GEOPHYSICAL SIGNATURES OF FRACTURE MECHANISMS

by

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A Dissertation

Submitted to the Faculty of Purdue University

In Partial Fulfillment of the Requirements for the degree of

Doctor of Philosophy

Lyles School of Civil Engineering

West Lafayette, Indiana

December 2017

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ABSTRACT

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Degree Received: December 2017
Title: Geophysical Signatures of Fracture Mechanisms
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Fractures and discontinuities have a significant influence on the mechanical and hydraulic properties of brittle materials such as rock. The prediction of rock mass behavior requires information on the location and character of the initiation, propagation, and coalescence of new and pre-existing cracks. Methods based on the interpretation of seismic waves are of great interest because the waves can be used to probe internal damage in rock. The objective of this research is to characterize crack initiation, propagation, and coalescence inside rock using wave propagation. Digital image correlation (DIC) was employed to investigate crack evolution on the surface of rock specimens under load. Uniaxial compression experiments were performed on pre-cracked Indiana limestone specimens that contained one or two parallel pre-existing cracks. In the experiments, the uniaxial compression was applied with a constant displacement rate until failure. Reflected and transmitted waves, both compressional (P) and shear (S), were propagated through a specimen while digital images of the specimen surface were acquired during the test.

From the DIC data, tensile and shear crack initiation were identified as a jump in the displacement field around the tips of pre-existing cracks. A distinct decrease in the amplitude of transmitted waves occurred prior to the detection of tensile crack on the specimen surface using DIC. In addition, degradation and opening/closing of tensile cracks under uniaxial cyclic compression-compression loading was monitored using the amplitude of the transmitted waves. The amplitude of the transmitted wave was observed to increase as the specimen was unloaded and the cracks closed, and decrease in amplitude during re-loading.

In contrast to the tensile crack behavior, the amplitude of the transmitted waves did not change during shear crack initiation. However, seismic wave conversions (P-to-S or S-to-P wave) were found to be effective in identifying the initiation of shear cracks in rock. P-to-S wave conversion occurs in the presence of an array of oriented open micro-cracks, which is one mechanism for the formation of shear cracks. These converted-mode seismic signatures were observed well before tensile and shear cracks were detected on the rock surface using DIC. With crack propagation, the amplitude of the transmitted waves decreased while the amplitude of the converted waves increased.

Coalescence occurred through the propagation of new tensile or shear cracks between the flaws. Crack coalescence was associated with a significant decrease in the amplitudes of wave transmission and conversion, and with an increase in the reflected wave amplitudes. As an additional benefit of recording both transmitted and reflected waves is that the arrival time of the reflected waves from tensile and shear cracks was used to locate the new cracks in the rock. The observed changes in the amplitude of transmitted, converted, and reflected waves provided a method for determining when and where damage had occurred in the rock. The findings of this research have a number of potential applications such as predicting failures (e.g. sliding along faults in earthquakes) and other instabilities (e.g. rock slope instability) due to rock discontinuities or to locate and characterize the initiation and propagation of induced discontinuities in hydraulic fracturing.

Keywords: Crack initiation and propagation, Crack coalescence, Digital image correlation (DIC), Seismic wave monitoring