DOI: 10.23977/ftte.2024.040112
ISSN 2616-2334 Vol. 4 Num. 1

The Current Status and Development Trends of Bridge Inspection Technology in Bridge Inspection and Evaluation

Wenjie Yang[1,2,a], Gongxing Yan[3,b,*], Wangming Wu[4,c], Xiaoping Zou[1,d], Yuhu Sun[4,e]

[1]*Sichuan Jinghengxin Construction Engineering Testing Co., Ltd, Luzhou, 646000, China*
[2]*School of Materials Science and Engineering, Wuhan Institute of Technology, Wuhan, 430205, China*
[3]*School of Intelligent Construction, Luzhou Vocational and Technical College, Luzhou, 646000, China*
[4]*Aneng Third Bureau Chengdu Engineering Quality Testing Co., Ltd, Chengdu, 611130, China*
[a]*158284644@qq.com*, [b]*yaaangx@126.com*, [c]*149852848@qq.com*, [d]*18982406335@qq.com*, [e]*306787639@qq.com*
[*]*Corresponding author*

Keywords: Bridge Inspection, Inspection and Evaluation, Development Trend, Current Development

Abstract: With the increasing expansion and improvement of the transportation network, the durability of bridges, as an important transportation infrastructure connecting urban and rural areas and crossing rivers and canyons, is directly related to the safety of people's lives and properties and the stable development of society. This paper firstly introduces the background and significance of bridge inspection technology in detail, and then deeply analyzes the current problems and challenges in bridge inspection and evaluation. Then, this paper elaborates the research contents and methods of this paper, including the comprehensive and accurate inspection of bridges using advanced inspection technology, the processing and analysis of inspection data using big data and artificial intelligence technology, and the construction of bridge safety assessment model. Through these studies, this paper proposes an efficient bridge inspection and assessment method to provide a strong guarantee for the safe operation of bridges. Through experimental investigation, the accuracy of its bridge inspection technology fluctuates between 93.5% and 98.4%; while the efficiency is always above 80%, which fully demonstrates the high efficiency of ultrasonic technology in bridge inspection. This paper finds that the efficiency and accuracy of bridge inspection can be greatly improved by adopting advanced inspection technology. At the same time, combined with big data and artificial intelligence technology, rapid processing and analysis of bridge inspection data can be realized, providing strong support for bridge safety assessment.

1. Introduction

With the acceleration of urbanization and the continuous improvement of transportation network, the number of bridges, as an important means of transportation connecting rivers, canyons and other geographical barriers, has been increasing, and their structural forms are becoming more and more complex. However, bridges will inevitably suffer from various damages and diseases during long-term use due to the influence of various factors such as natural environment and vehicle loading, which will not only affect the normal use of bridges, but even cause serious safety accidents. Therefore, it is necessary to carry out regular inspection and evaluation of bridges to find and repair the damages and diseases in time.

This paper firstly summarizes the research results of scholars at home and abroad in bridge inspection technology, and analyzes the shortcomings of the current research. Then, the research content and methods of this paper are introduced in detail, including the classification of bridge inspection technology, the selection of inspection indexes, and the optimization of inspection methods. Then, through experimental investigation, the current status of bridge inspection technology is evaluated and its development trend is discussed. Finally, the research results of this paper are summarized and the places that can be improved in the future are proposed.

The contribution of the current status and development trend of bridge inspection technology in bridge inspection and evaluation is mainly reflected in the following aspects:(1) This paper improves the inspection efficiency and accuracy. Currently, bridge inspection technology has developed from the traditional stage of empirical visual inspection to the stage of nondestructive testing and real-time monitoring. These advanced technologies can greatly improve the efficiency and accuracy of inspection, reduce manual errors, and ensure accurate assessment of the safety condition of bridges. Ultrasonic inspection obtains information about the internal state of the bridge without damaging its structure, providing more accurate data support for evaluation. (2) This paper promotes the scientificization of bridge maintenance. Bridge inspection technology makes bridge maintenance work more scientific and refined. Through regular inspection and evaluation of bridges, potential safety hazards can be found and repaired in time to avoid accidents.

2. Related Work

Scholars at home and abroad have carried out a lot of research on bridge inspection technology, including nondestructive testing technology, intelligent inspection technology, etc. These technologies have improved the efficiency and accuracy of bridge inspection to a certain extent, but there are still some problems. These technologies have improved the efficiency and accuracy of bridge inspection to a certain extent, but there are still some problems. Although non-destructive testing technology can be carried out without destroying the bridge structure, it requires high skills of inspectors and is difficult to find some hidden damages and diseases. Nguyen D C et al. designed mixed reality application based on Building Information Modelling (BIM) to improve the efficiency of bridge inspection and maintenance. They improved the accuracy of bridge inspections by combining BIM and mixed reality [1]. Bertola N J et al. assessed the condition of bridges based on a risk-based approach through which the risk and condition of bridges were accurately assessed [2]. Li Y et al. developed a training and evaluation system based on virtual reality, and combined it with drone assistance to improve the abilities of inspectors [3]. Figueiredo E et al. studied statistical pattern recognition methods for structural health monitoring of bridges [4]. Malekloo A et al. studied machine learning to provide an overview of research on structural health monitoring, as well as investigating emerging technologies and high-dimensional data sources to facilitate the monitoring of structural health [5]. Akillolu M et al. conducted a bibliometric review of emerging research trends on the status of building safety management technology and analyzed future development directions [6]. Sabato et al. systematically reviewed non-contact sensing technologies for structural health monitoring and explored the application of artificial intelligence in these technologies [7]. Gharehbaghi V R et al. conducted a critical review of structural health monitoring, pointing out current research issues and future research directions [8]. Gupta M et al. studied non-destructive testing (NDT) and optimized materials and structures using NDT techniques [9]. Xu J G et al. utilized a data-driven rapid damage assessment method to improve the efficiency of seismic assessment of the life cycle of regional reinforced concrete bridges [10]. Although intelligent detection technology can automatically identify and evaluate the damage and diseases of bridges, its ability to process and analyze data is limited, and the detection effect for complex structures of bridges is not ideal. Therefore, further research and improvement of bridge detection technology are needed to meet the needs of practical applications.

3. Method

3.1 Bridge Detection Technology

Ultrasonic testing technology is a widely used non-destructive testing method that utilizes the characteristics of reflection, transmission, and scattering of ultrasonic waves when propagating in a medium to detect internal defects in materials. In bridge inspection, ultrasonic testing technology is highly favored due to its high accuracy and reliability. The mathematical principles of ultrasonic testing technology are mainly based on wave equations. When ultrasound propagates in a medium, its propagation speed, amplitude, and waveform parameters will vary with the characteristics of the medium. In bridge inspection, ultrasonic testing technology is commonly used to detect defects such as cracks and voids in concrete and metal structures [11-12]. The detection process usually includes the following steps:

(1) Equipment preparation: according to the nature of the inspected material, selecting the appropriate ultrasonic testing instruments and probes. For thicker metal materials, low-frequency probes are needed to obtain deeper penetration; while for thinner or composite materials, high-frequency probes are needed to improve the resolution, to ensure that the selected instrument has sufficient accuracy and stability to meet the inspection requirements. Before use, calibrating the ultrasonic testing instrument to ensure its accuracy, check whether the probe is intact and undamaged, without cracks or wear and tear, so as not to affect the ultrasonic transmission and reception, test the connection between the instrument and the probe to ensure stable signal transmission.

(2) Inspection preparation: using appropriate cleaners or solvents to thoroughly clean the surface of the material being inspected to remove impurities such as oil, dust, rust and corrosion. These impurities will affect the propagation and reception of ultrasonic waves, resulting in inaccurate detection results. After cleaning, drying the surface with a clean cloth or paper towel to ensure that there is no residue [13-14]. In this paper, special ultrasonic coupling agent is selected and applied on the detection area. The role of the coupling agent is to reduce the ultrasonic energy loss between the probe and the material to improve the transmission effect, to ensure that the coupling agent is uniformly coated, no bubbles or impurities, so as not to affect the propagation of ultrasonic waves.

(3) Data acquisition: the ultrasonic propagation time (i.e., the time it takes for the ultrasonic waves to travel from emission to reception) in the material is recorded using ultrasonic inspection instruments. This time is related to the thickness of the material and the propagation speed of ultrasonic waves in the material [15-16]. The relationship between the velocity of propagation of ultrasonic waves in a material, v, and the elastic modulus of the material, E, the density, \rho, and the Poisson's ratio, \nu:

$$v = \sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}} \quad (1)$$

While the relationship between bridge displacement ΔL and stress σ, elastic modulus E and length L is as follows:

$$\Delta L = \frac{\sigma L}{E} \quad (2)$$

Where the self-oscillation frequency f of the bridge structure is related to the stiffness k and mass m as follows:

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}} \quad (3)$$

(4) Data analysis: in this paper, the collected data are analyzed and processed using the above formulas, and the fluctuation equations and related algorithms are used to calculate the material's sound velocity, acoustic impedance, and other parameters, as shown in Table 1, so as to assess the internal structure and defects of the material.

Table 1: Evaluation data parameters

Test number	Test location	Sound speed of the material (m/s)	Acoustic impedance (Rayls)
1	Bridge A	5900	36
2	Bridge B	5800	35
3	Bridge C	5700	34
4	Bridge D	5600	33
5	Bridge E	5500	32
6	Bridge F	5400	31
7	Bridge G	5300	30
8	Bridge H	5200	29
9	Bridge I	5100	28
10	Bridge J	5000	27

(5) Result determination: according to the results of data analysis, determining whether there are defects in the inspected materials, and determine the location, size and type of defects and other information.

3.2 Framework of Bridge Inspection and Evaluation

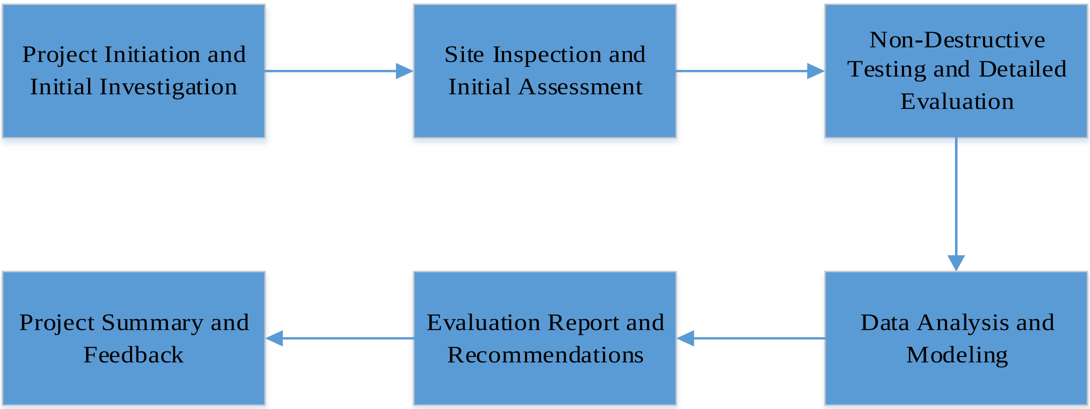

Figure 1: Process of bridge detection and evaluation

Figure 1 shows the flowchart of bridge inspection and assessment. During the initiation phase of the bridge project, this paper defines the objectives, scope, schedule, budget, and staff allocation of the project, and begins an exhaustive data collection process to collect and analyze the bridge's design documents, construction records, historical maintenance records, and environmental monitoring data. Subsequently, this paper conducted a site investigation and preliminary assessment, visually inspected the overall condition of the bridge, and utilized tools such as crack observers to examine in detail the location, length, and width of the cracks and other information, as well as observing the deformation of the bridge [17-18] and assessing the degree of corrosion and wear of the metal components. Immediately following, this paper conducted a non-destructive testing and detailed assessment, whereby the concrete, metal and steel portions of the bridge were inspected in depth through ultrasonic testing in order to assess their internal quality and potential defects. After completing the data collection, this paper performed data analysis and simulation. Firstly, this paper organized all the inspection data and analyzed them in detail. Then, the key performances of the bridge such as load carrying capacity and stability were evaluated using the structural mechanics model; finally, the response of the bridge under various loads and working conditions was simulated by the finite element model or other simulation software to obtain more comprehensive performance information [19]. In this paper, the whole testing and evaluation project was summarized and the feedback from the client was collected to assess the quality and effectiveness of the project.

4. Results and Discussion

4.1 Application Effect of Nondestructive Testing Technology

In this paper, according to the actual situation of the bridge and the detection needs, a detailed detection program is developed, the environmental conditions of the detection site are checked, and the safe operation procedures and emergency plans are formulated to ensure the safety of the detection process. Before formal testing, pre testing and calibrating the non-destructive testing equipment to ensure its accuracy. For complex bridge structures or special detection requirements, simulation testing can be conducted to verify the feasibility of the detection method.

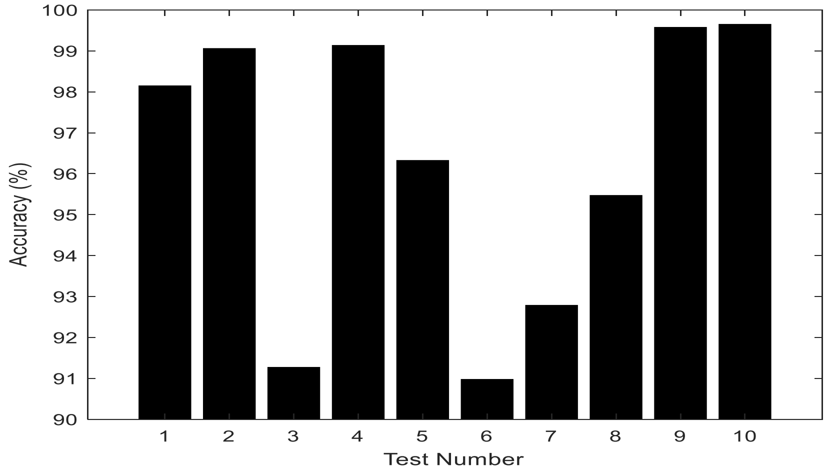

Figure 2: Accuracy of detection

From the data in Figure 2, the detection accuracy of ultrasonic technology in different environments is stable and maintained at a high level. In 10 consecutive tests, the accuracy is always above 90%, which clearly shows that the application of ultrasonic technology in NDT is effective and has a high degree of reliability and consistency. Meanwhile, although the accuracy fluctuates between 93.5% and 98.4%, such fluctuations provide an opportunity for in-depth analysis in this paper. Specifically, these fluctuations reveal differences in the performance of the ultrasonic technique under different testing conditions, such as material properties, subtle changes in the testing environment, or technical differences in the operating process. Through an in-depth study of these factors, this paper optimizes the testing process and improves the detection accuracy of ultrasonic technology, thus ensuring that its practical application in nondestructive testing achieves the best results. For the role of testing and evaluation, the data in Figure 2 not only provide direct evidence of the performance of ultrasonic technology, but also provide technicians with a direction to improve and optimize the technology. This kind of data-based analysis and evaluation has an important role in promoting the overall performance of NDT technology and promoting its application in various fields.

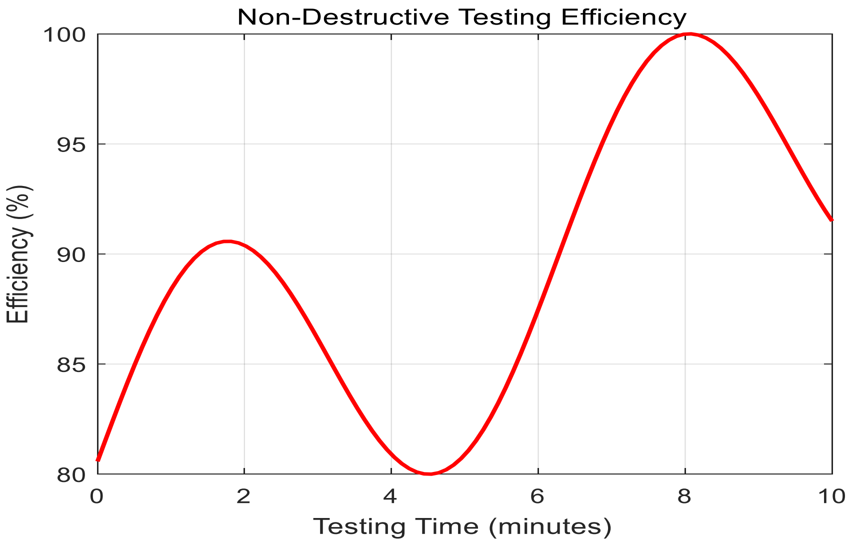

Figure 3: Detection efficiency

The data in Figure 3 shows that the efficiency of the ultrasonic technique for NDT fluctuates over time, but generally remains high at over 80%. The graph shows the relationship between test time (minutes) and efficiency (%) by testing the efficiency of the technique, which shows the periodic fluctuation and overall upward trend of efficiency over time. This fluctuation reflects the different levels of efficiency exhibited by the ultrasonic technique at different testing stages, with efficiency peaking at some points in time and decreasing slightly at others. However, even with such fluctuations, the efficiency of NDT was consistently above 80%, which demonstrates the efficiency and stability of ultrasonic technology in bridge inspection. This efficiency not only helps to accomplish the inspection task quickly, but also ensures the reliability of the inspection results. For the role of inspection assessment, the data in Figure 3 provides a visualization of the current status of bridge inspection technology. It shows that modern ultrasonic technology has significant advantages in improving inspection efficiency and accuracy, and has become an indispensable tool in the field of bridge inspection.

4.2 Functions and Advantages of Bridge Inspection Technology

The function and advantage of bridge inspection technology is that it can comprehensively and accurately assess the structural safety condition of the bridge and provide scientific basis for the maintenance and management of the bridge. Combined with the previous experimental data, this paper can see that the application effect of ultrasonic technology in nondestructive testing is particularly significant.

(1) Ultrasonic technology is able to penetrate the bridge material and detect whether there are cracks, voids and other defects inside by transmitting ultrasonic waves and receiving their reflected signals. This non-destructive testing method not only avoids the damage caused to the bridge structure by traditional destructive testing, but also can be carried out without affecting the normal use of the bridge.

(2) The detection efficiency of ultrasonic technology is very high. As mentioned earlier, the experimental data show that the nondestructive testing efficiency of ultrasonic technology fluctuates with time, but generally stays at a high level of more than 80%. This means that in a relatively short period of time, the technology can complete a comprehensive inspection of the bridge, providing a strong guarantee for the timely maintenance of the bridge.

(3) Ultrasonic technology can accurately measure the thickness, density and other physical parameters of bridge materials, so as to accurately assess the structural performance of the bridge. At the same time, because the ultrasonic signal is reproducible, it can be tested on the same bridge several times to ensure the accuracy of the test results.

5. Conclusion

With the increasing improvement of the transportation network, bridges, as important transportation hubs, have a direct relationship between their safety and stability and the safety of people's lives and property. Therefore, the study of bridge inspection technology is particularly important. This paper discusses the current situation and development of bridge inspection technology in depth to provide scientific basis and technical support for the safe operation of bridges. This paper firstly combed the research results of domestic and foreign scholars in this field. Through the review of existing literature, the difficulties of the current bridge detection technology are analyzed. On this basis, this paper elaborates the theoretical framework, experimental design, data analysis and other aspects of bridge detection technology. In order to assess the current status of bridge detection technology, this paper designs experiments. In the experimental process, this paper selects representative bridge samples, utilizes advanced testing equipment and means, and carries out comprehensive testing on the structure, materials, and stress condition of the bridge.

Through the collection and analysis of experimental data, we gained an in-depth understanding of the practical application effect of bridge detection technology. The experimental results show that the current bridge inspection technology has made significant progress and can more accurately assess the safety and stability of bridges.

However, in practical application, there are still some problems, the accuracy and stability of some detection equipment need to be improved, and for the detection of complex bridge structures, more accurate detection methods are still needed. Although this paper has achieved certain results in bridge detection technology, there are still some shortcomings. Firstly, due to the limitation of experimental conditions, the number of bridge samples selected in this paper is limited, which can't fully reflect the general law of bridge inspection technology. Secondly, in terms of data analysis, this paper mainly adopts statistical methods, and the processing and analyzing ability of complex data needs to be improved. Finally, this paper fails to deeply explore the economic and social benefits of bridge inspection technology, which is also an important direction for future research to focus on.

In response to the shortcomings of current research, this paper proposes the following improvement directions: (1) expanding the range of experimental samples and select more types of bridges for detection experiments to improve the universality of research results; (2) introducing advanced data analysis methods and technical means to improve the efficiency and accuracy of data processing; (3) strengthening the economic and social benefits evaluation of bridge inspection technology, and provide scientific basis for the government and enterprises to formulate relevant policies and investment decisions.

Acknowledgement

This work was supported by Sichuan Province Luzhou city of Stars science and technology planning project (2022-GYF-6) and scientific research and innovation team construction project of Luzhou vocational and Technical College (2021YJTD07).

References

[1] Nguyen D C, Nguyen T Q, et al. BIM-based mixed-reality application for bridge inspection and maintenance[J]. Construction Innovation, 2022, 22(3): 487-503.

[2] Bertola N J, Brühwiler E. Risk-based methodology to assess bridge condition based on visual inspection[J]. Structure and Infrastructure Engineering, 2023, 19(4): 575-588.

[3] Li Y, Karim M M, Qin R. A virtual-reality-based training and assessment system for bridge inspectors with an assistant drone[J]. IEEE transactions on human-machine systems, 2022, 52(4): 591-601.

[4] Figueiredo E, Brownjohn J. Three decades of statistical pattern recognition paradigm for SHM of bridges[J]. Structural Health Monitoring, 2022, 21(6): 3018-3054.

[5] Malekloo A, Ozer E, AlHamaydeh M, et al. Machine learning and structural health monitoring overview with emerging technology and high-dimensional data source highlights[J]. Structural Health Monitoring, 2022, 21(4): 1906-1955.

[6] Akinlolu M, Haupt T C, Edwards D J, et al. A bibliometric review of the status and emerging research trends in construction safety management technologies[J]. International Journal of Construction Management, 2022, 22(14): 2699-2711.

[7] Sabato A, Dabetwar S, Kulkarni N N, et al. Noncontact sensing techniques for AI-aided structural health monitoring: a systematic review[J]. IEEE Sensors Journal, 2023, 23(5): 4672-4684.

[8] Gharehbaghi V R, Noroozinejad Farsangi E, Noori M, et al. A critical review on structural health monitoring: Definitions, methods, and perspectives[J]. Archives of computational methods in engineering, 2022, 29(4): 2209-2235.

[9] Gupta M, Khan M A, Butola R, et al. Advances in applications of Non-Destructive Testing (NDT): A review[J]. Advances in Materials and Processing Technologies, 2022, 8(2): 2286-2307.

[10] Xu J G, Feng D C, Mangalathu S, et al. Data-driven rapid damage evaluation for life-cycle seismic assessment of regional reinforced concrete bridges[J]. Earthquake Engineering & Structural Dynamics, 2022, 51(11): 2730-2751.

[11] Schaap H S, Caner A. Bridge collapses in Turkey: causes and remedies[J]. Structure and Infrastructure

Engineering, 2022, 18(5): 694-709.
[12] Pan Y, Zhang L. Integrating BIM and AI for smart construction management: Current status and future directions[J]. Archives of Computational Methods in Engineering, 2023, 30(2): 1081-1110.
[13] Mihai S, Yaqoob M, Hung D V, et al. Digital twins: A survey on enabling technologies, challenges, trends and future prospects[J]. IEEE Communications Surveys & Tutorials, 2022, 24(4): 2255-2291.
[14] Garg R K, Chandra S, Kumar A. Analysis of bridge failures in India from 1977 to 2017[J]. Structure and Infrastructure Engineering, 2022, 18(3): 295-312.
[15] Wang Y, Tian Y, Wang J, et al. Integrated inspection of QoM, QoP, and QoS for AOI industries in metaverses[J]. IEEE/CAA Journal of Automatica Sinica, 2022, 9(12): 2071-2078.
[16] Usiagu G S, Adekoya O O, Okoli C E, et al. LNG as a bridge fuel in the transition to renewable energy: A global perspective [J]. World Journal of Advanced Research and Reviews, 2024, 21(2): 742-749.
[17] Palakurti N R. Bridging the Gap: Frameworks and Methods for Collaborative Business Rules Management Solutions [J]. International Scientific Journal for Research, 2024, 6(6): 1-22.
[18] Nejad A R, Keller J, Guo Y, et al. Wind turbine drivetrains: state-of-the-art technologies and future development trends [J]. Wind Energy Science, 2022, 7(1): 387-411.
[19] Macchiarulo V, Milillo P, Blenkinsopp C, et al. Monitoring deformations of infrastructure networks: A fully automated GIS integration and analysis of InSAR time-series[J]. Structural Health Monitoring, 2022, 21(4): 1849-1878.