SESSION 18
WELL DRILLING I

Materials were prepared by House of Water and Environment (HWE)

Lecturer

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1. Introduction to Drilling Methods

The choice of the most appropriate drilling method for any specific situation will depend upon many factors. Some of the more important considerations are:

- Lithology to be drilled through
- Purpose of the borehole
- Availability of drilling rigs
- Availability of funds
- Need for collection of accurate lithology samples
- Local regulations and bye-laws (some of which require special permission to introduce "contaminants" to an aquifer)
- Site restrictions, e.g. access, water supply.

1. Introduction to Drilling Methods

The three main problems to be overcome in the drilling of a hole are:

- The loosing of material in the base of the hole
- Removal of loosened material from the hole
- Maintaining a 'stable' hole behind the cutting tool

Each drilling method must either provide a means of solving each of these problems, or else should not be used in situations where the problem is likely to exist. The simplest methods, for example, do not provide a means for ensuring a stable hole, and so should only be used where the drilled hole will be self-supporting.

2. Augering

The use of auger methods is limited to unconsolidated strata that do not have boulders or cobbles. These methods are not widely used in water-well construction; however, they are widely used in the drilling of test holes for geotechnical and foundation investigations. Auger methods are being used increasingly in the installation of monitoring wells where subsurface conditions are favorable.

There are two fundamental types of auger drills: hollow-stem and solid stem. The use of a hollow-stem auger enables the collection of undisturbed samples (for example, drive samples, such as by split spoon or Shelby tube). An example of a hollow-stem auger that has a center boring bit and rods is shown in **Figure 2.1**.

2. Augering

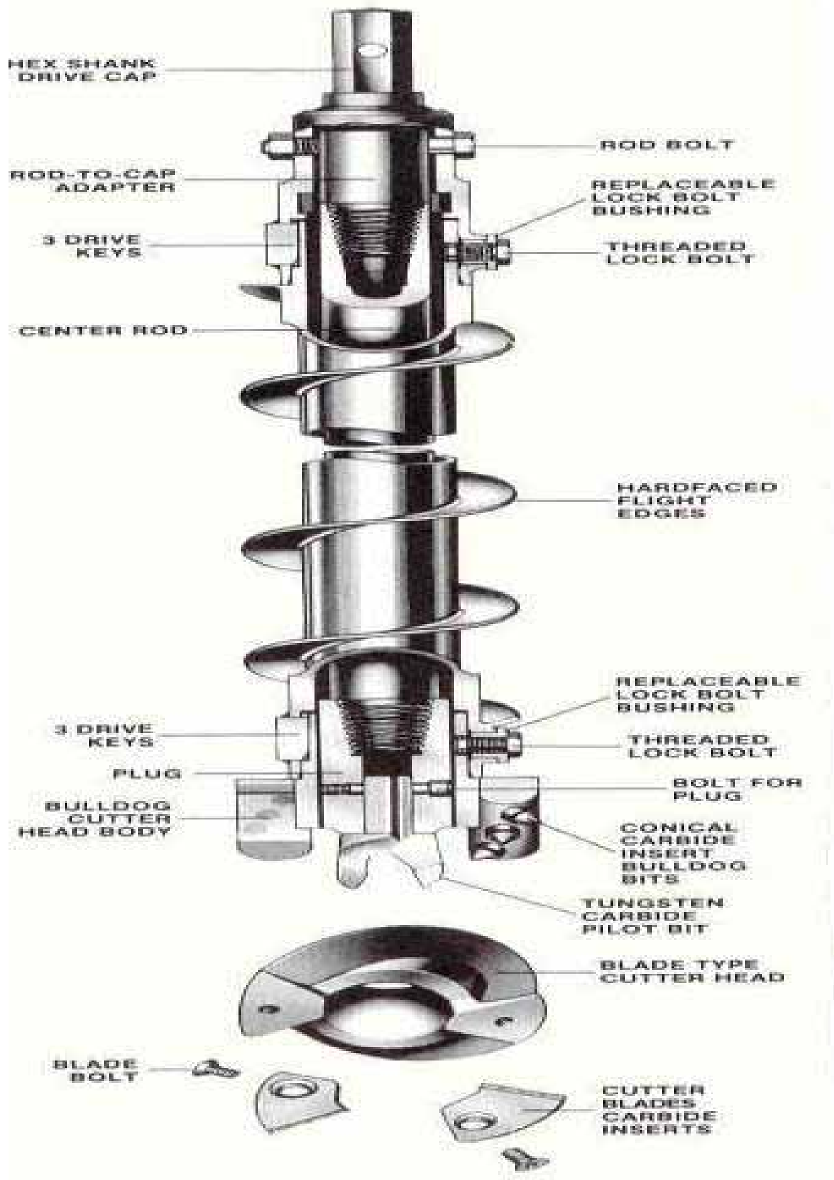


Figure 2.1: The lowest fight in a hollow-stem auger drill string is equipped with a cutter head and a pilot bit

2. Augering

Caving frequently is a problem in auger methods, but usually can be minimized by keeping the borehole full of water. Also, the pulling of the auger flights may create suction, which is a problem that may cause the collapse of the borehole. Therefore, the construction of monitoring wells by using augers usually is done inside the hollow stem as the augers pulled.

2.1 By Hand Auger

Mostly for soil surveys and the like, to be used where the soil or unconsolidated material has enough cohesion to prevent collapse of the hole. Consequently used shallow work- lack of power available in hand operation also restrict the depth range and diameters that can be drilled. Depths up to **10 m** and diameters to **20 cm** are possible. In groundwater, method mainly used for installation of piezometers.

2. Augering

2.2 By Power Auger

With engine power, the depths and diameters achievable by augering are increased. Power augers vary in size from mechanized hand augers, through use of small engines and rigs mounted on the back of pick-ups or tractors, to very large drilling rigs. The largest machines are used to construct bored piles for building foundation in extensive clay beds, but can be used for wells.

2. Augering

2.3 Augering Equipment for Drilling Wells

➢The equipment consists of an auger with connecting bore pipes. Holes with a small diameter can be made by augering sets which are operated by hand, but large diameter wells may be drilled with augering equipment which is truck mounted and driven by an engine (see **Figure 2.2**).

➢The hole is made by turning the auger around and lifting it to land surface disposing it of all the collected rock material.

➢The small diameter (0.05-0.10 m diameter) hand operated augers may reach maximum depths up to about 15 m below surface. At larger depths the friction on the auger usually becomes excessive. Also, the bore pipes must be broken each time the collected material is removed from the auger.

2. Augering

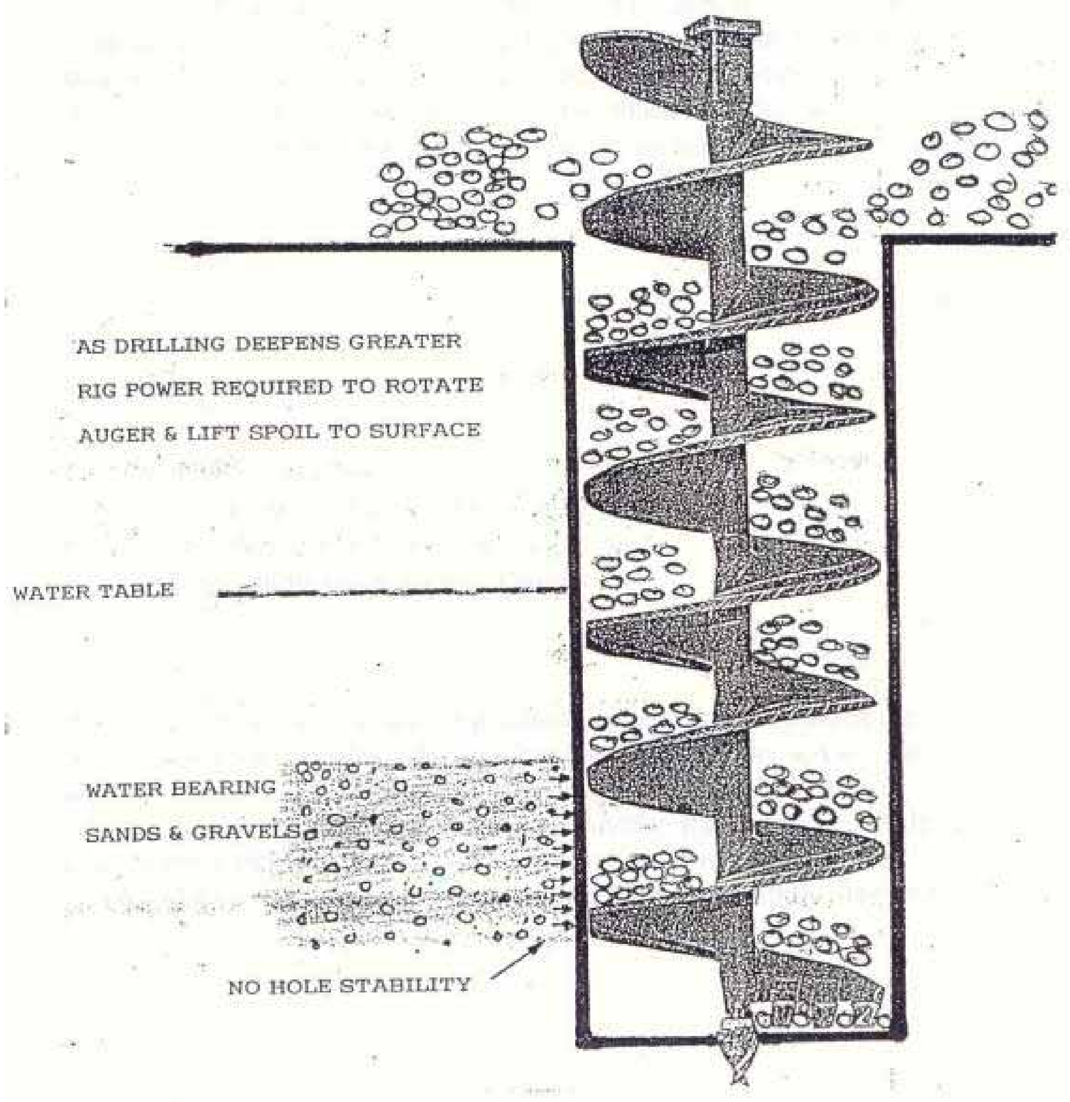


Figure 2.2: Auger drilling

2. Augering

2.4 Advantages

- It has good sample collection;
- It is rapid;
- It is usually cheap;

2.5 Disadvantages

- Limited depth and diameter range;
- Lithology MUST be loose (as little ability to loosen material at the base of the hole);
- The hole must be stable (i.e. remain open by itself), this usually means there has to be a fairly high proportion of clay, silt or loam in the material- all of which tend to make a poor aquifer.

3. Jetting Techniques

- Making wells with the jetting techniques is vary fast
- Simple jetting equipment may consist of a small diameter plastic pipe with a nozzle at the end. At the other side the pipe is connected to a pump. By pumping water through the nozzle a hole can be made in soft sandy formations. To support the hole, casing has to be installed right after the hole is completed to final depth. The casing is lowered simultaneously with the jetting pipe. Sufficient water pressure should be maintained in the well to prevent the entry of loose material (see **Figure 3.1**).

3. Jetting Techniques

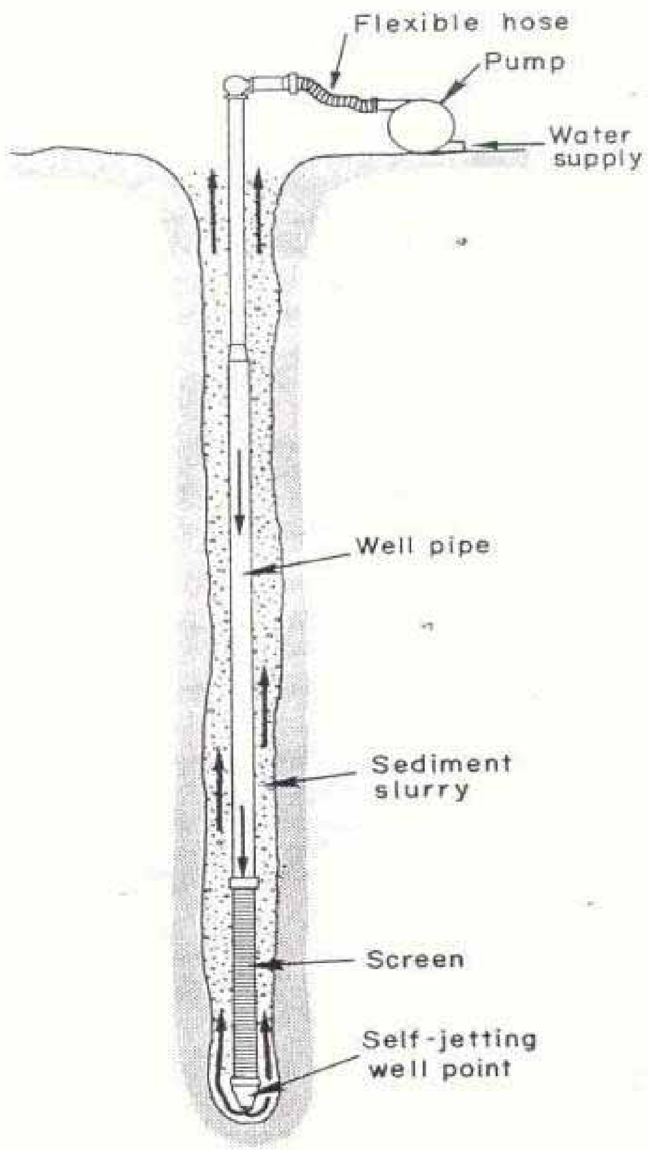


Figure 3.1: Jetting drilling method. Arrows indicate the direction of fluid flow

4. Driven Wells

➢ Driven wells can be installed only in soft formations that are relatively free, cobbles, or boulders. **Well points** commonly are driven to depths of 15 m or more in favorable conditions (see **Figure 4.1**).

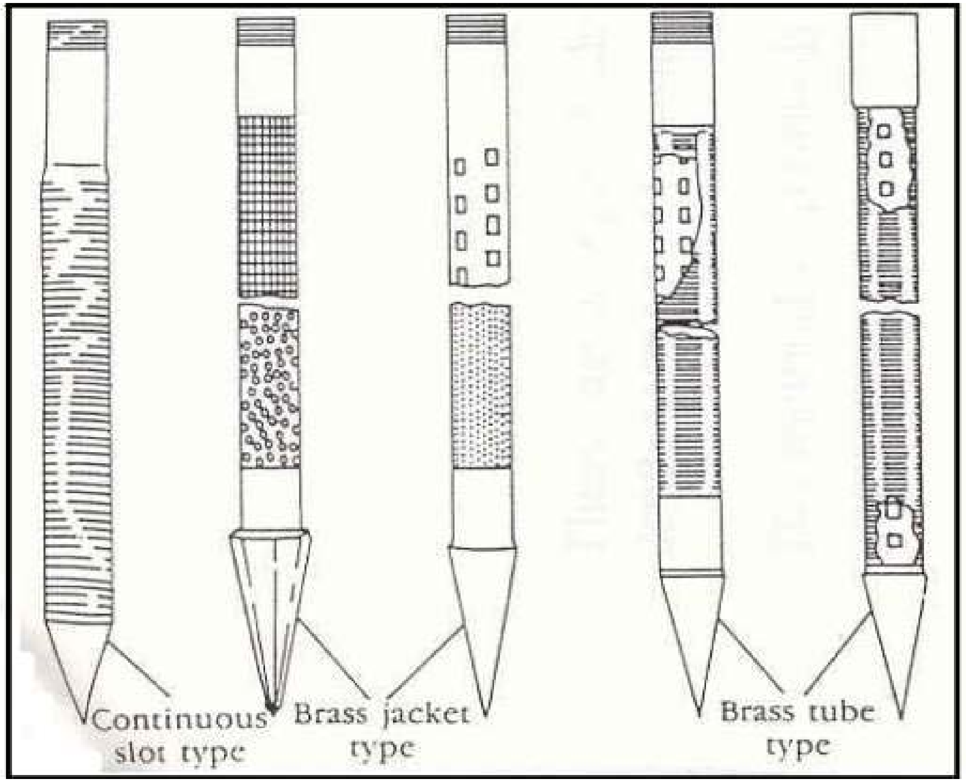


Figure 4.1: Various well point designs

4. Driven Wells

➢ Driven wells usually have a small diameter and are pumped by suction lift. However, the static water level needs to be shallow; for example, within about 3 to 5 m of the ground surface. If a 5-cm or larger pipe is used, certain types of pumps or cylinder pumps can be installed to lift water from greater depths (see **Figure 4.2**).

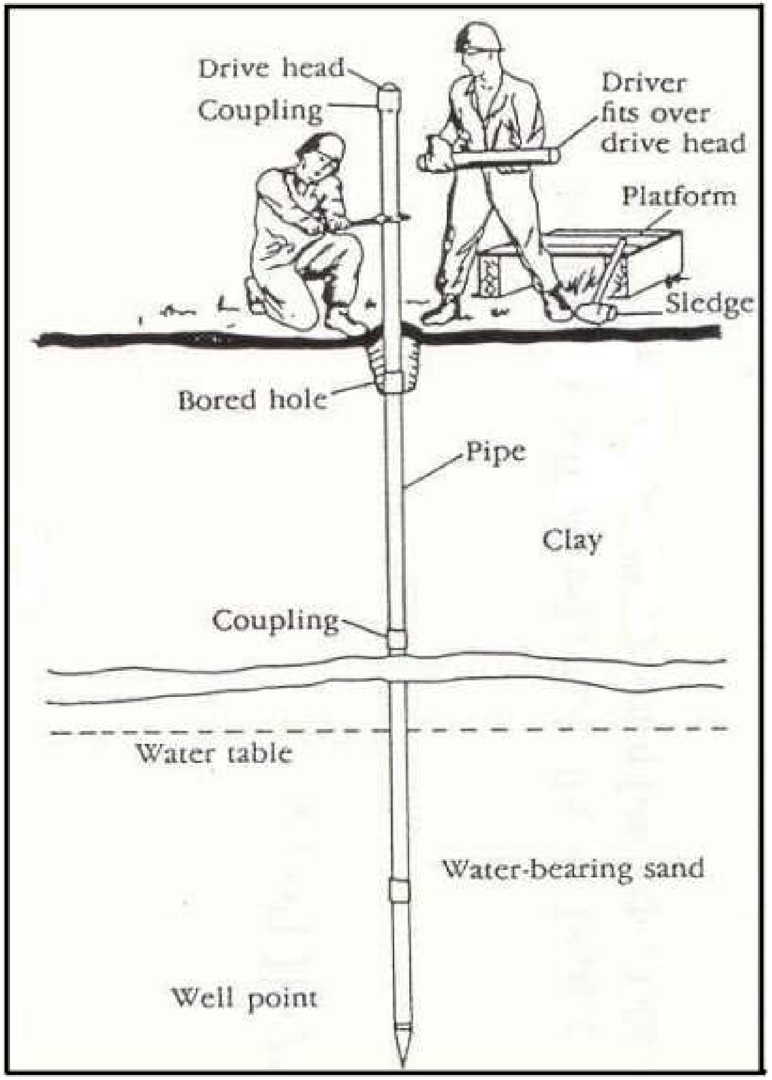


Figure 4.2: Driving a well point

5. Cable Tool Percussion Techniques

- Cable tool percussion drilling is one of the oldest (4000 years), but still one of the most popular drilling techniques (see **Figure 5.1**).

Figure 5.1: Cable too machine also are called percussion or "spudder" rigs

5. Cable Tool Percussion Techniques

5.1 Basics

➢The rock material is loosened and crushed by **drilling bit**. This is done by the up-and downward movement of the bet with a stroke that can be varied within the range of 0.15 to 0.9 m, a short stroke can be applied in unconsolidated material and a longer stroke (more force) in a hard rock environment (see **Figure 5.2** and **5.3**);

5. Cable Tool Percussion Techniques

Figure 5.2: Roller or cone-type bits are preferred when drilling consolidated rock.

5. Cable Tool Percussion Techniques

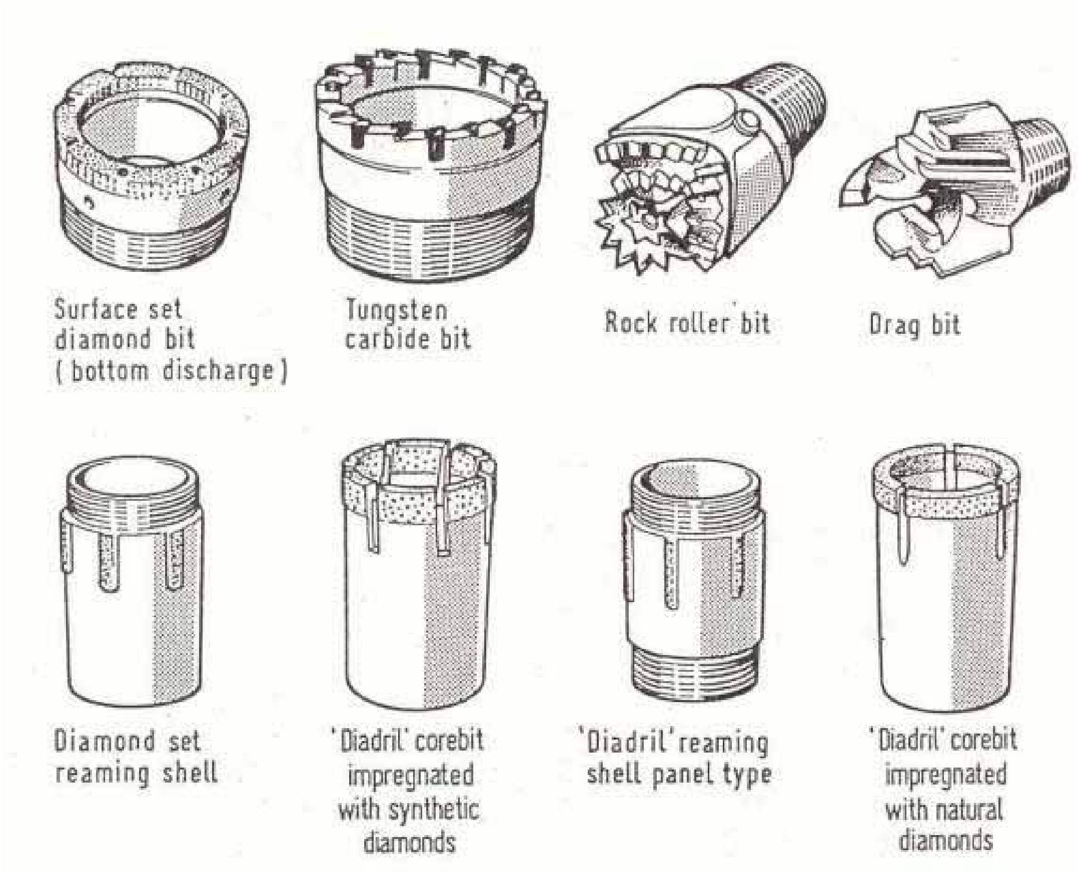


Figure 5.3: Different types of bits

5. Cable Tool Percussion Techniques

- Since the steel cable is twisted, the bit slowly rotates thereby exerting a force which is evenly distributed on the bottom of the hole. After the bit has progressed some **0.5 to 1.5 m** the **bailer** is lowered into the hole to remove the crushed rock material. When the bit is working above the groundwater table, water is usually added to the well to form a slurry or sludge. The reciprocating action of the tool mixes the crushed rock or loosened particles with the water. The resultant slurry is removed by “bailing” to prevent the accumulation of too much sludge so that too dense sludge will slow drilling;

5. Cable Tool Percussion Techniques

- **In consolidated rocks** cable percussion drilling can proceed without the installation of casing. Only a small section of 'surface casing" may be installed to prevent the collapse of soil and weathered rock material. **In unconsolidated rock**, the well usually has to be supported using temporary casing. The casing will move down simultaneously with the bit or the bailer;

- Excess water pressure has to be maintained within the casing to prevent the entry of sand and other fine materials at its bottom end. After the well has been completed to final depth permanent casing and screen, and a gravel pack may be installed within the temporary casing where after this assembly can be pulled back.

5. Cable Tool Percussion Techniques

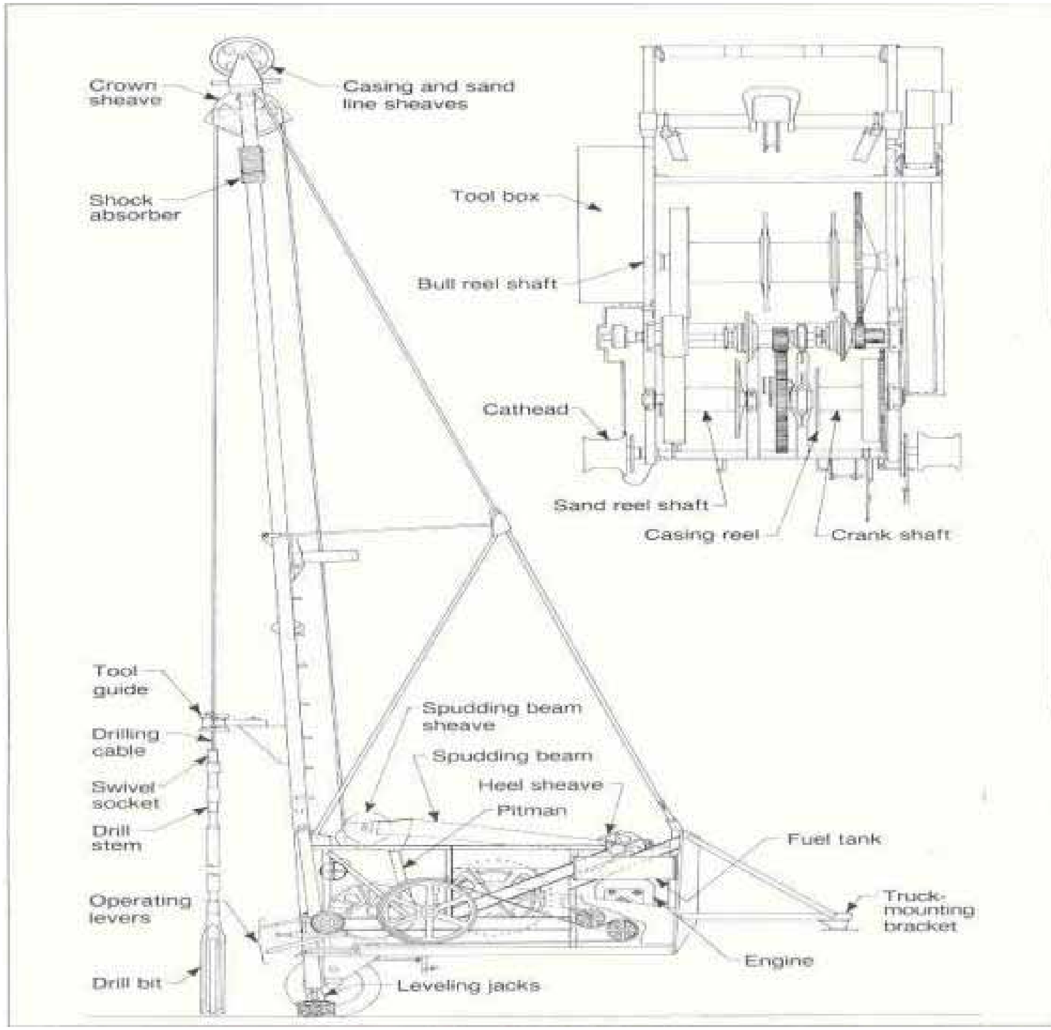
5.2 Terminology

- The up and down drilling is passed on to the drilling tools and the drill line (the wire cable that carries and rotates the drilling tools) by the spudding beam (see **Figure 4.5**).

- The **spudding beam** is pivoted at one end, the other end which carries a sheave for the drill line, is moved up and down by a single or double pitman pin on the crank gear varies the vertical stroke and the speed (see **Figure 5.5**).

5. Cable Tool Percussion Techniques

Figure 5.4: Engineering drawing shows how the drill line is reeved in a typical cable tool rig. The spudding action is imparted to the drill line by the vertical motion of the spudding beam. The shock absorber mounted beneath the crown block helps control the impact of the bit on the rock.



5. Cable Tool Percussion Techniques

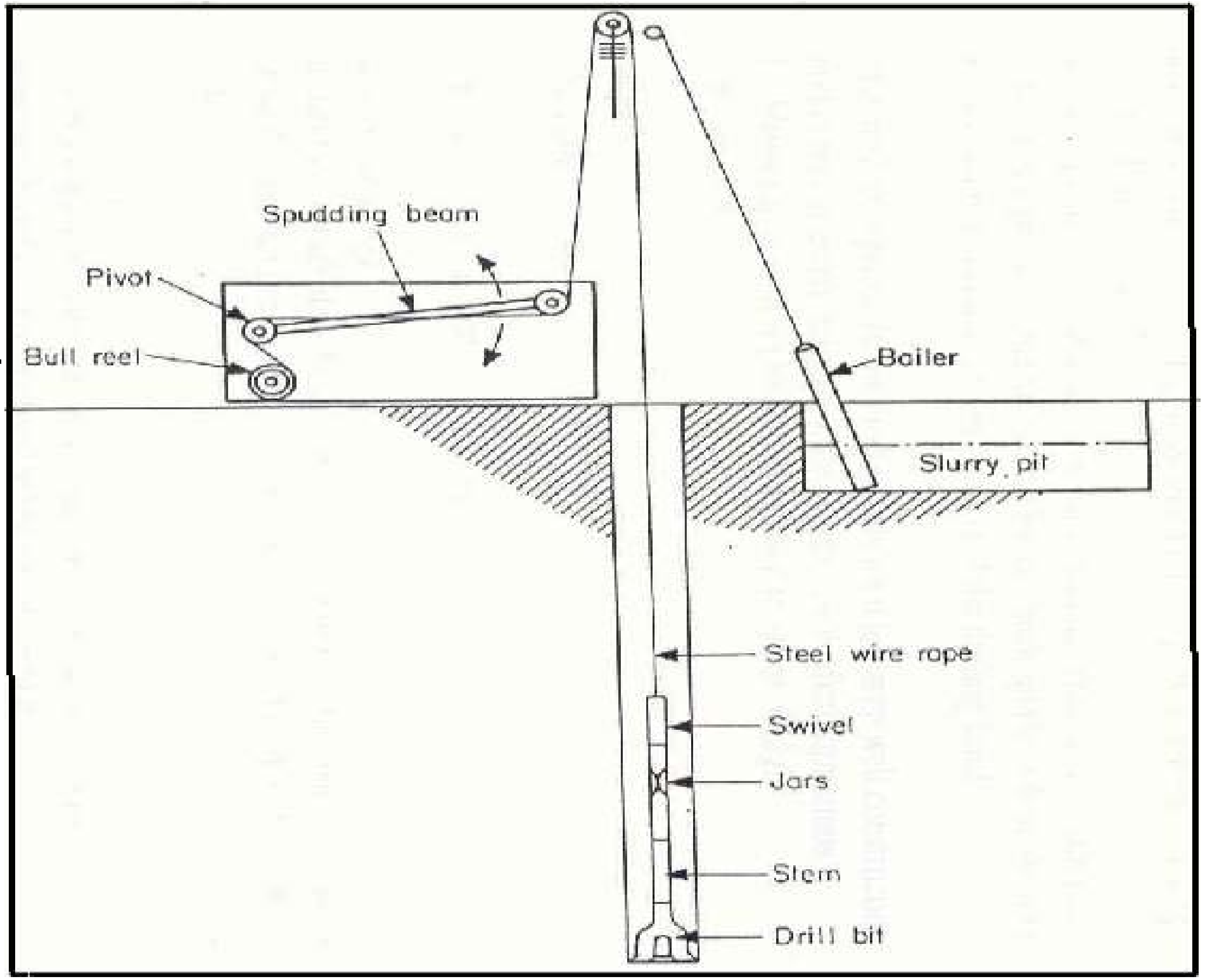


Figure 5.5: Cable tool or percussion drilling rig

5. Cable Tool Percussion Techniques

➢The **drilling string** consists of :

✓**Rope or swivel socket**: connects the tool string to the drill cable and provides weight to the upward energy to the jars when their use becomes necessary; the socket transmits the rotation of the cable to the tool string and bit so that new rock is cut on each downstroke, therefore assuring at a round, straight hole will be cut.

✓**Drilling jars**: consist of a pair of linked steel bars used to shake the bit loose when stuck.

✓**Drill stem**: provides weigh and its length helps to maintain a straight hole.

✓**Drill bit**.

5. Cable Tool Percussion Techniques

➢The **bailers** are used to remove the mud or rock slurry. The bailer consists of a pipe with check valve at the bottom. Another type of bailer is called the sand pump or suction bailer (see **Figure 5.6**).

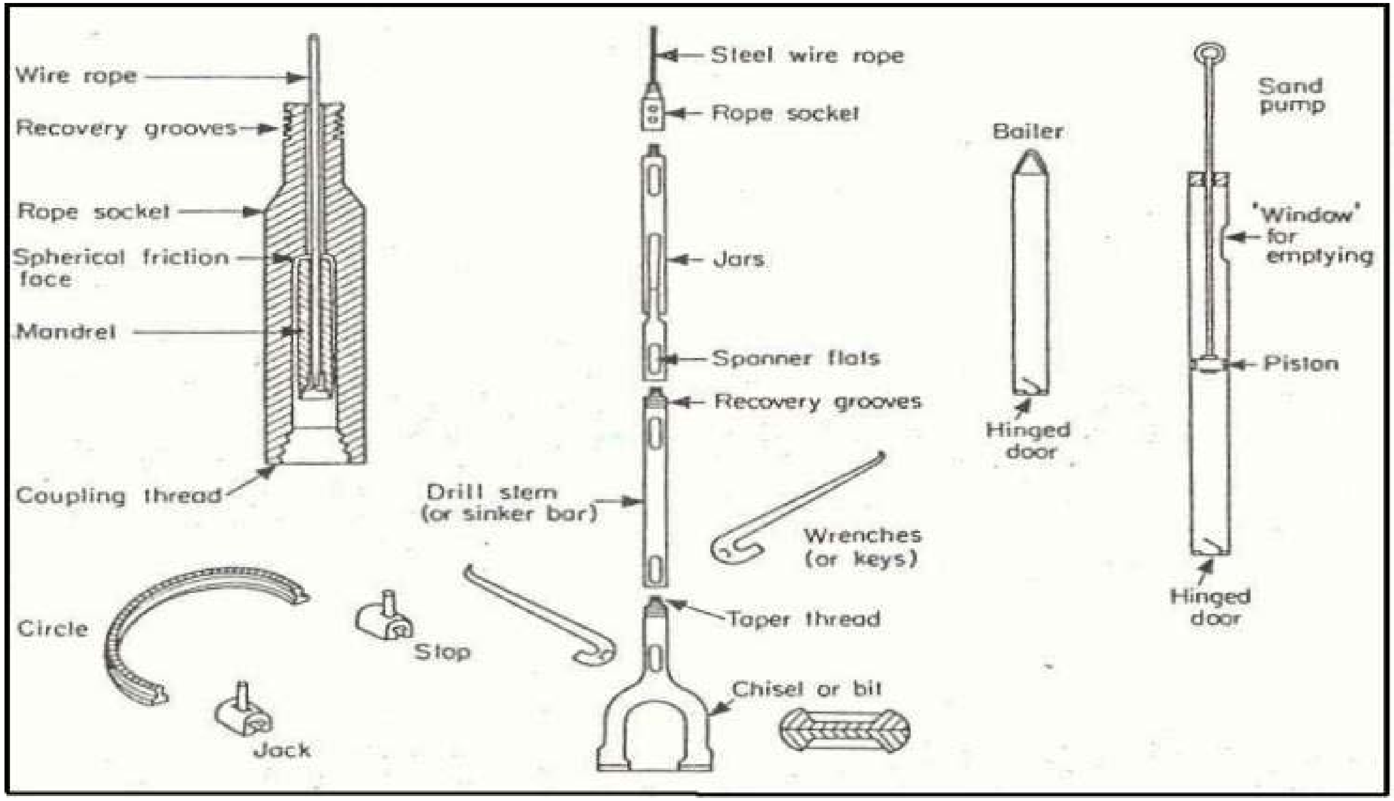


Figure 5.6: Cable tool or percussion drilling tools

5. Cable Tool Percussion Techniques

5.3 Advantages

- Good Samples or core can be obtained if the driller does not drill too far ahead of the casing.
- Good well development is accomplished by the use of surge blocks.
- Versatile depth and diameter can be achieved.
- Water-bearing formations are noted easily.
- The method is usable in crystalline rocks and hard formations, boulders, and gravelas.

5. Cable Tool Percussion Techniques

5.4 Disadvantages

- The method is slow and, therefore, may be costly for some subsurface conditions, especially in clays or clayey units.
- Frequent equipment failures can occur in older cable-tool rigs.
- Temporary casing may get stuck.
- Casing for deep holes may be difficult.
- Drilling usually begins with a larger borehole diameter and casing size than specified to enable installation of temporary surface casing to prevent caving.
- Cutting samples often are reduced to a slurry because of the repeated crushing action of the bit.

6. Rotary Drilling

- Rotary drilling consists of advancing the borehole by means of a rotating bit and removing the cuttings by circulation of a drilling fluid as the bit penetrates.

- Types :

  - ✓ Direct Rotary (or mud rotary)
  - ✓ Reverse Rotary
  - ✓ Air Rotary

6. Rotary Drilling

6.1 Direct Rotary (Mud Rotary)

6.1.1 Basics

- **Mud rotary** is perhaps the most developed drilling technique (see **Figure 6.1**). Compared to cable tool percussion drilling it is a fast technique. The equipment is usually truck mounted whereby **the mast**, **the engine and the mud pump** are often secured on the back of the vehicle. At the bottom end of the **drill pipe**, **drill collars** and the bit can be seen. Drill collars are extra heavy pipes fitted above the bit to provide essential weight and assist straight drilling by their stabilizing influence, and they are of large diameters so that a small annulus results causing high fluid velocity which rapidly carries away the cuttings from the bit vicinity.

6. Rotary Drilling

Roller bits for consolidated rock and “fish tail” bits for softer material are in use. The upper drill pipe is called the **Kelly** which can be rotated by a rotating cable attached to the drill head. This allows free vertical movements and thus permits the Kelly either to feed off down the hole as drilling proceeds or to be withdrawn.

At its top end the Kelly hangs on a swivel which is usually attached to a cable. The swivel has an entry for drilling fluid passing up from the mud-pump to the Kelly and it controls the fluid from static swivel to the rotating Kelly (see **Figure 6.2**).

6. Rotary Drilling

- In straight flush mud rotary drilling a well is made in the following way. The mud pump sucks the drilling fluid from the mud pit diverts it through the drill pipe to the bottom of the hole. The drilling fluid is usually a mixture of water and bentonite: the weight and the viscosity of the fluid should be kept carefully within certain limits for successful drilling operation. The rotating action of the bit crushes the rock and the fluid applied to the bottom of the well removes loose rock material using the space between the drill pipe and the side of the hole.

  When the material emerges at land surface it is led to a sitting pit. The rock material in the fluid is deposited on the bottom of the pit. During mud rotary drilling (steel) casing to support the sides of the well is not used, even in loose unconsolidated rock. The drilling fluid exerts sufficient pressure on the side of the well to prevent it from caving (see **Figure 6.3**).

6. Rotary Drilling

- In consolidated rock, the presence of large open fractures or solution openings like caves may result in the loss of drilling fluid. This may reduce fluid pressure causing the less solid parts of the hole to cave in. Despite these **pitfalls** mud rotary drilling is widely applied in hard rock areas because wells of considerable depth may be drilled at a reasonably fast rate.

6. Rotary Drilling

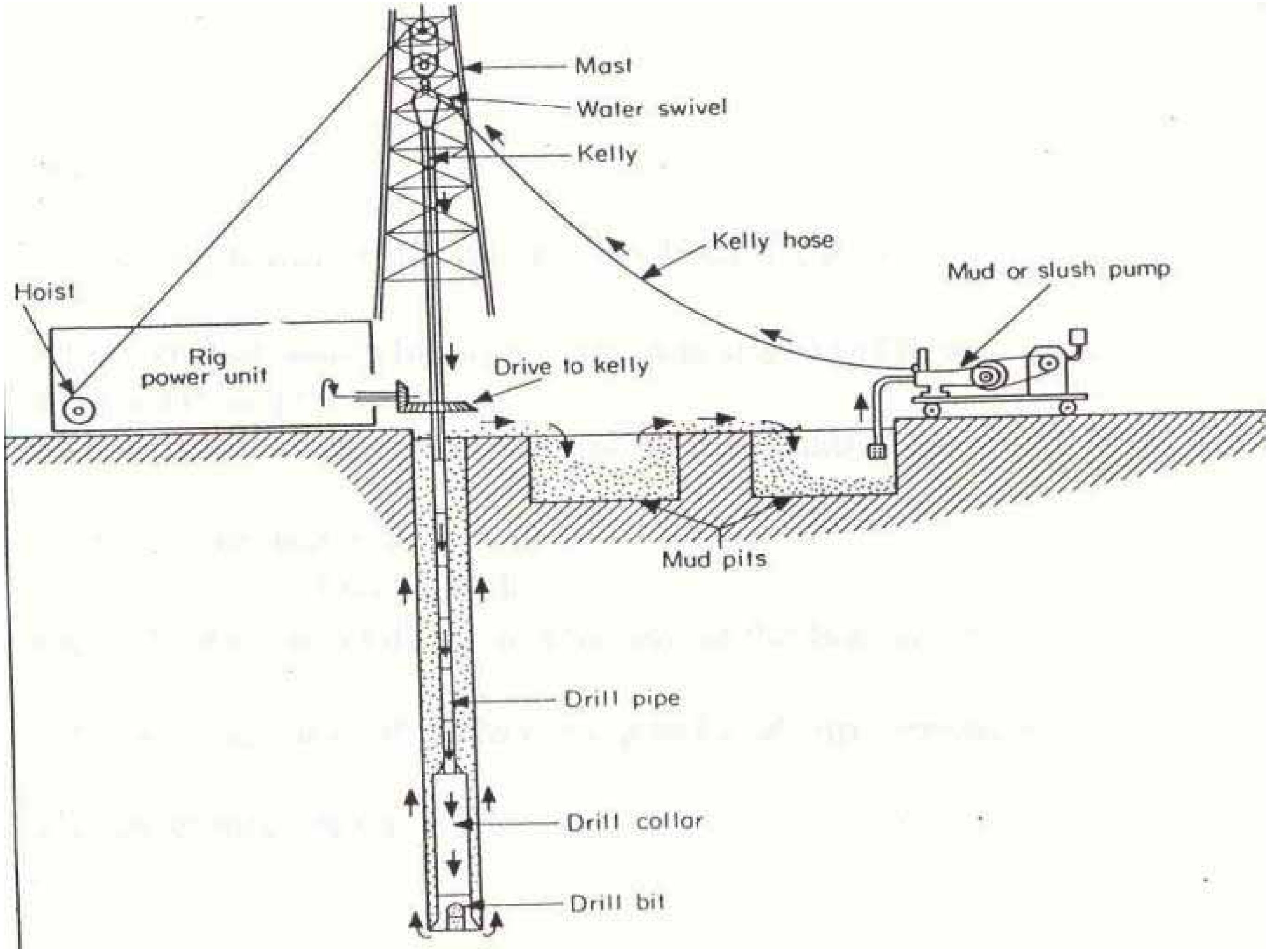


Figure 6.1: Normal direct circulation rotary drill

6. Rotary Drilling

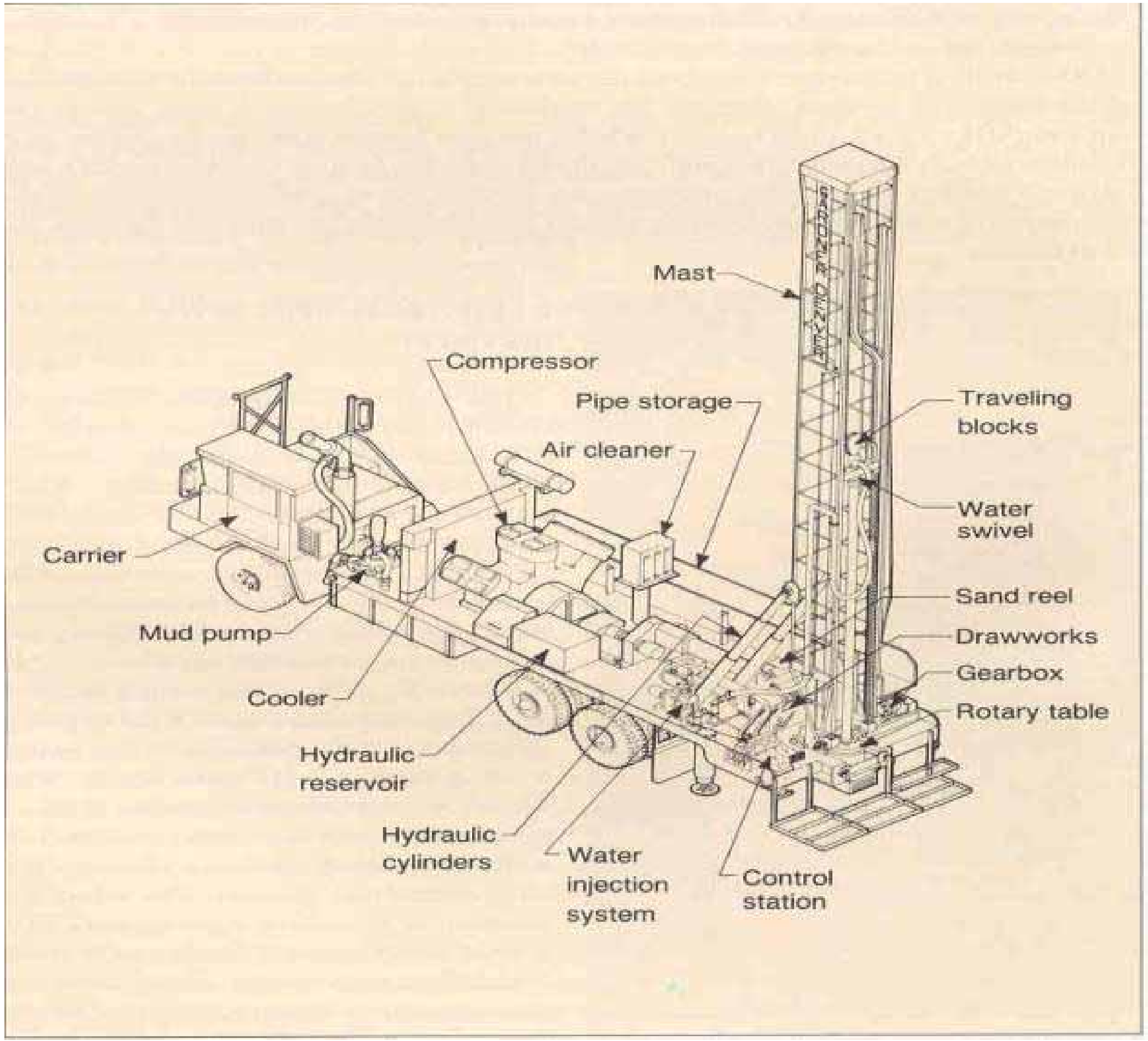


Figure 6.2: Schematic diagram of a direct rotary rig illustrates the important operational components of this truck-mounted drilling machine. This machine, operating with either an air-based or water-based drilling fluid, can drill more rabidly than a cable tool rig.

6. Rotary Drilling

Figure 6.3: Drilling fluid from the borehole flows into the larger pit where the cuttings settle out. The fluid then flows into the second pit through a constricted opening. The mud pump on the rig withdraws drilling fluid from this pit to inject down the drill rods to the bit. This Italian driller has lined the drilling fluid pits with polyethylene film to reduce fluid loss into the ground. Note the homemade hole cleaner or scratcher the driller uses to keep the borehole open during drilling.

6. Rotary Drilling

6.1.2 Advantages

- This is a rapid, relatively low-cost drilling method.
- Versatile depth and diameter capabilities; this method is applicable for shallow and deep wells in soft to medium-hard formations of either or larger water yields.
- The use of a drilling mud provides good control of formation stability. The drilling mud provides a good medium for geophysical logging.

6. Rotary Drilling

6.1.3 Disadvantages

- The collected samples are poor and more expertise is needed to interpret the cuttings. There is substantial potential for contamination of samples as mud flows upward between the borehole. Samples also are mashed by the rotating action of the drill bit.
- Mud or fluid enters the borehole and infiltrates into adjacent lithological units as a filter cake develops.
- Extensive development is needed to remove the resultant mud filter cake.
- The method is ineffective in boulder-rich formations, but can be used in alluvial gravels.

6. Rotary Drilling

6.2 Reverse Rotary

6.2.1 Basics

- In reverse-rotary drilling method, the fluid travels in reverse compared to the direct rotary-drilling method.
- The method needs a larger diameter drill stem and larger diameter openings at the bottom to enable cuttings to enter the pipe and be returned to the surface.
- The method needs minimal or no mud. This method uses the hydraulic head in the borehole to stabilize loose formations.
- Because of the larger diameter needed, the reverse-rotary method uses more equipment and, normally, has longer setup times than does conventional rotary drilling.
- This method also needs a larger water supply; however, drilling is rapid when setup is complete.

6. Rotary Drilling

- Water losses during drilling can increase suddenly, and, if the fluid level in the borehole drops below the ground surface, caving may result. Water loss can be decreased by adding clay to the drilling fluid; however, the addition of clay to the drilling fluid; however, the addition of clay normally is avoided when possible to prevent the clogging of the aquifer.
- Reverse-rotary drilling commonly is the least expensive method for drilling large diameter holes in soft, unconsolidated formations when geological conditions are favorable.
- The conditions that are favorable for the use of the reverse-rotary method include: sand, silt, and soft clay formations; the absence of hard clays or boulders; and a static water level that is three-meter or more below the ground surface. The conditions that limit the use of reverse-rotary drilling methods include: a static water level that is too high, the lack of a suitable water supply for adding water during drilling, a stiff clay or shale formation; and numerous cobbles or boulders (size limited by inside diameter of drill pipe)(see Figure 6.4).

6. Rotary Drilling

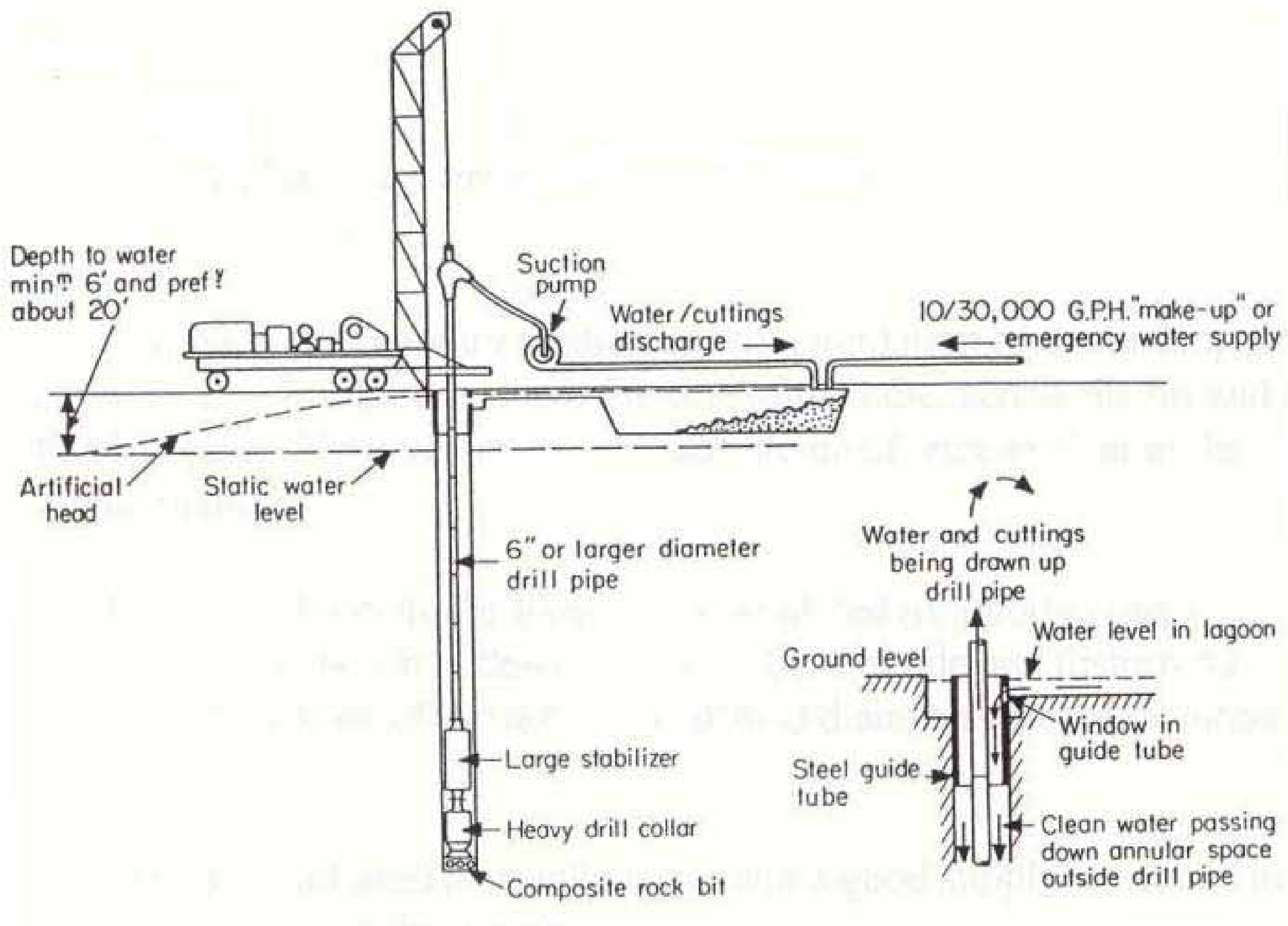


Figure 6.4: Reverse circulation rotary drill

6. Rotary Drilling

6.2.2 Advantages

- A smaller filter cake is formed on the wall of the borehole that is more cleaned out than the impervious mud cake common to conventional (direct) rotary drilling.

- Lost of circulation is virtually eliminated because the drilling cuttings are carried to the surface inside the drill pipe by formation water. In this way, it is almost guaranteed that the formation at the lost circulation zones is not damaged.

- Because the loss of circulation is nearly eliminated lithological description to the fractured zones can always be available.

6. Rotary Drilling

- Development of the well occurs normally through the drilling. Direct rotary with bentonite leaves any borehole with imminent need for development.
- The costs of drilling do not increase substantially as the borehole diameter is increased; hence' there is a favorable cost advantage when drilling large-diameter boreholes.
- The method easily penetrates coarse and permeable alluvium.
- There is good borehole stability in unconsolidated formations.
- A relatively clean borehole results.
- International experience show that this method is widely used for drilling large diameters, deep (>1000 m), high capacity wells in cavernous dolomites and limestones.

6. Rotary Drilling

6.2.3 Disadvantages

- Reverse-rotary drilling needs an independent and sometimes sustainable water supply; circulation losses can occur if a permeable zone is penetrated (see **Figure 6.5**).
- Consolidated or boulder-rich units cannot be drilled.
- Borehole caving may occur in impermeable units of shallow water-table conditions.
- The method is ineffective in boulder-rich formations, but can be used in alluvial gravels.

6. Rotary Drilling

Figure 6.5: The settling pit for a reverse rotary rig is considerably larger than for a direct rotary machine because fluid losses in the borehole are always much higher. The pit should contain at least three times the volume of the material to be removed during drilling.

6. Rotary Drilling

6.3 Air Rotary

6.3.1 Basics

➢An air-rotary drill uses compressed air as the drilling fluid rather than water and mud. The air is circulated down through the drill pipe and upward through the annular space. Air pumped at rapid velocities in the annulus carries the cuttings to the surface or into the rock crevices or pores (see **Figure 6.5**).

6.3.2 Advantages

➢Drill rig setup times are short.

➢This methods can be more cost-effective and rapid than mud rotary methods..

➢Relatively clean sample cuttings can be obtained.

6. Rotary Drilling

6.3.3 Disadvantages

- Surface casing is set to prevent near-surface air blowout.
- There is minimal control of borehole caving if unconsolidated sands and silts are drilled. This method may not be suitable in some unconsolidated formations.
- The depth capability may be limited in certain conditions.

6. Rotary Drilling

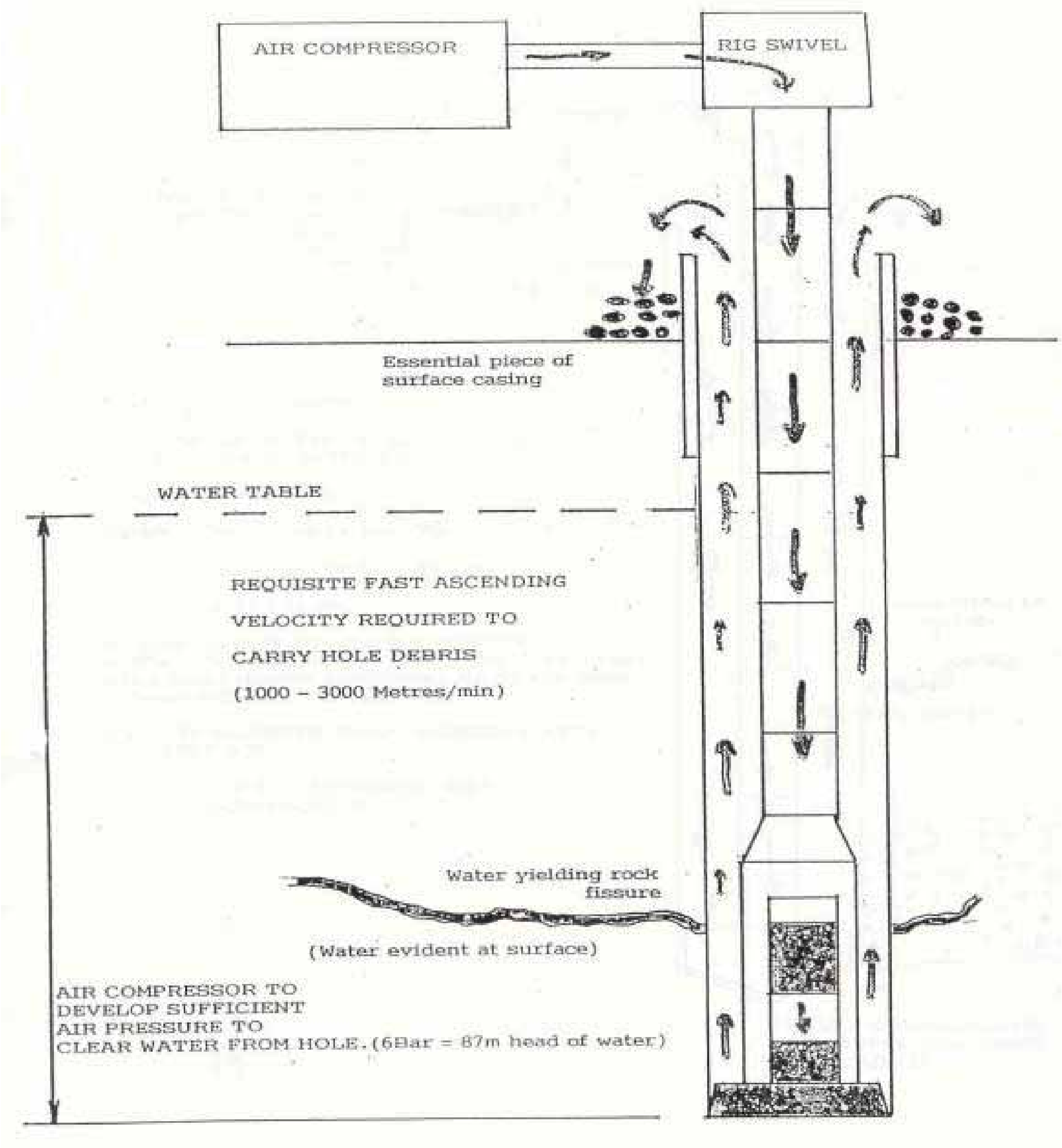


Figure 6.5: Air flush driling

SESSION 19
WELL DRILLING II

Materials were prepared by House of Water and Environment (HWE)

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Palestinian Water Authority

7. Pneumatic Air Rotary Percussion Drilling

- This method has been designed to drill into the hardest rock formations where cable tool percussion and mud rotary drilling are rather ineffective (see Figure 7.1).
- Although the general setup resembles the straight flush mud rotary method, but two significant differences can be observed:

- ✓ One is the enormous compressor which leads air at a large pressure through the system instead of drilling fluid.
- ✓ The other is the drilling bit which is able to rotate, but can also simulate a peneumatic "up and down" action.

- The rotating and pneumatic action of the bit makes it possible to crush the hardest rock. In unconsolidated rock the method tends to be less successful as the interruption of the flow of compressed air, each time a new drill pipe has to be added, tends to block the air nozzles in the bit and may cause caving of the hole.

7. Pneumatic Air Rotary Percussion Drilling

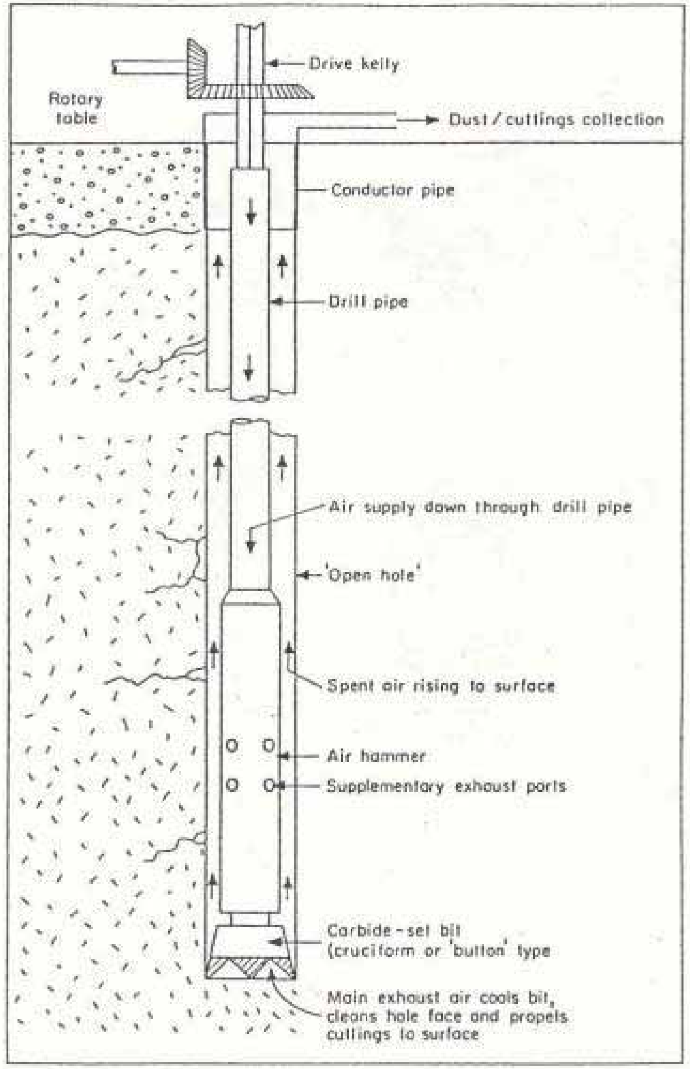


Figure 7.1: Down-the-hole hammer drill

8. Drilling Fluids

➢ ***The purpose of the drilling fluids are usually held to:***

✓ Remove all moveable solids and transport them to the surface as quickly as possible.

✓ Permit the maximum acquisition of reliable information on formations.

✓ Support and stabilized the hole.

✓ Seal borehole wall to reduce fluid loss and,

✓ Cool, clean and lubricate drill bit and the down the hole tools. In addition, the jetting out of the fluid may help to break up formation.

8. Drilling Fluids

- ***Important characteristics of the fluid are:***

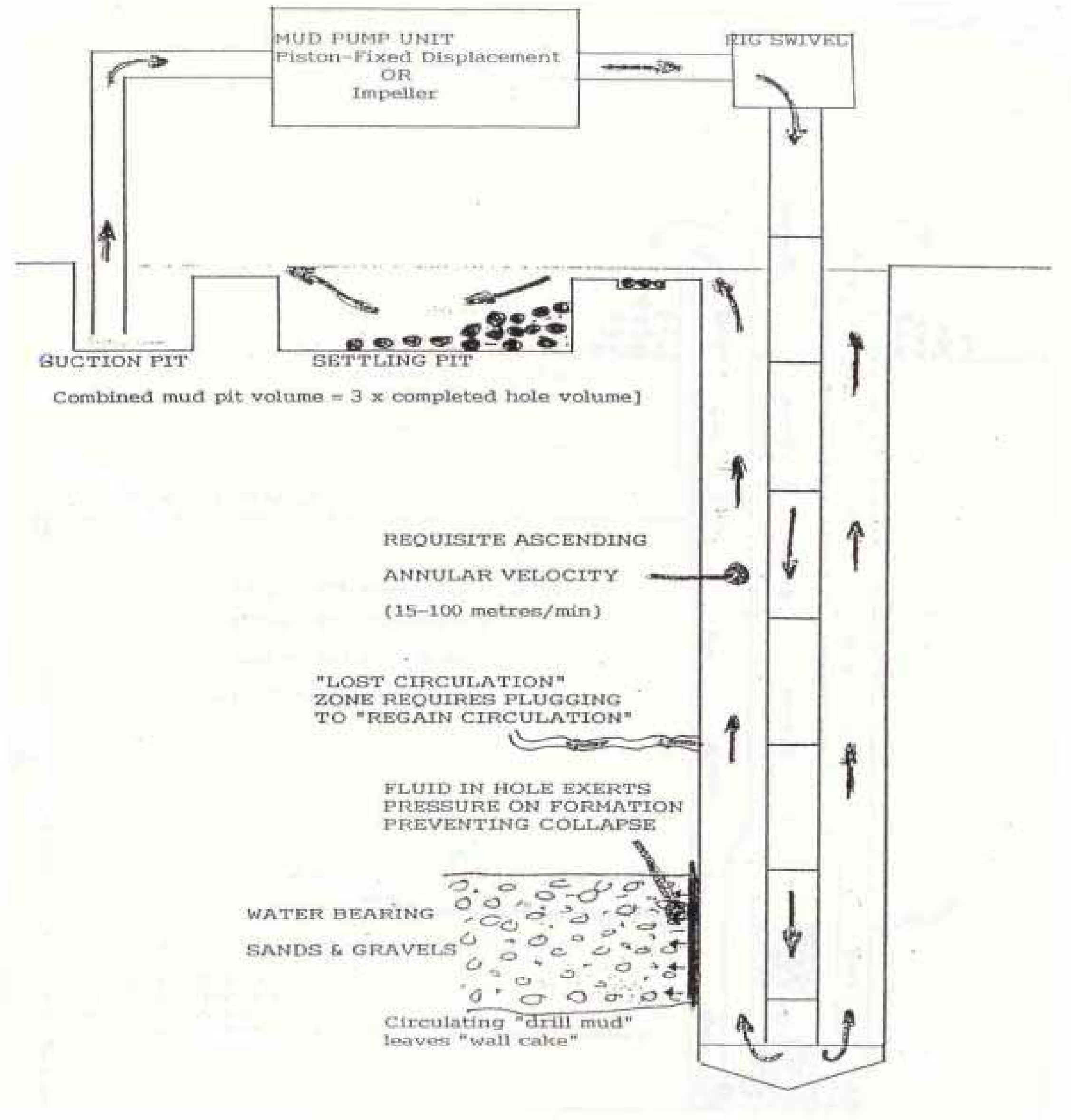
- ✓ Viscosity
- ✓ weigh

- ***Some commonly used are:***

- ✓ Bentonite muds (see **Figure 8.1**)
- ✓ Air
- ✓ Polymers
- ✓ Water
- ✓ Foam (see **Figure 8.2**)

8. Drilling Fluids

Figure 8.1: Mud circulati
drilling



8. Drilling Fluids

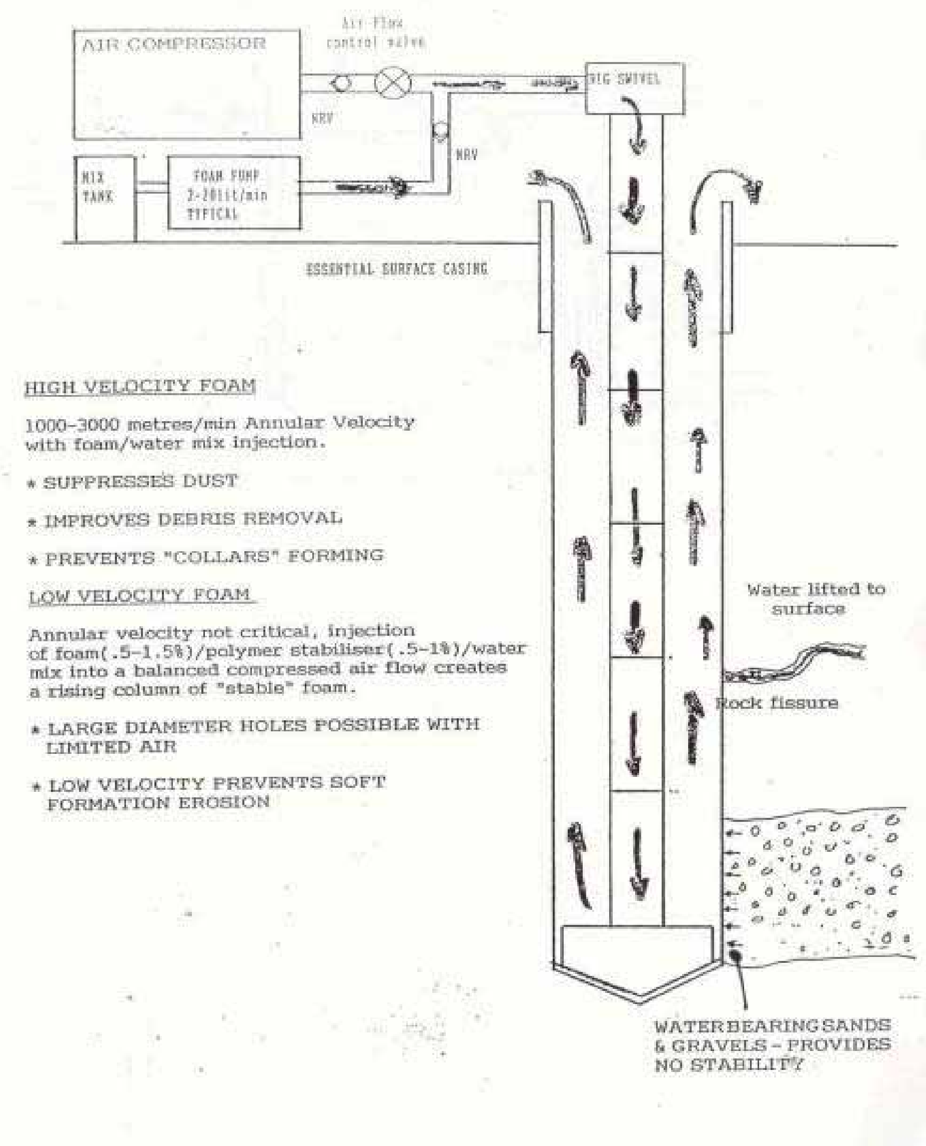


Figure 8.2: Foam drilling

9. Data Collection, Processing and Interpretation

- Data collection during exploration drilling usually consists of geological logging, geophysical logging and water quality sampling.
- Geological logging based on the collection of rock samples is carried out during the drilling process itself.
- Geophysical logging is carried out when a well has been drilled to about its anticipated depth. After a well has been drilled with the mud rotary drilling method the logs are run in the well which has still no casing and screens installed, and which is still full of drilling fluid. Also, the logs are usually run in a small diameter pilot hole which is drilled first. If the results are not encouraging, we may consider abandoning the drilling site and selecting another location. Once wells have been cased and screened the spontaneous potential and resistivity logs cannot be run anymore. The exception is gamma radiation logging which may be carried out in all sorts of casing wells.

9. Data Collection, Processing and Interpretation

- Water quality sampling can be carried out during the drilling process or after casing and screens have been installed. When using hand tool, jetting, cable tool percussion or pneumatic air rotary drilling water samples can be collected during the drilling process. When engaging mud rotary drilling sampling can be carried out after casing, screens have been installed, and the well has been properly developed.

10. Application of Logging Techniques

- Geological logging and water quality sampling should be carried out at every well drilled during an exploration programme. The methods are inexpensive and provide good insight into the hydrogeological conditions of an area.
- In mud rotary drilling, the collected rock samples may be of rather poor quality. Due to the crushing action of the drilling bit and the masking effect of the drilling fluid.
- More or less standard is to collect rock samples over I m intervals and after a change in geology has occurred.
- Tests may be carried out on collected rock samples in the field, but the rock material may also be stored in bottles or boxes. After transport, various tests can be done on the samples in the laboratory. Usually the weight of the collected sample is less than 0.5 kg.

10. Application of Logging Techniques

- In mud rotary drilling we have to separate the rock material from the drilling fluid. First cuttings mixed with fluid have to be collected from the setting pit, or a specially made sample collection pit. Then the separation can be done by pouring the mix over a sieve with an opening of about 0.1mm. Sand and gravel will be collected in the sieve while the much finer drilling fluid will pass through the sieve. Material from clay layers may be present in lumps which remain behind on the sieve. Unfortunately, it may be difficult to sample silt layers; by considering the drilling speed and using information from geophysical logs these layers may still be identified.

10. Application of Logging Techniques

- Mud rotary drilling at a larger depth high drilling rates causes another problem. The rock material which is emerging at land surface does not originate from the depth of the drill bit at that particular moment. As a result of the time it takes to travel to the surface, the rock material will be from a level higher in a hole than the position of the bit. Similar to percussion drilling, we may have contamination of the rock material as a result of caved in or re-circulating material from higher levels. Simple drilling fluid velocity calculations and close inspection of the samples will indicate to us from which depth the rock material originates.

10. Application of Logging Techniques

- When using hand tool methods samples can just be taken from the material removed from a dug well or samples can be collected from the auger bore when it is lifted to the surface.
- In cable tool drilling samples cab be taken from the material collected in the bailer. For detailed and precise rock sampling, the bailer is used more frequently. In uncased holes, we should be aware that the bailer may contain rock material that has fallen down from higher parts of the hole.

11. Sample Description and Data Processing

- **The hydrogeologist** makes the geological descriptions of the rock samples in close cooperation with the driller. Changes in rock type are usually associated with changes in drilling rate and the driller can relay this information to the hydrogeologist on site. Drillers are usually capable of making accurate geological descriptions of the samples themselves which may be of great use to the hydrogeologist. We will notice that the driller uses his own terminology whereby the emphasis is usually on texture (gravel, sand, silt or clay), on the hardness of the rock, the color of the samples and any smells of special form of the material.

11. Sample Description and Data Processing

- **The hydrogeologist** will usually add details on the sorting and angularity of the grains, mineral content and rock type, type of fossils, the presence of carbonates etc. as a real professional he will have his magnifying glass, sand ruler and bottle with hydrochloric acid at hand. Also, the hydrogeologist may try to predict the porosity and permeability of the drilled rock by careful analyses of the sample. He will be responsible for the storage of the samples in containers and he sticks on the labels in an adequate manner. On completion of these tasks the geological logs can be prepared. This can be done on an individual basis, or in combination with the results of other logging techniques.

12. Sample Collection

Depending on the method of drilling, the formation sample will be disturbed to varying degrees:

- ***Augering:***
- ✓ Disturbed – from auger stem
- ✓ Undisturbed – split spoon

- ***Rotary Drilling:***
- ✓ Disturbed – from drilling fluid returns
- ✓ Undisturbed – coring (very expensive)

- ***Percussion Drilling***
- ✓ Disturbed – bailer
- ✓ Undistubed – drive coring

12. Sample Collection

12.1 Augering Sampling

- **Disturbed Samples**
  - From the top of the hole as auger devices
  - Pull out auger and examine material on bit

- **Undisturbed Samples**
  - Pull out auger and drive a split spoon or core barrel ahead of the drilled hole
  - For hollow stem augers, pull out drill rods and insert split spoon through base of auger
  - Continuous sampling with split spoon

12. Sample Collection

12.2 Rotary Sampling

➢ **Disturbed Samples**

✓ **General Practice**

1. Collect samples from fluid return
2. Put in sample boxes to dry and describe (on site)
3. Pack in plastic bags and label properly
4. Transport to office/laboratory for further description and analysis

12. Sample Collection

✓ **Problems**

1. *Drill bit is destructive*

2. *Mixing of samples:*

- Different travel times for different particles,
  - Fine samples retained in mud/water,
  - Especially a problem in deep boreholes and thin bedded formations,
  - Investigate by raising drill string by one meter, circulate till fluid clear then recommencing drilling and sampling

3. *Sample interval (no fixed rules)*
   - Every one meter change in formation in shallow holes,
   - Less frequently in deep holes,

12. Sample Collection

➢ **Undisturbed Samples (Cors)**

✓ Not truly undisturbed hence caution needed in interpreting laboratory test results,

✓ Good for general description and some laboratory tests,

13. Selection Criteria for Drilling Methods

- Taking the wrong drilling method leads to a waste of time, energy, money and above all frustration.
- Several criteria can be formulated for the selection of the proper method:

- ✓ Rock type: some drilling techniques simply do not work in certain rock types and vice versa.
- ✓ Water quality
- ✓ Completeness of the geological logs
- ✓ Drilling depth
- ✓ The budget available for the drilling programme

- The following considerations may assist in the selection of the proper drilling techniques to be engaged in an exploration drilling programme.

13. Selection Criteria for Drilling Methods

➢ **Hand Tool Methods**

✓ The excavation of hand dug wells is usually restricted to areas with unconsolidated sediments including gravels, sands, silts, clays, chalk, fragile sandstones, weathered metamorphic and weathered igneous rocks.

✓ **Geological logs** from hand dug wells are usually excellent, but the method is hardly used in groundwater exploration programmes. Hand dug well are nearly always constructed to secure a water supply for an individual household or a small community.

✓ **Augering borings** can be carried out exclusively in loose sediments which must be free of boulders. Running sand may also cause the hole to cave or it may clog casing being used for hole support.

13. Selection Criteria for Drilling Methods

- ✓ Augering geological rock samples and groundwater samples are usually of good quality. Geophysical logs are usually not taken in augering borings. Augering is an inexpensive boring method which can give valuable information. However, one should be well aware of its depth restriction; depending on sediment type the maximum boring depth will not be more than 15 m below surface.

13. Selection Criteria for Drilling Methods

- **Jetting Methods**

- These methods can only be used in unconsolidated loose sediments free of boulders.

- **Rock samples** can be collected, but are of a rather poor quality as they usually represent a large vertical section of the hole. Nevertheless a rough idea on the subsurface geology can be obtained.

- **Jetting methods** are quick and inexpensive. In many places the method is used to install a shallow (PVC) casing and screen assembly to provide household water supplies or to initiate groundwater monitoring.

13. Selection Criteria for Drilling Methods

- **Cable Tool Percussion Drilling**
- ✓ In principle the method can be used to drill holes up to large depths in about any rock type.

- ✓ **Drilling rates** are very slow in very hard rock including volcanic rocks (e.g. 0.1-0.2 m/day in columnar basalt), fresh intrusive and metamorphic rocks. Drilling rates in massive limestones and solid sandstones will also be low. In **unconsolidated sediments** the presence of running sands or large boulders may cause a problem.

13. Selection Criteria for Drilling Methods

- ✓ **Geological samples and water samples** are usually of good quality and free from pollution by chemicals (as used in mud rotary drilling). This is precisely the reason why this method is now becoming popular in groundwater pollution studies. In case no steel casing is used, spontaneous potential and resitivity logs can be run in the hole. Gamma logs can always be run. With drilling rates for unconsolidated sediments in the range of (10-30) m/day the **cable tool percussion method** is not exactly a fast method. However, in places were labor costs are low, the method can be considered as relatively inexpensive.

13. Selection Criteria for Drilling Methods

- **Mud Rotary Drilling**

- ✓ It can be used in most of the unconsolidated and consolidated rock types. The method is less suitable for drilling in very hard rock. It is also less suited for consolidated rocks such as sandstones, shales, limestones or basalt when they are known to contain large open fractures, solution holes …etc.

- ✓ The loss of and reduction in drilling fluid pressure may cause the hole to collapse.

- ✓ Rock samples collected during straight flush rotary drilling are usually of rather quality and proper water samples cannot be taken at all. Therefore, the running of geophysical logs is essential to obtain a correct impression of the hydrogeological conditions at the well.

13. Selection Criteria for Drilling Methods

- **Reverse Flush Rotary Drilling**

- ✓ It carried out in unconsolidated formations including sands, gravels, silts and clays. Since rock samples are not contaminated with material from higher parts of the hole (upward transport it through the tube) rock sampling is better than for straight rotary drilling.

- ✓ Both straight flush and reverse mud rotary drilling techniques are relatively fast drilling methods, but they are considered expensive.

13. Selection Criteria for Drilling Methods

- **Pneumatic Air Rotary Percussion Drilling**

- ✓ This method (down the hole hummer drilling) is well suited to penetrate very hard rock. These rocks may include gneiss, schist, quartzite, limestones, granite etc. The method works well in dry rock, but is also able to continue below groundwater tables when the inflow of water into the well can be lifted by the air pressures applied.

- ✓ Geological rock sampling and groundwater samples are usually of reasonable to good quality. However, one should not forget that the rock may be severely crushed by the bit.

- ✓ Drilling with the pneumatic air rotary percussion method is expensive.

13. Selection Criteria for Drilling Methods

Note: see the table in the next page which is about a comparison of common water well drilling techniques, and range of sutability

Comparison of common water well drilling techniques, and range of suitability

Drilling method	*Range of diameter and depth possible*	*Formations which suit the method*	*Formations which do not suit the method*	*Typical penetration rates*	*Advantages of the method*	*Disadvantages of the method*
Percussion (or cable tool)	75–600 mm. Possibly up to 900 mm. Depth from 100 to 600 m depending on rig weight and hole diameter. Record depth 3397 m	Consolidated rock, clay. Unconsolidated material, sands and gravels if cased	Running sands may cause problems. Hole must be cased to full depth to prevent caving	Hard rock 1–3 m/day. Soft sandstone and sandy clay 15–30 m/day. Sticky clay and shale 5–15 m/day. Loose fine sand or quicksand 3–6 m/day	Relative simplicity. Low initial equipment cost. Low daily operating cost. Low rig set up time. Suitable for almost all conditions. Drilling rates comparable to rotary methods in some types of rock at shallow depths. Good cutting samples with no contamination of rock fragments. Easy identification of aquifers and easy water quality sampling. Low water requirement. Minimum contamination of aquifers	Slow penetration in hard rock. Limited economical depth. Lack of control over water flow from penetrated formations. Lack of control over borehole stability. Unconsolidated formations have to be supported with multiple columns of casing. Recovery of casing may be difficult or impossible if well aborted. Frequent drill line failures. Lack of experienced personnel—an art not a science. Usually necessitates a telescopic design to reduce friction during drilling
Direct circulation rotary drilling using mud as drilling fluid	75–1500 mm. Depth 00's to 000's of metres	Consolidated soft and hard rock formations. Unconsolidated material	Difficulty encountered in formations which are highly permeable, cavernous, or fractured due to fluid loss causing possible collapse of hole. Boulders prove difficult to drill through	Consolidated rock 10–15 m/day. Soft unconsolidated sediments 100–150 m/day	Borehole can be drilled to great depth at quite good penetration rates in most materials. Unconsolidated formations are supported without the use of casing	Relatively high cost of equipment—perhaps twice that of cable tool rig. Risk of losing all mud into fissures. Risk of mudding-off or contaminating aquifers. Considerable quantities of make-up water required. Cuttings recovery not good, and fragments are contaminated by mud. Difficulty in recognizing aquifers. Boulders difficult to drill through
Reverse circulation rotary drilling using water as drilling fluid	400–1800 mm. Depth 120–350 m	Loose formations such as soft unconsolidated sand and silt. Soft clay. Also stiff clay and soft rock, but at reduced efficiency	A suction dredging technique rather than a true drilling method, so not effective on hard rock or boulders. Water losses may cause collapse as in rotary drilling above. Water table should be 3 m or more below ground	Rates of 12 m/h are quite common. Occasionally up to 0.6 m/min. Under favourable conditions	Very rapid drilling possible even at large diameters, particularly in sands and gravel. Rapid production of very good samples. No risk of mudding-off or contaminating aquifer if circulating water kept clean. Casing unnecessary except at surface to control drilling fluid	High cost of equipment. Large quantities of make-up water required—perhaps 9–70 m^3/h. Essentially a suction-dredging technique so material larger than the drill bit openings or drill stem (such as boulders, cobbles) may have to be fished out
'Down the hole' hammer drill using air	50–375 mm. Possibly up to 750 mm. Depth depends on conditions	Hard dry rock	Will not operate in unconsolidated materials or clays. May be defected by water	Hard dry rock—3 m/h or better	Fast penetration in hard rock. Drilling mud not required. Aquifer not mudded off or contaminated. Good return of uncontaminated cuttings	Inability to support hole-mud back-up may be required. Efficiency falls with depth below water