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Finite-size scaling for the connectivity, permeability, and dispersion of discrete fracture networks

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Translating fracture statistics to global hydraulic properties in subsurface fractured rocks is a complex but appealing task, as measuring parameters such as permeability can be prohibitively expensive. To tackle this challenge, we developed the finite-size scaling (FSS) hypothesis, drawing inspiration from percolation theory in statistical physics. We created numerous Monte Carlo iterations using our CUDA-based code, cuDFNsys, to simulate flow and transport in discrete fracture networks (DFNs). We generated a wide range of DFN scenarios with vastly different input parameters to ensure generality. We then nondimensionalized the obtained connectivity, permeability, (asymptotic) dispersion coefficients, density of fractures, domain sizes, and so on. By analyzing the dimensionless quantities, we found that the FSS hypothesis can predict connectivity, permeability, and dispersion as an invariant function of dimensionless density and domain sizes with several universal critical quantities. Furthermore, the FSS function can identify the transition point of dimensionless density, where permeability remains constant regardless of domain sizes. Around this point, the scale-dependence of permeability changes from negative to positive. Our findings provide a strong theoretical foundation for understanding the relationship between fracture attributes and field-scale hydraulic properties. This research inspires further investigation into applying the FSS function at the field scale, which will improve the information that earth scientists can obtain from fracture statistics

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