Determination of the hydraulic fracturing initiation pressure for different types of the well completion

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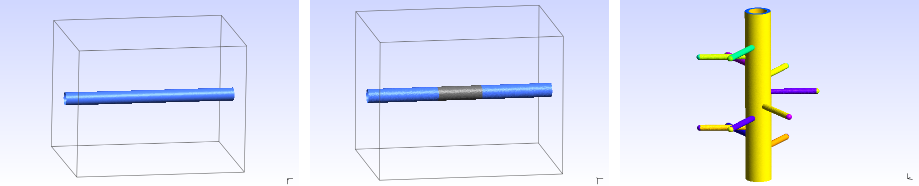
Problem formulation

The problem of determining the maximum pressure referred to the hydraulic fracturing initiation. Completion systems of a well:

- open wellbore (a),
- open wellbore with packer (b),
- cased well with perforations (c).



a) Открытый ствол b) Well with packer c) Cased well with perforations

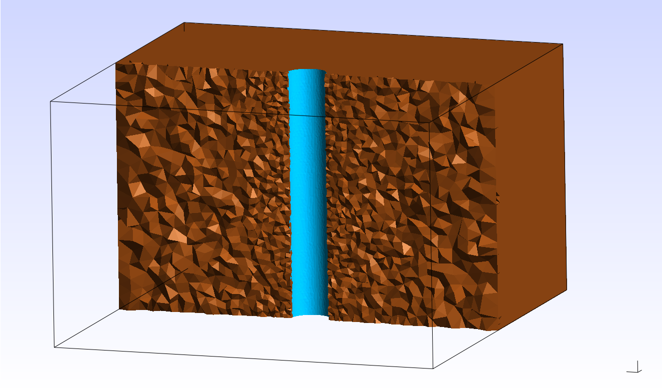
Рис.: Types of well's completion

It is necessary to locate fracturing well zones and to determine the pressure value, which produce this fractures.

Open wellbore. Elasticity model

$$\Pi : \operatorname{div} \boldsymbol{\sigma} = 0, \boldsymbol{\sigma} = \mathbf{A}\boldsymbol{\varepsilon},$$
$$\partial\Pi_w : \boldsymbol{\sigma}\langle\mathbf{n}\rangle = -p_w\mathbf{n},$$
$$\partial\Pi_o : \boldsymbol{\sigma} = \boldsymbol{\sigma}^1(\mathbf{x}),$$

where $\boldsymbol{\sigma}^1(\mathbf{x})$ — an analytic solution of infinite hole without perforations in an elastic media with arbitrary is-situ stresses [Ching H. Yew, Xiaowei Weng, 2015].

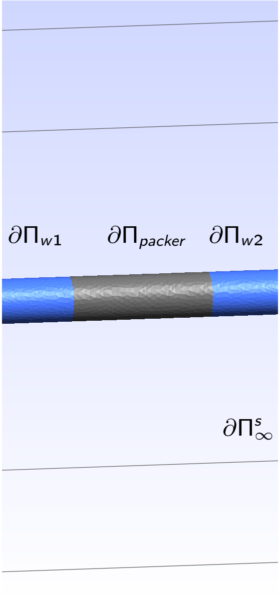


Open wellbore with packer. Boundary conditions

- Inner parts of the open well without packer
  $\partial\Pi_{w1}$: $\boldsymbol{\sigma}\langle\mathbf{n}\rangle = -p_{w1}\mathbf{n}$,
  $\partial\Pi_{w2}$: $\boldsymbol{\sigma}\langle\mathbf{n}\rangle = -p_{w2}\mathbf{n}$.
- The site of the contact between the packer and the rock
  $\partial\Pi_{packer}$: $\boldsymbol{\sigma}\langle\mathbf{n}\rangle = -p_{packer}\mathbf{n}$.
- Side, top and bottom parts of the border
  $\partial\Pi^s_\infty \cup \partial\Pi^t_\infty \cup \partial\Pi^b_\infty$: $\boldsymbol{\sigma} = \boldsymbol{\sigma}^1(\mathbf{x})$,

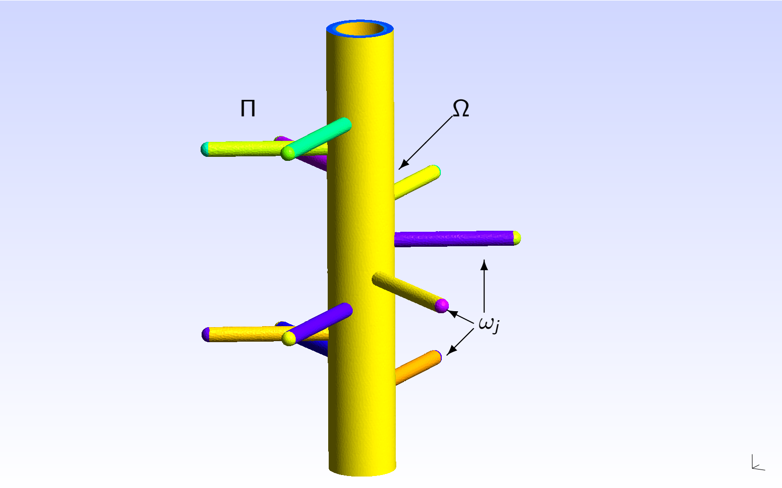
where p_{packer} — an analytic solution of elastic puck, inserted in a hole of a rigid plate [Muskhelishvili, 1966]:

$$p_{packer} = \left(1 - \frac{D}{D_p}\right)\frac{E_p}{1 - \nu_p - 2\nu_p^2}.$$



Cased wellbore with perforations

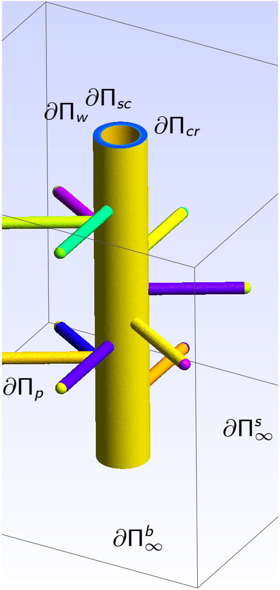
The main domain is presented as parallelepiped Π, containing the well Ω (cylinder). Well consists from the steel pipe, the coaxial shell of cement stone and the surrounding rock. Perforations ω_j are presenting as cylindrical bodies with a spherical ending, situated perpendicular to the well's axis.



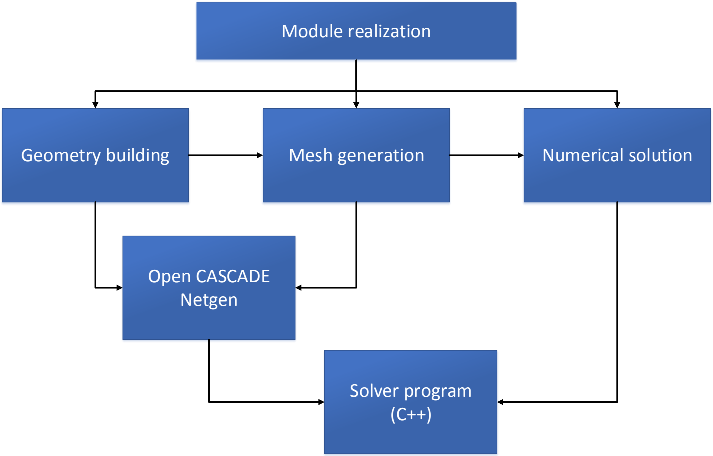
Cased wellbore. Boundary conditions

- Inner surfaces of the well and perforations:
  $\partial\Pi_w \cup \partial\Pi_p : \quad \boldsymbol{\sigma}\langle \mathbf{n} \rangle = -p_w \mathbf{n}, \quad p = p_w.$
- Boundaries between steel pipe, cement shell and rock $\partial\Pi_{sc} \cup \partial\Pi_{cr}$: displacements are continuous functions.
- Side, top and bottom parts of the border $\partial\Pi^s_\infty \cup \partial\Pi^t_\infty \cup \partial\Pi^b_\infty$: $\boldsymbol{\sigma} = \boldsymbol{\sigma}^1(\mathbf{x})$.

where $\boldsymbol{\sigma}^1(\mathbf{x})$ — an analytic solution of infinite hole without perforations in an elastic media with arbitrary is-situ stresses [Ching H. Yew, Xiaowei Weng, 2015].



Realization

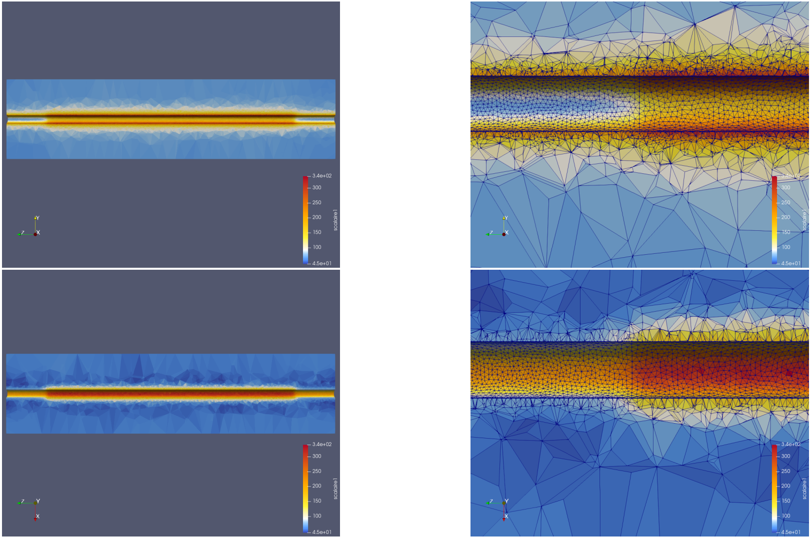


Typical values of the model's parameters

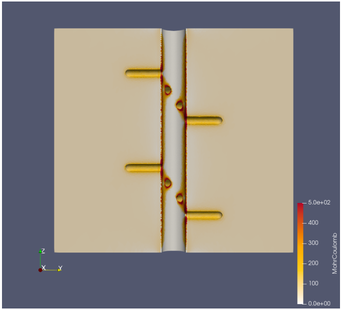
Symbol	Value	Unit	Name
P	50	MPa	Pressure inside the well
D	160	mm	Well's diameter
d_s	1	cm	Thickness of steel pipe
d_c	2	cm	Thickness of cement shell
l	1	m	Perforation length
d	10	mm	Perforation diameter
ρ	10	hole / m	Perforation density
h	1	m	Length of perforation area
θ	60	degree	Perforations phasing
E_r	10	GPa	Young's modulus of the rock
E_c	14	GPa	cement
E_s	200	GPa	steel
ν_r	0.15	-	Poisson's ratio of the rock
ν_c	0.22	-	cement
ν_s	0.27	-	steel
σ_{xx}^{∞}	70	MPa	Rock in-situ stresses
σ_{yy}^{∞}	30	MPa	
σ_{zz}^{∞}	50	MPa	
σ_{xy}^{∞}	3	MPa	
σ_{yz}^{∞}	1	MPa	
σ_{xz}^{∞}	2	MPa	
σ_r^c	40	MPa	Rock uniaxial compression strength
σ_r^t	4	MPa	Rock uniaxial tensile strength
σ_r^y	40	MPa	Rock yield strength
σ_c^c	45	MPa	Cement uniaxial compression strength
σ_c^t	4.5	MPa	Cement uniaxial tensile strength
σ_c^y	45	MPa	Cement yield strength
σ_s^c	1500	MPa	Steel uniaxial compression strength
σ_s^t	900	MPa	Steel uniaxial tensile strength
σ_s^y	1500	MPa	Steel yield strength

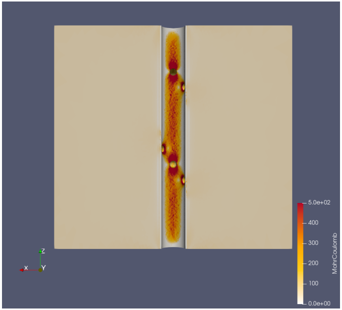
Numerical results. Packer case

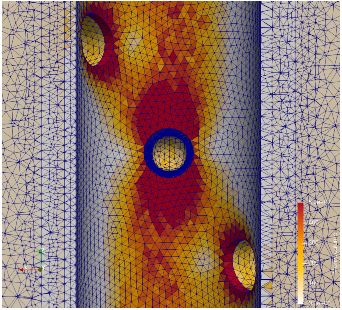
Failure criteria intensity: $I_\sigma = \begin{cases} f(\sigma_{ij}) - g(\sigma_c, \sigma_t, \ldots), & f(\sigma_{ij}) \geq g(\sigma_c, \sigma_t, \ldots), \\ 0, & \text{otherwise}, \end{cases}$

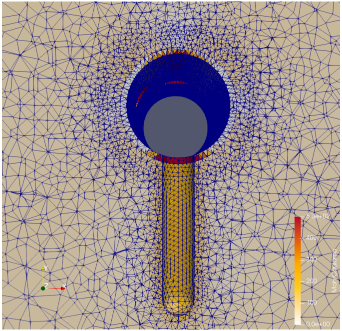


Numerical results. Cased wellbore with perforations









Stresses jump nearby perforation base

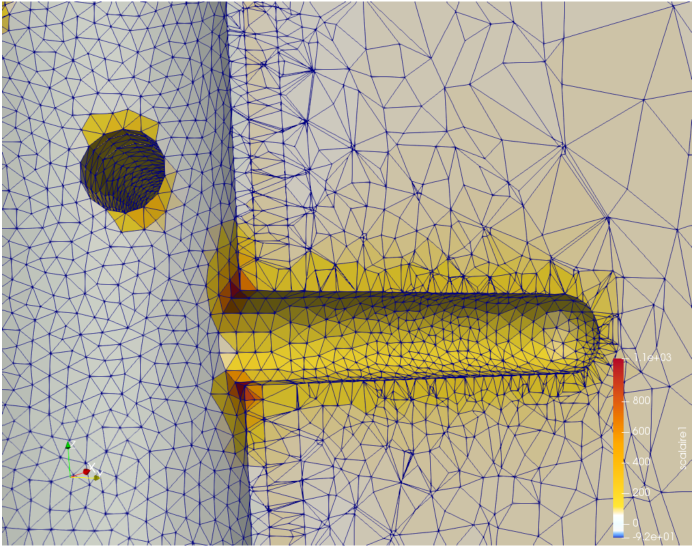
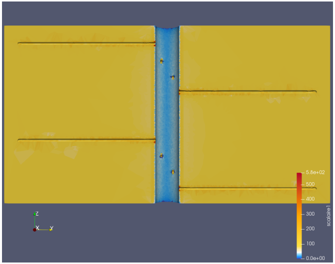
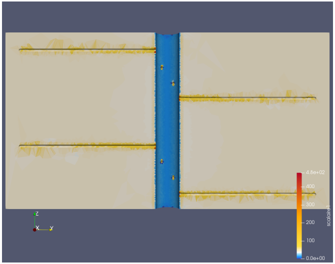


Рис.: Failure criteria: Mohr — Coulomb

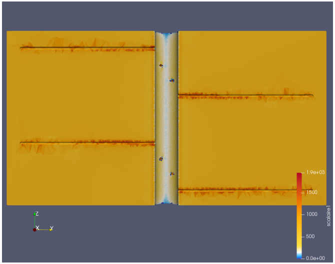
Numerical results. Cased wellbore with perforations



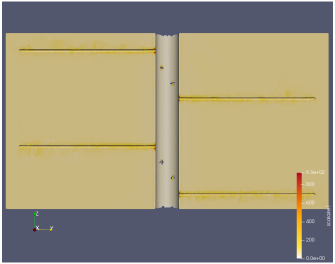
Drucker — Prager



Drucker — Prager (parabolic)



Willam — Warnke



Mohr — Coulomb

Рис.: Different failure criteria

Conclusion

Results

- Takes into account a complex geometry of the domain
- Building of the geometry and mesh generation work automatically via such program libraries as Open CASCADE and Netgen
- Parameters of all presented materials (rock, cement, steel, elastomer) are considered
- All computations are parallelized by MPI
- Is-situ stresses have arbitrary values and the well's axis situated at arbitrary angles to the rock
- Checks several failure criteria

Plans

- Make the model more complex (take into account poroelastic and elastoplastic effects)
- Explore an evolution of the distraction zone
- Add calculations on isoparametric elements and a mesh adaptation features
- Make calculations on P2 elements (increase accuracy)

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