

Safety Evaluation of Dam and Geotechnical Engineering, Volume II

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1. Introduction to the Special Issue

Dams and geotechnical structures are fundamental infrastructure for global water allocation, flood control, clean energy production, and agricultural irrigation [1]. Their long-term safe operation directly underpins engineering system stability, public safety, and regional socioeconomic development [2]. In recent decades, large-scale water conservancy projects have expanded rapidly. Dams now operate under increasingly complex conditions, with more diverse loading regimes, geological settings, and environmental disturbances [3,4]. Meanwhile, global climate change has intensified extreme events such as strong earthquakes, heavy rainfall, and prolonged droughts [5]. These factors have significantly elevated dam safety risks under complex hydrogeological conditions. Adverse events such as dam overtopping and failure can trigger catastrophic cascading consequences, leading to severe casualties, irreversible property damage, and long-term ecological degradation [6]. Accordingly, dam safety evaluation has become a foundational and pressing research theme in hydraulic engineering [7].

Against this background, the development of scientific, systematic, and dynamic safety assessment approaches for dams and geotechnical engineering structures has become a major research focus [8,9]. Traditional dam safety evaluation systems rely heavily on empirical formulations, single-point monitoring data analysis, and deterministic numerical simulations [10]. Despite their certain practical value in engineering applications, such approaches are often inadequate to satisfy the demands of refined management and real-time early warning when confronted with complex, multi-source, and uncertain engineering systems [11]. They cannot capture spatiotemporal correlations in structural responses, quantify the effects of material variability and random loads, or detect potential hazards in advance. Consequently, integrated evaluation methods have advanced rapidly. These methods combine monitoring data, numerical simulations, intelligent algorithms, risk analysis, and multi-physics coupling [12].

This Special Issue is devoted to gathering state-of-the-art theoretical progress and engineering practices in the field of dam and geotechnical engineering safety evaluation. It focuses on key challenges including deformation monitoring, seepage detection, seismic safety, fragility analysis, slope stability, soil strength degradation, and intelligent parameter inversion. The research included in this Special Issue explores the key technical bottlenecks existing in the contemporary dam safety management system from perspectives such as theoretical methods, experimental testing, numerical analysis, intelligent modeling, and engineering applications. It provides a valuable reference basis for the safety management of water conservancy infrastructure and the reduction in disaster risks.



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2. Main Contributions of This Special Issue

This Special Issue includes 12 high-quality research papers. These papers cover five core thematic areas: intelligent deformation prediction, seismic safety and source characteristics, seepage detection and foundation reinforcement, parameter inversion and reliability analysis, and soil–structure interaction under environmental cyclic actions. Collectively, these studies advance the frontier of dam safety evaluation. They reflect the field's shift from single static analysis to integrated approaches combining multi-source monitoring, intelligent prediction, and risk quantification.

Accurate deformation prediction is the cornerstone of dam safety monitoring and early warning. Rock masses in rock slopes are characterized by intersecting geological structural planes, resulting in reduced strength and the creation of multiple fracture flow channels. These factors contribute to the heterogeneous, anisotropic, and size-dependent properties of the macroscopic deformation parameters of the rock mass, influenced by the coupling of seepage and stress. To address these challenges, one study introduced the theory of equivalent continuous media and discrete fracture network (DFN) simulation. It established a method to calculate equivalent deformation parameters under seepage–stress coupling, and built a hybrid prediction model combining numerical simulation and statistical regression. This model achieved high-precision slope deformation prediction with limited monitoring data [contribution 1]. For higharch dams, deformation exhibits strong spatiotemporal correlations. A deep learning-based monitoring model was proposed to account for these correlations. First, the measurement points are clustered to capture the spatial relationship. Successive multivariate mode decomposition is applied to extract the common mode components among the correlated points as spatial influencing factors. Second, the relationship between various factors and deformation components is extracted using factor screening. Finally, a deep learning prediction model is constructed with stacked components to obtain the final prediction. It achieved a root mean square error (RMSE) of 0.344 and a coefficient of determination (R^2) of 0.998 in one year of engineering validation [contribution 2]. To combine the strengths of multiple models, a machine learning ensemble strategy based on the Greedy Weighted Algorithm (GWA) was developed. It uses Boosted Regression Tree (BRT), Random Forest (RF), and neural networks (NNs) as first-level models (experts), with GWA as a second-level meta-learner. Compared to the best single model, this stacking approach improved prediction accuracy by 16.12%. The GWA improves on the optimal expert in most cases, including at extreme values of error, with improvement rates up to 41.74%. It effectively reduced prediction uncertainty [contribution 3]. Traditional neural networks often suffer from redundant model parameters, difficulty in tuning, and long computation times. An EMD-SSA-LSTM hybrid model was proposed to solve this problem. It uses Empirical Mode Decomposition (EMD) to extract effective time series components. Simultaneously, by combining the Sparrow Optimization Algorithm to optimize the LSTM neural network computation process, it reduces the complexity of model parameter selection. The model maintains high prediction accuracy while significantly reducing computation time, making it suitable for real-time early warning [contribution 4].

Seismic hazards are a critical threat to dam safety. This Special Issue presents in-depth research on two core topics: reservoir seismic source parameters and dam dynamic reliability under seismic sequences. These studies form a complete framework from source characterization to seismic performance evaluation. Using the digital observation data obtained from a high-density seismic monitoring network deployed in the Baihetan reservoir area of the lower Jinsha River, the distribution of seismic source parameters was inverted. The results show that reservoir impoundment significantly increases earthquake stress drops and radiated energy. This finding provides a critical basis for reservoir-induced seismicity risk assessment [contribution 5]. A new method for stochastic dynamic response

analyses and reliability assessments of dams during seismic sequences has been proposed. Firstly, a simulation method of stochastic seismic sequences is described, considering the dependence between mainshock and aftershock based on the Copula function. Then, a novel practical framework for stochastic dynamic analysis is established, combined with the improved point selection strategy and the direct probability integration method (DPIM). This framework efficiently and accurately evaluates earth dam dynamic responses and failure probabilities. It quantitatively confirms that aftershocks significantly increase failure risk, especially under strict limit states [contribution 6].

Seepage failure and foundation instability are the primary causes of dam accidents. An integrated geophysical approach combining Electrical Resistivity Tomography (ERT), Self-Potential (SP), and Multichannel Analysis of Surface Waves (MASW) was used to investigate the Chimney Rock Dam embankment. The method successfully delineated preferential seepage pathways and saturated zones, enabling rapid, non-destructive detection of seepage hazards [contribution 7]. Fine sand layer reinforcement is a long-standing challenge in dam engineering. Systematic grouting tests were conducted using a new permeable polymer with excellent impermeability and high strength. The tests clarified the effects of grouting pressure, curing time, moisture content, and porosity on reinforcement strength. The results show that 96% of the ultimate strength is achieved after 14 days of curing. The influence order of factors is: grouting pressure > moisture content > porosity. Compressive strength increases with grouting pressure and curing time, and decreases with sand layer moisture content and porosity. These findings provide material support and design parameters for rapid fine sand layer reinforcement [contribution 8]. Dam substations are often built on inclined soft soil foundations. A pile foundation reinforcement dam slope model on an inclined soft soil foundation is established. The influence of different pile spacings, the pile length, and the soft soil foundation angle on the slope safety factor is studied. The failure mechanism and stability of pile-supported dam slope foundation are analyzed. It also identified the main stress and deformation zones of piles. The results provide theoretical guidance for dam substation design [contribution 9].

Parameter uncertainty is the core factor limiting the accuracy and reliability of dam safety evaluation. An original strategy for optimizing the inversion of concrete dam parameters based on the multi-strategy improved Sooty Tern Optimization algorithm (MSSTOA) is proposed to address the issues of low efficiency, low accuracy, and poor optimization performance. It introduces chaos mapping, a nonlinear convergence factor, and Gaussian perturbation to enhance optimization performance. Compared to traditional algorithms, it reduces computation time by more than 48%, and produces more accurate inversions of elastic modulus and hydrostatic pressure components [contribution 10]. Monte Carlo simulation is widely used for fragility analysis but requires excessive computational resources. This study proposed two methods to estimate the fragility curves of water-retaining structures, thereby allowing for the assessment of failure probabilities related to important quantities such as the steady-state seepage rate, exit gradient, and uplift force, which make them suitable for practical applications. These methods generate fragility curves with only 10% of the computational effort of traditional Monte Carlo simulation. The vulnerability curves obtained by using the proposed method are of great significance for risk assessment, design and decision-making [contribution 11].

Long-term environmental cyclic processes control soil slope stability. Laboratory dry–wet cycle tests were conducted on shallow granite residual soil from a slope in Fuzhou. The results show that both cohesion and internal friction angle decrease with increasing moisture content. These relationships can be described by power functions, whose fitting parameters depend on the number of dry–wet cycles. A shear strength prediction model was established that accounts for both moisture content and cycle number. The model has

high prediction accuracy and low uncertainty. It reveals the degradation law of residual soil slopes under seasonal climate changes, and provides key parameters for long-term stability evaluation [contribution 12].

The studies in this Special Issue represent the latest advances in dam and geotechnical safety evaluation. They enrich the theoretical system of hydraulic engineering safety and solve key technical problems in practical engineering. Looking forward, advances in digital twin, artificial intelligence, multi-physics coupling, and big data monitoring will drive dam safety evaluation toward an integrated, intelligent, precise, and systematic paradigm. This will enable real-time perception, dynamic prediction, and risk control throughout the full life cycle, further ensuring the safe and sustainable operation of water conservancy infrastructure.

Conflicts of Interest: The authors declare no conflicts of interest.

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