Fundamentals of Drilling – Course Outline

(1) Basics of Rotary Drilling
(2) Rotary Operations/Coring - Rotary Process
(3) Directional Drilling - Rotary Process
(4) Fishing - Bit
(5) Casing/Drill String and Well Control
(6) Principles of Drilling Fluid Technology
(7) Principles of Borehole Stability
(8) Principles of Hydraulic Testing
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
  - Hole discarded
- Production/injection of fluids/gases (oil/gas/water)
  - Hole completed into well
- Monitoring of subsurface properties (aquifer pressure, stress state etc)
  - 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
Drilling Techniques – Classification by Hole Making Methods

Discontinuous Process
- Cable
- Standard Rotary
- Slim-Hole Rotary
- Hydraulic

Continuous Process

Soft formation only
Principles of Drilling Techniques – Percussion Cable Tool Drilling

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 - Rotary 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 penetrates.

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

B. Engeser/Fundamentals of Drilling (1)
Types of Rotary Bits

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

Rock Characterization
- Soft
- Very Hard
- Medium Hard
- Soft

<table>
<thead>
<tr>
<th>Soft</th>
<th>Very Hard</th>
<th>Medium Hard</th>
<th>Soft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roller Cone Bit Milled Steel Tooth</td>
<td>Roller Cone Bit Tungsten Carbide Inserts</td>
<td>Diamond Bit Natural Diamonds</td>
<td>Diamond Bit Polycrystalline Diamond Compact Cutters</td>
</tr>
</tbody>
</table>

B. Engeser/Fundamentals of Drilling (1)
Cutting Action of Rotary Drill Bits

Roller Cone Bits
Percussion Bits

Chip Making

Rock Crumbles

Roller Cone Bits
Diamond Bits

Chip Making

Shovel Pushed In.

Roller Cone Bits with Offset
Diamond Bits

Chip Clearing

Chips

Nozzles of Roller Cone Bits

WATER JET

Chips
Cutting Action of Rotary Drill Bits

Cone of Roller Bits do not only roll on the bottom but always slide, tear and gouge.

Offset of cones increases sliding, tearing gouging action.

Direction of Rotation

Hard Rock  Soft Rock
Elements of Roller Cone Bits

- Cone
- Inserts
- Shank
- Cone
- Journal Bearing
- Ball Bearings
- Lubricant Reservoir
- Pressured Compensator
- Jet Nozzle
- Threaded Joint

Shape Types of Inserts

**Soft Formation**
- Shaped Gauge
- Sharp Tooth Shape

**Medium Formation**
- Tooth Shape
- Long-Extension Conical Shape

**Hard to Very Hard Formation**
- Chisel Tooth Shape
- Medium-Extension Conical Shape
- Short-Extension Conical Shape
- 90° Double Conical Shape
- 120° Double Conical Shape
- Spherical Shape
### IADC Roller Cone Bit Classification

<table>
<thead>
<tr>
<th>First Figure Series</th>
<th>Second Figure Hardness (1 – 4)</th>
<th>Third Figure Design Option</th>
</tr>
</thead>
</table>

#### Example: 5-1-7

**Sealed Journal Bearing**

**Roller Cone Bit with Tungsten Carbide Inserts**

**IADC-Code: 5-1-7**
Bottom Hole Cleaning of Roller Cone Bits

Schematic of Nozzles Action

Effect of Nozzle Velocity on Rate of Penetration

Increasing Nozzle velocity

B. Engeser/Fundamentals of Drilling (1)
Typical Operating Parameters for Roller Cone Insert Bits

- high WOB
- low RPM

Size:
- 7 7/8” - 8 ¾”

B. Engeser/Fundamentals of Drilling (1)
Cutting Action of Diamond Bits

Cutting Size

- Shearing
- Plowing
- Grinding

PDC-Bit
Surface set diamond bit
Impregnated Diamond Bit

B. Engeser/Fundamentals of Drilling (1)
Cutting Action of Diamonds

Exposure

\[
\frac{\text{LOAD}}{\text{AREA}} \leq \text{STRENGTH OF ROCK}
\]

\[
\frac{\text{LOAD}}{\text{AREA}} \geq \text{STRENGTH OF ROCK}
\]

B. Engeser/Fundamentals of Drilling (1)
Sizes and Texture of Hard Rock Cuttings dependent on Bit Type

course chips

fine flour

B. Engeser/Fundamentals of Drilling (1)
Operating Parameters of Diamond Bits

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

Low WOB
High RPM
The **Drillstring** is the Mechanical Assemblage Connecting 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 Tooljoints:
- **Ancillary Components**
  - Crossover subs
  - Stabilizers
  - Reamers

B. Engeser/Fundamentals of Drilling (1)
Rotary Drillpipe Characteristics

Rotary DP is 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>
<th>Pipe Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 ½”</td>
<td>E-75</td>
<td></td>
<td>Range 1: 18-22 ft</td>
</tr>
<tr>
<td>5”</td>
<td>X-95</td>
<td></td>
<td>Range 2: 27-30 ft</td>
</tr>
<tr>
<td>4 ½”</td>
<td>G-105</td>
<td></td>
<td>Range 3: 38-45 ft</td>
</tr>
<tr>
<td>4</td>
<td>S-135</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 ½”</td>
<td></td>
<td>Wall Thickness</td>
<td></td>
</tr>
<tr>
<td>2 7/8”</td>
<td></td>
<td>Friction welded with upset pipe body annealed and machined</td>
<td></td>
</tr>
<tr>
<td>2 3/8”</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

18° shoulder for Elevator

Stands of 3 Thribble

Tool Joints Steel Grade: 120000 psi

Thread Type
- NC 50
- NC 38

Friction welded with upset pipe body annealed and machined

Rotary DP needs sufficient annular clearance due to Tooljoint Sizes

B. Engeser/Fundamentals of Drilling (1)
Design Criteria for Rotary Drill Pipe

Drill Pipe has to be designed for:

- Tension
- Torque
- Twist off
- Burst (Inside Pressure)
- Reversal Stresses
- Fatigue
- Bending While Rotation

Drill Pipe is the most stressed component of rotary equipment.
Drillpipe Stands and Drillcollars set on the Rig Floor
Putting Weight on Bit by Drill Collars

Buckling of Drillpipe under compressional load

B. Engeser/Fundamentals of Drilling (1)
Typical Examples for Stabilized Bottom Hole Assemblies (BHA)
Drilling Fluid – why it’s called Mud

Mud coming out of hole
(beneath shaker screens)

Mud going into hole
(Suction pit)
Drilling Mud – A Multipurpose Fluid

Major Functions

(1) Bottomhole Cleaning
(2) Cuttings Transport
(3) Borehole Wall Support
(4) Balancing Formation Pressure
(5) Cooling the Bit
(6) Hydraulic Power Transmission
(7) Data Transmission (MWD)
(8) Reducing Friction
(9) Corrosion Protection
(10) Scientific Information Carrier
Principal Functions of a Rotary Drilling Rig

- Hoisting System
- Pumping/Circulation System
- Rotating System

Put Weight on the Bit/Handling the Drillstring
Circulate Fluid/Solids Control
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)
Drilling line work is the product of the load times the distance travelled.
Height governs the maximum length of Drillpipe Stands:
- 2-joint stands (18 m)
- 3-joint stands (27 m)

Structural tower assembled/dismantled piece by piece
Assembling/Dismantling is time consuming
Used mainly offshore

Square shaped Rig floor

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
Types of Rotary Rig Drawworks

Chain driven drawworks

Modern gear driven drawworks

Advantages of gear driven drawworks:
• High performance
• High availability
• Less noise
• Less vibration
• Increased safety
Methods of Rotating the Bit

- Rotating the Bit Using a Downhole Motor/Turbine
- Rotating the Drillpipe directly by a Top Drive or Power Swivel which moves down with the pipe
- Rotating a Rotary Table which turns the Drillpipe as it slides through which moves down with the pipe
Rotating the Drillstring with a Rotary Table

- Swivel: sustains weight of drill string
- Kelly: permits rotation
- Rotary Table: provides passageway for drilling fluid
  - Rotating seal allows drilling fluid to be injected under pressure

Kelly
- Standard Length: 40 ft (12.2 m)

B. Engeser/Fundamentals of Drilling (1)
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

Saves time
Safer and easier operation

Requires trolley beam guide system to be installed in the derrick
Circulation and Solids Control System of a Rotary Rig
Flow Scheme and Main Components
Drilling Fluid Circulating Pumps

Typical Operating Parameters

max. pressure: 35 MPa

17 ½": 3500 l/min
12 ¼": 2500 l/min
8 ½": 1500 l/min
6": 600 L/min

heavyweight rigs
2 pumps 1200 kW each

lightweight rigs
2 pumps 600 kW each
### Power Supply System of Rotary Drilling Rigs

<table>
<thead>
<tr>
<th>Depth reached (m)</th>
<th>Hook load (t)</th>
<th>Drawworks rating (kW)</th>
<th>Pump rating (kW)</th>
<th>Total installed capacity (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6000-9000</td>
<td>400-600</td>
<td>1500</td>
<td>2000-2600</td>
<td>3000-3750</td>
</tr>
<tr>
<td>4000-6000</td>
<td>300-400</td>
<td>1100</td>
<td>1800-2000</td>
<td>2250-3000</td>
</tr>
<tr>
<td>3000-4000</td>
<td>200-300</td>
<td>750</td>
<td>1100-1800</td>
<td>1850-2250</td>
</tr>
<tr>
<td>900-3000</td>
<td>100-170</td>
<td>300-525</td>
<td>750-1100</td>
<td>1100-1850</td>
</tr>
</tbody>
</table>

- **DC-DC Concept**
- **AC-DC/SCR-Concept**
Classification of Drilling Rigs

Classification by **Depth Rating**
- Lightweight Rigs: 1500 – 2000 m
- Intermediate Rigs: 3500 m
- Heavyweight Rigs: 6000 m
- Ultraheavy Rigs: 8000 – 10000 m

Classification by **Horsepower**
Rule of Thumb:
Every 100 ft of borehole Requires 10 hp at drawworks

Diamond Drilling Rig
- Lightweight Rigs: 650 hp
- Intermediate Rigs: 1300 hp
- Heavyweight Rigs: 2000 hp
- Ultraheavy Rigs: 3000 hp
Typical Rig Organization Scheme
## Drilling Contracts

<table>
<thead>
<tr>
<th>Contract Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Footage Contracts</strong></td>
<td>Operator pays the contractor a <strong>stipulated amount</strong> for each foot or meter drilled <strong>regardless of how long</strong> it takes the contractor to drill it. <strong>Contractor</strong> assumes many of the risks of drilling.</td>
</tr>
<tr>
<td><strong>Daywork Contracts</strong></td>
<td>Operator pays a <strong>stipulated amount per hour</strong> based on the work the rig and crew are doing.</td>
</tr>
<tr>
<td></td>
<td>• Drilling time</td>
</tr>
<tr>
<td></td>
<td>• Standby Time (Logging, Testing, etc)</td>
</tr>
<tr>
<td><strong>Combination Contracts</strong></td>
<td>Combination of Footage and Dayrate Contracts</td>
</tr>
<tr>
<td><strong>Turnkey Contracts</strong></td>
<td>Operator pays an <strong>agreed-on amount</strong> when the contractor <strong>completes the well</strong>. Contractor furnishes all equipment, material and personnel to drill the well. <strong>Contractor</strong> controls the entire drilling operation with little or no supervision. <strong>Contractor</strong> assumes all the risks and adjusts the price charged to reflect these risks. <strong>Operator</strong> benefits by not assuming any risks.</td>
</tr>
</tbody>
</table>

B. Engeser/Fundamentals of Drilling (1)
Average Meter Costs dependent on Depth

Source: 1999 Joint Association Survey on Drilling Costs

- **Deepwater Gulf**
- **Europe Onshore**
- **South Louisiana**
- **Offshore LA**
- **Federal OCS**
- **North Louisiana**

Avg. Cost ($/m)
Semisubmersible: 160,000 $
Drillship (Dyn. Pos): 150,000 $
KTB-Rig: 90,000 $

*Publicly Traded Company Reported Utilization

Source: Company Reports, Land Rig Newsletter