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Editorial

Progress in Resilience Design: Innovative Approaches for Civil Infrastructure from Maintenance Aspect

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1. Introduction

At present, global climate change is intensifying and extreme natural disasters are frequent. The corresponding impacts show cross-domain and cross-regional systemic risk characteristics, which poses new major challenges to infrastructure security. Therefore, it is urgent to evaluate the realistic basis and development trend of China's infrastructure security resilience construction and build a future-oriented technological development strategic framework [1–3]. Resilient infrastructure can better resist natural disasters (such as earthquakes and floods) while ensuring rapid recovery of key services (transportation, energy and water supply) after disasters, thereby minimizing the loss of life and property caused by disasters [4–6]. At present, the research on infrastructure resilience is fragmented in various professional fields, and related innovation achievements are scattered in different directions such as structural design, material science and intelligent monitoring. To this end, this paper integrates 13 high-impact research results in the key areas of infrastructure design, resilience and operation and maintenance, analyzes innovative methods and unsolved problems in structural optimization, material research and development, multi-disaster response, intelligent monitoring, etc., comprehensively expounds the latest research progress in the field of resilient infrastructure, and proposes future research directions.

2. Development of Resilience Design and Maintenance

2.1. Structural Optimization for Enhanced Performance

This section focuses on the optimization design of infrastructure structure, analyzes the key research progress oriented to improving the resilience of engineering structure, and systematically combs the innovative methods and practical results at the component and node levels, aiming to provide theoretical and practical basis for readers to understand how to achieve structural performance breakthrough through optimization design [7–9].

This section consists of the following four articles:

The first article (contribution 1) 'Research on mechanical properties and bearing capacity calculation methods of concrete filled steel tubular members under axial compression' explores the axial compression bearing capacity characteristics of self-stressing concrete filled steel tubular columns. In this study, the researchers used nine specimens (one traditional specimen, eight self-stressing concrete-filled steel tubular specimens) to carry out axial compression tests. The study found that within a specific expansion agent content range, self-stressing can significantly improve the axial compression bearing capacity of the component. Aiming at the optimization design pain point of this widely used structural member, a modified simplified theoretical calculation method of bearing capacity is proposed. This innovation not only improves the accuracy of bearing capacity prediction, but

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also provides a practical tool for engineering and technical personnel to optimize design parameters in construction projects.

The second article (contribution 2) 'Optimization design of seismic beam variable cross-section I-shaped beam members' constructs and verifies the optimal design scheme for the variable cross-section I-shaped beam members in the three-story steel frame. The researchers carried out a comparative analysis using a beam with a dog-bone weakened section. It is found that the variable cross-section beam can not only effectively avoid brittle failure, but also maintain the stiffness and bearing capacity of the component, and achieve the performance balance between structural safety and material utilization efficiency. The research results provide a feasible alternative for traditional beam design, and have important application value in earthquake-prone areas with the core goal of improving seismic resilience.

The third article (contribution 3) 'Prediction of shear strength of anisotropic structural plane considering size effect' focuses on the prediction of shear strength of anisotropic structural plane considering size effect. By constructing models with different roughness (joint roughness coefficient), different sizes and different normal stresses, the key influencing factors of shear strength are analyzed, and the parameter correlation range is given. Based on the numerical test data, a back propagation neural network prediction model with multiple input parameters is constructed. The model has high prediction accuracy and can effectively predict the peak shear strength, which provides a scientific reference for the evaluation of engineering rock mass stability.

In the fourth article (contribution 4) 'Innovative Design of Railway Sleepers', it is pointed out that in the heavy haul railway infrastructure, the new sleeper reinforcement system (new-tie) can effectively solve the problems of high operation and maintenance costs and subgrade diseases caused by excessive stress transferred from sleepers to ballast. The modular "'Z'-shaped" structure can be compatible with the existing sleepers. Through the multi-sleeper collaborative force, the load diffusion range is expanded, and there is no need to carry out large-scale transformation of the existing track infrastructure. The finite element analysis shows that the system can reduce the effective stress of ballast by 24%, the maximum displacement of sleeper by 12%, and the deformation of ballast by 2%, which significantly improves the durability of track. At the same time, the engineering case verification in the soft soil area of the Black Rock Desert concludes that compared with the traditional geotechnical improvement scheme and the slab track scheme, the new sleeper reinforcement system has more advantages in economy, construction convenience and environmental friendliness.

2.2. Multi-Hazard Resilience and Risk Management

This section focuses on the key issues in the field of civil engineering structure and disaster prevention and mitigation, and systematically reviews the relevant research progress from four dimensions: multi-disaster resilience, structural seismic design, material properties and traditional building protection [10–13].

This section consists of the following five articles:

The first article (contribution 5) 'Modeling and Comparison of Design Features of Pendulum and Radial Micro Hydropower Stations Considering the Variability of Design Parameters' found that in the low-speed water energy collection scenario, the torque output per unit specific area of the pendulum micro hydropower station is increased by up to 12 times compared with the traditional scheme by adjusting the blade area and the lever length. Although the pendulum design is a cyclic operation mode, it is superior to the radial system in terms of low-speed water energy conversion efficiency, which provides the possibility for efficient power generation in underutilized low-flow waters.

The second article (contribution 6) 'Evaluation of seismic isolation design method: Comparison of simplified linear method and nonlinear time history analysis method' By comparing the seismic isolation design methods in the American 'Building Seismic Code' (ASCE/SEI 7-22) [14] and the European 'Seismic Code' (EN 1998-1) [15], a six-story steel structure building with lead rubber isolation bearings (LRBs) and curvature self-centering isolation bearings (CSSs) was used as a case to verify the reliability of the two methods. In this study, 20 ground motion records were used to carry out nonlinear time history analysis, and the key performance indexes of the isolated structure were verified. This study clarifies the advantages and disadvantages of the two standard systems: EC8 is more reliable for the design guidance of lead rubber isolation bearings, while ASCE 7-22 is too conservative for the design requirements of curvature self-centering isolation bearings. This provides guidance for engineers and technicians to choose a reasonable seismic isolation design method, and helps to achieve a balance between safety and cost-effectiveness in structural design in earthquake-prone areas.

The third article (contribution 7) 'Discussion on the calculation formula of additional pressure for seismic design of circular silos in European Code EN1998-4' points out and corrects a key technical defect in the European Code for Seismic Design of Circular Silos (EN 1998-4) [16]. The correction scheme makes the calculation formula of the specification fit with the classical physical model of Trahail theory, so as to ensure that the calculation results can reflect the actual dynamic mass of granular materials under an earthquake. The correction eliminates the problem of overestimation of the original calculated value in the specification. On the premise of ensuring the safety reserve set by the specification, it avoids the over-design of the silo wall, and can greatly save the cost of silo construction in the medium and high seismic intensity area.

The fourth article (contribution 8) 'Influence of the coupling form of the spherical steel bearing and the thickness of the anti-friction interlayer on the structural performance' takes the L-100 spherical steel bridge bearing as the research object, and systematically explores the coupling form of the anti-friction interlayer and the lower steel plate and the influence of the thickness of the interlayer on the structural performance of the bearing. The results of the finite element analysis show that the simulation effect of viscoelastic model is significantly better than that of elastic–plastic model. In all kinds of coupling forms, the fully bonded form can minimize the stress and strain level of the bearing. Increasing the thickness of the interlayer will expand the plastic deformation range of the bearing. This study provides an accurate and efficient engineering reference for geometric optimization, material selection and numerical modeling of bridge bearings.

The fifth article (contribution 9) 'Evaluation of road reconstruction potential based on historical road accident data' proposes a data-driven road reconstruction potential evaluation method based on the historical road accident data of Greece from 2016 to 2022. The key factors affecting road safety are analyzed, including road conditions, intersection design, traffic signs and lighting, road geometric characteristics, and so on. This evaluation method breaks through the limitations of traditional research relying on driving behavior analysis, provides a data-driven scientific basis for road reconstruction planning under limited funds, and has strong cross-regional applicability.

2.3. Intelligent Technologies for Monitoring and Maintenance

This section integrates the latest research results of intelligent monitoring, defect detection, operation and maintenance strategy in the field of railway engineering and geotechnical engineering, and shows the deep integration of technological innovation and engineering practice [17–19].

This section consists of the following four articles:

The first article (contribution 10) 'Intelligent inversion analysis of surrounding rock parameters and deformation characteristics of water diversion surge shaft' focuses on intelligent monitoring and operation and maintenance of tunnels, and constructs an intelligent early warning model of surrounding rock deformation based on coded particle swarm optimization (PSO) and support vector machine (SVM). The model improves the prediction accuracy of surrounding rock deformation. The verification results show that the model can effectively control the deformation of surrounding rock and reduce the risk of large deformation. In addition, the proposed adaptive algorithm and reinforcement learning framework can improve the long-term reliability of railway infrastructure operation and maintenance under complex geological conditions.

The second article (contribution 11) 'Innovative road operation and maintenance: the application of intelligent technology in local infrastructure' takes road operation and maintenance technology as the research object, and compares the operation efficiency of traditional detection methods (flatness index method and artificial visual detection) and innovative technical applications (roadroid mobile phone application and Movi Pro 2 detection equipment). The research shows that the digital detection technology shortens the detection time by 60%, and provides an extensible implementation framework for the digital transformation of pavement operation and maintenance while maintaining high detection accuracy.

The third research review article (contribution 12) 'Railway Network Security: Systematic Bibliometric Analysis' comprehensively analyzes the research status of railway network security. Through bibliometric analysis and systematic review, this study answers the core issues in the field of railway networks, sorts out the research trends, hotspots and emerging directions in this field, and puts forward specific suggestions for improving the resilience of railway network security and promoting technological iteration.

In the fourth paper (contribution 13), 'Prediction of clay shrinkage cracking and shrinkage strength factors based on artificial intelligence', a data-driven method is proposed to predict the cracking and shrinkage strength characteristics of clay due to shrinkage. Four prediction models were evaluated: multiple linear regression (MLR), conditional random field (CRF), adaptive neuro-fuzzy inference system (ANF), and Gaussian process (GP). Among them, the artificial neural network (ANN) model based on Bayesian regularization performs best. The model provides a reliable tool for the risk assessment of clay subgrade, soft soil foundation and expansive soil foundation, which reduces the demand for physical tests and improves the safety of geotechnical engineering. This section systematically synthesizes the latest research in railway and geotechnical engineering, spanning intelligent monitoring, defect detection, and maintenance strategies, to demonstrate the deep integration of technological evolution and engineering practice.

3. Conclusions

This study systematically integrates 13 innovative research results in the field of infrastructure design, resilience and operation and maintenance, and comprehensively expounds the latest research progress in this field. Based on the 13 research results sorted out in this paper, infrastructure resilience design and intelligent operation and maintenance are the core directions for the future development of civil engineering. The importance of infrastructure resilience design and intelligent operation and maintenance is mainly reflected in the following three dimensions:

First, it can effectively break through the inherent limitations of traditional civil engineering in terms of insufficient multi-hazard resistance, low life cycle efficiency, and limited technical adaptability, and accurately respond to the dual strategic needs of global multi-hazard frequency and sustainable development.

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Second, relying on structural optimization, new material research and development, intelligent operation and maintenance innovation technology integration, etc., it can systematically improve the safety, durability and economy of geotechnical engineering, transportation infrastructure, underground structure and other core field projects, and provide scientific and feasible technical guidance for engineering practice.

Third, it can help the civil engineering industry to transform to intelligent and low-carbon, enhance the resilience of the whole life cycle of infrastructure, and lay a solid foundation for the high-quality development of the industry.

At present, researchers have a clear understanding and technical countermeasures on the mechanism of a single disaster or single environmental action, the degradation mechanism and recovery method of structural material performance under a single environmental action, and the disaster response and control of a single structure under a single disaster [20–22]. However, the catastrophic mechanism of civil engineering infrastructure under the action of multiple disasters and complex environments is more complex and the improvement of resilience is more difficult. It mainly faces the following four challenges:

(1) The universality of the resilience evaluation system needs to be further improved to adapt to different types of infrastructure and regional conditions.
(2) The large-scale application of new materials and new structures is restricted by cost barriers and lack of technical specifications.
(3) Multi-disaster response strategies need to be further optimized to solve the complex spatio-temporal correlation between disasters.
(4) It is necessary to establish a long-term coordination mechanism among various stakeholders to promote the deep integration of resilient infrastructure construction with community and urban development.

In the future, it is necessary to further study the disaster mechanism and resilience improvement method of civil engineering infrastructure systems under the action of multiple disasters and complex environments, develop a global infrastructure resilience improvement innovation method, and accelerate the application of infrastructure resilience improvement technology [23–25].

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List of Contributions

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