

学位論文の要旨

Abstract of Thesis

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学位論文題目 Title of Thesis (学位論文題目が英語の場合は和訳を付記)

Application of machine learning methods to geotechnical designs based on data-driven probabilistic framework
データ駆動型確率論的フレームワークに基づく地盤工学設計への機械学習手法の応用

学位論文の要旨 Abstract of Thesis

Geotechnical design faces fundamental challenges due to the inherent uncertainty and spatial complexity of subsurface conditions across diverse engineering applications including foundations, retaining structures, tunnels, and slope systems. Traditional deterministic design approaches rely on sparse field measurements that sample only a tiny fraction of the investigation domain, creating substantial knowledge gaps that limit design reliability and optimization potential.

This dissertation develops a comprehensive machine learning-enhanced framework that transforms sparse field measurements into reliable probabilistic geotechnical design parameters while systematically accounting for spatial variability, measurement uncertainty, and temporal dynamics. While the methodology has broad applicability across geotechnical engineering, this research demonstrates and validates the framework through slope stability applications, which provide an ideal testbed for the developed methods due to their complex spatial heterogeneity, time-dependent behavior, and critical safety requirements. The framework represents a paradigm shift from deterministic, experience-based analysis toward objective, machine learning-enhanced evaluation supporting risk-informed decision-making across various geotechnical design applications.

The methodology integrates four interconnected innovations functioning as a cohesive system. Tucker decomposition-Bayesian compressive sensing revolutionizes three-dimensional spatial reconstruction through tensor-based sparse representation that preserves anisotropic geological patterns while providing uncertainty quantification. Multivariate Gaussian process trend kriging enhances spatial characterization by systematically integrating heterogeneous measurement types through cross-correlations between geotechnical and geophysical data.

Building upon enhanced spatial predictions, laboratory-calibrated transformation relationships convert indirect measurements into engineering parameters while accounting for soil behavior-dependent uncertainty. Monte Carlo-based stability analysis propagates all uncertainty sources through the complete analysis chain, providing comprehensive probabilistic reliability assessment. PCLA-Net, a hybrid deep learning architecture, addresses temporal dimensions by processing spatial material variability and temporal environmental loading patterns for real-time probabilistic hazard assessment.

Extensive validation through synthetic and real-world case studies demonstrates superior performance

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compared to conventional approaches across diverse geological conditions. The framework successfully captures fine-scale spatial heterogeneities while providing realistic uncertainty quantification. Systematic uncertainty reduction through data fusion enables more confident reliability assessment while maintaining computational efficiency for practical applications.

The research establishes new theoretical foundations for probabilistic geotechnical analysis, advancing tensor-based spatial reconstruction theory and multivariate modeling frameworks for heterotopic measurements. The comprehensive uncertainty propagation methodology provides systematic approaches for reliability assessment that acknowledge all sources of uncertainty in complex geotechnical systems.

The practical significance lies in transforming slope stability assessment toward objective, risk-informed evaluation that optimizes safety and economic considerations. The framework enables more effective utilization of investigation resources while supporting dynamic risk management strategies adaptable to changing environmental conditions. This work bridges sophisticated theoretical developments with practical engineering applications, establishing foundations for future developments in probabilistic geotechnical analysis and digital twins for geotechnical systems.