HILL PUBLISHING

Engineering Advances, 2025, 5(1), 30-36
https://www.hillpublisher.com/journals/ea/
ISSN Online: 2768-7961

Disease Analysis of Modular Expansion Joints in Long-span Bridges

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How to cite this paper: Bingqi Wang, Chong Chen, Chuang Ma, Xinpan Xia. (2025) Disease Analysis of Modular Expansion Joints in Long-span Bridges. *Engineering Advances*, 5(1), 30-36.
DOI: 10.26855/ea.2025.01.006

Received: December 30, 2024
Accepted: January 28, 2025
Published: February 26, 2025

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Abstract

In order to comprehensively and accurately understand the condition of modular expansion joints in large-span bridges during their service life, and to develop reasonable and effective disease control strategies, this paper explores a more timely and precise evaluation method for the state of expansion joints. This method focuses on typical issues associated with modular expansion joints, utilizing on-site detection and health monitoring, building upon existing general evaluation methods for bridges. Taking a suspension bridge as an example, on the basis of verifying the feasibility of the expansion joint state evaluation method, a performance degradation model and monitoring evaluation results were established based on the detection technology condition evaluation score. Analysis shows that the combination of sub-item classification and single-item quantitative control indicators for on-site detection, and the analysis of temperature correlation characteristics of expansion joint displacement monitoring, can effectively determine the service performance and disease impact of expansion devices, providing more scientific and reasonable support for the development of disease control strategies for modular expansion devices.

Keywords

Bridge engineering; Long-span bridges; Expansion device; Status assessment

1. Introduction

The structural stiffness of long-span bridges is relatively small, the structural deformation is large, and the structural system is more complex, which puts higher requirements on the performance of their expansion devices under load. At present, the commonly used expansion joint devices in long-span bridges mainly include pot-type rubber, steel comb plate, modular, and various new types of expansion joints [1]. Among them, the modular expansion device has been widely used in large-span bridges due to its good shock absorption and buffering performance, good sealing performance, comfortable driving on the bridge deck, and the ability to arbitrarily assemble and design displacement according to a certain modulus according to actual needs. However, due to deficiencies in current design, construction, management, and maintenance, modular expansion devices are widely affected by diseases [2]. For example, the Akashi Kaikyo Bridge in Japan, which was completed and opened to traffic in 1998, had only been in service for about 3 years, and subtle cracks appeared at the hinge positions of its expansion joints [3]. Therefore, analyzing the types and causes of diseases in modular expansion joints of highway bridges, exploring disease control strategies and maintenance methods, and reducing the maintenance costs and frequency of expansion joints have important social and economic significance.

2. Analysis of Disease Causes

Bridge structures belong to durability structures. Even if the quality control of bridge components is good during the design and construction stages, with the continuous extension of service time and the comprehensive influence of complex external environmental factors, bridge expansion devices will also produce various types of diseases [4, 5]. At present, common diseases of modular expansion devices for large-span bridges mainly include wear and failure of sliding materials, fracture of steel sections, rupture of rubber waterstops, damage to control springs, and cracking of anchorage concrete. Diseases can be mainly divided into six categories according to the type of device components: corrosion of steel components, diseases of middle beam steel, diseases of the displacement control system, diseases of elastic support components, diseases of the waterproof sealing system, and diseases of the anchoring system. The following mainly analyzes the causes of the typical diseases mentioned above.

2.1 Disease of medium beam steel

When there is accumulated debris in the expansion joint that affects the free deformation of the expansion joint, it will reduce the firmness of the beam anchor between the angle steel and the concrete. Under the repeated impact of vehicle loads, the stress amplitude of supporting steel components such as crossbeams and middle beams will exceed the design value for a long time, which will also lead to the fracture of expansion joint-shaped steel, as shown in Figure 1.

Figure 1. Beam fracture in the expansion joint.

2.2 Disease of displacement control system

As is well known, the structural flexibility of long-span bridges is high, and the main beam will experience significant longitudinal displacement under external dynamic loads such as vehicles and wind. The accumulation of a large amount of longitudinal reciprocating travel at the end of the beam will cause wear and extrusion of the sliding material of the expansion joint device, which will further wear down the elastic support material, as shown in Figure 2. In actual engineering, both Jiangyin Yangtze River Bridge (main span 1385m suspension bridge) and Runyang Yangtze River Bridge (main span 1490m suspension bridge) have taken measures to replace the expansion joints as a whole due to severe wear and tear of the sliding materials of the expansion devices. When the elastic support is worn or even squeezed out, it can also cause diseases such as the fracture of the supporting crossbeam and middle beam.

Figure 2. Expansion device sliding material grinding.

2.3 Damage to waterproof sealing system and elastic support components

The rubber waterstop of the expansion joint is prone to accumulating garbage inside, and the blockage and compression of hard objects in the garbage can cause damage to the waterstop. Meanwhile, as the service life of the expansion joint device extends, the aging of the rubber material and the transverse angle of the main beam will also accelerate the damage of the waterstop, leading to water seepage in the expansion joint, as shown in Figure 3. Expansion joint control springs are generally made of polyurethane or rubber materials. When subjected to repeated tension, compression, or shear forces, the side is prone to cracking, and water leakage from the expansion joint will further accelerate the aging of the elastic body, ultimately leading to damage and failure, as shown in Figure 4.

Figure 3. The waterstop is broken.

Figure 4. Cracks appear in the expansion joint spring element.

2.4 Anchor system diseases

The concrete in the anchorage zone of the expansion joint belongs to the post-poured strip concrete. Under repeated impacts and crushing by vehicles, concrete is prone to cracking and damage, resulting in the obvious jumping of vehicles. The vehicle load is amplified, and in severe cases, it may lead to abnormal longitudinal movement of the main beam when heavy vehicles pass through at night.

3. State Evaluation Method for Telescopic Devices

The causes of diseases in modular expansion devices are diverse and complex. To ensure the normal working condition of expansion joints during the long-term operation of bridges, it is necessary to carry out regular maintenance and upkeep to extend their service life. The evaluation of the working status and service performance of the expansion device can provide basic support for developing effective disease maintenance plans, reducing the cost of expansion joint maintenance and inspection frequency. This section discusses and verifies the evaluation method of expansion joint status for modular expansion devices of long-span bridges from the perspectives of detection and monitoring.

3.1 Principles and methods of detection and evaluation

At present, the on-site inspection methods for bridges mainly rely on manual visual inspection and auditory judgment. The detection system for modular expansion devices is not yet perfect, and some disease detection indicators have missing items. The description of disease scales is mostly qualitative indicators, lacking specific quantitative indicators, which leads to strong subjectivity in the evaluation results of expansion device detection. To improve the scientific and comprehensive on-site detection method of modular expansion devices, corresponding quantitative indicators were determined based on the types and characteristics of diseases mentioned earlier, as shown in Table 1.

Table 1. Disease detection content and quantitative indicators

Disease type	Inspection content	Quantitative indicators
Corrosion of steel components	Coating peeling and rusting of steel components	Corrosion area
Disease of medium beam steel	Uneven unevenness, gaps, deformation and fracture	Disease area, height difference of middle beam, gap spacing difference
Disease of displacement control system	Sliding material extrusion, support shear deformation	Extrusion quantity of sliding material, deformation of compression spring, and shear deformation angle
Diseases of elastic support components	Loose or cracked elastic support	Number of looseness and cracking
Diseases of waterproof sealing system	Cracking and leakage of rubber waterstop	Garbage accumulation and damaged areas of waterstop
Anchor system diseases	Concrete anchoring defects	Number, width, and area of concrete cracks

Table 2. Disease detection scoring criteria

Scale	Disease type: Corrosion of steel components	Disease type: Disease of medium beam steel	Deduction value
1	--		0
2	Corrosion area≤5%	Disease area<10%, Height difference of the central beam<1mm, 0mm＜Gap spacing difference≤20mm	10
3	Corrosion area＞5%and≤20%	10%＜Disease area≤30%, 1mm＜Height difference of the central beam≤2mm, 20mm＜Distance difference≤40mm	25
4	Corrosion area＞20%	Disease area＞30%, Height difference of the central beam＞2mm, Gap spacing difference＞40mm	40
Scale	**Disease type: Diseases of elastic support components**	**Disease type: Disease of displacement control system**	**Deduction value**
1		compression deformation＞Design value20%, Shear deformation angle<25°	0
2	Number of looseness≤10%, Number of cracks≤10%	Number of damaged springs≤10%, Shear deformation angle≤35°, Mechanical hinge damaged≤2	10
3	10%＜4/10000 Number of looseness≤30%,10%＜Number of cracks≤30%	Compression spring deformation exceeds the limit or is crushed, quantity＞10%; Shear spring shear deformation＞35°Or cut, quantity＞10%; Mechanical hinge damaged＞2The displacement control function has failed	25
4	Number of looseness＞30%, Number of cracks＞30%	compression deformation＞Design value20%，Shear deformation angle<25°	40
Scale	**Disease type: Diseases of waterproof sealing system**	**Disease type: Anchor system diseases**	**Deduction value**
1	---	----	0
2	Accumulated area<10%	Less than 5 locations, crack width≤3mm, Cracking area≤10%	10
3	10%＜area≤30%	Crack location ≥ 5, 10%＜are≤30%, or3mm＜crack width≤10mm	25
4	area＞30%	Crack width and crack area＞30%, crack width≥10mm, Penetrating the trough area	40

The on-site inspection of defects in modular expansion devices should be carried out in the order of first inspecting the appearance defects, then inspecting the main load-bearing components and parts for defects, and finally inspecting the support anchoring connections and waterproof system defects. The appearance inspection mainly involves visually checking whether the sliding support and spring gap are clean, whether the steel beam is straight, and whether there is rust on the surface of the steel beam. The main load-bearing components and parts include edge beams, center beams, supporting crossbeams, displacement boxes, pressure bearings, control springs, rubber waterstops, etc. Disease detection and evaluation should adopt a combination of sub item classification and single quantitative control indicators for classification and grading evaluation. The scoring criteria for quantitative control indicators of various diseases are shown in Table 2.

Referring to the "Technical Condition Evaluation Standards for Highway Bridges and Culverts" (JTG/T H21-2011) [6], the technical condition score of expansion devices can be calculated according to equations (1) to (3).

$$\mathrm{MCI} = 100 - \sum_{x=1}^{k} U_x \tag{1}$$

$$\text{When } x = 1,\ U_1 = DP_1 \tag{2}$$

$$\text{When } x \geq 2,\ Ux = \frac{DP_x}{100 \times \sqrt{x}} \times \left(100 - \sum_{y=1}^{x-1} U_y\right) \tag{3}$$

In the formula: DP_j is the deduction value for the jth type detection indicator of the telescopic device. When $DP_j = 100$, MCI = 0.

Taking a suspension bridge as an example, the trend of changes in the technical condition scores of expansion joints at different stages calculated using the above method is shown in Figure 5. In Figure 5, there is a significant upward trend in the rating results for 2020 and 2022. The reason for this is that the expansion joints of the bridge underwent large-scale repairs in 2019 and 2021, respectively, which alleviated the deterioration rate of expansion joint diseases and effectively improved the service performance of the expansion device. The results in Figure 5 indicate that the technical condition score of the expansion device calculated by the above method can better characterize the performance of the expansion device.

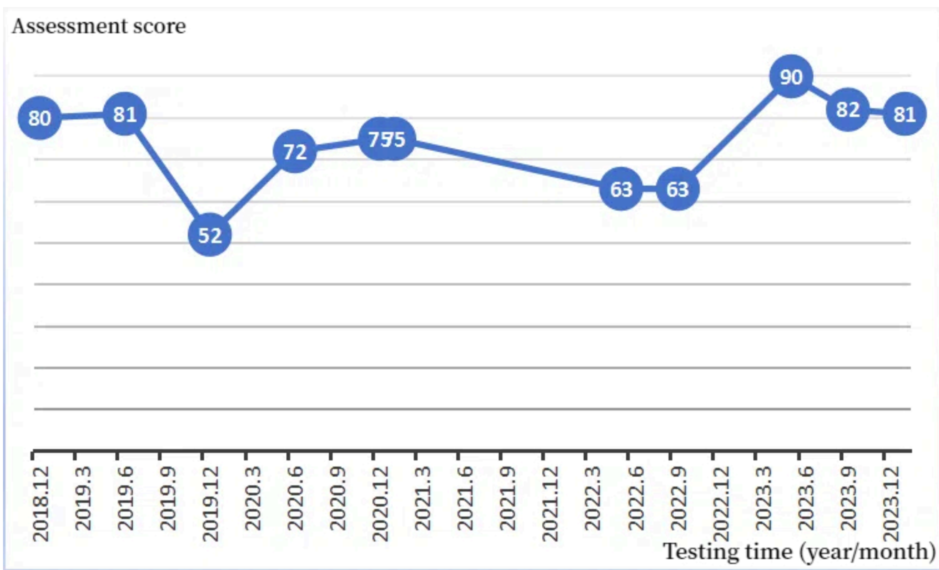

Figure 5. The trend of change in the scoring ratio of expansion joint technology status.

According to the "Maintenance Specification for Highway Bridges and Culverts" (JTGH11-2004) [7], on-site inspections of expansion devices can be divided into five categories: initial inspection, daily inspection, regular inspection, periodic inspection, and special inspection. The assessment of the technical condition of the expansion device is based on various inspection data for scoring and evaluation, providing basic support for its maintenance and repair. The requirements and cycles for various types of inspections are as follows:

(1) Initial inspection: For newly built or renovated bridges, it shall be conducted simultaneously with the handover acceptance.

(2) Daily inspection: once a day, mainly based on visual inspection while riding, promptly report obvious defects and abnormal conditions.

(3) Regular inspection: once a month, using visual inspection combined with auxiliary tools, and promptly reporting serious damage to important components.
(4) Regular inspection: once a year, compare and analyze previous inspection reports to determine the cause and scope of the disease, determine the technical condition evaluation level of the expansion device, and explain the development of the disease.
(5) Special inspection: Special inspections are required for situations where it is difficult to determine the cause and extent of component damage during regular inspections, or where abnormal conditions such as floods, ice flow, landslides, earthquakes, wind disasters, fires, and impacts occur.

In addition, with the development of non-destructive testing technology, advanced technologies such as laser, penetration, and ultrasound can also be used as supplementary means for on-site testing of telescopic devices [8]. For example, for the uniformity of expansion joint gaps, it is possible to consider using a three-dimensional laser scanning instrument to detect the deviation between adjacent edge beams and center beams; For concealed parts that cannot be visually inspected (such as sliding supports, sliding springs, and stainless steel plates on sliding surfaces), industrial endoscopes can be considered for auxiliary detection.

3.2 Evaluation method for fusion of inspection and monitoring information

With the rapid development of bridge informatization and intelligence, bridge health monitoring has played a good complementary role in routine structural testing. At present, the displacement of expansion joints in the health monitoring system of long-span bridges is mostly monitored by tension rope sensors. Previous studies have shown that there is a strong correlation between the displacement of expansion joints and environmental temperature, and the temperature-dependent characteristics of expansion joint displacement can serve as important indicators for determining the working status of expansion devices. Under normal conditions, the influence characteristics of temperature on the displacement of expansion joints are relatively fixed, while abnormal diseases of expansion joints may cause changes in this influence characteristic. Based on the temperature correlation characteristics of expansion joint displacement, the abnormal working state of expansion joints can be identified to achieve the evaluation of their service performance. In addition, as the cumulative stroke of expansion joints is an important factor affecting the service life of expansion devices, life prediction can be achieved by establishing the cumulative displacement time curve of expansion joints. From this, it can be seen that integrating expansion joint detection and monitoring information can establish a more timely and comprehensive modular expansion device state evaluation method, as shown in Figure 6.

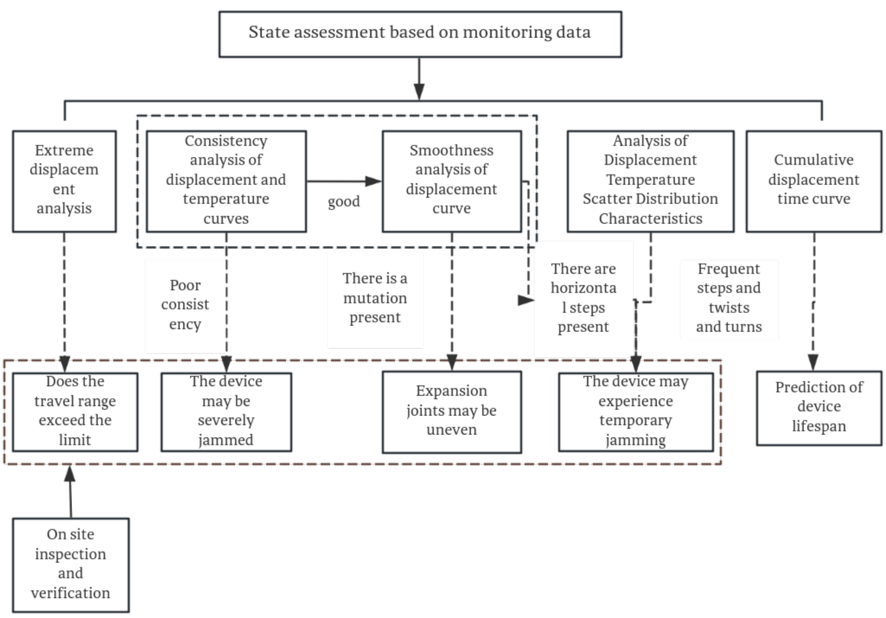

Figure 6. Assessment of the state of the telescopic device for integrating inspection and monitoring information.

(1) Statistics are conducted on the annual monitoring displacement extreme values of expansion joints to calculate the amplitude of displacement changes throughout the year, which can determine whether there is a risk of exceeding the design range of the expansion device.

(2) By performing 1-hour mean processing on the displacement of expansion joints and environmental temperature data, and comparing the consistency of the mean fluctuation curves between the two, it can be preliminarily determined whether the expansion device has serious abnormal diseases that affect the longitudinal expansion and contraction of the main beam, such as severe blockage and jamming; At the same time, by observing the smoothness of the displacement mean curve (whether sudden changes occur frequently), the working status of the expansion device can be evaluated to a certain extent.
(3) By analyzing the scatter distribution diagram of displacement temperature in a short period of time, observing the phenomenon and frequency of bumps and steps in the diagram, and qualitatively determining the blockage and jamming phenomena during the movement of the expansion device.
(4) Based on long-term monitoring of displacement of expansion joints, a time growth curve of cumulative travel can be established to assist in predicting the service life of expansion devices.

Based on the fusion evaluation method of inspection and monitoring mentioned above, analyzing the displacement monitoring data of expansion joints corresponding to 2023 in Figure 5, it can be seen that there are many abrupt jump points in the 1-hour mean curve of expansion joint displacement at night, and the smoothness of the curve is poor. The reason may be that the unevenness of the expansion device during heavy vehicle traffic leads to abnormal movement of the beam end; These results validate the feasibility and rationality of the expansion joint condition evaluation method based on the fusion of inspection and monitoring information.

4. Conclusion

As an important component of long-span bridges, modular expansion devices not only directly affect the service life of the bridge, but also play a crucial role in the comfort of vehicle traffic. Therefore, it is necessary to conduct comprehensive inspections and long-term monitoring of the bridge during its long-term operation, in order to timely grasp its working condition and disease development, and achieve effective control of the expansion device diseases.
(1) According to the type of components, the diseases of modular expansion devices can be divided into six categories: steel component corrosion, beam type steel disease, displacement control system disease, elastic support element disease, waterproof sealing system disease, anchoring system disease, etc.
(2) During the long-term operation of the bridge, the working status of the expansion device can be comprehensively evaluated through on-site inspection and long-term monitoring. On-site inspection mainly adopts a combination of sub-item classification and single-item quantitative control indicators for disease scoring, while integrating the temperature-related characteristics of expansion joint displacement to comprehensively judge the movement form of the device and the impact of diseases, in order to improve the timeliness and accuracy of the state assessment method.

Funding

(1) 2024 National College Student Innovation Training Program in Henan Province (Project Name: Bridge Expansion Joint Upgrade Plan - Extending Bridge Life and Guarding Traffic Safety; Project Number: 202414040004).
(2) College Student Innovation Training Program Project, Project Name: Development of a New Type of Truss Type Transfer Layer and Its Connecting Components.

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