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Deformation and fracture structures in strike-slip faulting

Yu.P. Stefanov [a,b,*], R.A. Bakeev [c]

[a] ISPMS SB RAS, 2/4, Akademicheskii Ave., Tomsk 634021, Russia
[b] IPGG SB RAS, 3, pr. Akademika Koptyuga, Novosibirsk 630090, Russia
[c] ISPMS SB RAS, 2/4, Akademichesky Ave., Tomsk 634055, Russia

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ABSTRACT

The paper presents the results of 3D numerical modeling of fault formation due to strike-slip displacement of basement blocks on the example of model rock massifs differing in thickness. It is shown that the material thickness and initial stress state substantially influence the form of fracture structures arising in strike-slip faulting. The formation of a vertical fault with feathering Riedel fractures is characteristic of high-strength material and small thickness. If the material thickness is large, there arises a complex spatial flower structure with inclined fractures oriented in the horizontal plane at an angle of ~40° to the shear axis. The inclined fractures represent strain localization bands or so-called shear bands developing as pairs of “flakes” that resemble opened oyster valves. A main fault with clearly defined feathering fractures of different orientations is formed from the top down once these strain localization bands reach a free surface.

1. Introduction

The deformation and fracture of geological objects feature a series of peculiarities associated with their properties and structure as well with specificity of their loading conditions. The heterogeneous structure and initial damages present in rocks govern the dependence of their strength properties on the stress state in which the rocks are. Another fact responsible for deformation peculiarities of geological objects is that they persistently experience gravity forces, and hence they are always in the stress state. If we consider geological objects of size larger than hundred meters, and the more so than hundred kilometers, this initial stress may not be ignored. The initial stress state of geological objects can be decisive and critical for the processes occurring in them not only because their properties depend on the stress state but also because this initial state can approximate or even be higher than their limit of elasticity.

The fault structures observed on the Earth surface normally represent a broken line with feathering fractures. The segments of the broken line and its feathering fractures are periodic and are arranged at certain angles to the main fault line. Experimental studies on different geomaterials show that many fault structures observed in nature are induced by strike-slip displacement of basement blocks [1–3]. So, this type of faults receives much attention in studying deformation in the upper layers of the Earth’s crust, and the abundance of mineral deposits in their zones generates applied interest in them [4].

Despite numerous available data on strike-slip faults and fractures in them, there remain many questions on their structure, formation conditions, and stress state. By now, all types of fractures in fault zones have been classified relying on generalized natural observations and experimental findings [2–3]. However, experiments give no way of studying the details of fault

* Corresponding author at: ISPMS SB RAS, 2/4, Akademicheskii Ave., Tomsk 634021, Russia.
E-mail addresses: stefanov@ispms.tsc.ru (Yu.P. Stefanov), rustam@ispms.tsc.ru (R.A. Bakeev).

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Nomenclature

g	gravity acceleration
x, y, z	coordinates
u_i	velocity vector components
ρ	density
ν	Poisson's ratio
K	bulk modulus
μ	shear modulus
t	time
V	relative volume
σ_x, σ_y, σ_z	gravity-induced stresses
σ_{ij}	Cauchy stress tensor components
s_{ij}	deviator stress tensor components
σ	pressure
τ	tangential stress intensity
d_{ij}	total strain rate tensor components
d_{ij}^e	elastic components of strain rate
d_{ij}^p	plastic components of strain rate
γ^p	plastic shear strain intensity
ω_{ij}	rotation rate tensor components
δ_{ij}	Kronecker delta
f	yield surface function
G	plastic potential function
ε_{ij}^p	plastic (inelastic) strain components
$d\lambda$	plastic multiplier
α	yield surface parameter
Y	yield surface parameter
h	hardening function parameter
σ^*	negative pressure limited parameter
Λ	dilatancy factor

structures and stress state in their vicinity. Based on analytical estimates, the authors of [5] examined the directions of principal stress axes and orientation of fractures induced by strike-slip displacement of basement blocks taking into account possible transformation of the medium to the inelastic state. However, the questions as to the fault structures and stress state in their vicinity remained open.

The structure of faults at all stages of their evolution can be analyzed by numerical simulation. To do this requires 3D calculations with sufficient detail and with approaches which allow description of strain localization and fracture of the medium. Now, there are very few papers devoted to solution of this problem, e.g., [6,7], which points to its complexity. The possibility of numerically describing the formation of 3D strain localization bands in a deformed geomaterial layer was demonstrated elsewhere [8]. In the paper presented, we consider the influence of the deformed rock thickness on the structure of strain localization bands (or shear bands) induced by strike-slip displacement of basement blocks.

2. Problem statement and basic equations

Let us consider a rock massif consisting of two layers: an elastoplastic layer and a thinner elastic layer (Fig. 1). The rock massif experiences gravity force and lies on an immobile horizontal plane. In the lower elastic layer, there is a vertical notch throughout its length which simulates the presence of two blocks capable of horizontal displacement relative to each other.

The initial elastic stress state of the rock massif is described as

$$\sigma_z(z) = -g\int_0^z \rho(z)dz, \quad \sigma_x(z) = \sigma_y(z) = \sigma_z(z)\xi, \tag{1}$$

where $\xi = \frac{\nu}{1-\nu}$, ν is Poisson's ratio, and ρ is the density of the medium.

The deformation of the massif is specified through gradual displacement of the left and right blocks of the base in opposite directions along the notch:

$$u_x = u_0(t), \quad \text{for } (x,y,z) \in B,$$
$$u_x = -u_0(t), \quad \text{for } (x,y,z) \in C,$$