Numerical Simulation Study on Size Effect and Fracture Mechanism of Basalt Columns Under Compression: Postprint

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Abstract

To investigate the size effect on strength and deformation of basalt columns under compression, as well as their fracture mechanisms and failure modes, this study constructs images of basalt columns with different sizes. By integrating meso-damage mechanics, statistical strength theory, and continuum mechanics, and based on digital image processing in RFPA3D-CT, the basalt column images are transformed into finite element mesh models, with mechanical material parameters assigned to joints and rock separately, wherein the heterogeneity of both joints and rock is considered. Numerical experiments on basalt columns under compression are conducted to analyze the influence of confining pressure and direction perpendicular to the column axis (/) on the mechanical size effect of basalt columns, as well as the stress field evolution and damage-fracture characteristics during the fracture process. The research indicates: For case (direction perpendicular to the column axis), when the confining pressure is 0 MPa, the specimen compressive strength exhibits no significant size effect; when the confining pressure is 2 MPa, the critical value for the size effect of specimen compressive strength is 4 m; when the confining pressure is 4, 6, or 8 MPa, the critical value for the size effect of specimen compressive strength is 6 m. For case (direction perpendicular to the column axis), when the confining pressure is 0 or 2 MPa, the specimen compressive strength exhibits no significant size effect; when the confining pressure is 4 MPa, the critical value for the size effect of specimen compressive strength is 4 m; when the confining pressure is 6 or 8 MPa, the critical value for the size effect of specimen compressive strength is 6 m. When the confining pressure ranges from 0 to 8 MPa, as the model size increases, the transverse anisotropy coefficient of specimen compressive strength varies within the range of 0.75–1.15; the transverse anisotropy coefficient of specimen equivalent deformation modulus varies within the range of 0.90–1.15. Therefore, basalt columns can be approximated as transversely isotropic. The complete process of joint cracking, stress concentration, crack

initiation and propagation, and crushed zone formation in basalt columns under various confining pressures, model sizes, and directions perpendicular to the column axis (/), along with the acoustic emission characteristics, is analyzed.

Full Text

Preamble

This manuscript contains extensive mathematical derivations and model specifications that are central to the methodological framework. The following sections present the core mathematical components of our approach.

The primary mathematical expressions are structured as sequential developments of the core model. Beginning with foundational definitions, the derivations progress through several key transformations. The initial formulation establishes the basic parametric relationships underlying the system. This is subsequently expanded to incorporate additional constraints and optimization criteria. Further developments introduce specialized terms accounting for boundary conditions and convergence properties. The mathematical sequence continues with intermediate calculations that bridge the theoretical framework with practical implementation considerations. Additional mathematical specifications address computational efficiency and numerical stability. The derivations then proceed to advanced transformations necessary for the optimization procedure. Subsequent mathematical components refine the model architecture through systematic modifications.

The framework incorporates several auxiliary equations that support the main theoretical results. Further mathematical developments establish the convergence criteria and error bounds. The mathematical foundation extends to specialized cases and extensions. Additional specifications address implementation details and algorithmic considerations. The mathematical sequence continues with formulations for empirical validation. Further derivations address robustness and generalization properties. The framework includes mathematical components for performance evaluation. Additional mathematical specifications support the experimental design. The derivations incorporate terms for statistical analysis. Further mathematical developments address computational complexity. The mathematical sequence includes formulations for comparative analysis. Additional specifications support the theoretical claims. The framework concludes with mathematical components for practical deployment.

The following sections apply these mathematical foundations to specific problem domains, with detailed derivations supporting each application. These mathematical foundations provide the basis for the experimental results and comparative analyses presented in subsequent sections.

Note: Figure translations are in progress. See original paper for figures.

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