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Wellbore Stability and Predicted Cuttings Volume in Deviated Wells and Bedded Formations

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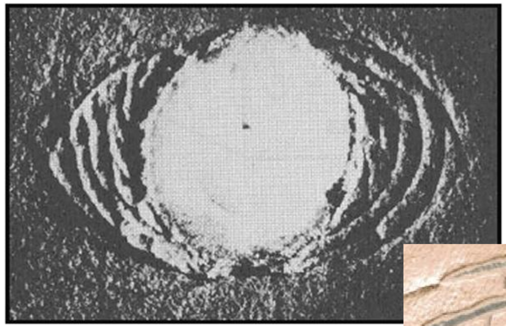
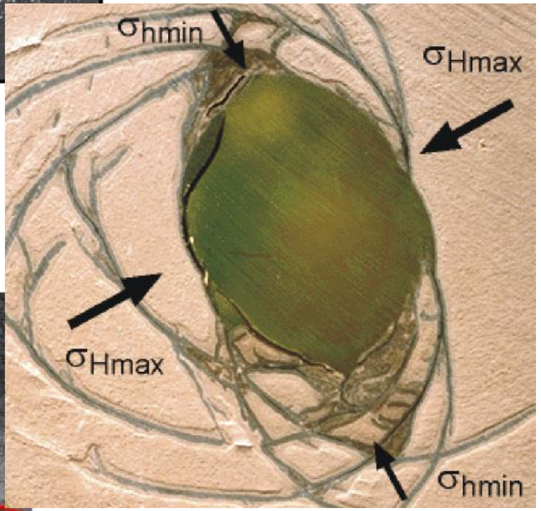
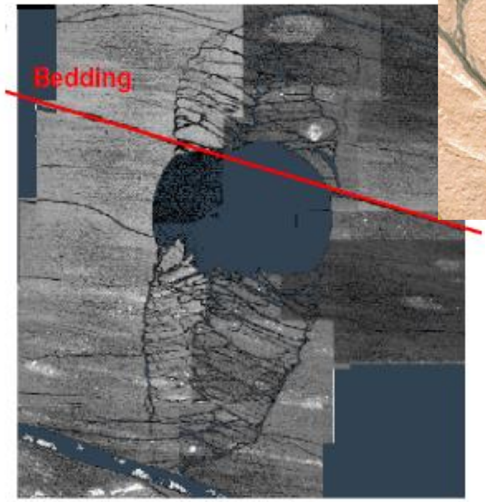
Introduction

- Instability of subsurface excavations affect project planning
- Oil & gas industry facing increasingly difficult geological conditions
- Prediction of instabilities is a key aspect in the success of a project
- Conventional wellbore stability analysis can be overly conservative
- Formation strength anisotropy affects failure pattern
- Efficient numerical modelling accounting for post-yield response and bedding plane effect
- Assess wellbore stability in deviated well and heterogeneous formations
- Estimate operational parameters (cuttings volume prediction)



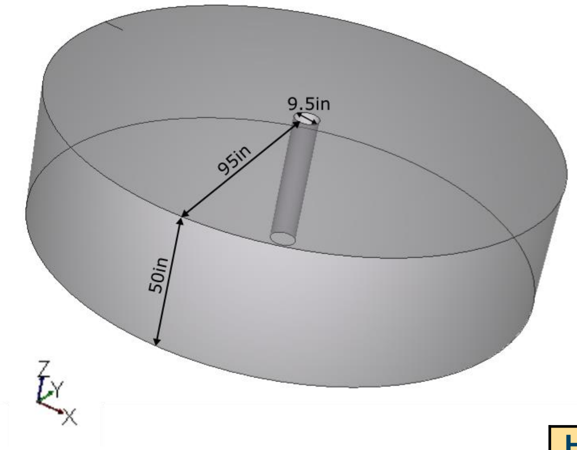


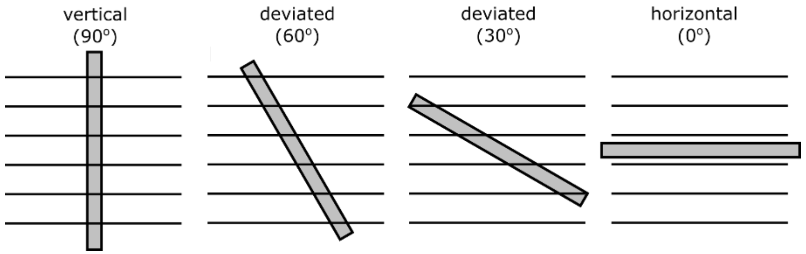


*Zhang, J. (2013). Borehole stability analysis accounting for anisotropies in drilling to weak bedding planes. International journal of rock mechanics and mining sciences, 60, 160-170.
Reinecker, J., Tingay, M., & Müller, B. (2003). Borehole breakout analysis from four-arm caliper logs. World stress map project, 1-5.
Okland, D., & Cook, J. M. (1998, January). Bedding-related borehole instability in high-angle wells. In SPE/ISRM rock mechanics in petroleum engineering. Society of Petroleum Engineers.

Model Set-Up

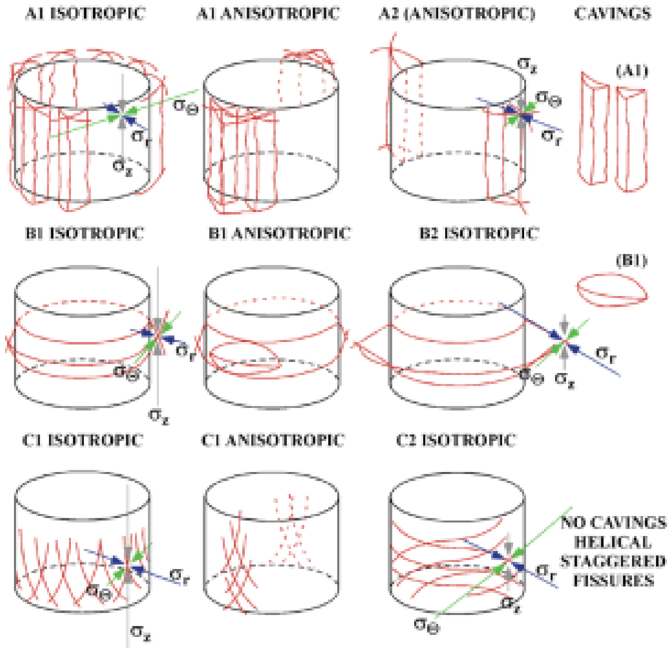
- Vertical well – well axis aligned with vertical stress direction
- Well inclination with and without PoW
- Sandstone material
- ±10% stochastically varying elasticity
- Mohr-Coulomb elasto-plasticity with a Rankine tension cut-off
- Strain softening
- PoW properties: elastic (normal and tangential stiffness), plastic (friction, cohesion)





Host Rock Elastic Properties	
Young's Modulus, E (psi)	3e6
Poisson's Ratio, v (-)	0.2
Density, ρ (g/cc)	0.0058
Host Rock Plastic Properties	
Cohesion, c (psi)	865
Friction Angle, ϕ (°)	30
Dilatancy, ψ, (°)	30
Uniaxial Compressive Strength, *UCS* (psi)	2995
Tensile Strength, σ_t (psi)	217
Planes of Weakness Properties	
Stiffness Ratio Normal to PoW, E_w/E (-)	0.5
Stiffness Ratio Tangential to PoW, G_w/G (-)	0.5
Cohesion, c_w (psi)	200
Friction Angle, ϕ_w (°)	15
Tensile Strength, σ_t (psi)	0

Model Conditions

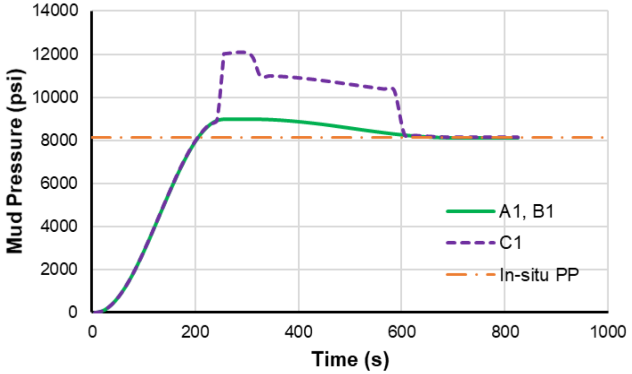


Theoretical rupture modes under compressional stress states (Etchecopar et al., 1999)

- A1, A2: tangential stress exceeds material strength
- B1, B2: excessive vertical stress relatively to the internal pressure
- C1, C2: excessive internal pressure relatively to external stress

- A1: thrusting stress regime
- B1, C1: extensional stress regime

	A1	B1	C1
Vertical stress, σ_v (psi)	*isotropic and anisotropic*		
	10195.7	12744.8	12744.8
Max horizontal stress, σ_H (psi) – *aligned N-S*	*isotropic and anisotropic*		
	12744.8	10195.7	10195.7
Min horizontal stress, σ_h (psi)	*isotropic*		
	12744.8	10195.7	10195.7
	anisotropic		
	11744.8	9800.7	9800.7
In-situ Pore Pressure, P_{form} (psi)	8131.09	8131.09	8131.09
Max mud weight, P_{mud} (psi)	9000	9000	12000

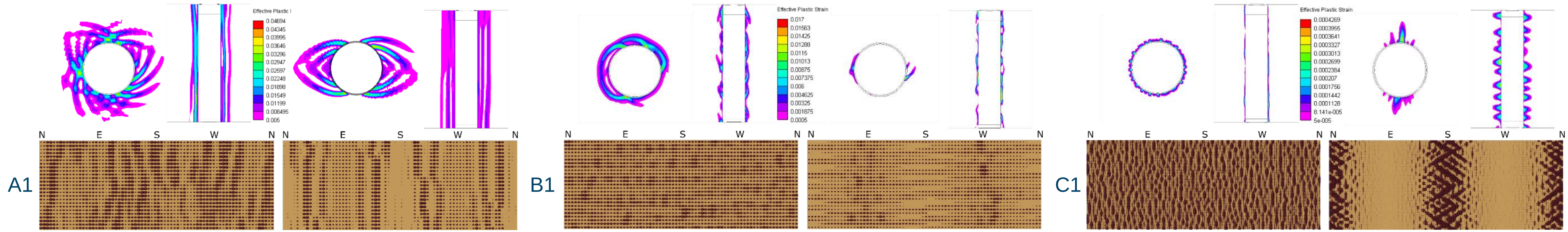


*Etchecopar, A., P. A. Pezard, and V. Maury. "New borehole imagery techniques: an aid for failure modes and in situ stress analysis and for minimizing drilling incidents." SPWLA 40th Annual Logging Symposium. Society of Petrophysicists and Well-Log Analysts, 1999.

Vertical well in homogeneous formation

Failure modes

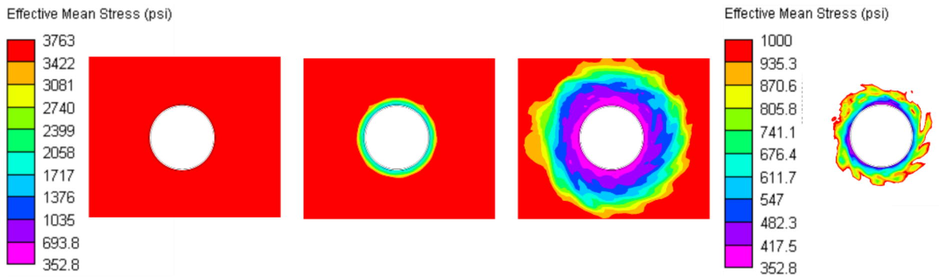
isotropic σ field | anisotropic σ field | isotropic σ field | anisotropic σ field | isotropic σ field | anisotropic σ field



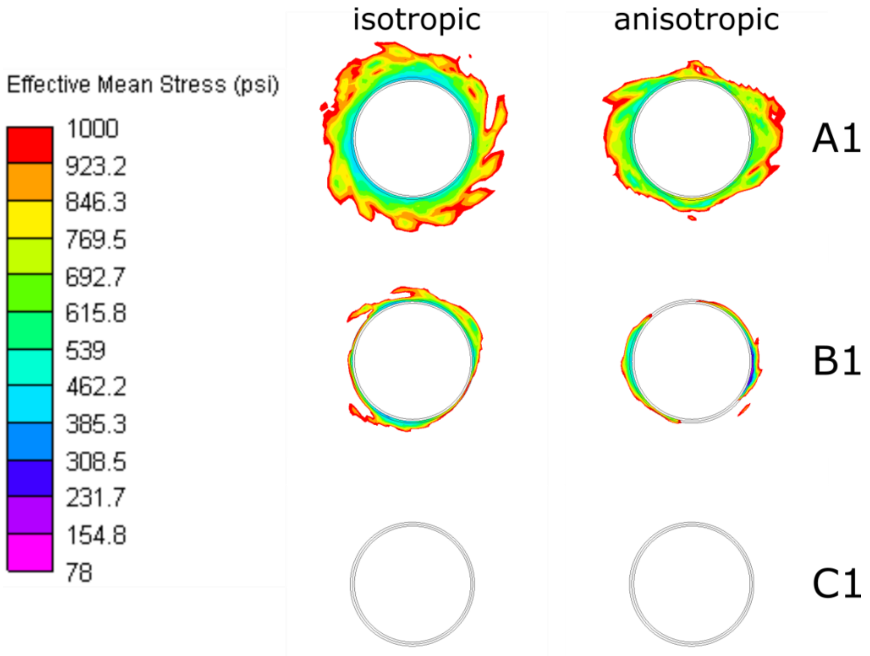
- A1: breakouts parallel to the well axis
- B1: breakouts perpendicular to the well axis
- C1: helical fractures
- Isotropic σ field: drilling stresses do not vary around the well; observed patterns occur all around the well
- Anisotropic σ field: drilling stresses vary; failure occurs in the direction of max/min stress

Vertical well in homogeneous formation

Volume of cuttings and cavings

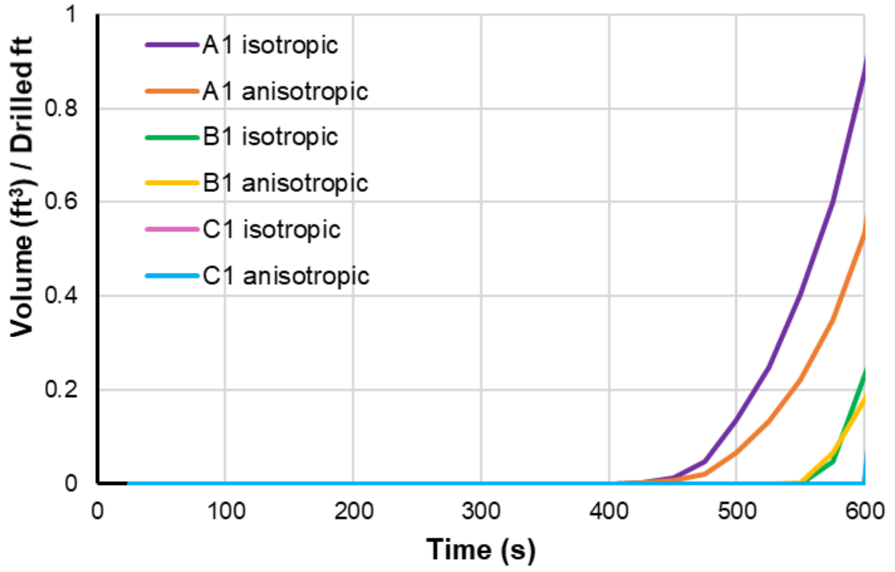


- Progressive material damage around well
- Calculation of continuously changing stresses around well
- Calculation of the volume of cuttings and cavings based on mean stress threshold (<1000 psi)
- It is assumed that undamaged material may become cavings, e.g. material bounded by localised shear bands
- Implications for predicted volume of material to surface, combined cuttings and cavings volume

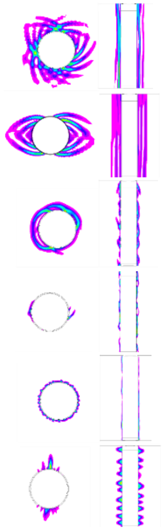


Vertical well in homogeneous formation

Volume of cuttings and cavings



	Predicted V_{total} (ft^3/drilled ft)
A1 isotropic	1.09
A1 anisotropic	0.84
B1 isotropic	0.54
B1 anisotropic	0.56
C1 isotropic	0.49
C1 anisotropic	0.49

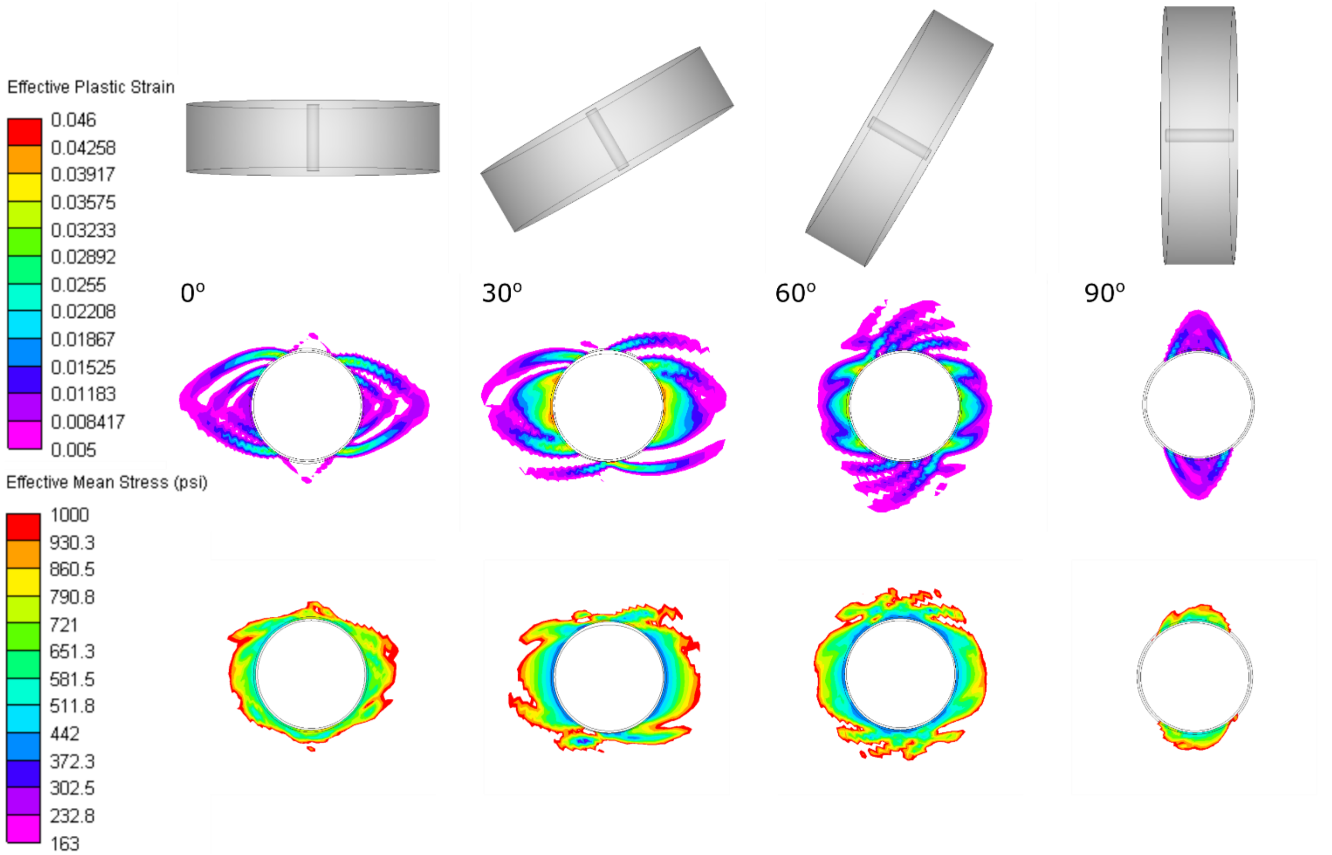


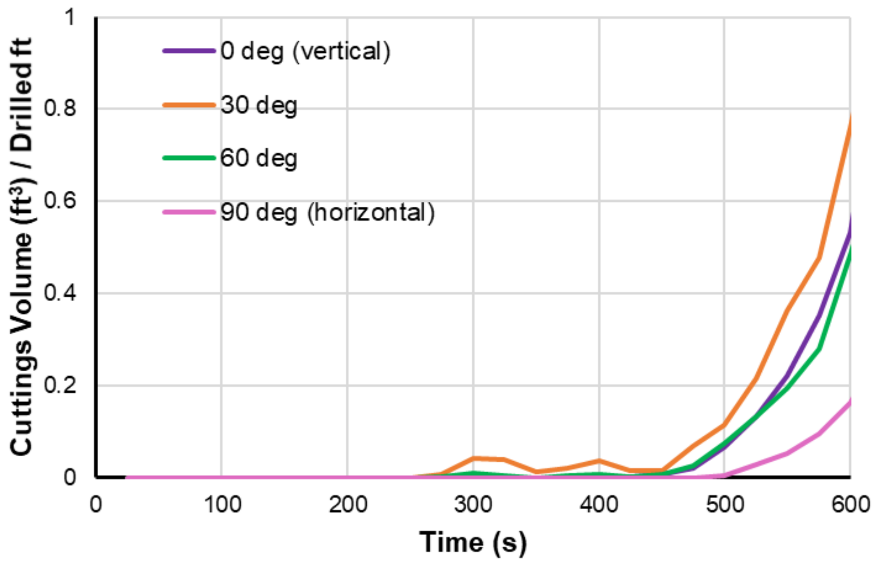
$$V_{total} = V_{cuttings} + V_{cavings}$$

$V_{cuttings} = \pi r^2 h/l$ (based on the well diameter)

$V_{cavings}$: *volume of elements per drilled ft with EMS < 1000 psi (note: others magnitudes of EMS may be assessed)*

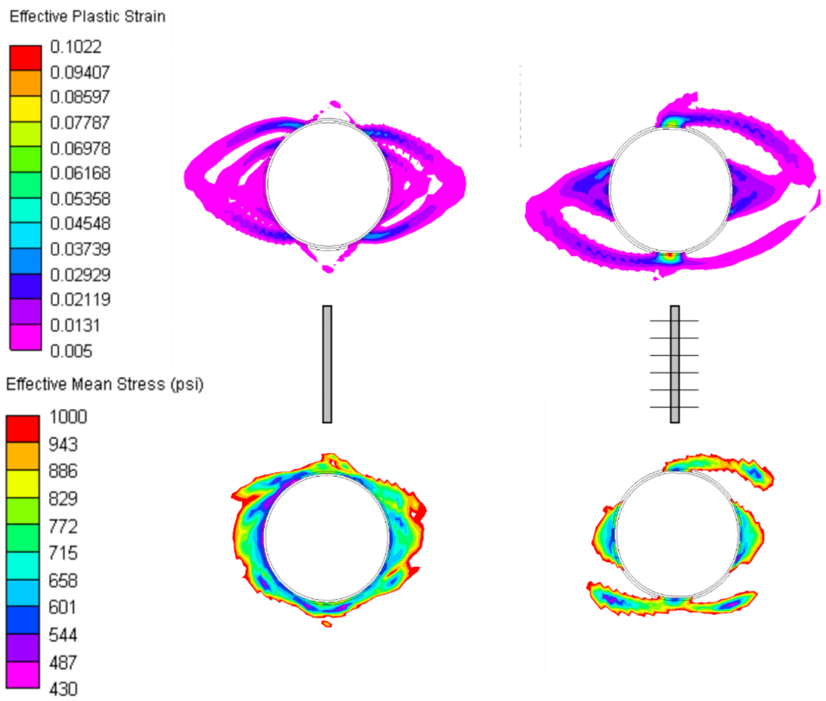
Deviated well in homogeneous formation



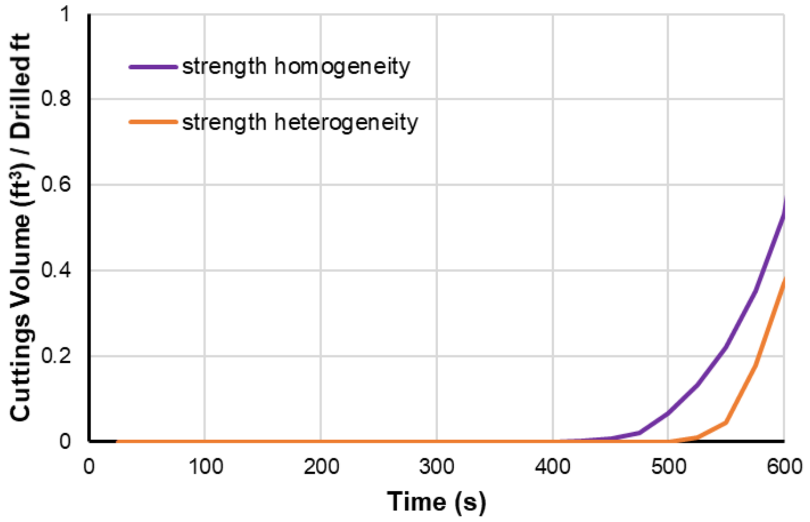


- Limited plastic strain for a horizontal well
- Higher plastic strain and larger damaged volume for 30° and 60°

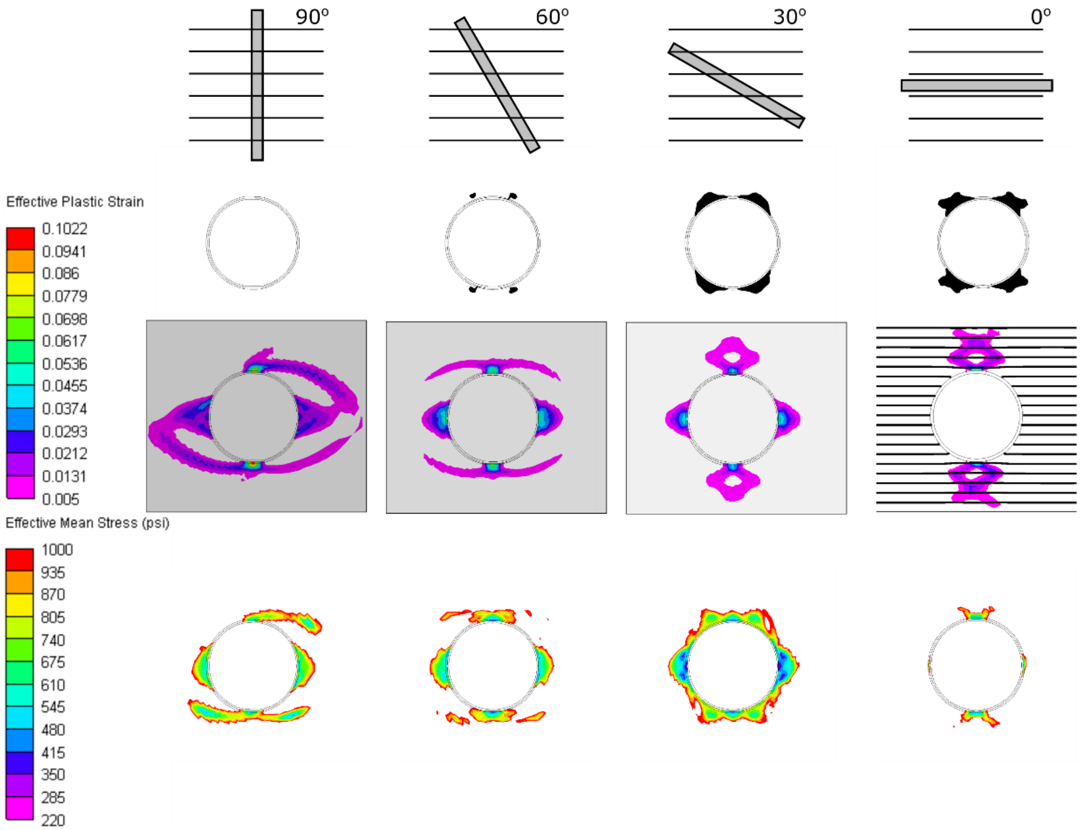
Vertical well in heterogeneous formation

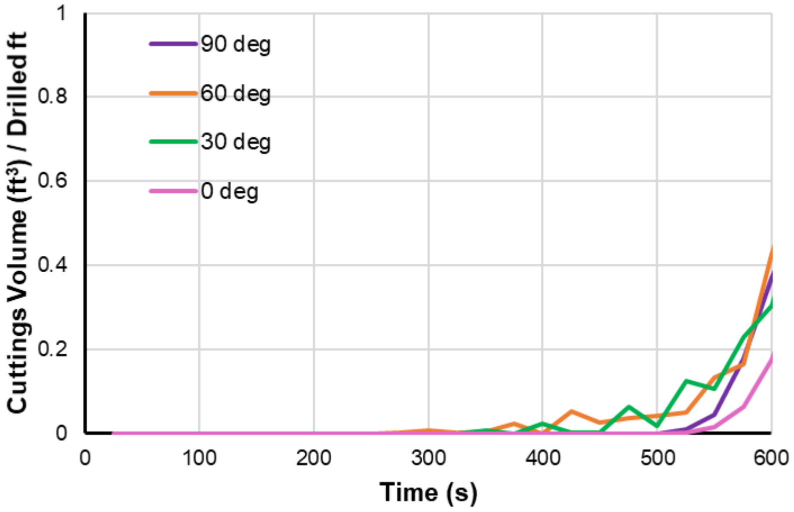


- Strength heterogeneity under A1 stress and loading conditions
- Well drilled perpendicularly to the PoW (safest configuration, high attack angle)
- Higher but more localized deformation
- Smaller cavings volume considering heterogeneous formation
- Limited bedding slip



Deviated well in heterogeneous formation



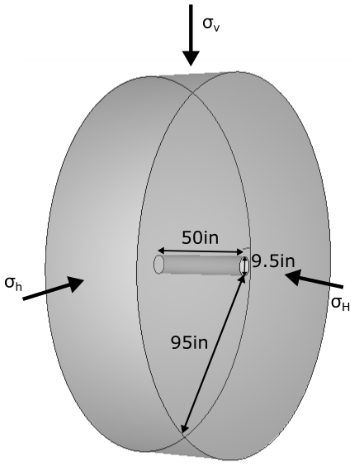


- As the well is inclined, the volume affected by bedding slip becomes larger
- Transition of plastic strain location and pattern
- For high attack angles, cavings are the dominant failure mechanism
- For low attack angles, bedding slip becomes dominant
- Largest volume for 30° attack angle
- Smallest volume for 90° attack angle

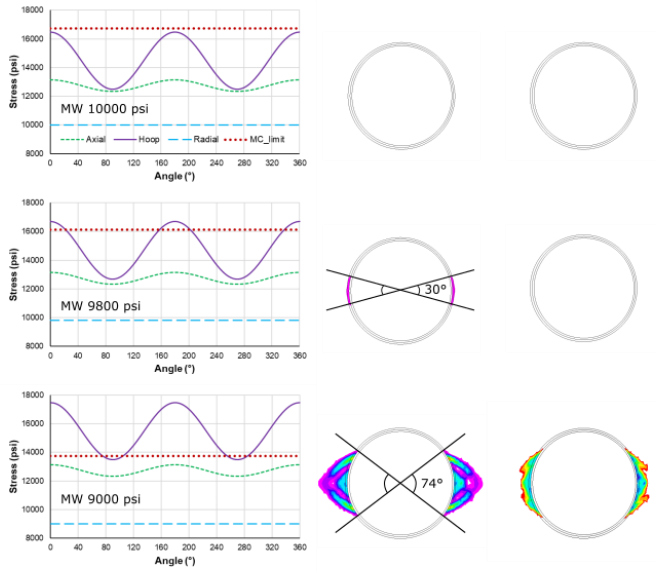
Conclusions

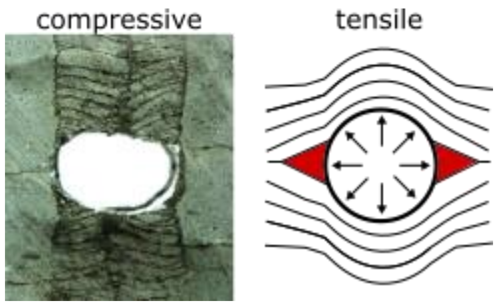
- Validation of software against theoretical rupture modes
- Numerical modelling to investigate complex failure modes when drilling in challenging environments
- Sensitivities considering variable well alignment with respect to the principal stresses, heterogeneous formation or both
- Complex failure patterns well represented along with post-yield softening response and dynamically changing stresses
- Calculation of representative volume corresponding to deteriorated material and undamaged cavings separated from well surface, providing information for operational parameters
- Combination of appropriate modelling, results assessment techniques and real-time field monitoring can significantly limit the risks associated with drilling in difficult conditions.

Ongoing

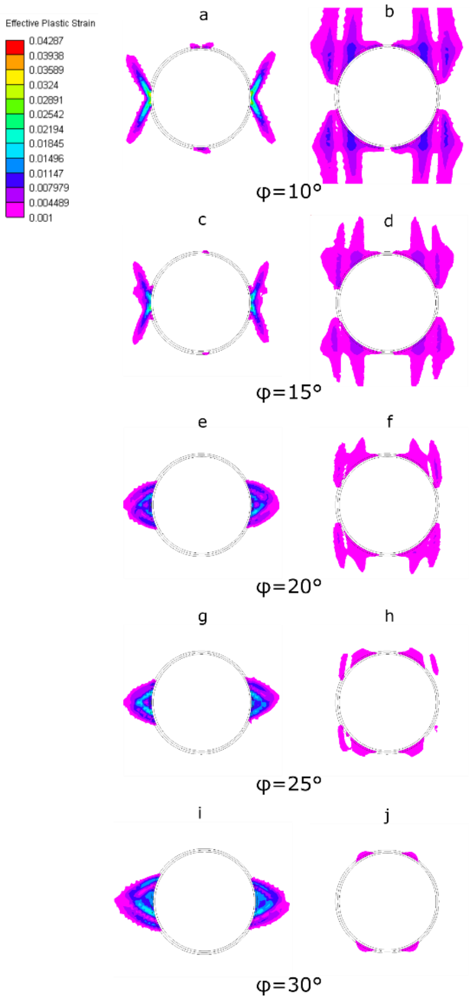


Horizontal well

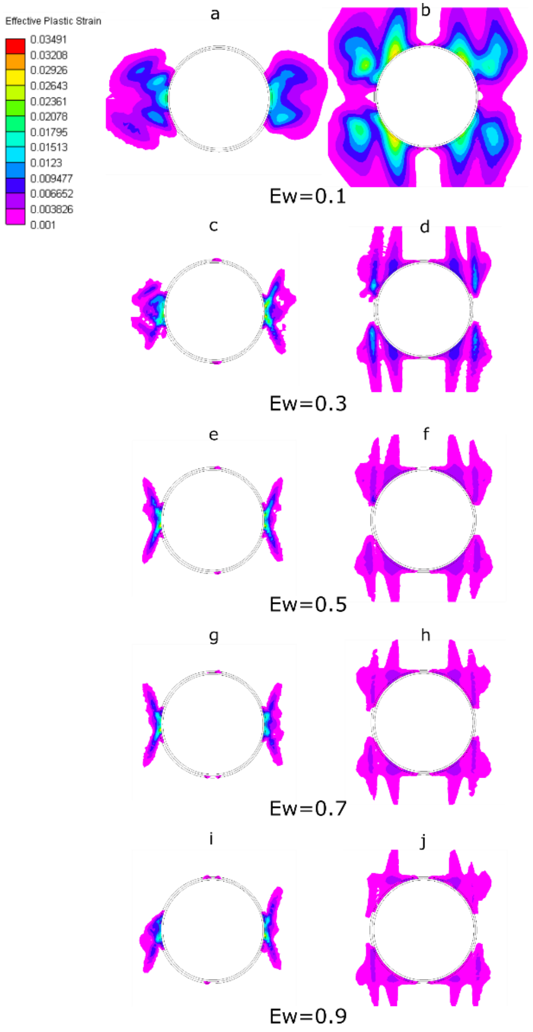




PoW friction variation



PoW stiffness variation



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