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Inverse modeling of the overpressure distribution in an extension fracture with an arbitrary aperture variation: application to non-feeder dikes in the Miyake-jima Volcano, Japan

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We derived a solution for the overpressure distribution acting on the walls (surfaces) of an extension fracture (a hydrofracture) with an arbitrary opening-displacement (or aperture) variation. In the proposed model, we assume that the overpressure distribution can be described by Fourier cosine series. We at first present a solution for the forward model giving the fracture aperture when it is opened by an irregular overpressure variation obtained using the Fourier cosine series. Next, by changing the form of the solution for the forward model, we obtain a matrix equation that can be used to estimate the Fourier coefficients to obtain the overpressure distribution from the fracture aperture variation. As simple examples of this inverse analysis, we estimate the overpressure conditions from crack apertures given analytically for two cases, namely, 1) the overpressure in the crack is constant, and 2) the overpressure variation in the crack varies linearly from its center. The estimated overpressure distributions were found to be correct, although a small "noise" was present.

Since the method presented here gives the overpressure distribution as a Fourier series by the aperture data measured at a finite number of points, the overpressure conditions for forming the fracture can be determined for each wavelength. The Fourier coefficient of n = 0 is an important coefficient that gives the average value of the overpressure acting inside the crack. With the exception of n = 0, the Fourier coefficient of n = 1 expresses the longest wavelength component of the irregular overpressure. Thus, because this coefficient including the coefficient of n = 0 gives the longest wavelength component in the irregular overpressure, the component may be an important indicator of the overpressure condition that decides the basic form of the crack.

We applied the solution for the inverse analysis to the thickness data of 19 non-feeder dikes exposed in the caldera wall of the Miyake-jima Volcano, Japan. In the analysis, the host-rock Young's modulus and Poisson's ratio were taken as 1 GPa and 0.25. The results show that most of the estimated overpressures increase toward the tips of the dikes and reach about 5 to 15 MPa (average was 8 MPa). In addition, results indicate host-rock fracture toughnesses between 60 MPa $m^{1/2}$ and 170 MPa $m^{1/2}$ (average 100 MPa $m^{1/2}$). For comparison, we also estimated the magma overpressure by the least square method, assuming constant overpressure. This method gives overpressure between 1.5 MPa and 4 MPa (average 2.8 MPa). Similarly, the fracture toughnesses estimated in this way range between 30 MPa $m^{1/2}$ and 120 MPa $m^{1/2}$ (average 55 MPa $m^{1/2}$). These methods and assumptions thus yield somewhat different results, as expected, but indicate the likely ranges of the magma overpressures and host-rock fracture toughnesses both of which are very reasonable and agree with earlier results obtained by different methods.