Quantification of Uncertainty on Fracture Intensity Distribution (Part 1)
亀裂頻度分布における不確実性の定量化（パート 1）

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1. The purpose and background of this study

Safety and performance analysis for underground facilities in fractured rock requires a quantitative understanding of flow and transport. The discrete fracture network approach provides a proven technology for calculating groundwater flow, considering the details of the geometry and hydraulic properties of the individual fractures which effect flow and transport at the local scale. Dershowitz[1)] described a procedure for deriving the geometric and hydraulic properties of fracture networks from readily available site characterization data. This approach has since been adapted by SKB as a standard procedure for assessment of radioactive waste disposal facilities[2)]. For SKB, Hermanson et al[3)]. have developed the concept of "tectonic continuum" to derive fracture size distributions by interpolating between a range of scales: i.e., mapped lineaments, outcrop mapping, and borehole intersections. The "tectonic continuum" assumes that the fracture counts at each scale can be normalized and plotted on a common axis to determine a single "power law" distribution. However, this "power law" distribution is critical to many safety assessment calculations, and it is therefore important to characterize the uncertainty of this assessment. This paper describes an approach to quantify this uncertainty, for those cases where the "Fisher distribution"[4)] can be used as an approximation of the orientation of the fractures at each scale. The procedure takes advantage of the approach of Wang[5)] which relates the two dimensional fracture intensity $P21$ (m/m^2) to the one dimensional intensity $P10$ (1/m) as a function of the fracture orientation distribution, the fractal dimension of the size distribution (Kr), and the mean fracture radius (R_μ). For more information on these intensity measures see Dershowitz and Herda[6)].

The procedure is as follows:

(1) From surface outcrop and borehole fracture data, calculate the orientation distribution as a Fisher distribution described by mean pole (θ, φ) and Fisher dispersion parameter κ

(2) From the method of "tectonic continua", estimate the fractal dimension of the size distribution (Kr)

(3) From outcrops and lineament maps, calculate the intensity P21 for fractures at each scale, and the intensity $P10$ for fractures at each scale

(4) Derive the relationship between the measured intensity $P10$ and $P21$, as $P21 = C21 \times P10$, where $C21$ is found from the field data

(5) Using the method of Wang determine the range of values of Kr and R_{min} which satisfy the value of $C21$ found from the site data

(6) Utilize the equations derived below to define uncertainty ranges on the intensity $P20$ used in the tectonic continuum plots, to determine the range of Kr and R_{min} values which could be fit within, for example, one standard deviation on the tectonic continuum plot

(7) Compare the values of Kr and R_{min} from Wang with those obtained through the method of "tectonic continua". Plot the distributions of Kr and R_{min} from Wang on the tectonic continua plots to obtain a quantitative assessment of the level of uncertainty in these parameters. These uncertainties in Kr and R_{min} can then be propagated to uncertainty analyses carried out as part of safety assessment.

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2. Derivation of Uncertainty on Tectonic Continuum Estimate of Size Distribution

Wang et al. derived for the relationship estimation between intensity measures P21 (m/m2) and P32 (m2/m3) from intensity P10 (1/m) for Fisher distributed fracture orientations.

$$\frac{P21}{P10} = C21 = \left[\int_0^{\pi} \left|\cos\alpha\right| f(\alpha) d\alpha\right]^{-1} \left[\int_0^{\pi} \sin\beta f(\beta) d\beta\right] \quad \text{Eq.1}$$

where,

$$f(\alpha) = \frac{1}{\pi} \int_{R_\delta} \frac{\sin\alpha \cdot \left(\kappa e^{\kappa Cos\delta} Sin\delta\right)}{\left(e^{\kappa} - e^{-\kappa}\right)\sqrt{\sin^2\delta \sin^2\rho - (\cos\alpha - \cos\delta\cos\rho)^2}} d\delta \quad \text{Eq.2}$$

$R_\delta = [\rho - \alpha, \rho + \alpha]$, if $\alpha \le \rho$ or $R_\delta = [0, \rho + \alpha]$ if $, \alpha > \rho$, ρ :The angle between Fisher mean pole and sampling line, α :The angle between sampling line and fracture normal and $|\delta - \rho| \le \alpha \le \delta + \rho$, β : The angle between sampling plane normal and fracture normal and $|\delta - \rho| \le \beta \le \delta + \rho$

Assuming disk shaped fractures, with size distributed according to a Power Law Distribution, the expected value for trace lengths of fractures on any plane, $E(l)$, is as follows (Eq.3).

$$E(l) = \frac{\pi \cdot R_\mu{}^2}{2 \cdot R_\mu} = \pi \cdot Kr \cdot R_{\min} \cdot \{2(Kr-1)\}^{-1} \quad \text{Eq.3}$$

Therefore, the expected value for $P20$ (1/m^2), trace density, on a certain plane could be derived by Eq.1 and Eq.3.

$$P20 = P21 \big/ E(l) = P10 \cdot C21 \cdot \left[\pi \cdot Kr \cdot R_{\min} \cdot \{2(Kr-1)\}^{-1}\right]^{-1} \quad \text{Eq.4}$$

Additionally, the standard deviation of $P20$ for observed area A (m^2) could be derived as Eq.5 if the generation of each fracture assumed to be Poisson process.

$$\sigma_{P20} = \sqrt{\frac{P21 \cdot A}{E(l)}} \cdot A^{-1} = (P10 \cdot C21)^{0.5} \cdot \left[A \cdot \pi \cdot Kr \cdot R_{\min} \cdot \{2(Kr-1)\}^{-1}\right]^{-0.5} \quad \text{Eq.5}$$

Eq.4 and Eq.5 can be used directly to apply uncertainty to each point on the tectonic continuum plot for fracture size, using the range values of *Kr*. This provides a quantitative measure for the uncertainty in the derived power law radius distribution.

3. Conclusion

The approach of the "tectonic continuum" provides a single "best fit" value of fracture intensity and power law size distribution. For purposes of safety assessment and periodic safety review for facilities conducted after tunnel excavation, it is important to quantitatively assess the uncertainty in this derivation. This paper provides a method to do that, by utilizing the relationships between fracture intensity measures *P*10, *P*21, and *P*20.

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