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Safety Evaluation and Management of Engineering Structures Based on Intelligent Technology

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Abstract: With the rapid development of science and technology, the application of intelligent technology in the field of civil engineering is more extensive, especially in the safety evaluation and management of engineering structures. This paper discusses the role of intelligent technologies (such as artificial intelligence, Internet of Things, BIM, big data analysis, etc.) in the monitoring, evaluation, and maintenance of engineering structure safety. By studying the principle, application scenarios, and advantages of intelligent technology in structural safety evaluation, this paper summarizes how intelligent technology can improve engineering management efficiency and reduce safety risks, and puts forward the trend and challenge of future development.

Keywords: Intelligent technology; Engineering structure; Safety evaluation; Structural health monitoring; BIM; Big data

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1. Introduction

The safety of engineering structures is one of the most critical research topics in the field of civil engineering. With the increasing complexity of modern buildings, the traditional structural safety evaluation methods are insufficient [1]. The long lifecycle of engineering structures and the complex and changeable environment require more efficient and accurate monitoring and maintenance methods. In recent years, the application of intelligent technology in the field of civil engineering has been continuously promoted, especially in the evaluation and management of structural safety, and has achieved remarkable results.

Traditional methods of engineering structure safety management mainly rely on experience, regular inspection, and follow-up maintenance, which have lag and inaccuracy. The application of intelligent technologies (such as AI, Internet of Things, big data, BIM, etc. [2]) has brought unprecedented changes to the safety evaluation of engineering structures, providing more real-time, dynamic, and accurate monitoring and prediction means.

It is important to explore how these emerging technologies can play a role in the safety management of engineering structures to improve the safety and maintenance efficiency of engineering. This paper aims to analyze the application

status and prospects of intelligent technology in engineering structure safety evaluation and management, explore its feasibility in practical projects, and put forward the challenges and directions of future development.

2. The role of intelligent technology in the safety management of engineering structures

The traditional safety evaluation of engineering structures depends on manual inspection and limited monitoring means, which are easily affected by subjective judgment and the coverage is limited. With the rapid development of intelligent technologies such as the Internet of Things (IoT), big data, and artificial intelligence (AI), the security evaluation and management methods of engineering structures have been greatly improved [3]. The introduction of intelligent technology not only makes real-time monitoring of the structure possible but also enables early warning prediction and health management through algorithm optimization, which greatly improves the efficiency and accuracy of engineering safety.

3. Application of intelligent technology in the safety evaluation of engineering structures

3.1. Intelligent development of structural health monitoring system

Structural health monitoring (SHM) is one of the key methods to evaluate the safety of engineering structures [4]. Through sensor networks and intelligent data processing technology, SHM can achieve all-weather monitoring of structures such as bridges and large buildings.

Case study: For example, in some large bridge projects in China, the whole lifecycle monitoring is carried out through embedded sensor networks, the data is uploaded to the cloud in real time, and the AI model can predict the fatigue damage of the bridge according to the monitoring data.

Advantages of intelligent SHM: Strong real-time, high degree of automation, and reduced manual intervention.

3.2. Application of intelligent technology in disaster warning

Natural disasters (such as earthquakes, typhoons, floods, etc.) pose a major threat to structural safety. Intelligent technology can use sensors and big data platforms to monitor the structural response when disasters occur in real time, and quickly make safety assessments and early warnings.

Using seismic wave sensors and AI analysis systems, engineers can quickly assess the safety status of buildings after an earthquake and determine whether immediate evacuation and repair are needed.

Case study: When a typhoon hits a large high-rise building, wind sensors and displacement sensors monitor the impact of wind load on the structure in real time, and the data is transmitted to the control center, which is analyzed by the AI model and gives countermeasures.

3.3. BIM-based security management and maintenance

BIM technology is widely used in all stages of the engineering lifecycle, especially in the later security maintenance and assessment, and can play an important role [5].

Integration of BIM and IoT: By combining sensor data with BIM models, managers can view structural health status in real time and make maintenance plans in a 3D visual environment.

Case study: A large commercial complex has significantly improved management efficiency in daily maintenance through the integration of BIM and IoT; the sensor feeds back structural data in real time, and the risk

area in the BIM model automatically generates an early warning report [6].

4. Challenges and countermeasures of intelligent technology in structural safety management

4.1. Data security and privacy issues

With the popularization of intelligent monitoring systems, massive sensor data needs to be stored and transmitted, and data security and privacy protection become a major challenge.

Adopting efficient data encryption and identity authentication technology to ensure the security of data transmission and storage. At the same time, distributed storage technologies such as blockchain can also be used to improve data security.

Intelligent monitoring systems rely on a large number of sensor devices, which may fail in long-term use, affecting the monitoring accuracy.

Countermeasure: Strengthen the daily maintenance and regular testing of equipment, establish an equipment health monitoring mechanism to ensure that sensors and other equipment are always in good condition.

4.2. Intelligent technology cost and popularization problems

At present, the application cost of intelligent technology is high, especially the construction and maintenance cost of large-scale sensor networks and data processing systems, which limits its popularity in small and medium-sized engineering projects [7].

With the continuous maturity of technology, hardware costs are expected to gradually decline, while promoting the government and industry to introduce corresponding support policies to encourage small and medium-sized projects to adopt smart technology.

5. The development trend of intelligent technology in future engineering structure management

5.1. Full lifecycle intelligent monitoring

The future engineering structure management will pay more attention to the intelligent management of the whole lifecycle [8]. From design and construction to operation and maintenance, intelligent technology will be deeply involved in every stage of the project to achieve a full range of safety monitoring from source to use.

5.2. Cloud-based security management platform

With the wide application of IoT devices, cloud computing technology will play a greater role in engineering structure management. Through the cloud platform, structural safety data can be freely shared and processed between different locations and devices to achieve efficient remote security management.

5.3. Intelligent prediction and adaptive maintenance

The development of AI technology makes the future structure safety management more intelligent, not only can it predict the potential problems of the structure, but also can automatically generate maintenance plans according to the monitoring data, and even automatically perform some maintenance tasks through the adaptive control system.

6. Application of intelligent technology in engineering structure safety management

6.1. Bridge safety management

As an important infrastructure of transportation, the safety of bridges is related to public safety [9]. By installing intelligent sensors, the stress, vibration, displacement, and other parameters of the bridge can be monitored in real time. When the sensor detects an anomaly, the system will automatically issue an alarm, prompting the management to take appropriate measures. In addition, through AI algorithms, it is possible to predict the fatigue damage and remaining life of the bridge, so as to formulate an effective maintenance plan.

6.2. Safety management of high-rise building structure

High-rise buildings are prone to structural deformation or damage under earthquake and wind loads. Smart sensors can be installed at key structural locations, such as frame columns, shear walls, etc., to assess the safety of buildings by monitoring changes in stress and displacement in real time [10]. The application of big data technology can combine the monitoring data of buildings with changes in the surrounding environment (such as weather and seismic activity) to further improve the accuracy of safety assessment.

6.3. Safety management of tunnels and underground structures

The safety of tunnels and underground structures is affected by many factors such as geological conditions, groundwater level, and load variation. By installing a smart sensor network to monitor parameters such as deformation, water seepage, and cracks in the tunnel structure, and combining AI technology for data analysis, potential hazards can be quickly identified and early warnings can be provided. At the same time, through edge computing and cloud computing technology, the tunnel data can be efficiently processed and monitored remotely.

7. Engineering structure safety evaluation technology

7.1. Structural health monitoring system (SHM)

Structural health monitoring system (SHM) is a real-time monitoring and evaluation of structural health status by collecting structural data through a sensor network. The core of the SHM system is the sensor, data acquisition equipment, and data processing and analysis model. The addition of intelligent technology greatly improves the efficiency of the SHM system, especially in data analysis and health assessment. An intelligent algorithm can greatly improve the accuracy of damage identification.

7.2. Safety monitoring based on intelligent sensor

Intelligent sensors can monitor the physical state of the structure (such as stress, strain, acceleration, etc.) with high precision. The commonly used intelligent sensors include fiber grating sensors, piezoelectric sensors, and wireless sensors. Through the intelligent sensor network, the monitoring data can be quickly transmitted to the monitoring center to analyze the security status of the structure in real time.

7.3. Data-driven structural safety evaluation

The combination of big data and artificial intelligence technology makes it possible to evaluate the safety of structures based on data. By collecting historical data, operational data, and external environment data of the engineering structure, a data-driven safety evaluation model can be built. By training and optimizing a large amount of data, these models can accurately predict the structural state and warn the potential risks.

8. Conclusion

The safety evaluation and management of engineering structures based on intelligent technology provides a new solution for modern civil engineering. Through AI, IoT, BIM, and big data technologies, the security management of engineering structures is becoming more accurate, real-time, and efficient. However, with the rapid development of technology comes some challenges, such as data security, equipment maintenance, and cost issues. In the future, with the continuous maturity of technology, the application prospects of intelligent technology in the safety evaluation and management of engineering structures will be broader, and the entire industry will be promoted to a more intelligent and digital direction.

Disclosure statement

The authors declare no conflict of interest.

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