Fracture contact state inferred from longitudinal wave velocity: Theoretical and experimental approach

*Eranga Gayanath Jayawickrama[1], Hayata Tamai[2], Jun Muto[1], Hiroyuki Nagahama[1]

1. Department of Earth Science, Tohoku University, 2. East Japan Railway Company

Seismic tomography has provided many important details of the earth's interior in the past few decades and variation in wave velocity has been a key factor in understanding the seismograms. Therefore, by velocity inversions the understanding of low velocity zones within the earth's crust has been improved and in general these low velocity zones are identified as zones with fluids or geologically weak zones. In reflection seismology, low velocities can be identified as weak zones, basically as fractures. Even though these inversions have the ability to show the fractured zones, they have not been able to show the degree of opening of the fractures. Therefore, to understand the fracture contact state, it is important to achieve a relationship between the contact state and the velocity, so that by the variation in velocity the contact state can be inferred.

As to the current knowledge, the elastic wave velocity is highly affected by the fractures, and this indicates that the contact state has a strong influence over the variation in velocity. The wave velocity increases as the contact state changes its relative displacement with increasing pressure. This change in displacement was explained by Nagumo (1963) for different types of single contacts. In this study, we have extended this pressure-displacement relationship of single contacts to a velocity-pressure relationship, and discuss the multiple contact state variation inferred from the change in velocity with increasing pressure.

From one dimensional wave equation, a power law relationship of longitudinal wave velocity and pressure is introduced with a pressure exponent representing the contact state of fractures. For single cone, ball and flat contacts, the pressure exponent λ takes values of 1/2, 1/3 and 0, respectively. By extending this to multiple contacts the pressure exponent μ representing multiple contacts have been deduced as 2/3, 3/5 and 1/2 for multiple cone, ball and flat contacts, respectively. Using previously published experimental data and an empirically derived equation (Kobayashi and Furuzumi, 1972) which is similar to the theoretically derived relationship in the current study, the applicability of the theory is tested. From the results, we show that the contact state changes form conical contacts, to ball contacts and finally to flat contacts with increasing pressure.

The study has also shown that the lithology, microstructures and presence of water are factors that control the contact state with increasing pressure. Granite and gabbro show pressure exponents $\mu < 1/2$ indicating complete closure of fractures while serpentinite is yet to close completely at the same pressure. Also, rocks with equally low porosity but different lithologies show different contact states at equal pressures. These indicate that lithology is a major factor controlling the contact state. Further a marked difference in contact states can be observed depending on the direction of measurement with respect to the foliation and depending on the water existence. The velocity change with increasing pressure also can be explained in terms of contact state of fractures using the current contact state theory since the prominent velocity change is mimicked by an equally prominent contact state change at the same pressure.

As shown from our study, this method is applicable to assess the contact state of fractures in an area of interest. By obtaining velocity data from reflection seismology and seismic tomography, and using the wave velocity-contact state relationship introduced here, the degree of fracture opening can be estimated. Therefore, we believe this method can be used in wide range of applications from shallow depth exploration geophysics to understanding the anomalies in lower crust.

Keywords: Contact state, Fractures, Wave velocity

