stuck, the drilling line is slackened and then lifted upward. This causes an upward blow to the tools because of which tools are released.

4) Swivel/rope Socket: Swivel/rope socket connects the tool string to the cable. The wire cable, which carries and rotates the drilling tool on each upstroke, is known as drill line.

5) Bailer : Drill cuttings are removed from the well by a bailer or sand bucket. A bailer consists of a section of pipe with a valve at the bottom and a ring at the top for attachment to the bailer line. The valve allows the cuttings to enter the bailer but prevents them from escaping. After filling, the bailer is hoisted to the surface and emptied.

Drilling is accomplished by regular lifting and dropping of the tool string. As a result, the drilling line is rotated, the drill bit forms a round hole through the formation, the tool string is lifted and the hole is bailed.

The cable tool method is capable of drilling holes of 8 to 60 cm in diameter through consolidated rock materials to depths of 600 m. It is least effective in unconsolidated sand and gravel formations, especially quicksand, because the loose material slumps and caves around the drill bit.

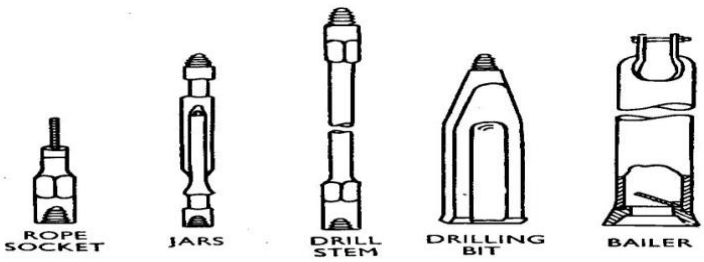


Fig. 5.14. Basic well-drilling tools for the cable tool method.
(Redrawn from California Agrl. Expt. Stn. Cir. 404)

### 3) Rotary Drilling

Rotary drilling method is a rapid method for drilling in unconsolidated formations. The most important components in the rotary drilling method are the drill bit and the drilling fluid. The drilling fluid may be air or mud (usually a mixture of water and bentonite). The drilling process involves boring a hole by using a rotating bit to which a downward force is applied. The drilling fluid is pumped down through the drill pipe and out through the nozzles in the drill bit. The bit is rotated by a hollow stem through which a drilling fluid is circulated. The cuttings are carried upward in the hole by the rising mud, which flow to a settling pit where the cuttings settle out and the mud fluid overflows to a storage pit from where it is re-circulated again.

The reverse-circulation rotary method has become increasingly popular for drilling large-diameter boreholes in unconsolidated geologic formations. In fact, it is the most rapid drilling technique available for unconsolidated formations. The large diameters facilitate completion of the wells by artificial gravel packing. The main disadvantage of this method is that it requires a large quantity of water to be readily available.

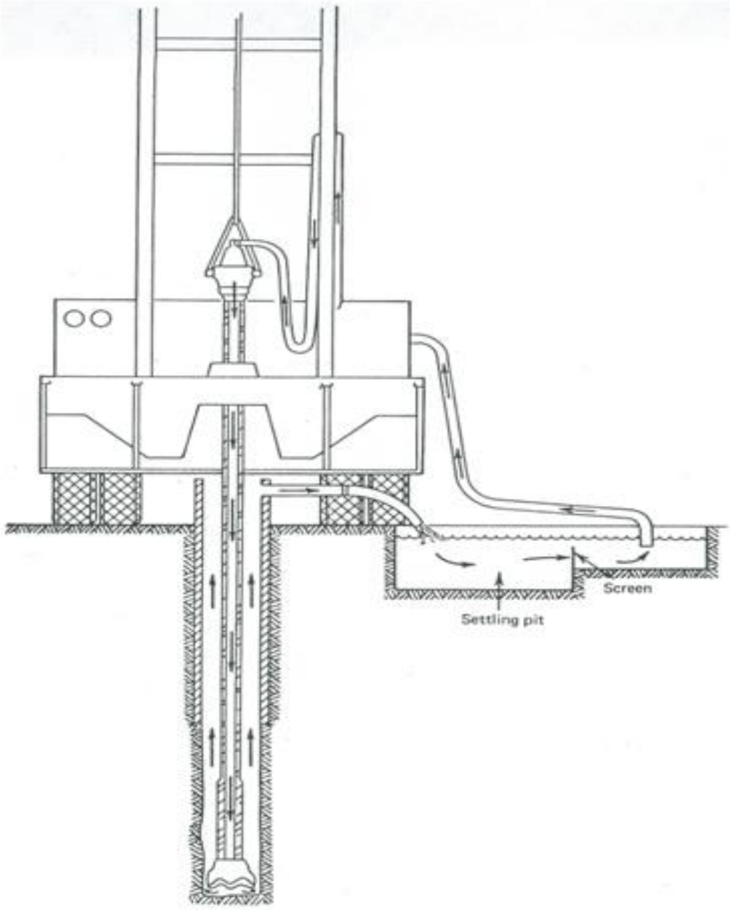



Fig. Drilling mud circulation system for the rotary method

### 3) Rotary-Percussion Drilling

This method of drilling combines the percussion effect of cast tool drilling and the rotary action of rotary drilling. It is also known as 'Rotary-cum-Hammer drilling'. It uses compressed air as the drilling fluid which provides the fastest method for drilling in hard-rock formations (Todd, 1980); it can drill 15-20 cm holes to a depth of 120 m in 10-15 hours (Raghunath, 2007). A rotating drill bit, with the action of a pneumatic hammer delivers 10 to 20 impacts (blows) per second to the bottom of the hole. The diameter and depth of the hole is limited by the volume of air that can be exhausted through the hammer to remove the cuttings. A flush pump is used for flushing the hole and bringing the cuttings to the ground surface. Air compressor, pump and prime mover are usually mounted on a truck.

Compressed air must be supplied at a pressure of 750 to1350 kN/m$^2$ (to effectively remove the cuttings) and free air supply of at least 9 to 10 m$^3$/min for drilling 15-cm holes. The upward velocity in the space outside the drill pipe should be about 900 m/min. The rotation speed of the drill bit should be from 15 to 50 rpm (Raghunath, 2007).

**4) Reverse Circulation Rotary Drilling**

A reverse circulation rotary drills works on the same principle as the direct rotary method except that the drilling fluid is circulated in reverse to the direction of that of the rotary drilling method. The drill fluid is fed from tank down the annular space between hole and drill pipe and is recovered along with the drilling cutting through the drill pipe and discharged into the tank where cutting are allowed to settle. Considerable supply of water in the range of 3 to 9 litres per second is required from the time the drilling is started till the gravel packing of well has been completed.

Reverse circulation rotary is cheapest way to drill large diameter holes in soft unconsolidated formations. It is generally used to drill holes of size 35 cm and above. Its use is restricted to locations where ample water supply is available as it requires about five times the amount of water that is normally needed for direct rotary drilling. It is suitable only for gravel pack tube wells.

## WELL LOG

Well log is recording (description) of different characteristics of materials which is collected during drilling. The description includes the depth, thickness and chief characteristics of formation such as texture, colour and hardness of formation.

## WELL SCREEN INSTALLATION

Well casing and screens are installed on the basis of the well log. Procedures for installing well screens are depends on the design of the well and method employed in drilling. The screen have to be located opposite the water bearing strata in order to draw water from the strata. Installation of well screen is done by assembling together the whole length of screen and the casing pipe. After complete installation of screen, the outer blind casing pipe is removed. As the casing pipe is withdrawn, the surrounding materials get loosened and grip the screen.

## WELL DEVELOPMENT

The process of removing silt, sand and very fine gravel from the aquifer surrounding the perforated section of casing is known as well development.

. After the completion of a well, the new well is developed to increase its specific capacity (well discharge per unit drawdown), prevent sand pumping and obtain maximum economic well life. Well development is the process which causes reversals of flow through the screen openings so as to remove the finer material from the natural formations surrounding the perforated sections of the casing. As a result, the well provides clear (sand-free) water, thereby maximizing its specific capacity and well efficiency. The main objectives of well development are....

1) To correct any damage or clogging of water bearing formations.
2) To increasing porosity and permeability of the water bearing formations.
3) To stabilize the sand formation around a screened well so that the well will yield sand-free water.

Various methods are available for developing a well, which include: (i) pumping, (ii) surging, (iii) use of compressed air, (iv) hydraulic jetting, (v) addition of chemicals/dispersing agents, (vi) hydraulic fracturing, (vii) backwashing, and (viii) use of explosives. These methods are briefly discussed below.

**1) Pumping Method**

This method of well development involves pumping a well in a series of steps from a low discharge to one exceeding the design capacity. At each step, the well is pumped until the water clears, after which the power is shut off and water in the pump column surges back into the well. The step is repeated until only clear water appears. The discharge rate is then increased and the procedure repeated until the final rate is the maximum capacity of the pump or well. This process agitates the fine material surrounding the well so that it can be carried into the well and pumped out.

**2) Surging Method**

Surging is one of the most effective methods of developing a well. In this method, a plunger is moved up and down against the perforated casing. It causes the movement of water into and out of well alternately. As the plunger rises, it draws water into the well and while lowering, it forces the water out into the aquifers. This reverse action of flow loosens the fine particles and brings them into the well. Surging is started slowly at first and speed is increased as the development proceeds. The process is continuous until no more sand and mud enter the well. The procedure is completed when the loose materials accumulating in the bottom of the well become negligible.

**4) Using Compressed Air**

To develop well by compressed air, an air compressor is connected to an air pipe inserted into the well. To begin with, the air pipe is closed and the air pressure is allowed to build up 7 to 10 kg/cm$^{2.}$ After that it is released suddenly into the well by means of quick opening valve. The compressed air creates a powerful surge within the well. The process loosens the fine material surrounding the screen (stainer) which is brought into the well by continuous air injection. The operation is repeated at intervals until the well is completely developed and clean water is discharged continuously. This method essentially involves both surging and pumping.

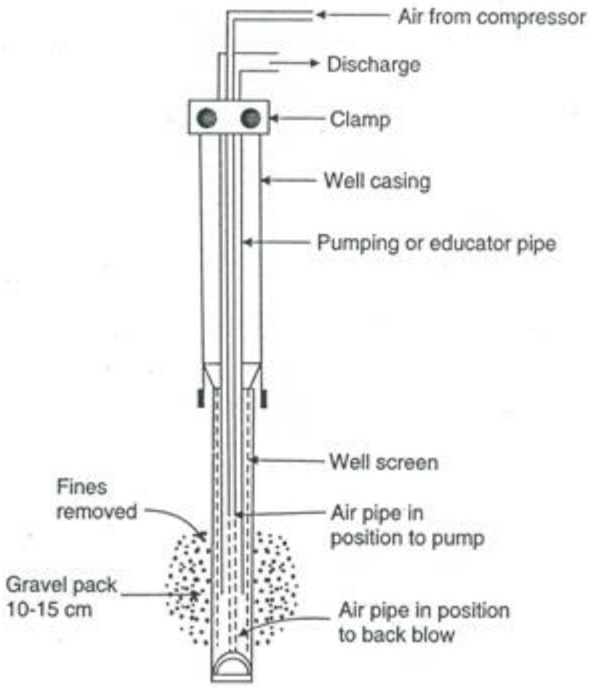



Fig. Well development by compressed air.

**5) Hydraulic Jetting**

In this method, a high velocity jet of water is applied horizontally through the screen openings with the tip of the nozzle at about 12-25 mm from the inner wall of the screen (Raghunath, 2007). A jetting tool coupled to the end of the pipe is lowered into the well. The top of the pipe is connected by a hose to a high pressure pump.

As a pump is started, the jetting tool is slowly rotated and gradually raised or lowered so that the entire surface of the screen receives jetting action. The well is pumped by another pump to maintain the hydraulic gradient so that water and the loosened fine particles will keep entering the well. Hydraulic jetting is particularly effective in developing gravel-packed wells (Todd, 1980). However, this method is not suitable when a perforated pipe is used as a screen. The disadvantage of the hydraulic jetting method is that it requires considerable amount of water for effective operation.

**5) Backwashing**

The backwashing method provides a surging effect for well development and is widely used by well drillers. In this method, the top of the well is fitted with an air-tight cover. The backwashing system consists of a discharge pipe, a long air pipe, a short air pipe, and a three-way valve as shown in Fig.

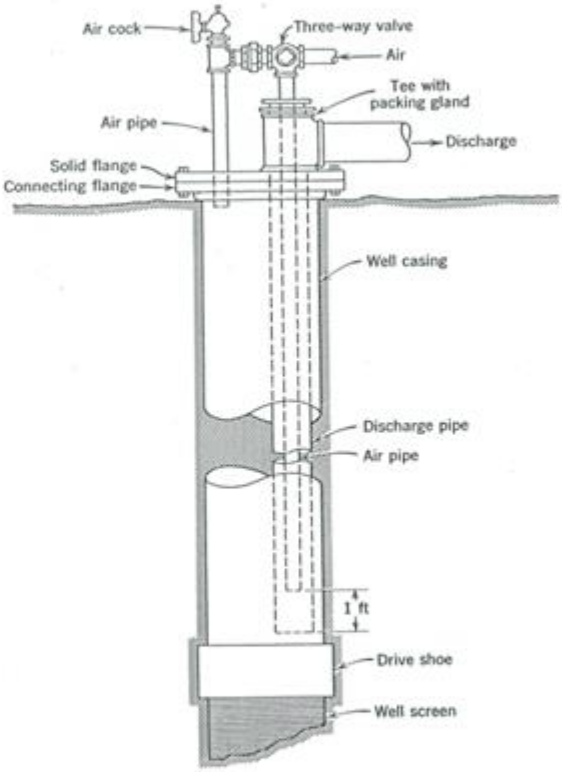



Fig. Setup for well development by backwashing with air.

Compressed air is released through the long air pipe, forcing air and water out of the well through the discharge pipe. After the water becomes clear, the air supply is stopped and the water is allowed to return to its static level. Thereafter, the three-way valve is turned to supply air into the top of the well through the short air pipe. This backwashes water from the well through the discharge pipe and at the same time agitates sand grains surrounding the well. Air is forced into the well until it starts escaping from the discharge pipe, after which the three-way valve is turned and the air supply is again directed down the long air pipe to pump the well. This procedure is repeated until the well is fully developed.