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Drilling Methods and Applications in Engineering and Geology: A Review

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Abstract
This paper provides an overview of the common drilling methods and their applications in geology and engineering. The five-drilling methods discussed in the paper are auger drilling, rotary drilling, percussion drilling, core drilling and directional drilling. This paper highlights the geological and engineering application of these drilling methods, including mineral exploration, geotechnical investigation, oil and gas exploration, and underground infrastructure development. The choice of drilling method depends on geological and engineering objectives, the depth of the target and type of rock formation. This paper also includes some case histories lighting some problems associated to drilling.

Keywords: *Drilling, Percussion, Directional Drilling, Wellbore, Geotechnical, Petroleum Oil/Gas exploration/development.*

1.0 INTRODUCTION

Drilling, a fundamental technique in the reams of engineering and geology, serves as a crucial tool for delving into earth subsurface miseries. As our understanding of the earth composition and structure continues to evolve so does the need for sophisticated drilling methods that can unearth valuable insights and contribute to a mirage of applications (Bornemann *et al.*, 1998).

Drilling is a process whereby a hole is bored using a drill bit to create a well for oil and natural gas production. The term drilling also indicates the whole complexity of operations necessary to construct a well of circular sectors applying excavation techniques. Drilling methods represent the cornerstone of subsurface exploration, playing a pivotal role in diverse fields such as engineering and geology. These techniques are employed to extract valuable resources, access geological formation and advance scientific understanding (Hossain and Islam., 2018). The versatility of drilling methods lies in their ability to adapt to different terrains and purposes making them an indispensable tool in various industries (Keyonnie *et al.*, 1957). Various drilling methods includes:

i. Rotary Drilling: Common in oil and gas exploration, this method involves a rotating drill bit to penetrate the earth.

ii. Percussion Drilling: Utilizing repetitive impacts, this method is effective in hard rock formation.

iii. Auger Drilling: Suitable for softer soils, this method employs a helical screw blade to extract samples or install subsurface instruments.

iv. Reverse Circulation Drilling: This method circulates drilling fluids to collect rock cuttings.

v. Directional Drilling: Directional drilling is the practice of drilling non-vertical bores.

vi. Abrasion Based Drilling Methods: This utilizes the abrasive action of various materials to break down and remove rock formation.

vii. Core Drilling: Core drilling is the process that produces cores of subsurface materials.

2.0 DRILLING METHODS

2.1 Rotary Drilling

The rotary method is comparatively new, having first been practiced by Lescott, a French civil engineer, in 1863. United state patents on rotary equipment were issued as early as 1866 but as was the case for case tools, the early application was for water well drilling. It was not until approximately 1900 that two water well drilling contractors, M.C and C.E. Baker moved their rotary equipment from South Dakota to Corsicana, Texas where it found use in the soft rock drilling of that area. In Texas in 1901 captain Lucas drilled the spindle top discovery well with rotary tools. This spectacular discovery is created well with rotary tools. This spectacular discovery is credited with initiating both the southwest's oil industry and the widespread use of rotary methods. The inherent advantage of this method in the soft rock areas of Texas and California ensured its acceptance, and it was in general used by the early 1920's. It is interesting to note that in the 1914 -18 period, cable tools drilled 90% of U.S wells. At the present time these figures are approximately reversed.

In the rotary method, the hole is drilled by a rotating bit to which a downward force is applied. The bit is fastened to and rotated by a drill string composed of a high-quality drill pipe and drill collars, with new sections or joints being added as drilling progresses. The cuttings are lifted from the hole by drilling fluid which is continually circulated down the inside of the drill string through water courses or nozzles in the bit, and upward in the annular space between the drill pipe and the borehole. At the surface, the returning fluid (mud) is diverted through a series of tanks or pits which afford a sufficient period to allow cutting separation and necessary treating. In the last of these pits the mud is picked up by the pump suction and repeats the cycle.

2.1.1 Basic Rig component

Rotary drilling equipment is complex, and any detailed discussion would of necessity involve intricate mechanical design problems. Petroleum engineers, for whom this book is designed are normally neither required nor qualified to solve these problems. The basic rig components include:

a. Drilling Rig: A drilling rig is an integrated system that drills wells, such as oil or water wells, or holes for piling and other construction purposes, into the earth's subsurface.

b. Rotary Table: A rotary table is a mechanical device on a drilling rig that provides clockwise (as viewed from above) rotational force to the drill string to facilitate the process of drilling a borehole.

c. Drill String: A drill string on a drilling rig is a column, or string, of drill pipe that transmits drilling fluid (via the mud pumps) and torque (via the kelly drive or top drive) to the drill bit.

d. Drill bit: In the oil and gas industry, a drill bit is a tool designed to produce a generally cylindrical hole (wellbore) in the Earth’s crust by the rotary drilling method for the discovery and extraction of hydrocarbons such as crude oil and natural gas.

e. Mud Pump: A mud pump or drilling mud pump is used to circulate drilling mud on a drilling rig at high pressure. The mud is circulated down through the drill string, and back through the annulus at high pressures.

f. Mud Tank: This is an equipment used for mixing and storing mud.

g. Bop: A large valve at the top of a well that may be closed if the drilling crew loses control of formation fluids.

h. Derrick or Mast: An oil derrick, also known as an oil rig or drilling rig, is a towering structure used in the extraction of oil and gas resources from underground.

i. Casing and Cementing Equipment: Oil Well Cementing Equipment is essential for the Oil/Gas exploration or production wells and is a must use oilfield equipment while drilling a well. Casing pipe will be installed at various depths while drilling. It is held in place by cement, which also provides zone isolation. (Wikipedia, 2017)

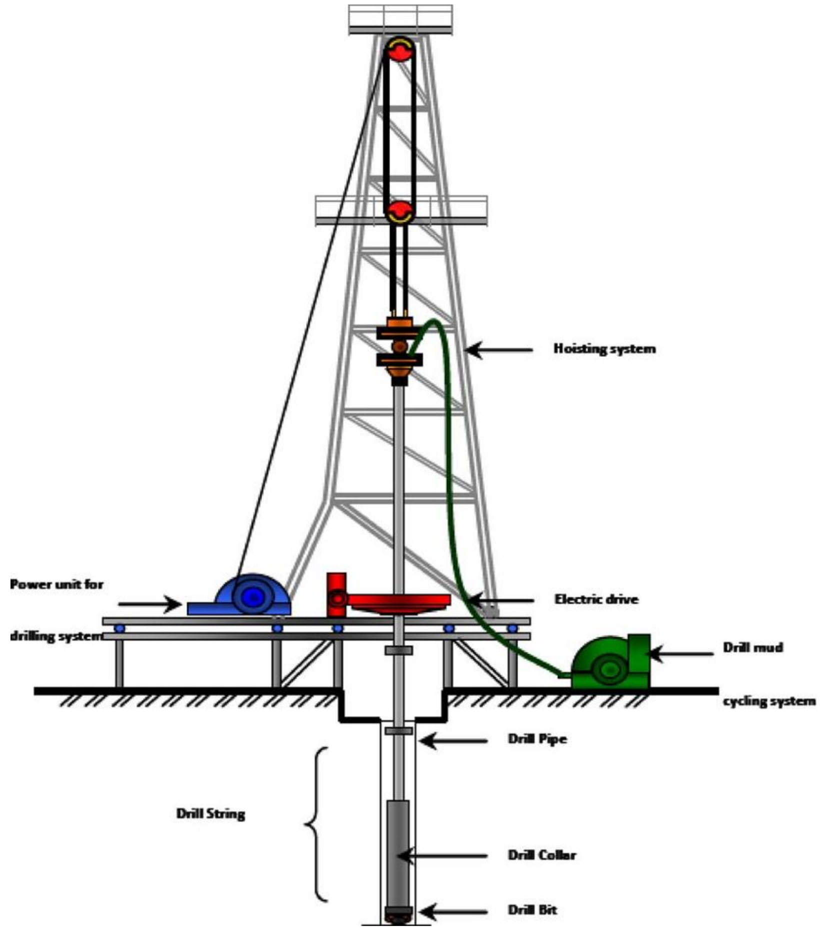

Figure 1. schematic diagram of a rotary drill rig. Source: (Mansour, 2009).

2.2 Percussion Drilling

Percussion drilling methods rely on hammering force to break down rock formations. They are some of the oldest and most basic drilling techniques, known for their simplicity and effectiveness in specific applications. Percussion drilling is employed when auger or wash boring is not possible in very stiff soil or rock. It also can be used on most soil types.

Here, the advancement of a hole is achieved by alternatively lifting and dropping a heavy cutting or hammering bit that is attached to a rope or cable that is lowered into an open hole or inside a temporary casing. Usually, a tripod is used to support the cable. The stroke of the bit varies according to the ground condition.

The major disadvantage of this method is that it is not possible to get good-quality undisturbed samples. In very hard rock (and especially fractured hard rock), down the hole (DTH) drilling can be employed. In this Case the hammer, applying repeated percussive pressure, is Located just behind the drill bit inside the hole, unlike the open percussion drilling, where the hammer is on top of the drawing string. The drilling string provides the necessary force and rotation to the hammer and bit, as well as compressed air or fluids to the hammer and for the flushing of cuttings.

This arrangement also allows for many drill bits, as mentioned previously, are the tools for cutting soil/rocks. These drill bits come in many different sizes and shapes (e.g. spoon bit, Spiral pointed, cone type, diamond coated, forstner bits etc.)

2.2.1 Percussion Drilling Methods and Their Variations:

2.2.1.1 Manual Percussion Drilling: This traditional method involves manually lifting and dropping a heavy cutting bit attached to a rope or cable. The repeated impact of the bit on the rock fractures and loosens the material, which is then removed using a bailer. This method is labor-intensive and slow, but it remains useful for:

i. Drilling shallow holes in remote or inaccessible locations where machinery is impractical.
ii. Drilling in fragile environments where minimizing vibrations and noise is crucial.
iii. Educational purposes, demonstrating the basic principles of drilling to students.

2.2.1.2 Cable Tool Drilling: An evolution of manual percussion drilling, cable tool drilling employs a mechanical hoist or winch to raise and drop the cutting bit. This allows for faster drilling and greater depth capabilities compared to manual methods. It is commonly used for:

i. Drilling water wells in areas with limited access to electricity or heavy machinery.
ii. Installing monitoring wells for environmental investigations and groundwater studies.
iii. Drilling exploratory holes for mineral exploration and geological surveys.

2.2.1.3 Top Hammer Drilling: In this method, a pneumatically powered hammer strikes a piston connected to the drill bit. The impact energy is transferred to the bit, causing it to break the rock. Top hammer drilling is:

i. More efficient and faster than cable tool drilling.
ii. Suitable for drilling deeper holes and harder rock formations.
iii. Widely used in construction, mining, and quarrying applications.

2.2.1.4 Down-the-Hole (DTH) Hammer Drilling: This advanced method utilizes a pneumatic hammer located directly at the bottom of the drill string. This eliminates energy loss through the drill string, resulting in:

i. Significantly faster drilling rates and deeper penetration capabilities.
ii. Increased efficiency and productivity.
iii. Widely used in large-scale mining operations, tunneling projects, and deep well construction.

2.2.2 Equipment and Tools Used In Percussion Drilling

Several tools and equipment are essential for carrying out percussion drilling effectively.

i. Drill Rig: The drill rig serves as the primary equipment for percussion drilling. It consists of a sturdy structure that supports the drilling apparatus and provides stability during operation. The rig may be mounted on tracks, wheels, or a stationary platform, depending on the terrain and drilling requirements.

ii. Hammer: The hammer is a crucial component of percussion drilling. It delivers rapid impacts to the drill bit, facilitating the penetration of rock or soil. Various types of hammers are available, including pneumatic (air-powered), hydraulic, and mechanical hammers, each suited for different drilling conditions and depths.

iii. Drill Bit: The drill bit is the cutting tool attached to the end of the drill string. It comes in different shapes and sizes, depending on the desired hole diameter and the composition of the subsurface material. Common types of drill bits used in percussion drilling include button bits, cross bits, and chisel bits.

iv. Drill String: The drill string is a series of connected pipes or rods that transmit rotational force and impact energy from the hammer to the drill bit. It must be durable enough to withstand the stress and vibration generated during drilling operations.

v. Support Equipment: Various support equipment is necessary to facilitate percussion drilling operations. This may include air compressors or hydraulic power units to supply energy to the hammer, water pumps for cooling and lubricating the drill bit, and mud tanks for managing drilling fluids.

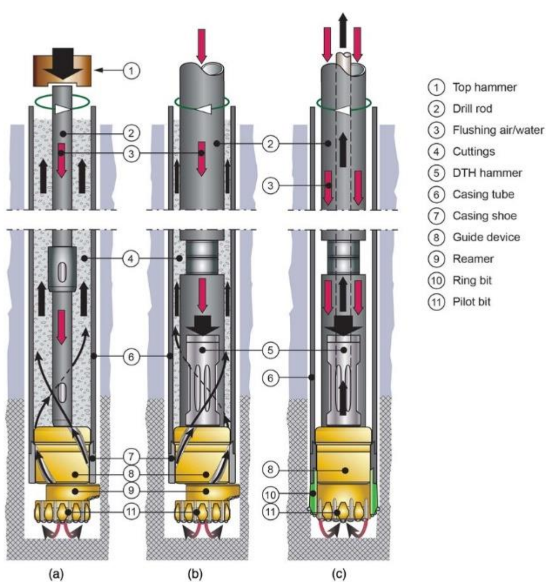

Figure 2. Percussive duplex drilling methods and drill bits used for overburden drilling. Source: (Einar, 2020).

2.3 Core Drilling

Core drilling produces cores of Subsurface material and is the most used method of obtaining information about the presence of minerals or precious metals, as well as rock formations. The core drilling gives the geologist the opportunity to analyze the sample by eye as well as by more advanced methods. As the samples are placed in core bones piece by piece and carefully marked, it gives a full picture of the rock strata.

2.3.1 Core drilling techniques.

Selecting which method to use for sampling work depends on the actual conditions, surface or underground, depth of the holes, rock conditions and the preference of the geologist. But it also depends on the Confidence that he or she places in the quality of the samples.

Modern core drilling rigs carry out fast and efficient core Sampling at differing hole diameters to very large depth. In addition, core drilling rigs have been developed to be highly efficient and safe, regardless of the method used.

2.3.2 Importance of core drilling

Core drilling is carried out to find the geological strata underground, it is used for foundation Sampling while building dams, Placement of piles & mineral prospecting.

A drill machine is used for rotating a drill string. Since the drill bit is hollow, it drills around the geologic strata Normally foundation sampling is done vertically and prospecting for minerals is done at an angle slanted to the horizontal and covers a greater area of mineralization.

2.3.3 Equipment and Tools Used in Core Drilling

Core Drill Rig: The core drill rig is the primary equipment used for core drilling operations. It typically consists of a stable base, a vertical column, and a motorized drill head that can rotate and advance the drill string into the ground or structure. Core drill rigs come in various sizes and configurations to accommodate different drilling depths and diameters.

Core Bit: The core bit is the cutting tool attached to the end of the drill string. It is designed to extract cylindrical cores of the subsurface material as the drill advances. Core bits may feature diamond-tipped, or tungsten carbide inserts for enhanced cutting performance and durability.

Drill String: The drill string comprises a series of connected drill rods or tubes that transmit rotational force and downward pressure from the drill rig to the core bit. The drill string must be robust enough to withstand the forces encountered during drilling and retrieval of core samples.

Core Barrel: The core barrel is a cylindrical container that surrounds the core bit and collects the extracted core samples. It typically consists of an outer tube with a cutting shoe at the bottom to guide the core bit and an inner tube that holds the core sample securely during retrieval.

Water Supply System: Many core drilling operations require a continuous supply of water to cool the core bit, lubricate the drilling process, and flush out cuttings from the borehole. Water may be supplied through hoses connected to a water tank or a pressurized water pump integrated into the drill rig.

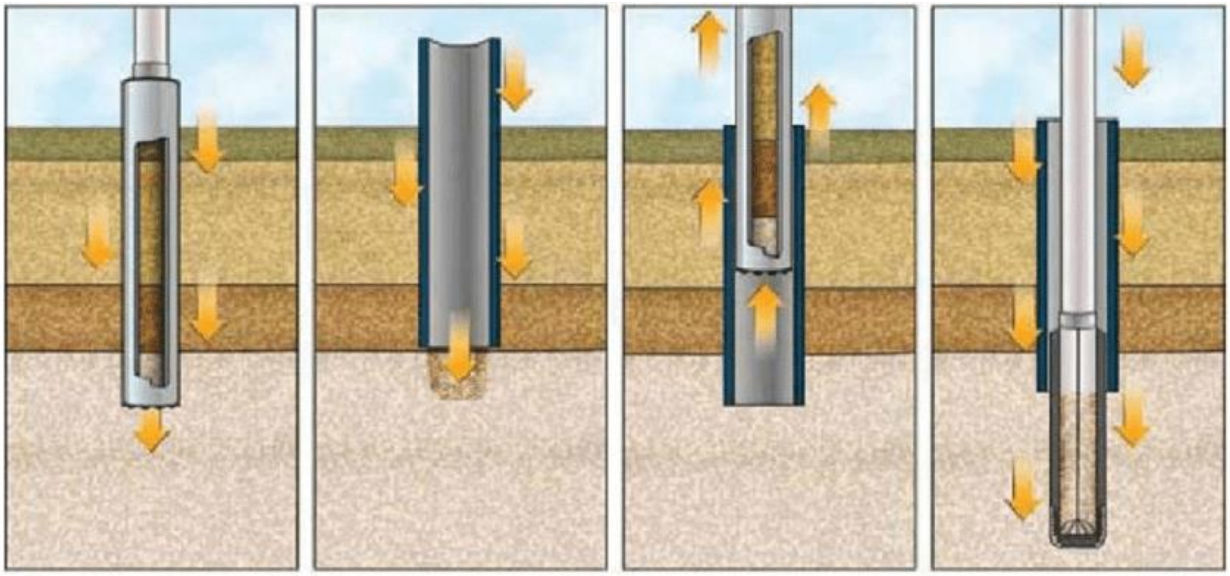

Figure 3. Diagram Illustrating the processes of core drilling. Source: (Jurij, 2017).

2.4 Auger Drilling

Auger drilling is a drilling method primarily used for soil Sampling and ground exploration. In essence, it's a technique that has helped environmental forms, civil engineers, and Construction Forms for years.

This is a process wherein a helical screw (or auger) is driven into the ground. As the auger rotates and delves into the soil, it brings the excavated Materials to the surface. This process ensures that the borehole remains open and free from collapse. The Spiral design of the auger blades helps in this excavation process.

2.4.1 Types of Auger drilling

There are mainly two types including:

i. **hollow stem auger drilling:** This method uses a hollow, cylindrical stem and auger flights. Once the desired depth is reached, samples can be extracted through the hollow stem without having to remove. auger from the ground.

ii. **Solid or continuous flight Auger drilling:** This involves a continuous, Solid stem. As it drills, the auger carries the Soll to the surface in a continuous Spiral motion.

2.4.2 Benefits of Auger drilling.

i. **Efficient Soil Sampling:**

Given its design, auger drilling is perfect for obtaining. Undisturbed soil Samples, allowing for accurate geotechnical or environment analysis.

ii. **versatilities:**

It can be employed in a wide range of soil types, including Sandy, clayey or silty soils.

iii. **Safety:**

This method inherently stabilizes the borehole, minimizing the rest of collapse and ensuring a safer work environment.

2.4.3 Common Applications of Auger drilling

1. Geotechnical exploration
2. Environmental Sampling.
3. Groundwater monitoring.

2.4.4 Auger Drilling Equipment and Tools

i. **Auger Bit:** This is the primary tool used for drilling. Auger bits come in various sizes and designs depending on the specific application. They typically consist of a helical screw-like blade (auger flight) attached to a solid shaft.

ii. **Drill Rig:** A drill rig provides the power and support for the auger drilling process. It can be a truck-mounted, skid-mounted, or trailer-mounted unit, depending on the mobility requirements and scale of the drilling project.

iii. **Power Source**: Auger drilling rigs are usually powered by hydraulic systems, although some smaller rigs may be powered by gasoline engines or electric motors.

iv. **Mud Pump**: In some cases, especially in environmental and geotechnical drilling, a mud pump may be used to circulate drilling fluid (mud) through the auger to aid in the drilling process and remove cuttings.

v. **Support Equipment:** This includes items such as stabilizers, jacks, and leveling devices to ensure the stability and proper alignment of the drill rig during operation.

vi. **Safety Equipment**: Personal protective equipment (PPE), such as hard hats, steel-toed boots, gloves, and safety glasses, is essential for the safety of the drilling crew.

vii. **Tooling and Accessories**: Various tooling and accessories may be used depending on the specific requirements of the drilling project. This may include extensions to reach greater depths, core barrels for sampling, and cleaning tools for maintaining the auger bit.

viii. **Transportation Equipment**: Trucks or trailers may be needed to transport the drill rig, equipment, and crew to and from the drilling site.

ix. **Monitoring and Measurement Equipment:** Instruments such as inclinometers, piezometers, and soil samplers may be used to monitor drilling progress, soil properties, and environmental conditions.

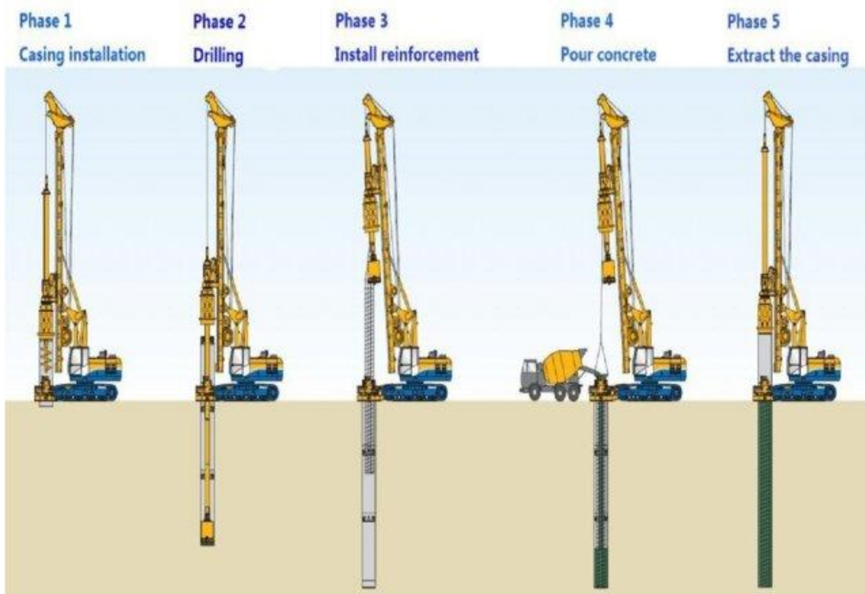

Figure 4. Auger drilling phases. Source: (curt, 2017).

2.5 Abrasion Based Drilling Method

Abrasion-based drilling methods utilize the abrasive action of various materials to break down and remove rock formations. These methods are known for their effectiveness in hard and abrasive material offering a valuable alternative to conventional drilling techniques (Abidin et al., 2011) there includes type of abrasion-based driving and its diverse applications.

2.5.1 Types of Abrasive Based Drilling Method

2.5.1.1 Abrasive Water Jet Drilling (AWJD)

AWJD is a highly precise and versatile method that uses a high-pressure jet of water mixed with abrasive particles to cut through rock concrete, and other hard material. The abrasive particles typically Sand or garnet, provides the Cutting power While the water jet removes the cutting and cools the drill head. AWJD is commonly used for:

i. Driving holes for anchoring and bolting in Construction and mining applications.
ii. Creates intricate cuts and design in stone and other materials for decorative purposes.
iii. Removing damaged concrete and other materials in repair and restoration Projects.
iv. Drilling in sensitive environments where conventional driving methods are not suitable.

2.5.1.2 Sandblasting:

Sandblasting utilizes compressed air to propel abrasive Particles at high velocity against a Surface, removing material through erosion. While primarily used for clearing and surface preparation.

Sandblasting can also be used for:

i. Drilling Shallow holes in soft rock formations and Concrete:
ii. Creating rough Surfaces for better adhesion of Coating and materials
iii. Removing Surface imperfections and contaminants.

2.5.1.3 Ultrasonic Drilling

This method utilizes vibrations generated by an Ultrasonic transducer to create microscopic cracks in the material, causing it to break down. Abrasive particles suspended in a liquid carrier are then used to remove the fragmented material. Ultrasonic drilling is commonly used for:

i. Drilling Small holes in printed circuit boards and Other electronic components.
ii. Creating intricate cuts and design in jewelry and other decorative items.
iii. Drilling holes in delicate materials such as glass and ceramics

2.5.1.4 Laser Abrasion Drilling:

This advanced method utilizes a focused laser beam to vaporize material, allowing For Precise and controlled drilling in various materials. Laser abrasion drilling is often used for:

i. Drilling holes for microfluidics and medical devices.
ii. Creating micro-nodes for feat injection and other high precision components.
iii. Abrasion of Surface Layers for material analysis of modification.

2.5.2 Abrasive Based Drilling Equipment and Tools

i. **Abrasive Jet Nozzle:** This is the primary tool used to create the high-velocity abrasive stream. The nozzle typically consists of a small diameter orifice through which the abrasive mixture is forced at high pressure.
ii. **High-Pressure Pump**: Abrasive jet drilling requires a high-pressure pump to generate the pressure needed to propel the abrasive particles through the nozzle. These pumps can operate at pressures ranging from hundreds to thousands of bar (or psi).
iii. **Abrasive Material:** Various abrasive materials can be used, including garnet, aluminum oxide, silicon carbide, and others. These abrasive particles are typically mixed with water or another carrier fluid and fed into the abrasive jet nozzle.
iv. **Water Supply System:** A continuous supply of water is needed to mix with the abrasive particles and create the abrasive jet. The water supply system typically includes pumps, filters, and hoses.
v. **Control System:** A control system is necessary to regulate the flow rate of the abrasive mixture, adjust the pressure of the high-pressure pump, and control the movement of the drilling apparatus.

vi. **Drill Head or Manipulator:** The drill head or manipulator holds the abrasive jet nozzle and guides it over the surface of the workpiece to create the desired hole pattern. It may be mounted on a CNC (Computer Numerical Control) system for precise control and automation.

vii. **Workpiece Fixture:** The workpiece fixture holds the workpiece securely in place during drilling to prevent movement or vibration that could affect hole quality and accuracy.

viii. **Safety Equipment**: Personal protective equipment (PPE) such as safety glasses, gloves, and hearing protection is essential due to the high-pressure and high-velocity nature of abrasive jet drilling.

ix. **Abrasive Recovery System:** To minimize waste and environmental impact, an abrasive recovery system may be used to collect and recycle the abrasive particles after they have passed through the workpiece.

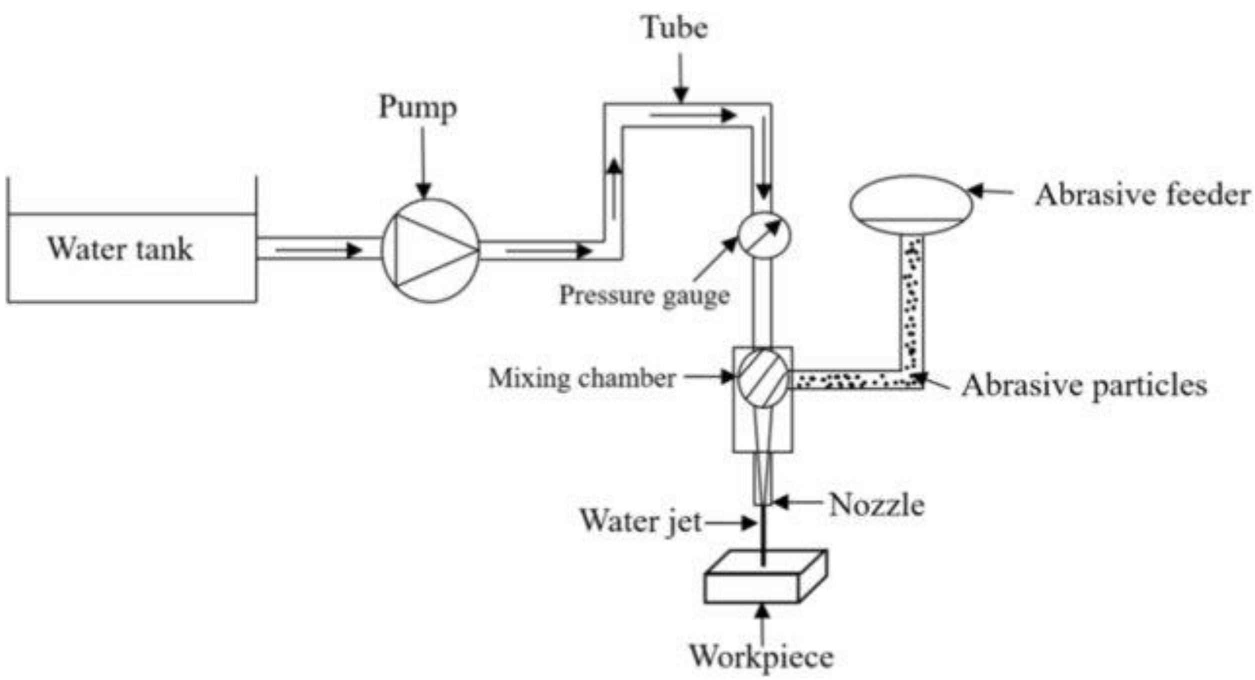

Figure 5. Abrasive water jet drilling processes. Source: (The International Journal of Advanced Manufacturing Technology, 2020).

2.6 Directional Drilling

Directional drilling (or slant drilling) is the practice of drilling non-vertical cores it can be broken down into four main groups: oil field directional drilling, utility installation directional drilling, directional boring, and surface in seam, which horizontally intersects a vertical bore target to extract coal bed methane. Gas was located under the sea, but the high cost of drilling offshore wells prohibited their exploitation. The number of individual drilling platforms could be reduced by drilling directional wells from one central platform. Many offshore fields would not be economically viable without directional wells. Offshore developments led to a big expansion in the use of directional drilling. The continuing need to reduce drilling costs provided the incentive to produce new tools and techniques to improve efficiency. Directional drilling has now become an essential element in oilfield (Inglis n.d.**)**.

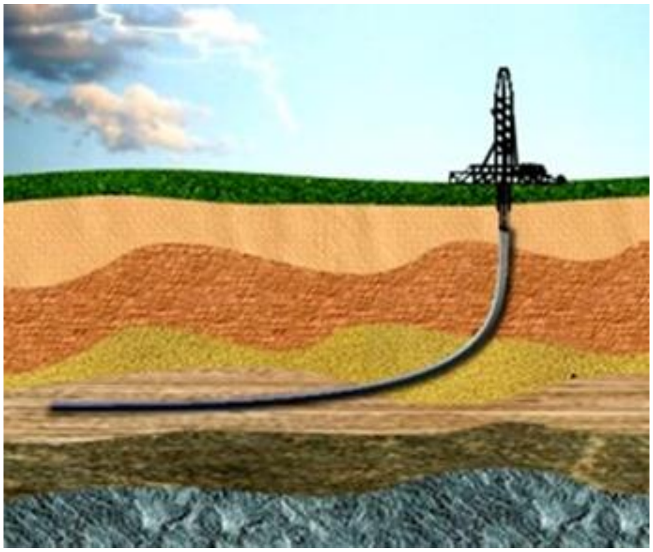

Figure 6. Directional Drilling. Source: (Rigzone, n.d.).

2.6.2 Benefits of directional drilling

wells are drilled directionally for several purposes:

i. Increasing the exposed section length through the reservoir by drilling through the reservoir at an angle.
ii. Drilling into the reservoir where vertical access is difficult or not possible for instance an oil field under a town, under a lake, or underneath a difficult to drill formation.
iii. Allowing more well heads to be grouped together on one Surface Location can allow fewer rig moves, less surface area disturbance, and make it easier and cheaper to complete and produce the wells for instance, on an oil platform or jacket offshore, 40 or more wells can be grouped together. The wells will fan out from the platform into the reservoir(s) below. This concept is being applied to land wells, allowing multiple subsurface locations to be reached from one pad, reducing costs.
iv. Drilling along the underside of a reservoir-constraining fault allows multiple productive sands to be completed at the highest Stratigraphic points.
v. Drilling a relief well to relieve the pressure of a well producing without restraint (a blowout). In this scenario, another well could be drilled starting at a safe distance away from the blowout but intersecting the troubled wellbore. Then, heavy fluid is pumped into the relief well bore to suppress the high pressure in the original well bore causing blowout.

Most directional drillers are given a blue well path to follow that is predetermined by engineers and geologists before the drilling commences. When the directional driller starts the drilling process, periodic survey is taken with a downhole Instrument to provide survey data of the well bore.

2.6.3 Disadvantages of directional drilling

Until the arrival of modern downhole motors and better tools to measure inclination and azimuth of the hole, directional drilling and horizontal drilling was much slower than vertical drilling due to the need to stop regularly and take time-consuming surveys and due to slower progress in drilling itself (lower rate of penetration). These disadvantages have shrunk overtone as downhole motors became more efficient and semi-continuous surveying became possible.

what remains is a difference in operating costs: for wells with an inclination of less than 40 degrees, tools to carry out adjustment or repair wort can be lowered by gravity on cable into the hole. For higher inclinations, more expensive equipment has to be mobilized to push tools down the hole.

Another disadvantage of wells with a high inclination was that prevention of sand influx into the well was less reliable and needed higher effort. Again, this disadvantage has diminished such that provided sand control is adequately Planned, it is possible to carry it out reliably.

2.6.4 Equipment used:

Specialized drill bits: A drill bit is the cutting device located at the end of a drilling machine's drill string. Like the bit on a hand-held drill, it creates a passage through the material into which it bores are used to improve performance and reduce the chance of failure.

Mud Motors: Downhole steerable mud motors get positioned near the drill bit, which has a bend in it. What happens is that at the correct depth the drill string stops rotating, then drilling fluid is pumped through the mud motor so that the drill bit starts to turn just due to the force of the liquid. This mud pressure pushes the drill bit into a different angle and begins to bite into the formation at a different angle to the central well trajectory. Once the sensors verify that the drill bit is pointing in the right direction, the drill string starts to turn again.

Rotary Steerable Systems (RSS): A rotary steerable system (RSS) is a form of drilling technology used in directional drilling. It employs the use of specialized downhole equipment to replace conventional directional tools such as mud motors. Directional drilling by using the mud motor means that often the drill pipe needs to be slid forward while the drill is motionless. A rotary steerable system can drill and steer at the same time. This means that previously inaccessible formations can be accessed.

Bottom Hole Assembly (BHA): The bottom hole assembly (BHA) is a portion of the drill string that affects the trajectory of the bit and, consequently, of the wellbore. The bottomhole assembly must provide force for the bit to break the rock (weight on bit), survive a hostile mechanical environment, and provide the driller with directional control of the well.

Multi-Shot cameras: These are fitted inside the drill string. They're set to take regular pictures on a time-lapse setting. Then these images are sent to the surface control.

Custom whipstocks: A whipstock is a wedge-shaped tool inserted into the wellbore that redirects the drilling path. It's typically placed at a predetermined depth within the well, and its orientation dictates the direction in which the drill bit will travel (progryndpumps, 2023). There are two primary types of whipstocks: conventional and retrievable.

Conventional Whipstocks: Conventional whipstocks are permanently placed in the well and serve as a fixed reference point for drilling. Once the whipstock is in place, the drill bit follows its lead, deviating from the original path. Conventional whipstocks are often used when a consistent and predictable trajectory is needed.

Retrievable Whipstocks: Retrievable whipstocks, on the other hand, can be removed from the well after drilling is complete. This flexibility is especially valuable in situations where multiple directional changes are required, as they allow engineers to fine-tune the well's path as needed. They are also more cost-effective in the long run as they can be reused in different wells.

Networked or wired pipe: This enables real time bidirectional drilling data that is recorded to significantly reduce the time spent on drilling.

2.6.5 How do the engineers know where the end of the drill is?

It's not possible to see hundreds of meters underground, in fact, the drillers and engineers rely entirely on technology to 'see' where they are going. A directional driller has a guide that has been created by engineers and geologists. Every 10-150 meters, (with 30-40 being typical), survey data is sent back to make sure that the original 'blue line' well path is being followed.

Directional drilling software receives input from multiple measurements while drilling (MWD) sensors in the drill bit, and at any branches or junctions. (Other measurement tools include Electromagnetic MWD and Global Positioning Sensors (GPS)). In addition to MWD technology, mud loggers use logging while drilling (LWD) sensors and software. The drill bit has vibration sensors that can detect the type of formation being drilled at any point. Collars can be added along the length of the well, sending back information to the surface regarding torque, weight and bending.

From the surface, electromagnetic sensors can also track the progress of the drill bit. When all the data from the drill bit, collars, motors, and the surface equipment enter the control panel, a complete representation occurs.

As well as being able to know what is going on, even a mile along the drill bore, drilling engineers can adjust in real-time to ensure that everything is going to plan. This is especially relevant when unexpected things occur concerning geology or severe equipment stress. (Lavis, n.d).

2.6.6 How can the drill make a turn?

If you were to imagine the mechanics of directional drilling without seeing the technology, you might wonder how the drill could suddenly change direction. Since the motor that turns the drill is at the surface, how can the drill string continue to rotate at 360 degrees while going around a corner? We now have downhole drilling motors, that can drive the drill bit in a completely different direction to the usual 180-degree downhole starting point.

Turbodrills and rotary steering drills are employed in directional situations where they're best suited. The rotational speed of the drill and the weight and stiffness of the drill string can also be used to influence direction. One of the original methods was jetting, a high-pressure nozzle shot water or drilling fluid from one edge to the drill bit, creating a weaker side in the formation.

Another traditional method was to use a whipstock. A whipstock is a type of wedge that can redirect the drill. At the desired depth the drill is withdrawn to the surface, a whipstock gets put in place, then the drill goes back down and gets redirected by the whipstock. Next, the drill is brought to the surface again, the whipstock pulled out and then drilling resumes and the bore changes path.

Drill bit sensors can tell the driller about external weight, and rotary speed that can also be used to influence the trajectory. Mud motors can also be used to change direction. With a steerable drill pipe, there's a bend near the bit. The drill string stops turning, and then there is plenty of time to use chosen directional techniques to reposition the bit to the desired trajectory. When it starts spinning again, it'll start going in the direction that it's now pointing towards. (More about steerable mud motors in the next section).

2.6.7 Applications of directional drilling

The applications of directional drilling can be grouped into the following categories:

(a) sidetracking.

(b) drilling to avoid geological problems.

(c) controlling vertical holes.

(d) drilling beneath inaccessible locations.

(e) offshore development drilling.

(f) horizontal drilling.

(g) Other applications

Sidetracking

During the drilling of a well, an obstruction (or fish) may become stuck at the bottom of the hole. This may be the result of a drill string failure or an intentional back-off where the lower part of the string is left in the hole. No further progress can be made if the fish cannot be pulled out of the hole. In the early days of rotary drilling, it was soon realized that it was much cheaper to drill around the obstruction rather than abandon the hole and start again.

A cement plug is placed on top of the fish and is allowed to set firmly. This forms a good foundation from which the new section of hole can be kicked off. A whipstock was the first tool designed to deflect the wellbore around a fish, but a downhole motor and bent sub are more likely to be used today. The bent sub can be oriented in the required direction by using MWD or a steering tool that will provide continuous monitoring of the well path. Once the sidetrack has been drilled around the obstruction, the hole is continued down to the target (see Fig. 7).

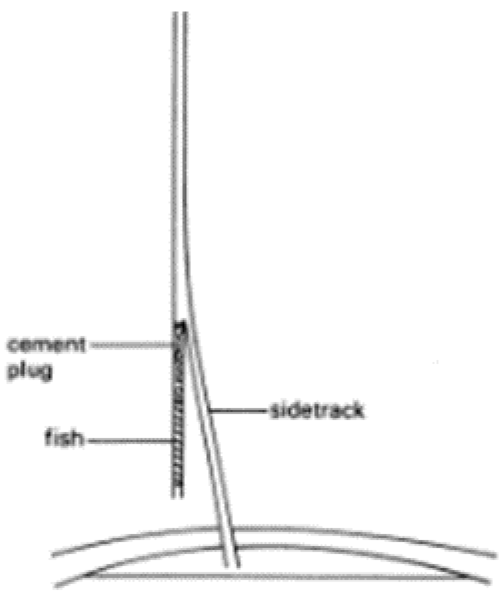

Figure 7. Sidetracking around a fish. source: (Inglis, n.d.).

Sidetracking may also be carried out for a re-drill or re-completion. If the original well did not locate the anticipated formation or is producing from a zone that has become depleted, the hole can be plugged back and then sidetracked towards a new target. If the kick-off point is in a section of cased hole, a window must be milled out of the casing to allow the sidetrack to be drilled. The same principle can be employed in an exploration well to test several different zones using the same wellbore.

Drilling to avoid geological problems.

Petroleum reservoirs are sometimes associated with salt dome structures. Part of the salt dome may be directly above the reservoir, so that a vertical well would have to penetrate the salt formation before reaching the target. Drilling through a salt section introduces certain drilling problems such as large washouts, lost circulation, and corrosion. In this situation it would be wiser to avoid the salt formation by drilling a directional well.

If a well is drilled vertically through a steeply dipping fault plane there is a risk of movement or slippage along that plane. This problem can also be avoided by drilling a directional well.

Controlling straight wells

To keep vertical wells on target and prevent them from straying across lease boundaries, directional techniques must be used. Small deviations from the planned course can be corrected by altering certain drilling parameters or changing the bottom hole assembly (BHA). More serious deviations may require the use of a downhole motor and bent sub to make a correction run or drill a sidetrack. The same problem may occur in the tangential section of a directional well.

Inaccessible locations

Oilfields are often located directly beneath natural or man-made obstructions. Permission may not be granted to drill in some sensitive areas, since there may be a risk to the environment. In such cases, it may be possible to exploit the reserves by drilling directional wells from a surface location outside the restricted area.

When a blow-out destroys or damages the rig in such a way that capping operations are impossible, relief wells are drilled to bring the blow-out safely under control. Improved directional techniques have enabled relief wells to reach targets less than 10 ft from the blow-out. Often two relief wells are drilled simultaneously from different surface locations to ensure that the blow-out is killed.

Horizontal drilling

Conventional directional wells may be drilled to an inclination of around 60°. Inclinations beyond 60° give rise to many drilling problems that substantially increase the cost of the well. However, there are certain advantages in drilling highly deviated wells and horizontal wells. These include:

(a) increasing the drainage area of the platform.

(b) prevention of gas coning or water coning problems.

(c) increased penetration of the producing formation.

(d) increasing the efficiency of enhanced oil recovery (EOR) techniques; (e) improving productivity in fractured reservoirs by intersecting several vertical fractures.

The extra cost of drilling a horizontal well must be justified by the increased productivity it will provide. The potential benefits and the risk involved must be carefully considered before drilling the well. Normal drilling procedures may have to be modified and special drilling equipment may have to be installed to drill and complete a horizontal well Horizontal drain holes (short radius drilling) can also be applied to overcome certain reservoir problems.

Other applications include.

Mining industry

The drilling of small-diameter boreholes in rock to measure thickness of the strata and to obtain core samples is well established. Indeed, some of the techniques used in the oil industry were adopted from earlier techniques used in mining (e.g. borehole surveying to measure inclination and direction). Directional wells are also used to produce methane gas that is contained in coal seams. The methane presents a safety hazard and must be drained off before mining operations can begin. In deep coal seams that are beyond the reach of conventional mining techniques, directional wells have been drilled for in situ gasification projects.

Construction industry

An unusual application of directional drilling is the installation of pipelines beneath riverbeds. A small-diameter pilot hole is drilled in a smooth arc beneath the river until it emerges on the other side. This acts as a guide for the larger-diameter pipe that forms the conduit. The pilot hole is drilled using a downhole motor and bent sub. The hole is drilled through soft sediments about 40 ft below the riverbed. The technique has been used to cross rivers up to 200 ft wide.

Geothermal energy

In certain areas of the world the high geothermal gradient found in some rocks can be harnessed to provide energy. The source rock (e.g. granite) is generally impermeable except for vertical fractures. Extracting the heat from this rock requires the drilling of injection and production wells. The wells are directionally drilled to take advantage of the orientation of the fractures. The high temperatures and hardness of the rock cause some major drilling problems (such as severe abrasion of downhole components, reduction in yield strength of steel at temperatures greater than 200°C, and the need for special downhole motors).

3.0 APPLICATION OF DRILLING IN GEOLOGY AND ENGINEERING

3.1 Application of Drilling in Geology

Drilling plays a crucial role in geological research and exploration. It allows scientists to access and analyze sub-surface materials, providing valuable insights into the Earth's history, composition, and structure. Various drilling methods are employed in geology, each with its own advantages and limitations depending on the specific application (shan., 2019). Diverse applications of drilling methods in geology include:

1. Mineral Exploration:

i. Diamond Core Drilling: Widely used to extract core samples of rock formations for detailed analysis and identification of potential mineral deposits.
ii. Reverse Circulation Drilling: Provides rapid sample collection for evaluating mineral potential and guiding further exploration activities.
iii. Aircore Drilling: Employed for cost-effective exploration of shallow mineral deposits, particularly in arid regions.

2. Petroleum Exploration:

i. Rotary Drilling: Used to create deep boreholes to access oil and gas reserves located underground.
ii. Directional Drilling: Allows for drilling deviated or horizontal wells to reach hydrocarbon deposits in difficult-to-access locations.
iii. Wireline Logging: Provides real-time data about the rock formations encountered while drilling, aiding in reservoir characterization and well planning.

3. Geotechnical Investigations:

i. Auger Drilling: Suitable for shallow soil investigations to determine soil properties and assess foundation suitability for construction projects.
ii. Standard Penetration Test (SPT): Provides data on soil strength and bearing capacity crucial for foundation design and construction safety.
iii. Cone Penetration Test (CPT): Measures soil resistance and provides continuous data on soil properties for geotechnical analysis.

4. Groundwater Investigations:

i. Rotary Drilling: Used to install monitoring wells for observing groundwater levels and collecting water samples for quality analysis.
ii. Aquifer Testing: Analyzes the hydraulic properties of aquifers to assess their potential for sustainable groundwater extraction.

iii. Geophysical Logging: Provides information about the water-bearing properties of rock formations and helps locate productive aquifers.

5. Environmental Investigations:

i. Hollow Stem Auger Drilling: Facilitates collecting soil samples for contamination analysis and monitoring the movement of pollutants in the subsurface.
ii. Direct Push Technology (DPT): Enables rapid and cost-effective collection of soil and groundwater samples without excavation.
iii. Vapor Pin Installation: Allows for monitoring the presence and concentration of volatile organic compounds (VOCs) in the subsurface.

6. Geological Mapping:

i. Core Drilling: Provides core samples for identifying rock types, studying geological formations, and reconstructing the Earth's history.
ii. Rotary Drilling: Used to create deep boreholes to obtain information about the subsurface geology and map bedrock formations.
iii. Geophysical Logging: Offers insights into the physical properties of rock formations, aiding in geological interpretation and mapping.

Additional Applications includes:

i. Archaeology: Investigating buried archaeological sites and artifacts.
ii. Geothermal Exploration: Locating and assessing geothermal energy resources.
iii. Glaciology: Studying ice sheets and glaciers to understand climate change.
iv. Seismology: Installing seismic instruments to monitor earthquakes and study the Earth's interior.

3.2 Application of drilling in engineering

Drilling is a fundamental technique across various engineering disciplines, playing a crucial role in construction, mining, exploration and more. Here are some of the key applications of drilling in engineering.

Foundation drilling: creating holes for foundation of buildings, bridges, and other structures. Different drill types like augers, rotary hammers, and core drills are used depending on the soil conditions and foundation depth.

Micro pilling: reinforcing weak soil or supporting existing structures using small diameter piles installed through precise drilling.

Tunnel construction: drilling pilot holes for tunnel boring machines or blasting holes for excavation in traditional tunneling method.

Utility installation: drilling trenches for underground pipes and cables for water, sewers, electricity, and other utilities. Horizontal directional drilling (HDD) allows for trenchless installation under obstacles like roads or waterways.

Geotechnical investigation:

Site investigation: investigating soil and rock conditions for construction projects, foundations, and slope stability analysis.

4.0 CASE HISTORY OF PROBLEMS OF DRILLING IN PETROLEUM INDUSTRY

4.1 Case History 1: Wellbore Collapse During Exploration in the North Sea

4.1.1 Background

The Ekofisk field, located in the Norwegian sector of the North Sea, presents drilling challenges due to the presence of weak Ekofisk Formation chalk (Aadnoy et all 1996). In 1994, during the drilling of exploration well 11/6A-6, a wellbore collapse occurred in the chalk formation at approximately 3,090 meters below the surface (Aadnoy et all 1996). This incident serves as a well-documented example of wellbore instability problems in the petroleum industry.

4.1.2 Drilling Problems Encountered

While drilling the wellbore through the Ekofisk Formation chalk, a wellbore collapse incident occurred (Aadnoy et all 1996). The collapse resulted in significant challenges:

i. Stuck pipe: The drill pipe became lodged in the collapsed wellbore section, hindering further drilling operations (Aadnoy et all 1996).
ii. Loss of wellbore integrity: The collapse compromised the wellbore's structural integrity, jeopardizing the entire drilling campaign (Zoback 2007)

4.1.3 Causes of Wellbore Collapse

The wellbore collapse in well 11/6A-6 was attributed to a combination of factors (Aadnoy et all 1996) (Zoback 2007).

i. Formation characteristics: The Ekofisk Formation chalk is known for its low mechanical strength, high porosity, and sensitivity to pressure changes (Aadnoy et all 1996).
ii. Wellbore trajectory: The wellbore trajectory included a deviated section through the chalk formation, which can induce higher stresses on the wellbore wall compared to a vertical wellbore (Zoback 2007).
iii. Pore pressure depletion: The drilling process can reduce the pressure of formation fluids within the chalk, weakening the rock matrix and contributing to instability (Aadnoy et all 1996).

4.1.4 Consequences of Wellbore Collapse

The wellbore collapse resulted in several negative consequences for the drilling project:

i. Cost overruns: The time and resources required to address the stuck pipe incident and sidetrack the wellbore significantly increased the overall drilling cost (Zoback 2007).
ii. Schedule delays: The wellbore collapse caused substantial delays in the drilling program, impacting the project timeline (Zoback 2007).
iii. Potential environmental impact: The incident necessitated the use of additional drilling fluids and lost circulation materials, posing a potential environmental risk if not managed effectively (Zoback 2007).

4.1.5 Solutions Implemented

To overcome the wellbore collapse and continue drilling the well, the following solutions were implemented:

i. Wellbore reaming: The collapsed section of the wellbore was reamed to remove debris and allow passage for the drill pipe (Aadnoy et all 1996).
ii. Sidetrack drilling: A sidetrack was drilled to bypass the collapsed section and continue wellbore construction towards the target reservoir (Aadnoy et all 1996).
iii. Mud weight optimization: The drilling fluid properties were adjusted to provide better wellbore wall support and prevent further collapse in the chalk formation (Zoback 2007).

4.1.6 Outcomes

By implementing these corrective actions, the drilling team was able to overcome the wellbore collapse and successfully complete the drilling of well 11/6A-6 [1]. However, this incident highlights the critical importance of proactive wellbore stability analysis, considering formation characteristics, wellbore trajectory, and appropriate drilling fluid design to ensure wellbore integrity during drilling operations in challenging formations.

4.2 Case History 2: Lost Circulation in a Deepwater Well Offshore Brazil

4.2.1 Background

Deepwater drilling presents unique challenges, including encountering fractured and depleted formations prone to lost circulation events. Lost circulation refers to the uncontrolled escape of drilling fluids into the formation, which can lead to several problems (Bellar., et al 1990) This case history examines a lost circulation incident during the drilling of a deepwater well offshore Brazil.

4.2.2 Drilling Problem Encountered

While drilling a well in the Santos Basin, a critical area for Brazilian oil production, the drilling team encountered a severe lost circulation event at approximately 2,400 meters below the seafloor (Bellar., et al 1990). The wellbore intersected a fractured and depleted reservoir formation, causing drilling fluids to leak into the formation and hindering drilling progress (Misra., et al 2010).

i. Impacts of Lost Circulation: Lost circulation events can have significant negative consequences for drilling operations, as experienced in this case:
ii. Formation collapse: The loss of drilling fluids can reduce pressure support on the wellbore walls, potentially leading to wellbore instability and collapse (Bellar., et al 1990).
iii. Stuck pipe: Lost circulation events can cause differential sticking, where the drill pipe becomes stuck due to the pressure variations between the wellbore and the formation (Misra., et al 2010).

iv. Increased drilling costs: Lost circulation incidents necessitate additional operations to regain circulation and can significantly increase drilling costs (Misra., et al 2010).

4.2.3 Solutions Implemented

To address the lost circulation event and continue drilling the well, the following solutions were adopted:

i. Lost circulation materials (LCM): Specific materials were pumped into the drilling fluid to help plug the formation fractures and minimize fluid loss (Bellar., et al 1990).
ii. Wellbore strengthening: Depending on the severity of the lost circulation, wellbore strengthening techniques like casing liners or wellbore enlargements might be employed to improve wellbore stability (Misra., et al 2010).
iii. Managed pressure drilling (MPD): This technique allows for precise control of the bottomhole pressure, helping to maintain wellbore stability and mitigate lost circulation events (Misra., et al 2010).

4.2.4 Outcomes

By implementing these corrective actions, the drilling team was able to regain circulation and continue drilling the well (Bellar., et al 1990). This case history emphasizes the importance of proactive measures to identify potential lost circulation zones during well planning and utilizing appropriate drilling fluids and techniques to mitigate this drilling problem.

5.0 CONCLUSION

In conclusion, drilling method emerge as a cornerstone technology with wide range of applications in engineering, geology and notably, the petroleum industry. The study shows the crucial role played by drilling techniques in resource exploration, environmental assessment, and infrastructure development. The challenges faced in the petroleum industries including drilling problems such as lost circulation, well bore collapse were also highlighted in the case history.

As the demand for energy resources continues to rise, the integration of cutting-edge drilling method becomes imperative. The relationship between engineering and geology, facilitated by drilling technologies, contributes significantly to sustainable resource management and environmental studies. By addressing drilling challenges in the petroleum industries, researchers and practitioners can enhance efficiency, reduce environmental impact, and ensure responsible extraction of hydrocarbons.

REFERENCES

Aadnoy, S., et al. (1996). Wellbore Stability Challenges in the Ekofisk Field - A Case Study. Presented at the SPE/IADC Drilling Conference, Amsterdam, Netherlands, March 5-8.

Abidin, M.H. Z., Saad, R., Ahmad, F., Wijeyesekera, D. C., & Baharuddin, M.F.T., 2011. Application of Geophysical methods in Civil Engineering. In Malaysian Technical Universities International Conference on Engineering and Technology; pp. 35.

Austin, E. H. 2012. Drilling engineering handbook. Springer Science and Business media.

Bellar, J. A., et al. 1990. Lost circulation: Mechanisms, causes, and cure. Presented at the SPE Annual Technical Conference and Exhibition, New Orleans, LA.

Bornemann. E., Bourgeois, T., Bramlett, K., Hodenfield, K., & Maggs, D. 1998, may. The application and accuracy of geological information from Logging-while -drilling density tool. In SPWLA Annual logging Symposium (pp. SPWILA-1998).

Chen, C., Ji, G., Wang, H., Huang, H., Baug, P., & Wu, Q. 2022. Geology-engineering integration to improve drilling speed and Safety in ultra-deep clastic reservoirs of qiulitage structural belt. Advances in Geo-Energy Research; 6(4), 347-356.

Curt, T. (2017, December). Auger Drilling phases. [Scientific Diagram] ResearchGate. https://www.researchgate.net/publication/321886597_COLUMBIA_UNIVERSITY_MANHATTANVILLE_CAMPUS_CONSTRUCTION_PROJECT_PHASE_II/figures?lo=1

Einar J.L (2020, August). Percussive duplex drilling methods and drill bits used for overburden drilling. [Scientific Diagram] ResearchGate. https://www.researchgate.net/publication/343367436/figure/fig1/AS:919771222654976@1596301956369/Rotary-percussive-duplex-drilling-methods-and-drill-bits-used-for-overburden-drilling.jpg

Hossain M.E., $ Islam, M. R. 2018. Drilling Engineering Problems and Solutions: A field Guide for Engineers and students. John Wiley & Sons: PP(82-84).

Inglis, T. (n.d.). Directional Drilling. Springer Science & Business Media.

Inglis, T. (n.d.). Sidetracking around a fish. [Scientific Diagram]. Springer Science & Business Media.

Jurij .S. (2017, January). *Diagram Illustrating the processes of core drilling*. [Scientific Diagram] ResearchGate. https://www.researchgate.net/publication/318147909/figure/fig4/AS:668322748174346@1536351968651/The-process-of-core-drilling-using-the-high-frequency-method.png

Krynine, D. P., Judd, W. R., & Krynine, D. P. 1957. Principles of engineering geology and geotechnics. New York: McGraw-Hill: (PP.1-3).

Lavis, J. (n.d.) Directional Drilling: Everything You Ever Wanted To Know. Retrieved from https://drillers.com/directional-drilling-everything-you-ever-wanted-to-know/

Mansour, K. (2009, January). *Schematic Diagram of a Rotary Drill Rig*. [Scientific Diagram] ResearchGate. https://www.researchgate.net/figure/Representative-schematic-of-a-rotary-drill-rig_fig1_267591385.

Misra, M. I., et al. 2010. Lost circulation: A review of mechanisms and mitigation techniques. Journal of Petroleum Technology, 62(6), 116-125.

progryndpumps. (2023, September 18). Whipstock: A Key Tool for Directional Drilling in Oil and Gas Wells. Retrieved from Whipstock: A Key Tool for Directional Drilling in Oil and Gas Wells | by progryndpumps | Medium

Rai, P., Schunesson, H., Lindquist, P. A., & Kumar, U. 2015 An overview on measurement-while -drilling techniques and its Scope in excavation industry. Journal of the Institution of Engineers (India): Series D, 96, 57-66

Shan, Q., $ Qin, T. 2019. The improved drilling cutting method and its engineering application. Geotechnical and Geological Engineering; 37, 3715-3726.

The International Journal of manufacturing Technology. (2020, January). Diagram of abrasive water jet drilling processes. [Scientific Diagram] ResearchGate. https://www.researchgate.net/publication/338005218_Developments_of_non-conventional_drilling_methods-a_review/figures?lo=1

Zoback, M. D. (2007). Wellbore Breakouts and In-Situ Stresses in Deep Wells. SPE Drilling & Completion, 22(2), 186-194.

Zongqi, C.H.E.N., Xianguia, L.I.U., Binzhan, B.A.I., & Hao, Y. I. 2022. Technical progress and development Consideration of drilling and completion engineering for ultra-deep wells in the shunned oil and gas field 50(H), 1-10.