EXPERIMENTAL STUDY OF SEISMIC SHORT-IMMINENT PRECURSORY MECHANISM BY NEW METHODS AND TECHNIQUE

Xu Zhaoyong(1) Yang Runhai(1) Zhao Jinming(1) Wang Yunyun(1) Li Peilin(1)

Wang Bin(1) Mei Shirong(2) Xiong Bingheng (3) Wang Zhengrong(3) Lu Xiaoxu(3)

Zhong Liyun(3) Zhang Yongan(3) She Canlin(3)

(1) Seismological Bureau of Yunnan Province, Kunming 650041, PRC (2) Earthquake Analysis Center of CSB, Beijing 100036, PRC (3)Laser Institute of Kunming Technology University, Kunming 650041,PRC

Abstract

The new instrument and technology and methods have been used in study of fracture phenomenon. A multi-functional high-frequency seismometer (0.5Hz-20KHz) and high-speed strainmeter are used to study burst strain disturbance and Short-imminent precursor and precursor in far field. The real-time holographic and caustic method are used to study the process and nature of micro-cracks nucleation, at the same time transient wave recorder is used to study feature of micro-crack and relativity of precursor with slow earthquake. These initial results are described in this paper.

1 Foreword

Besides studying phenomenon precursory mechanism should be made clear, especially the short-imminent precursory mechanism. The authors are very interested in these studies. In recent years the new instrument and technology have been used to study fracture phenomenon, and some results have been achieved. A brief description is as followings.

2 Burst strain disturbance and short-imminent and far field precursor.

A multi-functional high-frequency seismometer (0.5Hz-20KHz, which is low-frequency for test of rocks fracture), the new instrumental system, and high-speed strainmeter are used to recorder multi-point strain variations of rock samples in the process of fracture development.

2.1 Burst disturbance and short-imminent precursor

The results indicate that strain in each point appears burst disturbance synchronously besides a tendency variation before main fracture (Fig.1). There are characteristic variations of sudden shaking and disturbance several 100^{-1}-10^{-1} seconds before fracture and several seconds before (Fig.2).

2.2 Precursor in far field

Interaction between seismogenic body and wall rock of force-supply is used to study precursor in far field and ultra-far field. Observation studies of stress and strain are made on force-supplying body, I.E.the machine frame, or on block of transferring pressure. The results show that there appears mutation or disturbance precursor of strain in the force-sensor or on block of transferring pressure before rock fracture beside anomaly variation appearing in all observing points on sample (Fig.1/Fig.2). The observing points on block of transferring pressure are 25-90 cm away from sample, which are 3-10 times of fracture sizes. It is explained that precursor anomaly is possible appearing in far places from seismogenic area. The reason forming far field precursor is primarily studied.

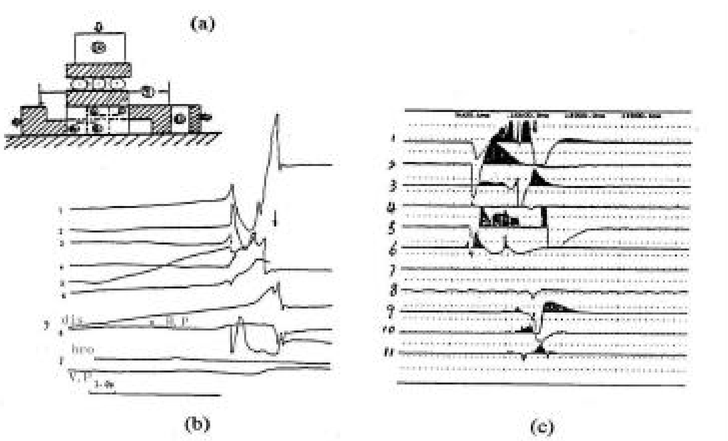


Fig.1 Strain (stress) variations with time in preparing fracture of single shearing for marble

a. Diagram for sample settlement and distribution of points (1,2,3,4 before 5,6,7,8 behind sample)

b. Recordings in SC-16 light oscillometer

c. Recordings in SWG multi-functional seismometer

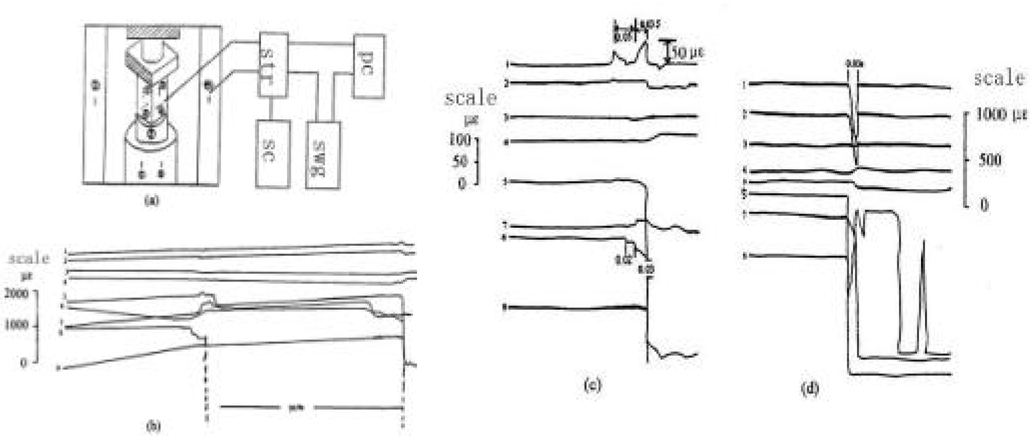


Fig.2 Strain (stress) variations with time in preparing fracture for uniaxial compression

a. Diagram for sample installation and point distribution (1,2,3,4 out of sample 5,6,7,8 on the sample)

b. Whole time progress for sample No.2 in the fracture test

c. Time progress for sample No.2 before and after main fracture

d. Time progress for sample No.3 before and after main fracture

3 Latest study results by real-time holographic interferometry and caustic methods

A sample of plexiglass with $200x200x15mm^3$ in size is used. On which the penetration fissures with

35mm in length and 30° with direction of maximum principal stress σ_1 (σ_y) are cut by laser, forming two kinds sample. Ones contain a block of Y- border consisting of en echelon fault, others are single fissure. A small biaxial pressure machine has been set on anti-seismic platform, with maximum 300KN at vertical and horizontal lateral pressures. Beginning from the force loading, it starts image recording by real-time holographic interferometry (Fig 3). At the same time micro-crack (acoustic emission) is recorded by transient wave recorder. The stress-strain curves at those places are measured to study yield or plasticity.

Using mapping relation of pure geometry, caustic line transforms an object, especially the complicated deformation in the area of stress concentration, into a simple and clear optical diagram with shadow. The related mechanical parameters can be obtained by measuring and computing caustic lines. It is a method usually used in stress analysis in test (J.F.Kalthoff, 1987). Presently we have introduced the method into seismic simulation test.

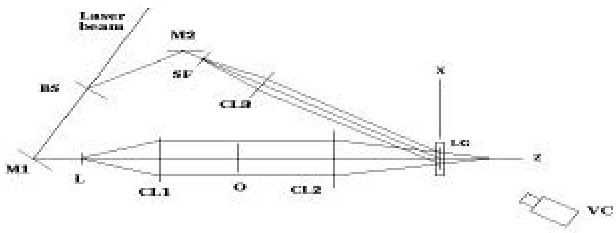


Fig.3 Schematic diagram of the optical setup for this real-time holographic testing method

BS：Beam splitter M_1、M_2：Mirror SF：Spatial filter CL_1：Φ300mm Collimator O：specimen

CL_2：Φ450 mm Imaging lens CL_3：Φ100 mm Collimator L：concave lens LG：Liquid gate

3.1 Physical nature in nucleation area

3.1.1 Formation and development of strain (stress) core and caustic (shadow) area

As expected, stress concentration areas are formed at ends of each pre-cut fissure starting from low stress. Interference fringe at the ends of each pre-cut fissure in denser seen from image. This area of denser fringe is called strain core. Dark shadow (caustic) area are formed near the edge and its ends of pre-cut fissure when σ_y increases to about 30% of fracture stress, and it is bigger at the ends. It has obvious borderline from the fringe area with high density nearby. Those shadow become bigger with the increase of loading, and smaller when unloading. However, the shadow areas keep unchanged when reaching at a certain extent. The micro-crack occurs at the ends of fissure when stress keeps increasing. This maximum area is called critical shadow area.

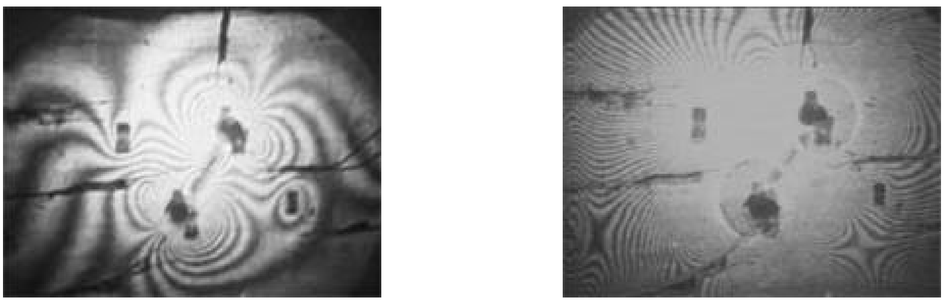


Fig 4 Caustic area (dark shadow) is formed for single pre-cut fissure.

Left: at low-stress (strain core); right: at high-stress (dark shadow)

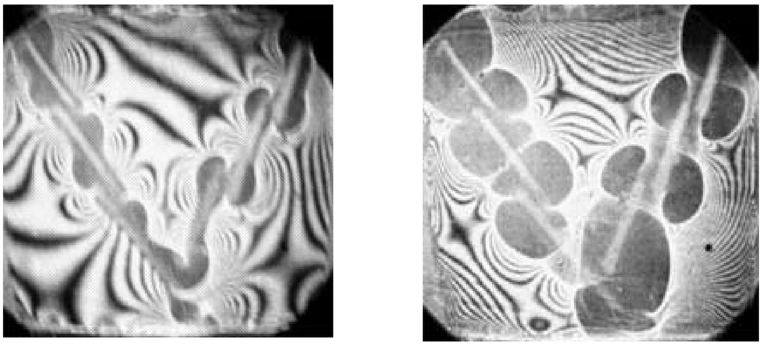


Fig 5 Caustic area (dark shadow) is formed for many pre-cut fissure.

Left: at low-stress; right: at high-stress

3.1.2 Physical nature of shadow area, yield or plastic variation to the materials

The variations of model's thickness and material's refractivity are all very obvious and non-uniform when the model on loading due to near the singular area of stress. When a certain condition is met, the lights out of front and rear surfaces of the model deviate from parallel and form a 3-D enveloping surface, i. e. caustic curved surface. Therefore, it can judge from the appearance and development of shadow areas that the material property at the place is certainly changed. However its changing degree needs further studying. It can be seen from the comparison that stress-strain curves inside and outside of the shadow areas have big differences, it is big differences also at various places inside of shadow. It is inferred that the shadow areas are caused by the yield or plastic variation of the materials. However, it needs studying to make sure that it is due to yield or plasticity. It is possible that there appear different variations to different materials. For example, there appears yield for rocks and plastic variation for metal or plastics. Furthermore, the variation degrees are different in different points in the same material (even adjacent points). In any case, it indicates that the property of material has changed.

Fracture mechanics of elastic-plasticity indicates that there exists a plastic area at the sharp end of crack. To the mode II crack, the plastic size along the crack is:

$$r_0 = \frac{k_{ii}^{\ 2}}{2ps_y^{\ 2}} \qquad (1)$$

and

$$G_{ii} = k_{ii}^{\ 2} / E' \qquad (2)$$

So, the critical size of plastic is:

$$r_{0c} = E' G_{iic} /(2ps_y^{\ 2}) \qquad (3)$$

In which G_{iic} is critical energy of shear fracture, σ_y is yield stress. Therefore, The related mechanical parameters can be obtained by using relativity of the plastic size with caustic lines. But the transversal size near the ends of crack mentioned here means tensile shear crack, little to compressive shear crack.

3.1.3 Relations between caustic (shadow) area and nucleation area

Micro-crack always happens within the shadow areas at the end of pre-cut fissure, however the concentration area of micro-crack is much smaller than the shadow area. If taking the concentration area of micro-crack and nearby area as nucleation area and the shadow area as yield (or plasticity) area, the nucleation area is always within the yield area, and the yield area is always greater than nucleation area.(Fig.6)

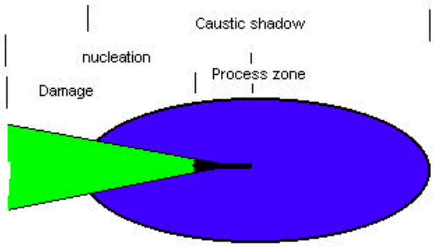


Fig.6 Relations between caustic (shadow) area and nucleation area

3.2 Recordings of main fracture at real time

3.2.1 Dynamic process accompanying with formation and spreading of main (big) fracture

It is excited that a whole dynamic process of strain vary has been recorded from forming at ends of pre-cut fissure, then gradually enlarging and finally fracturing (breaking). Continuously loading was made on samples No.1 and No.4 until the whole samples break down. Several seconds before the fracture, caustic area at the end of pre-cut fissure rapidly changes from ellipse, spreading, becoming core with closed angles, and suddenly expanding (obvious shadow area) until passing through the whole sample. The details of fracture for the two samples are not necessarily the same, but both have rapid spreading of shadow area with closed angles.

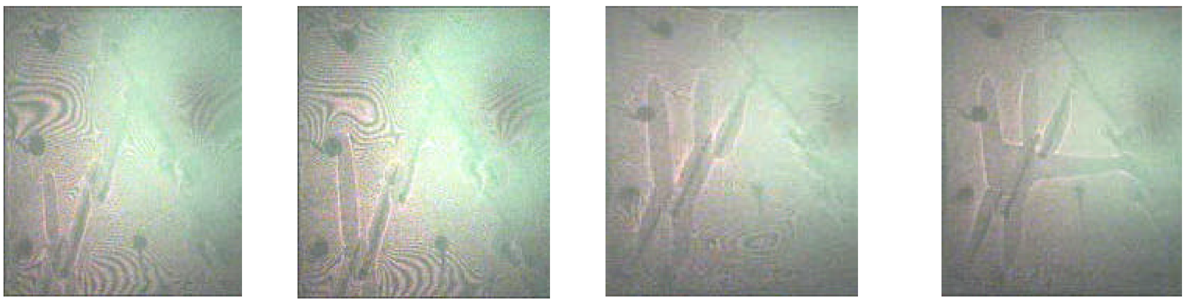


Fig 7 Caustic area (dark shadow) with closed angles is formed before main fracture

3.2.2 Dynamic process of formation and spreading of stress core in unloading

Loading stops when reaching at 70% of fracture stress for samples of No.2, No.3 and No.5, and then unloading. The micro-crack seems active in the process of unloading (stress adjustment) and ears can hear many sounds. It can been from the interference fringe that the fringe is becoming less dense and stress is decreasing, and at the same time the shadow area with closed angles is spreading. A difference is that there is a circle dark shadow area at the sharp end. These shadow areas decrease gradually and disappear finally when stress decreases to zero.

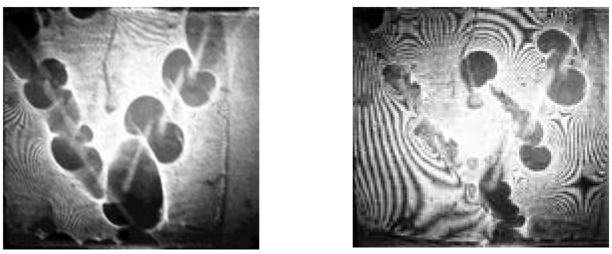


Fig .8 Caustic area (dark shadow) is formed for unloading.

Left: at high-stress; right: at low-stress

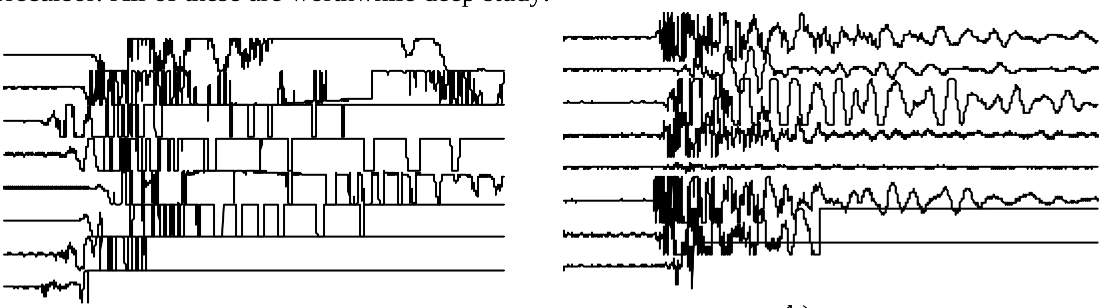
3.3 Sequence of earthquake generating for multi-seismogenic areas

In spite of different details, it is that fractures of the shadow area have sequence. I.E. the one becoming big and reaching at rated value (like fracture strength) fractures first.(Fig.5/Fig.8)

We used to call the low strain area surrounded by the high strain area as strain gap. There are strain gaps in both cases of loading and unloading. The micro-crack appears in strain core, however, the main fracture starts from strain core, then rapidly develops towards strain gap.(Fig.7)

4 Relations between mechanism of slow earthquake and short-imminent (slow) precursor

Besides studying slow earthquake phenomenon, evidence and mechanism for a long time T. H. Jordan, H. Kanamori et al have also linked slow earthquake with nucleation, and studied slow precursor and short-term prediction. Many references consider that slow earthquakes take place on transferring fault. Other mechanism is seldom discussed and test study is even rarely been seen. We have discovered in the fracture tests by rocks and plexiglass that amplitude is small and period is big in the first half period and even several periods seen in waveform recordings of big fracture event, afterwards, big amplitude and small period (Fig 9). These low frequency events are probably the slow earthquakes, which happen in the shadow areas. It is inferred that yield or plastic deformation is probably an important mechanism producing slow earthquakes. It is a vital short-imminent precursor. All of these are worthwhile deep study.



(a) (b)

Fig.9 Waveform recordings of some big fracture with small amplitude and big period

a. Slow event b. Fast event

5 Future study

The results mentioned above part 3 and 4 are made in plexiglass. It needs to make deep study on rock sample by using holographic interferometry and caustic methods.

References

[1] Kalthoff, J.F., Shadow optical method of caustics, Handbook of experimental mechanics, Ed by A .S. Kobayashi, Chap.9, pp430-500 ,1987 .

[2]Jordan,T.H.,Far-field detection of slow precursors to fast seismic ruptures, Geophys. Res.Let. vol.18 no.11,2019-2022,1991.

[3]Kanamori ,H., and Hauksson ,E.,A slow earthquake in santa maria basin,california, B.S.S.A.,Vol.82, No. 5, pp.2087-2096, 1992.