Oil & Gas Operations & Formation Failure

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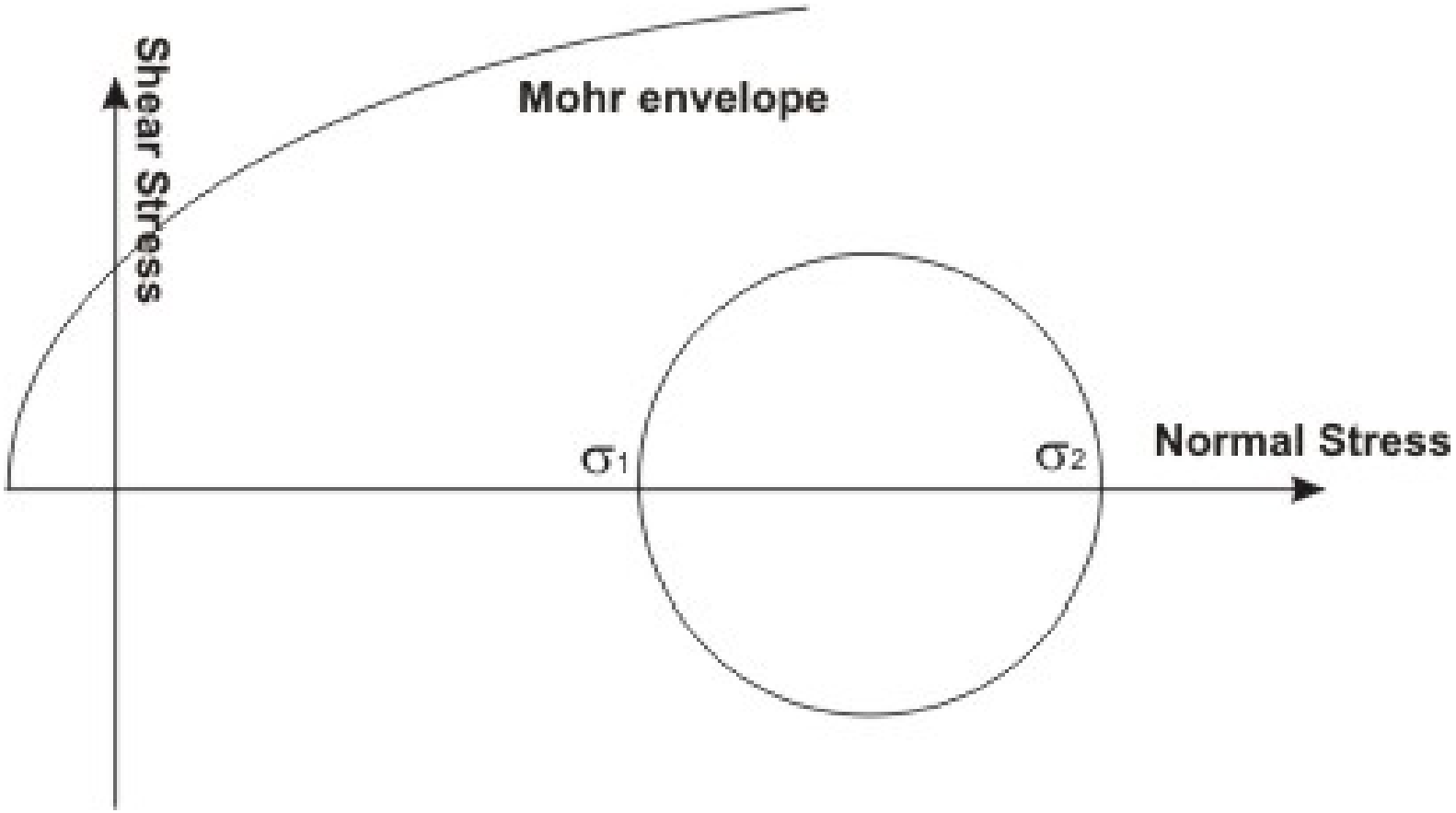
Mechanics of Rock Failure

Two conditions can trigger failure of previously intact rock;

- **Change in In-situ stresses**
  - **Tectonic activity**
  - **Change in pore pressure**
- **Reduction of rock strength**

Mohr Failure Envelope

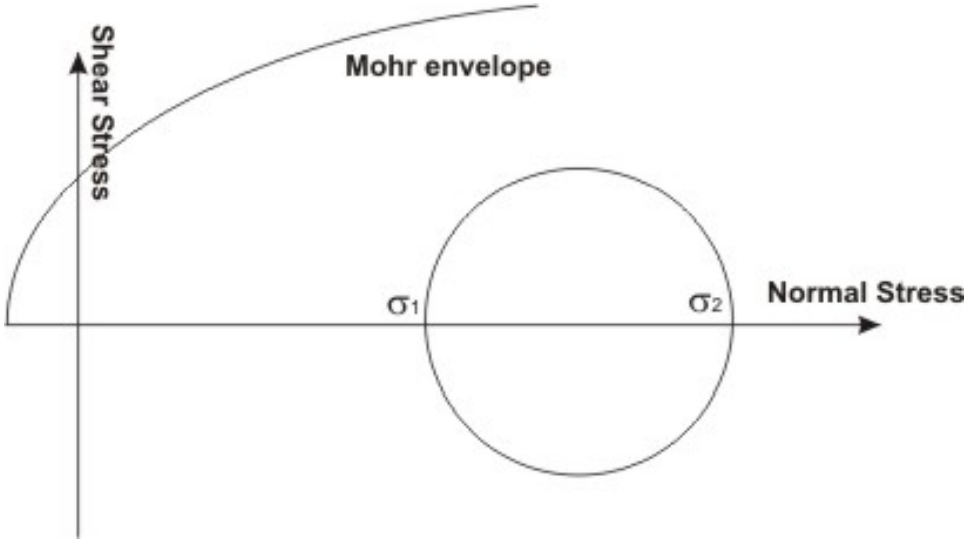


Failure Requirements

- **Pre-disposition to failure due to existing natural planes of weakness (faults) in the formation**
- **Narrow gap between formation strength and existing stress state**

Production Induced Stress Change

- **Reduction in pore pressure increases the effective stresses in the formation and actually pushes the Mohr Circles away from the failure envelope**



Production Induced Reservoir Deformation

- Removal of fluid from the formation causes compaction/shrinkage of the reservoir which may result in ground subsidence
- Magnitude of subsidence depends on formation properties & is negligible in competent formations
- Known cases of measurable subsidence include Ekofisk reservoir in North Sea and Diatomaceous earth in Bakersfield

Ground Subsidence

- **Large formation compaction can cause differential slippage along bedding planes in overlying formations which can trigger casing collapse. This type of failure is very local and is not known to have caused any major surface damage**

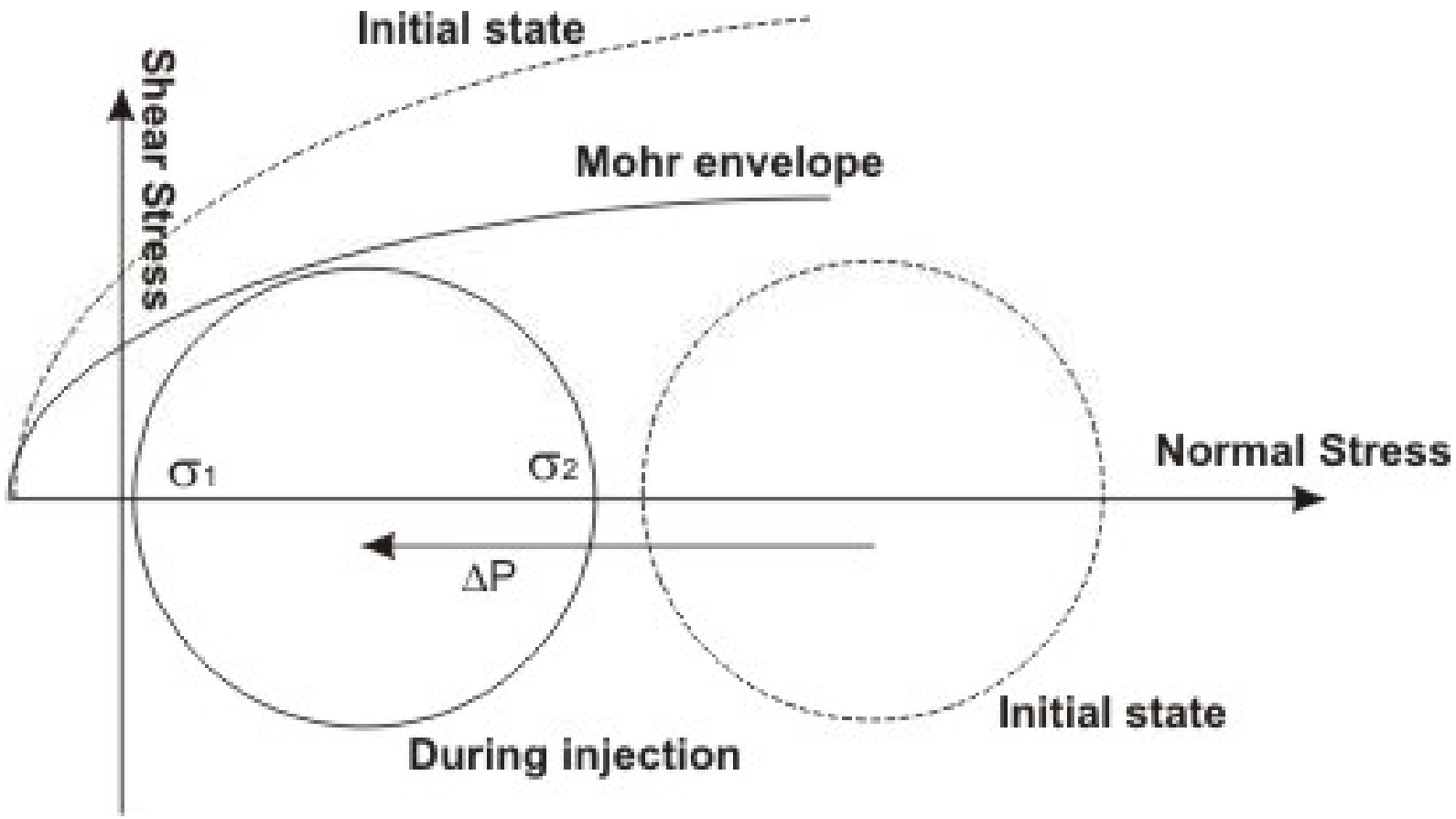
What Triggers Earthquakes

- **Susceptibility to failure which causes minor changes in formation conditions to push it to fail**
  - **Changes in stress state**
  - **Reduction of formation strength**

Review of Past History

- First documented case of earthquake triggered by human activity was reported in Rangely Field in the Rio Blanco County in Northwestern Colorado
- The trigger mechanism was waste water injection
  - Decrease of effective stresses caused by increase in pore pressure
  - Lubrication of existing fault plane caused by large volumes of waste water injection

Failure Mechanism



Consequences of Failure

- **The earlier the failure, the lower its intensity**
  - **Less damage**
- **Stress relief**
  - **Post-failure stresses are lower than the initial values**
  - **Delayed next failure**

Rangely Study Recommendations

- **In areas of known earthquake susceptibility, intentional early triggering of earthquakes reduces their damage and allows better preparation**

Mechanics of Hydraulic Fracturing

- Hydraulic fracturing is the result of tensile failure of the rock
  - Main mode of failure in earthquakes is shear
- There is very little, if any, shear stress along the fracture plane
- Fractured formation volume is very small compared to the volumes involved in earthquakes
- Subsequent production of the reservoir actually increases the effective stresses and pushes the Mohr circles away from the failure envelope

Conclusions

- **Hydraulic fracturing is not likely to directly trigger earthquakes**
- **Waste water injection has the potential to trigger earthquakes in areas already susceptible to failure. If so, earlier failure will;**
  - **Reduce earthquake intensity & possible damage**
  - **Delay the next earthquake occurrence**
  - **May serve as a way of controlling earthquake occurrence and damage**
- **Site geology needs to be closely scrutinized when deciding waste water disposal.**