Geotechnical Multi-Source Data Graph Convolutional Models Integrating Bias Correction and Desmoothing Strategies: A Postprint

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Abstract

In the domain of rock mechanics and engineering, the fusion analysis of multi-source heterogeneous data including lithology and stress constitutes the core foundation for geological hazard early warning and underground engineering stability assessment. Current rock data modeling approaches based on Graph Convolutional Networks (GCN) exhibit two critical issues: first, features of dominant categories are continuously reinforced through neighborhood propagation, inducing "popularity bias"; second, the inherent over-smoothing problem of GCN leads to blurring of local features. To address these challenges, this paper proposes a graph convolutional framework that integrates bias correction, collaborative signal enhancement, and de-smoothing strategies (PCD-GCN). The framework encompasses three core modules: the collaborative signal enhancement module quantifies the collaborative contributions of multi-source rock data, thereby strengthening the representation of multi-field coupling information for "lithology-stress-deformation"; the bias correction module combines rock clustering analysis with iterative reweighting strategies to alleviate the excessive dominance of dominant data; the de-smoothing strategy suppresses global topological influence through vector perturbation, with modules optimized from the dual dimensions of "global suppression-local preservation". This study validates the effectiveness of PCD-GCN in bias correction and over-smoothing suppression, providing a precise modeling paradigm for geotechnical hazard early warning and underground engineering stability analysis, and offering a novel technical approach for cross-scale correlation analysis of "data-structure-mechanical response" in rock mechanics.

Full Text

Graph Convolutional Model for Geotechnical Multi-source Data Integrating Bias Correction and De-smoothing Strategies

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Abstract

In the field of rock mechanics and engineering, fusion analysis of multi-source heterogeneous data—including lithology, stress, and other geotechnical parameters—forms the cornerstone of geological disaster early warning and underground engineering stability assessment. However, current rock data modeling approaches based on Graph Convolutional Networks (GCN) suffer from two critical limitations. First, features of dominant categories are continuously reinforced through neighborhood propagation, leading to "popularity bias." Second, the inherent over-smoothing problem of GCNs results in blurred local features, compromising the fidelity of localized geological information.

To address these challenges, this paper proposes a novel Graph Convolutional framework called PCD-GCN that integrates bias correction, collaborative signal enhancement, and de-smoothing strategies. The framework comprises three core modules: (1) a collaborative signal enhancement module that quantifies the cooperative contributions of multi-source geotechnical data, thereby strengthening the expression of multi-field coupling information across "lithology-stress-deformation" domains; (2) a bias correction module that combines rock clustering analysis with iterative reweighting strategies to mitigate the excessive dominance of prevalent data categories; and (3) a de-smoothing strategy that suppresses global topological influence through vector perturbation, achieving optimization from dual perspectives of "global suppression and local preservation." Experimental validation demonstrates the effectiveness of PCD-GCN in both bias correction and over-smoothing suppression, providing a precise modeling paradigm for geotechnical disaster early warning and underground engineering stability analysis, while offering a new technical pathway for cross-scale correlation analysis of "data-structure-mechanical response" in rock mechanics.

Keywords: Graph Convolutional Networks; Recommendation Algorithm; Bias Correction; Multi-source Data

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