references:


Fundamentals of Drilling

drilling means to **make a hole** in order to get access to the earth’s subsurface

**Objectives may be**

- gaining information about the subsurface from sampling/testing/logging
  \[\Rightarrow \text{hole discarded}\]
- production/injection of fluids/gases (oil/gas/water)
  \[\Rightarrow \text{hole completed into well}\]
- monitoring of subsurface properties (aquifer pressure, stress state, etc.)
  \[\Rightarrow \text{hole completed into well}\]

Objectives define hole/well construction
Fields of Drilling Applications

Exploration/Production of Natural Resources
- Oil and Gas
- Water
- Geothermal Energy

Site Investigation
- Scientific
- Foundation/Construction
- Environmental

Mining Exploration

Blast Hole/Seismic
- Quarry
Fields of Drilling Applications

Exploration/Production of Natural Resources
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Mining Exploration

Blast Hole/Seismic
- Quarry
Drilling Techniques – Classification by Hole Making Methods

- **Discontinuous Process**
  - Cable

- **Continuous Process**
  - Standard Rotary
  - Slim-Hole Rotary

- **Soft formation only**
  - Hydraulic
  - Auger

- **Clearing Methods**
  - Fluid Clearing
  - Mechanical Clearing

- **Breaking Methods**
  - Rock Breaking
  - Excavating
very old drilling technique (applied more than 2000 years ago by the Chinese)

**2 Phase Technique** *(discontinuous)*

**Phase 1: Rock Drilling**
free falling bit strikes the bottom with a heavy blow – repeated lifting and dropping makes the bit drill

**Phase 2: Removal of Cuttings**
interruption of drilling to remove cuttings by bailing

- suitable only for hard rock
- total efficiency of drilling process is fairly low
Principles of Drilling Techniques – Percussion Cabel Tool Drilling
Principles of Drilling Techniques – Percussion Cabel Tool Drilling
Drilling Fluid is circulated by being pumped down the drill string.

The Drill String is rotated to turn the bit; it is fed down as the bit penetration.

Bit is pushed into the bottom and rotation makes it cut.

Return circulation carries cuttings up the annulus between the drill string and the wall of the hole.

Key Elements:
- Drill Bit
- Drill String
- Drilling Fluid
### Types of Rotary Bits

#### Performance Parameters of Drill Bits:
- **Penetration Rate** (Drilling Speed: m/h)
- **Bit Life** (Meters Drilled)

#### Rock Characterization

<table>
<thead>
<tr>
<th>Rock Characterization</th>
<th>Soft</th>
<th>Very Hard</th>
<th>Medium Hard</th>
<th>Soft</th>
</tr>
</thead>
</table>

- **Roller Cone Bit**
  - **Milled Steel Tooth**
  - **Tungsten Carbide (inserts)**
- **Diamond Bit**
  - **Natural Diamonds**
  - **Polycrystalline Diamond Compact Cutters**
Cutting Action of Rotary Drill Bits

Roller Cone Bits
Percussion Bits

Chip Making
Hammer

Roller Cone Bits
Diamond Bits

Chip Making
Shovel
Pushed in

Roller Cone Bits with Offset
Diamond Bits

Chip Clearing
Rake

Nozzles of Roller
Cone Bits
Water Jet
Cones of Roller Bits do only roll on the bottom but always slide, tear and gouge. Offset of cones increases sliding, tearing, gouging action.
Elements of Roller Cone Bits

Shape Types of Inserts

- **Soft Formation**
  - Shaped Gauge
  - Sharp Tooth Shape
- **Medium Formation**
  - Chisel Tooth Shape
  - Medium-Extension Conical Shape
  - Short-Extension Conical Shape
- **Hard to Very Hard Formation**
  - 90° Double Conical Shape
  - 120° Double Conical Shape
  - Spherical Shape
Bottom Hole Cleaning of Roller Cone Bits

Schematic of Nozzles Action

Effect of Nozzle Velocity on Rate of Penetration

- Jet sizes are stated by number. The number is the nozzle diameter in \( \frac{1}{32} \) inches.
- Replaceable nozzles allow jets to suit the clearing energy requirement.
- High energy jet action directed on bottom of hole releases chips fractured by bit teeth.

Increasing Nozzle velocity

Graph showing the effect of nozzle velocity on rate of penetration (ROP) with WOB (Weight on Bit) as a variable.
Typical Operating Parameters for Roller Cone Inserts Bits

**Diagram:**
- **Weight × 1,000 lb:** X-axis
- **rpm:** Y-axis

- **high WOB**
- **low RPM**

- **50% of bits**
- **90% of bits**
- **99% of bits**

- **Size:** 7 7/8” - 8 3/4”
Cutting Action of Diamonds

Exposure
Sizes and Texture of Hard Rock Cuttings Dependent on Bit Type
Operating Parameters of Diamond Bits

Rotational Speed
300 – 600 RPM
Mainly used with Downhole Motors/Turbines

Low WOB
High RPM
Typical Rotary Drill String Assembly

The drill string is the mechanical assemblage connection the rotary drive on surface to the drilling bit on bottom of the hole.

Functions of the Drillstring:
- flow line for circulating drilling fluid
- provides weight on bit
- transmits rotation and torque to bit
- guides and controls trajectory of the bit

Main Components:
- **Drill Collars:** thick wall steel pipe with Pin/Box threaded connection
- **Drill Pipe:** steel pipe with Pin/Box threaded toolioints

Ancillary Components:
- crossover subs
- stabilizers
- reamers
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- Drill Collars: thick wall steel pipe with Pin/Box threaded connection
- Drill Pipe: steel pipe with Pin/Box threaded tool joints

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- Reamers
Typical Rotary Drill String Assembly

The drill string is the mechanical assemblage connection the rotary drive on surface to the drilling bit on bottom of the hole.
Rotary Drillpipes are standardized by API

<table>
<thead>
<tr>
<th>Outer Diameter of Pipe Body</th>
<th>Steel Grades of Pipe Body</th>
<th>Nominal Weight of Pipe Body</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E – 75</td>
<td></td>
</tr>
<tr>
<td>5 ½“</td>
<td>X – 95</td>
<td></td>
</tr>
<tr>
<td>5“</td>
<td>G – 105</td>
<td></td>
</tr>
<tr>
<td>4 ½“</td>
<td>S – 135</td>
<td></td>
</tr>
<tr>
<td>4“</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 ½“</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 7/8“</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 3/8“</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1“</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 ft = 30.48 cm

Tool Joints Steel Grade: 120 000 psi (827.4 Mpa)
Thread Type: NC 50, NC 38
Friction welded with upset pipe body annealed and machined

Pipe Length
Range 1: 18 – 22 ft
Range 2: 27 – 30 ft
Range 3: 38 – 45 ft

1 ft = 30.48 cm
Rotary Drillpipe Characteristics

<table>
<thead>
<tr>
<th>Tooljoint</th>
<th>Welded</th>
<th>Pin and Box Tooljoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit Sub</td>
<td>Bit Sub</td>
<td>Kelly Saver Subs</td>
</tr>
<tr>
<td>Straight O.D. Subs</td>
<td>BOX x PIN</td>
<td>Box x Box</td>
</tr>
<tr>
<td></td>
<td>BOX x PIN</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BOX x BOX</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PIN x PIN</td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
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</tbody>
</table>

Nominal Weight of Pipe Body
- Tool Joints Steel Grade: 120,000 psi (827.4 Mpa)
- Thread Type: NC 50, NC 38
- Friction welded with upset pipe body annealed and machined

Steel Grades of Pipe Body
- E – 75
- X – 95
- G – 105
- S – 135

Outer Diameter of Pipe Body
- 5 ½" (139.7 mm)
- 5" (127 mm)
- 4 ½" (114.3 mm)
- 4" (101.6 mm)
- 3 ½" (91.4 mm)
- 2 7/8" (73.0 mm)
- 2 3/8" (60.3 mm)
- 1" (25.4 mm)

1" = 2.54 cm
Drill pipe is the most stressed component of rotary equipment!!!
Putting Weight on Bit by Drill Collars

Buckling of Drillpipe under Compressional Load!
Typical Examples for Stabilized Bottom Hole Assemblies (BHA)

- Non-Mag Collar
- Stabilizer
- MWD/LWD
  - Runs with Most MWD/LWD Operations & Suppliers
  - Collar Sizes:
    - 9 3/4" - 8" - 6 3/4" - 4 3/4"
    - Contact Gyrodata or your MWD supplier for more information
- Gyro-Guide Probe
- Motor
- Riser with Most Motors and Rotary Steerable Services
- String stabilizer
- 4 9/16-in. drill collar
- Lower DDS sub and MWD
- Adjustable gauge stabilizer
- Near bit stabilizer
- 6 1/8 in. PDC bit
Drilling Fluid – Why it’s Called MUD
Drilling Fluid – Why it’s Called MUD

- Treated Fluid to the Well
- Returns from the Well
- Removal Section
- Additions Section
- Suction and Testing Section
Drilling Fluid – Why it’s Called MUD
Drilling Fluid – Why it’s Called **MUD**

Mud coming out of hole (beneath shaker screens)
Drilling Mud – A Multipurpose Fluid

Major Functions:

- Bottomhole Cleaning
- Cuttings Transport
- Borehole Wall Support
- Balancing Formation Pressure
- Cooling the Bit
- Hydraulic Power Transmission
- Data transmission (MWD)
- Reducing Friction
- Corrosion Protection
- Scientific Information Carrier
Drilling Fluid Circulating Pumps

Typical Operating Parameters:

- max pressure: 35 Mpa
- 17 ½“ = 3 500 l/min
- 12 ¼“ = 2 500 l/min
- 8 ½“ = 1 500 l/min
- 6“ = 600 l/min

heavyweight rigs => 2 pumps 1 200 kW
lightweight rigs => 2 pumps 600 kW
Drilling Fluid Circulating Pumps

Typical Operating Parameters:
- Max pressure: 35 MPa
- 17 ½" = 3,500 l/min
- 12 ¼" = 2,500 l/min
- 8 ½" = 1,500 l/min
- 6" = 600 l/min

Heavyweight rigs => 2 pumps 1 200kW
Lightweight rigs => 2 pumps 600 kW
Principal Functions of a Rotary Drilling Rig

- **Hoisting System**: Put Weight on the Bit/Handling the Drillstring
- **Pumping/Circulation System**: Circulate Fluid/Solids Control
- **Rotating System**: Rotate the Bit

**Power Supply**
Main Components of the Hoisting System

- **crown block**
- **derrick/mast**
- **drilling line**
- **travelling block with hook**
- **drawworks**
- **deadline anchor (where hookload is measured)**

- **Fast Line**
- **Dead Line**
Schematic of a Rotary Rig’s Block and Tackle

Drilling line work is the product of the load times the distance travelled.

(a) Arrangement and nomenclature of block and tackle.

(b) Free body diagram of traveling block.

(c) Free body diagram of crown block.
Hoisting System of Drilling Rigs – Hoisting Tower

Structural tower assembled/ dismantled piece by piece

Assembling/ dismantling is time consuming

Used mainly offshore

Square shaped rig floor
Hoisting System of Drilling Rigs – Hoisting Tower

A-shaped structure which can be pulled or lowered to a upright position by the drawworks without completely assembling or disassembling

Good mobility

Used mainly with onshore rigs
Rotary Rig Drawworks

Advantages of Gear Driven Drawworks:

• high performance
• high availability
• less noise
• less vibration
• increased safety
Rotating the Drillstring with a Rotary Table
Rotating the Drillstring with a Rotary Table
Rotating the Drillstring with a Top Drive

TOP DRIVE means a Power Swivel which directly turns the drillstring without need for a kelly and rotary table

Advantages of a Top Drive System:
- drill string can be pulled out while rotating and circulating → Back Reaming
- can be reconnected to the drill string at any mast height during tripping
- drilling with 3-joint stands of drill pipe is possible
- with hydraulic driven power swivel static torque can be applied for much longer time

Save time!!!
Safer and easier operation!!!
Rotating the Drillstring with a Top Drive

**TOP DRIVE** means a **Power Swivel** which directly turns the drillstring without the need for a kelly and rotary table.

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- Drilling with 3-joint stands of drill pipe is possible with a hydraulic driven power swivel.
- Static torque can be applied for much longer time.

**Save time!!! Safer and easier operation!!!
Classification of Drilling Rigs

Classification by Depth Rating:
- lightweight rigs: 1 500 – 2 000 m
- intermediate rigs: 3 500 m
- heavyweight rigs: 6 000 m
- ultraheavy rigs: 8 000 – 10 000 m

Classification by Horsepower:
- lightweight rigs: 650 HP (484.7 kW)
- intermediate rigs: 1 300 HP (969.4 kW)
- heavyweight rigs: 2 000 HP (1491 kW)
- ultraheavy rigs: 3 000 HP (2 237 kW)

Rule of Thumb: every 100 ft (30.5 m) of borehole requires 10 HP (7.5 kW) at drawworks
Typical Rig Organization Scheme
<table>
<thead>
<tr>
<th>Drilling Contracts</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Footage Contracts</strong></td>
<td>Operator pays the contractor a <strong>stipulated amount for each foot or meter</strong> drilled regardless of how long it takes the contractor to drill it. <strong>Contractor assumes many of the risks of drilling</strong></td>
</tr>
</tbody>
</table>
| **Daywork Contracts** | Operator pays a **stipulated amount per hour** based on the work the rig and crew are doing:  
  - Drilling time  
  - Standby Time (Logging, Testing, etc) |
| **Combination Contracts** | Combination of Footage and Dayrate Contracts |
| **Turnkey Contracts** | Operator pays an **agreed-on amount** when the contractor **completes the well**. Contractor furnishes all equipment, material and personnel to drill the well. **Contractor controls the entire drilling operation** with little or no supervision. **Contractor assumes all the risks and adjusts the price** charged to reflect these risks. **Operator benefits by not assuming any risks**. |
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