Details of Lecture Note (Lesson Plan) of Course No. IDE-302

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6. Topic Name : Lecture 12. Different Methods of Well Drilling

7. Evaluation of Ground Water Potential

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Lecture 12. Different Methods of Well Drilling

A well is an excavation or structure created in the ground by digging, driving and drillingto access liquid resources, usually water. Wells may be dug, bored, driven or drilled. Simple drilling methods like drive point jetting and hand boring can be adopted in favourable conditions for construction of shallow wells up to 25cm diameter and 45m deep. Selection of drilling equipments depends upon the hydrogeology of the formation, diameter and depth of production wells, availability of funds, maintenance and spares, production capacity, volume of work, operating crew and easy movement of the rig. Different methods of well construction and their suitability is displayed in Table-12.1.

Table 12.1. Methods of well construction and their suitability (Source: Todd, 1980)

Well Construction Method	Most Suitable Materials	Most Suitable Water Table Depth (m)	Usual Maximum Depth (m)	Normal Range of Diam. (cm)	Usual Casing Material	Customary Use	Well Yield (m^3/day)	Remarks
1.Augering (a) Hand Auger	Clay, silt, sand, gravel (<2 cm)	2-9	10	5-20	Sheet metal	Domestic, drainage	15-250	Most effective for penetrating and removing clay. Limited by gravel over 2 cm. Casing required if material is loose.
(b) Power Auger	Clay, silt, sand, gravel less than 5 cm	2-15	25	15-90	Concrete, steel or wrought-iron pipe	Domestic, irrigation, drainage	15-500	Limited by gravel over 2 cm, otherwise same as for the hand augers.
2. Driving (Hand, Air Hammer)	Silt, sand, gravel less than 5 cm	2-5	15	3-10	Standard weight pipe	Domestic, drainage	15-200	Limited to shallow water table, no large gravel.
3. Jetting (Light, Portable Rig)	Silt, sand, gravel less than 2 cm	2-5	15	4-8	Standard weight pipe	Domestic, drainage	15-150	Limited to shallow water table, no large gravel.
4. Drilling (a) Cable Tool	Unconsolidated and consolidated medium hard and hard rocks	Any Depth	450[b]	8-60	Steel or wrought-iron pipe	All uses	15-15,000	Effective for water exploration. Requires casing in loose materials. Mud-scow and hollow rod bits

								developed for drilling unconsolidated fine to medium sediments
(b) Rotary	Silt, sand, gravel less than 2 cm; soft to hard consolidated rocks	Any Depth	45[b]	8-45	Steel or wrought-iron pipe	All uses	15-15,000	Fastest method for all except hardest rock. Casing usually not required during drilling. Effective for gravel envelope wells.
(c) Reverse Circulation Rotary	Silt, sand, gravel, cobble	2-30	60	40-120	Steel or wrought-iron pipe	Irrigation, industrial, municipal	2500-20,000	Effective for large-diameter holes in unconsolidated and partially consolidated deposits. Requires large volume of water for drilling. Effective for gravel envelope wells.
(d) Rotary Percussion	Silt, sand, gravel less than 5 cm; soft to hard consolidated rock	Any depth	600[b]	30-50	Steel or wrought-iron pipe	Irrigation, industrial, municipal	2500-15,000	Now used in oil exploration. Very fast drilling. Combines rotary and percussion methods (air drilling); cuttings removed by air. Would be economical for deep water wells.

Note: [a]Yield influenced mainly by the geology and availability of groundwater; [b]Greater depths reached with heavier equipment

12.1 Digging

A pick and shovel are the basic implements for digging open wells in shallow aquifers. Loose material is brought to the surface in a container by means of rope and pulleys. Large dug wells can be constructed rapidly with portable excavating equipment such as clamshell and orange-peel buckets. For safety and to prevent caving, lining of wood or sheet piling should be placed in the hole to brace the walls (Todd, 1980; Michael and Khepar, 1999).

The depth of a dug well may be up to 20 m or more depending on the position of the water table, with the well diameter usually ranging from 1 to 10 m. Fig. 12.1 shows a typical dug well which is permanently lined with a casing/curb of wood staves, brick, rock, concrete or metal. The curb is perforated for entry of water and is firmly seated at the bottom. Gravel is backfilled around the curb and at the bottom of the well to control sand entry and possible caving. A properly constructed dug well penetrating a permeable aquifer can yield 2500 to 7500 m^3/day, although most domestic dug wells yield less than 500 m^3/day (Todd, 1980). Dug wells are generally used for individual water supplies in areas containing unconsolidated glacial and alluvial deposits. Further details of open-well (dug well) construction in alluvial and hard rock formations can be found in Michael and Khepar (1999).

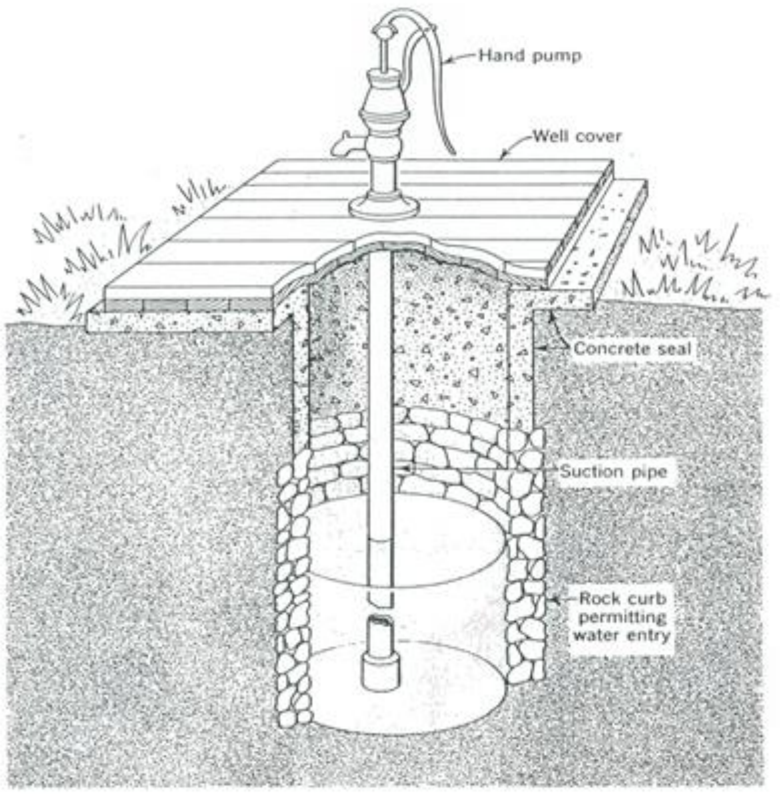

Fig.12.1. Typical domestic dug well with a rock curb, concrete seal and hand pump. (Source: Todd, 1980)

12.2 Boring

Augers are generally used for boring a well in shallow and unconsolidated aquifers. They are most suitable for the formations which don't cave. Augers are of two types: (a) Hand-operated augers, and (b) Power-driven augers.

12.2.1 Hand-Operated Augers

As shown in Fig. 12.2(a), hand-operated augers have cutting blades at the bottom that bore into the ground with a rotary motion. When the blades are full of loose earth, the auger is removed from the hole and emptied.

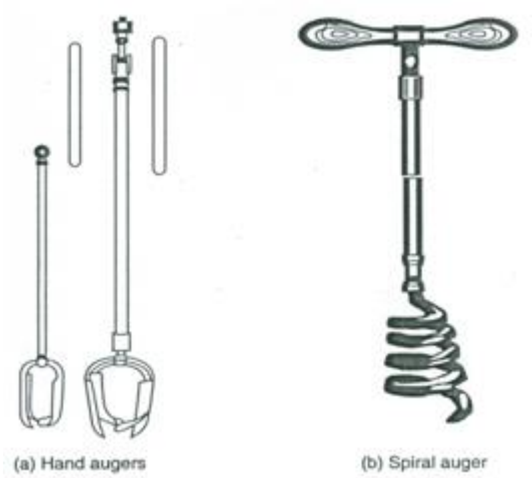

Fig. 12.2. Augers for boring wells: (a) Hand augers; (b) Spiral auger. (Source: Raghunath, 2007)

This procedure is repeated until the desired hole depth is reached. On the other hand, a spiral auger [Fig. 12.2(b)] is used to remove stones or boulders encountered during boring. Hand-bored wells can be up to 20 cm in diameter and 15 m in depth (Todd, 1980).

12.2.2 Power-Driven Augers

Power-driven auger consists of a cylindrical steel bucket with a cutting edge projecting from a slot in the bottom (Fig. 12.3). The bucket is filled up by rotating it in the hole by a drive shaft of adjustable length. When the container is full of excavated material, the auger is raised and emptied with the help of hinged openings located on the side or bottom of the bucket. Reamers, attached to the top of the bucket, help in enlarging holes to diameters exceeding the auger size. Power-driven augers can bore holes up to 1 m in diameter and to depths greater than 30 m (Todd, 1980).

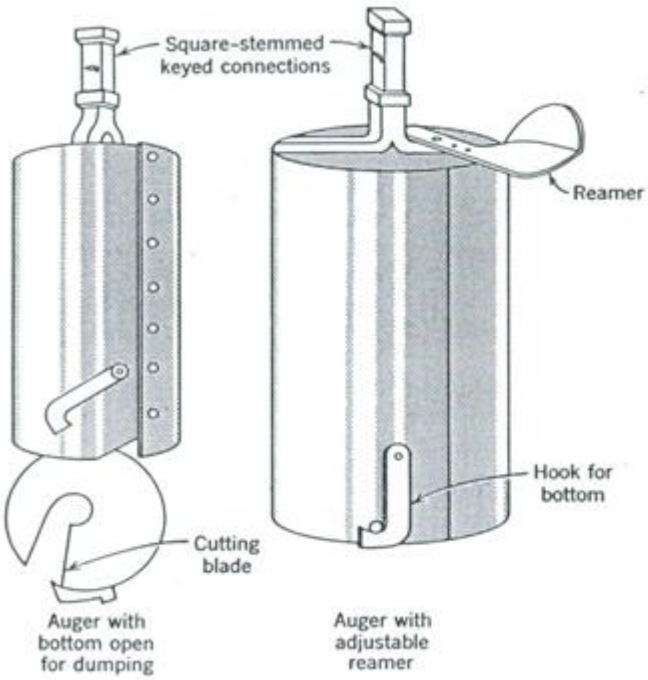

Fig. 12.3. Power-driven augers (Source: Todd, 1980).

There is another kind of power-driven auger called Continuous-flight power auger which has a spiral extending from the bottom of the hole to the surface. A screw conveyer is provided to carry the cuttings to the surface and the sections of the auger can be added as the depth increases. It is usually truck-mounted and can be operated by one person and can bore up to depths more than 50 m in unconsolidated formations devoid of large boulders. Note that where sticky clay formations are encountered, augers supplement other well-drilling methods because augers are more effective than any other penetrating device under such conditions.

12.3 Driving

In this method of well construction, a series of connected lengths of pipe is driven by repeated impacts into the ground to depths below the water table. Water enters the well through a drive point at the lower end of the well. A driven well with its driving mechanism is shown in Fig. 12.4. This consists of a screened cylindrical section protected during driving by a steel cone at the bottom. Driving can be done with a sledge, drop hammer or air hammer. The diameters of driven wells are in the range of 3 to 10 cm, and their depths are usually less than 15 m although a few wells exceed 20 m depth (Todd, 1980). Suction-type pumps are used to extract water from driven wells.

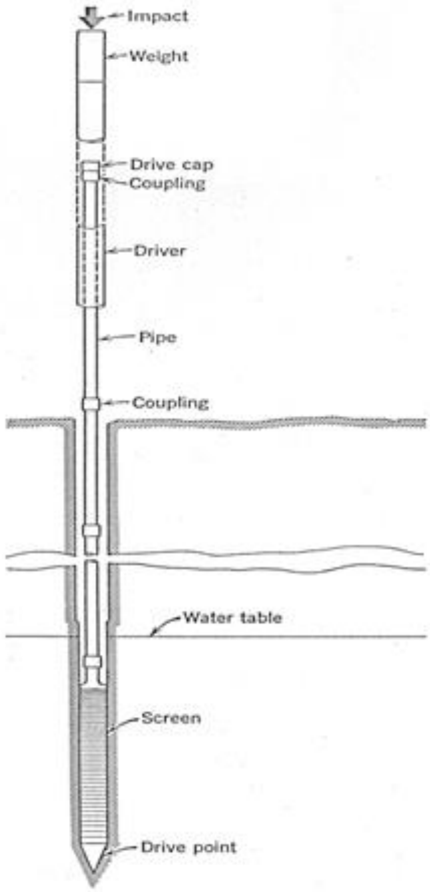

Fig. 12.4. A driven well with driving mechanism. (Source: Todd, 1980)

Driven wells can be installed only in unconsolidated formations which are relatively free of large gravels or rocks. The yield of driven wells is generally about 100-250 m^3/day (Todd, 1980). Driven wells are mostly used for domestic water supplies, temporary water supplies, and for exploration and observation. A series of driven wells connected by a suction header to a single pump is known as a well-point system which is used for dewatering excavations for foundations and other subsurface construction works. The main advantages of driven wells are that they can be constructed in a short time, at minimum cost, and even by one person.

12.4 Jetting

Jetted wells are constructed by the cutting action of a downward directed stream of water. The force of high velocity stream or jet of fluid loosens the subsurface materials and transports them upward and out of the hole. Jetting (Jet drilling) is achieved by a chisel-shaped bit attached to the lower end of a pipe string. Holes on each side of the bit serve as nozzles and water jets through these nozzles keep the bit clean and help loosen the material being drilled. Various types of jetting drill bits are shown in Fig. 12.5.

Fig. 12.5. Types of jetting drill bits. (Source: Todd, 1980)

A tripod and pulley, winch and a small pump of approximately 680 L/min at a pressure of 3.5 to 5 kg/cm^2 is used to force the drilling fluid (often normal water and in special cases, soft mud) through a hose on to the drill pipe and bit as shown in Fig. 12.6. During the jetting operation, the drill pipe is turned slowly to ensure a straight hole. When the casing extends to below the water table, the well pipe with screen attached is lowered to the bottom of the hole inside the casing. The outer casing is then removed, gravel is inserted in the outer space, and the shallow jetted well is completed.

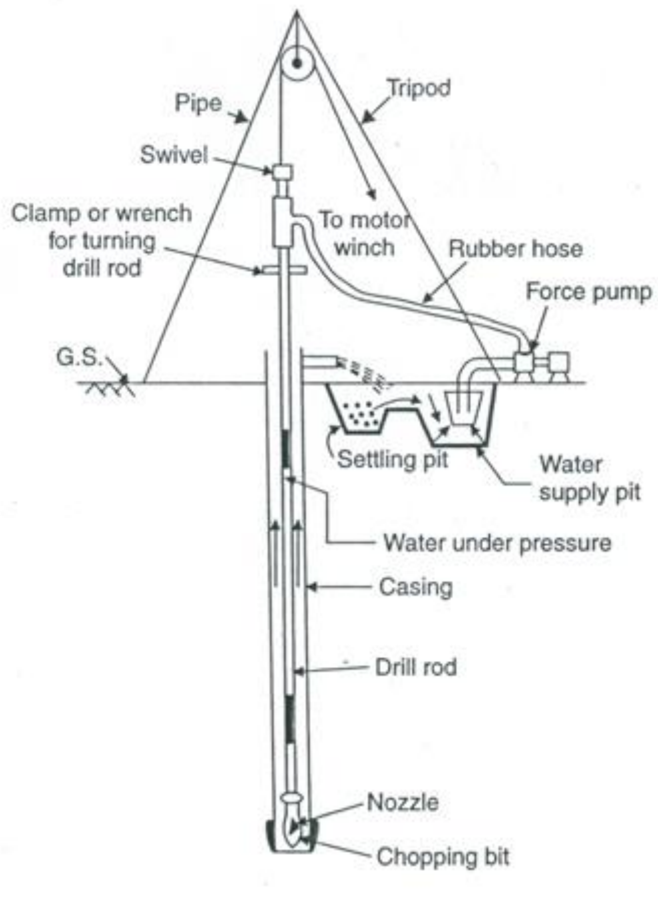

Fig. 12.6. Water jet method. (Source: Raghunath, 2007)

Jetting method is suitable for unconsolidated formations and can produce small- diameter holes of 3 to 10 cm to depths greater than 15 m (Todd, 1980). Jetted wells have only small yields, and are useful for exploratory test holes, observation wells and well-point systems.

12.5 Percussion Drilling

Percussion drilling is also known as 'cable tool drilling' or 'standard drilling', and it 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. 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 (Fig. 12.7). Thus, the percussion/cable tool drilling rig consists of a mast, a multiline hoist, a walking beam and an engine. In modern designs, the entire assembly is truck mounted for easy portability.

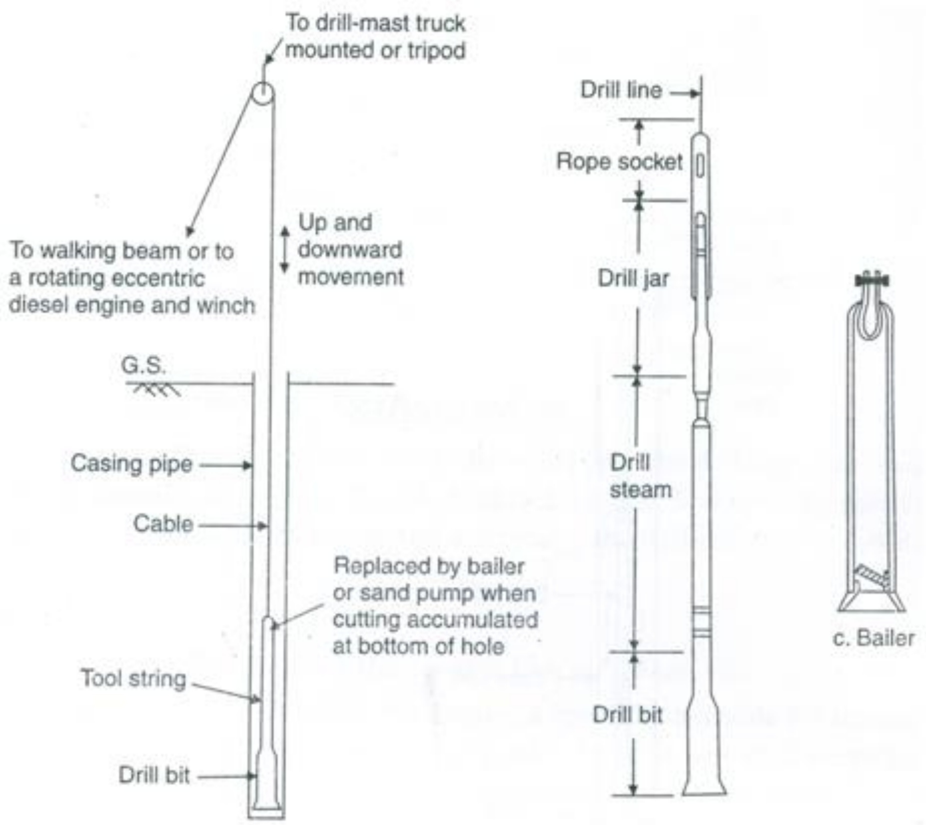

Fig. 12.7. Percussion drilling setup. (Source: Raghunath, 2007)

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. 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. 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. 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 (Fig. 12.7).

Drill cuttings are removed from the well by a bailer or sand bucket (Fig. 12.7). 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 (Todd, 1980). It is least effective in unconsolidated sand and gravel formations, especially quicksand, because the loose material slumps and caves around the drill bit.

Some of the advantages of the percussion drilling method are: (a) It is highly versatile in its ability to drill satisfactorily over a wide range of geologic conditions; (b) minimum water is required for drilling, a matter of concern in arid and semi-arid regions; (c) reasonably accurate sampling and logging of the formation material can be readily achieved; (d) the simplicity of design, ruggedness, and easy maintenance and repair of the rigs and tools are important advantages in isolated areas; and (e) rough checks on the water quality and yield from each water-bearing stratum can be made as drilling progresses. On the other hand, major drawbacks of the percussion drilling method are: (a) Slower drilling rate, (b) limitation of the drilling depth, (c) necessity of driving casing coincidentally with drilling in unconsolidated geologic formations, and (d) difficulty in pulling casing from deep boreholes.

12.6 Rotary Drilling

Rotary drilling method is a rapid method for drilling in unconsolidated formations. It consists of a rotating drill bit for cutting the borehole with a continuously circulated drilling fluid (usually a mixture of water and bentonite). The drilling fluid is forced through the hollow drill pipe on to the drill bit by a mud pump for removing the materials loosened by the drill bit (i.e., cuttings). 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 recirculated again (Fig. 12.8). The mud forms a clay lining on the wall of the borehole, which provides an adequate support for the wall of the hole, and hence casing is not normally required during drilling. The rotary drilling rig consists of a mast (derrick), a hoist, a power-operated revolving table that rotates the drill stem and bit, a pump for drilling mud, and an engine.

Deep wells up to 45 cm in diameter, and even larger with a reamer, can be constructed by the rotary drilling method (Todd, 1980). Drill bits for rotary drilling are available in different forms and commonly used designs are: (a) fishtail drill bit, (b) cone-type rock drill bit, and (c) carbide button drill bit as shown in Fig. 12.9.

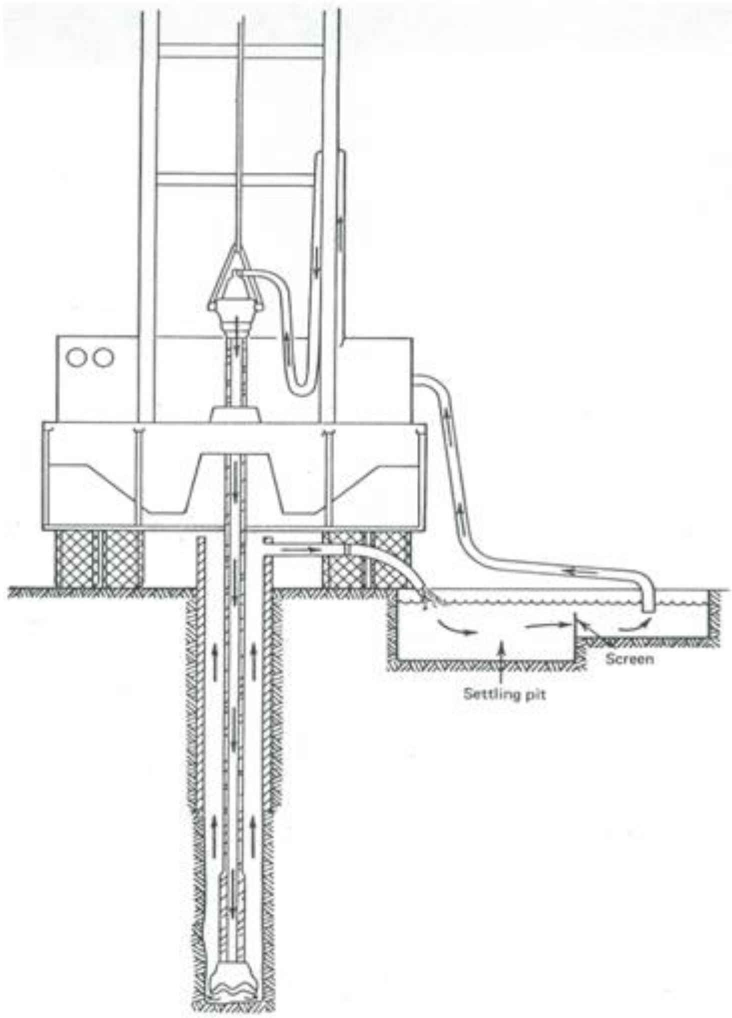

Fig. 12.8. Drilling mud circulation system for the rotary method. (Source: Todd, 1980)

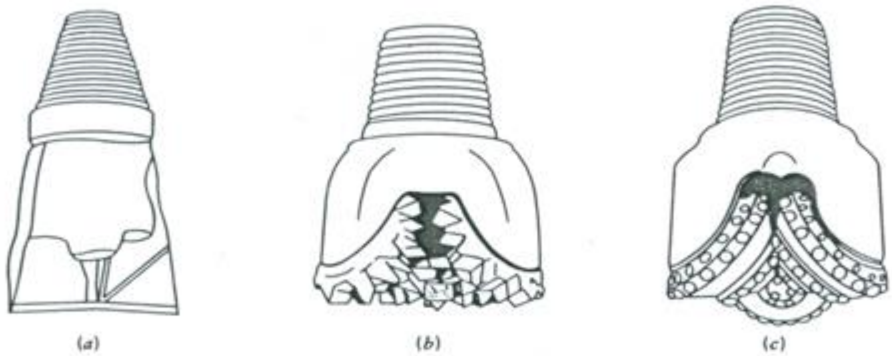

Fig. 12.9. Common types of rotary drill bits: (a) Fishtail drill bit, (b) Cone-type rock drill bit, (c) Carbide button drill bit. (Source: Todd, 1980)

The speed of rotation of drill bit in the borehole is 30 to 60 rpm. Drilling mud is essentially bentonite clay and the density of the mud fluid varies from 1.02 to 1.14 g/cm^3. The upward velocity of flow in the borehole is 0.7 to 1 m/s (Raghunath, 2007). Initially, rotary drilling was employed for drilling oil wells and its application to water-well drilling has gradually increased over the years. The main advantages of the rotary drilling method are: (a) fast drilling rate, (b) no requirement of casing during drilling, and (c) the convenience for electric logging. There are also some disadvantages of this drilling method, which are: (a) high equipment cost, (b) more complex operation, (c) necessity to remove mud cake (clay lining) during well development, and (d) the problem of lost circulation in highly permeable or cavernous geologic formations.

12.6.1 Air Rotary Method

Rotary drilling can also be done using compressed air instead of drilling mud. This technique is rapid and convenient for small-diameter holes in consolidated geologic formations (e.g., fractured rocks) where a clay lining is not required to support the walls against caving. Large-diameter holes can be drilled by employing foams and other air additives (Todd, 1980). It can be used for drilling wells to the depth of more than 150 m under favorable conditions. Air rotary drilling is used in fractured/fissured rocks and is especially suitable for limestones. A striking feature of the air rotary drilling is its ability to drill consolidated geologic formations with little or no water.

12.6.2 Reverse-Circulation Rotary Method

The reverse-circulation rotary method is a modified form of the standard rotary method of drilling. In this method, the direction of water flow is reversed, i.e., from the annular space between the drill pipe and the wall of the hole through the drill bit into the hollow drill pipe upwards and discharged by a large-capacity pump into a large settling pit where cuttings settle out. The clear water returns to the borehole by gravity flow (Fig. 18.4). Relatively high velocity of water in the drill pipe (usually >2 m/s) enables the cuttings to be carried to the ground surface without the use of clay or other additives; the use of additives will increase viscosity which is not desirable for this method.

12.7 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). Reduced speed is required for drilling in harder and more abrasive rocks. In case of caving formations or incidence of large quantities of water, this method is not suitable. In this situation, the conventional rotary drilling with mud as a drilling fluid works satisfactorily (Todd, 1980).

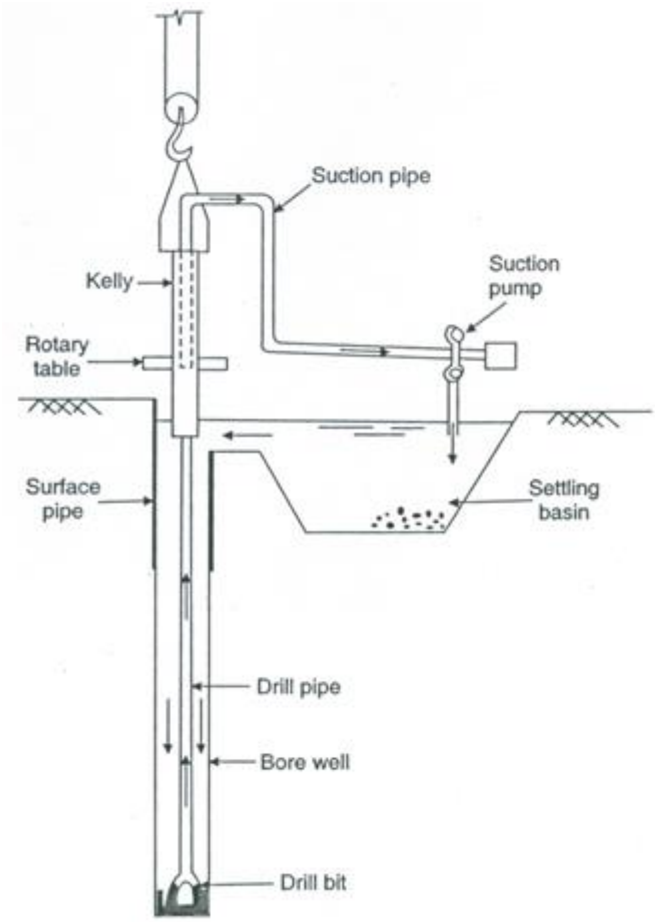

Fig. 12.10 Hydraulic rotary drilling with reverse circulation. (Source: Raghunath, 2007)

In this system, drilling is done without a casing and hydrostatic pressure is used to support the walls of a borehole during drilling. Water level in the borehole is maintained at about 2 m above natural level or at ground level. The settling pit is about three times the volume of the material to be removed from the borehole. The diameter of the borehole is large compared to the drill pipe so that the velocity of the descending water in the annular space is low (≤ 30 cm/s), and the drill bit and drill pipe are rotated at speeds ranging from 10 to 40 rpm (Raghunath, 2007). The diameter of drill bits varies from 0.4 to 1.8 m. The reverse-circulation rotary rigs generally can drill to depths of 125 m; though suitable modifications with air-lift pumping can substantially increase this depth limit (Todd, 1980). 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 minimum borehole diameter should be about 40 cm in order to avoid the erosion of the sides of the borehole (Todd, 1980), thereby restricting the downward velocity of the water in the borehole. The main disadvantage of this method is that it requires a large quantity of water to be readily available.