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Surface deformation from a pressurized subsurface fracture: Problem description

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1 Overview

This document specifies a set of problems that entail the calculation of ground surface deformation caused by a pressurized subsurface fracture. The solid medium is assumed to be isotropic-homogeneous where linear elasticity applies. The effects of the fluid in the fracture is represented by a uniform pressure applied onto the two fracture walls. The fracture is assumed to be rectangular in shape and various dipping angles are considered. In addition to the full 3D solution, we reduce the 3D problem to a plane-strain geometry, so that 2D codes can participate in the comparison and results can be compared with those available in the literature.

2 Problem specifications

The 3D geometry of the problem is largely based on the 2D geometry used in [Pollard and Holzhausen, 1979]. The rectangular fracture is $2a$ wide and $2b$ long with a dipping angle β. As shown in the Figure 1, we establish a global coordinate system and a local coordinate system. The origin of the global $x-y-z$ coordinate system is at the projection of the fracture center on the ground surface. The y-axis is along the vertical direction pointing upwards and the z-axis is along the strike direction. The origin of the local $u-v$ coordinate system is at the fracture center. The u-axis is along the strike or the length direction while the v-axis is along dipping or the width direction. The fracture center is at a depth of d, so the $u-v$ coordinate system's origin $(u=0, v=0)$ has a coordinate $(0, -d, 0)$ in the global coordinate system. If $b >> a$, this 3D geometry can be modeled as a 2D plane-strain problem. The 2D geometry is essentially a vertical cut of the 3D model by the x-y plane.

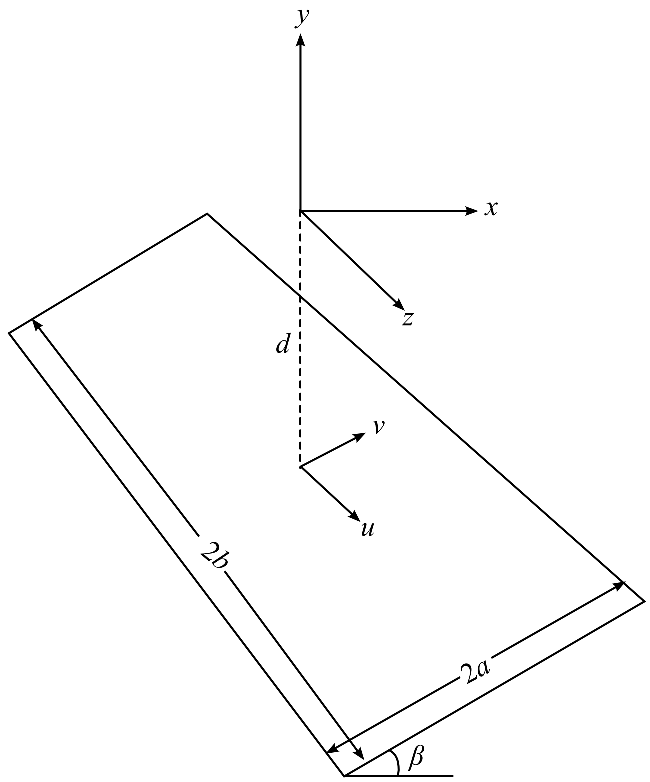

Figure 1: Geometry of the fracture in 3D and the coordinate systems.

Since this problem concerns the deformation of an infinite half space, the simulation domain has to be sufficiently large so that the boundary condition applied at the far-field has minimal effects on the near-field responses.

If *in situ* stress is concerned, the pressure applied on the fracture surfaces p_0 should be considered the "net pressure", which is the difference between the fluid pressure and the *in situ* normal stress acting on the fracture plane. Anisotropy of *in situ* stress will not affect the the results for horizontal and vertical fractures, but will affect the results for oblique fractures (e.g. $\beta = 45°$). Therefore, the setup of the problem implies isotropic *in situ* stress.

Due to the relatively slow transient processes associated with fluid and heat flow compared with the transient processes in the solid phase (namely, wave propagation), we only consider the pseudo-static solution of this problem.

The geometrical and material parameters are given in the Table 1. All results will be presented in a non-dimentionalized form, units are only given for adding some engineering sense to the problem.

Table 1: Geometrical and material properties

Parameter	Value	Comment
a (m)	100	
b (m)	300	Not used in 2D
d (m)	125	
$\beta(^\circ)$	0, 45, 90	Variable
E (Young's modulus, GPa)	10.0	
ν (Poisson's ratio)	0.25	
p_0 (Net fluid pressure, MPa)	1.0	

Parameters used in this problem are provided in the table below.

3 Observables

3.1 Observables in the 2D model

The following observables are desired from the 2D plane-strain model.

- Vertical surface displacement δ_y from $x = -4a$ to $x = 4a$. The results should be normalized by δ_∞, which is the maximum normal displacement of the walls of a 2D fracture in an elastic infinite domain. According to equation (9c) in [Pollard and Holzhausen, 1979], $\delta_\infty = p_0 a(1-\nu)/G$ where G is the shear modulus. Results for $\beta = 0^\circ$ and 90° can be compared with those in Fig. 8 of [Pollard and Holzhausen, 1979]. Note that the decimal points of the values along the vertical axis of that figure are hardly visible. Also note that an arbitrary constant may have been added to each curve in that figure, so only the shapes of the curves are useful, not the vertical locations.

- The mode-I and mode-II stress intensity factors at the two fracture tips ($v = \pm a$). We term the tip closer to ground surface tip A and the other tip B. Stress intensity factors should be normalized by $p_0\sqrt{\pi a}$. Results can be compared with those in Fig. 6 of [Pollard and Holzhausen, 1979].

- Report the mesh resolution near the fracture.

- Optional: The variation of results with respect to mesh resolution and element types.

3.2 Observables in the 3D model

The following observables are desired from the 3D model.

- Vertical surface displacement δ_y along the z-axis from $x = -4a$ to $x = 4a$.
- Vertical surface displacement δ_y along the x-axis from $z = -4b$ to $z = 4b$. Vertical displacement should be normalized by the same δ_∞ as that calculated for the 2D model.
- Optional: The mode-I and mode-II stress intensity factors along the four edges of the fracture. Stress intensity factors along the long edges should be normalized by $p_0\sqrt{\pi a}$; stress intensity factors along the short edges should be normalized by $p_0\sqrt{\pi b}$.
- Report the mesh resolution near the fracture.

4 Acknowledgments

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5 References

- Pollard DD, Holzhausen G (1979) On the mechanical interaction between a fluid-filled fracture and the earth's surface. Tectonophysics 53:27–57. doi: 10.1016/0040-1951(79)90353-6.