Academic Journal of Applied Sciences
ISSN: 3105-0549 (Print), ISSN: 3105-0557 (Online) | Vol. 1, No. 1, 2026

Analysis of road bridge inspection technology research

Yu Bian

School of civil engineering, Henan Polytechnic University, Jiaozuo 454000, China

Abstract: Highway bridges are an important part of transport, and their safety and reliability are crucial to ensure smooth traffic flow. The development of highway bridge inspection technology is of great significance for the timely detection of structural damage and potential safety hazards of bridges. This paper discusses the classification and characteristics of non-destructive and destructive inspection techniques through the overview and analysis of road bridge inspection techniques

Keywords: Highway bridges; Inspection techniques; Analysis; Practical application.

1. Introduction

As a crucial component of transportation infrastructure, highway bridges carry a significant volume of traffic and freight transportation tasks[1] However, due to long-term service and the influence of natural environments, bridge structures may develop various defects and damages, such as cracks, corrosion, and deformation [2]. If these issues are not detected and repaired in a timely manner, they can severely impact traffic safety and economic development[3]. Therefore, regular inspection and evaluation of highway bridges are particularly important[4]. Traditional bridge inspection methods mainly rely on manual inspection and visual observation, which suffer from drawbacks such as low efficiency, strong subjectivity, and an inability to provide a comprehensive assessment[5]. With technological advancements, various advanced highway bridge inspection technologies have emerged[6]. Based on this, this paper aims to analyze and apply highway bridge inspection technologies, exploring their feasibility and effectiveness in practical engineering projects[7]. Furthermore, the advancement of bridge inspection technology is closely related to the national infrastructure development strategy. In recent years, China has successively issued policy documents such as the “Action Plan for New Infrastructure Construction in the Transportation Sector,” which explicitly require strengthening the capacity for bridge structural health monitoring and safety assessment. Against this backdrop, promoting the innovative development of bridge inspection technology is not only an urgent need for engineering practice but also an important support for achieving the strategic goal of building a country with strong transportation networks.

2. Overview of Highway Bridge Inspection Technology

2.1. Importance of Highway Bridge Inspection

Highway bridge inspection refers to the regular or irregular inspection and evaluation of highway bridges to ensure their structural safety and normal operation[8]. The importance of highway bridge inspection is reflected in the following aspects: (1) Safety Assurance: Regular inspections enable the timely detection of structural damage, defects, and potential hazards, allowing for appropriate repair and reinforcement measures[9]. (2) Economic Assurance: Through inspection and evaluation, structural problems can be identified promptly, avoiding traffic interruptions and economic losses caused by bridge damage[10]. (3) Service Life Extension: Regular inspections facilitate the timely detection and repair of structural aging and fatigue issues, thereby extending the service life of the bridge[11]. (4) Operational Efficiency Improvement: Inspection and evaluation allow for the timely identification of bridge issues, ensuring normal bridge operation and enhancing the efficiency of transportation[12]. In addition, bridge inspection also has significant social benefits. As public infrastructure, the safety condition of bridges is directly related to the travel safety and quality of life of the public. In the event of a major accident such as a bridge collapse, it would not only cause casualties and property losses but also trigger public concern and a crisis of public trust. Therefore, strengthening bridge inspection work is a concrete manifestation of the principle of “life first, safety foremost.” From a life-cycle management perspective, bridge inspection is an important means of preserving and enhancing the value of bridge assets. Scientifically sound inspection and evaluation can help managers understand the technical condition of bridges, formulate optimal maintenance and repair plans, avoid the passive approach of “repairing after failure,” and achieve a transition from “reactive maintenance” to “preventive maintenance,” thereby significantly reducing life-cycle costs.

2.2. Classification and Characteristics of Highway Bridge Inspection Technologies

Highway bridge inspection technologies can be broadly classified into non-destructive testing (NDT) and destructive testing[13]. Non-destructive testing refers to obtaining information about the bridge structure without causing damage to it[14]. NDT methods primarily include visual inspection, acoustic testing, ultrasonic testing, infrared thermography, and electromagnetic testing[15]. Destructive testing involves conducting load tests or sampling tests on the bridge structure to obtain its mechanical properties and material characteristics[16]. The characteristics of highway bridge inspection technologies include diversity, high efficiency, high precision, cost-effectiveness, and non-destructiveness[17]. The two types of technologies are often used in conjunction with each other in practical applications. Non-destructive testing is suitable for large-scale rapid screening and routine inspections, enabling timely detection of apparent defects and potential flaws. Destructive testing is suitable for in-depth evaluation of key components or critical sections, providing precise data for structural safety assessment and reinforcement design. The combination of the two forms a complete inspection system that spans from macro to micro levels and from qualitative to quantitative analysis. In recent years, with the rapid advancement of sensing technology, communication technology, and data processing capabilities, the boundaries of inspection technologies are also continuously expanding. For example, distributed optical fiber sensing technology enables continuous distributed monitoring of strain and temperature in bridge structures, combining the safety of non-destructive testing with the accuracy of destructive testing, and has become a research hotspot in the field of bridge health monitoring. The emergence of such hybrid technologies is reshaping the traditional classification system of inspection technologies.

3. Analysis of Highway Bridge Inspection Technologies

3.1. Non-Destructive Testing Techniques

Acoustic testing technology utilizes the propagation characteristics of sound waves in materials to detect defects and damage in bridge structures[18]. This technique involves transmitting acoustic signals and receiving reflected signals to identify issues such as cracks, corrosion, and loosening within the bridge structure. Acoustic testing is characterized by being non-destructive, rapid, and accurate. In practical applications, acoustic testing is commonly used for detecting internal voids in concrete structures, measuring crack depth, and evaluating the grouting density of prestressed ducts. By analyzing parameters such as wave propagation velocity, waveform variation, and energy attenuation, the degree of internal defects in concrete can be quantitatively assessed. Acoustic testing technology has also made new advances in recent years, such as phased array ultrasonic technology and guided wave ultrasonic technology. Phased array ultrasound achieves focusing and steering of the acoustic beam through multi-element probes, enabling high-resolution imaging inspection of components with complex geometries. Guided wave technology is suitable for rapid inspection of long-span linear components such as pipes and cables, significantly improving inspection efficiency.

Magnetic particle testing is a technique that uses the behavior of magnetic particles in a magnetic field to detect cracks and weld defects in bridge structures. By applying magnetic particles to the bridge surface and introducing a magnetic field, the accumulation of particles at defect locations can be observed, thereby assessing the health of the bridge structure. Magnetic particle testing has extremely high sensitivity to surface and near-surface defects in ferromagnetic materials, capable of detecting cracks as narrow as a few micrometers. This technology is widely used in weld quality inspection of steel bridges, fatigue crack monitoring, and regular inspections of critical load-bearing components. The limitation of magnetic particle testing is that it is only applicable to ferromagnetic materials, and the surface to be inspected must be cleaned before testing. Furthermore, it is difficult to detect deep internal defects, necessitating the combined use of other testing methods (such as ultrasonic testing). In practical engineering, magnetic particle testing is often combined with penetrant testing to comprehensively evaluate the weld quality of steel bridges.

Infrared thermography is a technique that utilizes the characteristics of infrared radiation to detect temperature distribution and thermal damage in bridge structures. This method uses an infrared thermal imager to capture thermal images of the bridge surface, and by analyzing the temperature distribution in these images, the condition of the bridge structure can be assessed. Infrared thermography offers advantages such as non-contact operation, long-range detection, and rapid scanning of large areas. It is particularly suitable for detecting issues such as voids in bridge deck pavements, water seepage in piers, and internal defects in cable towers. When combined with drone platforms, it enables rapid inspection of hard-to-reach areas such as high piers and cable towers. The accuracy of infrared thermography is significantly influenced by environmental factors such as sunlight, wind speed, and temperature variations. To overcome this limitation, active infrared thermography has emerged, which uses an external heat source to heat the structure under test and identifies defects by analyzing anomalies in the heat conduction process. This technology shows promising application prospects in the inspection of grouting density in external prestressed ducts and the bonding quality of CFRP reinforcement layers.

3.2. Destructive Testing Techniques

Steel Bar Flaw Detection: Steel bar flaw detection is a commonly used destructive testing technique for identifying issues such as corrosion, fracture, and rust in steel reinforcement within bridges[18]. Common methods include magnetic particle inspection, ultrasonic testing, and electromagnetic induction testing. and electromagnetic induction testing. Steel corrosion is one of the main factors affecting bridge durability. Electromagnetic induction testing can quantitatively assess the degree of corrosion and cross-sectional loss of steel reinforcement, providing key data for predicting the remaining service life of bridges. For prestressed tendons, acoustic emission technology is often used to monitor fracture signals in real time. In recent years, non-destructive testing technologies for steel reinforcement based on electromagnetic field theory have developed rapidly, such as pulsed eddy current testing and magnetic flux leakage testing. These technologies can assess the corrosion state of internal reinforcement without damaging the concrete cover, combining the accuracy of destructive testing with the safety of non-destructive testing, representing an important development direction for reinforcement inspection technology.

Concrete Strength Testing: Concrete strength testing is used to evaluate the strength and quality of concrete in bridges. Non-destructive methods include ultrasonic testing, resistivity measurement, and rebound hammer testing; destructive methods involve taking concrete core samples and conducting compression or flexural tests to directly determine the concrete strength. In practical engineering, the rebound hammer method is widely used for preliminary assessment of concrete strength due to its simplicity and low cost, though its results are significantly influenced by surface conditions. Core sampling, while causing some damage to the structure, provides the most accurate strength data and is often used as the final basis for strength evaluation. The combined use of these two methods can balance efficiency and accuracy. In recent years, significant progress has also been made in concrete strength testing technologies based on the piezoelectric effect, such as the impact-echo method and piezoelectric ceramic sensing. The impact-echo method can simultaneously obtain information on concrete strength and internal defects by analyzing the propagation characteristics of stress waves in concrete. Piezoelectric ceramic sensing utilizes the direct and inverse piezoelectric effects of piezoelectric materials to achieve real-time monitoring of concrete strength development. These new technologies provide more diverse options for concrete strength testing.

Bridge Structural Dynamic Response Testing: This technique is used to assess the structural health and dynamic response characteristics of bridges[18]. Common testing methods include accelerometer testing, shake table testing, and laser vibrometer testing. Dynamic response testing reflects the overall performance of bridges and has unique advantages in identifying global damage such as structural stiffness degradation and support loosening. In recent years, operational modal analysis based on ambient excitation has developed rapidly, enabling the identification of bridge modal parameters without traffic closure, significantly improving inspection efficiency. With the development of intelligent sensing technology, new types of sensing devices such as wireless accelerometers and fiber Bragg grating sensors have begun to be used in bridge dynamic response testing. These devices are characterized by small size, low power consumption, and easy deployment, enabling long-term, continuous dynamic monitoring of bridge structures. Combined with cloud platforms and big data analysis technologies, real-time assessment and early warning of bridge structural health status can be achieved, promoting the transformation of bridge inspection from "periodic inspection" to "continuous monitoring."

4. Development Trends of Highway Bridge Inspection Technology

Innovations and improvements in highway bridge inspection technology include: the development of high-precision measurement techniques and the application of remote monitoring technologies . High-precision measurement technology is moving toward micron-level accuracy and three-dimensional visualization. 3D laser scanning technology can rapidly acquire high-precision point cloud models of bridge structures, enabling accurate measurement of structural deformation and displacement. Remote monitoring technology, through the deployment of low-power wireless sensors, enables long-term, continuous monitoring of bridge structural conditions, providing a data foundation for structural health management. In the field of high-precision measurement, structural displacement measurement technology based on computer vision has developed rapidly in recent years. By capturing feature points on the structural surface with high-resolution cameras and analyzing the displacement field using image correlation algorithms, non-contact, long-distance, high-precision structural deformation measurement can be achieved. This technology has low cost and flexible deployment, showing broad application prospects in bridge load testing and long-term deformation monitoring.

Developments in data processing and analysis methods for bridge inspection include: the application of data mining and machine learning techniques, the use of image processing and pattern recognition technologies, and the implementation of data visualization techniques. With the explosive growth of inspection data, traditional manual analysis methods can no longer meet the demand. Machine learning algorithms can automatically identify damage patterns and predict structural performance degradation trends. Deep learning technology has demonstrated accuracy superior to manual judgment in crack detection and defect classification. Data visualization technology transforms complex inspection results into intuitive 3D models and dynamic charts, assisting decision-makers in quickly grasping the safety status of bridges. In terms of data processing, the rise of digital twin technology provides a new paradigm for bridge inspection. Digital twins create virtual models of bridge structures that are mapped in real time to the physical bridges, integrating multi-source information such as inspection data, monitoring data, and historical maintenance records to achieve digital management of the entire life cycle of bridge structures. Bridge inspection systems based on digital twins can not only reflect the current state of the bridge but also predict and simulate future performance evolution, providing a scientific basis for maintenance decision-making.

The application prospects for intelligent inspection equipment include: utilizing drones for bridge inspections, employing sensor networks for real-time bridge monitoring, and leveraging Internet of Things (IoT) technology to enable information sharing and collaborative work among inspection devices. Drones equipped with high-definition cameras, infrared thermal imagers, and LiDAR sensors can achieve comprehensive inspection of hidden parts of bridges, with inspection efficiency several times higher than traditional methods. The integration of sensor networks with IoT platforms enables real-time data transmission and remote monitoring. In the future, with the development of 5G communication and edge computing technologies, bridge inspection will transition from "periodic physical examination" to "real-time monitoring." In the field of intelligent inspection equipment, specialized robots such as wall-climbing robots and underwater robots have also begun to be used in bridge inspection. Wall-climbing robots can carry inspection equipment to move vertically along piers, towers, and other vertical structures, enabling detailed inspection of tall structures. Underwater robots are suitable for inspecting underwater structures such as deep-water piers and foundations. These robotic devices can replace humans in entering dangerous or hard-to-reach areas, greatly improving the safety and accessibility of inspections. In the future, the deep integration of robotics and artificial intelligence will drive bridge inspection toward fully automated and intelligent development.

5. Conclusion

In summary, the analysis and application of highway bridge inspection technologies demonstrate their importance in ensuring the safe operation of highway bridges Non-destructive techniques such as acoustic testing, magnetic particle testing, and infrared thermography can help in the timely detection of structural damage, while destructive techniques like steel bar flaw detection and concrete strength testing can provide a more accurate assessment of structural safety. With continuous technological innovation and improvement, highway bridge inspection technologies will become more precise and reliable, and the application of intelligent inspection equipment will further enhance the convenience and efficiency of bridge inspections, modern bridge inspection technologies are developing toward diversification, intelligence, and systematization. Each type of inspection technology has its own advantages, and in practical applications, they should be selected appropriately based on specific conditions to complement one another. In the future, with the deep integration of emerging technologies such as big data, artificial intelligence, and the Internet of Things, bridge inspection will gradually shift from a predominantly manual, periodic approach to an automated, real-time continuous monitoring model, providing a more solid technical foundation for the life-cycle safety of highway bridges.

Looking ahead, highway bridge inspection technology will exhibit the following important trends: First, the integration of inspection and monitoring, combining periodic inspection with real-time monitoring to form a full-time-domain bridge health perception system. Second, the integration of inspection and maintenance decision-making, directly generating maintenance recommendations through data analysis to achieve closed-loop application of inspection results. Third, the deep integration of inspection technology with new materials, developing specialized inspection technologies for new bridge materials (such as high-performance concrete and composite materials). Fourth, the standardization and normalization of inspection technology, promoting uniformity in inspection processes, data formats, and evaluation methods to improve the comparability and mutual recognition of inspection results. The gradual realization of these trends will vigorously promote the management and maintenance level of highway bridges in China to a new stage.

References

[1] Zhou T, Zheng K F. Research on Safety Inspection and Evaluation Methods for Highway Bridges[J]. Bridge Construction, 2020, 50(1): 45-51.

[2] Wu J P, Sun L J. Research Progress on Structural Damage Identification Technology for Bridges[J]. Journal of Vibration and Shock, 2018, 37(12): 134-140.

[3] Huang H W, Zhang D M. Bridge Health Monitoring Technology and Its Application[J]. China Civil Engineering Journal, 2017, 50(5): 78-85..

[4] Chen Z Q, Hua X G. Bridge Structure Inspection and Assessment Technology[M]. Beijing: China Communications Press, 2019: 102-115.

[5] Li A Q, Miao C Q. Structural Health Monitoring and Safety Assessment of Bridges[J]. China Journal of Highway and Transport, 2016, 29(5): 56-63.

[6] Wang J H, Sun L M. A Review on the Development of Modern Bridge Inspection Technology[J]. Highway Engineering, 2020, 45(2): 88-94.

[7] Zhang Y F, Zhu X W. Research on Bridge Inspection and Reinforcement Technology[J]. Journal of China & Foreign Highway, 2018, 38(4): 112-117.

[8] Liu H L, Ding X M. Current Status and Prospect of Bridge Foundation Inspection Technology[J]. Chinese Journal of Geotechnical Engineering, 2019, 41(1): 1-10.

[9] Yang Y B, Chen J W. Research on Structural Safety Inspection Technology for Bridges[J]. Transportation Science & Technology, 2017, 34(6): 45-50.

[10] Han D J, Yan Q S. Structural Damage Identification and Health Monitoring of Bridges[M]. Guangzhou: South China University of Technology Press, 2018: 78-92.

[11] Sun Z, Wang H. Structural Damage Identification Method for Bridges Based on Vibration Testing[J]. Engineering Mechanics, 2016, 33(3): 112-119.

[12] Ou J P, Li H. Design and Application of Bridge Health Monitoring Systems[J]. China Civil Engineering Journal, 2015, 48(3): 56-64.

[13] Ren W X, Lin Y Q. Research on Modal Parameter Identification Methods for Bridge Structures[J]. Journal of Vibration Engineering, 2014, 27(2): 201-208.

[14] Zhang Q W, Li G P. Bridge Structure Inspection and Evaluation Technology[J]. Bridge Construction, 2013, 43(5): 78-84.

[15] Wang C S, Chen A R. Inspection and Assessment Technology for Existing Bridges[J]. Journal of Tongji University, 2012, 40(8): 1123-1130.

[16] Liu X L, Song X B. Durability Inspection and Assessment of Bridge Structures[J]. China Journal of Highway and Transport, 2011, 24(4): 56-63.

[17] Ye J S, Wang J. Highway Bridge Inspection Technology and Application[M]. Nanjing: Southeast University Press, 2020: 134-150.

[18] Wang C F, Chen X C. Research Progress on Dynamic Inspection Technology for Bridge Structures[J]. World Earthquake Engineering, 2010, 26(3): 89-95.