Effects of Contact Geometry of Faults on Transmission Waves

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Abstract — In order to clarify the effects of contact geometry of faults on transmission waves, we have performed a series of experiments in which P and S waves with known wavelength were transmitted through an artificial fault. A pair of piezo-electric transducers (PZT) with various resonant frequency were used for the transmitter and the receiver. Parallel grooves were cut on disk surfaces and two disks were placed face to face with the grooves on one disk being perpendicular to those on the other disk. This yields evenly spaced square contacts on the fault. We regard the square contacts as asperity contacts, the size and the height of which were controlled by changing the width and the depth of the grooves. We found that the transmissivity of the waves is solely determined by the ratio of the groove depth/width to wavelength. The shallower and the narrower the groove depth and width are, the larger the amplitude of first arrival is for both P and S waves. When the groove depth is shallower than a quarter of wavelength, the effect of groove depth is negligible; deeper grooves significantly reduce the amplitude. We have made a mathematical model based on the stiffness of fault. By comparing the model calculations with the observation we found that the model has a limit at which the prediction by the model deviates from the data. The deviation occurs when the ratio of the groove depth/width to wavelength becomes 0.25. We refer to the wavelength as the critical wavelength. When the wavelength is larger than the critical wavelength, the observed data can be well explained by the model. Above this threshold, the model no longer fits the data. In this range, the amplitude of transmitted waves is found to be proportional to the real contact area. Although it is a kind of paradox that the amplitude, not the energy, is proportional to the real contact area, it is possibly explained by taking a non-uniform distribution of stress on the surface of the receiver PZT into account.

Key words: Transmission waves, contact geometry, contact stiffness, wavelength, transmission coefficient, piezo-electric transducer.

1. Introduction

Seismic waves are known to be affected (slowed and attenuated) by the cracks at all scales (from microcracks to faults) in rocks. A number of theoretical and experimental works have so far been performed (JOHNSTON et al., 1979, and PYRAK-NOLTE et al., 1990) present a good review of previous works). Many of them treat the study in a way that a number of small cracks (meaning the scale of the cracks is much smaller than the wavelength) attenuate the amplitude and reduce the velocity of the incident seismic waves (consult O’CONNELL and BUDIANSKY, 1977, for example). Here, however, we

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restrict our attention to a single fault which also produces significant effects on wave propagation (Schoenberg, 1980; Myer et al., 1985; Pyrak-Nolte et al., 1990; Chen et al., 1993), and particularly to the effects of its contact geometry on transmission waves. In order to clarify the motivation of our study, it is necessary to address an example of possible applications below before developing the main subject.

It has been recognized that some earthquakes are preceded by very slow, precursory slips without seismic wave radiation. Mogi (1982) re-analyzed the crustal deformation observed twice just prior to the 1944 Tonankai Earthquake ($M = 7.9$) and established there was certainly a precursory slip prior to the earthquake. Earthquakes with smaller magnitude may also be preceded by precursory slips even if they are not detectable. Precursory slips have also been observed in laboratory experiments (Scholz et al., 1972; Ohnaka et al., 1986; Iwasa and Yoshioka, 1998). Many other theoretical works support the existence of precursory slips prior to earthquakes (Rudnicki and Chen, 1988; Ohnaka, 1992; Dieterich, 1992; Yamashita and Knopoff, 1992).

If we could somehow detect the precursory slips, it would facilitate earthquake prediction. A possibility of the detection may arise when we consider the change in the contact condition of asperities on the fault surfaces due to precursory slips. It is well known that real contact area on contacting rough surfaces increases with the logarithm of time (Dieterich, 1972; Scholz and Engelder, 1976). If precursory slip occurs, the time effects will vanish because old contacts are replaced by new contacts due to the precursory slip, and thus it causes a reduction in real contact area and hence in stiffness of the fault. The change in fault stiffness may be detected by transmission waves across the fault (Myer et al., 1985; Pyrak-Nolte et al., 1990; Yoshioka and Kikuchi, 1993; Iwasa and Yoshioka, 1998).

Iwasa and Yoshioka (1998) performed an experiment in which an artificial fault was loaded normally and tangentially, and elastic waves transmitted across the fault were continuously observed until a final stick-slip event occurred. They noticed two characteristic features. First, the shear loading caused a significant increase in amplitude of transmitted waves. Second, the increasing rate of the amplitude was slightly decreased with the onset of precursory slip. The second feature may be attributed to the reduction in stiffness at some contacts due to precursory slips. The slight change in transmission waves reflects the change in the contact condition of asperity contacts on the fault.

Thus it is very important to investigate the effects of asperity contacts of a single fault on transmission waves. In order to understand the details of the relation between asperity size, asperity spacing and wavelength of transmission waves, we have performed a laboratory experiment in which P and S waves with known wavelength were transmitted across an artificial fault. We have focused our investigation on the size of asperity contacts comparable to the scale of wavelength. In addition, a theoretical model was constructed and a simulation was performed to interpret the experimental results.