Geomechanical modelling of fault reactivation related to pore pressure changes.

Elin Skurtveit, Fabrice Cuisiat, Hans Petter Jostad, Lars Andresen

FORCE HPHT workshop 10.Nov.2010
Focus of the talk

- HPHT reservoirs and depletion
- Geomechanical modelling related to depletion
- Laboratory testing of hydro-mechanical parameters
- Case studies: Kristin and Statfjord Field
HPHT reservoirs and depletion

\[ \Delta \varepsilon = \frac{(\Delta \sigma - \Delta p)}{K} + \frac{\Delta p}{K_s} \]
Effect of depletion on fault in reservoirs

- Flow and pressure barriers
- Affect horizontal and vertical flow paths
- Pressure compartments and large differential pressure across faults
- Stress concentration

Færetseth et al. 2007
Geomechanical modelling of pressure depletion at NGI

Fault integrity
Well integrity

Special laboratory testing on intact and faulted material
Geomechanical modelling

- Geometry
- Stresses
- Depletion
- Geomechanical properties
  - Stiffness
  - Strength
  - Permeability
How to model fault zones

Geometry
Complexity
Fault core – type of material
Damage zone
Laboratory tests
Standard Triaxial testing

Parameters
• Strength
• Deformation
• Permeability
• Seismic velocities
• Resistivity

Test conditions
• Confining Pressure up to 100 MPa
• Pore Pressure up to 80 MPa
• Temperatures up to 160°C
Challenges related to testing

- Relevant material
- Fresh and undisturbed material
- Fault zone material – bad quality or missing

Fault zone

Shale
Ring shear test equipment

Investigating basic mechanisms involved in faulting

Parameters tested:
Shearing of pure sand, sand mixed with clay and clay layers producing clay smear
Varying porosity, burial depth, clay content, number of clay layers

Clausen & Gabrielsen, 2002
Ring shear tests

Effect of various burial depth during shearing

3 clay layers separated by sand

Loading the sample to required burial depth

Faulting simulated by rotating lower part of ring cell

Flow measurements
Observation of shear zone

- clay smear
- grain rolling
- cataclasis

Increasing shear strength with increasing burial depth
Field cases

Kristin Field – HPHT reservoir
Statfjord Field – Statfjord Late Life
Kristin Field - Halten bank

Geomechanical modeling of depletion:

- Reservoir deformation due increased effective stress
- Total stress reduction in horizontal direction, develop shear deformation
- Stress concentration around internal faults

5000 m depth
90 MPa pore pressure
Temperature 170 ºC
Planned depletion: 60 MPa
Special laboratory tests

Material properties for calculation of compaction and deformation during depletion

Compressibility of the reservoir depends on the initial porosity and possibly quartz cementation
Fault integrity during depressurization of the Statfjord Field

Poroelastic model to account for grains compressibility during depletion

Use existing observations from Brent-Statfjord as verification/calibration

Sealing fault under existing pressure depletion in Brent field (300 bars)

late life pore pressure depletion $\Delta p \sim 300$ bar

Behaviour of Horst barrier during depletion?
Fault properties

- Throw from seismic sections
- Empirical relationship between fault throw and thickness from field analogue
- Shale Gauge Ratio to define the clay content of the fault
- Uncertainty in thickness and damage zone investigated in parametric study (Sperrevik et al.)
Mechanical properties of fault material

Controlled by clay content from SGR analysis

- Clay rich fault rock assumed same properties as intact shale
- Sealing fault rock with less clay assumed same properties as sandstone or even stronger/stiffer (cataclasites)
Max. shear stress in Horst structure

Highest shear stress for Brent group

Failure possible in Brent group

Stress changes less than for Brent fault

20 MPa depletion
Sources of uncertainties – parameter study

- stiffness properties (reservoir, shale layers and overburden);
- fault geometry (inclination, thickness, drag and juxtaposition);
- pressure distribution and drainage of fault core zone.
Effect of fault core thickness

Highest shear stress mobilisation in sand:sand juxtaposition at the bottom of the depleted reservoir.

Maximum shear stress $\tau_{\text{max}}$ in fault not significantly affected by reduced fault zone

FZT = 10 m

$\Delta P = 20 \text{ MPa}$

$\tau_{\text{max}} = 11 - 12 \text{ MPa}$

FZT = 5 m

$\tau_{\text{max}} = 11 - 12 \text{ MPa}$

Sand reservoir fm

BASCE CASE (1)
Effect of damage zone

’damage zone’ modelled as stiffer material
small positive effect

\( \tau_{\text{max}} = 11 - 12 \text{ MPa} \)

\( E = 20 \text{ MPa} \)

Small reduction in shear stress (0.6 MPa)

\( E = 10 \text{ MPa} \)
Results from parametric study

- Maximum shear stress in fault core zone is relatively insensitive to variations in geometry and stiffness parameters
- positive effect of drag
- largest uncertainty related to the fault peak shear strength
Conclusions

• Geomechanical modeling tools for fault integrity during depletion and methods for assessing material properties has been presented

• 2D models have been used but 3D is needed for more complex geometries

• Largest uncertainty related to the fault (core) peak shear strength

• Further work:
  • Effect of shear mobilization on hydraulic communication
  • Determination of fault strength
Thanks!

