Petroleum Geomechanics for Drilling, Completion and Production Cycles

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Outline

- Geomechanical Challenges in Petroleum Fields
- Introduction to Geomechanics
- Drilling and Completion
  - Wellbore Stability
  - Fault Reactivation
- Hydrocarbon Production
  - Reservoir Pressure Reduction (depletion) and Fluid Injection
  - Sand Production
  - Hydraulic Fracturing
  - Compaction and Subsidence
- Summary and Conclusions
Terminologies

- LOT = Leak off pressure test
- Mud Wight = Drilling fluid pressure
- Mud Weight Window = Operating range of drilling fluid pressure inside the wellbore
- Fracture Pressure = Minimum pressure required to create a tensile fracture at the wellbore wall by injecting fluid into wellbore
- Breakout = Shear failure of wellbore wall by applying inadequate wellbore pressure
- Formation = Lithology of wellbore/reservoir (e.g. sandstone, shale, claystone)
- Mud Loss = Significant invasion of drilling fluid into formation
- UCS = Unconfined Compressive Strength (measured in the lab on cylindrical samples)
- Reservoir Depletion = Reservoir (pore) pressure reduction due to production
- Sand Production = Producing unwanted formation sand grains with hydrocarbon
- Fault Reactivation = Slippage of fault surfaces due to pressure and in situ stress change
- Wellbore Stability = Preventing any type of collapse on the wellbore wall
- Cuttings = Expected drilling debris coming out of the wellbore during drilling
- Cavings = Unexpected chunks of failed rocks coming out of the wellbore
Geomechanical Challenges in Petroleum Fields

- Wellbore stability issues (stuck pipe, mud loss, wellbore collapse)
- Reservoir depletion and injection may cause fault reactivation
- Natural fractures, permeable zones and hydraulic fracturing stimulation
- Sand production prediction
- Subsidence
- Casing deformation
- Geomechanical Challenges in Petroleum Fields
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Earth Stresses and Rock Mechanical Properties

- $S_v$: Vertical Stress
- $S_{Hmax}$: Maximum Horizontal Stress
- $S_{hmin}$: Minimum Horizontal Stress
- $P_p$: Pore Pressure

Rock Mechanical Properties:
- UCS, Cohesion, Friction, Elastic Moduli
Field Data Requirements

- Pore Pressure, Wireline Logs, Logging While Drilling Data as GR, Bulk Density, Resistivity, Porosity, Image, Seismic
- Leak-off and microfrac insitu tests to calculate fracture leak-off pressure
- Analysis of wellbore failure using Image logs and “active” geological structures
- Laboratory measurements, logs, analysis of wellbore failure

Insitu Stress, pore pressure
Insitu Stress, pore pressure
Insitu Stress, pore pressure
Rock mechanical properties
Rock Mechanical Properties

- Elastic (Young’s) Modulus
- Poisson’s Ratio
- Peak Compressive Strength

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<th>IF</th>
<th>UCS</th>
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![Diagram of stress and strain in rock](image)

- $\sigma_z$: Uniaxial compressive strength
- $\sigma_x$: Yield stress

- Elastic Region
- Ductile Region
- Brittle Region
Horizontal Stress ($S_{\text{Hmax}}$ and $S_{\text{hmin}}$)

Log-derived $S_{\text{hmin}}$ based on poroelastic theory

$S_{\text{hmin}}$ profile calibrated with insitu stress measurements from leak-off tests.
Fully Integrated Subsurface Geomechanical Modelling

Well Centric 1-Dimensional Geomechanical Model

Estimate Pp and insitu stresses in well location
Estimate rock properties in well location

Well log data

3D Geomechanical Model

Pad-drilling

Pp
S_v
S_{Hmax}
S_{hmin}
Rock Props.

Finite Element Simulations for 3D Dynamic Modelling and its Applications
Mud Weight Window and Wellbore Geometry

- Washsout
- Shear Failure Breakout
- In-gauge
- Fracture Slip
- Tensile Fracture

Stable Window:
- \( P_{\text{collapse}} \)
- \( P_{\text{min}} \)

Safe Window:
- \( P_{\text{pore}} \)
- \( P_{\text{frac}} \)

Relative Mud Weight or ECD:
- low
- high
Wellbore Stability

Ultrasonic Image Log Wellbore View

- **Collapse pressure**
- **Fracture pressure**
- **Safe Mud Weight**
- **Mud window** = 10.9 - 13.1 ppg
- **Mud window** = 11.9 - 15.7 ppg
- **Seawater**

- **20” casing @ 680mMDRT**
- **13 3/8” casing @ 2835mMDRT**
- **9 5/8” casing @ 3781mMD**
Wellbore Failure Inferred from Cavings/Cutting

Normal drilling cuttings usually contain “bit marks”

Cavings are categorized into three basic types:

- **Angular shear failure**: rough, curved surfaces
- **Splintery abnormal pressure**: long, thin, concave surfaces
- **Tabular/blocky bedding failure**: flat, parallel, old surfaces
Wellbore Placement

Target formation

Well A
Azi: 220 deg.
Dev: 90 deg.

Well B
Azi: 280 deg.
Dev: 90 deg.
Effects of Well Trajectory on Wellbore Stability

FIP = Fracture Initiation Pressure

High dependency of FIP to wellbore azimuth.

Stereonet (lower hemisphere) plot
Finite Element Model for Sanding Analysis

Arbitrarily Oriented Well Trajectory:
Open hole & Cased and perforated completions

Mesh shows the results of FE simulations with pore pressure contoured in color
Changes of Horizontal Stresses with Depletion

Using instantaneous application of force and pressure with no lateral strain:

\[ \Delta S_H = \alpha \frac{(1-2\nu)}{(1-\nu)} \Delta P_p \]

\[ A = \frac{\Delta S_H}{\Delta P_p} \approx 0.75 \]

L: Length (lateral extent) of reservoir
h: Height (thickness) of reservoir
\( \Delta P_p \): Change in pore pressure
\( \Delta S_H \): Change in horizontal stresses
\( S_H \equiv S_{hmin} \equiv S_{Hmax} \)

\( \nu \): Poisson’s ratio
\( \alpha \): Biot’s coefficient
A: Stress Path
Stress and Pressure Evolution

The crest and flank of the reservoir follow a typical normal faulting stress path, indicating that normal faulting may be contributing to the subsidence as well as maintaining permeability in the reservoir.
Mapped Pore Pressure in 3D FEM Dynamic Model

1974

Seabed

Final Depth

Production

Reservoir Units

2006

Seabed

Final Depth

Pore pressure Contours

Pore pressure Contours
FE Model of Subsidence Due to Reservoir Compaction and Pore Collapse

There are real examples in the world that subsidence due to reservoir compaction were observed and made severe issues (e.g. Ekofisk subsidence 1980s) in North Sea.
Summary

- Geomechanics helps to understand the mechanics of interactions of drilling fluid (mud), principal insitu stresses, pore-fluid pressure and formation rock mechanical properties in the entire Petroleum Engineering process.

- In drilling phase, it helps to define the safe mud weight to avoid influx of formation pore-fluid into the well while maintaining wellbore stability without fracturing the wellbore wall.

- During well completions, an improperly defined geomechanical model can lead to unexpected costly problems such as sand production.

- In production phase, a coupled 3D dynamic reservoir geomechanical model is essential for field development plans such as fluid injection to enhance production or reservoir stimulation by hydraulic fracturing.
Thank you

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