SOME PROBLEMS OF DYNAMIC FRACTURE MECHANICS

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ABSTRACT

We examine solutions of some dynamic fracture mechanics problems which were obtained on the basis of kinematic description of fracture processes. Conditions for dislocation fault branching and peculiarities of generated wave fields are investigated. Results under investigation are applied to the earthquake sources and underground explosions simulation.

KEYWORDS

Dislocation fault, stress intensity factors, synthetic seismograms, seismic effect.

INTRODUCTION

It is known that there are two approaches to fracture processes description in fracture mechanics, namely: dynamic and kinematic. When the dynamic approach is used values of stresses, acting on fracture area before the beginning of fracture process and conditions for crack sides interaction, are given as boundary conditions. When the kinematic approach is used value and direction of final dislocation vector on fracture area are given as boundary conditions. In this connection it is interesting to compare results obtained on the basis of these two approaches. In particular such kind of comparison was done by Bykovtsev and Cherepanov (1981a,b) and by Bykovtsev (1983). In these papers the kinematic approach was used to solve problems which were solved before with the use of dynamic approach. Obtained resultes are in good qualitative agreement with dynamic approach ones and quantitative differences do not exceed few per cent. However very often kinematic approach has advantage related with the fact that problem solutions become simpler from mathematical point of view. So using kinematic description we can solve great number of dynamic fracture mechanics problems which do not have effective solution when dynamic descriptin of fracture processes is used.

In this paper results of some dynamic problem solution using kinematic approach are studied. Examples of effective use of obtained results in some physical models are given.

ON TWO-DIMENSIONAL AND THREE-DIMENSIONAL FAULT PROPAGATION ALONG PLANE AND CURVILINEAR TRAJECTORIES. EARTHQUAKE SOURCE MODEL.

In a homogeneous isotropic elastic medium let a dislocation fault start to move at a constant velocity v (Fig. 1a - two-dimensional problem, Fig. 1b - three-dimensional problem). Constant jump of displacement $B(B_x, B_y, B_z)$ is given on the fault. B_x and B_z are the shear components and B_y is the tensile component. Analytical solution for these problems ware obtained by Bykovtsev (1986) and by Bykovtsev and Kramarovsky (1987,1989). Let us study some of obtained results.

Two-Dimensional Problem. In Fig. 2 stress intensity factors for pure shear rupture (B_x=1, B_y=B_z=0, Fig. 2a) and for pure cleavage rupture (B_y=1, B_x=B_z=0, Fig. 2b) are presented. Upper series presents stress intensity factors for dislocation fault (kinematic approach), lower series is for cracks (dynamic approach). Lines 1-4 in Fig. 2 correspond to different velocities of fault or crack propagation.

For dislocation fault Fig. 2 shows that the increase in velocity is accompanied by an increase in the values of the coefficients K_{zz} in all directions, for all types of faults; although characteristic maxima appear in the values of the coefficients $K_{\varphi\varphi}$, their magnitude decreases in all directions for all types of fault. The behaviour of $K_{z\varphi}$

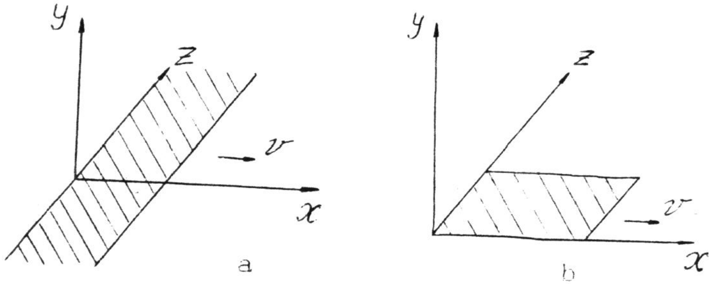

Fig. 1 Coordinates system for two-dimensional (a) and three-dimensional (b) problems.

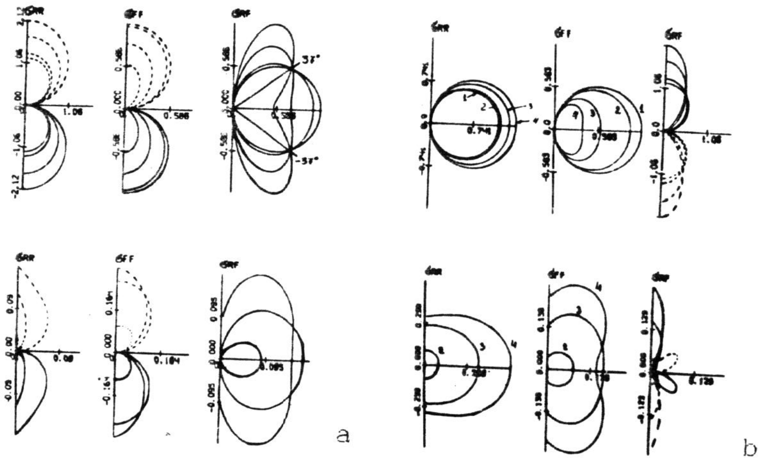

Fig. 2 Stress intensity factors for pure shear rupture (a) and for pure cleavage rupture (b).

depends essentially on the direction. Thus all types of faults are characterized by two directions in which the values of $K_{z\varphi}$ are practically independent of the velocity of propagation of the fault. The directions divide the space between the front of the moving fault into two zones. In one of these zones the values of $K_{z\varphi}$ decreases, and in the other it increases.

Thus, when $-63° \leq \varphi \leq 63°$ for pure cleavage fault, $-37° \leq \varphi \leq 37°$ for pure shear fault, the value of $K_{z\varphi}$ decreases, while for the remaining values of the angle φ it increases with increasing velocity of the fault propagation. If we then assume that the directions in which the values of the coefficients $K_{z\varphi}$ are practically independent, of the velocity of the fault propagation are responsible for the formation of branched segments of the fault, we obtain the values of the smallest possible branching angles ±63° for pure cleavage fault, and ±37° for pure shear fault.

Thus, analysing Fig. 2 we find that if the process of fundamental development of the fault begins with pure cleavage element of the fracture, then as the velocity of propagation of the fault increases we have, apart from the appearance of two symmetrical maxima in the stresses $\sigma_{\varphi\varphi}$, also a sharp increases in the stress $\sigma_{z\varphi}$ along specified parts of the zone situated in front of the moving fault edge. This must lead to symmetrical branching of the fault and the formation of considerable shear components of the displacement vector on the bounded segments.

If the fundamental fault propagation begins from shear fracture element, then as the velocity of propagation increases we have, in addition to the appearance of two symmetrical maxima in the stresses $\sigma_{z\varphi}$, also the formation of a discontinuity in the field of tensile stresses on one hand, and of a zone of compressive stresses on the other hand. This should lead either to deviation of the trajectory of motion by an angle φ from its initial direction and the formation of a considerable cleavage component of the displacement vector on the deviating segment of the fault, or to splitting of the fault into two branches. On one of these branches the displacement vector will have only the shear component, and both the shear and cleavage component on the other branch.

Three-Dimensional Problem. Obtained results can be applied to the earthquake source simulation. In order to investigate high-frequency seismic radiation let us follow the model by Bykovtsev (1979, 1990), Bykovtsev and Cherepanov (1980a,b) and present earthquake source in form of dislocation faults propagating along curvilinear trajectories. Let us investigate the change of synthetic seismograms form when the fault trajectory changes.

One of the possible trajectory of fault propagation is shown in Fig. 3 (dashed line is the trajectory which unites the beginning and the end of broken one). The vector of final dislocation in Fig. 3 is horizontal and its length B=60 cm. Its components on every subfault are determined by relationships $B_x=B\cdot\cos\alpha_i$; $B_y=B\cdot\sin\alpha_i$ (α_i are angles between subfaults and x-axis). The width of all faults along z-axis is 18 km (z-axis is perpendicular to the plane of Fig. 3 and it does not shown in Fig. 3). The movement along curvilinear trajectory has the following character: at first the first part of broken trajectory rips. Then the moving fault front stops for 2 s, after that the second part of broken trajectory rips and so on. By moving from one part of broken trajectory to another the moving fault front stops its propagation for 2 s.

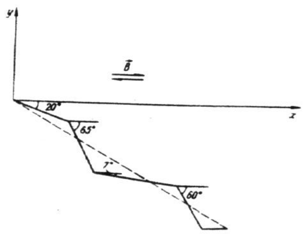

Fig. 3 Trajectories of fault propagation

The time for straight fault propagation (dashed line) equal to that for system of five faults (accounting the stops). Observation points are placed around z-axis and have the following coordinates: a) x=61.5; y=-35.5; b) x=61.5; y=35.5; c) x=-61.5; y=35.5; d) x=-61.5; y=-35.5. Coordinate z=71 (all values are given by km).

Synthetic seismograms for these faults and for these points of observation are shown in Fig. 4 (graph 1 corresponds to the straight-forward fault (dashed

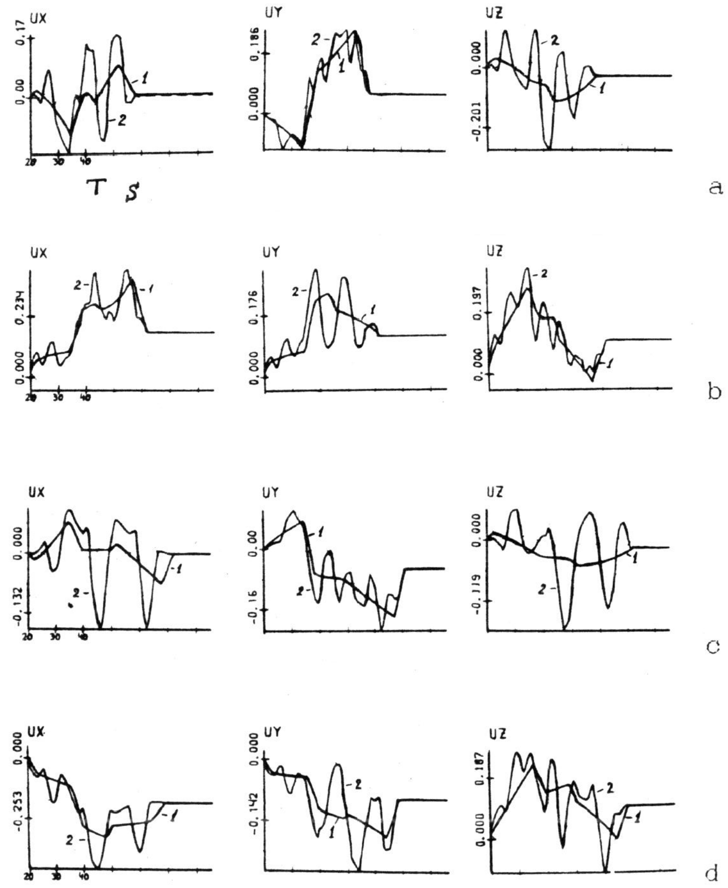

Fig. 4 Synthetic seismograms for straight-forward and curvilinear fault.

line in Fig. 3), graph 2 corresponds to the system of five faults; displacements in Fig. 4 are shown by cm). It can be concluded from Fig. 4 that the seismograms for system of five faults have more complicated form than that for straight-forward fault: they are complicated by high-frequency radiation, the displacements have alternating-sign form in some directions. The alternating-sign form and high-frequency of natural seismograms can be also connected with complex geometry of real earthquake source.

MODEL OF UNDERGROUND EXPLOSION

The zones of cavity, crush, radial cracks and elastic deformation are usually picked out around initial cavity with explosive. The zone of cavity appears near the initial cavity with explosive as a result of its expansion; farther is the zone of crush, more farther is the zone of radial cracks and lastly the zone of elastic deformations. It is known on the basis of experimental data that the radius of cavity zone $r_1 \leq 2.5r_0$ (r_0 is the radius of initial cavity with explosive), the radius of crush zone $r_2 \leq 10r_0$ and the radius of radial crack zone $r_3 \leq 100r_0$ (Fig. 5). The use of theoretical investigations makes it possible to determine sizes of these zones more precisely for materials and rocks.

A model of underground explosion based on results by Bykovtsev (1986) and Bykovtsev and Kramarovsky (1989) was proposed by Bykovtsev et al. (1992), Bykovtsev and Kramarovsky (1994). For explosive source model construction we assume:

1. Process takes place in infinite isotropic elastic medium.
2. Star-like system of cleavage faults having common origin (Fig. 6) start their propagation in consequence of explosive detonation.
3. Parameters of faults such as lengths, openings are connected with explosive and surrounding medium ones and are obtained on the basis of additional investigations.

Algorithm for fault lengths and their openings using parameters of explosive and surrounding medium was given by Bykovtsev et al. (1992) and Bykovtsev and Kramarovsky (1994). As distinct from other models this model takes into consideration system of radial cleavage faults, appearing around cavity with explosive. Solutions obtained by Bykovtsev (1986) and Bykovtsev and Kramarovsky (1989) allows

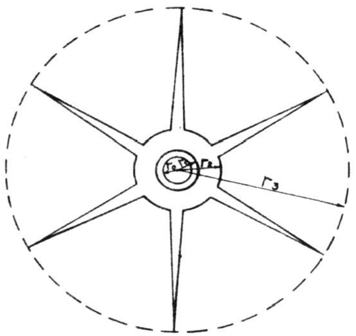

Fig. 5 Scheme of real explosion.

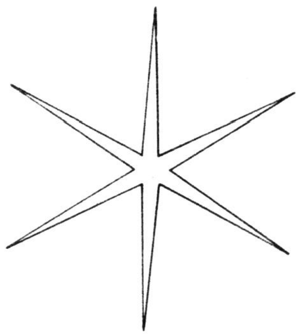

Fig. 6 Model of explosive source.

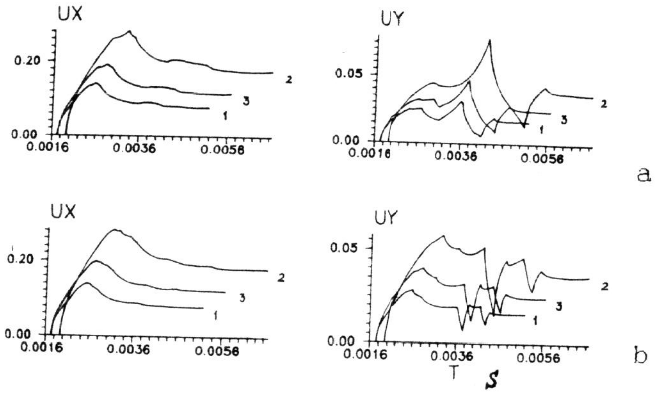

Fig. 7 Synthetic seismograms for model with 4 (a) and 6 (b) radial faults.

us to construct synthetic seismograms for this model. Using these seismograms we can evaluate seismic effect on surrounding objects.

In Fig. 7 we present synthetic seismograms for our model. Fig. 7a was constructed for model with 4 radial faults and Fig. 7b was constructed for model with 6 radial faults. Lines 1-3 correspond to three kinds of rocks with different properties. From Fig. 7 we can conclide that models with different amount of radial faults are in good agreement. Amplitudes and form of these seismograms depend mainly on explosion energy and parameters of explosive and surrounding medium.

Using the present model we can also predict seismic effect when great number of separate sources are exploded. Such occurrences often take place in mining industry for minerals extruction. This question was studied by Bykovtsev et al. (1992) for different schemes of separate explosive sources detonations.

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