Fundamentals of Drilling – Course Outline

(1) Basics of Rotary Drilling
(2) Rotary Operations/Coring
(3) Directional Drilling
   - Fields of Application
(4) Fishing - Planning of Well Course
(5) Casing/Completion - Measuring Equipment
(6) Well Control - Fluid Technology
(7) Principles of Drilling - Steering Equipment
(8) Principles of Borehole Stability
(9) Principles of Hydraulic Testing
Reasons for Directional Drilling/Deviation Control

(1) to reach a planned target area

Paired Geothermal Wells

- Producing well (hot water)
- Injection well (cold water)

Hot water reservoir

Targets beneath inaccessible Sites

- Many Wells from the same Site (offshore)
- Relief wells to control a blowout
- Well drilled under a mountain
Reasons for Directional Drilling/Deviation Control

(2) to obtain/control a planned hole trajectory

Preventing Hole Deviation
Limiting Crookedness
(Dog Leg Severity)

Dogleg
Abrupt Change
Of Inclination/Azimuth
Reasons for Directional Drilling/Deviation Control
(3) to sidetrack or abandon a portion of a hole
Terminology of Directional Well Profiles

Radius of Curvature = Buildup Rate

True Vertical Depth TVD

B. Engeser/Fundamentals of Drilling (3)
Classification of Buildup-Rates

<table>
<thead>
<tr>
<th>Classification</th>
<th>Build Rate (°/100 ft)</th>
<th>Radius (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long</td>
<td>2 to 8</td>
<td>2865 to 716</td>
</tr>
<tr>
<td>Medium</td>
<td>8 to 30</td>
<td>716 to 191</td>
</tr>
<tr>
<td>Intermediate</td>
<td>30 to 60</td>
<td>191 to 95</td>
</tr>
<tr>
<td>Short</td>
<td>60 to 200</td>
<td>95 to 28</td>
</tr>
</tbody>
</table>

B. Engeser/Fundamentals of Drilling (3)
A Wellbore Course is a Curve in 3D-Space

3D-Curve is determined by 3 Coordinates
X = West-East
Y = South-North
Z = Vertical Depth

Coordinates must be determined from Measurements between 2 Points of the Hole
Calculation of Coordinates by Radius of Curvature Method

Section between 2 Survey Points is assumed to be a spherical arc

3D-Coordinates

General case: \( A_1 \neq A_2, \ l_1 \neq l_2, \ i_i = \frac{l_i \cdot \pi}{180}, \ a_i = \frac{A_i \cdot \pi}{180} \)

\[
\Delta \text{North}_i = \frac{\Delta MD}{(i_2 - i_1)(a_2 - a_1)} (\sin A_2 - \sin A_1) (\cos l_1 - \cos l_2)
\]

\[
\Delta \text{East}_i = \frac{\Delta MD}{(i_2 - i_1)(a_2 - a_1)} (\cos A_1 - \cos A_2)(\cos l_1 - \cos l_2)
\]

\[
\Delta \text{Vert}_i = \frac{\Delta MD}{i_2 - i_1} (\sin l_2 - \sin l_1)
\]

Dogleg Severity (DLS) means Curvature of the Hole expressed in Degrees/100ft

\[
\text{DLS} = \frac{100}{\Delta MD} \arccos(\cos l_1 \cdot \cos l_2 + \sin l_1 \cdot \sin l_2 \cdot \cos(A_2 - A_1))
\]

DLS is critical for
- Building of Keyseats
- Torque and Drag
- Casing Running Operation
- Running Logging Sondes

B. Engeser/Fundamentals of Drilling (3)
Key Seat Buildup in Doglegs
Instruments for Directional Measurements

Gyroscope

The Challenge is to integrate these sensible instruments in the downhole equipment and to transmit data while drilling.

B. Engeser/Fundamentals of Drilling (3)
Directional Measurements with Wireline Transmission

Principle of Steering Tool

Drillstring non-rotating

Bit rotated by DHM

Side Entry Sub
Measurement While Drilling (MWD) Techniques

Positive Pressure
Signal transmitted by Mud

Electromagnetic Transmission
Why hole deviation occurs
Equilibrium of Forces at Bit – Cartwheel Analogy

Point of Tangency

\[ WOB = 0 \]

\[ WOB = F_w \]
Influence of Formation Anisotropy

Why hole deviation occurs

Formations have higher drillability perpendicular to the bedding plane than parallel to it.

Basic Assumption

Equilibrium Angle

Situation without Formation Influence
Equilibrium Angle dependent on Foliation Dip Angle, Factor of Anisotropy and WOB

Anisotropy Factor \( h \)

\[ h = \frac{(\text{ROP}_\perp - \text{ROP}_\parallel)}{\text{ROP}_\perp} \]

- \( h = 0.01 \)
- \( h = 0.02 \)
- \( h = 0.03 \)

Weight on Bit

- 60 kN
- 40 kN
- 20 kN

Calculated for 6"-Borehole

B. Engeser/Fundamentals of Drilling (3)
Controlling Hole Inclination by Bottom Hole Assembly (BHA)

BHA = Assembly of Drill Collars and Stabilizers

- **Packed (Angle-Holding) Assembly**
  - Stabilizers
  - 20 to 30 ft
  - 10 to 20 ft
  - 5 to 10 ft

- **Pendulum (Angle-Dropping) Assembly**
  - 20 to 30 ft
  - 30 to 90 ft

- **Fulcrum (Angle-Building) Assembly**
  - 3 to 8 ft
Principle of Packed Hole Assemblies

Basic Idea
3 Points define Borehole Curvature
Controlling Hole Inclination with Adjustable Stabilizers

- **Adjustable Stabilizer 5/8-in. UG**
- **First Stabilizer 3/16-in. UG**

**Holding Angle**

- **3 Points Defining Borehole Curvature**

- **Adjustable Stabilizer 1 1/4-in. UG**
- **First Stabilizer 3/16-in. UG**

**Building Angle**

- **Adjustable Stabilizer Full Gauge**
- **First Stabilizer 3/16-in. UG**

**Dropping Angle**
Controlling Wellbore Trajectory with Steerable DHM

AKO/ABS Motor
- Bit Offset Device: Adjustable Kick-Off Sub and Adjustable Bunt Sub
- Power Section: Navi-Drill Mach 1
- Build Rates: 10" to 24"/100 ft (30 m)

AKO Steerable Motor
- Bit Offset Device: Rigsite Adjustable Kick-Off Sub
- Power Section: Navi-Drill Mach 1 or Mach 2
- Build Rates:

DTU Steerable Motor
- Bit Offset Device: Double-Tilted U-Joint Housing
- Power Section: Navi-Drill Mach 1 or Mach 2
- Build Rates: 1" to 4"/100 ft (30 m)
Types of Downhole Motors used for Directional Drilling

Positive Displacement Motor (PDM)
- Low – Medium RPM
- High Torque
- Ideal for Roller Cone Bits

Turbine Type Motor
- High RPM
- Ideal for Diamond Bits

Characteristics of PDM
- Low – Medium RPM
- High Torque
- Ideal for Roller Cone Bits

Characteristics of Turbines
- High RPM
- Ideal for Diamond Bits
Positive Displacement Motor Components

- Coupling
- Driveshaft
- Stabilizer
- Bearing Pack
- Adjustable Bent Housing
- Dump Valve
- Power Section

B. Engeser/Fundamentals of Drilling (3)
Performance Characteristic of a Positive Displacement Motor

PDM can be adjusted to wide range of operating conditions
Performance Characteristic of Drilling Turbines

Power and Rotational Speed slow down when high torque is required

Stalling Torque
Vertical Drilling System used in KTB Ultradeep Hole
Wellbore Course of KTB Pilothele and Ultradeep hole

Horizontal Projection

KTB Pilothele

VB (4000m)

HB (6000m)

Ultradeep hole Drilled with Vertical Drilling Systems

East

North
Directional Drilling with DHM-Steering Systems

Motor Steering System MSS-6-12 with DIMA and Bent Sub for Directional Drilling

- Stabilizer
- Flexible Non-Magnetic Drill Collar
- Magnetometer (MA)
- Bent Sub
- Mud Pulser
- Drift Indicator (DI)

- Downhole Motor
- Steering Rib
- Drill Bit
- Stabilizer Pad (exchangeable)
Open Hole and Cased Hole Sidetracking with a cement plug
Sidetracking with Oriented Whipstock Technique