Drilling Rigs Part 1

Introduction to Drilling Rigs

A drilling rig is a machine which creates holes (usually called boreholes) and/or shafts in the ground. Drilling rigs can be massive structures housing equipment used to drill water wells, oil wells, or natural gas extraction wells or they can be small enough to be moved manually by one person. They sample sub-surface mineral deposits, test rock, soil and groundwater physical properties, and to install sub-surface fabrications, such as underground utilities, instrumentation, tunnels or wells. Drilling rigs can be mobile equipment mounted on trucks, tracks or trailers, or more permanent land or marine-based structures (such as oil platforms, commonly called ‘offshore oil rigs’). The term “rig” therefore generally refers to the complex of equipment that is used to penetrate the surface of the earth’s crust.

Drilling rigs can be:

- Small and portable, such as those used in mineral exploration drilling, water wells and environmental investigations.

- Huge, capable of drilling through thousands of meters of the Earth’s crust. Large “mud pumps” circulate drilling mud (slurry) through the drill bit and the casing, for cooling and removing the “cuttings” while a well is drilled. Hoists in the rig can lift hundreds of tons of pipe.
**History**

Until internal combustion engines came in the late 19th century, the main method for drilling rock was muscle power of man or animal. Rods were turned by hand, using clamps attached to the rod. The rope and drop method invented in Zigong, China used a steel rod or piston raised and dropped vertically via a rope. Mechanized versions of this persisted until about 1970, using a cam to rapidly raise and drop what, by then, was a steel cable.

In the 1970s, outside of the oil and gas industry, roller bits using mud circulation were replaced by the first efficient pneumatic reciprocating piston Reverse Circulation RC drills, and became essentially obsolete for most shallow drilling, and are now only used in certain situations where rocks preclude other methods. RC drilling proved much faster and more efficient, and continues to improve with better metallurgy, deriving harder, more durable bits, and compressors delivering higher air pressures at higher volumes, enabling deeper and faster penetration. Diamond drilling has remained essentially unchanged since its inception.

**Mobile Drilling Rigs**

In early oil exploration, drilling rigs were semi-permanent in nature and were often built on site and left in place after the completion of the well. In more recent times drilling rigs are expensive custom-built machines that can be moved from well to well. Some light duty drilling rigs are like a mobile crane and are more usually used to drill water wells.
Larger land rigs must be broken apart into sections and loads to move to a new place, a process which can often take weeks.

Small mobile drilling rigs are also used to drill or bore piles. Rigs can range from 100 ton continuous flight auger (CFA) rigs to small air powered rigs used to drill holes in quarries, etc. The drilling mechanisms outlined below differ mechanically in terms of the machinery used, but also in terms of the method by which drill cuttings are removed from the cutting face of the drill and returned to surface.

**Drilling Rig Classification**

There are many types and designs of drilling rigs, with many drilling rigs capable of switching or combining different drilling technologies as needed. Drilling rigs can be described using any of the following attributes:

- By power used
  - human - percussion is performed by pulling a rope over a pulley or a lever and rotary action (if any) by one or more workers, in manual well drilling
  - electric - the rig is connected to a power grid usually produced by its own generators and uses electric motors to drive individual components such as draw works, mud pumps and rotary tables.
- Mechanical - the rig uses torque converters, clutches, and transmissions powered by its own engines, often diesel
- Hydraulic - the rig primarily uses hydraulic power
- Pneumatic - the rig is primarily powered by pressurized air

- By pipe used
  - Cable - a cable is used to raise and drop the drill bit or drill string
  - Conventional - uses metal or plastic drill pipe of varying types
  - Coil tubing - uses a giant coil of tube and a down hole drilling motor

- By height
  - Single - can drill only single drill pipes, has no vertical pipe racks (most small drilling rigs)
  - Double - can store double pipe stands in pipe racks
  - Triple - can store stands composed of three pipes in the pipe rack (most large drilling rigs)
  - Quad - can store stands composed of four pipes in the pipe rack

- By method of rotation or drilling method
  - No rotation includes direct push rigs and most service rigs
  - Rotary table - rotation is achieved by turning a square or hexagonal pipe (the kelly) at drill floor level
  - Top-drive - rotation and circulation is done at the top of the drill string, on a motor that moves along the derrick
  - Sonic - uses primarily vibratory energy to advance the drill string

- By position of derrick
Drill Types

There are a variety of drill mechanisms which can be used to sink a borehole into the ground. Each has its advantages and disadvantages, in terms of the depth to which it can drill, the type of sample returned, the costs involved and penetration rates achieved.

There are two basic types of drills: drills which produce rock chips, and drills which produce core samples.

Auger Drilling

Auger drilling is done with a helical screw which is driven into the ground with rotation; the earth is lifted up the borehole by the blade of the screw. Hollow stem Auger drilling is used for environmental drilling, geotechnical drilling, soil engineering and geochemistry reconnaissance work in exploration for mineral deposits. Solid flight augers/bucket augers are used in construction drilling. In some cases, mine shafts are dug with auger drills. Small augers can be mounted on the back of a utility truck, with large augers used for sinking piles for bridge foundations.

Auger drilling is restricted to generally soft unconsolidated material or weak weathered rock. It is cheap and fast.
Percussion Rotary Air Blast Drilling (RAB)

RAB drilling is used most frequently in the mineral exploration industry. The drill uses a pneumatic reciprocating piston-driven **hammer** to energetically drive a heavy drill bit into the rock. The drill bit is hollow, solid steel and has ~20 mm thick tungsten rods protruding from the steel matrix as 'buttons'. The tungsten buttons are the cutting face of the bit.

The cuttings are blown up the outside of the rods and collected at surface. Air or a combination of air and foam lift the cuttings.

RAB drilling is used primarily for mineral exploration; water bore drilling and blast-hole drilling in mines, as well as for other applications such as engineering, etc. RAB produces lower quality samples because the cuttings are blown up the outside of the rods and can be contaminated from contact with other rocks. RAB drilling rarely achieves more than 150 meters depth as encountering water rapidly clogs the outside of the hole with debris, precluding removal of drill cuttings from the hole.

This can be counteracted, however, with the use of **stabilizers** also known as **reamers**, which are large cylindrical pieces of steel attached to the drill string, and made to perfectly fit the size of the hole being drilled. These have sets of rollers on the side, usually with tungsten buttons, that constantly break down cuttings being pushed upwards.
The use of multiple high-powered air compressors, which push 900-1150cfm of air at 300-350psi down the hole, also ensures drilling of a deeper hole up to ~1250m due to higher air pressure which pushes all rock cuttings and any water to the surface. This, of course, is all dependant on the density and weight of the rock being drilled, and on how worn the drill bit is.

**Air Core Drilling**

Air core drilling and related methods use hardened steel or tungsten blades to bore a hole into unconsolidated ground. The drill bit has three blades arranged around the bit head, which cut the unconsolidated ground. The rods are hollow and contain an inner tube which sits inside the hollow outer rod barrel. The drill cuttings are removed by injection of compressed air into the hole via the annular area between the inner tube and the drill rod. The cuttings are then blown back to surface up the inner tube where they pass through the sample separating system and are collected if needed. Drilling continues with the addition of rods to the top of the drill string. Air core drilling can occasionally produce small chunks of cored rock.

This method of drilling is used to drill the weathered regolith, as the drill rig and steel or tungsten blades cannot penetrate fresh rock. Where possible, air core drilling is preferred over RAB drilling as it provides a more representative sample. Air core drilling can achieve depths approaching 300 meters in good conditions. As the cuttings are removed inside the rods and are less prone to contamination compared to conventional drilling
where the cuttings pass to the surface via outside return between the outside of the drill rob and the walls of the hole. This method is more costly and slower than RAB.

Cable Tool Drilling

Cable tool rigs are a traditional way of drilling water wells internationally and in the United States. The majority of large diameter water supply wells, especially deep wells completed in bedrock aquifers, were completed using this drilling method. Although this drilling method has largely been supplanted in recent years by other, faster drilling techniques, it is still the most practicable drilling method for large diameter, deep bedrock wells, and in widespread use for small rural water supply wells.

Also sometimes called spudders, these rigs raise and drop a drill string to finely pulverize the subsurface materials. The drill string is comprised of the upper drill rods, a set of "jars" (inter-locking sliders that help transmit additional energy to the drill bit and assist in removing the bit if it is stuck) and a drill bit. During the drilling process, the drill string is periodically removed from the borehole and a bailer is lowered to collect the drill cuttings (rock fragments, soil, etc.). The bailer is a bucket-like tool with a trapdoor in the base. If the borehole is dry, water is added so that the drill cuttings will flow into the bailer. When lifted, the bailer closes and the cuttings are then raised and removed. Since the drill string must be raised and lowered to advance the boring, casing (larger diameter
outer piping) is typically used to hold back upper soil materials and stabilize the borehole.

Cable tool rigs are simpler and cheaper than similarly sized rotary rigs, although loud and very slow to operate. The world record Cable Tool Well was drilled in New York to a depth of almost 12,000 feet. The common Bucyrus Erie 22 can drill down to about 1,100 feet. Since cable tool drilling does not use air to eject the drilling chips like a rotary, instead using a cable strung bailer, technically there is no limitation on depth.

**Reverse Circulation (RC) Drilling**

RC drilling is similar to air core drilling, in that the drill cuttings are returned to surface inside the rods. The drilling mechanism is a pneumatic reciprocating piston known as a hammer driving a tungsten-steel drill bit. RC drilling utilizes much larger rigs and machinery and depths of up to 500 meters are routinely achieved. RC drilling ideally produces dry rock chips, as large air compressors dry the rock out ahead of the advancing drill bit. RC drilling is slower and costlier but achieves better penetration than RAB or air core drilling; it is cheaper than diamond coring and is thus preferred for most mineral exploration work.

Reverse circulation is achieved by blowing air down the rods, the differential pressure creating air lift of the water and cuttings up the inner tube which is inside each rod. It reaches the bell at the top of the hole, and then moves
through a sample hose which is attached to the top of the cyclone. The drill cuttings travel around the inside of the cyclone until they fall through an opening at the bottom and are collected in a sample bag.

The most commonly used RC drill bits are 5-8 inches (12.7–20.32 cm) in diameter and have round metal 'buttons' that protrude from the bit, which are required to drill through rock and shale. As the buttons wear down, drilling becomes slower and the rod string can potentially become bogged in the hole. This is a problem as trying to recover the rods may take hours and in some cases weeks. The rods and drill bits themselves are very expensive, often resulting in great cost to drilling companies when equipment is lost down the bore hole. Most companies will regularly 'sharpen' the buttons on their drill bits in order to prevent this, and to speed up progress. Usually, when something is lost (breaks off) in the hole, it is not the drill string, but rather from the bit, hammer, or stabilizer to the bottom of the drill string (bit). This is usually caused by a blunt bit getting stuck in fresh rock, over-stressed metal, or a fresh drill bit getting stuck in a part of the hole that is too small, due to having used a bit that has worn to smaller than the desired hole diameter.

Although RC drilling is air-powered, water is also used, to reduce dust, keep the drill bit cool, and assist in pushing cutting back upwards, but also when collaring a new hole. A mud called liqui-pol is mixed with water and pumped into the rod string, down the hole. This helps to bring up the sample to the surface by making the sand stick together. Occasionally, 'super-foam' (AKA 'quik-foam') is also used, to bring all the very fine
cuttings to the surface, and to clean the hole. When the drill reaches hard rock, a collar is put down the hole around the rods which is normally PVC piping. Occasionally the collar may be made from metal casing. Collaring a hole is needed to stop the walls from caving in and bogging the rod string at the top of the hole. Collars may be up to 60 meters deep, depending on the ground, although if drilling through hard rock a collar may not be necessary.

Reverse circulation rig setups usually consist of a support vehicle, an auxiliary vehicle, as well as the rig itself. The support vehicle, normally a truck, holds diesel and water tanks for re-supplying the rig. It also holds other supplies needed for maintenance on the rig. The auxiliary is a vehicle, carrying an auxiliary engine and a booster engine. These engines are connected to the rig by high pressure air hoses. Although RC rigs have their own booster and compressor to generate air pressure, extra power is needed which usually isn't supplied by the rig due to lack of space for these large engines. Instead, the engines are mounted on the auxiliary vehicle. Compressors on an RC rig have an output of around 1000 cfm at 500 psi (500 L·s⁻¹ at 3.4 MPa). Alternatively, stand-alone air compressors which have an output of 900-1150cfm at 300-350 psi each are used in sets of 2, 3, or 4, which are all routed to the rig through a multi-valve manifold.
Diamond Core Drilling

Diamond core drilling (Exploration diamond drilling) utilizes an annular diamond-impregnated drill bit attached to the end of hollow drill rods to cut a cylindrical core of solid rock. The diamonds used are fine to micro fine industrial grade diamonds. They are set within a matrix of varying hardness, from brass to high-grade steel. Matrix hardness, diamond size and dosing can be varied according to the rock which must be cut. Holes within the bit allow water to be delivered to the cutting face. This provides three essential functions; lubrication, cooling, and removal of drill cuttings from the hole.

Diamond drilling is much slower than reverse circulation (RC) drilling due to the hardness of the ground being drilled. Drilling of 1200 to 1800 meters is common and at these depths, ground is mainly hard rock. Diamond rigs need to drill slowly to lengthen the life of drill bits and rods, which are very expensive.

Core samples are retrieved via the use of a lifter tube, a hollow tube lowered inside the rod string by a winch cable until it stops inside the core barrel. As the core is drilled, the core lifter slides over the core as it is cut. An overshot attached to the end of the winch cable is lowered inside the rod string and locks on to the backend, located on the top end of the lifter tube. The winch is retracted, pulling the lifter tube to the surface. The core does not drop out the inside of the lifter tube when lifted because a "core lifter spring," located at the bottom of the tube allows the core to move inside the tube but not fall out.
**Diamond Core Drill Bits**

Once a rod is removed from the hole, the core sample is then removed from the rod and catalogued. The Driller's offside screws the rod apart using tube clamps, then each part of the rod is taken and the core is shaken out into core trays. The core is washed, measured and broken into smaller pieces using a hammer to make it fit into the sample trays. Once catalogued, the core trays are retrieved by geologists who then analyze the core and determine if the drill site is a good location to expand future mining operations.

Diamond rigs can also be part of a multi-combination rig. Multi-combination rigs are a dual setup rig capable of operating in either a reverse circulation (RC) and diamond drilling role (though not at the same time). This is a common scenario where exploration drilling is being performed in a very isolated location. The rig is first set up to drill as an RC rig and once the desired meters are drilled, the rig is set up for diamond drilling. This way the deeper meters of the hole can be drilled without moving the rig and waiting for a diamond rig to set up on the pad.

**Direct Push Rigs**

Direct push technology includes several types of drilling rigs and drilling equipment which advances a drill string by pushing or hammering without rotating the drill string. This should perhaps not properly be called drilling; however the same basic results (i.e. a borehole) are achieved. Direct push rigs include both cone penetration testing (CPT) rigs and direct push sampling rigs such as a Geoprobe. Direct push rigs typically are limited to drilling in unconsolidated soil materials and very soft rock.
CPT rigs advance specialized testing equipment (such as electronic cones), and soil samplers using large hydraulic rams. Most CPT rigs are heavily ballasted (20 metric tons is typical) as a counter force against the pushing force of the hydraulic rams which are often rated up to 20 kn. Alternatively, small, light CPT rigs and offshore CPT rigs will use anchors such as screwed-in ground anchors to create the reactive force. In ideal conditions, CPT rigs can achieve production rates of up to 250-300 meters per day.

Geoprobe rigs use hydraulic cylinders and a hydraulic hammer in advancing a hollow core sampler to gather soil and groundwater samples. The speed and depth of penetration is largely dependent on the soil type, the size of the sampler, and the weight and power the rig. Direct push techniques are generally limited to shallow soil sample recovery in unconsolidated soil materials. The advantage of direct push technology is that in the right soil type it can produce a large number of high quality samples quickly and cheaply, generally from 50 to 75 meters per day. Rather than hammering, direct push can also be combined with sonic (vibratory) methods to increase drill efficiency.