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Geological Cube: Characterizing Tunnel Rock Mass Property Through 3D discontinuity Trace Recognition

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ABSTRACT

The refined characterization of fracture networks in tunnel faces is critical for evaluating rock mass stability and mitigating excavation risks. This study proposes an integrated point cloud processing methodology combining edge detection and skeletonization techniques to accurately extract the geometric topology of face fractures. The edge extraction is achieved through feature point covariance matrix analysis and surface differential thresholding, while Laplacian-based contraction algorithms enable precise skeletonization. For discontinuity characterization, a computational framework for the discontinuity index P31 is established, with its rationality validated through similarity analysis between P31 and P21 indices. The innovative "Geo-Cube" conceptual model is introduced to enable multi-planar refined discontinuity characterization, providing a theoretical foundation for comprehensive fracture distribution analysis and internal rock mass structure evaluation. Furthermore, the size-dependent numerical distribution patterns of P31 calculations are systematically investigated. The proposed methodology advances quantitative characterization of tunnel rock mass fractures through three key contributions: 1) A hybrid edge-skeleton processing chain for high-fidelity fracture topology extraction; 2) A multi-scale discontinuity index system bridging micro-macro fracture properties; 3) A three-dimensional characterization framework integrating spatial and statistical fracture features. Case studies demonstrate the framework's effectiveness in supporting excavation risk prediction and optimized support design, offering robust data-driven insights for geotechnical engineering practice. This research establishes a new paradigm for intelligent fracture network analysis in underground engineering applications.

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