STICK-SLIP UNSTABLE SHEAR FAILURE AS A SOURCE OF HIGH FREQUENCY ELASTIC RADIATION

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Summary: The results of laboratory measurements on square perspex models with a stress concentrator under uniaxial compression are presented. An attempt was made to interpret these results in order to determine the mutual relations between the mechanical parameters characterizing the treated models, including their focal zones, parameters of model loading, parameters of seismogenic displacement and parameters of radiated elastic pulses. Particular attention was given to the study of slip displacement, slip velocity, rupture velocity, nucleation points of rupture propagation, nucleation points of elastic radiation and to the frequency analysis of radiated pulses. Measurements of the displacement in the focal zone enabled us to determine the source function, to construct theoretical seismograms in a far field and to compare them with the real pulses from ultrasonic transducers located there. This allowed testing theoretical and experimental approaches to the study of how slip displacement, slip velocity and rupture velocity are related to the parameters of radiated pulses.

I. INTRODUCTION

Brace and Byerlee [1] claim that a stick-slip frictional, instability occurring in the Earth due to the tectonic stresses, is a possible general mechanism for a shallow focus earthquake. Much work has been done to establish clear physical relations between the three categories in question: the seismic source medium, tectonic stresses (loading this medium) and the seismic acoustic radiation which may occur there.

The investigation of breakdown processes can be successfully applied under laboratory conditions since the physical models allow direct observations and investigations of the physics of fracturing and seismic energy release as well.

In studying frictional sliding under load and various aspects of the dynamic processes of stick-slip failure, a large number of authors published a series of both theoretical and experimental papers [2—11]. In these papers a wide range of physical questions dealing with mechanical and radiation properties of rocks and other model materials were investigated in detail. Special attention was paid to stress field measurement and analysis, boundary conditions (friction, asperities, barriers, displacement, rupture velocity and rupture propagation), and partly also to radiation properties.

Besides testing rocks, numerous tests were also performed on amorphous (artificial) materials, such as perspex, which seem to simulate better the long-term rheological properties of rocks [3, 12—14]. Recent results in the field were summarized in [15].

Among others, the paper by Ohnaka et al. [16] was found to be worthy of special attention, since valuable new results and relations, which characterize the dynamic breakdown accompanied with high-frequency radiation on physical rock plate models under biaxial loading, were presented and discussed there. Particularly the shear stress and longitudinal strain measurements, the determination of slip velocity and the values of displacement along the slipping zone and fixing the rupture propagation velocity presented in the paper are of special interest.

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The paper stimulated us to perform similar measurements on square perspex models under load, with a diagonally located stress concentrator. Our attention was focussed on recording, evaluating and interpreting the high-frequency elastic radiation occurring during an unstable stick-slip failure in the course of loading these seismogenic structures. An attempt is made to compare and discuss the results obtained with those presented in [16].

2. EXPERIMENTAL

A square perspex plate (200 × 200 mm), 10 mm thick was used as the model, in the center of which a diagonally located linear notch (length 72 mm, width 1 mm) was cut. A special procedure was applied in preparing a frictional contact along the notch which simulated the tectonic fault with the faces in accoustical contact, the frictional conditions on the faces were achieved by surface grinding; for details see Košťák and Kozák [14]. The elastic properties of the perspex used are given by
\[ v_p = 2.73 \text{ km s}^{-1}, \quad v_s = 1.39 \text{ km s}^{-1} \quad \text{and} \quad \rho = 1.23 \text{ kg dm}^{-3}. \]

The Griffiths-like type of model used enabled us to apply the regime of uniaxial compression, since the complementing confining lateral pressure was substituted by two hardening columns of the model medium framing, on the left and right, the stress concentrator located in the centre. In measuring, the loading cycles were repeated three times so that three series of seismogenic stick-slip instabilities were recorded. The results obtained by analysing these series displayed a low degree of scattering of the results in the individual series, and thus the same conclusions could be drawn from each of them. During the experiment the model was subjected to linearly increasing compression 1.9 MPa min\(^{-1}\). The critical load value at which tensitional cracks appeared at the crack tips was approx. 20 MPa; therefore, the model was loaded only to 14 MPa. Beginning with the normal stress value equal to 5-9 MPa up to 13.5 MPa, a series of 5 unstable stick-slip shear failure processes connected with high-frequency elastic radiation were observed and recorded by means of 10 ultrasonic piezoceramic transducers located on the model surface.

Two types of transducers were used. Six of the bimorphic type, which were sensitive to displacement. These were located along the fault edge, the first being fixed near the slit tip, the others mounted at 8 mm intervals along the fault. These pick-ups were mounted in a special carrier fixed gently to both hardening columns of the model (left and right edges), which enabled us to record the slip displacement during the stick-slip instabilities at the desired position along the fault. As for the frequency response, the transducers were tested in the interval from 1 kHz up to 90 kHz; the amplitude frequency distortion in this frequency range did not exceed 10\%. The four remaining pick-ups, ultrasonic accelerometers, were located 60 mm from the model centre. The accelerometers used had calibrated amplitude/frequency transfer characteristics from 1 kHz up to 1 MHz. The array is depicted in Fig. 1.

The displacement signals and high-frequency elastic radiation signals, detected by the above transducers, were recorded by means of a 10-channel measuring system.