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Editorial: Monitoring, early warning, and mitigation of natural and engineered slopes – volume IV

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Editorial on the Research Topic
Monitoring, early warning, and mitigation of natural and engineered slopes – volume IV

Introduction

Landslides and slope instabilities pose significant threats to infrastructure, human safety, and the environment, making it essential to develop effective monitoring, early warning, and mitigation strategies (Zhou et al., 2022; Wei et al., 2024; Qiu et al., 2025). The growing impacts of climate change, extreme weather conditions, and human activities have further intensified the risks of slope instability, highlighting the critical need for effective hazard assessment and risk mitigation strategies (Hürlimann et al., 2022; Pei et al., 2023; Zhu et al., 2024). Recent advancements in slope control technology, coupled with the development of interdisciplinary and multidisciplinary interaction theories, have created new opportunities for the early detection, dynamic monitoring, and risk reduction of unstable slopes (Fang et al., 2024; Liu et al., 2024; Cifaldi et al., 2025). However, achieving large-scale, long-term, and cost-effective monitoring, along with precise risk assessment, accurate early warning, and efficient disaster recovery, remains a significant challenge that requires further technological and methodological advancements (Thirugnanam et al., 2022; Wang et al., 2022). Building on the contributions of Volume III, which included 16 research papers (Qiu et al., 2024), Volume IV presents 30 new studies that reflect key advancements in landslide hazard assessment, predictive modeling, and innovative mitigation strategies. The selected articles offered an interdisciplinary perspective and incorporating approaches from geotechnical engineering, remote sensing, and artificial intelligence. By integrating real-time monitoring tools, deep learning models, and optimization techniques, these studies have greatly improved the ability to forecast, assess, and mitigate landslide risks, contributing to the advancement of safer and more resilient infrastructures.

Slope hazard mitigation: mechanisms and technologies

Seventeen of the 30 research papers in this volume investigated advancements in landslide risk assessment methodologies, real-time monitoring technologies, and innovative mitigation strategies, with the goal of providing scientific insights and practical solutions for slope stabilization and disaster prevention. Huang et al. present a hybrid Principal Component Analysis (PCA)-Sparrow Search Algorithm (SSA)-Support Vector Machine (SVM) model to enhance the slope stability prediction accuracy. PCA reduces data dimensionality while preserving essential features, and the SSA optimizes SVM parameters, overcoming the limitations of traditional methods. Wang et al. conducted a back-analysis by using a coupled particle flow model and an elastic viscoplastic model to study the dynamic process of the Yanghuachi (YHC) landslide-triggered debris flow. Han et al. proposed an automated failure mode identification method for slope stability monitoring by integrating rainfall, surface displacement, and vertical displacement data. Using a deep convolutional autoencoder model, this approach extracts features from normal operational data and detects anomalies based on reconstruction error variations. Feng et al. systematically analyzed the spatial relationships between landslides and fault zones and established a correction coefficient value table and distribution map. An improved Newmark model incorporating fault effects was developed and compared with the traditional model under seismic conditions (10% exceedance probability over 50 years). Liu et al. developed an intelligent monitoring, early warning, and forecasting system for a transmission line tower with high and steep sandstone slope along a highway under construction in Guangxi, China. The study analyzed automatic monitoring data, assessed an emergency rescue program, and evaluated the effectiveness of slope protection measures. Zhang constructed a landslide susceptibility spatial distribution prediction model using an integrated particle swarm optimization in Lianhe Village, Sichuan Province. The study analyzed the sensitivity and weighting of influencing factors and applied a support vector machine (SVM) for prediction. By incorporating simulated annealing and mutation operations, the model effectively extracted high-weight features and improved landslide susceptibility mapping, thereby enhancing hazard prediction accuracy. Mihu-Pintilie et al. analyzed climatic, anthropogenic, geological, and geomorphological factors that contributing to a debris flow-slide event in October 2023 through field investigations and UAV-based data reconstruction. The study further explored the reactivation potential of landslides, dam stability concerns, and the future evolution of the impounded lake, providing insights into hazard assessment and mitigation strategies. He et al. proposed a rapid landslide hazard assessment method to reduce reliance on large datasets while improving efficiency and accuracy. Using the Analytic Hierarchy Process (AHP) combined with Information Value (IV), Certainty Factor (CF), and Frequency Ratio (FR) methods, this study assessed landslide risk in Yongxing Town, Sichuan Province. The results showed that AHP-IV and AHP-FR assign a moderate risk level to the region aligning well with field investigations, whereas AHP-CF produced a slightly lower hazard assessment due to the exclusion of water system factors. Cifaldi et al. developed a low-cost Arduino©-based wire extensometer for landslide monitoring, capable of measuring bi-directional displacements between fixed points. Unlike traditional extensometers, which use potentiometers with limited measurement capacity, the device integrates a capacitive rotary encoder, enabling the monitoring of infinite displacements over time. Li et al. proposed an integrated automatic recognition method for coastal slope landslide detection combining Image Clipping (IC), Image Information Enhancement (IE), Adaptive K-means Clustering Segmentation (AKS), and optimization (O). This approach can achieve the precise extraction of deformation areas in landslide images, thereby improving the accuracy and efficiency of slope stability assessment using image-based analysis. Saik et al. conducted a stress-strain state modeling study on rock mass at Vostochny Quarry in the East Saryoba field to identify vulnerable quarry slopes and develop strengthening strategies. Utilizing geodetic, geophysical, and aerospace technologies, their research enhanced the predictive accuracy of technogenic disasters. Li et al. combined image information enhancement technology with image segmentation techniques to improve landslide identification accuracy. Verified on a coastal slope landslide in Pingtan, the method achieved an average relative error of 5.20% in the X-direction and 5.14% in the Y-direction. Key advantages include the enhanced identification of blurred landslide areas, extended temporal monitoring capability, and improved boundary condition segmentation, contributing to more precise and reliable coastal slope monitoring. Wu et al. developed a numerical model incorporating elevation conditions and slope shape factors using the modified Sadovsky formula to analyze the vibration attenuation law of open-pit slopes under blasting. Taking the Yunfu area in Guangdong Province as an example, FLAC3D software was used for analysis, and the results showed that considering slope shape factors reduced the relative error from 15% to 10% compared to field data. While the peak particle velocities in the simulations were higher owing to the simplified rock mass modeling, the proposed model provided more accurate results, offering a reliable reference for slope stability assessment under blasting conditions. Liu et al. applied the minimum distance principle and quantitative theory to assess coal burst risk in isolated working faces. Taking Yangcheng Coal Mine as an example, a three-dimensional risk assessment model was established, and it was found that abutment pressure and elastic strain energy density initially increase exponentially before declining to *in situ* stress. Compared to one-dimensional and two-dimensional models, the three-dimensional model significantly improved the risk assessment accuracy and effectively identified strong coal and gas outburst risks. Zhang et al. studied stick-slip instability in deep coal-rock structures, identifying weak surface conditions and friction behavior as key factors. They found that grinding slip and soft interlayers increased the failure risk, triggering dynamic disasters. Local stick-slip in coal seams generates compression pulses that cause layer cracking and fragment ejection. Numerical simulations of a coal bump accident in the Yima coal mine confirmed this instability mechanism. Shao et al. proposed a GF-DeepAR model for slope deformation prediction, combining a Gaussian-filter (GF) denoising algorithm with the DeepAR deep learning method for point and probability analysis.

The model was validated using two slope engineering cases, showing improved accuracy over the GF-LSTM, GF-XGBoost, and GF-SVR models. The results demonstrated that the model has effective noise reduction effect, higher R^2 values, and lower prediction errors, and can reliably capture the complex deformation trends. The study highlights the GF-DeepAR model's superior performance in slope deformation prediction, offering a useful reference for early warning systems in geotechnical engineering. Zhou and Wei studied the challenges associated with earth pressure in slope retaining structures, a critical Research Topic in geotechnical engineering that remains inadequately understood. Their study categorizes research into three main approaches: theoretical calculations, model testing, and numerical simulations, summarizing existing findings, and highlighting unresolved Research Topic. They emphasized the need for further research on earth pressure distribution in complex conditions, such as stratified soils or groundwater presence, as well as the displacement behavior of retaining structures. Additionally, they pointed out the lack of experimental verification and engineering measurements for the existing calculation formulas and assumed fracture surfaces.

Natural disasters and their ecological-land use impacts across regions

Geographical and tectonic variations significantly influence the diversity of disaster risks across different regions, thereby affecting the ecological stability and spatial patterns. Consequently, these factors have become the central focus of scholarly research. Yang et al. developed a flood forecasting framework that integrates Geomorphological Instantaneous Unit Hydrograph (GIUH) with the Xinanjiang model, and optimized it using the Cooperation Search Algorithm (CSA). Applied to six Chinese catchments, CSA achieved NSE >0.9 with only 16 trials, outperforming SCE-UA algorithms. The model effectively handled data-sparse regions and accurately simulated extreme rainfall events, thereby proving its potential for global flood forecasting. Teng et al. proposed an optimized method for rapid and accurate flood inundation extraction using Sentinel-1 SAR (Synthetic Aperture Radar and Sentinel-2 MSI (Multi-spectral Image) images. By integrating the normalized difference water index (NDWI), a refined threshold method and a filtering process, the approach effectively identifies pre- and post-flood water bodies. When applied to the 2020 Tongling flood, the method achieved kappa accuracies of 98% (optical images) and 89% (SAR), demonstrating its potential for dynamic flood monitoring and emergency response. Liu et al. analyzed future precipitation variations in the Daxi River Basin using CMIP6 data and applied distributed hydrological models to simulate flash flood discharges. The study found that precipitation under the SSP5-8.5 scenario was the highest, whereas the CREST model underestimated peak floods compared to the CNFF model. The results indicate a low probability of flash floods exceeding a 10-year return period from 2026 to 2070, thereby providing insights for disaster prevention. Wei et al. investigated the impact of climate warming on permafrost landslides along the Qinghai-Tibet Engineering Corridor (QTEC). Their findings showed that rising temperatures have caused permafrost to thaw, increasing the thickness of the active layer and leading to more frequent landslides, particularly in 2016. Laboratory tests confirmed that as the soil temperature approached 0°C to −1°C, its strength decreased, making the slopes more unstable. Li et al. investigated Zhongbao landslide reactivation in Chongqing, China, on 25 July 2020. Their analysis revealed that heavy rainfall, stratigraphic lithology, and sliding surface morphology triggered failure, which progressed through four stages: initiation, shear-out, acceleration, and accumulation blockage. He et al. analyzed the "720" flood in the WZD-HGZ basin, attributing it to heavy rainfall, complex terrain, backwater obstruction, and human activity. Flood amplification occurs in three stages: runoff concentration, infrastructure collapse, and backwater formation. Weak flood awareness, unclear warnings, and poor emergency responses further worsen the disaster. The study offers insights into improving flood prevention. Ren et al. developed a remote sensing method to improve shallow landslide identification in low-resolution images under complex lighting. To reduce the misjudgment caused by spectral similarity, they applied an improved Otsu algorithm with a multi-feature threshold at the Yangjunba disaster site in Leshan City. Using the Retinex theory, image enhancements and morphological transformations were implemented to detect landslide areas. The method achieved a recognition rate of no less than 95%, demonstrating its effectiveness for accurate landslide identification.

Experimental investigation, stabilization mechanisms and mitigation of soil erosion

These six studies focused on the experimental investigation, stabilization mechanisms, and mitigation strategies of soil erosion, and examined the effects of internal and external factors on erosion processes. Zhang et al. explored the use of chemical stabilizers to enhance the erosion resistance of sandy silt soils. The study on the effects of lignosulfonate (LS), lime (LI), and lignin fiber (LF) found that LF increased the critical shear stress, while LI reduced the erosion coefficient, thereby improving soil stability. SEM analysis revealed that LF promoted agglomerate formation and enhanced resistance, whereas LS had a minimal impact. Guo et al. analyzed the time series of soil erosion deformation in the Yuanmou dry-hot valley from 2018 to 2022 using Small Baseline Subset InSAR (SBAS-InSAR) technology, revealing erosion patterns significantly influenced by altitude, rainfall, and fractional vegetation cover (FVC). The study found severe erosion area concentrated in river basins and confluence zones, with deformation rates reaching −101.68 mm/yr to 30.57 mm/yr. Erosion intensity varied with elevation, being rainfall-dominated below 1,350 m and variations in FVC become the primary factor for soil erosion in dry red soil. Yao et al. discussed the backward erosion piping mechanism in dike foundations, emphasizing the impact of the model size on hydraulic gradients and piping behavior. Numerical simulations and small-scale experiments reveal that dikes without blanket layers experience steady gradient increases, leading to failure, whereas blanket layers induce a self-healing effect that mitigates erosion. Huang et al. explored the effectiveness of check dam openings in controlling debris flow by analyzing 67 check dams in Wenxian County, Gansu Province. Experimental testing of five check dams with opening rates ranging from 2.1% to 10.4% revealed that increasing the opening rate initially reduced the volumetric water content and pore water pressure. The findings highlight an optimal opening range of 4.2%–6.3%. Dam II (4.2%) outperformed others in reducing flow energy and trapping coarse particles,but required higher strength. Jiang et al. performed laboratory experiments on landslide dam breaching under varying inflow rates (1–4 L/s) and revealed a consistent three-stage breach process, with the peak discharge increasing as the inflow increased. Breach width and depth expand proportionally, with the width-to-depth ratio progressing toward 1. The breaching process follows a logistic function, where the shape parameter k exhibits an exponential relationship with the inflow rate, providing insights for predicting dam failure dynamics. Chu et al. studied that Loess with 10% moisture transitioned from strain softening to hardening after six cycles, while at 18% moisture, it shifted from strong to weak hardening. The strength degradation was most significant after the first cycle, and tended to stabilize after ten cycles, with the cohesion deteriorating more than the internal friction angle. SEM analysis showed increased overhead pores and particle contacts, explaining the strength loss due to freeze–thaw cycles.

Prospectives

This volume emphasizes the integration of modern technologies, data-driven approaches, and multidisciplinary techniques for monitoring, early warning, and mitigation of risks associated with natural and engineered slopes. The application of remote sensing, machine learning, and numerical simulation models has significantly enhanced the slope stability assessment. However, under the influence of extreme weather events, global climate change, and large-scale construction activities, slope failure requires renewed attention. In this context, further in-depth studies are necessary to advance disaster-mitigation strategies. This study provides a reference for damage reduction and risk management from the following key aspects: 1) Advancing AI-driven monitoring solutions for real-time landslide detection. 2) Enhancing interdisciplinary collaboration for holistic slope stability analysis. 3) Developing eco-friendly and sustainable mitigation methods to balance infrastructure safety and environmental conservation. 4) Establishing long-term monitoring frameworks to assess gradual slope deformations and predict future failures.

Author contributions

HQ: Writing – original draft. WN: Writing – original draft. AA: Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

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